Year : 2011

Analysis of gene expression patterns in animals

Frédéric BASTIAN

UNIL | Université de Lausanne
Faculté de biologie et de médecine

Département d'écologie et évolution

ANALYSIS OF GENE EXPRESSION PATTERNS IN ANIMALS

Thèse de doctorat ès sciences de la vie (PhD)

présentée à la

Faculté de biologie et de médecine
de l'Université de Lausanne

par

Frédéric BASTIAN

Master en bioinformatique de l'Université de Rennes I

Jury

Prof. Christian Hardtke, Président
Prof. Marc Robinson-Rechavi, Directeur de thèse
Prof. Ioannis Xenarios, Expert
Dr. Alvis Brazma, Expert

Lausanne 2011

UNIL | Université de Lausanne
Faculté de biologie
et de médecine

Ecole Doctorale

Doctorat ès sciences de la vie

Imprimatur

Vu le rapport présenté par le jury d'examen, composé de

Président	Monsieur	Prof. Christian **Hardtke**
Directeur de thèse	Monsieur	Prof. Marc **Robinson-Rechavi**
Experts	Monsieur	Dr Alvis **Brazma**
	Monsieur	Prof. Ioannis **Xenarios**

le Conseil de Faculté autorise l'impression de la thèse de

Monsieur Frédéric Bastian

Master II recherche bioinformatique université de Rennes, France

intitulée

Analysis of gene expression patterns in animals

Lausanne, le 30 septembre 2011

pour Le Doyen
de la Faculté de Biologie et de Médecine

Prof. Christian Hardtke

Remerciements

J'aimerais remercier les membres de mon jury, pour le temps qu'ils ont consacré à la lecture et à l'évaluation de mon travail de thèse, et pour les très intéressantes discussions qui en ont découlé : Christian Hardtke, Marc Robinson-Rechavi, Ioannis Xenarios et Alvis Brazma.

J'aimerais tout particulièrement remercier mon directeur de thèse, Marc Robinson-Rechavi, pour avoir su me faire progresser et évoluer, que ce soit : dans ma manière d'appréhender le travail en sciences d'une manière générale ; ou en me permettant d'acquérir d'avantage de recul et de perspective dans les réflexions sur mon propre travail. Je le remercie pour avoir su m'offrir une complète autonomie, mais dans le même temps, une supervision rigoureuse, formatrice et enrichissante.

J'aimerais également remercier les membres passés et présents du groupe Robinson-Rechavi, pour leur aide précieuse, leurs discussions stimulantes, ou tout simplement pour les bons moments passés ensemble ! Je remercie donc Grigouris Amoutzias, Briséïs Castella, Aurélie Comte, Fernando Cruz, Joséphine Daub, Walid Gharib, Vidhya Jagannathan, Yohan Jarosz, Alice Koechlin, Balazs Laurenczy, Antonia Mayer, Sébastien Moretti, Anne Niknejad, Patricia Palagi, Gilles Parmentier, Barbara Piasecka, Frederic Ricci, Julien Roux, Hannes Schabauer, Romain Studer, et Laurie Vuillet.

Je remercie tout particulièrement Julien Roux, pour avoir été un contributeur indispensable de chaque étape de mon travail de thèse, et pour m'avoir montré la « Voie du Doctorant », notamment en me fixant, à son insu, un idéal scientifique à atteindre !

Finalement, je remercie ma compagne, Clémence Hazebroucq, pour son soutien indispensable, et pour avoir enduré autant voire d'avantage de tourments que moi durant la rédaction du présent manuscrit. Merci pour son aide sans laquelle je n'aurais pu réussir.

Étude des patrons d'expression de gène chez les animaux

Frédéric Bastian, sous la supervision du Professeur Marc Robinson-Rechavi
Département d'Ecologie et Evolution, Biophore, Université de Lausanne

Durant ma thèse, mon but a été de fournir de nouveaux outils pour améliorer notre capacité à analyser les patrons d'expression de gènes, et d'étudier à grande échelle leur evolution chez les animaux. Les patrons d'expression (où et quand un gène est exprimé) sont une caractéristique clé pour comprendre la fonction des gènes, notamment au cours du développement. Il paraît clair aujourd'hui que l'évolution des processus développementaux et des phénotypes est déterminée à la fois par l'évolution des séquences codantes, et par l'évolution de l'expression des gènes.
Étudier l'évolution de l'expression des gènes chez les animaux, qui possèdent des patrons d'expression complexes par rapport aux tissus et aux stades de développement, est encore de nos jours un défi. Aucun outil n'est disponible pour comparer de manière routinière les patrons d'expression de différentes espèces, avec précision, et à grande échelle. Les études de l'évolution de l'expression se contentent donc d'étudier des jeux de données de taille restreinte, ou utilisent des descriptions imprécises des patrons d'expression.

Le but de ma thèse était de développer de nouvelles ressources bioinformatiques, permettant d'étudier l'évolution de l'expression des gènes. Pour cela, j'ai développé la base de données Bgee (*Base for Gene Expression Evolution*). Bgee transforme des données d'expression hétérogènes (*ESTs*, puces à ADN, hybridations *in-situ*) en information de présence - absence d'expression, et annote ces données par rapport à des représentations standardisées de l'anatomie et du développement de différentes espèces (ontologies anatomiques). Un travail approfondi a permis de définir des relations entre les anatomies de différentes espèces, basées sur une hypothèse d'homologie. Ce processus d'annotations précises par rapport à l'anatomie des espèces, et ce travail approfondi de définitions de relations entre espèces, sont les atouts majeurs de Bgee. Ma contribution principale a été le développement et la gestion de la base de données Bgee et de son application Internet.

Bgee en est maintenant à sa 9^{e} mise à jour, et inclut un important jeu de données d'expression pour 5 espèces (humain, souris, drosophile, poisson zèbre, et la grenouille *Silurana tropicalis*), les espèces les mieux représentées étant l'humain, la souris et le poisson zèbre. En utilisant ces trois espèces, j'ai conduit une analyse de l'évolution de l'expression des gènes après duplication chez les vertébrés.

La duplication de gène est supposée être une source majeure d'innovations morphologiques, et participer au phénomène de spéciation. Il a été suggéré que l'évolution des patrons d'expression pourrait participer à la rétention de gènes dupliqués. J'ai réalisé une comparaison à large échelle des patrons d'expression de centaines de gènes dupliqués, à leur orthologue singleton dans une autre espèce, apparus à la suite de duplication à courte, ou large échelle, dans trois espèces de vertébrés (humain, souris, poisson zèbre), et en utilisant des descriptions très précises des patrons d'expression. Mes résultats ont montré de manière inattendue des taux très élevés d'acquisition *de novo* de domaines d'expression après duplication (neo-fonctionnalisation), au moins aussi élevés que les taux de partitionnement des domaines d'expression (sous-fonctionnalisation). J'ai trouvé des différences dans l'évolution de l'expression des dupliqués émergeants d'évènements de duplication à courte ou large échelle, les dupliqués émergeants de duplications à courte échelle étant d'avantage soumis au processus de neo-fonctionnalisation. Les dupliqués présentant de la néo-fonctionnalisation semblent évoluer sous des pressions de sélection purifiante moins élevées au niveau de leur séquence codante. Finalement, même en utilisant des données d'expression abondantes et précises, la destinée la plus commune que j'ai identifiée ne fut ni la néo-, ni la sous-fonctionnalisation, ce qui suggère un rôle majeur d'autres mécanismes pour expliquer la rétention de gènes dupliqués.

Analysis of Gene Expression Patterns in Animals

Frederic Bastian, under the supervision of Pr. Marc Robinson-Rechavi
Department of Ecology and Evolution, Biophore, University of Lausanne
CH-1015 Lausanne, Switzerland

During my PhD, my aim was to provide new tools to increase our capacity to analyse gene expression patterns, and to study on a large-scale basis the evolution of gene expression in animals. Gene expression patterns (when and where a gene is expressed) are a key feature in understanding gene function, notably in development. It appears clear now that the evolution of developmental processes and of phenotypes is shaped both by evolution at the coding sequence level, and at the gene expression level.

Studying gene expression evolution in animals, with complex expression patterns over tissues and developmental time, is still challenging. No tools are available to routinely compare expression patterns between different species, with precision, and on a large-scale basis. Studies on gene expression evolution are therefore performed only on small genes datasets, or using imprecise descriptions of expression patterns.

The aim of my PhD was thus to develop and use novel bioinformatics resources, to study the evolution of gene expression. To this end, I developed the database Bgee (Base for Gene Expression Evolution). The approach of Bgee is to transform heterogeneous expression data (ESTs, microarrays, and *in-situ* hybridizations) into present/absent calls, and to annotate them to standard representations of anatomy and development of different species (anatomical ontologies). An extensive mapping between anatomies of species is then developed based on hypothesis of homology. These precise annotations to anatomies, and this extensive mapping between species, are the major assets of Bgee, and have required the involvement of many co-workers over the years. My main personal contribution is the development and the management of both the Bgee database and the web-application.

Bgee is now on its ninth release, and includes an important gene expression dataset for 5 species (human, mouse, drosophila, zebrafish, Xenopus), with the most data from mouse, human and zebrafish. Using these three species, I have conducted an analysis of gene expression evolution after duplication in vertebrates.

Gene duplication is thought to be a major source of novelty in evolution, and to participate to speciation. It has been suggested that the evolution of gene expression patterns might participate in the retention of duplicate genes. I performed a large-scale comparison of expression patterns of hundreds of duplicated genes to their singleton ortholog in an outgroup, including both small and large-scale duplicates, in three vertebrate species (human, mouse and zebrafish), and using highly accurate descriptions of expression patterns. My results showed unexpectedly high rates of *de novo* acquisition of expression domains after duplication (neofunctionalization), at least as high or higher than rates of partitioning of expression domains (subfunctionalization). I found differences in the evolution of expression of small- and large-scale duplicates, with small-scale duplicates more prone to neofunctionalization. Duplicates with neofunctionalization seemed to evolve under more relaxed selective pressure on the coding sequence. Finally, even with abundant and precise expression data, the majority fate I recovered was neither neo- nor subfunctionalization of expression domains, suggesting a major role for other mechanisms in duplicate gene retention.

Introduction

I am a PhD student supervised by Prof. Robinson-Rechavi since 2007. My aim was to build innovative resources for comparative transcriptomics, and to use them to tackle unanswered questions about the evolution of gene expression in animals.

1 Of the importance of gene expression patterns

1.1 In functional genomics

Gene expression patterns (when and where a gene is expressed) are an important aspect of the study of gene function, especially in multicellular organisms such as animals. The second level of molecular characterization, after determining sequence, is almost always determining expression, whether in small-scale studies (qPCR or *in situ* hybridization after cloning a gene) or in large-scale studies (microarray or RNA-seq after genome sequencing). Association studies, using gene expression as a quantitative traits, have demonstrated the important relations between expression patterns and establishment of phenotypes ((Cookson, Liang*, et al.*, 2009) for a review about associations to diseases). For instance, obesity traits could be associated with gene expression patterns in murines (Schadt, Monks*, et al.*, 2003), and in human (Emilsson, Thorleifsson*, et al.*, 2008).

1.2 In evolution

Gene expression patterns are also an important aspect of the evolution of organisms. There is an ongoing argument concerning whether evolution is driven mostly at the coding sequence level, or at the regulatory level, especially for the evolution of development and of morphology (Carroll, 2008; Haag and Lenski, 2011; Hoekstra and Coyne, 2007; Pennisi, 2008). It does appear clear that the evolution of developmental processes, and of phenotypes, is shaped not only by evolution at the coding sequence level, but also by evolution of *cis*-regulatory elements (Pennisi, 2009). For instance, pelvic reduction in sticklebacks could be attributed to loss of a tissue-specific enhancer of Pitx1 by a mutation in a regulatory region (Chan, Marks*, et al.*, 2010). In Drosophila, variations of abdomen pigmentation could be attributed to five mutations in regulatory regions, modifying the level of expression of the *ebony* gene (Rebeiz, Pool*, et al.*, 2009). Moreover, there is also increasing evidence for the importance of the evolution of gene regulation for other aspects than development (e.g., (Fraser, Moses*, et al.*, 2010)).

2 The need for comparative approaches

In biological research, results obtained in different organisms are routinely compared. A comparative approach may be chosen for practical reasons, because the organism of interest

(humans, farm animals) may be less amenable to experimentation than more or less distant model species (as mouse, rat, zebrafish, or fruit fly).

Early studies seemed to indicate that such comparisons might be irrelevant, because of high tissue expression divergence between orthologous genes in mouse and human (Yanai, Graur, *et al.*, 2004; Yang, Su, *et al.*, 2005). More recent studies have shown that, when correcting for discrepancies in between-species analyses, and comparing to an appropriate neutral expectation, tissue expression profiles have significant conservation between orthologs (Jordan, Marino-RamÌrez, *et al.*, 2005; Liao and Zhang, 2006a; Liao and Zhang, 2006b; Zheng-Bradley, Rung, *et al.*, 2010; Piasecka, Robinson-Rechavi and Bergmann, unpublished). The comparative study of gene expression between species has the potential to be a powerful tool for functional genomics. For example, comparing multiple samples from humans and rodents allowed for significant improvement in tumour characterisation (Schlicht, Matysiak, *et al.*, 2004).

Transcriptome data have also been compared between species to gain direct insight into evolutionary processes. For instance, yeast microarray data have provided evidence for divergence of expression after genome duplication (Gu, Nicolae, *et al.*, 2002), and further studies have succeeded in extracting some evidence for the evolution of new gene functions after genome duplication in yeast and human lineages (Gu, Zhang, *et al.*, 2005; He and Zhang, 2005). More recently, different studies have compared expression patterns of duplicated genes to singleton orthologs in vertebrates, to test different models of gene expression evolution after duplication (Farre and Alba, 2010; Huminiecki and Wolfe, 2004; Kassahn, Dang, *et al.*, 2009; Sémon and Wolfe, 2008). A comparative approach thus allows to understand the mechanisms and the consequences of gene expression evolution.

3 No established tool for expression patterns comparison

Tools to compare DNA or protein sequences between species are routinely used, and the ever-growing availability of new sequenced genomes keeps increasing our ability to study gene and protein evolution. But studying gene expression evolution in animals, with complex expression patterns over tissues and developmental time, is still challenging. Despite the ever-growing availability of transcriptomics data, and the development of high-throughput and accurate techniques, such as RNA-Seq, no tools are available to routinely compare expression

patterns between different species, with precision, and on a large-scale basis. Studies on gene expression evolution are therefore performed only on small genes datasets, or using imprecise descriptions of expression patterns.

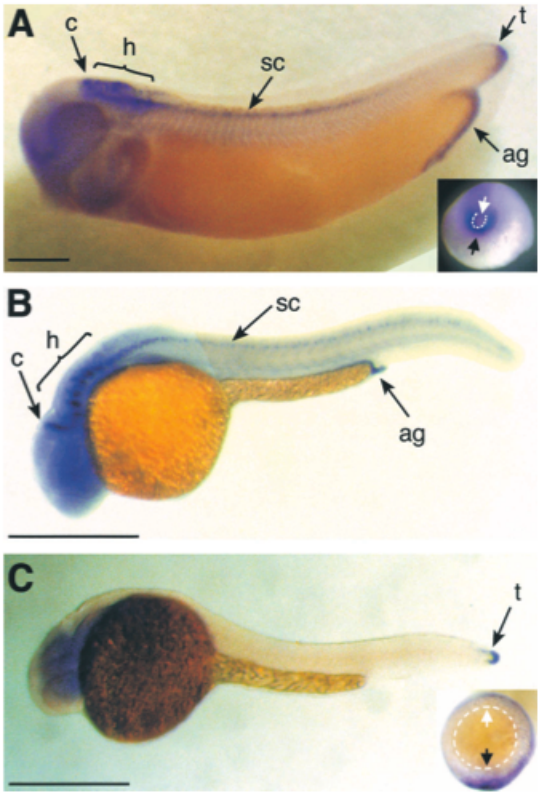


Fig. 1: Expression patterns of *evx1*-related genes of *X. laevis* (*Xhox3*, **A**) and *D. rerio* (*evx1*, **B** and *eve1*, **C**), studied by whole-mount *in situ* hybridizations at end of gastrulation, from (Avaron, Thaëron-Antono, *et al.*, 2003). Expression pattern of *Xhox3* shows partitioning between *evx1* and *eve1*.

The first type of studies generally implies the use of accurate description of expression patterns, obtained for instance by *in situ* hybridizations, and their manual comparison between species. Such a small-scale comparative study between Xenopus and zebrafish, highlighting a case of partitioning of expression domains, is presented in Figure 1 (Avaron, Thaëron-Antono, *et al.*, 2003). Such analyses have produced interesting results about the evolution of gene expression, by a comparative approach, e.g.: the evolution of RARα and RARγ in vertebrates (Escriva, Bertrand, *et al.*, 2006), of POMCα and POMCβ in teleosts (de Souza, Bumaschny, *et al.*, 2005), or of pax6 and pax6b in zebrafish relative to mouse (Kleinjan, Bancewicz, *et al.*, 2008). While such analyses provide interesting examples of possible fates of gene expression evolution, they remain anecdotal, and fail to scale to the level of genome-wide studies.

The second type of studies provides genome-wide analyses, using ESTs, microarrays, or RNA-Seq data. Expression information is often retrieved from a few, selected a priori tissues. This is a general problem of tissues sampling with high-throughput technologies (see e.g., (Nelson and Wilfred, 2009)). For instance, Chain, Ilieva and Evans (Chain, Ilieva, *et al.*, 2008) used only 5 different conditions (organ/stage) to compare expression patterns between two species of clawed frogs, using microarrays. Similarly, EST data from 11 tissues were used in Sémon and Wolfe (Sémon and Wolfe, 2008) on the same species; 16 tissues were studied by microarrays in mouse and human in (Huminiecki and Wolfe, 2004). In all previous

examples, the species studied were phylogenetically very close, implying similar biology and easy mapping between anatomies.

4 Bgee: a dataBase for Gene Expression Evolution

The main aim of my PhD was to address the need for tools allowing large-scale and precise comparisons of expression patterns between species. The result is the Bgee database (http://bgee.unil.ch). The approach of Bgee is to combine heterogeneous expression data (EST, Affymetrix, *in situ* hybridization data) into present/absent calls, and to map them to formal representations of anatomies and developments of different species. Relationships between species-specific anatomies are then manually curated, based on a clear definition of homology, and broad equivalences between their developments are defined, to allow automated comparisons of gene expression patterns.

Bgee is a collaborative effort. Notably, Julien Roux has developed the statistical testing. I am the main developer of the database and of the application. I also coordinate all aspects of the project.

4.1 Designing homology relationships between anatomies: the Homolonto software

To annotate expression patterns to formal representation of anatomies, we use anatomical ontologies (see Fig. 2 for an example): they allow to unambiguously describe anatomies of species in a computer-understandable way, using well-defined concepts and designing relationships amongst them (e.g., “telencephalon” *part_of* “forebrain”, *part_of* “brain”). Thus our first efforts concerned the annotation of gene expression to ontology terms, and then the creation of relations of homology between species-specific anatomical ontologies.

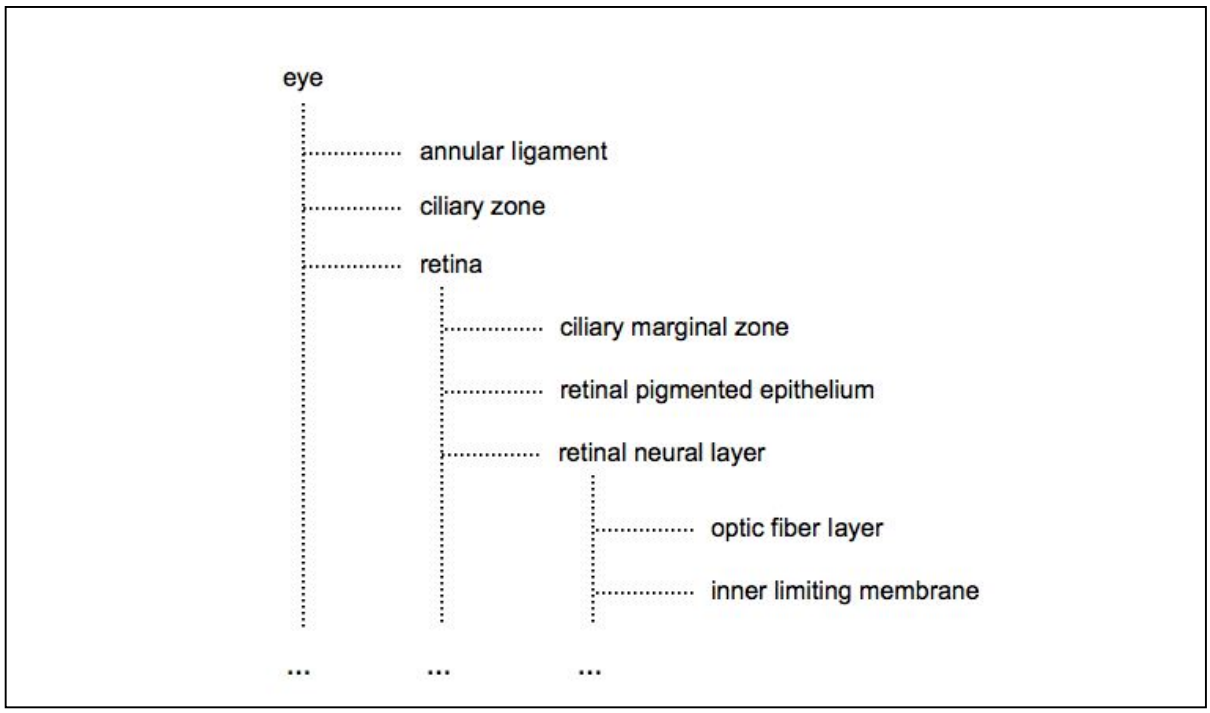


Fig. 2: A part of the zebrafish anatomical ontology from ZFIN (Bradford, Conlin*, et al.*, 2011)

To this end, we have used an ontology alignment approach. Indeed, to provide relationships between anatomies, hundreds of terms should be compared between ontologies that can differ both in the actual biology modelled (i.e., a fish is not a mammal), and in the representation used (e.g., the term "head" is absent from the human anatomical ontologies used (Aitken, 2005; Kelso, Visagie*, et al.*, 2003)). Although a purely manual annotation of homologies is possible, it would be too time consuming to be done for all terms between several divergent species. This is why we developed a software, Homolonto, using a supervised ontology alignment approach, to propose putative homology relations between two anatomies. Each proposed mapping is manually validated by an expert. We had to develop our own tools, as most other algorithms use unsupervised approaches (e.g., LOOM (Ghazvinian, Noy*, et al.*, 2009), AROMA (Jerome, 2007)). And as pointed out by Ghazvinian, Noy and Musen (2009), almost none of the published ontology aligners are available or maintained. For the available aligners, the question of using homology to align anatomical ontologies has never been explicitly addressed. Alignments are based on semantic similarities and functional equivalence, not based on formal information about homology.

Homolonto is presented in chapter 1 and has been published in *Bioinformatics* (Parmentier, Bastian*, et al.*, 2010). My contribution was to develop algorithms to organize the results of

several alignments, after their merging, and is detailed in section 5 of the chapter. I am also responsible for the maintenance of this software.

4.2 From multi-species mappings to multi-species ontology: vHOG and HOG ontologies

We have thus used Homolonto to generate mappings between species. The resulting mappings are merged into Homologous Organs Groups (HOGs). The HOGs can then be organized as a multi-species ontology, by designing relationships between them, such as *part_of* and *is_a*. This was achieved by the use of algorithms I designed (see above).

We thus obtained the HOG ontology, an ontology for bilaterian animals, with a focus on vertebrates. The mappings to species-specific ontologies are provided in a separated file (in the same way that annotations of genes to the Gene Ontology (Ashburner, Ball*, et al.*, 2000) are provided in the Gene ontology Association File (GAF[1])). The first advantage of this approach is that no hypothesis of homology is explicitly stated in the ontology itself. The other advantage is that we provide, for each mapping, confidence codes and references when available.

We have then generated a very high quality subset of the HOGs, specific to vertebrates, limited to highly supported strict historical homology, and following CARO standards (Haendel, Neuhaus*, et al.*, 2008), to enhance interoperability: the vHOG ontology (vertebrate Homologous Organs Group). vHOG is part of the OBO Foundry library (Smith, Ashburner*, et al.*, 2007), and also available from the NCBO Bioportal (Noy, Shah*, et al.*, 2009).

Several other multi-species anatomical ontologies are under active development, for instance: UBERON (Haendel, Gkoutos*, et al.*, 2009), an ontology with the aim of generating all possible mappings between anatomical ontologies, with no biological interpretation; TAO (Dahdul, Lundberg*, et al.*, 2010), restricted to teleost fishes; or the EFO (Malone, Holloway*, et al.*, 2010), which is not focused on inter-species comparisons but does provide mappings between anatomies, especially for the annotation of experiments in the Gene Expression Atlas (Kapushesky, Emam*, et al.*, 2010). Most multi-species ontologies have the aim to propose the most extensive possible mappings between anatomies; our ontologies have a different

[1] http://www.geneontology.org/GO.format.gaf-2_0.shtml

purpose, and aim at generating high quality mappings, with references, based on their biological significance, between distant animals. Symptomatic of this difference, ours is the only project to provide mapping in a separate annotation file, instead of in the "xref" field of the ontology file, which does not allow confidence codes.

The vHOG ontology is presented in chapter 2, and will be submitted to *Bioinformatics*. My contribution was to develop algorithms to help the curation process, and to co-supervise this work with Marc Robinson-Rechavi.

4.3 Integration of multi-species data: the Bgee database and application

After the annotation of expression data to anatomies of different species, and the design of homology relationships between species, the following step is the analysis of expression data. The aim is to obtain information about absence or presence of expression, over tissues and developmental times. Present/Absent calls can then be easily compared between species. The use of such present/absent calls can be debated, but in practice, many experimental biologists do not use gene expression as a continuum (see for instance example from Fig. 1). This is supported by the observed bimodality of the intensity signal on many microarray experiments (an example is presented by Hebenstreit, Fang *et al.* (2011)). This observation can also be made with data from RNA-Seq (Hebenstreit, Fang*, et al.*, 2011), or with fluorescence *in situ* hybridizations (Raj, Rifkin*, et al.*, 2010).

Concerning the analyses of expression data, in brief: we only use data reporting expression under "normal" conditions, i.e., non pathological, no mutants, no treatments, etc. Based on EST libraries (from Unigene (Pontius, Wagner*, et al.*, 2003)) and Affymetrix (from ArrayExpress (Parkinson, Sarkans*, et al.*, 2011)), genes are reported as "expressed" with "high" or "low" confidence, based on statistical analysis relative to background. For ESTs, statistical tests developed by Audic and Claverie are used (Audic and Claverie, 1997). For microarrays, normalizations are performed using gcRMA (Wu and Irizarry, 2005), when raw data are available, and background signal estimated from a subset of weackly expressed probesets (Schuster, Blanc*, et al.*, 2007). *In situ* hybridization data are recovered from reference databases (ZFIN (Bradford, Conlin*, et al.*, 2011), MGI (Finger, Smith*, et al.*, 2011), Xenbase (Bowes, Snyder*, et al.*, 2009), BDGP (Tomancak, Berman*, et al.*, 2007)), including quality scores when they are available. Quality scores for each condition are modified according to the consistency between all experiments for a data type.

Microarray experiments with more than 3 organs or developmental stages are also tested for over-expression of genes under some conditions. This is based on an ANOVA and a "multiple comparisons to the mean" procedure; this method was adopted after consultation with Misha Kapushesky, in charge of these analyses for the Gene Expression Atlas team at EBI (Kapushesky, Emam*, et al.*, 2010). Non-expression data is estimated based on microarrays and *in situ* hybridizations, with stringent criteria of statistical significance, data quality, and lack of contradiction between experiments. Of note, over-expression and non-expression cannot yet be queried through the web interface as of August 2011, although they are available through download and programmatic access.

The Bgee project thus now includes (i) a process of manual curation of expression data to ontology terms; (ii) Homolonto, an ontology alignment software dedicated to the detection of homology; (iii) custom bioinformatics tools to help manual curation of homology; (iv) a multi-species ontology of homologous organs (HOGs); (v) a statistical analysis pipeline to detect gene expression from EST or Affymetrix data; and (vi) the Bgee database itself, which integrate this information, plus gene annotations and gene homology information, and allows powerful queries.

4.4 State of the art of integrative transcriptomics resources

There exist many bioinformatics resources for gene expression and transcriptome data, but most have very different aims than Bgee. Notably, Bgee is the only resource with a focus on inter-species comparisons.

The Gene Expression Atlas (Kapushesky, Emam*, et al.*, 2010) of ArrayExpress (Parkinson, Sarkans*, et al.*, 2011) at EBI shares several aims with Bgee, most notably summarizing expression data for each gene. There are several differences between the Gene Atlas and Bgee. Bgee integrates some data types which are not covered by the Gene Atlas, such as *in situ* hybridizations and ESTs. Related to the use of *in situ* hybridization, Bgee has then a much higher anatomical resolution, including for cross-species queries. Gene Expression Atlas is intended to cover a broader sets of conditions, including disease states, sample treatments, but also organism parts and developmental stages. It was for instance used to generate a global picture of human genes expression (Lukk, Kapushesky*, et al.*, 2010). Bgee

does not include these various conditions, which is an advantage of Gene Atlas if the user is looking for, e.g., tumor data. But Bgee has a much higher resolution on organism parts and developmental stages, an advantage of Bgee if the user is looking for gene expression patterns which correspond to the normal gene function, as selected by evolution in nature. Finally, Bgee has a clear focus on cross-species comparison, with the explicit integration of carefully curated anatomical homology relations. Gene Atlas does not distinguish real homology from term similarity, as its focus is not the evolution of expression.

The NCBI *GEO* Profiles (Barrett, Troup*, et al.*, 2011) are similar in aim to the Gene Expression Atlas, but the data and the view are less organized, and it can be difficult to find the relevant information. There is no cross-species comparison, and no information of data quality or statistical significance.

4DXpress (Haudry, Berube*, et al.*, 2008) has a stated aim very similar to Bgee, although limited to *in situ* hybridization data. But homology relations between species have never been implemented, and the resource was last updated in July 2008.

The Gene Expression Barcode (McCall, Uppal*, et al.*, 2011) is relatively new resource. It shares the stated aim of deriving expression patterns from transcriptome data, by statistical treatment of microarray data. It is limited to human and mouse. Comparisons are only possible between conditions inside one species and one microarray platform; the platform must be specified by the user, who cannot access an integrated view of results.

Genevestigator (Hruz, Laule*, et al.*, 2008) is a combination of software platform and database, with curated microarray data. Like the Gene Expression Barcode, users must choose a specific microarray platform prior to searching, limiting access to any integrated view. Many of the more advanced features of Genevestigator are only accessible with a paying subscription. Genevestigator does not include any features to compare expression patterns between species.

Finally, each Model Organism Database (MGI, ZFIN, Xenbase, Flybase, etc.) contains many data types, some used in Bgee. But none of these includes cross-species comparisons among its aims, and most do not store other expression data than small-scale experiments (*in situ* hybridization, RT-PCR).

4.5 Concluding remarks

There exist many excellent resources for comparative genomics at the sequence level (such as Ensembl (Flicek, Amode*, et al.*, 2011)), but none for comparative transcriptomics, using precise descriptions of expression patterns, as we propose in Bgee. Moreover, a difference between expression and sequences is the diversity of data types, which can make it difficult to obtain an overview of all known information for a gene. Bgee is unique in providing such an integrated view.

Bgee as an integrated resource for expression data

Available resources which provide gene expression information tend to be specific of a data type, such as ESTs (NCBI Digital Differential Display), microarrays (GEO), or *in situ* hybridizations (which are usually in species specific databases, e.g., ZFIN or MGI). Bgee uniquely provides a one-stop overview of all the expression data for a gene, with moreover a guaranty that we have curated only "normal" conditions (non pathological, non treated). Especially since there does not seem to be one method emerging as the sole standard. While ESTs are no longer a major method, RNA-seq is strongly on the rise. Microarrays are still abundantly used (1588 Affymetrix experiments in GEO with publication date in 2011, as of mid-August). And *in situ* hybridization and other molecular techniques are increasingly used in large scale scans (e.g., Eurexpress project[2]; see also examples in (Finger, Smith*, et al.*, 2011)). It should be noted that for each data type, Bgee does not intend to replace the primary databases, and always links back to the data source. Thus, Bgee can provide a valuable service of centralizing information on gene expression, acting as a hub through which users can move from, e.g., UniProt sequence to, e.g., ArrayExpress or MGI expression data.

Bgee as a resource for comparative transcriptomics

There is no other resource which provides a cross-species overview of gene expression, with information of both gene homology and organ homology. Like conserved sequences, conserved gene expression can be more informative for function. Also changes in gene expression, e.g., between paralogs, can be informative on changes in function. In the same way that comparative genomics became widely used once it was available in an integrated and easy to browse form, comparative transcriptomics could become a major tool of molecular studies.

[2] http://www.eurexpress.org

The strengths of Bgee, relative to these two scientific needs, are high quality data and ontology curation, a powerful search engine, and a solid evolutionary biology outlook. Bgee is presented in chapters 3 and 4, and has been published in the peer-reviewed proceedings of the conference "Data Integration in Life Sciences" in 2008 (Bastian, Parmentier*, et al.*, 2008).

5 Real world application: study of the evolution of expression after duplication in vertebrates

From the beginning of the development of Bgee, one of the aims was to help our laboratory answer open questions in evolutionary biology. I have focused on one such question: what is the evolutionary trajectory of gene expression after duplication?

Since the 1990's, with the growing availability of molecular data, it became clear that duplication had played an important role in the evolution of vertebrate genomes (Holland, Garcia-Fernandez*, et al.*, 1994), yet the exact timing and mechanisms involved were debated (Sharman and Holland, 1995; Sidow, 1996). In 2002, notably using new phylogenetic data from amphioxus, Furlong and Holland presented strong evidence that two rounds of autotetraploidization occurred in vertebrates (Furlong and Holland, 2002). These two genome-wide duplications were then confirmed by comparison between the human and amphioxus genomes (Putnam, Butts*, et al.*, 2008). The study of the HOX cluster in vertebrates suggested a third event of large-scale duplication in teleost fishes (Amores, Force*, et al.*, 1998). This result was confirmed by the study of the genomes of Fugu (Christoffels, Koh*, et al.*, 2004) and Tetraodon (Jaillon, Aury*, et al.*, 2004). Thus, large-scale duplications have shaped the genomes of vertebrate lineages.

After a gene duplication, the most likely outcome is a return to the single-copy state: functional redundancy between the two copies is likely to result in relaxed selective pressure, so that one of the duplicates could accumulate null mutations and be quickly pseudogeneized (Lynch and Conery, 2000; Zhang, 2003), or be lost by genetic drift (Lynch, O'Hely*, et al.*, 2001). An important question is why so many are genes kept in duplicate, as compared to this neutral expectation of non-functionalization.

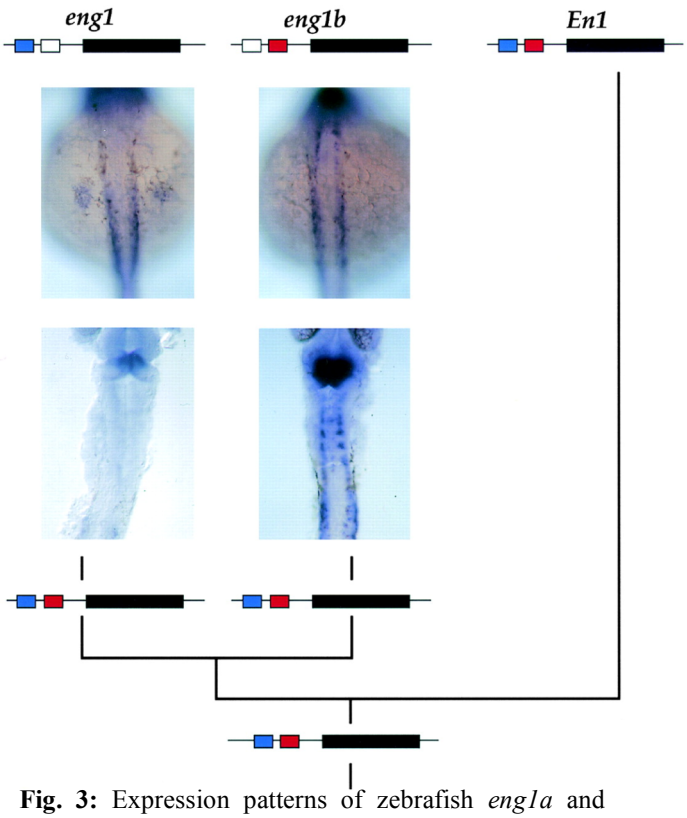


Fig. 3: Expression patterns of zebrafish *eng1a* and *eng1b*, from (Force, Lynch, *et al.*, 1999). Their fully divergent expression patterns support the hypothesis of subfunctionalization. To confirm it, expression pattern of a singleton ortholog in tetrapods should be examined.

A long-standing idea is that one of the duplicates could acquire new advantageous mutations, and be preserved by positive selection, while the other copy retains the ancestral function (Ohno, 1970). But the probability of such preservation by positive selection is expected to be low, especially in species with low population sizes (Lynch, O'Hely, *et al.*, 2001). Force and Lynch proposed an alternative model of neutral preservation by subfunctionalization (Force, Lynch, *et al.*, 1999; Lynch and Force, 2000): an accumulation of complementary mutations, resulting in a partitioning of the ancestral function between the two copies, especially at the level of regulatory sequences. In support of their model, Force and Lynch presented a comparison of the expression patterns of two duplicated genes in zebrafish: *eng1* (renamed *eng1a*) and *eng1b*. Their divergence of expression was compatible with the subfunctionalization theory, and the authors proposed to confirm this result by studying the expression pattern of the singleton ortholog in tetrapods (see Fig. 3). The expression patterns of the duplicates were expected to correspond to a partitioning of the singleton expression pattern.

This model of preservation by subfunctionalization was very attractive, because of the elegance of the idea, and because positive selection was not necessary. Several studies thus tried to estimate the prevalence of subfunctionalization in vertebrates, demonstrating expression divergence between whole-genome duplicates in *Xenopus laevis*, which was interpreted as supporting the subfunctionalization theory (Chain, Ilieva, *et al.*, 2008; Hellsten, Khokha, *et al.*, 2007; Morin, Chang, *et al.*, 2006). But, as pointed out by Force and Lynch in their original paper, a comparison of the expression pattern of a singleton gene in an outgroup must be performed. Otherwise, the ancestral state of expression cannot be inferred, and

different models of evolution cannot be distinguished. Only a few studies have addressed this issue in vertebrates, by comparing expression patterns of duplicates, to expression of singleton orthologs ((Huminiecki and Wolfe, 2004), (Sémon and Wolfe, 2008), (Kassahn, Dang*, et al.*, 2009), (Farre and Alba, 2010)). Most of these studies suffer from a lack of precision in the anatomical structures used. Or, when expression patterns are defined with precision, the number of duplicates studied is low (38 in (Kassahn, Dang*, et al.*, 2009)).

Using the abundant expression data stored in Bgee, and its capability to compare expression patterns between species with high resolution, it is possible to tackle this long-standing question. Thus I have performed probably the first large-scale comparison of expression patterns of hundreds of duplicate gene pairs to their singleton orthologs, conducted in vertebrates, using 199 homologous organs. My results showed unexpectedly high rates of *de novo* acquisition of expression domains after duplication (neofunctionalization), at least as high or higher than rates of subfunctionalization. I found differences in the evolution of expression of small- and large-scale duplicates, with small-scale duplicates more prone to neofunctionalization. Duplicates with neofunctionalization seemed to evolve under more relaxed selective pressure on the coding sequence. Finally, even with abundant and precise expression data, the majority fate I recovered was neither neo- nor subfunctionalization of expression domains, suggesting a major role for other mechanisms in duplicate gene retention.

Because of the convincing arguments supporting the subfunctionalization theory, and because of the elegant examples demonstrated by low-throughput methods, I was expecting to find a high prevalence of subfunctionalization. I have evaluated many parameters, with the aim of increasing its detection. Despite using the most favourable parameters for the detection of subfunctionalization, the rate detected remained low. Thus, I was led to revise my view of gene evolution after duplication. This study is presented in chapter 5, and will be submitted to *Genome Research*.

6 References

Aitken, S. (2005) Formalizing concepts of species, sex and developmental stage in anatomical ontologies, *Bioinformatics*, **21**, 2773-2779.

Amores, A., Force, A., Yan, Y.-L., Joly, L., Amemiya, C.*, et al.* (1998) Zebrafish hox Clusters and Vertebrate Genome Evolution, *Science*, **282**, 1711-1714.

Ashburner, M., Ball, C.A., Blake, J.A., Botstein, D., Butler, H.*, et al.* (2000) Gene Ontology: tool for the unification of biology, *Nat Genet*, **25**, 25-29.

Audic, S. and Claverie, J.-M. (1997) The Significance of Digital Gene Expression Profiles, *Genome Research*, **7**, 986-995.

Avaron, F., Thaëron-Antono, C., Beck, C.W., Borday-Birraux, V., Géraudie, J.*, et al.* (2003) Comparison of even-skipped related gene expression pattern in vertebrates shows an association between expression domain loss and modification of selective constraints on sequences, *Evolution & Development*, **5**, 145-156.

Barrett, T., Troup, D.B., Wilhite, S.E., Ledoux, P., Evangelista, C.*, et al.* (2011) NCBI GEO: archive for functional genomics data sets, 10 years on, *Nucleic Acids Research*, **39**, D1005-D1010.

Bastian, F., Parmentier, G., Roux, J., Moretti, S., Laudet, V.*, et al.* (2008) Bgee: Integrating and Comparing Heterogeneous Transcriptome Data Among Species. In Bairoch, A., Cohen-Boulakia, S. and Froidevaux, C. (eds), *Data Integration in the Life Sciences*. Springer Berlin / Heidelberg, pp. 124-131.

Bowes, J.B., Snyder, K.A., Segerdell, E., Jarabek, C.J., Azam, K.*, et al.* (2009) Xenbase: gene expression and improved integration, *Nucleic Acids Research*.

Bradford, Y., Conlin, T., Dunn, N., Fashena, D., Frazer, K.*, et al.* (2011) ZFIN: enhancements and updates to the zebrafish model organism database, *Nucleic Acids Research*, **39**, D822-D829.

Carroll, S.B. (2008) Evo-Devo and an Expanding Evolutionary Synthesis: A Genetic Theory of Morphological Evolution, *Cell*, **134**, 25-36.

Chain, F., Ilieva, D. and Evans, B. (2008) Duplicate gene evolution and expression in the wake of vertebrate allopolyploidization, *BMC Evolutionary Biology*, **8**, 43.

Chan, Y.F., Marks, M.E., Jones, F.C., Villarreal, G., Jr., Shapiro, M.D.*, et al.* (2010) Adaptive Evolution of Pelvic Reduction in Sticklebacks by Recurrent Deletion of a Pitx1 Enhancer, *Science*, **327**, 302-305.

Christoffels, A., Koh, E.G.L., Chia, J.-m., Brenner, S., Aparicio, S.*, et al.* (2004) Fugu Genome Analysis Provides Evidence for a Whole-Genome Duplication Early During the Evolution of Ray-Finned Fishes, *Molecular Biology and Evolution*, **21**, 1146-1151.

Cookson, W., Liang, L., Abecasis, G., Moffatt, M. and Lathrop, M. (2009) Mapping complex disease traits with global gene expression, *Nat Rev Genet*, **10**, 184-194.

Dahdul, W.M., Lundberg, J.G., Midford, P.E., Balhoff, J.P., Lapp, H.*, et al.* (2010) The Teleost Anatomy Ontology: Anatomical Representation for the Genomics Age, *Systematic Biology*, **59**, 369-383.

de Souza, F.v.S.J., Bumaschny, V.F., Low, M.J. and Rubinstein, M. (2005) Subfunctionalization of Expression and Peptide Domains Following the Ancient Duplication of the Proopiomelanocortin Gene in Teleost Fishes, *Molecular Biology and Evolution*, **22**, 2417-2427.

Emilsson, V., Thorleifsson, G., Zhang, B., Leonardson, A.S., Zink, F.*, et al.* (2008) Genetics of gene expression and its effect on disease, *Nature*, **452**, 423-428.

Escriva, H., Bertrand, S.p., Germain, P., Robinson-Rechavi, M., Umbhauer, M.*, et al.* (2006) Neofunctionalization in Vertebrates: The Example of Retinoic Acid Receptors, *PLoS Genet*, **2**, e102.
Farre, D. and Alba, M.M. (2010) Heterogeneous Patterns of Gene-Expression Diversification in Mammalian Gene Duplicates, *Mol Biol Evol*, **27**, 325-335.
Finger, J.H., Smith, C.M., Hayamizu, T.F., McCright, I.J., Eppig, J.T.*, et al.* (2011) The mouse Gene Expression Database (GXD): 2011 update, *Nucleic Acids Research*, **39**, D835-D841.
Flicek, P., Amode, M.R., Barrell, D., Beal, K., Brent, S.*, et al.* (2011) Ensembl 2011, *Nucleic Acids Research*, **39**, D800-D806.
Force, A., Lynch, M., Pickett, F.B., Amores, A., Yan, Y.-l.*, et al.* (1999) Preservation of Duplicate Genes by Complementary, Degenerative Mutations, *Genetics*, **151**, 1531-1545.
Fraser, H.B., Moses, A.M. and Schadt, E.E. (2010) Evidence for widespread adaptive evolution of gene expression in budding yeast, *Proceedings of the National Academy of Sciences*, **107**, 2977-2982.
Furlong, R.F. and Holland, P.W.H. (2002) Were vertebrates octoploid?, *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, **357**, 531-544.
Ghazvinian, A., Noy, N.F. and Musen, M.A. (2009) Creating mappings for ontologies in biomedicine: simple methods work. *AMIA Annu Symp Proc*. San Francisco (CA).
Gu, X., Zhang, Z. and Huang, W. (2005) Rapid evolution of expression and regulatory divergences after yeast gene duplication, *Proc Natl Acad Sci U S A*, **102**, 707-712.
Gu, Z., Nicolae, D., Lu, H.H. and Li, W.H. (2002) Rapid divergence in expression between duplicate genes inferred from microarray data, *Trends Genet*, **18**, 609-613.
Haag, E.S. and Lenski, R.E. (2011) L'enfant terrible at 30: the maturation of evolutionary developmental biology, *Development*, **138**, 2633-2637.
Haendel, M., Gkoutos, G., Lewis, S. and Mungall, C. (2009) Uberon: towards a comprehensive multi-species anatomy ontology. *International Conference on Biomedical Ontology*. Buffalo (NY), USA.
Haendel, M.A., Neuhaus, F., Osumi-Sutherland, D., Mabee, P.M., Mejino, J.L.V.*, et al.* (2008) CARO – The Common Anatomy Reference Ontology. In Burger, A., Davidson, D. and Baldock, R. (eds), *Anatomy Ontologies for Bioinformatics*. Springer London, pp. 327-349.
Haudry, Y., Berube, H., Letunic, I., Weeber, P.-D., Gagneur, J.*, et al.* (2008) 4DXpress: a database for cross-species expression pattern comparisons, *Nucleic Acids Research*, **36**, D847-D853.
He, X. and Zhang, J. (2005) Rapid Subfunctionalization Accompanied by Prolonged and Substantial Neofunctionalization in Duplicate Gene Evolution, *Genetics*, **169**, 1157-1164.
Hebenstreit, D., Fang, M., Gu, M., Charoensawan, V., van Oudenaarden, A.*, et al.* (2011) RNA sequencing reveals two major classes of gene expression levels in metazoan cells, *Mol Syst Biol*, **7**.
Hellsten, U., Khokha, M., Grammer, T., Harland, R., Richardson, P.*, et al.* (2007) Accelerated gene evolution and subfunctionalization in the pseudotetraploid frog Xenopus laevis, *BMC Biology*, **5**, 31.
Hoekstra, H.E. and Coyne, J.A. (2007) THE LOCUS OF EVOLUTION: EVO DEVO AND THE GENETICS OF ADAPTATION, *Evolution*, **61**, 995-1016.
Holland, P.W.H., Garcia-Fernandez, J., Williams, N.A. and Sidow, A. (1994) Gene duplications and the origins of vertebrate development, *Development*, **1994**, 125-133.
Hruz, T., Laule, O., Szabo, G., Wessendorp, F., Bleuler, S.*, et al.* (2008) Genevestigator V3: A Reference Expression Database for the Meta-Analysis of Transcriptomes, *Advances in Bioinformatics*, **2008**.

Huminiecki, L. and Wolfe, K.H. (2004) Divergence of Spatial Gene Expression Profiles Following Species-Specific Gene Duplications in Human and Mouse, *Genome Research*, **14**, 1870-1879.
Jaillon, O., Aury, J.-M., Brunet, F., Petit, J.-L., Stange-Thomann, N.*, et al.* (2004) Genome duplication in the teleost fish Tetraodon nigroviridis reveals the early vertebrate proto-karyotype, *Nature*, **431**, 946-957.
Jerome, D. (2007) Association Rule Ontology Matching Approach, *International Journal on Semantic Web and Information Systems*, **3**, 27-49.
Jordan, I.K., Marino-RamÌrez, L. and Koonin, E.V. (2005) Evolutionary significance of gene expression divergence, *Gene*, **345**, 119-126.
Kapushesky, M., Emam, I., Holloway, E., Kurnosov, P., Zorin, A.*, et al.* (2010) Gene Expression Atlas at the European Bioinformatics Institute, *Nucleic Acids Research*, **38**, D690-D698.
Kassahn, K.S., Dang, V.T., Wilkins, S.J., Perkins, A.C. and Ragan, M.A. (2009) Evolution of gene function and regulatory control after whole-genome duplication: Comparative analyses in vertebrates, *Genome Research*, **19**, 1404-1418.
Kelso, J., Visagie, J., Theiler, G., Christoffels, A., Bardien, S.*, et al.* (2003) eVOC: A Controlled Vocabulary for Unifying Gene Expression Data, *Genome Research*, **13**, 1222-1230.
Kleinjan, D.A., Bancewicz, R.M., Gautier, P., Dahm, R., Schonthaler, H.B.*, et al.* (2008) Subfunctionalization of duplicated zebrafish pax6 genes by cis-regulatory divergence, *PLoS Genet*, **4**, e29.
Liao, B.-Y. and Zhang, J. (2006a) Evolutionary Conservation of Expression Profiles Between Human and Mouse Orthologous Genes, *Molecular Biology and Evolution*, **23**, 530-540.
Liao, B.-Y. and Zhang, J. (2006b) Low Rates of Expression Profile Divergence in Highly Expressed Genes and Tissue-Specific Genes During Mammalian Evolution, *Molecular Biology and Evolution*, **23**, 1119-1128.
Lukk, M., Kapushesky, M., Nikkila, J., Parkinson, H., Goncalves, A.*, et al.* (2010) A global map of human gene expression, *Nat Biotech*, **28**, 322-324.
Lynch, M. and Conery, J.S. (2000) The Evolutionary Fate and Consequences of Duplicate Genes, *Science*, **290**, 1151-1155.
Lynch, M. and Force, A. (2000) The Probability of Duplicate Gene Preservation by Subfunctionalization, *Genetics*, **154**, 459-473.
Lynch, M., O'Hely, M., Walsh, B. and Force, A. (2001) The Probability of Preservation of a Newly Arisen Gene Duplicate, *Genetics*, **159**, 1789-1804.
Malone, J., Holloway, E., Adamusiak, T., Kapushesky, M., Zheng, J.*, et al.* (2010) Modeling sample variables with an Experimental Factor Ontology, *Bioinformatics*, **26**, 1112-1118.
McCall, M.N., Uppal, K., Jaffee, H.A., Zilliox, M.J. and Irizarry, R.A. (2011) The Gene Expression Barcode: leveraging public data repositories to begin cataloging the human and murine transcriptomes, *Nucleic Acids Research*, **39**, D1011-D1015.
Morin, R.D., Chang, E., Petrescu, A., Liao, N., Griffith, M.*, et al.* (2006) Sequencing and analysis of 10,967 full-length cDNA clones from Xenopus laevis and Xenopus tropicalis reveals post-tetraploidization transcriptome remodeling, *Genome Research*, **16**, 796-803.
Nelson, P.T. and Wilfred, B.R. (2009) In situ hybridization is a necessary experimental complement to microRNA (miRNA) expression profiling in the human brain, *Neuroscience Letters*, **466**, 69-72.
Noy, N.F., Shah, N.H., Whetzel, P.L., Dai, B., Dorf, M.*, et al.* (2009) BioPortal: ontologies and integrated data resources at the click of a mouse, *Nucleic Acids Research*, **37**, W170-W173.
Ohno, S. (1970) *Evolution by Gene Duplication*. Springer-Verlag.

Parkinson, H., Sarkans, U., Kolesnikov, N., Abeygunawardena, N., Burdett, T.*, et al.* (2011) ArrayExpress update - an archive of microarray and high-throughput sequencing-based functional genomics experiments, *Nucleic Acids Research*, **39**, D1002-D1004.
Parmentier, G., Bastian, F.B. and Robinson-Rechavi, M. (2010) Homolonto: generating homology relationships by pairwise alignment of ontologies and application to vertebrate anatomy, *Bioinformatics*, **26**, 1766-1771.
Pennisi, E. (2008) Deciphering the Genetics of Evolution, *Science*, **321**, 760-763.
Pennisi, E. (2009) Spineless Fish and Dark Flies Prove Gene Regulation Crucial, *Science*, **326**, 1612-.
Pontius, J.U., Wagner, L. and Schuler, G.D. (2003) UniGene: a unified view of the transcriptome. In McEntyre, J. and Ostell, J. (eds), *The NCBI Handbook.* National Center for Biotechnology Information (US), Bethesda (MD).
Putnam, N.H., Butts, T., Ferrier, D.E.K., Furlong, R.F., Hellsten, U.*, et al.* (2008) The amphioxus genome and the evolution of the chordate karyotype, *Nature*, **453**, 1064-1071.
Raj, A., Rifkin, S.A., Andersen, E. and van Oudenaarden, A. (2010) Variability in gene expression underlies incomplete penetrance, *Nature*, **463**, 913-918.
Rebeiz, M., Pool, J.E., Kassner, V.A., Aquadro, C.F. and Carroll, S.B. (2009) Stepwise Modification of a Modular Enhancer Underlies Adaptation in a Drosophila Population, *Science*, **326**, 1663-1667.
Schadt, E.E., Monks, S.A., Drake, T.A., Lusis, A.J., Che, N.*, et al.* (2003) Genetics of gene expression surveyed in maize, mouse and man, *Nature*, **422**, 297-302.
Schlicht, M., Matysiak, B., Brodzeller, T., Wen, X., Liu, H.*, et al.* (2004) Cross-species global and subset gene expression profiling identifies genes involved in prostate cancer response to selenium, *BMC Genomics*, **5**, 58.
Schuster, E., Blanc, E., Partridge, L. and Thornton, J. (2007) Correcting for sequence biases in present/absent calls, *Genome Biology*, **8**, R125.
Sémon, M. and Wolfe, K.H. (2008) Preferential subfunctionalization of slow-evolving genes after allopolyploidization in Xenopus laevis, *Proceedings of the National Academy of Sciences*, **105**, 8333-8338.
Sharman, A.C. and Holland, P.W.H. (1995) Conservation, Duplication, and Divergence of Developmental Genes During Chordate Evolution, *Netherlands Journal of Zoology*, **46**, 47-67.
Sidow, A. (1996) Gen(om)e duplications in the evolution of early vertebrates, *Current Opinion in Genetics & Development*, **6**, 715-722.
Smith, B., Ashburner, M., Rosse, C., Bard, J., Bug, W.*, et al.* (2007) The OBO Foundry: coordinated evolution of ontologies to support biomedical data integration, *Nat Biotech*, **25**, 1251-1255.
Tomancak, P., Berman, B.P., Beaton, A., Weiszmann, R., Kwan, E.*, et al.* (2007) Global analysis of patterns of gene expression during Drosophila embryogenesis, *Genome Biol*, **8**, R145.
Wu, Z. and Irizarry, R.A. (2005) Stochastic Models Inspired by Hybridization Theory for Short Oligonucleotide Arrays, *Journal of Computational Biology*, **12**, 882-893.
Yanai, I., Graur, D. and Ophir, R. (2004) Incongruent Expression Profiles between Human and Mouse Orthologous Genes Suggest Widespread Neutral Evolution of Transcription Control, *OMICS: A Journal of Integrative Biology*, **8**, 15-24.
Yang, J., Su, A.I. and Li, W.-H. (2005) Gene Expression Evolves Faster in Narrowly Than in Broadly Expressed Mammalian Genes, *Molecular Biology and Evolution*, **22**, 2113-2118.
Zhang, J. (2003) Evolution by gene duplication: an update, *Trends in Ecology & Evolution*, **18**, 292-298.

Zheng-Bradley, X., Rung, J., Parkinson, H. and Brazma, A. (2010) Large scale comparison of global gene expression patterns in human and mouse, *Genome Biology*, **11**, R124.

Homolonto: Generating homology relationships by pairwise alignment of ontologies and application to vertebrate anatomy

Gilles Parmentier[1,2], Frederic B. Bastian[1,2] and Marc Robinson-Rechavi[1,2,*]

[1]University of Lausanne, Department of Ecology and Evolution, Quartier Sorge, 1015 Lausanne, Switzerland.

[2]Swiss Institute of Bioinformatics, Lausanne, Switzerland.

[*]Corresponding author. Email: marc.robinson-rechavi@unil.ch

Abstract

Motivation**:** The anatomy of model species is described in ontologies, which are used to standardize the annotations of experimental data, such as gene expression patterns. To compare such data between species, we need to establish relations between ontologies describing different species.

Results: We present a new algorithm, and its implementation in the software Homolonto, to create new relationships between anatomical ontologies, based on the homology concept. Homolonto uses a supervised ontology alignment approach. Several alignments can be merged, forming homology groups. We also present an algorithm to generate relationships between these homology groups. This has been used to build a multi-species ontology, for the database of gene expression evolution Bgee.

Availability: Download section of the Bgee website http://bgee.unil.ch/

My contribution to this project was to develop algorithms to organize mappings into an ontology, and to help curation, and is detailed in section 5. Note that this algorithm has evolved since the publication of this paper. An updated description is available as supplementary information.

This papier has been pubished in *Bioinformatics* (2010).
Bioinformatics (2010) 26 (14): 1766-1771. Doi: 10.1093/bioinformatics/btq283

1 Introduction

Databases dedicated to model species rely on the usage of ontologies, for example the zebrafish anatomy for ZFIN (Sprague, Bayraktaroglu, *et al.*, 2006), or the Mouse gross anatomy and development (Baldock, Bard, *et al.*, 2003). Such ontologies of anatomy and development facilitate the organization of functional data pertaining to a species. For example, all gene expression patterns described in ZFIN are annotated using the zebrafish anatomical ontology. A list of such ontologies is kept on the Open Biomedical Ontologies (OBO) website (Smith, Ashburner, *et al.*, 2007).

To pool the experimental data from different model species, we need to encode corresponding information between ontologies which describe different anatomies (e.g. zebrafish and human). For example, we are interested in integrating and comparing gene expression patterns between several species (Bastian, Parmentier, *et al.*, 2008). The most widely accepted criterion to make such comparisons in biology is homology (Hall, 1994; Hossfeld and Olsson, 2005). When we compare two elements, whether or not they are derived from the same ancestral element defines our expectation of similarity between them, and the interpretation of differences. For example, if a chicken wing is not homologous to a fly wing, we do not expect the same underlying structures, and similarities can be attributed to functional convergence. Whereas the chicken wing is homologous (as a limb) to the human arm, thus we do expect the same underlying structures, and differences can be attributed to divergent evolution. There are different definitions of homology (Roux and Robinson-Rechavi, 2010), and our algorithm does not in itself impose one on the user. We do recommend choosing an explicit definition and using it consistently throughout the analysis.

In practice, hundreds of terms must be compared between ontologies which may differ both in the actual biology modeled (i.e. a fish is not a mammal) and in the representation used. Although a purely manual annotation of homologies is possible, it would be too time consuming to be done for all terms between several divergent species. Kruger et al. (2007) have used a manual approach to find similarities between simplified anatomy ontologies for human and mouse. As both are mammals, they share most structures and terminology. There are also on-going efforts to integrate anatomical ontologies (e.g. Haendel, Neuhaus, *et al.*, 2008; Washington, Haendel, *et al.*, 2009), which are often geared towards the comparison of

phenotypes (Lussier and Li, 2004). As far as we know, the question of using homology to align anatomical ontologies has never been explicitly addressed.

Since the problem is to find correspondences between the concepts of two ontologies, we draw on methods from "schema matching", or "ontology alignment" (Euzenat and Shvaiko, 2007; Lambrix and He, 2008). As opposed to more generalist solutions, we present a algorithm which is specialized in the alignment of anatomical ontologies. The specificities of these ontologies include high redundancy of terms, and few types of relations. Finally, a specific issue is that structures which have the same name and are related to similar concepts may not be homologous. This is the case of the insect eye and the mammalian eye. While some underlying molecular mechanisms are similar, these structures evolved independently and are not considered homologous (discussed in Hall, 1994; Shubin, Tabin*, et al.*, 2009). Unsupervised alignment algorithms would misleadingly align such similarities; this is for instance the case for the LOOM software used on the NCBO portal (Ghazvinian, Noy*, et al.*, 2009).

In principle, an alignment algorithm should aim at finding the largest number of true positives, while avoiding false positives. In practice, our experience is that the size and structure of anatomical ontologies leads to very large numbers of false positives if a naive approach is taken (i.e. common words). Thus the basic aim of Homolonto is to propose in priority to the user the best candidate pairs of homologs, and avoid the need to consider many irrelevant pairs.

2 Systems and methods

Homolonto is implemented in Java. Ontologies are read in the OBO format (Smith, Ashburner*, et al.*, 2007). Homolonto is freely available in the download section of the Bgee website (http://bgee.unil.ch/).

3 Algorithm

3.1 Principle

Ontology alignment is the process of determining correspondences between ontology concepts. We present our approach based on the classification of ontology matching systems proposed by Euzenat and Shvaiko (2007; Shvaiko and Euzenat, 2005).

Biological ontologies simplify some aspects relative to the general case. The types of concepts (e.g. anatomical structures) and the relationships (e.g. *part_of*) are known in advance, and known to be common between the ontologies to align. Moreover, in the present implementation we only seek to establish one type of relation, homology.

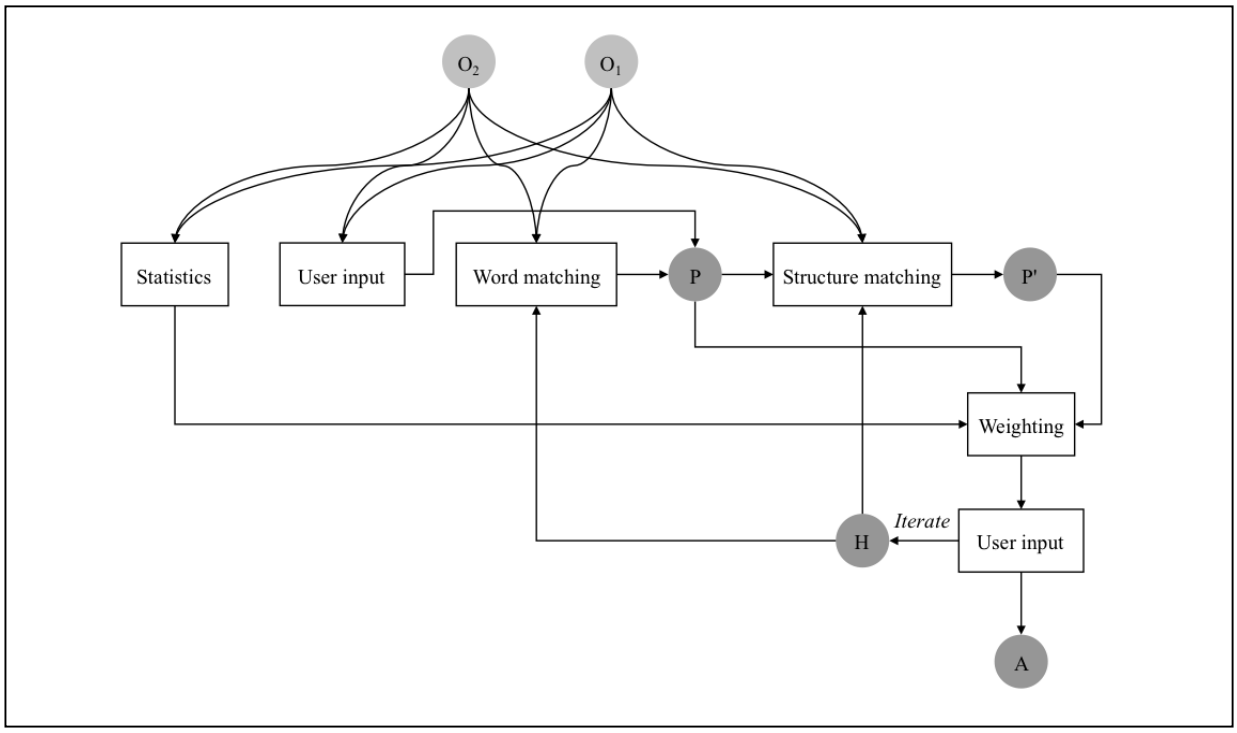


Fig. 1 : Homolonto pairwise alignment architecture

O_1 and O_2 are ontologies to align. P and P' are lists of propositions. H is a list of validated homologies and (invalidation information). A is the final alignment, generated when the user chooses to stop iterations. User input appears twice: to propose original pairings, and to validate propositions.

Our algorithm can be described as a composite system (Figure 1), using: (i) language based comparison of names with tokenization (element level, syntactic technique); (ii) graph based matching of children of elements (structure level, syntactic technique); (iii) data analysis, e.g. statistics on word occurrence (structure level, syntactic technique); (iv) external input from the user (element level, external technique) (classification following Euzenat and Shvaiko, 2007). We combine the results in parallel, as opposed to in sequence, by using a sum of scores from different techniques. Thus we make use both of schema and element level information. The algorithm produces in a first step anchors at the element level, generated by

language technique, and potentially by the user (external), then uses information from the schema, the elements, and user input, to improve the alignment based on these anchors.
Importantly, each proposition of homology between elements must be validated by the user (external input), to take into account such cases as the eye, discussed in the Introduction. Thus our process is a supervised one.
Finally, we note that the alignment we obtain is of the form many to many, not one to one.

3.2 Definitions

A central concept in our algorithm is that of a “proposition” (similar to "suggestion" in Lambrix and He, 2008). A proposition is a pair of terms (also called “class” in OWL) from the two ontologies for which a score has been computed. This may have been done based on homonymy (common words) of the term names (also called “class label” in OWL), or propagation through the ontology. It is important to note (i) that not all possible propositions (i.e. pairs of terms) are created during the alignment, and (ii) that the list of propositions evolves during iterations of the algorithm.
For performance, our algorithm is not symmetric. Propositions are managed relative to one ontology, “to align”, which is being aligned to the “reference ontology” (the one loaded first by the user). This allows us to store explicitly the information that term A of the ontology to align has two propositions, with term X and with term Y, of the reference ontology. If X has propositions with A but also with B of the ontology to align, this will not be taken into account explicitly.

3.3 Algorithm

(1) Computing word specific scores: score modifiers are computed for all words of the ontologies being aligned. Each word present at least once in both ontologies being aligned (O1 and O2) is given a score modifier based on its number of occurrences f(word, O):

$$\mathrm{Mod}(\mathrm{word}, O_i) = 1/(1+\log 10(f(\mathrm{word}, O_i))) \quad (1)$$

$$\mathrm{Mod}(\mathrm{word}) = \mathrm{Mod}(\mathrm{word}, O_1) * \mathrm{Mod}(\mathrm{word}, O2) \quad (2)$$

(2) Starting list of propositions (P in Figure 1): to initialize the algorithm we define first obvious similarities between the terms of the ontologies to align. Based on the assumption that two structures that have the same name are likely homologous, the initial propositions are

formed of terms with identical names. For example, “optic cup” of ZFA (zebrafish, Table 1) and “optic cup” of EHDAA (human, Table 1) will form a proposition. But “ventricle” and “cardiac ventricle” will not. In this process, we also consider the synonym field of the terms. For example the ZFA term “melanocyte” (synonym “melanophore”) will form a proposition with the term “melanophore” (synonym “melanocyte”) from XAO (Xenopus, Table 1).

Each pair of names n1, n2, is given a base score, dependent on the words shared:

$$\text{Base\_score}(n_1, n_2) = \frac{\text{base\_homonymy\_score} * \max(\text{Mod}(\text{word})) * |n_1 \cap n_2|}{\max(|n_1|, |n_2|)} \quad (3)$$

Where |n| is the number of words in n, |n1∩n2| is the number of words shared by n1 and n2, and max(Mod(word)) is computed over all shared words. In the starting list, |n1∩n2| = |n1| = |n2| by definition, but this is not the case at further iterations of the algorithm.
The comparison of terms names is intentionally quite basic, and does not take advantage of, e.g., etymology of words. In our experience, terms names used in anatomical ontologies are similar enough that more sophisticated approaches generate too many false positives, without improving the recovery of true positives.

(3) Initial propagation step: the score of these propositions is propagated between neighbors. This initial propagation is bidirectional, and limited to already defined propositions. For example, the score of the “optic cup” pair is added to the score of the “eye” pair, as “optic cup” is part of “eye”, and both pairs are initial propositions. Symmetrically the score of the “eye” pair is added to the “optic cup2 pair. But the score of “eye” is not propagated to e.g. the pairing of “visual system” (ZFA parent of “eye”) with “sensory organ” (EHDAA parent of “eye”), because this pair is not an initial proposition. The aim of this step is to increase the score of the most likely homologs (resulting in P' in Figure 1).

(4) Cleaning the initial proposition list: the design of some ontologies may generate many false positives, typically through repetition of the same name as a child of diverse structures (e.g. 76 occurrences of “mesenchyme” in EHDAA). To avoid this, if a term is a member of several propositions with different scores, we initially keep only the best scoring proposition.

If there are more than 5 highest scoring propositions for a given term, the algorithm removes all propositions for this term.

(5) Evaluation step: each proposition is presented to the user, in descending order of scores. The user has four options for each proposition: (i) validation as homology; this excludes further pairings of the form sibling of term A with term B, or A with sibling of B. (ii) Validation as "partial homology"; this allows further pairing of siblings of A with B, or of A with siblings of B. These may be due to differences in ontology representation. This is also useful to manage serial homology: all somites may be defined as homologous inside one individual. (iii) Invalidation. (iv) Delay decision concerning this proposition.
The user may chose to evaluate any number of propositions before provoking the computation step. It is recommended in most cases to proceed to computation ("iterate" in the GUI) after every decision.

(6) Computation step: if one of the terms of a validated pair is already a member of an homology group, then the other term is added to the homology group. Otherwise, a new homology group is created, containing both terms of the validated pair (H in Figure 1). The information of homology is propagated through the hierarchy by the use of a validated homology score (eq. 4). The underlying idea is that if two terms A and B are homologous, then one of the children of A is probably homologous to one of the children of B. During the propagation the validated homology score is added to the base score (eq. 3) of pairs of terms:

$$\text{Propagated\_score(a, b)} = \frac{\text{validated\_homology\_score} * (\text{max\_depth} + 1 - \text{present\_depth})}{(\text{max\_depth} + 1)} \quad (4)$$

$$\text{Total\_score(a, b)} = \text{Propagated\_score(a, b)} + \text{Base\_score}(n_a, n_b) \quad (5)$$

Where n_a is the name of term a. In the present implementation, the propagation depth is 1, and the validated homology score is 1.5 times the base homonymy score. For pairs of terms which are not yet a proposition, a new proposition is created, and the base score is computed. This will include cases of partial homonymy, for which eq. 3 down weights names which share a

lower proportion of words. Pairs which have been previously invalidated by the user will not receive a propagated score, and will remain invalidated.

To down weight potential false positives due to validation of terms with many children, the propagated score is reduced proportionally to the number of new propositions for each term of the ontology to align (eq. 5b).

$$\text{Total\_score}(a, b_i) = \frac{\text{Propagated\_score}(a, b_i)}{(|b|+1)*2} + \text{Base\_score}(n_a, n_{bi}) \quad (5b)$$

Where a is a term of the ontology to align, b_i is a term of the reference ontology, and |b| is the number of new propositions for term a. When a proposition (a, b_i) is invalidated, |b| is updated, and the Total score(a, b_i) increases for the remaining propositions.

When the terms of an invalidated proposition share common words, then the score modifiers of all shared words is diminished (eq. 6). As this is repeated, words which tend to generate false positives will be increasingly down weighted.

$$\text{Mod(word)} = \text{Mod(word)} * 0.9 \quad (6)$$

(7) Iteration: evaluation of propositions (step 5), ordered by total score (base score + propagated score), and computation (step 6), is repeated until the user decides to terminate, or no more propositions are generated (resulting in the alignment A in Figure 1).

4 Implementation and graphical user interface

Homolonto displays the input OBO ontologies under a tree representation form. The user may browse the ontology, and a basic "find" tool has been implemented. Before starting the alignment algorithm, the user has the possibility to manually specify homology relations. This allows potential anchoring of structures with very different names between species, based on known biology (e.g. limb and fin). Once the alignment algorithm is run, a new window opens and displays the best propositions, one at a time, in order of score. For each term of a proposition, the parents are shown for two levels, to help the decision. Clicking on a term identifier opens the first occurrence of that term in the ontology browser window, where the user can check for more information (e.g. synonyms, develops_from relations). Decisions can

be annotated with comments and with a link, similar to the "dbxref" field of OBO-Edit (Day-Richter, Harris*, et al.*, 2007).

To facilitate alignment of large ontologies, keyboard shortcuts are implemented for the most common decisions: enter key = validation as homology plus computation and iteration; escape key = invalidate plus computation and iteration; right and left arrows to see the next and previous propositions without computation.

When several pairwise alignments have been conducted, Homolonto offers a function to reconcile them, if they share a common ontology. Thus if both pairs human and mouse, and human and zebrafish, have been aligned, the triplets human - mouse - zebrafish are created. This means that the number of propositions to validate does not need to increase in $O(N^2)$. Rather, each new ontology must be fully aligned to only one already aligned ontology, then the missing homologies must be informed. A judicious choice of the initial pairwise alignment should minimize these missing homologies.

5 Relationships between homology groups

Homolonto is used to generate pairwise homology relationships between anatomical ontologies. As homology relationships are transitive, Homolonto offers the option to merge these pairwise alignments into homologous organs groups (HOGs). This generates both the HOGs, and the mapping of species-specific anatomical structures to these HOGs. HOGs then need to be structured as an ontology to allow reasoning on them. This means that, at a minimum, relationships amongst them have to be designed. Another algorithm has thus been developed to infer relationships between HOGs.

(1) Initial Step: all possible paths between HOGs are retrieved. For instance, if an anatomical structure "a", mapped to the HOG "A", has a *part_of* relationship to the anatomical structure "b", mapped to the HOG "B", then a putative *part_of* relationship is defined between HOGs "A" and "B". Relationships between HOGs are often indirect (e.g. structure "a", mapped to HOG "A", *part_of* structure "c", *part_of* structure "b", mapped to HOG "B"). If the first relation (the relation "outgoing" from the child HOG, "A" in the previous example) and the last relation (the relation "incoming" to the parent HOG, "B" in the previous example) are of

the same type (e.g. *part_of*, *is_a*), then the putative relationship is defined as this type. Otherwise, the relationship is defined as the SKOS type *broader_than*[3].

(2) Skipping relations from non-trusted ontologies: some ontologies do not follow the OBO principles, and implement for instance only one type of relation amongst all concepts (e.g. EV (Kelso, Visagie*, et al.*, 2003) only uses *is_a* relationships). The user may choose to not use these ontologies to define relation types. All the putative relations inferred by these ontologies at step 1 are then set as *broader_than*. But the final relation type between these HOGs can still be inferred thanks to other ontologies.

(3) Skipping relations defined by too few ontologies: if the proportion of ontologies defining a relation, compared to the total number of ontologies involved in the creation of the HOGs, is below a threshold defined by the user ("ontology coverage"), then the relation is defined to the type *broader_than*, and the algorithm stops examining relations between these HOGs.

(4) Defining within-ontology agreement: several anatomical structures from the same ontology can belong to the same HOG. This can generate a within-ontology conflict for defining a relation type. For instance, structures "a" and "b" allow to define a putative *part_of* relationship between HOGs "A" and "B", while structures "a' " and "b' ", belonging to the same ontology, define a putative *is_a* relationship between these HOGs. The algorithm then calculates, for each relation type, the proportion that the number of paths defining this relation type represents, compared to the total number of paths between these two HOGs for this ontology. If, for a type, this proportion exceeds a threshold ("within-ontology agreement"), defined by the user and at least greater than 0.5, then this relation type is attributed for this ontology between these HOGs. Otherwise, the relation is defined to the type *broader_than* for this ontology.

(5) Defining inter-ontology agreement: different ontologies can define different relation types between two related HOGs. This conflict is resolved in the same way as at step 4, by using a threshold ("inter-ontology agreement"), defined by the user and at least greater than 0.5.

[3] http://www.w3.org/TR/2008/WD-skos-reference-20080829/

(6) Removing cyclic relationships: by inferring automatically the relationships between HOGs, cycles may be generated (e.g. HOG "A" *part_of* HOG "B" *part_of* HOG "A"), whereas an ontology has to be acyclic. If such cycles are detected, the algorithm stops with an error message prompting the user to make a decision: the user has then to manually remove one of the involved relationships.

(7) Removing redundancies: if several relationships are redundant, only the deepest relationship is conserved; for instance, if a HOG "A" has two substructures by a *part_of* relationship, "B" and "C", and if "C" is also a substructure of "B", then the direct relationship between the HOGs "A" and "C" is removed.

(8) Curation step: a curator can then manually review the *broader_than* relations, to attribute them to a type defined by the OBO Relation Ontology (Smith, Ceusters*, et al.*, 2005). Some custom relationships, not inferred by the algorithm, can also be added at this step.

6 Results

To date, the use of Homolonto, followed by a curation process, has allowed to define 1,002 HOGs, involving 4,459 structures from 7 anatomical ontologies: ZFA (Sprague, Bayraktaroglu*, et al.*, 2006), EHDAA (Aitken, 2005; Hunter, Kaufman*, et al.*, 2003), EV (Kelso, Visagie*, et al.*, 2003), EMAPA (Aitken, 2005; Hunter, Kaufman*, et al.*, 2003), MA (Smith, Ashburner*, et al.*, 2007), XAO (Bowes, Snyder*, et al.*, 2008) and FBbt (Grumbling, Strelets*, et al.*, 2006). The algorithm to design relationships amongst the HOGs inferred 1,411 relations. With the most stringent parameters (ontology coverage = 1, within-ontology agreement = 1, inter-ontology agreement = 1), 222 of them were defined automatically as *part_of*, 15 as *is_a*, all the others as *broader_than*. After curation, there are 1179 *part_of* and 232 *is_a* relations. The resulting alignments are used in the database Bgee (Bastian, Parmentier*, et al.*, 2008). Thus an important result is that we have been able to implement in a practical manner anatomical homology relationships.

Here we present, in more detail, two alignments (Table 1): First, zebrafish / Xenopus, which illustrates a best case scenario of two consistent ontologies, conforming to the CARO standards (Haendel, Neuhaus*, et al.*, 2008), with annotations of synonyms and definitions, and low redundancy. On the other hand, Xenopus (a frog) and zebrafish (a ray-finned fish) present

important differences in anatomy. And second, human / mouse which, despite the similarity in anatomy, illustrates a more difficult scenario of large ontologies, with issues such as repetition of names (76 occurrences of “mesenchyme” in human, 93 in mouse), due to splitting of concepts among morphological structures or among developmental stages.

The main observation is that our algorithm is successful at ordering propositions. In the “easy” case of zebrafish / Xenopus (Sup Figure S1; Sup Figure S2), there are only seven invalidated propositions in the first 150 (95% validation). This is followed by a relatively short interval of iterations where validated and invalidated propositions are mixed: 46% of validations between iterations 151 and 200, and 20% between 201 and 250. Further iterations generate mostly invalidated propositions (3% validation from 251 to 735). Thus 93% of all validations occurred in the first 250 iterations. Looking in more detail, the first propositions are terms which share many children. Thus the first proposition pairs “organism subdivision” from each ontology, which share four children with identical names (“head”, “trunk”, “tail”, and “surface structure”). The second proposition pairs two terms which have different names, but are identified readily thanks to their synonyms: XAO:0000023 “skin”, synonym “integument”, and ZFA:0000368 “integument”, synonym “skin” (IDs correspond to the versions used for the alignment; Table 1). The first invalidated proposition (iteration 77) has a peculiar status, since both ontologies include a term “unspecified”, which are equivalent but cannot be defined as homologous. The next invalidated proposition (iteration 130) is between XAO:0000313 “head somite” and ZFA:0001462 “somite border”. Indeed, early in the iterations, sharing a parent “somite” plus sharing the word “somite” brings a relatively high score. But since propositions based on this are usually invalidated, the word “somite” loses weight (equation 6), and further propositions based on this similarity receive lower scores. Thus whereas there are in principle 24 possible propositions between the Xenopus and zebrafish ontologies based on “somite”, only 13 were considered in this very thorough alignment (including the validated pair XAO:0000058 “somite” - ZFA:0000155 “somite”). At the other extreme of the alignment, the last validated propositions (iterations 607-610) concern aortic arches which were named e.g. “aortic arch 4” in zebrafish, but “fourth aortic arch” in Xenopus. Their low scores were due to the high frequency of the words “aortic” and “arch” in both ontologies (Table 2).

	Zebrafish	Xenopus	Human	Mouse
Ontology [a]	ZFA	XAO	EHDAA	EMAPA
Number of terms	1974	569	2327	3525
with synonyms	1080	122	0	0
with definitions	772	186	0	0
Number of validations [b]	189		1959	
Number of invalidations	543		1003	
Number of unique terms aligned	183	182	1541	1754

Table 1: Summary of the alignments discussed.

(a) References for the ontologies aligned are: ZFA (Sprague, Bayraktaroglu, *et al.*, 2006) (version of 24:10:2007); XAO (Bowes, Snyder, *et al.*, 2008) (version of 07:11:2007); EHDAA (Aitken, 2005; Hunter, Kaufman, *et al.*, 2003) (version of 08:04:2005); EMAPA (Aitken, 2005; Baldock, Bard, *et al.*, 2003) (version of 08:04:2005).
(b) Including "partial" validations.

The pattern is similar for the human / mouse alignment (Sup Figure S3). In the first 1400 iterations, 99% of propositions are validated. In the next 600 iterations, the figure reduces to 63%, and in the last 962 iterations it falls to 21%. This slower decrease illustrates the complexity of this alignment. Although 2962 iterations may seem large, three points should be noted: (i) this is a worst case scenario, aligning two large anatomical ontologies, which lack important information such as definitions and synonyms, and are not up to recent standards (Haendel, Neuhaus, *et al.*, 2008). (ii) This represents in our experience only 15 person-days of work, which means an iteration takes on average 2 to 3 minutes (on a Dual-core processor at 2.66 GHz, with 2Go of DDR2 memory). This is possible because many answers are obvious to the annotator in context of the information provided by the graphical user interface. For example while the term EMAPA:18280 "intrinsic" may appear enigmatic, its *part_of* relationship to "skeletal muscle" *part_of* "tongue", makes its homology to EHDAA:9140 "intrinsic muscle" *part_of* "skeletal muscle" *part_of* "tongue" clear. Conversely, EMAPA:16370 "cardiovascular system" *part_of* "extraembryonic component", is not homologous to EHDAA:394 "cardiovascular system", *part_of* "organ system" *part_of* "embryo" (Table 2). (iii) The 2962 propositions evaluated represents much less than the 8,202,675 possible pairs of terms between these two ontologies (2327 × 3525; Table 1). The validation rate of 66% shows that these were mostly propositions worth considering, and that the time spend was due indeed to the size of the ontologies, not to a default in the algorithm. Results also show that manual expertise is necessary, since even in the high scoring propositions some are invalid (Table 2). The example of "cardiovascular system"

(EMAPA:16370 / EHDAA:394) given above appears at iteration 416, with a score improved by shared subcomponents ("venous system" and "arterial system"). Overall, 27% of invalidations are pairs of terms with identical names. Interestingly, Homolonto manages to give these misleading homonyms low priority: homonyms within the first 1000 iterations have a 99% chance of being homologs, whereas homonyms within the last 1000 iterations only have a 19% chance of being homologs. Thus 93% of invalidated homonyms appear after iteration 1400.

It is also of interest to consider the capacity of Homolonto to recover homologous terms which are not described by the same name, in a case such as human / mouse where synonyms are not available. Of the 1959 validated homologs, 17% do not have identical names. Many of these share partial homonymy, as between EMAPA:17865 "bulbo-ventricular region" and EHDAA:766 "bulbo-ventricular groove". Such propositions will be recovered by the combination of word matching and propagation of other validated homology relationships (i.e. both are *part_of* "heart"). Structural matching is also able to recover cases with no word matching, as in EMAPA:16211 "cardiac muscle" / EHDAA:430 "myocardium". In this case, both terms are *part_of* "early primitive heart tube". In both ontologies, the latter term has two other children, which are homonyms and homologs: "endocardial tube" and "cardiac jelly". When the homonymous terms have been validated, "cardiac muscle" and "myocardium" remain the only pair of children of "early primitive heart tube", which permits their pairing as a reasonable proposition, following equation 5b. Similarly, XAO:0003033 "nostril" and ZFA:0000550 "naris" are correctly identified as homologs, since both have *is_a* relations to "surface structure", and *part_of* "head".

Term 1	Term 2	Homolonto result	Frequency of shared words [a]
XAO:0000399 tendon fibroblast	ZFA:0009296 perijunctional fibroblast	False positive [b]	3
EMAPA:16370 cardiovascular system (part_of extraembryonic component)	EHDAA:394 cardiovascular system (part_of organ system part_of embryo)	False positive [b]	3
EMAPA:16754 central nervous system (part_of tail)	EHDAA:828 central nervous system (part_of nervous system)	False positive [b]	3
XAO:0000385 pronephric sinus (part_of pronephric kidney)	ZFA:0001557 pronephric glomerulus (part_of pronephros)	False positive [b]	36
XAO:0000119 lung (part_of respiratory system)	ZFA:0000354 gill (part_of respiratory system)	False positive [b]	-
XAO:0000355 fourth aortic arch	ZFA:0005008 aortic arch 4	False negative [c]	43
EMAPA:17340 right ventricle (part_of ventricle)	EHDAA:1916 right part (part_of ventricle)	False negative [c]	67
EMAPA:17853 naso-lacrimal duct (part_of nose)	EHDAA:7837 nasolacrimal duct (part_of nasolacrimal groove)	False negative [c]	75
XAO:0000050 mesoderm (part_of embryo)	ZFA:0000041 mesoderm (part_of primary germ layer)	False negative [d]	183

Table 2. Examples of false positives and false negatives.
a: Sum of frequencies in the two ontologies being compared.
b: Proposition with a high score between non homologous structures.
c: Proposition with a low score between homologous structures.
d: No proposition reported between homologous structures.

7 Discussion

The main feature of Homolonto is its efficiency in identifying and ranking valid pairs of terms. Although most homologies concern terms with the same name, the algorithm is successful both in generating relevant propositions for terms with different names, and in ranking poorly terms with the same name which are not homologs. The algorithm has been shown to perform well in proposing valid pairs of homologous terms for two quite different

cases. Zebrafish and Xenopus have divergent anatomies, from the two major branches of vertebrates (ray-finned fishes and tetrapodes), but are described by ontologies which follow consistent guidelines (Haendel, Neuhaus*, et al.*, 2008). The Xenopus ontology is also relatively small. Conversely, human and mouse have very similar anatomies (both are mammals), but are described by large ontologies with little structured information. Despite these differences, the results of Homolonto are consistent, proposing almost exclusively valid pairs in a first series of iterations covering approximately half of the smaller ontology: 250 iterations for Xenopus / zebrafish, 1400 iterations for human / mouse.

The size of some biological ontologies makes the user interface important. The GUI of Homolonto provides rapid access to information about the terms considered, and includes keyboard shortcuts. The combination of an algorithm which proposes relevant pairs of terms, and of this GUI, allows the alignment of large ontologies of anatomy in reasonable time (i.e. weeks).

As all propositions have to be manually validated, the expertise of the curator is important to consider. In our experience, most propositions between closely-related species represent "text-book" knowledge, that do not require the curator to be an anatomy expert (although s/he needs to be a biologist). On the other hand, when dealing with complex structures (e.g. substructures of the brain) or distant species (e.g. alignment of insect and vertebrate anatomies), such an expertise might be needed.

Future development of Homolonto should include more relationships than simple homology. For example, homoplasy (analogy in the common sense of the word) may be relevant in cases of functional equivalence, such as the vertebrate and insect eyes. Also, it would be of interest to model explicitly serial homology, to improve the management of e.g. somites.

Acknowledgements

We thank Aurélie Comte, Anne Niknejad and Emilie Person for manual verification of homology groups within Bgee.

Funding: We acknowledge funding from Etat de Vaud, Swiss National Science Foundation grant 116798, the Décrypthon program of AFM and the European program Crescendo.

8 References

Aitken, S. (2005) Formalizing concepts of species, sex and developmental stage in anatomical ontologies, *Bioinformatics*, **21**, 2773-2779.

Baldock, R.A., Bard, J.B., Burger, A., Burton, N., Christiansen, J.*, et al.* (2003) EMAP and EMAGE: a framework for understanding spatially organized data, *Neuroinformatics*, **1**, 309-325.

Bastian, F., Parmentier, G., Roux, J., Moretti, S., Laudet, V.*, et al.* (2008) Bgee: Integrating and Comparing Heterogeneous Transcriptome Data Among Species. Springer, Evry, France, pp. 124-131.

Bowes, J.B., Snyder, K.A., Segerdell, E., Gibb, R., Jarabek, C.*, et al.* (2008) Xenbase: a Xenopus biology and genomics resource, *Nucleic Acids Res*, **36**, D761-767.

Day-Richter, J., Harris, M.A., Haendel, M., The Gene Ontology, O.B.O.E.W.G. and Lewis, S. (2007) OBO-Edit - An Ontology Editor for Biologists, *Bioinformatics*, btm112.

Euzenat, J. and Shvaiko, P. (2007) *Ontology Matching*. Springer Verlag, Berlin, Heidelberg.

Ghazvinian, A., Noy, N.F. and Musen, M.A. (2009) Creating Mappings For Ontologies in Biomedicine: Simple Methods Work. *AMIA*. San Francisco, CA.

Grumbling, G., Strelets, V. and The FlyBase, C. (2006) FlyBase: anatomical data, images and queries, *Nucl. Acids Res.*, **34**, D484-488.

Haendel, M.A., Neuhaus, F., Osumi-Sutherland, D., Mabee, P.M., Jr., J.L.V.M.*, et al.* (2008) CARO —The Common Anatomy Reference Ontology. In Burger, A., Davidson, D. and Baldock, R. (eds), *Anatomy Ontologies for Bioinformatics: Principles and Practice*. Springer, New York, pp. 327-349.

Hall, B. (1994) Homology: The Hierarchical Basis of Comparative Biology. Academic Press.

Hossfeld, U. and Olsson, L. (2005) The history of the homology concept and the "Phylogenetisches Symposium", *Theory in Biosciences*, **124**, 243-253.

Hunter, A., Kaufman, M.H., McKay, A., Baldock, R., Simmen, M.W.*, et al.* (2003) An ontology of human developmental anatomy, *Journal of anatomy*, **203**, 347-355.

Kelso, J., Visagie, J., Theiler, G., Christoffels, A., Bardien, S.*, et al.* (2003) eVOC: a controlled vocabulary for unifying gene expression data, *Genome research*, **13**, 1222-1230.

Kruger, A., Hofmann, O., Carninci, P., Hayashizaki, Y. and Hide, W. (2007) Simplified ontologies allowing comparison of developmental mammalian gene expression, *Genome Biology*, **8**, R229.

Lambrix, P. and He, T. (2008) Ontology alignment and merging. In Burger, A., Davidson, D. and Baldock, R. (eds), *Anatomy Ontologies for Bioinformatics: Principles and Practice*. Springer, New York, pp. 133-149.

Lussier, Y.A. and Li, J. (2004) Terminological mapping for high throughput comparative biology of phenotypes. *Pac Symp Biocomput.*, pp. 202-213.

Roux, J. and Robinson-Rechavi, M. (2010) An ontology to clarify homology-related concepts, *Trends in Genetics*, **in press**.

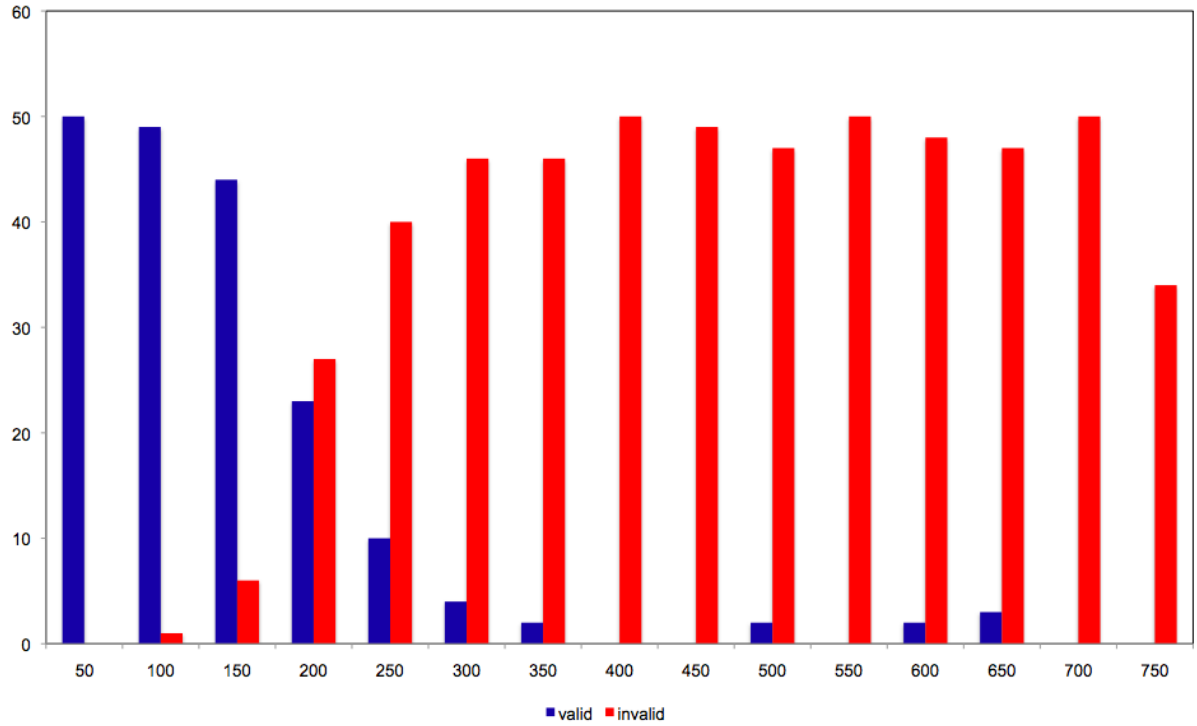
Shubin, N., Tabin, C. and Carroll, S. (2009) Deep homology and the origins of evolutionary novelty, *Nature*, **457**, 818-823.

Shvaiko, P. and Euzenat, J. (2005) A SURVEY OF SCHEMA-BASED MATCHING APPROACHES, *Journal on Data Semantics*, **IV**.

Smith, B., Ashburner, M., Rosse, C., Bard, J., Bug, W.*, et al.* (2007) The OBO Foundry: coordinated evolution of ontologies to support biomedical data integration, *Nat Biotech*, **25**, 1251-1255.
Smith, B., Ceusters, W., Klagges, B., Kohler, J., Kumar, A.*, et al.* (2005) Relations in biomedical ontologies, *Genome Biol*, **6**, R46.
Sprague, J., Bayraktaroglu, L., Clements, D., Conlin, T., Fashena, D.*, et al.* (2006) The Zebrafish Information Network: the zebrafish model organism database, *Nucleic acids research*, **34**, D581-585.
Washington, N.L., Haendel, M.A., Mungall, C.J., Ashburner, M., Westerfield, M.*, et al.* (2009) Linking Human Diseases to Animal Models Using Ontology-Based Phenotype Annotation, *PLoS Biol*, **7**, e1000247.

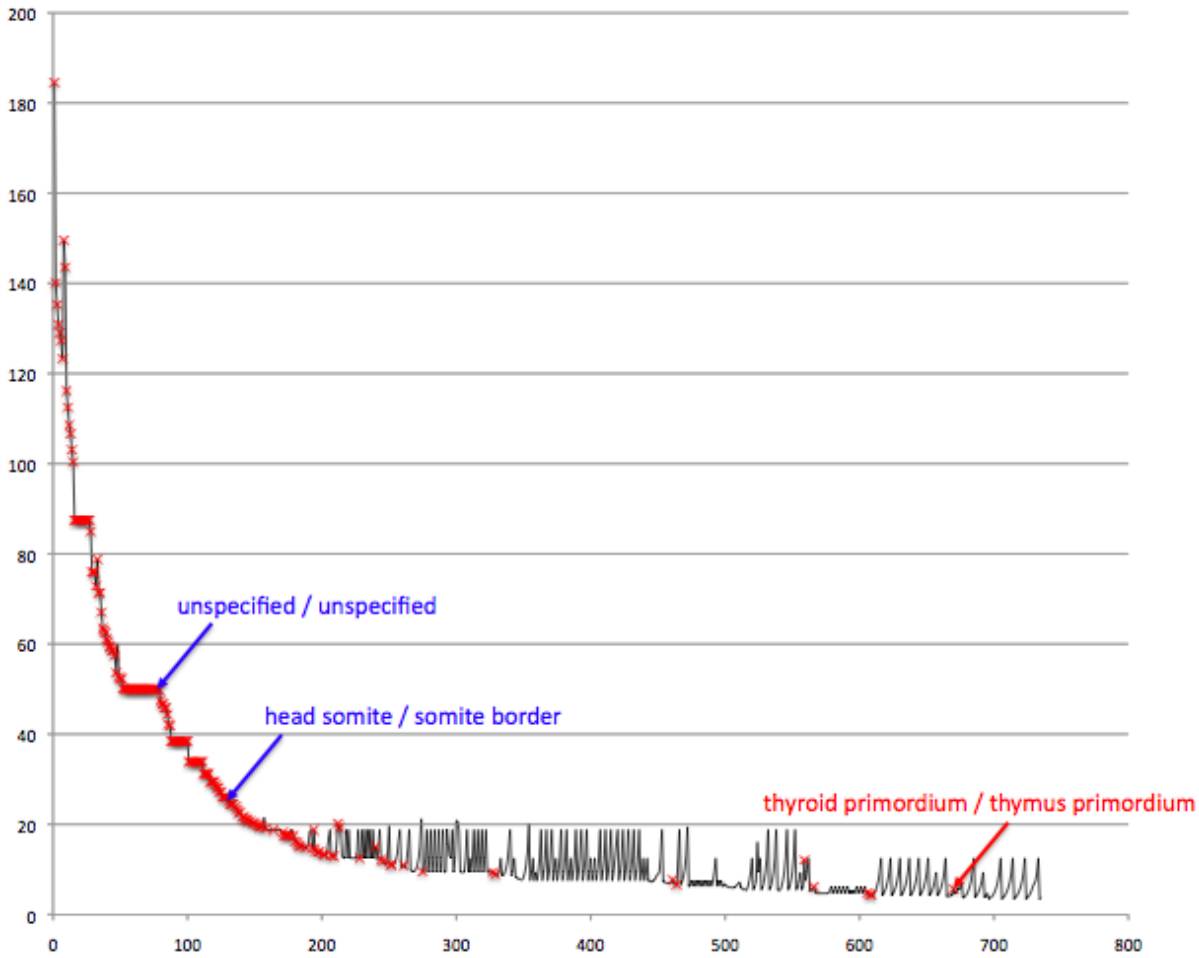
9 Supplementary Figures

9.1 Supplementary figure S1



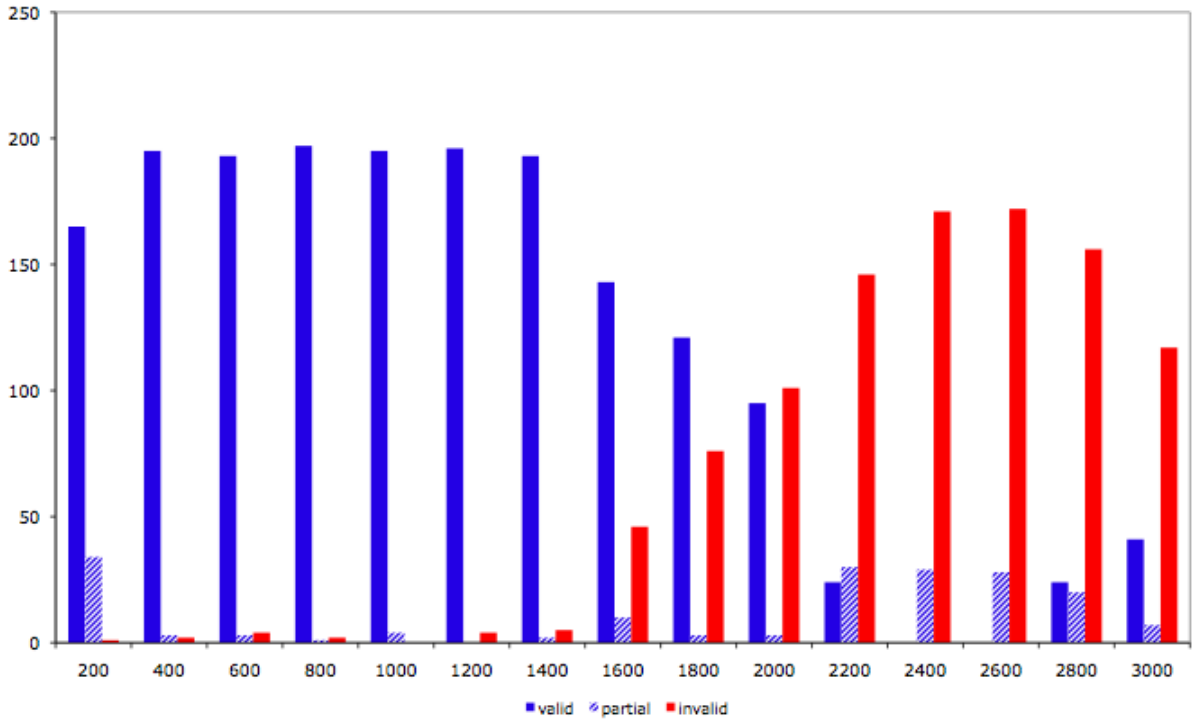
Supplementary Figure S1: Breakdown of decisions during iterations of the alignment of zebrafish (ZFA) and Xenopus (XAO). The ZFA and XAO ontologies (Table 1) were aligned. For each window of 50 iterations of the algorithm, the number of decisions of validation (blue) or invalidation (red) are plotted.

9.2 Supplementary figure S2



Supplementary Figure S2: Alignment scores between zebrafish (ZFA) and Xenopus (XAO)
The ZFA and XAO ontologies (Table 1) were aligned. Each point corresponds to one proposition. X-axis, iteration number; Y axis, the score of the proposition. Black line: all propositions generated by Homolonto. Red crosses: validated propositions. Blue arrows: first two invalidated propositions; red arrow: last validated proposition.

9.3 Supplementary figure S3



Supplementary Figure S3: Breakdown of decisions during iterations of the alignment of human (EHDAA) and mouse (EMAPA)
The EHDAA and EMAPA ontologies (Table 1) were aligned. For each window of 200 iterations of the algorithm, the number of decisions of validation (blue), validation as partial homology (hatched blue), or invalidation (red) are plotted.

10 Supplementary Information

The relationships between HOGs are generated though several steps. Several changes have been made since the publication of this paper. This is the most up-to-date version available from our website.

1. Initial Step: all possible paths between HOGs are retrieved. For instance, if an anatomical structure 'a', mapped to the HOG 'A', has a *part_of* relationship to the anatomical structure 'b', mapped to the HOG 'B', then a putative *part_of* relationship is defined between HOGs 'A' and 'B'. Relationships between HOGs are often indirect (e.g. structure 'a', mapped to HOG 'A', *part_of* structure 'c', *part_of* structure 'b', mapped to HOG 'B'). In such cases, based on OBO Foundry composition rules[4], *part_of* relations always "win". So, if a *part_of* relationship is seen along the path between two HOGs, then the putative relationship is *part_of*.
2. Skipping relations from non-trusted ontologies: some ontologies do not follow OBO principles, and implement for instance only one type of relation amongst all concepts. All the putative relations inferred by these ontologies during initial step are then set as the SKOS[5] type *broader_than*. But the final relation type between these HOGs can still be inferred thanks to other ontologies. For the current release of the HOG ontology, the non-trusted ontologies are: EV, EHDAA, EMAPA.
3. Skipping relations defined by too few ontologies: if the proportion of ontologies defining a relation, compared to the total number of ontologies involved in the creation of the HOGs, is below a defined threshold ('ontology coverage'), then the relation is defined to the SKOS type *broader_than*, and the algorithm stops examining relations between these HOGs. Note that if the relation is set to *broader_than* during this step, it is probably the existence of the relation itself that is uncertain, not especially the type of the relation. For the current release of the HOG ontology, the ontology coverage threshold is set to 1.
4. Defining within-ontology agreement: several anatomical structures from the same ontology can belong to the same HOG. This can generate a within-ontology conflict for defining a relation type. For instance, structures 'a' and 'b' allow to define a putative *part_of*

[4] http://wiki.geneontology.org/index.php/Relation_composition

[5] http://www.w3.org/TR/2008/WD-skos-reference-20080829/

relationship between HOGs 'A' and 'B', while structures 'a″ and 'b″, belonging to the same ontology, define a putative *is_a* relationship between these HOGs. The algorithm then calculates, for each relation type, the proportion that the number of paths defining this relation type represents, compared to the total number of paths between these two HOGs for this ontology. If, for a type, this proportion exceeds a defined threshold ('within-ontology agreement'), then this relation type is attributed for this ontology between these HOGs. Otherwise, the relation is defined to the type *broader_than* for this ontology. For the current release of the HOG ontology, the within-ontology agreement threshold is set to 1.

5. Defining inter-ontology agreement: different ontologies can define different relation types between two related HOGs. This conflict is resolved in the same way as at the previous step, by using a defined threshold ('inter-ontology agreement'). Note that *broader_than* relations are not taken into account at this step, e.g.: if three ontologies define a *broader_than* relation between two HOGs, and another ontology defines a *is_a* relation, the final relation will be *is_a*. If no agreement is found, the final relation type between these two HOGs is defined as *broader_than*.For the current release of the HOG ontology, the inter-ontology agreement threshold is set to 1
6. Removing cyclic relationships: by inferring automatically the relationships between HOGs, cycles may be generated (e.g. HOG 'A' *part_of* HOG 'B' *part_of* HOG 'A'), whereas an ontology has to be acyclic. If such cycles are detected, the algorithm stops, and one of the involved relationships is manually removed.
7. Removing redundancies: if several relationships are redundant, only the deepest relationship is conserved; for instance, if a HOG 'A' has two substructures by a *part_of* relationship, 'B' and 'C', and if 'C' is also a substructure of 'B', then the direct relationship between the HOGs 'A' and 'C' is removed. Note that according to OBO Foundry composition tules, the following relations are NOT redundant, e.g.: C *is_a* B *part_of* A / C *is_a* A => according to composition rules, C *is_a* B *part_of* A equals C *part_of* A, so C *is_a* A is not redundant.
8. The algorithm then searches for potential errors: HOGs with multiple or no *is_a* relations (according to the FMA policy[6] of single *is_a* inheritance and completeness), HOGs with too many or no *part_of* relations.

[6] http://sigpubs.biostr.washington.edu/archive/00000204/

9. Curation step: curators then manually review all the *broader_than* relations, to attribute them to a type defined by the OBO Relation Ontology[7]. Some custom relationships, not inferred by the algorithm, can also be added at this step, and some relations inferred by the algorithm can also be removed.

[7] http://www.obofoundry.org/ro/

vHOG, a multi-species vertebrate ontology of homologous organ groups

Anne Niknejad[1,2], Aurélie Comte[1,2], Gilles Parmentier[1,2], Julien Roux[1,2], Frederic B. Bastian[1,2,*], Marc Robinson-Rechavi[1,2]

[1] Department of Ecology and Evolution, Biophore, University of Lausanne, 1015 Lausanne, Switzerland

[2] Swiss Institute of Bioinformatics, 1015 Lausanne, Switzerland

[*] Corresponding author: frederic.bastian@unil.ch

Abstract

We describe the vertebrate Homologous Organs Groups ontology, vHOG. vHOG is a multi-species anatomical ontology for the vertebrate lineage. vHOG version 1 includes 1,176 terms, follows OBO principles, and is based on the Common Anatomy Reference Ontology (CARO). vHOG only describes organs with historical homology relations between model vertebrate species. The mapping to species-specific anatomical ontologies is provided as a separated file, so that no homology hypothesis is stated in the ontology itself. Each mapping has been manually reviewed, and we provide support codes and references when available. vHOG is available from the Bgee download site, as well as from the OBO Foundry and the NCBO Bioportal websites.

My contribution was to co-supervise this work with Marc Robinson-Rechavi.

This will be submitted to *Bioinformatics*.

1 Introduction

There has been an important effort to build ontologies which describe the anatomy of human and of animal model organisms (Bard, 2008). But these ontologies have tended to be species-specific, resulting in an increasing number of ontologies corresponding to different projects (see the OBO Foundry and the NCBO Bioportal, Noy, Shah, *et al.*, 2009; Smith, Ashburner, *et al.*, 2007). This makes the comparison between species difficult, since differences in representational schemes and in vocabulary are added to the differences in biology. Yet automatic comparisons are increasingly necessary, with large amounts of functional data generated in diverse model organisms. An integrated view is advantageous both for a fundamental understanding of animal biology and evolution, and for the efficient transfer of information from model organisms to human or veterinary medicine.

There are several ongoing efforts to create multi-species ontologies for animal groups. The most advanced, to our knowledge, is the Teleost Anatomy Ontology (TAO) (Dahdul, Lundberg, *et al.*, 2010). The TAO is based on the Zebrafish Anatomy Ontology (ZFA) (from the ZFIN database, Bradford, Conlin, *et al.*, 2011), and uses general (higher level) terms from the Common Anatomy Reference Ontology (CARO) (Haendel, Neuhaus, *et al.*, 2008). The CARO was created to provide a common basis for all future anatomy ontologies, and facilitate their inter-operability. Several other efforts follow the same model as the TAO, and include the Amphibian Anatomy Ontology, and the Hymenoptera Anatomy Ontology. In each of these cases, there is an effort to describe the morphological diversity of the clade. Consequently, each ontology will include terms which are found in several species of the clade. A species-specific ontology (e.g., ZFA) is considered a subset of the multi-species ontology (e.g., TAO), and terms from the former are related to their corresponding terms in the latter by *is_a* relations.

A multi-species ontology can also be created by merging the species specific ontologies, based on mapping. This is the approach that we have taken, based on our software Homolonto to align ontologies (Parmentier, Bastian, *et al.*, 2010), which generates a multi-species ontology of Homologous Organ Groups (HOGs). These HOGs are used in our database of gene expression evolution, Bgee (Bastian, Parmentier, *et al.*, 2008). A similar approach is

taken by the Uberon project[8]. A major difference between these two projects is that Uberon maps very liberally, and errs on the side of false positives, whereas mappings in the HOGs are restricted to manually curated relations of homology, and err rather on the side of false negatives.

Multi-species ontologies can also use different criteria for comparison between species. We use a strict definition of historical homology: "Homology that is defined by common descent" (HOM:0000007, Roux and Robinson-Rechavi, 2010).

The HOGs used in Bgee are part of the database schema, are constrained according to the database optimization, and are not formatted for easy external use. Yet it is also desirable to provide an ontology which is optimized for inter-operability and reuse by the community. Thus, we present here a CARO-compliant version of the HOG ontology, with all terms and relations carefully curated. The present version of this ontology is limited to vertebrates. Based on the alignment of two mammals, one frog, and one fish, it covers many of the morphological terms needed to describe most vertebrates. Thus we present the first large and high quality ontology of vertebrate anatomy, vHOG.

2 Methods

The following source ontologies were first aligned using Homolonto with manual validation: ZFA (zebrafish) (Bradford, Conlin*, et al.*, 2011), EHDAA (human development) (Aitken, 2005; Hunter, Kaufman*, et al.*, 2003), EV (adult human) (Kelso, Visagie*, et al.*, 2003), EMAPA (mouse development) (Aitken, 2005; Hunter, Kaufman*, et al.*, 2003), MA (adult mouse) (Smith, Ashburner*, et al.*, 2007), and XAO (Xenopus) (Bowes, Snyder*, et al.*, 2008). The alignments were merged and organized in an OBO-format ontology using the algorithms detailed in Parmentier et al. (2010).

We have developed an algorithm to add relevant updates of the HOG.obo file maintained for the Bgee database, to the vHOG ontology. Thus maintenance of the vHOG ontology follows the Bgee update calendar.

[8] http://obofoundry.org/wiki/index.php/UBERON:Main_Page

All other steps were performed by manual curation, and are further detailed in the Results section. Tools which were used for manual curation include OBO-Edit (Day-Richter, Harris, *et al.*, 2007), classical bibliography search engines (PubMed, Google Scholar), and browsing other anatomical ontologies at the NCBO Bioportal (Noy, Shah, *et al.*, 2009) and OBO Foundry (Smith, Ashburner, *et al.*, 2007) websites. We were especially careful to implement CARO in a manner consistent with other ontologies.

The vHOG ontology is distributed in OBO format through the OBO Foundry website, the NCBO Bioportal website, and the Bgee download website[9]. The OBO Foundry also generates an OWL format version of the vHOG[10].

3 Results and discussion

All terms of the vHOG ontology were manually curated, to verify that they correspond to groups of homologous organs between vertebrate species, linked by relations of strict historical homology, as defined in the HOM ontology (Roux and Robinson-Rechavi, 2010).

Relations between the terms were also manually curated, whenever there was any conflict between the source ontologies (see algorithm in Parmentier, Bastian, *et al.*, 2010), and set either to *is_a* or to *part_of*. We aim to provide exactly one *is_a* relation for each term, according to OBO Foundry guidelines. As noted in the TAO publication (Dahdul, Lundberg, *et al.*, 2010), it is at present difficult to implement this guideline in practice. Indeed, it is not yet fully implemented in any OBO Foundry ontology. In future versions of the vHOG we will continue working towards this aim.

The terms and relations thus generated were incorporated into the framework of the CARO (Haendel, Neuhaus, *et al.*, 2008). We were careful to implement this in a manner consistent with other anatomical ontologies using CARO: TAO, XAO and ZFA.

The vHOG ontology version 1 has 1,176 terms, 500 *is_a* relations, and 1,176 *part_of* relations. There are 969 synonyms; 544 terms have definitions; 67% of terms have only one

[9] http://bgee.unil.ch/?page=download

[10] http://www.obofoundry.org/cgi-bin/detail.cgi?id=vHOG

parent, 25% have two parents, and the others have three or more. There are 490 cross references (*xref*) to other multi-species OBO ontologies. These do not include the mappings to species-specific ontologies, as we consider that mappings from multi-species ontologies to species-specific ontologies should not be treated as simple xrefs, but deserve a proper annotation file, similar to the Gene Ontology Annotation mapping (Barrell, Dimmer*, et al.*, 2009).

All mappings of terms from the source ontologies to the vHOG terms were manually curated. There are 5,117 terms from species specific ontologies mapped to 1,161 vHOG terms, which represent 5,117 hypotheses of homology between vertebrates. These mappings were annotated with support codes (Table 1). We did not use the OBO Evidence Codes (ECO) for three reasons. First, because only two terms of the ECO correspond to our mappings: "background scientific knowledge" (ECO:0000001), and "traceable author statement" (ECO:0000033). Second, because some of our mappings derive from semantic similarity between anatomical terms, which is not covered by the ECO; we have made a formal suggestion for semantic similarity to be included in future versions of the ECO. And third, because the ECO does not capture the confidence that we have in the mapping, but only the source of evidence. This is important, because in some case homology hypotheses are extensively discussed in the literature, and we feel that a difference should be made between an uncontested traceable author statement to the effect that organs are homologous, a traceable author statement to the effect that homology is difficult to determine or uncertain, and conflicting traceable author statements. As an immediate solution to this problem, we have implemented the *ad hoc* support codes presented in Table 1.

Support code	Meaning	References [a]	Terms mapped	vHOGs with mapping [d]
Obvious	General knowledge, no need for reference	No	284	85
Well established	No debate in the literature	Yes	3,733	809
Debated	Debate in the literature [b]	Yes	4	1
Uncertain	Not clearly established	Variable [c]	292	77
Inferred	Deduced from references which do not discuss this mapping explicitly; or personal communication from experts	No	804	191

Table 1: Support for mapping of species specific anatomical ontologies to vHOG
(a) Yes if at least one bibliographic reference is provided for each mapping. (b) A consensus is chosen and presented, but the debate is documented. (c) Either there is a reference in which the homology is discussed as uncertain, and it is provided; or this code is used when well-established or obvious relations between closely related species (e.g., human and mouse) are extended to other species (e.g., zebrafish). (d) Note that the total is

more than the number of vHOG terms, because different mappings to a same vHOG term can have different support.

As a long term solution, we propose a Entity–Quality syntax (as discussed in Mabee, Ashburner*, et al.*, 2007), where the Entity would be an Evidence Code, and the Quality would be an assessment of its reliability; a small new ontology of Quality Codes is needed. For example, "traceable author statement ~ well established" could be distinguished from "traceable author statement ~ debated". This full implementation of such a proposal needs further discussion and agreement in the biological ontology community, which is why vHOG mappings at time of submission still use our *ad hoc* support codes.

In practice, the support codes "obvious" and "inferred" are essentially used for homology between the two mammals considered in our ontology, human and mouse: 98% and 97% of all mappings with these two codes, respectively. There is only one Homologous Organ Group noted "debated", which is the "vomeronasal organ" (VHOG:0000665). None of the three bibliographical references cited in the mapping file is conclusive concerning the existence and homology of this organ in different tetrapodes (Doving and Trotier, 1998; Kardong, 2006 p. 669; Smith, Siegel*, et al.*, 2001), and Doving and Trotier (1998) specify: "The opinions concerning the presence and functioning of the vomeronasal organ in humans are controversial". Conversely, 87% of all mappings for zebrafish, the most divergent species included in vHOG, are "well established" in the literature.

4 Conclusions

With increasingly abundant *in vivo* functional data from different model organisms, it is necessary to be able to relate and compare information between species. Different criteria for comparison can be relevant in different contexts: similarity, functional equivalence, evolutionary relationships, or the implication in similar phenotypes (Mabee, Ashburner*, et al.*, 2007; McGary, Park*, et al.*, 2010; Roux and Robinson-Rechavi, 2010). The most widely recognized criterion for comparisons of anatomical structures is homology. In addition to criteria for comparison, for large scale and reproducible comparisons between species, or multi-species studies, these criteria must be implemented in standard resources. To answer these needs, we propose the first ontology of vertebrate homologous organs, the vHOG. We use a strict definition of historical homology (HOM:0000007, Roux and Robinson-Rechavi,

2010). The vHOG adheres to OBO Foundry rules as much as possible, and makes use of the CARO framework.

A point which should be noted about the vHOG is that it does not aim to include all terms found in every species. Only terms with evidence of homology between at least two vertebrate species are included. At present, there is a further limitation to homologies between those model species for which anatomical ontologies are publicly available. We plan to extend the vHOG to more diverse species, but we intend to remain limited to terms describing organs or tissues with evidence of homology.

Fine-grained yet large scale comparisons between model organisms, especially vertebrates such as mouse or zebrafish, and humans, is increasingly important. In addition to providing a framework for evolutionary studies, the vHOG provides a unique tool for relating humans and model organisms.

Acknowledgements

Emilie Person and Balazs Laurenczy helped with annotations in earlier versions of the HOG ontology. We thank all members of the Robinson-Rechavi lab for helpful discussions.

Funding

This work was supported by Etat de Vaud; the Décrypthon program of Association Française contre les Myopathies; the European program Crescendo; and the Swiss National Science Foundation.

5 References

Aitken, S. (2005) Formalizing concepts of species, sex and developmental stage in anatomical ontologies, *Bioinformatics*, **21**, 2773-2779.

Bard, J.B. (2008) Anatomical ontologies for model organisms: the fungi and animals. In Burger, A., Davidson, D. and Baldock, R. (eds), *Anatomy Ontologies for Bioinformatics: Principles and Practice*. Springer, New York, pp. 3-25.

Barrell, D., Dimmer, E., Huntley, R.P., Binns, D., O,ÄôDonovan, C.*, et al.* (2009) The GOA database in 2009,Äîan integrated Gene Ontology Annotation resource, *Nucleic Acids Research*, **37**, D396-D403.

Bastian, F., Parmentier, G., Roux, J., Moretti, S., Laudet, V.*, et al.* (2008) Bgee: Integrating and Comparing Heterogeneous Transcriptome Data Among Species. In, *Data Integration in the Life Sciences*. pp. 124-131.

Bowes, J.B., Snyder, K.A., Segerdell, E., Gibb, R., Jarabek, C.*, et al.* (2008) Xenbase: a Xenopus biology and genomics resource, *Nucleic Acids Res*, **36**, D761-767.

Bradford, Y., Conlin, T., Dunn, N., Fashena, D., Frazer, K.*, et al.* (2011) ZFIN: enhancements and updates to the Zebrafish Model Organism Database, *Nucleic Acids Res*, **39**, D822-829.

Dahdul, W.M., Lundberg, J.G., Midford, P.E., Balhoff, J.P., Lapp, H.*, et al.* (2010) The Teleost Anatomy Ontology: Anatomical Representation for the Genomics Age, *Syst Biol*, **59**, 369-383.

Day-Richter, J., Harris, M.A., Haendel, M., The Gene Ontology, O.B.O.E.W.G. and Lewis, S. (2007) OBO-Edit - An Ontology Editor for Biologists, *Bioinformatics*, **23**, 2198-2200.

Doving, K. and Trotier, D. (1998) Review: Structure and function of the vomeronasal organ, *The Journal of Experimental Biology*, **201**, 2913-2925.

Haendel, M.A., Neuhaus, F., Osumi-Sutherland, D., Mabee, P.M., Jr., J.L.V.M.*, et al.* (2008) CARO —The Common Anatomy Reference Ontology. In Burger, A., Davidson, D. and Baldock, R. (eds), *Anatomy Ontologies for Bioinformatics: Principles and Practice*. Springer, New York, pp. 327-349.

Hunter, A., Kaufman, M.H., McKay, A., Baldock, R., Simmen, M.W.*, et al.* (2003) An ontology of human developmental anatomy, *Journal of anatomy*, **203**, 347-355.

Kardong, K. (2006) *Vertebrates: Comparative Anatomy, Function, Evolution*. McGraw-Hill, New York.

Kelso, J., Visagie, J., Theiler, G., Christoffels, A., Bardien, S.*, et al.* (2003) eVOC: a controlled vocabulary for unifying gene expression data, *Genome Res*, **13**, 1222-1230.

Mabee, P.M., Ashburner, M., Cronk, Q., Gkoutos, G.V., Haendel, M.*, et al.* (2007) Phenotype ontologies: the bridge between genomics and evolution, *Trends in Ecology & Evolution*, **22**, 345-350.

McGary, K.L., Park, T.J., Woods, J.O., Cha, H.J., Wallingford, J.B.*, et al.* (2010) Systematic discovery of nonobvious human disease models through orthologous phenotypes, *Proceedings of the National Academy of Sciences*, **107**, 6544-6549.

Noy, N.F., Shah, N.H., Whetzel, P.L., Dai, B., Dorf, M.*, et al.* (2009) BioPortal: ontologies and integrated data resources at the click of a mouse, *Nucleic Acids Research*, **37**, W170-W173.

Parmentier, G., Bastian, F.B. and Robinson-Rechavi, M. (2010) Homolonto: generating homology relationships by pairwise alignment of ontologies and application to vertebrate anatomy, *Bioinformatics*, **26**, 1766-1771.

Roux, J. and Robinson-Rechavi, M. (2010) An ontology to clarify homology-related concepts, *Trends Genet*, **26**, 99-102
Smith, B., Ashburner, M., Rosse, C., Bard, J., Bug, W.*, et al.* (2007) The OBO Foundry: coordinated evolution of ontologies to support biomedical data integration, *Nat Biotech*, **25**, 1251-1255.
Smith, T.D., Siegel, M.I., Bonar, C.J., Bhatnagar, K.P., Mooney, M.P.*, et al.* (2001) The existence of the vomeronasal organ in postnatal chimpanzees and evidence for its homology with that of humans, *Journal of Anatomy*, **198**, 77-82.

Bgee: Integrating and Comparing Heterogeneous Transcriptome Data Among Species

Frederic Bastian[1,2,4], Gilles Parmentier[1,2,4], Julien Roux[1,2], Sebastien Moretti[1,2], Vincent Laudet[3], Marc Robinson-Rechavi[1,2]

[1] Department of Ecology and Evolution, University of Lausanne, quartier UNIL-Sorge, 1015 Lausanne, Switzerland, [2] Swiss institute of bioinformatics, Lausanne, Switzerland, [3] Université de Lyon, Institut de Génomique Fonctionnelle de Lyon, ENS Lyon, Université Lyon 1, CNRS, INRA, Institut Fédératif 128 Biosciences Gerland Lyon Sud, France
4: co first authors
Marc.Robinson-Rechavi@unil.ch

Abstract

Gene expression patterns are a key feature in understanding gene function, notably in development. Comparing gene expression patterns between animals is a major step in the study of gene function as well as of animal evolution. It also provides a link between genes and phenotypes. Thus we have developed Bgee, a database designed to compare expression patterns between animals, by implementing ontologies describing anatomies and developmental stages of species, and then designing homology relationships between anatomies and comparison criteria between developmental stages. To define homology relationships between anatomical features we have developed the software Homolonto, which uses a modified ontology alignment approach to propose homology relationships between ontologies. Bgee then uses these aligned ontologies, onto which heterogeneous expression data types are mapped. These already include microarrays and ESTs. Bgee is available at http://bgee.unil.ch/

Bgee has involved many contributors, notably Julien Roux, who designed the statistical tests. I am the main developer of the Bgee application and database, and I coordinate all aspects of the project.

This work have been published in the peer reviewed proceedings of Data Integration in Life Sciences (2008) Bairoch A, Cohen-Boulakia S, and Froidevaux C (Eds.) Lecture Notes in Computer Science 5109: 124-131.
DOI: 10.1007/978-3-540-69828-9_12

1 Introduction

Gene expression patterns (when and where a gene is expressed) are a key feature that underlies the development of organisms and phenotypes of individuals. They are an important aspect of the study of gene function. Moreover, the study of the evolution of developmental processes, often called "evo-devo", has shown that the primary source of change in the evolution of phenotypes is changes in gene expression (Carroll, 2005) rather than sequence. Comparing gene expression patterns between animals is thus a major step in the study of gene function as well as of animal evolution, and also provides a link between genes and phenotypes.

In biological research, results obtained in different organisms are routinely compared. A comparative approach may be chosen for practical reasons because the organism of interest (humans, farm animals) may be less amenable to experimentation than more or less distant model species (as mouse, rat, zebrafish, or fruit fly).

Another reason is that components of gene expression may vary for no obvious reason (Yanai, Graur*, et al.*, 2004); this introduces the problem of distinguishing this signal from the noise caused both by random evolution and the inaccurate data measurements. Comparative study of gene expression in several species may contribute to this distinction. For example, comparing multiple samples from humans and rodents gave sufficient statistical evidence for a functionally relevant component of gene expression (Jordan, Marino-Ramirez*, et al.*, 2005), and allowed for significant improvement in tumour characterisation (Schlicht, Matysiak*, et al.*, 2004).

Transcriptome data have also been compared among species to gain direct insight into evolutionary processes. For instance, yeast microarray data provided evidence for divergence of expression after genome duplication (Gu, Nicolae*, et al.*, 2002), and further studies have succeeded in extracting some evidence for the evolution of new gene functions after genome duplication in yeast and human lineages (Gu, Zhang*, et al.*, 2005; He and Zhang, 2005). A comparative approach would allow to understand the mechanisms and the consequences of gene expression evolution.

We have developed Bgee (a dataBase for Gene Expression Evolution) to address these questions. Bgee must answer the following requirements, to enable large scale gene expression pattern comparison:

- Precise description of the anatomy and developmental stages of each species, stored in a computer-understandable way.
- Integration of expression data in order to know in which anatomical features (spatial mapping) and which developmental stages (temporal mapping) genes are expressed.
- Comparison criteria between anatomies, developmental stages, and genes.

To unambiguously describe anatomy and development of a species in a computer-understandable way, ontologies are required: they describe a domain of knowledge, by using well-defined concepts and designing relationships amongst them. Several databases provide species-specific ontologies that describe anatomical features for a species, such as ZFIN (Sprague, Clements*, et al.*, 2003) for the zebrafish. But as far as we know, no database provides relationships between these ontologies to allow comparisons.

The appropriate criterion to make comparisons in an evolutionary context is homology: we need to compare features that derive from the same ancestral element. We have thus designed homology relationships between anatomies of different species. This is a difficult task, and Bgee implements computational methods to achieve it (section 2). Then, we need homology relationships between genes. This point has already been abundantly treated in bioinformatics, and will not be discussed in detail in this paper. Finally, we need relationships between developmental stages. As these stages are artificial features that help to describe the continuous process of development, homology cannot be defined in a rigorous manner. We have rather designed a mapping of "equivalent" developmental stages between species (section 3).

To describe gene expression patterns, Bgee requires large amounts of data. To this end, heterogeneous data types are used (ESTs, microarrays, and soon *in situ* hybridizations). The common information to gather is whether an experiment has determined that a gene is expressed or not, and with which confidence. We have applied different statistical tests for each data type to obtain this information (section 4).

Thanks to the successful implementation of all these requirements (anatomical and developmental ontologies, comparison relationships between ontologies and genes, integration of heterogeneous expression data), Bgee allows the easy retrieval of gene expression data for different species, as well as the automated comparison of gene expression patterns.

2 Designing Homology Relationships between Anatomical Ontologies by an Ontology Alignment Approach

To study the evolution of gene expression patterns, comparisons have to be done between organs that evolved from a common ancestral structure. Thus designing relationships between anatomical ontologies consists in finding correspondences (homology relationships) between the concepts (organs) of these ontologies. This problem is a special case of "schema matching", or "ontology alignment".

Ontology alignment ((Shvaiko and Euzenat, 2007) for a review) is the process of determining correspondences between ontology concepts. Usually, this technique is used to find the common concepts present in two ontologies. In the case of anatomical ontologies, the concepts to align are not strictly common, but rather, related: a homology relationship is not an equivalence relationship. For this reason, ontology alignment approaches developed for other applications cannot be applied as is: these methods would be misled by the existence of elements of same names and related to the same concept, but not homologous (eye of insects and of vertebrates for instance), or reciprocally, homologous elements with different names (caudal fin and upper limb for instance). This is why we apply modified ontology alignment techniques in order to find putative homologies between two species anatomies. An expert has to manually validate the putative homologs. This method is implemented by Homolonto, a software that we have developed in Java. Homolonto will be presented in detail elsewhere; we present here the outline of its algorithm.

Our process is a supervised one: at each step, some homology relationships are proposed to the expert, who may validate them or not. Computations are made based on these decisions, and new propositions are made to the expert.

The algorithm starts with a list of pairs, which have identical names. This is based on the assumption that two structures that have the same name are likely homologous. For example, “optic cup” of the ZFIN ontology (zebrafish) and “optic cup” of the EHDA ontology (human) will be paired, but “optic cup” of ZFIN will not be initially paired with “optic nerve” of EHDA. The score of similarity between terms is up weighted by the proportion of common words, and down weighted by the frequency of these words (frequent words are less informative, e.g. “endoderm”). Moreover, scores are propagated between pairs which are neighbors in both ontologies. For example, the score of the “optic cup” pair is added to the score of the “eye” pair, as “optic cup” is part of “eye”. In the same way, the score of the “eye” pair is added to the “optic cup” one.

Each pair is proposed to the expert, in descending order of scores. The expert may validate or invalidate the hypothesis of homology, or delay decision. The expert may choose to evaluate any number of pairs before triggering an iteration, in which computations are performed. Computations create or extend homology groups. The new homology information is propagated through the ontologies. The underlying idea is that if two concepts A and B are homologous, then one of the sub-concepts of A is probably homologous to one of the sub-concepts of B even if they have different names. Of note, validated homology contributes a significantly higher score than name similarity. Propagation is down weighted by the number of sub-concepts, to avoid generating many false positives (e.g. all the children of “whole body”).

Evaluation of pairs, ordered by total score (base score + propagated score), and iteration, are repeated until the expert decides to terminate, or no more pairs are proposed. Compared to manual alignment of the ontologies, Homolonto reduces time considerably, with high sensitivity. Thus aligning the zebrafish (ZFIN; 2087 terms) and Xenopus (Xenbase; 480 terms) ontologies took one month by hand, but 2 days using Homolonto. The first 213 pairs proposed to the expert were valid at 80%, and contained 91% of all true positives.

To design homology relationships between several species, we merge the homology groups obtained by pair-wise alignment.

Finally, Homolonto generates an OBO (Smith, Ashburner*, et al.*, 2007) file containing the homology relationships. Bgee then parses this file to integrate the homologies into the database.

3 Mapping of the Developmental Ontologies

In relationship with the anatomical ontologies, Bgee uses for each species an ontology which describes its developmental stages, and links them using an *is_a* relationship by key states (e.g. embryo, hatching, larval).

To compare expression patterns, the comparisons have to be done both between homologous organs (see section 2), and at an equivalent developmental stage. But it is not possible to "simply" identify stages between species for which the state of the development is identical: organs do not develop at the same speed and with the same sequence, development is heterochronous (e.g. (Jeffery, Bininda-Emonds*, et al.*, 2005)).

A solution could be to identify, for each organ involved in a homology relationship, the different key states of their formation, and to design, organ by organ, equivalence relationship between these states in different species. This solution is difficult to implement, as it would imply manual definition for each organ separately, without any guiding principle in the data (i.e. we cannot use shared names and ontology structures as for anatomical homology).

Although there is no direct equivalence between the stages of two species because of heterochrony, it is instead possible to identify key events of development, common to all bilaterian animals. We have developed a small ontology of these common "metastages": embryo – including zygote, cleavage, blastula, gastrula, organogenesis –, post-embryonic development, adult. Then we have mapped the developmental stages of each species to these "metastages". This approach results in a loss of accuracy regarding the developmental ontologies, but allows to compare gene expression patterns taking into account the time dimension.

4 Integrating Heterogeneous Data on Anatomical and Developmental Ontologies

Integrating heterogeneous expression data is challenging, as it is difficult to compare the results of different types of techniques (e.g. ESTs, microarrays, *in situ* hybridizations) (Kuo, Liu*, et al.*, 2006; Lee, Sunkin*, et al.*, 2008), and even for a same type, to compare results between experiments (e.g. compare two microarray experiments made on different platforms). But as we want to be able to precisely describe expression patterns of genes, we need data as complete as possible. We also want to obtain data for all the species studied, and some techniques cannot be applied to all species, for instance *in situ* hybridizations on human. The information we want to collect is in which organs, and at which developmental stages, a gene is expressed. It means that for each experiment, we have to map the data to anatomical and developmental ontologies, and to apply statistical analyses, depending on the data type, to identify genes significantly expressed.

4.1 Mapping Expression Data to Ontologies

The main problem to map the data to ontologies is that annotations are often inconsistent between data sources: for instance, the description of the organs on which an experiment has been performed can be provided as free text, controlled vocabularies, or ontologies. Therefore, we have manually annotated each experiment stored in Bgee to determine the unique identifiers (ID) in the anatomical ontologies of the organs studied, and the ID of the developmental stages.

The granularity of the data is also highly variable. For instance, experiments can be reported on the organ “brain” or on the organ “forebrain”, at the stage “embryo” or at the stage “free blastocyst”. This is why ontologies are essential both for anatomy and for development: just listing the developmental stages would not have been sufficient.

4.2 Statistical Analyses

Bgee currently uses EST data from Unigene (Wheeler, Barrett*, et al.*, 2008) and Affymetrix data retrieved from ArrayExpress (Parkinson, Kapushesky*, et al.*, 2007). For each data type, Bgee applies statistical tests to identify genes that are significantly expressed, with two levels of confidence: low and high.

For experiments based on tag counting, such as EST, SAGE, or MPSS, a statistical test (Audic and Claverie, 1997) shows that a gene is expressed with a 95% confidence if 7 tags are mapped to this gene (the number of tags is statistically different from 0). So for EST data, we have considered a gene as expressed with a high confidence if an experiment has found at least 7 EST related to this gene, and with a low confidence from 1 to 6 EST.

Affymetrix data are measurements of fluorescence intensity. Labelled cDNAs prepared from samples are hybridized with oligonucleotide probes. All probes mapping to the same transcript constitute a probeset. Identifying genes significantly expressed consists in finding genes for which the signal of the probeset is significantly different from the background signal. This method is implemented by the MAS5 software (Liu, Mei*, et al.*, 2002); based on these statistical analyses, probesets are flagged as "present", "marginal", or "absent". This allows us to classify genes expressed with a high confidence when their probeset is flagged as "present", and with a low confidence when "marginal". Although MAS5 classification is efficient (Choe, Boutros*, et al.*, 2005), the estimation of the background signal can be biased depending on probe sequence affinity (Schuster, Blanc*, et al.*, 2007). We are currently implementing another method of detection (Schuster, Blanc*, et al.*, 2007), which uses the gcRMA algorithm (Wu, Irizarry*, et al.*, 2004) to normalize the signal taking into account probe sequences, and uses a subset of weakly expressed probesets for estimating the background. A Wilcoxon test is then applied to compare the normalized signal of the probesets with the background signal. Genes will be considered expressed with a high confidence if the p-value is lower than 1%, and with a low confidence if the p-value is between 1 and 5 %.

Bgee will soon include *in situ* hybridization data. For data based on image analyses, statistical tests cannot be applied easily. Determining if a gene is expressed is usually done manually by an expert. A quality annotation can also be provided, summarizing the quality of the image, the hybridization, and the probes design. Such information is already present in several databases (e.g. ZFIN (Sprague, Clements*, et al.*, 2003)), and Bgee will rely on them.

4.3 Database and Web-Interface of Bgee

The database of Bgee is developed with MySQL, and currently includes anatomical ontologies, developmental ontologies, and expression data for four species: human, mouse, zebrafish, and Xenopus:

- The anatomical ontologies come from eVoc (Kruger, Hofmann, *et al.*, 2007) for human, Xspan (Aitken, 2005) for human and mouse, MGD (Eppig, Blake, *et al.*, 2007) for adult mouse, ZFIN (Sprague, Clements, *et al.*, 2003) for zebrafish, and Xenbase (Bowes, Snyder, *et al.*, 2008) for Xenopus.
- EST data come from Unigene (Wheeler, Barrett, *et al.*, 2008) and Affymetrix data from ArrayExpress (Parkinson, Kapushesky, *et al.*, 2007). *In situ* hybridization will be collected from specialized databases, as ZFIN or BGEM (Magdaleno, Jensen, *et al.*, 2006).
- Gene ontology (Ashburner, Ball, *et al.*, 2000) annotations and homology relationships between genes are recovered from Ensembl (Hubbard, Aken, *et al.*, 2007).
- Bgee currently includes a total of 104,881 genes. 51,277 have expression data, in 587 anatomical structures and 93 developmental stages.

The web interface of Bgee is developed in Java using the servlet container Tomcat, with a Model-View-Controller architecture. The user experience is improved by the use of AJAX technologies (Asynchronous Javascript And XML). The website of Bgee, available at http://bgee.unil.ch/, proposes several ways to easily retrieve or compare expression data:

- Querying the database: data can be queried for genes, gene families, anatomical structures, or developmental stages, based on their names, synonyms, abbreviations, identifiers, or descriptions.
- Browsing the ontologies: anatomical and developmental ontologies can be browsed as a tree structured view. Information about the genes expressed is displayed for each anatomical structure or developmental stages. The display of these expression data can be adjusted by selecting data type and data quality, or by entering a list of gene identifiers or of GO terms.
- Retrieving the expression pattern of a gene: the expression pattern of a gene is also displayed as a tree structured view of the organs where it is expressed, at the selected developmental stage. The data used to define the pattern can be modified by selecting the data type or data quality.

- Comparing the expression patterns of homologous genes: the expression patterns of a gene family can be compared choosing the species studied, and as for the ontology browsing, by selecting data type and quality, list of genes or of GO terms.

The homology relationships and developmental ontologies, both in OBO format, the Homolonto software and source code, and the Bgee database and source code, will soon be available on our website.

5 Conclusions

We have developed pipelines to integrate ontologies and expression data to Bgee, and automatically perform statistical analyses. We also have developed the Homolonto software to facilitate the design of homology relationships. We have paid great attention to make the Java code of Bgee easy to evolve, with a clean architecture and reusable components. We have thus implemented all the requirements to add more species and more data types into Bgee in the future. We plan to add in the short-term *in situ* hybridization data.

The multi-species computer coding and storage of expression patterns was an essential key to perform high throughput analyses. We will now be able to design analysis tools dedicated to the comparison of expression patterns, and to address open biological questions, such as the relationships between evolution of development and of gene expression, or the identification of candidate genes for diseases.

Acknowledgements

We thank Frederic Ricci for data annotation. Funding was provided by Etat de Vaud, the program Crescendo, the SIB, the Decrypthon program.

6 References

Aitken, S. (2005) Formalizing concepts of species, sex and developmental stage in anatomical ontologies, *Bioinformatics (Oxford, England)*, **21**, 2773-2779.

Ashburner, M., Ball, C.A., Blake, J.A., Botstein, D., Butler, H.*, et al.* (2000) Gene ontology: tool for the unification of biology. The Gene Ontology Consortium, *Nature genetics*, **25**, 25-29.

Audic, S. and Claverie, J.M. (1997) The significance of digital gene expression profiles, *Genome Res*, **7**, 986-995.

Bowes, J.B., Snyder, K.A., Segerdell, E., Gibb, R., Jarabek, C.*, et al.* (2008) Xenbase: a Xenopus biology and genomics resource, *Nucleic Acids Res*, **36**, D761-767.

Carroll, S. (2005) *Endless Forms Most Beautiful: The New Science of Evo Devo and The Making of the Animal Kingdom*. W. W. Norton & Company, New York.

Choe, S.E., Boutros, M., Michelson, A.M., Church, G.M. and Halfon, M.S. (2005) Preferred analysis methods for Affymetrix GeneChips revealed by a wholly defined control dataset, *Genome biology*, **6**, R16.

Eppig, J.T., Blake, J.A., Bult, C.J., Kadin, J.A. and Richardson, J.E. (2007) The mouse genome database (MGD): new features facilitating a model system, *Nucleic Acids Res*, **35**, D630-637.

Gu, X., Zhang, Z. and Huang, W. (2005) Rapid evolution of expression and regulatory divergences after yeast gene duplication, *Proc Natl Acad Sci U S A*, **102**, 707-712.

Gu, Z., Nicolae, D., Lu, H.H. and Li, W.H. (2002) Rapid divergence in expression between duplicate genes inferred from microarray data, *Trends Genet*, **18**, 609-613.

He, X. and Zhang, J. (2005) Rapid subfunctionalization accompanied by prolonged and substantial neofunctionalization in duplicate gene evolution, *Genetics*, **169**, 1157-1164.

Hubbard, T.J., Aken, B.L., Beal, K., Ballester, B., Caccamo, M.*, et al.* (2007) Ensembl 2007, *Nucleic Acids Res*, **35**, D610-617.

Jeffery, J.E., Bininda-Emonds, O.R.P., Coates, M.I. and Richardson, M.K. (2005) A New Technique for Identifying Sequence Heterochrony, *Systematic Biology*, **54**, 230-240.

Jordan, I.K., Marino-Ramirez, L. and Koonin, E.V. (2005) Evolutionary significance of gene expression divergence, *Gene*, **345**, 119-126.

Kruger, A., Hofmann, O., Carninci, P., Hayashizaki, Y. and Hide, W. (2007) Simplified ontologies allowing comparison of developmental mammalian gene expression, *Genome biology*, **8**, R229.

Kuo, W.P., Liu, F., Trimarchi, J., Punzo, C., Lombardi, M.*, et al.* (2006) A sequence-oriented comparison of gene expression measurements across different hybridization-based technologies, *Nat Biotechnol*, **24**, 832-840.

Lee, C.K., Sunkin, S.M., Kuan, C., Thompson, C.L., Pathak, S.*, et al.* (2008) Quantitative methods for genome-scale analysis of in situ hybridization and correlation with microarray data, *Genome biology*, **9**, R23.

Liu, W.M., Mei, R., Di, X., Ryder, T.B., Hubbell, E.*, et al.* (2002) Analysis of high density expression microarrays with signed-rank call algorithms, *Bioinformatics (Oxford, England)*, **18**, 1593-1599.

Magdaleno, S., Jensen, P., Brumwell, C.L., Seal, A., Lehman, K.*, et al.* (2006) BGEM: An In Situ Hybridization Database of Gene Expression in the Embryonic and Adult Mouse Nervous System, *PLoS Biol*, **4**, e86.

Parkinson, H., Kapushesky, M., Shojatalab, M., Abeygunawardena, N., Coulson, R., *et al.* (2007) ArrayExpress--a public database of microarray experiments and gene expression profiles, *Nucleic Acids Res*, **35**, D747-750.
Schlicht, M., Matysiak, B., Brodzeller, T., Wen, X., Liu, H., *et al.* (2004) Cross-species global and subset gene expression profiling identifies genes involved in prostate cancer response to selenium, *BMC Genomics*, **5**, 58.
Schuster, E.F., Blanc, E., Partridge, L. and Thornton, J.M. (2007) Correcting for sequence biases in present/absent calls, *Genome biology*, **8**, R125.
Shvaiko, P. and Euzenat, J. (2007) *Ontology Matching*. Springer Verlag, Berlin Heidelberg.
Smith, B., Ashburner, M., Rosse, C., Bard, J., Bug, W., *et al.* (2007) The OBO Foundry: coordinated evolution of ontologies to support biomedical data integration, *Nat Biotechnol*, **25**, 1251-1255.
Sprague, J., Clements, D., Conlin, T., Edwards, P., Frazer, K., *et al.* (2003) The Zebrafish Information Network (ZFIN): the zebrafish model organism database, *Nucleic Acids Res*, **31**, 241-243.
Wheeler, D.L., Barrett, T., Benson, D.A., Bryant, S.H., Canese, K., *et al.* (2008) Database resources of the National Center for Biotechnology Information, *Nucleic Acids Research*, **36**, D13-D21.
Wu, Z., Irizarry, R.A., Gentleman, R., Martinez-Murillo, F. and Spencer, F. (2004) A Model-Based Background Adjustment for Oligonucleotide Expression Arrays, *Journal of the American Statistical Association*, **99**, 909-917.
Yanai, I., Graur, D. and Ophir, R. (2004) Incongruent expression profiles between human and mouse orthologous genes suggest widespread neutral evolution of transcription control, *Omics*, **8**, 15-24.

Bgee: a look under the hood

In this chapter, I will present the core aspects of Bgee, regarding the development of the pipeline, database and application, and regarding the annotation processes. This is mostly my work, with contributions by two students, Yohan Jarosz and Balazs Laurenzy, under my supervision.

1 Introduction

Bgee has evolved in several aspects since the publication of the original paper (Bastian, Parmentier*, et al.*, 2008). It includes now much larger amounts of expression data, from multiple data types and sources, in several species, which makes their efficient storage difficult. This requires optimizations at the level of the database schema, and even more important, at the level of the fine-tuning of the SQL queries. I will notably show how Bgee manages queries on tables with more than 250 millions rows, or how bypassing the DBMS optimizer can speed up a complex multi-species query by a factor of 300.

Bgee is intended to be a long-term project, and has already involved several contributors. The code structure is thus an important aspect of the project durability. I will present the standards and design patterns adopted. Some of them are particularly important with regards to the future addition of new data sources and new data types. These patterns also allow to propose a Bgee programming API, disconnected from the server-side aspects of the application (e.g., request handling, HTML generation).

Finally, the pipeline, and the curation processes, are important aspects of Bgee. Since the 2008 publication, the pipeline notably includes analyses for over-expression and absence of expression, and the curation process has been continuously improved.

2 Bgee database

2.1 Schema

Specifications

Bgee includes different data types, to date: EST, Affymetrix, *in situ* hybridization. A specification of the Bgee application is that the user must have the capability at any time to filter display of expression data, using different criteria, such as: data type, data quality, gene IDs, Gene Ontology terms, etc. This makes it difficult to precompute commonly requested data, such as: “how many genes are expressed in this anatomical structure”, “in how many anatomical structures this gene is expressed”, or “how many probesets showed evidence for this gene expression”. Another specification is to be able, at any time, to track back

expression data to the original data sources, to the specific Affymetrix chip, or image of *in situ* hybridization.

This means that the Bgee database, developed using MySQL, is used to store large amounts of data, and to gather on-the-fly data from exploded tables, to reconstruct expression patterns and origin of data. A single query could then systematically have to join several tables of millions of rows (about 1, 4, and 250 millions rows, see Table 1), based on criteria such as gene ID and organ ID requested.

Table name	affymetrixProbeset	expression	ESTs	inSituSpot
Rows	291,759,824	8,623,058	4,412,957	1,098,157

Table 1: number of rows for some tables of the Bgee database (release 09)

Expression modelling

My approach was to capture, in a single table (table *expression*, see Fig.1), the summary of all aspects of gene expression commonly requested: expression of a gene (field *geneId*), in an organ (*organId*), at a developmental stage (*stageId*), asserted by different methods, with a low or high confidence (fields *estData*, *affymetrixData*, *inSituData*). Information of expression of a gene, in an organ, at a developmental stage, corresponds to a single line in this table, however many thousands of Affymetrix probesets or ESTs gave this information. Thanks to this approach, all expression data stored in Bgee are summarized by "only" around 8 millions rows. Each line is given a unique identifier (field *expressionId*), that is then used to link to the original data sources (tables *expressedSequenceTag*, *affymetrixProbeset*, *inSituSpot*).

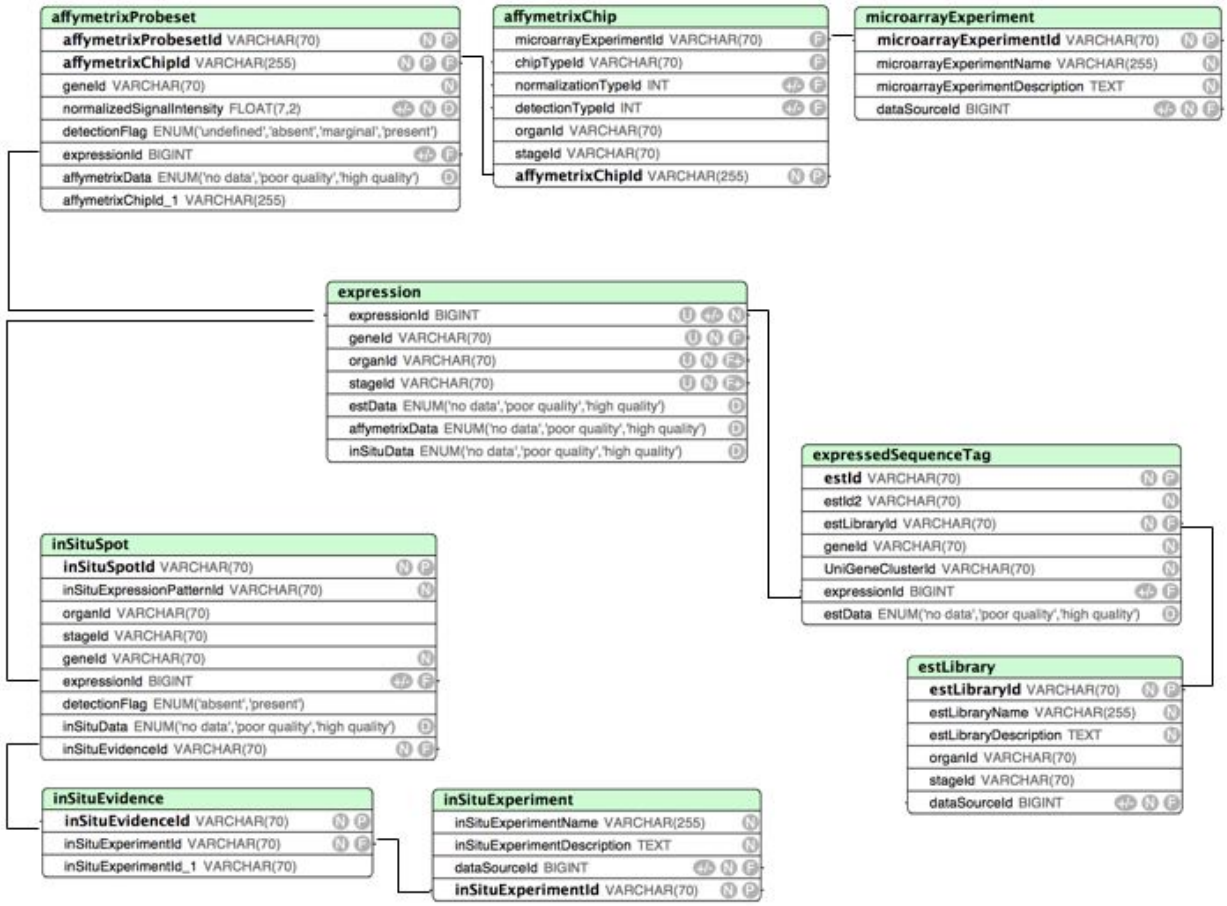


Fig. 1: Schema of a part of the Bgee database, relative to expression data.

The first important advantage of this approach is that any query of expression data, that does not require exact count of ESTs, probesets or *in situ* evidences, uses this table only. This avoids the need for costly joins between large tables, while still maintaining the capability to filter for data types or quality. This table is then the only large table used in the majority of Bgee queries. Another advantage is that this gene/organ/stage storage offers an efficient way to scan the expression table to retrieve expression IDs; these expression IDs are then also an efficient way to retrieve related ESTs, probesets, and *in situ* data. Without this schema, a single expression query should use the table *estLibrary* to retrieve organ/stage conditions, and the table *expressedSequenceTag* to retrieve genes, *affymetrixChip* for organ/stage and *affymetrixProbesets* for genes, and *insituSpot* for gene/organ/stage, resulting in low performances. Finally, when raw data are requested, the field related to each data type (*estData*, *affymetrixData*, *inSituData*) clearly states if results are available for this data type: scanning a large table for a row that does not exist in it can be extremely slow, and this schema avoids this problem.

Design of indexes

Another important aspect to obtain good performance is the careful design of indexes. For instance, many queries on the table *expression* use conditions on *geneId*, *organId*, *stageId* at the same time. It could seem obvious that this table requires a multiple-columns index on these three fields. The order of the columns in the index is most important, and should be based on the cardinality of the data; based on our data, there are fewer distinct stage IDs in the table *expression* than distinct organ IDs, and fewer distinct organ IDs than distinct gene IDs. The order of the columns in this index should then be: *stageId*, *organId*, *geneId*. But actually, almost all queries on the table *expression* use a condition on the field *geneId*. These queries would then get no benefits from the previous multiple-columns index, and require another index, starting with the field *geneId*. It could then be tempting to create all permutations of the 3-columns indexes, but it appears, based on my experience with these data, that when too many indexes are available for a table using the same fields, DBMS optimizers often pick up the wrong index. Explicitly indicating in each query the name of the index to use does not seem to be a long-term viable option. Thus, in Bgee, indexes have been carefully designed, only when tests have proven the need for some, and based on current data repartition, which changes between releases.

2.2 SQL query design and fine-tuning

Single species queries

Retrieving all genes expressed in an organ is straightforward using the table *expression*, e.g., to retrieve all genes expressed in zebrafish heart (without including substructures):

```
SELECT DISTINCT geneId FROM expression WHERE organId = 'ZFA:0000114';
```

To retrieve genes expressed in *n* organs requires performing *n-1* joins on the table *expression*. While queries using this approach were slow in previous versions of MySQL (and were accordingly optimized in Bgee), they now perform satisfactorily.

Multi-species queries

Performing multi-species queries requires to obtain additional information about gene homology, to retrieve, e.g., all homologous genes between mouse and zebrafish expressed in hearts of both species. In the Bgee database, homologous genes are grouped in gene families, stored in the table *geneFamily*. This table needs to be added to expression queries, such as those above, and this should also be usually done by using joins. For instance, consider the SQL query above, to retrieve genes expressed in zebrafish heart. The equivalent query for adult mouse is:

```
      SELECT DISTINCT t1.geneId FROM expression AS t1
WHERE t1.organId = 'MA:0000072';
```

A simple join on the table *geneFamily* should allow to retrieve gene families that contain genes expressed in heart of both species, e.g.:

```
SELECT DISTINCT t1.geneFamilyId
-- geneFamily table to retrieve only homologous genes
FROM geneFamily AS t1
-- tables to search for expression in zebrafish
INNER JOIN gene AS t2 ON t1.geneFamilyId = t2.geneFamilyId
INNER JOIN expression AS t3 ON t2.geneId = t3.geneId
-- tables to search for expression in mouse
INNER JOIN gene AS t4 ON t1.geneFamilyId = t4.geneFamilyId
INNER JOIN expression AS t5 ON t4.geneId = t5.geneId

WHERE t3.organId = 'ZFA:0000114' and t5.organId = 'MA:0000072';
```

And a last join on the table *gene* should allow to retrieve homologous genes, member of these gene families, expressed in the requested organs:

```
SELECT DISTINCT t6.geneId
-- geneFamily table to retrieve only homologous genes
FROM geneFamily AS t1
-- tables to search for expression in zebrafish
INNER JOIN gene AS t2 ON t1.geneFamilyId = t2.geneFamilyId
INNER JOIN expression AS t3 ON t2.geneId = t3.geneId
-- tables to search for expression in mouse
INNER JOIN gene AS t4 ON t1.geneFamilyId = t4.geneFamilyId
INNER JOIN expression AS t5 ON t4.geneId = t5.geneId
-- final join to retrieve genes satisfying the criteria
INNER JOIN gene AS t6 ON t6.geneId = t2.geneId OR t6.geneId = t4.geneId

WHERE t3.organId = 'ZFA:0000114' and t5.organId = 'MA:0000072';
```

It appears that this results in low performance, and that when adding more species or more organs, the DBMS optimizer actually decreases efficiency. This lead me to write complex queries using subqueries instead of joins. Finding gene families that contain genes expressed in heart of both species is then written:

```
SELECT DISTINCT t1.geneFamilyId
-- geneFamily table to retrieve only homologous genes
FROM geneFamily AS t1
-- searh for zebrafish expression
WHERE EXISTS (SELECT 1 FROM gene AS t2
     INNER JOIN expression AS t3 ON t2.geneId = t3.geneId
     WHERE t2.geneFamilyId = t1.geneFamilyId and t3.organId = 'ZFA:0000114')
-- searh for mouse expression
AND EXISTS (SELECT 1 FROM gene AS t4
     INNER JOIN expression AS t5 ON t4.geneId = t5.geneId
     WHERE t4.geneFamilyId = t1.geneFamilyId and t5.organId = 'MA:0000072')
```

This query is only capable of identifying gene families satisfying the criteria, whereas we want to retrieve genes. All genes which are members of the selected gene families might not fit the requested criteria, so the previous query has to be extended again to filter for genes,

members of these gene families. This means that every subquery, applied on gene families, has to be duplicated to be applied on genes (but separated by an OR operator, a single gene cannot be expressed in different species), e.g.:

```
SELECT DISTINCT t0.geneId
FROM gene AS t0
INNER JOIN geneFamily AS t1 ON t1.geneFamilyId = t0.geneFamilyId

WHERE (
-- filter for gene families
EXISTS (SELECT 1 FROM gene AS t2
    INNER JOIN expression AS t3 ON t2.geneId = t3.geneId
    WHERE t2.geneFamilyId = t1.geneFamilyId and t3.organId = 'ZFA:0000114')
AND EXISTS (SELECT 1 FROM gene AS t4
    INNER JOIN expression AS t5 ON t4.geneId = t5.geneId
    WHERE t4.geneFamilyId = t1.geneFamilyId and t5.organId = 'MA:0000072')

) AND (
-- filter for genes member of these gene families
EXISTS (SELECT 1 FROM gene AS t6
    INNER JOIN expression AS t7 ON t6.geneId = t7.geneId
    WHERE t6.geneId = t0.geneId and t7.organId = 'ZFA:0000114')
OR EXISTS (SELECT 1 FROM gene AS t8
    INNER JOIN expression AS t9 ON t8.geneId = t9.geneId
    WHERE t8.geneId = t0.geneId and t9.organId = 'MA:0000072')

)
```

While this solution might seem complicated, this type of queries has the best response time, speeding-up multi-species queries by a factor of 300. It is also the only way to have a scalable increase of complexity with the increase of requested criteria. The “join approach” was scalable for requests on two species and two organs, but produced never-ending queries for 5 organs in 5 species. With the “subquery approach”, while a slow response time is possible for complex queries, a result is always reached.

Bypassing the DBMS optimizer

As shown above, the use of subqueries is useful to tell the optimizer in which order it should scan the tables. When confronted to too many indexes, or too many joins, on big tables, the DBMS optimizer might fail to choose the appropriate order. For instance, consider the following query, to retrieve direct sub-stages of the developmental stage "Embryo", that have expression data (see nested set model explained below):

```
SELECT DISTINCT t2.* FROM stage AS t1
INNER JOIN stage AS t2
    ON t1.speciesId = t2.speciesId
    AND t1.leftBound > t2.leftBound AND t1.rightBound < t2.rightBound
    AND t1.level = (t2.level + 1)
INNER JOIN stage AS t3
    ON t3.leftBound >= t2.leftBound AND t3.rightBound <= t2.rightBound
    AND t3.speciesId = t2.speciesId
INNER JOIN expression ON expression.stageId = t3.stageId
where t1.stageId = 'DrerDO:0000001';
```

The tables are not examined in the optimal order (EXPLAIN command output, see Sup. Info), leading to a scan of the entire table *expression* (8,623,058 rows), despite the fact that the key distributions of indexes are correct[11]. When the order of tables examination is forced in the appropriate order (command straight_join in MySQL[12]), the estimation of the number of rows to examine is 472,256. Results are obtained 10 times faster.

These types of tricks should be used with caution: the reasons why the optimizer fails in choosing the appropriate order are not clear. As data distribution changes, or the SQL server is updated, the optimizer might choose the appropriate order again. Forcing this behaviour offers low evolvability, and might eventually degrade performances. Thus the performance of queries needs to be re-examined at each major release of Bgee.

[11] http://dev.mysql.com/doc/refman/5.6/en/analyze-table.html

[12] http://dev.mysql.com/doc/refman/5.6/en/join.html

2.3 Representation of ontologies and of expression data

An important aspect of Bgee is the use of precise descriptions of anatomy and development of species, by the use of ontologies. Ontologies are Directed Acyclic Graphs (DAGs), which are difficult to conveniently represent in databases. The simplest way to achieve it is the use of a table to store the terms of the ontology, and another table to represent the relationships amongst terms. Retrieving all descents of a term on different levels (i.e., indirect descents, such as "descents of descents") then usually requires the use of recursivity.

Nested set model

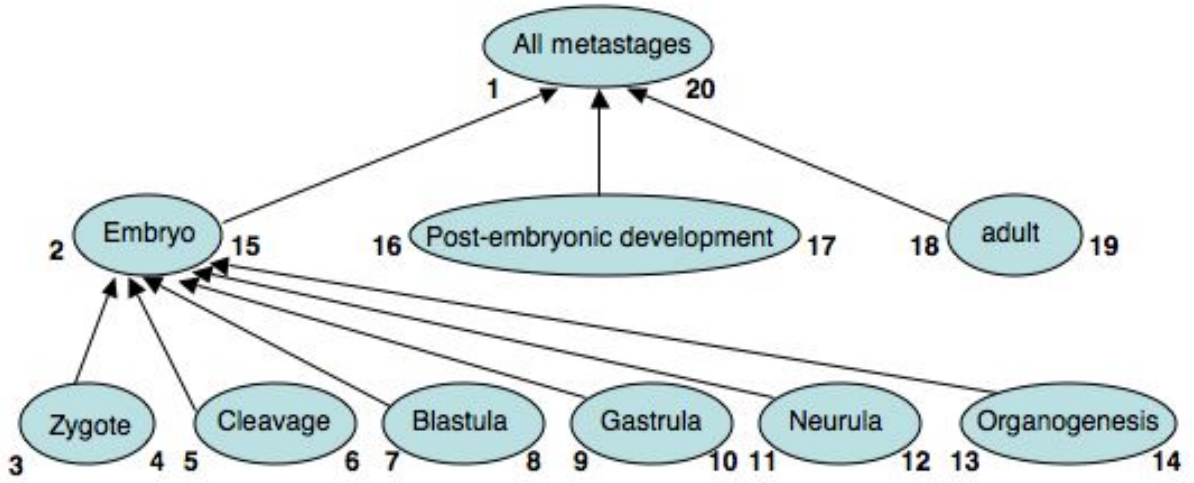


Fig. 2: Representation of the Bgee multi-species developmental ontology. Each term is given a left bound and a right bound. They are such that all descents of a term have bounds included in the bound range of their parent.

This problem can be easily circumvented with ontologies where terms have always only one parent. This is the case for developmental ontologies. In this case, we use a nested set model representation[13]: each term is given two numbers, a left bound and a right bound. They are such that all descents of a term have bounds included in the bound range of their parent (see Fig. 2 for example). All descents of a term, even on multiple levels, can then be retrieved in a single query. This approach allows to easily retrieve all expression data at a developmental stage, including its sub-stages. For instance, to retrieve all genes expressed during the developmental stage "Embryo", including sub-stages (e.g., Zygote, Cleavage):

[13] http://en.wikipedia.org/wiki/Nested_set_model#Variations or http://communities.bmc.com/communities/docs/DOC-9902

```
SELECT DISTINCT t1.geneId FROM expression AS t1
INNER JOIN stage AS t2 ON t1.stageId = t2.stageId
INNER JOIN stage AS t3
          ON t2.leftBound >= t3.leftBound AND t2.rightBound <= t3.rightBound
          AND t2.speciesId = t3.speciesId
WHERE t3.stageId = 'DrerDO:0000002'
```

Classical representation

For other ontologies used, such as anatomical ontologies, a term can have several parents. The classical approach is then to use a table to store relationships between terms, with at least two columns: one for the ID of the parent term, the other for the ID of the descent term (see Fig. 3 for an example). Each row in this table then corresponds to one relationship between two terms (e.g., "midbrain" *part_of* "brain"). And a query can only retrieve direct descents of a term, not indirect descents. Thus recursive algorithms are needed to retrieve all descents of a term.

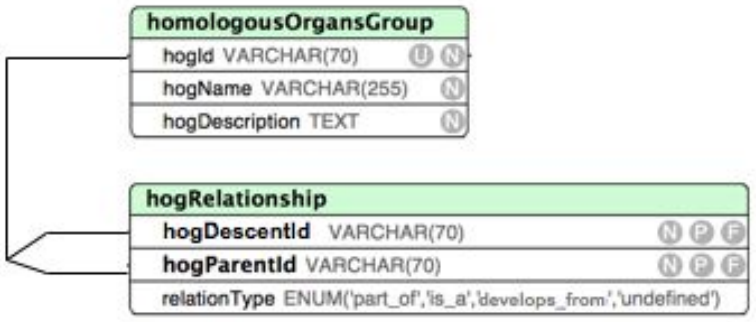


Fig. 3: Representation of the relations between terms of an ontology, here, the HOG ontology.

This represents an issue when we want to retrieve genes expressed in a structure, including all its sub-structures. For instance, when we want to retrieve all genes with expression annotated to zebrafish heart, but also to myocardium, ventricular myocardium, etc. With the schema described above, this means that we first need to retrieve organ IDs of all descents of a term, and in a second time to query the table *expression*, using a list that can contains hundreds of organ IDs. Performing queries on multiple structures and multiple species can then lead to generate strings of several kilobytes. This represents an important overhead for communications between the application and the database, especially considering that the Bgee application is developed in Java, which uses the TCP/IP protocol to communicate with

databases, rather than sockets. Another problem is that DBMS are not good at managing queries with multiple OR conditions.

A solution to avoid the need for recursive algorithms, and the pre-loading of list of organ IDs, is to use the same schema as described above, but by linking a term to all its descent terms, even indirect. The trade-off is that it is then not possible to distinguish direct and indirect descents without adding an additional field. But it is possible to retrieve all expression data from the substructures of an organ, with a single query, e.g., to retrieve expression data in the substructures of the zebrafish heart:

```
SELECT DISTINCT t1.geneId FROM expression AS t1
INNER JOIN organRelationship AS t2 ON t1.organId = t2.organDescentId
WHERE t2.organParentId = 'ZFA:0000114';
```

But retrieving expression data in an organ and its substructures, at the same time, makes the query more complex, e.g., for expression data in zebrafish heart and substructures:

```
SELECT DISTINCT t3.geneId FROM organ AS t1
LEFT OUTER JOIN organRelationship AS t2 ON t1.organId = t2.organParentId
INNER JOIN expression AS t3
    ON t3.organId = t1.organId OR t3.organId = t2.organDescentId
WHERE t1.organId = 'ZFA:0000114';
```

Joining a table using OR conditions on multiple tables results in low performance. Again, this solution appeared rapidly non-viable with rapid Bgee data growth. Another solution could be to consider an organ as descent of itself in the table *organRelationship*, so that only one join between *expression* and *organRelationship* is needed (as simple form of the query above). This solution is not viable if used with multiple organs and multiple species query.

A (bad?) solution: more data redundancy

The solution adopted was to create a new table, called *globalExpression*, with the same schema than the table *expression*. In this new table, expression data linked to an organ ID represent expression data for the organ itself, but also all its substructures. This results in high

data redundancy, but high gain of performance. Requesting expression data in zebrafish heart and all substructures is simply written:

```
SELECT DISTINCT geneId FROM globalExpression
WHERE organId = 'ZFA:0000114';
```

We face the same type of issues with homology relationships between species: to compare expression patterns between species, Bgee uses a multi-species anatomical ontology (HOG ontology, Homologous Organs Groups), with mappings to species-specific ontologies. In the examples above, to retrieve expression in hearts of mouse and zebrafish, the IDs of these structures needed to be known for both species. In the Bgee application, these IDs would have been retrieved first by querying the multi-species HOG ontology. This could result in the same requirement to pre-load large lists of organs, using recursivity, or of adding several joins to the queries. Again, the solution adopted was to create a new table, *hogExpression*, with the same schema than the table *expression*. But here, the anatomical and developmental terms are not species-specific, but correspond to anatomical and developmental multi-species ontologies. In this table, when expression of a gene is reported in a HOG, this means that expression has been retrieved from every organ mapped to the HOG in the corresponding species, and all their substructures. Multi-species queries described in the previous section are then performed on the table *hogExpression* rather than *expression*, using common HOG IDs, rather than species-specific organ IDs that should be recovered first.

3 Bgee application

The Bgee application is developed in Java. This choice was made first because of its clear object-oriented design. It was also an easy solution to build code that could be used both for web-applications, by the use of Java servlet containers[14], and for stand-alone programming. A stand-alone application would then benefit from the portability of Java, thanks to its Virtual Machine. Moreover, Java is one of the standard languages of bioinformatics development, allowing easy integration on the long term.

[14] http://en.wikipedia.org/wiki/Java_Servlet

The design of the application is an important factor for the durability of the whole project. For instance, adding new data types implies modifications on the code of the application itself, not only on the database side (unlike, e.g., adding a new species). The source code should then offers maximum modularity. I will present here the design patterns adopted to answer these requirements.

3.1 Model-View-Controller

The Model-View-Controller (MVC) is a well-established design pattern[15]. The MVC separates application domains in three different layers: the model, the core application logic, responsible for managing the data; the view, responsible for the display of the data; the controller, responsible for event handling and for communication between the two previous layers. The model is totally unaware of the view and controller layers, and is totally independent from them. For instance, a change in the view layer will have no effect on the model. The view is aware of the model, and intrinsically connected to it, in order to display the data. A change in the model would impact the view. Finally, the controller is aware of both the model and the view. It handles requests from the user, triggers action on the model in response, and calls a view that uses the model to display results.

There are two main reasons for the choice of this pattern in Bgee: first, the need to manage highly complex data requires to isolate business logic in a separate layer; this isolation would also allow to propose a stand-alone application. Second, Bgee needs to offer different data visualizations, such as HTML through web pages, TSV for data downloads, or XML for programmatic access and communications with other databases. The MVC pattern allows to easily "plug" different views on the exact same code for data processing and event handling. Different design patterns, described below, are used in combination with the MVC to enhance its capabilities.

3.2 Data access layer

Data Access Objects and Data Transfer Objects

Even inside the Model layer, it is convenient to separate data access, such as queries to the database, from business logic, such as collecting and organising all information about a gene

[15] http://en.wikipedia.org/wiki/Model–view–controller

from multiple queries. In Bgee, access to the database is performed by Data Access Objects (DAOs[16]), proposing interfaces to the Model, hiding content and structure of the data source. This way, the Model is independent from the data source, which could be switched without affecting the business layer (see also Factory pattern below). Communication between DAOs and the Model is performed through Data Transfer Objects (DTOs[17]). In Java, DTOs are serializable objects (i.e., objects that can be converted for communication over networks or for storage), used to transfer data between different server applications. This offers an even greater separation between the Model and the DAOs. DAOs could for instance be implemented on an applicative server, and be remotely requested by clients (i.e., the Bgee API), that would obtain in return DTOs to process the data. This means that the database access could be completely hidden and isolated from public clients.

Database access through the Singleton pattern, and an assumed choice of not using Hibernate

When accessing a database in an application, it is convenient to have a controlled and uniform way to access it over the entire application. For instance, to offer cache capabilities, to log the queries, to limit the number of simultaneous connections, or to ensure that transactions are not interrupted by conflicting queries. This is achieved through the use of the Singleton pattern[18] for designing the connector to the database. The Singleton pattern ensures that one and only one object from a class is instantiated at the same time. The constructor of the class is private so that it cannot be instantiated by other classes, and the corresponding object can only be requested through static methods. These static methods check whether an object is already instantiated, instantiate one if needed, and return it. All DAOs in the Bgee application then use this unique connector for querying the database.

It is very common in the development of Java server-side applications to use Hibernate[19] to access databases. Hibernate is an Object-relational mapping (ORM[20]), that allows to convert data stored in a database into high-level objects. Notable advantages of ORMs are that they

[16] http://en.wikipedia.org/wiki/Data_access_object

[17] http://en.wikipedia.org/wiki/Data_transfer_object,
http://java.sun.com/blueprints/patterns/TransferObject.html

[18] http://en.wikipedia.org/wiki/Singleton_pattern

[19] http://www.hibernate.org/

[20] http://en.wikipedia.org/wiki/Object-relational_mapping

avoid the need to write all the DAOs presented above, and that they are highly portable to different databases. But an important disadvantage is that they are poorly customizable, and certainly not enough to allow the complex queries presented in the previous section. While it might be useful to other projects, I have chosen not to rely on it.

Abstract Factory pattern

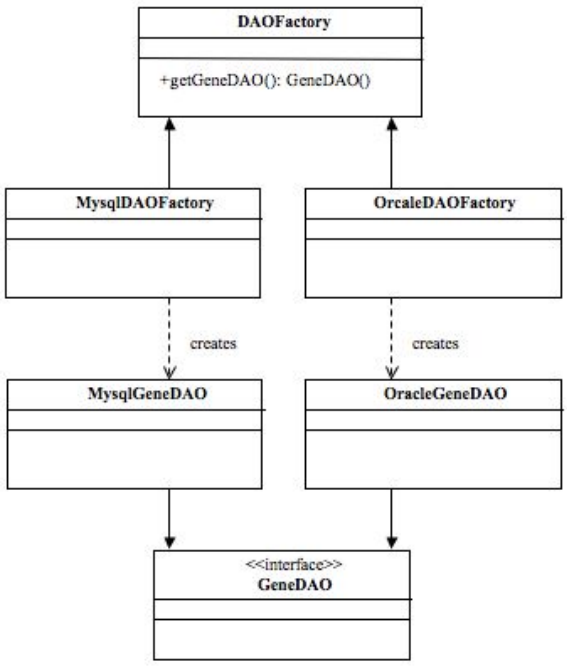


Fig. 4: Simplified class diagram of the Abstract Factory pattern. DAOFactory is an abstract class with the abstract method getGeneDAO(). MysqlDAOFactory and OracleDAOFactory extend this class. They must implement the method getGeneDAO(). Through these methods, MysqlGeneDAO or OracleGeneDAO are created. They implement the same interface GeneDAO.

To ensure that no modifications are needed on the business layer in case of a change in the data source, I used the Abstract Factory pattern[21]. Concrete Factories[22] are classes specialized in the creation of objects. Instantiating an object sometimes requires complex operations, such as initializing some attributes. Factories are ways to encapsulate these creation processes. An Abstract Factory is a way to group different Concrete Factories, and to hide which concrete implementation is used. Consider for instance if Bgee were to use two data sources, a MySQL database, and an Oracle database. The Bgee application then would possess: MySQL DAOs; Oracle DAOs; a corresponding MySQL Concrete Factory, in charge of instantiating MySQL DAO objects; an Oracle Concrete Factory, in charge of instantiating Oracle DAO objects. Both Concrete Factories would implement the same interface, the DAO Factory Interface. If the Model requires a DAO to obtain information from a data source, it calls the DAO Abstract Factory. This Abstract Factory determines which Concrete Factory to return to the Model. The Model does not know which Concrete Factory it

[21] http://en.wikipedia.org/wiki/Abstract_factory_pattern

[22] http://en.wikipedia.org/wiki/Factory_object

gets, and does not care, as they implement the same interface. From there, all returned DAOs will be MySQL DAOs, or Oracle DAOs, implementing the same interfaces, so that the Model does not know which data source it uses (see Fig. 4). And in any case, these DAOs will return Data Transfer Objects (see above).

DataParametersTO and DAOParent

Bgee is intended since the beginning to allow the inclusion of new data types as they become available. The code had to be robust to such additions, meaning that queries to the database should not need to be modified. For this purpose, a specific Transfer Object, DataParametersTO, is always used to transmit expression parameters to the data access layer. If new parameters appear in the future, such as a new data type, a modification to this class will impact all DAOs. Moreover, all DAOs are subclasses of the same parent class, DAOParent. The aim of the DAOParent is to finalize every query, in order to modify it if necessary, according to the query parameters, passed through a DataParametersTO object. When adding new expression parameters to Bgee (e.g., new data type, quality, gene biotype, filter), the only modifications to perform on the data access layer are located in these two classes.

3.3 View

This layer is in charge of displaying the data to the user. Bgee has to be capable to generate different visualisations of the same data (HTML, TSV, etc).

Abstract Factory Pattern

This pattern is of particular interest here, as the view has to easily switch between different representations. To date, Bgee proposes, depending on the pages, up to three different formats: HTML, TSV, XML. This means that the Bgee application includes a HTML Concrete Factory, a TSV Concrete Factory, and a XML Concrete Factory, implementing all the same interface. And all corresponding views, in these different formats, also have the same interfaces. The controller uses the corresponding Abstract Factory to obtain a Concrete Factory, without being aware of which one. Views can then be generated in different formats, without modifying the code of the controller, nor of the model.

ViewParent

Like the DAOs, all views are subclasses of a few parent classes, such as the HTMLParent. The purpose of this parent class is notably to handle all outputs related to expression parameters: display of HTML forms to select data types, listing of available filters for a web-service for XML, etc. When adding new expression parameters in Bgee (new data type, quality, gene biotype, filter, etc), the only modifications to perform on the view layer are located in these parent classes.

Considerations about JSP

When building web applications in Java, it is common to use the JavaServer Pages (JSP) to dynamically generate HTML. I did not. The reason is simple: JSP is a template engine. What is exactly a template engine? It is a technology for generating layouts, using its own language, often with idiosyncratic syntax, meant to be easy to use by graphic designers, adding another layer of complexity to an application, slowing down the generation of outputs. What is the purpose of template engines? To separate the business logic from the presentation logic. The purpose of a template engine in a MVC pattern already separating business and presentation logic is not obvious. As a result, all views in Bgee, including HTML, are generated through standard Java code.

3.4 Controller

The controller is responsible for handling user requests, analyse them, triggering the appropriate action on the model, then calling the view and giving it the model, for display.

Front Controller and Page Controllers

Bgee uses a Front Controller[23] as the main pattern for the controller layer. Front Controller defines a single entry point for the entire application. All requests are handled through it. After processing user authentication, security check, and analysing the query, the Front Controller can delegate further actions to a Page Controller[24] (or "Dispatcher" in Java), specialized in one application domain (handling search form queries, handling ontologies visualisation, or handling redirections, etc). The Page Controller is then in charge of using the

[23] http://java.sun.com/blueprints/corej2eepatterns/Patterns/FrontController.html , http://en.wikipedia.org/wiki/Front_Controller_pattern

[24] http://msdn.microsoft.com/en-us/library/ff649595.aspx

model and delegating to the view. The Front Controller pattern then offers a full control on the entire application from a single place.

Class RequestParameters

Analysing and generating URLs are important aspects in web applications. URLs could be seen as the equivalent of listeners of the controller in standard applications: a "click" on the URL will trigger an action and update the view. This aspect should then be managed by the controller. In Bgee, a request to the server is always passed through an instance of the RequestParameters class. This object analyses the parameters of the query, secure them, and store them (each allowed parameter in requests to the server correspond to an attribute in the RequestParameters class). The controller then uses this object, and value of its attributes, to decide what action to trigger. This class thus acts as a filter from the external world, and enforce data typing of the parameters, providing enhanced security. Of note, when adding new expression information in Bgee (e.g., new data types), only this class needs to be modified in the controller layer to reflect the modifications, and handle the new parameters.

When the view needs to generate an URL to provide the user a link to browse another page, it also uses a RequestParameters object. The view populates the attributes of this object according to its needs. The object can then generate the requested URL based on its attributes. This is extremely important when patterns of URLs have to change, for instance for the use of URL rewriting. A common mistake of many web applications is to hard-code their URLs.

4 Pipeline and curation process

When developing the pipeline for Bgee, like for the application, the emphasis was about making it robust and adaptable. The field of biology is famous for the low persistency of available resources (Wren, 2008). This motivated the design decision to rely on well established reference databases (Ensembl (Flicek, Amode, *et al.*, 2011), ArrayExpress (Parkinson, Sarkans, *et al.*, 2011), Unigene (Pontius, Wagner, *et al.*, 2003), ZFIN (Bradford, Conlin, *et al.*, 2011), MGI (Finger, Smith, *et al.*, 2011), Xenbase (Bowes, Snyder, *et al.*, 2009), BDGP (Tomancak, Berman, *et al.*, 2007)). These are more likely to be maintained on the long-term and to be regularly updated. Nevertheless, integrating data from many sources is challenging: our pipeline must be composite, as some sources provide database access, others provide flat files download, yet others access through an API. And at each update of

Bgee, there have always been changes in at least one source, requiring code modifications on our side.

As the pipeline is one of the most critical components of Bgee, we have paid special attention to the transmission of knowledge on its usage and functionalities. An extensive documentation is available on the wiki of our group (see Appendix 1), and three people have already successfully run it, demonstrating that the code and the documentation are clear.

The data generated through our curation processes are key to the Bgee pipeline. The two main tasks are: i) the annotation of expression data, to ensure data "normality", and to map them to anatomies and developments of species; ii) the development of relationships between anatomies of species. In the same way as for the development of our pipeline, we have aimed to standardize annotation processes through an extensive documentation available to curators (see Appendix 2).

To provide high quality data, it is preferable to check, over time and over annotators, the consistency of the annotations. This should also allow to provide to annotators feedback about the quality of their work, assessed by collaborators. We do not have yet the resources to fully implement these gold-standard methods. However, the annotation process in Bgee has first involved several master students, then a professional curator starting from March 2009. All annotation have thus been first double-checked between students, then all reprocessed by our curator. We are thus confident that Bgee provides high quality annotations.

5 Evolution of Bgee: improvements since the 2008 publication

5.1 Over-expression and no-expression data

It is of interest to extract "biologically pertinent" gene expression from microarray data, which might be more similar to the signal reported by *in situ* hybridizations. For instance, during the staining process of an *in situ* hybridization, the time of coloration is adapted to obtain a good signal/noise ratio. The fixation step is performed when the background noise, representing non-specific expression, starts to increase.

For microarray data, statistical analyses are required to identify differential expression. They have been chosen to be consistent with the Gene Expression Atlas (Kapushesky, Emam*, et al.*, 2010) analyses. We select experiments with at least three conditions studied (at least three organ/stage conditions), and at least 2 replicates for each. An ANOVA is used to determine whether a gene has a significant variation of its level of expression over the conditions. A multiple-comparison to the mean is performed to identify genes over-expressed in specific conditions (see Fig. 5). Each condition is contrasted to the mean, thus the contrasts are not independent. To overcome this issue, it is possible to compute simultaneous confidence intervals using multivariate statistics. But this approach is computationally very intensive. After discussions with Misha Kapushesky, who performs such analyses for the Gene Expression Atlas, we decided to keep the single non-independent procedure, which does not seem to affect the results in practice. After analyses, if the adjusted p-value is between 1% and 5%, the over-expression information is considered as low quality. If the adjusted p-value is below 1%, over-expression information considered as high quality.

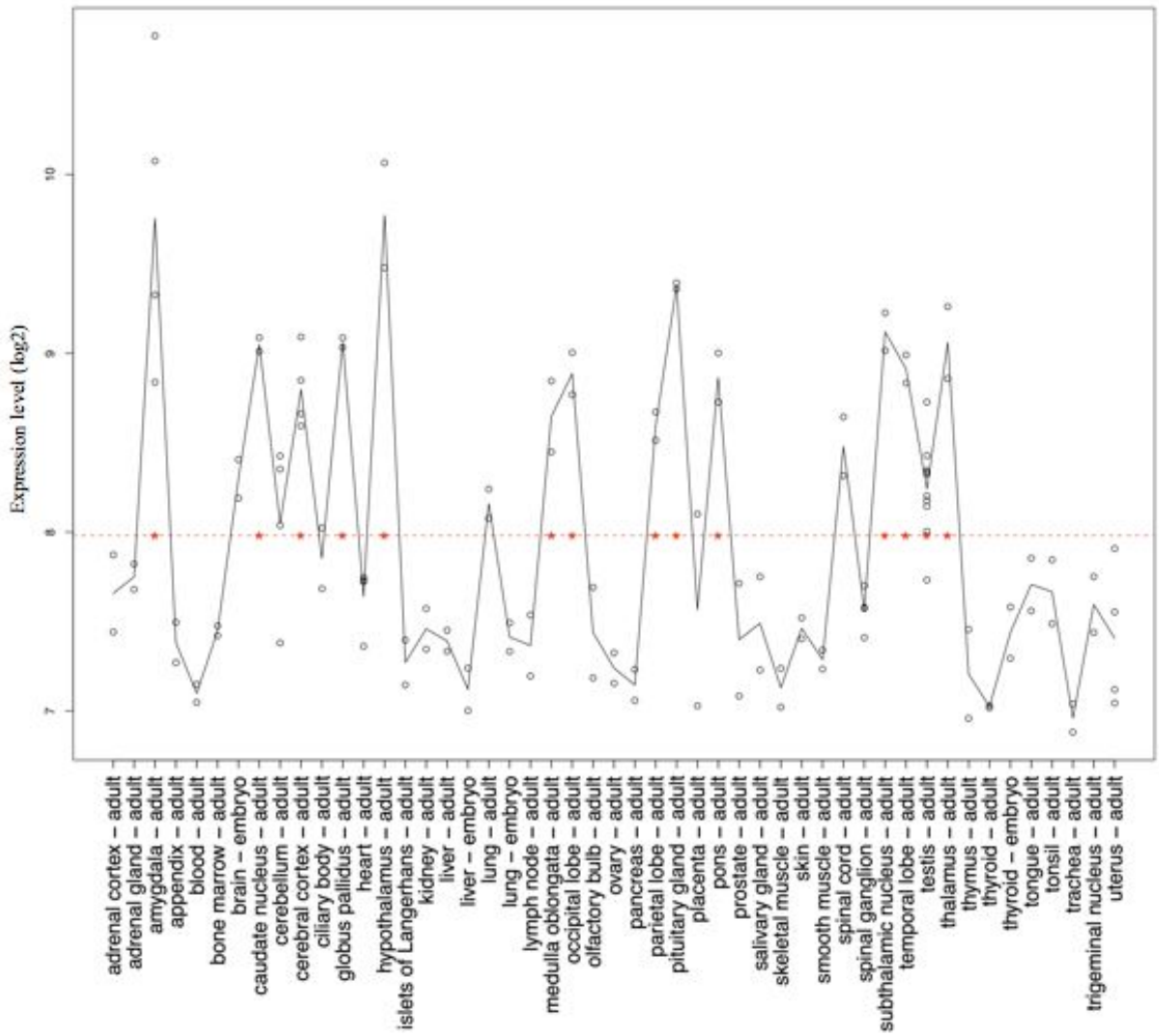


Fig. 5: expression profile of the probeset gnf1h08859_at from the Su *et al.* dataset (Su, Wiltshire*, et al.*, 2004). Dots represent expression measurements; black lines connect mean expression values for each condition; red dashed line is the mean value of expression for the probeset across all conditions; red stars mark conditions where significant over-expression is detected.

For reports of absence of expression, Bgee uses formal reports from *in situ* hybridizations, or statistical analyses performed on Affymetrix from ArrayExpress (Parkinson, Sarkans*, et al.*, 2011). We use the same approach as to detect expression, but only using chips with available raw data (i.e., not only MAS5 present/absent calls). We first normalize the signal of the probesets by the gcRMA algorithm (Wu and Irizarry, 2005), and perform a Wilcoxon test on the signal of the probesets against a subset of weakly expressed probesets (see (Schuster, Blanc*, et al.*, 2007)). If the signal of a probeset is not significantly different from the background signal, the gene is considered as not expressed. If any other result is inconsistent (another experiment/chip has detected expression of this gene in the same anatomical

structure at the same developmental stage), the gene is considered as expressed, with a low quality. If any other result found expression of the same gene in a substructure or a child stage, the no-expression result is also removed.

Over-expression and absence of expression information are not yet available from the Bgee interface, but are available from direct download. Reports of absence of expression should be easy to integrate, as the representation of these data is very close from the representation of expression data. Over-expression information is more complicated to integrate, as an interface should display the different conditions tested, to propose filters on the number of these conditions, and to distinguish between comparisons between developmental times, or anatomical structures, on in both.

5.2 Improved search engines

We have developed two new search engines to query Bgee. First, a engine for advanced users, inspired from BioMart (Smedley, Haider*, et al.*, 2009), called BgeeMart[25] (see Fig. 6). This tool allows to perform almost any queries, e.g., multi-species queries using species-specific anatomical structures, or using multi-species ontologies, to filter for gene IDs, or GO terms, exactly as BioMart. Raw data can also be retrieved (IDs of Affymetrix chips, of ESTs, etc). All results can be exported in CSV or TSV.

[25] http://bgee.unil.ch/?page=expression&action=bgeemart

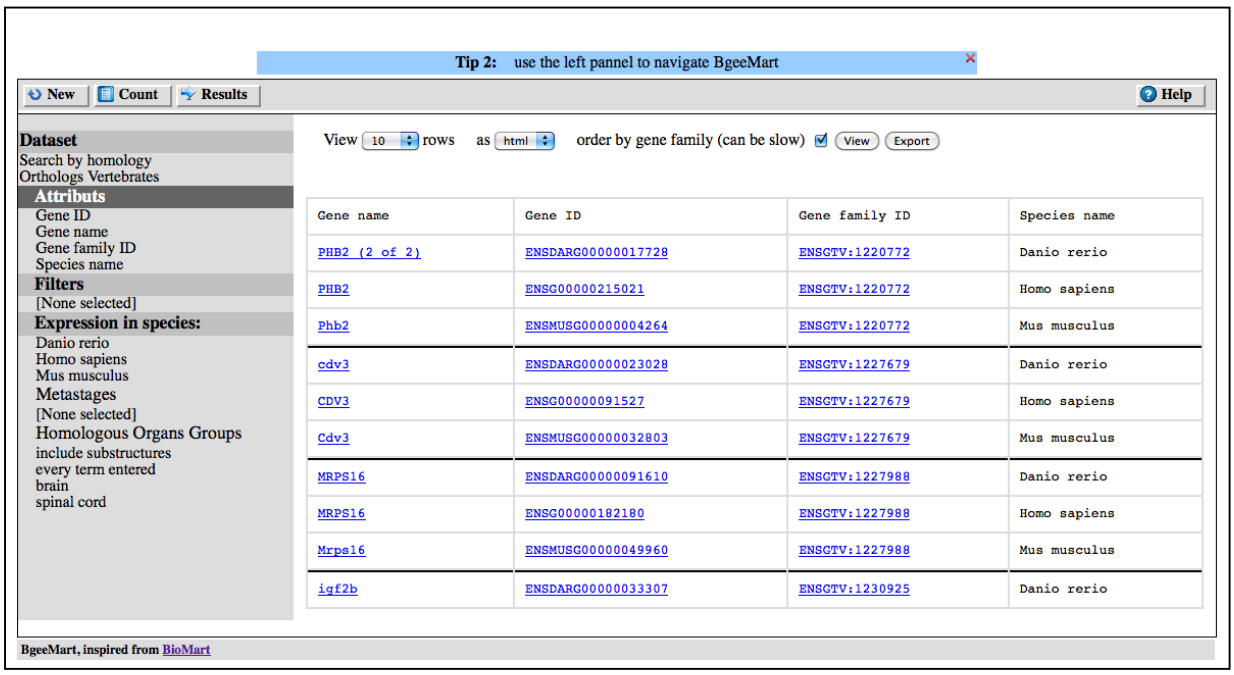


Fig. 6: Interface of BgeeMart.

Second, we developed an engine for beginner users, with restricted capabilities, but an easier interface[26] (see Fig. 7). This tool proposes only queries based on multi-species ontologies, which is the main originality of Bgee. This should give beginner users an outlook of Bgee capabilities.

[26] http://bgee.unil.ch/bgee/bgee?page=expression&action=easy_search

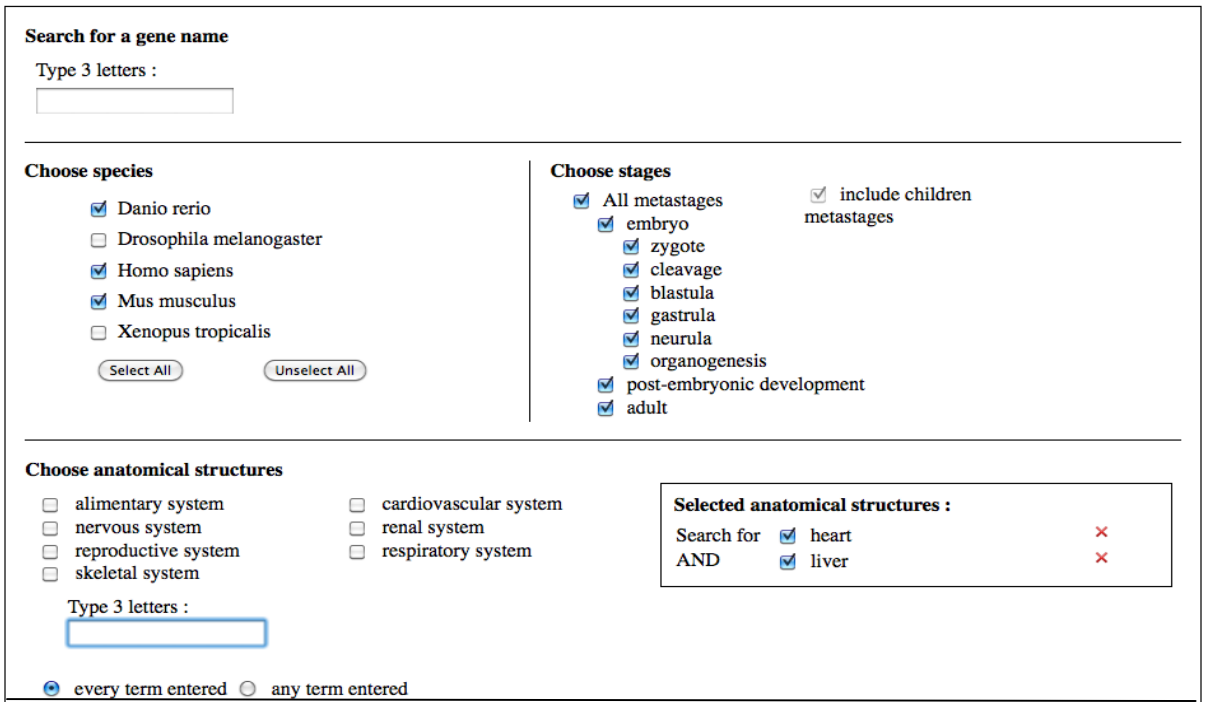


Fig. 7: Interface of the "easy search engine".

6 Conclusion

My ambition for Bgee is to make it a reference database, maintained on the long-term, with regular updates. The first implication is that response times to complex queries, involving large amounts of data, should be kept reasonable. This has motivated a continuing effort to optimize the database and the query syntax.

The second implication is that, over time, several people will have to work on the project, and that the continuation of the project should be robust to major changes in the development team. It was then clear from day one that the database, the application, the pipeline and the curation processes should be clearly documented, and that several people should work on each part, to secure the transmission of the project. It was also clear that data would evolve over time, at a minimum thanks to the addition of new species and data types. This implies that the code had to be highly evolvable.

This aim seems to be reached. The numerous internal documentations generated, and the clear structure of the code, are the guarantees that the project will be maintained, and that other collaborators could join the project and work collaboratively. For instance, two students have already worked under my supervision on the Bgee application. One of them has developed a

DAS web-service used for visualization of Bgee data in the Ensembl website. The second one has notably developed the search engine for beginner users. The code of Bgee thus seems usable and extendable.

The long term success of Bgee will depend on user adoption, but it is unlikely to be hampered by an outdated pipeline, or by a poor code structure.

7 References

Bastian, F., Parmentier, G., Roux, J., Moretti, S., Laudet, V., *et al.* (2008) Bgee: Integrating and Comparing Heterogeneous Transcriptome Data Among Species. In Bairoch, A., Cohen-Boulakia, S. and Froidevaux, C. (eds), *Data Integration in the Life Sciences*. Springer Berlin / Heidelberg, pp. 124-131.

Bowes, J.B., Snyder, K.A., Segerdell, E., Jarabek, C.J., Azam, K., *et al.* (2009) Xenbase: gene expression and improved integration, *Nucleic Acids Research*.

Bradford, Y., Conlin, T., Dunn, N., Fashena, D., Frazer, K., *et al.* (2011) ZFIN: enhancements and updates to the zebrafish model organism database, *Nucleic Acids Research*, **39**, D822-D829.

Finger, J.H., Smith, C.M., Hayamizu, T.F., McCright, I.J., Eppig, J.T., *et al.* (2011) The mouse Gene Expression Database (GXD): 2011 update, *Nucleic Acids Research*, **39**, D835-D841.

Flicek, P., Amode, M.R., Barrell, D., Beal, K., Brent, S., *et al.* (2011) Ensembl 2011, *Nucleic Acids Research*, **39**, D800-D806.

Kapushesky, M., Emam, I., Holloway, E., Kurnosov, P., Zorin, A., *et al.* (2010) Gene Expression Atlas at the European Bioinformatics Institute, *Nucleic Acids Research*, **38**, D690-D698.

Parkinson, H., Sarkans, U., Kolesnikov, N., Abeygunawardena, N., Burdett, T., *et al.* (2011) ArrayExpress update - an archive of microarray and high-throughput sequencing-based functional genomics experiments, *Nucleic Acids Research*, **39**, D1002-D1004.

Pontius, J.U., Wagner, L. and Schuler, G.D. (2003) UniGene: a unified view of the transcriptome. In McEntyre, J. and Ostell, J. (eds), *The NCBI Handbook.* National Center for Biotechnology Information (US), Bethesda (MD).

Schuster, E., Blanc, E., Partridge, L. and Thornton, J. (2007) Correcting for sequence biases in present/absent calls, *Genome Biology*, **8**, R125.

Smedley, D., Haider, S., Ballester, B., Holland, R., London, D., *et al.* (2009) BioMart - biological queries made easy, *BMC Genomics*, **10**, 22.

Su, A.I., Wiltshire, T., Batalov, S., Lapp, H., Ching, K.A., *et al.* (2004) A gene atlas of the mouse and human protein-encoding transcriptomes, *Proceedings of the National Academy of Sciences of the United States of America*, **101**, 6062-6067.

Tomancak, P., Berman, B.P., Beaton, A., Weiszmann, R., Kwan, E., *et al.* (2007) Global analysis of patterns of gene expression during Drosophila embryogenesis, *Genome Biol*, **8**, R145.

Wren, J.D. (2008) URL decay in MEDLINE, a 4-year follow-up study, *Bioinformatics*, **24**, 1381-1385.

Wu, Z. and Irizarry, R.A. (2005) Stochastic Models Inspired by Hybridization Theory for Short Oligonucleotide Arrays, *Journal of Computational Biology*, **12**, 882-893.

8 Supplementary information

Output of EXPLAIN commands, with or without the use of “straight_join”. Number of rows evaluated are an extimate.

```
mysql> explain SELECT   DISTINCT t1.* FROM stage AS t2   INNER JOIN stage AS t1 ON t1.speciesId =
t2.speciesId AND t1.leftBound > t2.leftBound AND t1.rightBound < t2.rightBound AND t1.level = (t2.level +
1)   INNER JOIN stage AS t3 ON t3.leftBound >= t1.leftBound   AND t3.rightBound <= t1.rightBound AND
t3.speciesId = t1.speciesId  INNER JOIN expression ON expression.stageId = t3.stageId  where t2.stageId =
'DrerDO:0000001';
+----+-------------+------------+--------+-------------------------------+-----------+---------+-----------
| id | select_type | table      | type   | possible_keys                 | key       | key_len | ref
| rows    | Extra                 |
+----+-------------+------------+--------+-------------------------------+-----------+---------+-----------
|  1 | SIMPLE      | t2         | const  | PRIMARY,speciesId,speciesId_2 | PRIMARY   | 212     | const
|       1 | Using temporary       |
|  1 | SIMPLE      | t1         | ref    | speciesId,speciesId_2         | speciesId | 8       | const
|      31 | Using where           |
|  1 | SIMPLE      | expression | index  | stageId                       | stageId   | 212     | NULL
| 8500621 | Using index; Distinct |
|  1 | SIMPLE      | t3         | eq_ref | PRIMARY,speciesId,speciesId_2 | PRIMARY   | 212     |
bgee_v09_ens62_2.expression.stageId |       1 | Using where; Distinct |
+----+-------------+------------+--------+-------------------------------+-----------+---------+-----------

mysql> explain SELECT STRAIGHT_JOIN DISTINCT t1.* FROM stage AS t2  INNER JOIN stage AS t1 ON t1.speciesId
= t2.speciesId AND t1.leftBound > t2.leftBound AND t1.rightBound < t2.rightBound AND t1.level = (t2.level +
1)   INNER JOIN stage AS t3 ON t3.leftBound >= t1.leftBound   AND t3.rightBound <= t1.rightBound AND
t3.speciesId = t1.speciesId  INNER JOIN expression ON expression.stageId = t3.stageId  where t2.stageId =
'DrerDO:0000001';

+----+-------------+------------+-------+-------------------------------+-----------+---------+------------
| id | select_type | table      | type  | possible_keys                 | key       | key_len | ref
| rows   | Extra                |
+----+-------------+------------+-------+-------------------------------+-----------+---------+------------
|  1 | SIMPLE      | t2         | const | PRIMARY,speciesId,speciesId_2 | PRIMARY   | 212     | const
|      1 | Using temporary      |
|  1 | SIMPLE      | t1         | ref   | speciesId,speciesId_2         | speciesId | 8       | const
|     31 | Using where          |
|  1 | SIMPLE      | t3         | ref   | PRIMARY,speciesId,speciesId_2 | speciesId | 8       |
bgee_v09_ens62_2.t1.speciesId |     57 | Using where; Distinct |
|  1 | SIMPLE      | expression | ref   | stageId                       | stageId   | 212     |
bgee_v09_ens62_2.t3.stageId   | 472256 | Using index; Distinct |
+----+-------------+------------+-------+-------------------------------+-----------+---------+------------
```

High rates of neofunctionalization and conservation of expression patterns after duplication in vertebrates

Frederic B. Bastian[1,2], Julien Roux[1,2], and Marc Robinson-Rechavi[1,2,*]

[1]University of Lausanne, Department of Ecology and Evolution, Quartier Sorge, 1015 Lausanne, Switzerland.

[2]Swiss Institute of Bioinformatics, Lausanne, Switzerland.

[*]Corresponding author. Email: marc.robinson-rechavi@unil.ch

Abstract

The evolution of gene function after duplication remains a largely open question. Changes in expression patterns have been suggested to play an important role. In accordance with this idea, several studies have demonstrated divergence of expression between duplicates. But distinguishing between different models of evolution after duplication has proven difficult, due to the need to compare expression patterns of duplicated genes to a singleton ortholog. We present here a large-scale comparison of expression patterns of hundreds of duplicated genes to their singleton ortholog in an outgroup species, including both small and large-scale duplicates, in three vertebrate species (human, mouse and zebrafish), using highly accurate descriptions of expression patterns. Our results showed unexpectedly high rates of *de novo* acquisition of expression domains after duplication (neofunctionalization), at least as high or higher than rates of partitioning of expression domains (subfunctionalization). We found differences in the evolution of expression of small- and large-scale duplicates, with small-scale duplicates the most prone to neofunctionalization. Duplicates with neofunctionalization seemed to evolve under more relaxed selective pressure on the coding sequence. Finally, even with abundant and precise expression data, the majority fate we recovered was neither neo- nor subfunctionalization of expression domains, suggesting a major role for other mechanisms in duplicate gene retention.
Online supplementary material: we provide a web-interface to browse all results, and related raw data at http://bioinfo.unil.ch/supdata/Bastian_2011/html/

My contribution was to perform all the analyses, extract the data from Bgee, and lead the biological interpretation of the results.

This work will be submitted to *Genome Research*. Supplementary material is attached to this manuscript, and is also available as online supplementary material at: http://bioinfo.unil.ch/supdata/Bastian_PhD_thesis/index.html

1 Introduction

Gene duplication is thought to be a major source of novelties and cause of speciation (Conant and Wolfe, 2008; Lynch and Conery, 2000; Lynch and Conery, 2003), and to have played a major role in vertebrate evolution (Furlong and Holland, 2002; Ohno, 1970; Putnam, Butts*, et al.*, 2008). After a gene duplication, the most likely outcome is a return to single-copy state: functional redundancy between the two copies is likely to result in relaxed selective pressure, and loss of one of the duplicates (Lynch and Conery, 2000; Lynch, O'Hely*, et al.*, 2001; Zhang, 2003). An important question is why so many are genes kept in duplicate. Several models have emerged to explain this excess of retention (reviewed in Innan and Kondrashov, 2010; Sémon and Wolfe, 2007).

One of these models, neofunctionalization (Ohno, 1970), considers as the main source of preservation that one copy acquires new advantageous mutations, and is preserved by positive selection, while the other copy retains the ancestral function. As the probability of such preservation by positive selection is expected to be low, especially in species with low population sizes (Lynch, O'Hely*, et al.*, 2001), Force, Lynch, and collaborators, proposed an alternative model of neutral preservation by Duplication-Degeneration-Complementation (DDC), a special case of subfunctionalization (Conant and Wolfe, 2008; Force, Lynch*, et al.*, 1999; Lynch and Force, 2000): an accumulation of complementary loss of function mutations, resulting in a partitioning of the ancestral function between the two copies. The DDC subfunctionalization model was originally proposed for expression patterns, and is often discussed in this context.

To what extent these processes account for preservation of duplicate genes in vertebrates is an open question. Anecdotal examples have demonstrated the existence in vertebrates of patterns of expression compatible both with neofunctionalization: RARα and RARγ in vertebrates (Escriva, Bertrand*, et al.*, 2006), hoxa1a in zebrafish (McClintock, Carlson*, et al.*, 2001), or hoxa2a in Fugu (Amores, Suzuki*, et al.*, 2004); and with subfunctionalization: POMCα and POMCβ in teleosts (de Souza, Bumaschny*, et al.*, 2005), or pax6a and pax6b in zebrafish (Kleinjan, Bancewicz*, et al.*, 2008). Several large scale studies have tried to estimate the contribution of these models to the preservation of duplicates in vertebrates, notably by studying their divergence of expression in *Mus musculus*, *Homo sapiens*, and *Xenopus laevis*

(Chain, Ilieva, *et al.*, 2008; Freilich, Massingham, *et al.*, 2006; He and Zhang, 2005; Hellsten, Khokha, *et al.*, 2007; Morin, Chang, *et al.*, 2006).

A major issue with most large-scale analyses is that both neo and subfunctionalization models predict a divergence of expression between duplicates. Only a comparison to an outgroup species allows to infer the putative ancestral expression pattern, and to distinguish between these two models (see also Innan and Kondrashov, 2010; Sémon and Wolfe, 2008). This important step towards a better discrimination of neo and subfunctionalization by the use of an outgroup has been conducted in vertebrates by a few studies only (Farre and Alba, 2010; Huminiecki and Wolfe, 2004; Kassahn, Dang, *et al.*, 2009; Sémon and Wolfe, 2008). A trade-off of these approaches is often that expression information is retrieved in a few, selected *a priori*, homologous tissues (11 in (Sémon and Wolfe, 2008), 16 in (Huminiecki and Wolfe, 2004), 29 in (Farre and Alba, 2010)). Or, when the descriptions of expression patterns are not restricted to a subset of tissues, the number of gene pairs studied is low (38 in (Kassahn, Dang, *et al.*, 2009)).

Here we propose what we believe to be the first large-scale comparison of expression patterns of hundreds of duplicate gene pairs to their singleton orthologs, conducted using three species of vertebrates (*Danio rerio*, *Homo sapiens*, *Mus musculus*), and expression information from 199 homologous tissues, studying both whole-genome and small-scale duplicates.

On the one hand we have studied the evolution of expression of zebrafish whole-genome duplicates, arisen from the third round of whole-genome duplication encountered in vertebrates, specific to teleost fishes (3R WGDs (Amores, Force, *et al.*, 1998; Christoffels, Koh, *et al.*, 2004; Jaillon, Aury, *et al.*, 2004)). On the other hand, we have studied the evolution of expression of small-scale duplicates, both in human and mouse, arisen after the divergence of these two lineages. We defined “triplets” (Sémon and Wolfe, 2008) of genes, grouping two duplicates and their corresponding singleton ortholog in another species, of four types: triplets of zebrafish 3R WGDs and corresponding human singleton, triplets of zebrafish 3R WGDs and corresponding mouse singleton, triplets of human lineage-specific duplicates and corresponding mouse singleton, triplets of mouse lineage-specific duplicates and corresponding human singleton.

For each triplet, we performed a comparison of the expression patterns of the three genes, to determine whether the evolution of the duplicates corresponds to neo- or subfunctionalization at the level of their spatio-temporal expression patterns. This was achieved by the use of the Bgee database (Bastian, Parmentier*, et al.*, 2008) (see Methods for details).

We found unexpectedly high rates of neofunctionalization, at least as high as rates of subfunctionalization, for all types of triplets. Small-scale duplicates seemed especially prone to neofunctionalization. And even with abundant expression data, the majority fate was neither neo- nor subfunctionalization at the expression level, suggesting a major role for other mechanisms in duplicate gene retention. Duplicates with a neofunctionalization pattern tend to evolve under more relaxed selective pressures, whereas duplicates with neither neo- nor subfunctionalization tend to evolve under stronger purifying selection.

2 Results

2.1 Construction of the triplets and determination of expression patterns

We used EnsemblCompara GeneTrees (Vilella, Severin*, et al.*, 2009) to identify zebrafish duplicates dating from the time of the 3R whole-genome duplication, and which did not duplicate more recently, as well as their single copy orthologs in mouse or in human. We also identified genes which duplicated in one of the human or mouse lineages, after the divergence between Glires and Primates, resulting in paralogs existing in two copies in one species, while their orthologs in the other species are single copy (see Methods and Sup. Table 1). For each triplet, we performed two types of comparisons: i) a comparison of the spatio-temporal expression patterns of the genes composing the triplet (i.e., where and when the genes are expressed); and ii) a comparison of their spatial-only expression patterns (i.e., ignoring timing of expression). For this, we retrieved from the Bgee database the expression data, the homology relationships between species-specific anatomical structures (see Methods and Sup. Table 2), and the broad equivalences between species-specific developmental stages, represented as independent “metastages” (key events of development common to all bilaterians: zygote, cleavage, blastula, gastrula, neurula, organogenesis, post-embryonic development, adult; see Sup. Table 3).

We developed an algorithm to retrieve, independently for each triplet, the most precise and independent homologous anatomical structures, shared by the two species involved in the triplet, and with sufficient data to determine the state of expression for the three genes (see Methods). This approach allowed us to not be restricted to a predefined subset of tissues, but to fully scan gene expression patterns, while avoiding the use of redundant or non-independent structures. For the spatio-temporal expression patterns, we selected anatomical structures and retrieved expression data independently for each metastage, resulting in independent combinations of anatomical structure – metastage (see Fig. 1 for examples). For the spatial-only expression patterns, the expression data are gathered from all developmental stages, resulting in a list of independent anatomical structures (see Sup. Fig. S1 for examples). We removed from the spatio-temporal analysis triplets with less than 3 combinations of anatomical structure – metastage (3 anatomical structures in the spatial-only analysis), or including genes with no expression ever detected in any selected combination (or anatomical structure). The number of triplets, and associated anatomical structures and metastages, are detailed in Table 1.

Type of triplet	spatio-temporal analysis				spatial-only analysis	
	triplets	structures	metastages	combinations	triplets	structures
3R - mouse	431	111	8	198	419	128
3R - human	322	34	4	54	361	54
human dupl.	55	85	4	107	57	90
mouse dupl.	107	98	4	122	111	104

Table 1: Summary of data used in the analyses.
"3R" denotes zebrafish whole-genome duplicates, with the outgroup used specified. "Human (resp. mouse) dupl." denotes human (resp. mouse) lineage specific duplicates, with mouse (resp. human) as outgroup. "Combinations" are combinations of metastages and anatomical structures used.

Together, these analyses use 199 homologous organs. We provide a web-interface to browse results for each triplet, and retrieve related raw data (see online Sup. Material).

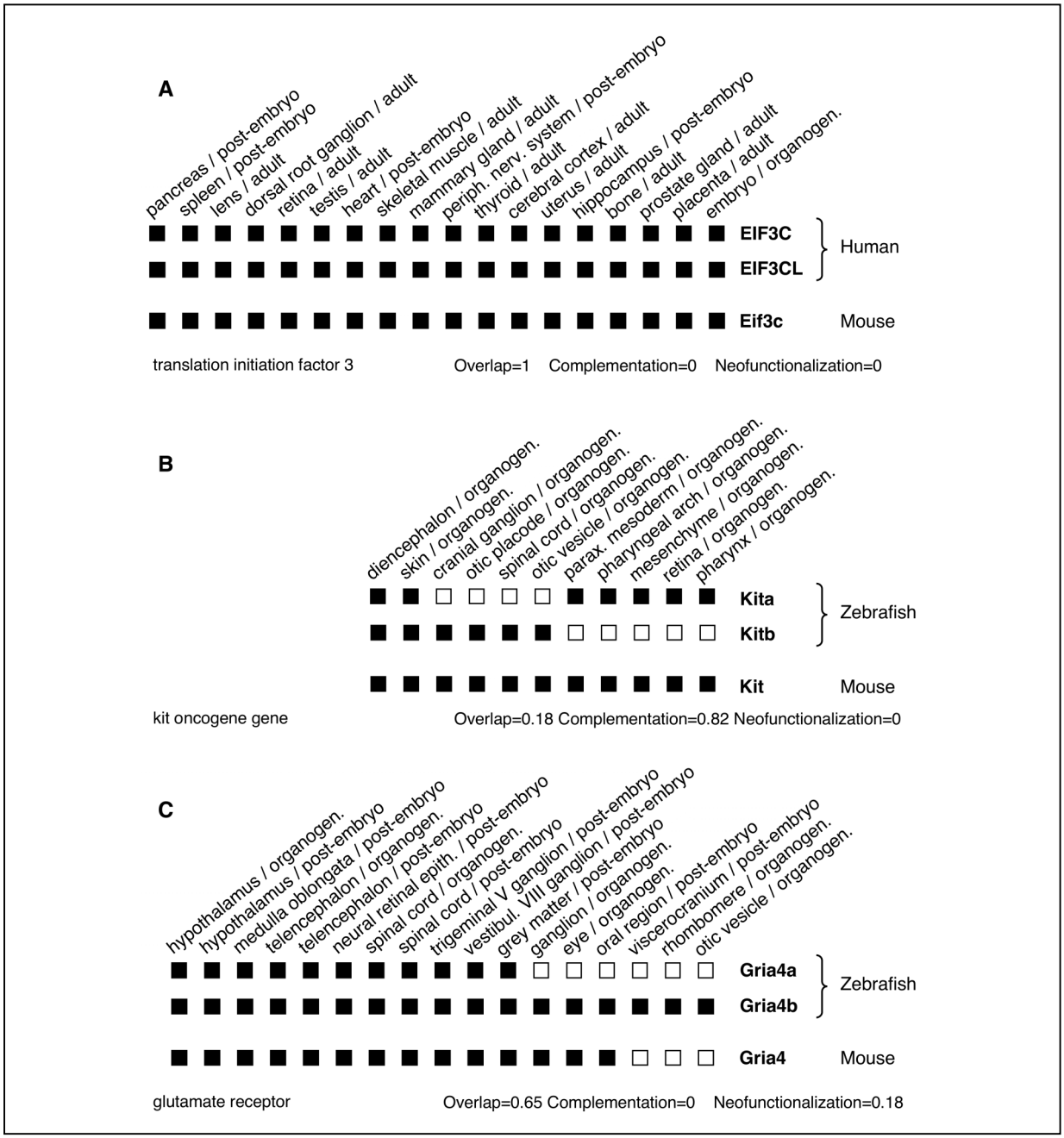


Fig. 1: Examples of comparison of expression patterns.
We adopted the representation formalism used in Farre and Alba (2010). Filled boxes represent combinations of anatomical structure – metastage with expression (spatio-temporal analysis, see Results). White boxes represent conditions with absence of expression. The two first lines correspond to expression patterns of the duplicates in one species, the third line to the expression pattern of the singleton ortholog in another species. For readability purpose, we chose only examples with information of expression in less than 20 conditions. Names of anatomical structures and metastages are displayed in the form: "structure / metastage".
Post-embryo: post-embryonic development; organogen.: organogenesis; vestibul.: vestibulocochlear; parax.: paraxial.

2.2 Spatio-temporal analyses

Metrics

We defined different metrics of gene expression divergence, similar to those used in Farre and Alba (2010), to distinguish between models of neo- and subfunctionalization: "Overlap" is the

proportion of combinations of tissue - metastage where both duplicates are expressed, representing a lack of divergence of expression after duplication (see Fig. 1A for an example); “Complementation” is the proportion of combinations with partitioning of the expression of the singleton between the two duplicates, compatible with subfunctionalization (see Fig. 1B for an example); “Neofunctionalization” is the proportion of combinations where only one of the duplicates is expressed and not the singleton, the most parsimonious explanation being a *de novo* acquisition of the pattern by that duplicate after the duplication (see Fig. 1C for an example). We then classified the triplets into four classes: triplets with overlap only (neither complementation nor neofunctionalization), with complementation, with neofunctionalization, or with both complementation and neofunctionalization.

High conservation of expression

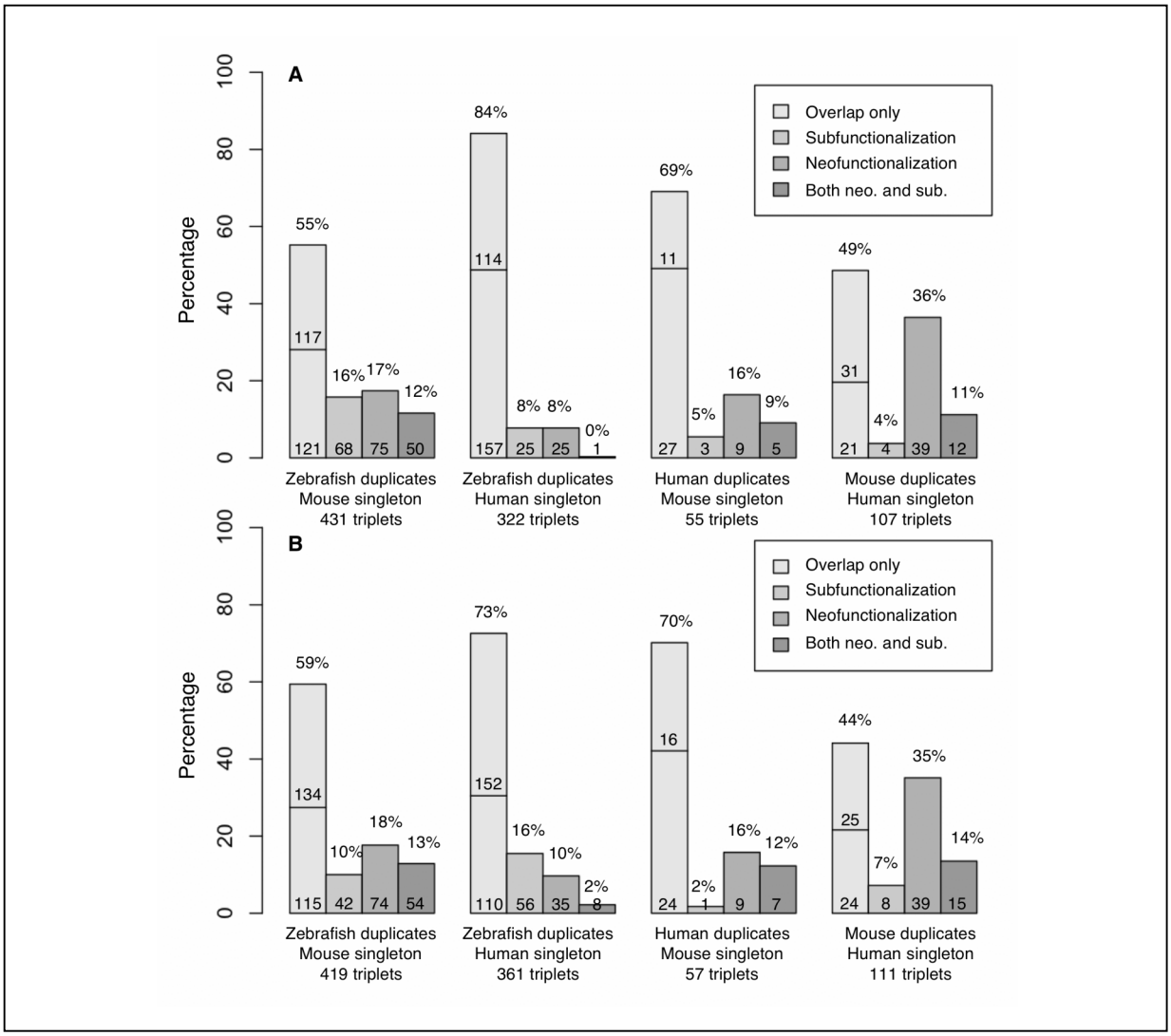
A high proportion of each type of triplets (between 49% and 84%, see Fig. 2A) exhibits overlap only, with no detectable signal of neo or subfunctionalization of expression. Moreover, among these triplets with overlap only, between 40% and 71% of the duplicates have the exact same expression patterns (see Fig. 1A for an example). The remaining triplets have a partial degeneration of expression affecting only one of the duplicates. The triplets with partial degeneration, and those with exact conservation of pattern, do not differ otherwise in any manner which we could detect (i.e., functional categories, anatomical structures, evolutionary rate, data not shown). Thus in the following we will always treat them together as one "overlap only" category.

Of note, even for triplets classified in the neofunctionalization or complementation categories, the expression overlap is high (mean overlap for these triplets between 0.45 and 0.57, see online supplementary material). Only 5% of all these triplets have no overlap at all, i.e., "pure" neo- or subfunctionalization.

Differences between whole-genome and small-scale duplicates, and prevalence of neofunctionalization

Interestingly, neofunctionalization appears at least as common as subfunctionalization of expression domains. Whole-genome duplicates include as many triplets with neofunctionalization only, as with subfunctionalization only (about 17% each when using mouse as an outgroup, 8% when using human, see Fig. 2A).

Among small-scale duplicates, the proportion of triplets with neofunctionalization only is higher than with subfunctionalization only (respectively 16% vs. 5% for human duplicates; respectively 36% vs. 4% for mouse duplicates). This is statistically significant only for mouse duplicates (Fisher exact test, corrected $p=1.7\ 10^{-4}$). These duplicates are also less prone to subfunctionalization than whole-genome duplicates (4% to 5 % of "subfunctionalization only" for the small-scale, 8% to 17% for the whole-genome duplicates).



Fig, 2: Percentages of triplets exhibiting overlap only, subfunctionalization, neofunctionalization, or both neo- and subfunctionalization, in **A:** spatio-temporal analyses, and **B**: spatial-only analyses.
Numbers inside the bars represent count of triplets in this category. Numbers above the bars are percentage of triplets in this category. For the category "overlap only", the bar is split in two parts: the bottom bar represents proportion of triplets with complete overlap (overlap score = 1), the upper bar represents the remaining triplets (overlap score < 1, complementation score = 0, neofunctionalization score = 0).

2.3 Spatial analyses

Increase in the precision of localisation of expression

We repeated these analyses, but pooling expression data from all developmental stages. This allows an increase in the number of anatomical structures used to define expression patterns (see Sup. Table 2 and online supplementary material), because not all developmental stages are sampled in each species. More importantly, it allows to obtain more precise descriptions

of expression patterns (e.g., “heart atrium” and “heart endocardium” vs. “heart”; further discussed in Sup. Information).

Similar high conservation of expression

We robustly retrieved the pattern of a high proportion of triplets exhibiting neither neo- nor subfunctionalization (between 44% and 73%, see Fig. 2B), including a high proportion of duplicates with the exact same expression pattern (between 42% and 60%). The overlap is still high for triplets exhibiting neo- or subfunctionalization (mean overlap between 0.39 and 0.45, see online supplementary material). Thus this pattern was not due to insufficient precision of anatomical structures annotated in the spatio-temporal data.

Similar high prevalence of neofunctionalization, and differences between whole-genome and small-scale duplicates

For whole-genome duplicates, we observed the same pattern of similar proportions of triplets exhibiting neo- or subfunctionalization only (any differences are not significant Fig. 2B). We find 10% to 18% of whole-genome duplicates with neofunctionalization only or subfunctionalization only, echoing the spatio-temporal results (8% to 17%).

Small-scale duplicates still include more triplets with neofunctionalization only than with subfunctionalization only, again statistically significant for mouse duplicates (Fisher exact test, corrected $p=4\ 10^{-3}$). Again, these duplicates seem less prone to subfunctionalization than whole-genome duplicates (2% to 7 % of subfunctionalization for the small-scale, 10% to 16% for the whole-genome duplicates).

2.4 Robustness of the analyses

Impact of missing data

The high proportion of “overlap only” triplets could be due to a lack of sensitivity of our analysis. Indeed, for members of this class with an overlap score different from 1, one of the duplicates exhibits partially degenerated expression pattern compared to the ancestral state. Finding anatomical structures where the other duplicate also exhibits a degeneration of expression would lead to consider these duplicates as subfunctionalized. It is also possible that we missed structures exhibiting a neofunctionalization of one of the duplicates.

To test the impact of missing data on our results, we used a "delete-m" jackknife-like approach on the triplets of zebrafish duplicates with mouse singletons. We successively removed from 10 to 90% of the data, randomly, with a 10% step. Our results were extremely robust, with no significant changes in the classes structure for values as high as 70% of data removed (independence exact Fisher test, see Sup. Fig. S2). This implies satisfactory data saturation for the tissues used in this analysis. It is possible that this saturation is caused by a lack of diversity in the tissues studied by expression experiments, but this seems unlikely, given the abundance of precise *in situ* hybridization data for zebrafish and mouse.

For more than 70% of data removed, missing data resulted in a lower detection of neofunctionalization. Thus missing data does not seem responsible for our observation of relatively high rates of neofunctionalization.

Impact of the quality of the mapping between anatomies of species

An insufficiently precise mapping between anatomies of species could partly explain the pattern of high overlap between expression patterns of duplicates. Indeed, if expression data can only be compared between broad structures (e.g., "nervous system", "cardiovascular system"), the lack of detail might cause spurious reports of expression conservation.

To test the impact of the quality of the mapping between anatomies of species, and of a possible bias of data reports in some tissues, we again used a jackknife-like approach, to randomly remove from 10% to 90% of the mappings between species, using the triplets of zebrafish duplicates with mouse singletons. Our results were robust, with no significant changes until 50% of mappings removed (exact Fisher test, see Sup. Fig. S3). For 80 and 90% of mappings removed, the relative proportion of neofunctionalization dropped, reporting more subfunctionalization than neofunctionalization. Thus the high proportion of neofunctionalization that we have reported does not seem due to an insufficiently precise mapping between species.

Impact of parameters for absence of expression: "Expression vs. No Expression"

We repeated the spatial-only analysis using a different method to consider a gene as not expressed. We considered genes as not expressed only when we had formal evidence for a lack of expression. It is indeed usual for authors of *in situ* hybridization data to report only localization of expression, making difficult to know if structures with no reported expression

were not analyzed, or actually exhibited no expression (see Methods). This could lead to an over-estimation of absence of expression, potentially responsible for the important rate of neofunctionalization that we have reported. We thus used for this analysis only formal reports of absence of expression, including explicit reports from *in situ* data, and statistical analysis of Affymetrix data (denoted as "Expression vs. No Expression" analysis). We expect it to be more difficult to detect neofunctionalization, since it implies that both the singleton gene and one of the duplicates were reported as not expressed.

For the study of zebrafish duplicates, the proportion of the class "overlap only" was greatly increased (from 59% to 93% when using mouse as an outgroup, from 73% to 97% when using human as an outgroup, see Sup. Fig. S4A). This shows the importance of the *in situ* hybridization dataset in the analysis of these triplets. Yet the "neofunctionalization only" class was not reduced more than the "subfunctionalization only" class. We conclude that our finding of a similar rate of neo and subfunctionalization for whole-genome duplicates was not due to an over-estimation of absence of expression by *in situ* hybridization data.

For the study of small-scale duplicates using human and mouse, the analysis "Expression vs. No Expression" gave the same results as the standard analysis. This denotes the fact that human data are the limiting factor. When data were available in a tissue for human, there were always Affymetrix data available for mouse in the corresponding tissue, to explicitly state an absence of expression. Despite the amount of mouse *in situ* hybridization data, they were not responsible for the important rate of neofunctionalization reported for small-scale duplicates.

Impact of parameters for detection of expression: high quality expression data only

In this analysis, we only used reports of expression flagged as "high quality" in Bgee (see Methods), the detection of absence of expression remaining unchanged (i.e., "expressed low quality" was not considered as "not expressed").

No differences were found compared to the standard analysis for zebrafish duplicates using human outgroup (exact Fisher test, p=0.73). Only 14 human duplicates could be studied using high quality data, and showed no statistical differences either (p=0.21). Class structures for the mouse duplicates were marginally different from the standard analysis (p=0.04, corrected p=0.18), because of a higher rate of neofunctionalization reported (54% of "neofunctionalization only" with high quality data, 35% for the standard analysis). Thus our

result of a higher rate of neofunctionalization than subfunctionalization for small-scale duplicates was robust to different thresholds for detection of expression.

The only notable discrepancy between standard and high quality analyses concerned the relative proportions of neo and subfunctionalization of zebrafish duplicates using the mouse outgroup: neofunctionalization was significantly higher than subfunctionalization with high quality data ($p=7\ 10^{-4}$). This difference was present but marginal for the standard analysis ($p=0.046$, corrected $p=0.19$). However, a similar rate of neo- and subfunctionalization was found for zebrafish duplicates using mouse outgroup in the spatio-temporal analysis and in the "Expression vs. No Expression" analysis, and was consistently found when using human as an outgroup in every analysis. Thus the data seem to overall support the observation of similar levels of neo- and subfunctionalization for zebrafish whole-genome duplicates.

2.5 Relationships between evolution of sequences and of expression patterns

We then studied differences in selective pressure on duplicate genes sequences, which differ in their patterns of neo- and subfunctionalization at the expression level. We contrasted synonymous (dS) and non-synonymous (dN) substitutions rates, based on the results from our spatial-only analysis.

For zebrafish whole-genome duplicates, we used dN/dS between fugu and tetraodon as a proxy, because of dS saturation (see Methods). Almost no difference was found between categories; only the category "both neo- and subfunctionalization", when using human as an outgroup, exhibited a significantly higher dN/dS ratio, but it included only 9 genes with dN/dS information. It is possible that using fugu and tetraodon as a proxy lacks power (Sup. Fig. S5).

For both human and mouse small-scale duplicates, we consistently found a lower dN/dS ratio for triplets with overlap only, as compared to the union of all other categories (Wilcoxon test, corrected p-values ≤ 0.018, Fig. 3A-B). We also consistently found a positive correlation between neofunctionalization scores and dN/dS ratios (Spearman correlation, respectively for human duplicates and mouse duplicates, $\rho=0.42$ and 0.24, corrected $p=3.6\ 10^{-4}$ and 0.012; see Fig. 3C-D). For human duplicates, we also found a positive correlation with the complementation score ($\rho = 0.35$; corrected $p=7\ 10^{-3}$), and a negative correlation with the

overlap score (ρ = -0.3; corrected p=0.05). These results were found to be due to both dN and dS values for mouse duplicates (respectively ρ=0.3 and 0.36, corrected p=4 10^{-4} and 7 10^{-6}), but only to dN for the human duplicates.

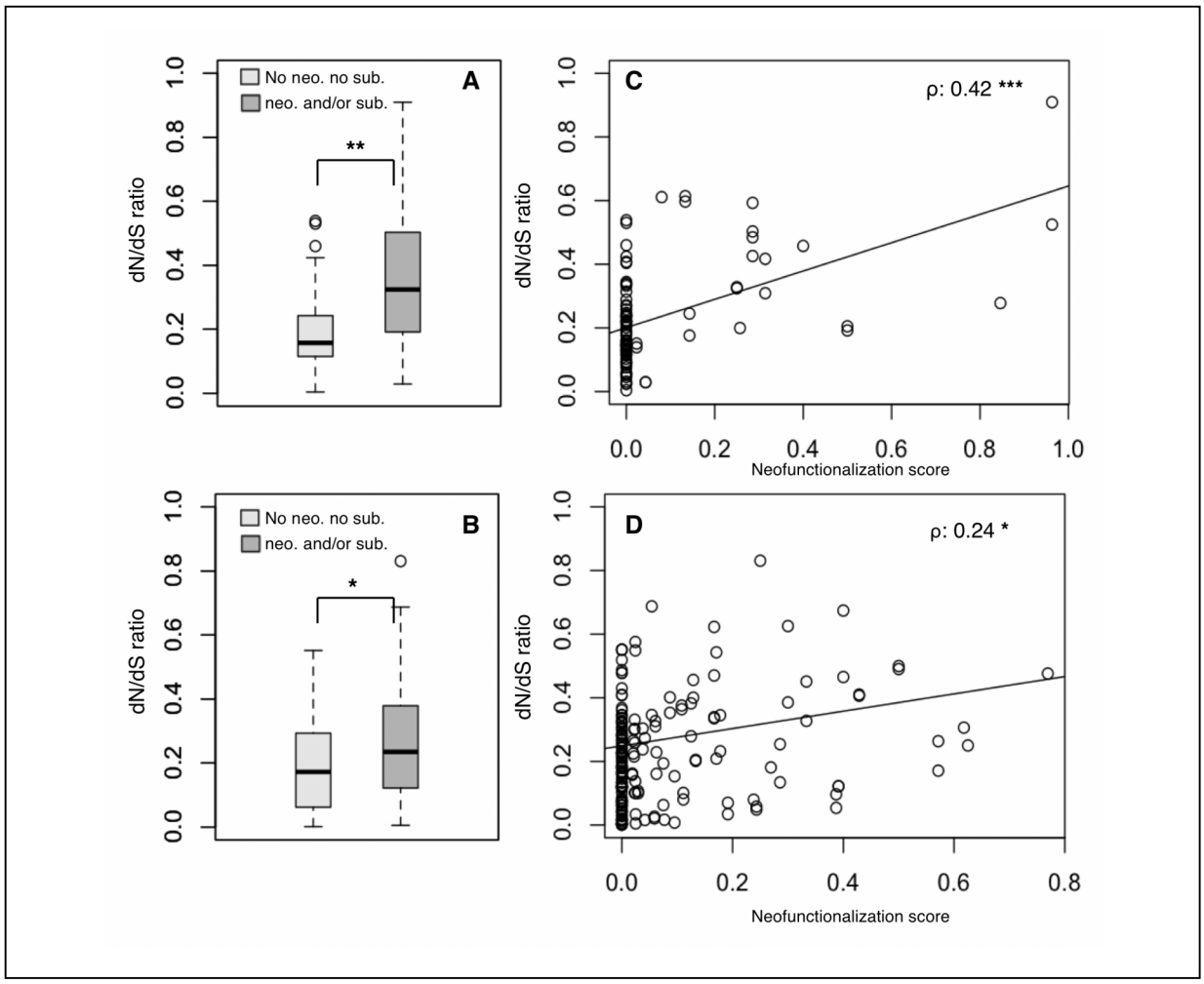


Fig. 3: Relationship between dN/dS ratios and patterns of gene expression evolution.
A, B: boxplots of dN/dS ratios for triplets exhibiting overlap only, and for triplets exhibiting some neo- and/or some subfunctionalization, for **A:** spatial analysis on human duplicates with mouse singletons, **B:** spatial analysis on mouse duplicates with human singletons. **C, D:** linear regressions between dN/dS ratio and neofunctionalization score, for **C:** spatial analysis on human duplicates with mouse singletons, **D:** spatial analysis on mouse duplicates with human singletons. ***: corrected p-values ≤ 0.001, **: corrected p-values ≤ 0.01, *: corrected p-values ≤ 0.05, for **A, B:** Wilcoxon test, **C, D:** two-sided Spearman correlation test. For **B** and **D**, note that 3 genes with a dN/dS ratio > 1 do not appear on the figures, for clarify, but they are still taken into account for computations of Wilcoxon test, Spearman correlation, and linear regression.

2.6 GO enrichment and depletion tests

We performed Gene Ontology (Ashburner, Ball*, et al.*, 2000) enrichment and depletion analyses. The main pattern is a depletion of terms such as “integral to membrane”, “plasma membrane part”, “calcium ion binding”, or “extracellular region”, associated with “overlap

only" duplicates (Sup. Table 4). This is consistent across different species comparisons and types of duplications.

3 Discussion

We have conducted what we believe to be the first large-scale comparison of expression patterns of hundreds of duplicated gene pairs to their corresponding singleton ortholog in an outgroup, in vertebrates. Notably, we detected high rates of neofunctionalization. This is especially true for small-scale duplicates, with higher rates of neo- than subfunctionalization. Whole-genome duplicates appear more prone to partitioning of expression domains (also called "qualitative subfunctionalization") than small-scale duplicates, yet still have relatively high rates of neofunctionalization (i.e., as high as subfunctionalization). And we found unexpectedly high rates of overlapping expression patterns, without any traces of neo- or subfunctionalization at the level of expression domains, for both whole-genome and small-scale duplicates (between 44% and 73% of duplicates).

This high proportion of duplicates with expression "overlap only" does not seem to be due to a bias in our analyses: our results showed satisfactory data saturation, and were robust to the removal of up to 70% of expression data, and of up to 50% of mappings between homologous tissues. Moreover, the "overlap only" duplicates share common features, such as dN/dS ratios or Gene Ontology categories, which support a biological interpretation of the observations, as opposed to a methodological bias interpretation. Similarly, our observation of a rate of neofunctionalization at least as high as that of qualitative subfunctionalization was robust to data removal, and to the use of different methods to assess expression or absence of expression. Of note, without the use of an outgroup, the partially overlapping expression patterns could have been interpreted as evidence of neofunctionalization (expression of only one of the duplicates in some tissues).

The depletion of GO categories such as "integral to membrane" for the "overlap only" category is consistent with the suggestion that the increased concentration of membrane proteins might be disadvantageous immediately following a duplication (Gout, Kahn*, et al.*, 2010). This might explain why, when genes producing membrane proteins are conserved in duplicate, expression overlap would be counter-selected.

Small-scale duplicates exhibiting higher scores of neofunctionalization were found to be under more relaxed purifying selection. Relations between expression divergence and rates of non-synonymous substitutions (dN) have been previously reported (e.g., Ganko, Meyers*, et al.*, 2007; Nuzhdin, Wayne*, et al.*, 2004). In addition to correlations to dN, we also found correlations to the rate of synonymous substitutions (dS) for the mouse duplicates; a correlation between dS and expression divergence was also shown in Makova and Li (2003). We did not recover the pattern described in Sémon and Wolfe (2008), that duplicates with subfunctionalization might evolve at slower rates (see Sup. Fig. S5). Farre and Alba (2010) also failed to recover this pattern, and found subfunctionalization of rapidly evolving genes. To study the selective pressures acting before duplication, similarly to Sémon and Wolfe (2008), we also measured substitution rates between species whose genomes have not been duplicated. We used single-copy orthologs of our duplicates, in chicken (*Gallus gallus*) and zebra finch (*Taeniopygia guttata*), but still did not detect slow evolution for duplicates exhibiting subfunctionalization (no results were significant when using these species, data not shown). Since mouse and human have low numbers of duplicates with subfunctionalization, and zebrafish is very divergent from the birds used, we might have lacked statistical power.

Whole-genome duplicates seem to be more prone to qualitative subfunctionalization than small-scale duplicates, with very high rates of neofunctionalization for small-scale duplicates. This supports the idea that differences in the creation processes of large and small-scale duplicates could lead to different evolutionary trajectories for neo- or subfunctionalization (Lynch and Katju, 2004). This is in accordance with models predicting higher rates of neofunctionalization for small-scale duplicates (Hughes and Liberles, 2007). It is also known that small and large-scale duplicates are enriched in different functional categories (Conant and Wolfe, 2008; Hakes, Pinney*, et al.*, 2007; Maere, De Bodt*, et al.*, 2005).

The important proportion of duplicates with “overlap only” could have several interpretations. These duplicates might have diverged mostly at the protein level. In that case, we would expect relaxed purifying selection or positive selection on the coding sequence, whereas we detected more constrained selection. We also compared protein divergence between zebrafish duplicates, using data from Kassahn et al. (2009). The authors provided information about divergence of protein functions between zebrafish duplicates, by studying domains architecture and subcellular localisations of these proteins. Our analysis using their data indicated that duplicates with “overlap only” are not more divergent in their protein functions

than other types of duplicates; they are even more similar in their subcellular localisation (exact Fisher tests using 131 and 114 duplicates pairs present in both studies, respectively, when using the mouse outgroup and the human outgroup, data not shown).

Alternatively, there could be selection for increased gene dosage (Kondrashov, Rogozin*, et al.*, 2002; Kondrashov and Kondrashov, 2006). The higher level of purifying selection for these duplicates is also in accordance with the gene balance hypothesis (Birchler and Veitia, 2007; Birchler and Veitia, 2010). Indeed, this model predicts low divergence between duplicates, because of purifying selection for conserved stoichiometry. But it also predicts that small-scale duplicates should be less likely to be preserved for stoichiometry reasons. However, we have not found important differences in the proportions of duplicates with "overlap only" between large-scale and small-scale duplicates. We also have found no enrichment of functional categories representative of genes with more deleterious effect when stoichiometry is disrupted, such as transcription factors.

An explanation for both our results of a low proportion of subfunctionalization, and a high proportion of duplicates with overlap only, could be that our methodology does not detect putative quantitative subfunctionalization (Chain, Ilieva*, et al.*, 2008; Lynch and Force, 2000; Woolfe and Elgar, 2007): mutations for reduction of expression in both duplicates, allowing the recovery of the ancestral level of expression of a single copy. Our qualitative approach might indeed fail to detect such patterns. The relative importance of this mechanism has been investigated by a few studies only (Chain, Ilieva*, et al.*, 2008; Qian, Liao*, et al.*, 2010), and is mostly unknown.

Previous studies of the expression of vertebrate duplicated genes which included an outgroup have recovered low rates of subfunctionalization: only one example of subfunctionalization in Huminiecki and Wolfe (2004), 1.2% to 11% in Sémon and Wolfe (2008), 11%, plus 26% with both neo and subfunctionalization, in Kassahn et al. (2009), 23% to 25% in Farre and Alba (2010). These values are very close to our results: 2% to 16% of duplicates with subfunctionalization, plus 0% to 14% of duplicates with both neo- and subfunctionalization. These low proportions are often attributed to the difficulty in detecting quantitative subfunctionalization. In any case, straightforward qualitative subfunctionalization does not appear to be a dominant mode of evolution after duplication in vertebrates.

Our most robust result is the consistent high proportion of neofunctionalization, which is also consistent with some previous reports: 53% in Kassahn et al. (2009), 42% to 52% in Farre and Alba (2010), and 8% to 35%, plus 0% to 14% with both neo- and subfunctionalization, in the present analysis. It is notable that these different studies used different methods, different data and different species. Part of this divergence of expression between one duplicate and the singleton ortholog might not be directly due to the duplication event itself (Studer and Robinson-Rechavi, 2009), but neofunctionalization still seems to be a major mechanism. An open question is the role of this neofunctionalization in the preservation of the duplicate genes. In many cases, as in the example of Fig. 1C, the copy with a new expression domain did not lose any expression domains, which would be uniquely preserved by the other copy. Neofunctionalization with loss of ancestral domains only concerns half of all triplets with a neofunctionalization pattern.

Using population genetics reasoning, Shiu et al. (2006) have suggested that positive selection played a more important role in duplicate retention than neutral subfunctionalization. He and Zhang (2005) proposed a model of "subneofunctionalization", where duplicates encountered rapid subfunctionalization followed by a prolonged neofunctionalization phase. This is supported by our observation of 14% of triplets which have patterns both of sub- and neofunctionalization. By a modelling approach, MacCarthy and Bergman (2007) suggested that neofunctionalization rates could increase with time even in the absence of positive selection, thanks to "evolutionary plasticity", and that subfunctionalization might not be the main force acting on duplicates retention. Thus there seems to be a convergence of evidence supporting an important role of neofunctionalization in the divergence and preservation of duplicate genes.

In conclusion, our results clearly show that qualitative subfunctionalization is not the most likely outcome of gene duplication in vertebrates. In the absence of clear evidence for the prevalence of quantitative subfunctionalization, our results of high expression conservation are most consistent with selection for increased gene dosage, and to a lesser extent (i.e., lack of support from functional categories) with selection for gene stoichiometry conservation. Our observation of high rates of neofunctionalization might not be due to positive selection only. It seems probable that other processes, such as "evolutionary plasticity" (MacCarthy and Bergman, 2007), are involved. Further studies should focus on testing the different

models predicting high neofunctionalization rates, and on assessing the existence and magnitude of the quantitative subfunctionalization process.

4 Methods

4.1 Identification of triplets of duplicate genes and corresponding singletons

Triplets of whole-genome 3R duplicates and corresponding mouse or human singleton

We used the Perl API and BioMart (Smedley, Haider*, et al.*, 2009) to query the EnsemblCompara GeneTrees (Vilella, Severin*, et al.*, 2009) on the Ensembl database release 62 (April 2011) (Flicek, Amode*, et al.*, 2011), and scan for specific gene tree topologies. A precise description of the methods used to build these trees can be found on the Ensembl website[27]. We selected sets of genes with or without duplications on specific branches of the vertebrate phylogenetic tree. The Perl scripts used are available upon demand.

Regarding the fish-specific whole genome duplication in zebrafish, we selected trees displaying a duplication node dated "Clupeocephala" (bony fishes). A single zebrafish Ensembl ID was allowed on each side of the duplication (no later duplication). To support the duplication more confidently, we imposed that another fish gene (among the 4 other fish species present in Ensembl) should be found on each side of the duplication. Finally we kept only the duplicate pairs having a single-copy ortholog in mouse or human, granted that the divergence between the duplicates and this ortholog was dated "Euteleostomi" (bony vertebrates). We found 1422 zebrafish duplicate pairs with a single ortholog in human, and 1428 with a single ortholog in mouse (see Sup. Table 1).

Triplets of small-scale duplicates using mouse and human

We used BioMart (Smedley, Haider*, et al.*, 2009) to obtain lists of human genes with corresponding orthologs in mouse, with information about the homology relation (1-to-1, 1-to-many, …), and about common ancestor node between these orthologs, derived from the Ensembl gene trees (see above). We selected orthologs that diverge at the *Eutheria* or *Euarchontoglires* nodes (the closest annotated nodes before the divergence of mouse and

[27] http://www.ensembl.org/info/docs/compara/homology_method.html

human lineages). We kept human genes with 1-to-many relationships to mouse, ensuring that the dataset includes no human paralogs, but mouse paralogs, emerged since the divergence of these taxa. We selected group of orthologs including only 2 mouse paralogs to constitute our triplets of mouse duplicates with human singleton. We proceeded in the same way to generate triplets of human duplicates with mouse singleton, by inversing the queries. This resulted in 276 triplets of human duplicates with mouse singletons, and 303 triplets of mouse duplicates with human singletons (see Sup. Table 1).

4.2 Overview of the Bgee database

We performed our analyses using the Bgee database release 09 (June 2011) (Bastian, Parmentier*, et al.*, 2008), available at http://bgee.unil.ch/. This public resource combines heterogeneous expression data (EST, Affymetrix, *in situ* hybridization data) into present/absent calls, and maps them to formal representations of anatomies and developments of different species. It defines manually-curated homology relationships between anatomies of these species (Parmentier, Bastian*, et al.*, 2010), and broad equivalences between their developments, to allow automated comparisons of gene expression patterns. This extensive mapping of homologous tissues between vertebrate species allows to directly compare expression patterns in 1007 tissues between human and mouse, in 316 tissues between zebrafish and mouse, and in 249 tissues between zebrafish and human

4.3 Expression data of the Bgee database

Bgee aggregates expression data from different sources and different types, into present/absent calls. It includes, respectively for mouse, zebrafish and human: 6317, 172, and 5992 Affymetrix chips retrieved from the ArrayExpress database (Parkinson, Sarkans*, et al.*, 2011); 713, 108, and 2414 EST libraries from Unigene (Pontius, Wagner*, et al.*, 2003); 175593, 33986, and 0 *in situ* hybridization evidences (i.e., figures or publications) from MGI (Finger, Smith*, et al.*, 2011) and ZFIN (Bradford, Conlin*, et al.*, 2011). Mappings to Ensembl genes from Affymetrix probesets, Model Organism Database gene IDs, and ESTs, are retrieved from Ensembl release 62 (April 2011) (Flicek, Amode*, et al.*, 2011), and only unambiguous mappings are used.

Affymetrix and EST data are curated by the Bgee team, to ensure that the data fit criteria of "normality" (no knock-outs, no treatments, no tumors…), and are manually mapped to precise descriptions of anatomy and development of species. *In situ* data are already mapped to

anatomies by source databases. This represents direct annotation of expression data to 2468 tissues and 37 developmental stages in mouse, 1136 tissues and 49 developmental stages in zebrafish, 162 tissues and 22 developmental stages in human.

Statistical analyses are performed on EST and Affymetrix data to assess gene expression with confidence information. Based on Audic and Claverie (1997), a gene is considered as expressed with a low confidence if, in a EST library, one to six ESTs are unambiguously mapped to transcripts of a gene, with a high confidence if at least 7 are unambiguously mapped. For Affymetrix data, when no raw data are available, the "present" and "marginal" MAS5 calls (Liu, Mei*, et al.*, 2002) are used, and given a low confidence. When raw data are available, gcRMA (Wu, Irizarry*, et al.*, 2004) is used to renormalize the data, and a method developed by Schuster et al. (2007) is used to assess expression with high or low confidence. For *in situ* hybridization data, the source databases already provide quality information, which Bgee relies on. For each data type, ambiguous results are not considered (e.g., "expression low quality" using a chip and "no expression" using another), or are given a lower confidence (e.g., "expression high quality" and "no expression" summarizes as "expression low quality").

Formal information about absence of expression is retrieved from Affymetrix data and *in situ* data. Only when Affymetrix raw data are available, probesets with signal not statistically different from the background signal (see above) are considered as evidence for absence of expression. For *in situ* data, authors sometimes provide formal annotations of absence of expression, that Bgee uses. Note that this type of annotations is rare, and that in most *in situ* data, only information of expression is reported, absence of expression being often implicitly assumed in all other tissues. For each data type, only unambiguous results are conserved (i.e., no conflict of expression detected in the same tissue or any substructures of the tissue).

For more details about the analysis of expression data in Bgee, see the online documentation[28].

4.4 Multi-species comparison

The Bgee database defines manually curated mappings between tissues of different species, based on homology hypotheses. Each mapping is provided with references and support codes

[28] http://bgee.unil.ch/?page=documentation#sectionDataAnalysis

during the curation process. Organs mapped in different species are merged into Homologous Organs Groups (HOGs). Those are then organized into a formal multi-species anatomical ontology, so that relations between HOGs are known (e.g. "diencephalon" *part_of* "forebrain" *part_of* "brain"…) (Parmentier, Bastian*, et al.*, 2010). This approach allows to propagate expression data annotated in different species, to comparable multi-species representation of anatomy. The HOG ontology, and the mappings to species-specific tissues, are available at http://bgee.unil.ch/?page=download. A list of the HOGs used in the present study is presented in Sup. Table 2.

To allow a comparison of the timing of expression between species, Bgee defines broad equivalence relationships between developmental stages. It is indeed not possible to identify precise equivalent stages between species because of heterochrony (see e.g., Jeffery, Bininda-Emonds*, et al.*, 2005), but it is instead possible to identify key events of development, common to all bilaterian animals (called "metastages" in Bgee). These metastages are organized as an ontology in Bgee, but we conserved only independent metastages for this study (zygote, cleavage, blastula, gastrula, neurula, organogenesis, post-embryonic development, adult). The metastages ontology and the mappings to species-specific developmental stages are available from the download section of Bgee[29]. The restricted subset that we used is available in Supplementary Table 3.

4.5 Description of the algorithm of the analysis

Presentation

To query Bgee data, we used a local copy of the MySQL database of Bgee release 09 (June 2011). We developed algorithms in Java described below, using the Java Bgee API. The content of the database, the API, our source code, and compiled classes, are available upon request.

Selection of HOGs

For each triplet, the algorithm of the analysis aims at choosing the most granular, still independent HOGs. It uses a leaf-to-root approach: a HOG is examined only once all of its substructures have been examined (granularity), and if none have been selected

[29] http://bgee.unil.ch/?page=download

(independence). Selecting a HOG thus automatically prevents all of its parent structures from being selected (e.g., selecting “forebrain” prevents “brain” from being studied), but not its siblings (e.g., “midbrain”, “hindbrain”, “brain meninges”), nor unrelated structures (e.g., “heart”). A HOG is selected only if the state of expression is known for all three genes of a triplet (see below), and at least one of the duplicates is expressed. For the spatio-temporal analyses, data were collected independently for each metastage. For the spatial-only analyses, data were collected from any time point. We disregarded HOGs with expression of the singleton gene only, as it is not informative with regards to neo and subfunctionalization processes (it could be either interpreted as a loss of expression before duplication in one lineage, or a gain of expression in the other lineage), and would prevent the algorithm from examining parent structures, where there might be evidence of expression of the duplicates.

Determination of state of expression for all genes of a triplet

A gene was considered as expressed in a HOG if expression was reported in any tissues directly mapped to the HOG, or any of their substructures (these reports of expression are summarized in the MySQL table “hogExpression”). For the spatio-temporal analyses, we examined data at each metastage independently, while we looked for expression at any time point for the spatial-only analyses.

When expression of a gene is not reported in a HOG, it is needed to distinguish between an absence of data, and an actual absence of expression. A gene was considered as not expressed in a HOG in two ways. First, if absence of expression was explicitly stated in one of the organs directly mapped to the HOG, thanks to Affymetrix or *in situ* data (see data description above). We did not considered absence of expression reported in HOG substructures, but only in tissues directly mapped to the HOG (these reports of absence of expression are summarized for species-specific structures in the MySQL table “noExpression”).

Second, absence of expression was assessed by considering expression patterns described by *in situ* data as complete. It is indeed usual for authors of *in situ* hybridizations to report only localizations of expression, implicitly stating absence of expression in all other tissues. This opinion is shared by the team of the MGI *in situ* database, and leaded them to propose a search form based on the same assumption of absence of expression where no expression is

reported (see the online documentation[30]). When *in situ* data were available for a gene, we considered that absence of expression was assumed in every HOGs that have: i) direct mapping to organs existing at the developmental stage studied in the *in situ*, and ii) no report of expression in the HOG or its substructures by any data type (the developmental stages which in situ experiments were performed on, were retrieved from the MySQL table "inSituSpot", and lifespan of organs from the table "organ"). Note that we excluded this manner of using *in situ* data when we tested the robustness of our analyses in the "Expression vs No Expression" analyses (see Results).

If expression or absence of expression were not possible to be stated by methods described above, for at least one of the genes involved in the triplet, the HOG was disregarded and other HOGs were examined.

We provide a web-interface to browse results for each triplet, and retrieve related raw data (see online Sup. Material).

4.6 Analysis of dN/dS

We used BioMart (Smedley, Haider*, et al.*, 2009) to query the EnsemblCompara GeneTrees (Vilella, Severin*, et al.*, 2009) on the Ensembl database release 62 (April 2011) (Flicek, Amode*, et al.*, 2011), to obtain dN and dS values. Precise description of how these values are computed can be found on the Ensembl website[31]. We queried human genes with mouse orthologs and corresponding dN and dS values, and kept only genes with a one-to-many relationships (that includes genes with duplicates in human and singleton in mouse), present in our analysis. Each triplet could then be assigned to two distinct values of dN/dS, one for each duplicate. We proceeded the same way for mouse duplicates, by querying BioMart for mouse genes with human orthologs.

Values of dN and dS between zebrafish duplicates and mouse or human singletons could not be retrieved from BioMart, because of data saturation (see documentation pointed above). Instead we used dN and dS values between orthologs of zebrafish duplicates, in fugu and tetraodon. We used BioMart to retrieve zebrafish genes with *Takifugu rubripes* and *Tetraodon*

[30] http://www.informatics.jax.org/userdocs/gxd_expanded_help.shtml#and_not

[31] http://www.ensembl.org/info/docs/compara/homology_method.html

nigroviridis orthologs. We kept only orthologs with one-to-one relationships between the three species (genes with no further duplications in any of these lineages since the 3R duplication). We then queried BioMart to retrieve tetraodon genes with fugu orthologs and corresponding dN and dS values, restricted to the subset of orthologs to zebrafish, so that each triplet has been assigned up to two values of dN/dS, one for each duplicate. We then removed from our analyses duplicates with a dS greater than 1. Complete lists of dN and dS values can be retrieved with the list of triplets (see Sup. Table 1).

4.7 Gene Ontology enrichment and depletion tests

We performed Gene Ontology (Ashburner, Ball*, et al.*, 2000) enrichment and depletion analyses. We retrieved mappings between GO terms and Ensembl gene IDs from Ensembl release 62 (Apr. 2011) (Flicek, Amode*, et al.*, 2011), using the Bioconductor package biomaRt. For each triplet, we used annotations to the singleton gene (i.e., always a mouse or a human gene). We performed the GO analyses using the TopGO package for R (Alexa, Rahnenfuhrer*, et al.*, 2006) on version 2.4.1 of GO.db, on the "spatial-only" results. TopGO allows to decorrelate the GO graph, to eliminate local dependencies and to identify only the most precise terms. P-values were corrected by FDR, and a FDR threshold of 25% was used.

Complete list of terms identified can be retrieved in Sup. Table 4.

4.8 P-values corrections

Unless stated otherwise, we corrected p-values by a Bonferroni correction. The number of repetitions considered for each test is presented in Sup. Info.

Acknowledgments

We thank Jaime Huerta-Cepas for suggestions about the algorithm for selecting independent anatomical structures.

5 References

Alexa, A., Rahnenfuhrer, J. and Lengauer, T. (2006) Improved scoring of functional groups from gene expression data by decorrelating GO graph structure, *Bioinformatics*, **22**, 1600-1607.

Amores, A., Force, A., Yan, Y.-L., Joly, L., Amemiya, C.*, et al.* (1998) Zebrafish hox Clusters and Vertebrate Genome Evolution, *Science*, **282**, 1711-1714.

Amores, A., Suzuki, T., Yan, Y.-L., Pomeroy, J., Singer, A.*, et al.* (2004) Developmental Roles of Pufferfish Hox Clusters and Genome Evolution in Ray-Fin Fish, *Genome Research*, **14**, 1-10.

Ashburner, M., Ball, C.A., Blake, J.A., Botstein, D., Butler, H.*, et al.* (2000) Gene Ontology: tool for the unification of biology, *Nat Genet*, **25**, 25-29.

Audic, S.p. and Claverie, J.-M. (1997) The Significance of Digital Gene Expression,ÄâProfiles, *Genome Research*, **7**, 986-995.

Bastian, F., Parmentier, G., Roux, J., Moretti, S., Laudet, V.*, et al.* (2008) Bgee: Integrating and Comparing Heterogeneous Transcriptome Data Among Species. In Bairoch, A., Cohen-Boulakia, S. and Froidevaux, C. (eds), *Data Integration in the Life Sciences*. Springer Berlin / Heidelberg, pp. 124-131.

Birchler, J.A. and Veitia, R.A. (2007) The Gene Balance Hypothesis: From Classical Genetics to Modern Genomics, *The Plant Cell Online*, **19**, 395-402.

Birchler, J.A. and Veitia, R.A. (2010) The gene balance hypothesis: implications for gene regulation, quantitative traits and evolution, *New Phytologist*, **186**, 54-62.

Bradford, Y., Conlin, T., Dunn, N., Fashena, D., Frazer, K.*, et al.* (2011) ZFIN: enhancements and updates to the zebrafish model organism database, *Nucleic Acids Research*, **39**, D822-D829.

Chain, F., Ilieva, D. and Evans, B. (2008) Duplicate gene evolution and expression in the wake of vertebrate allopolyploidization, *BMC Evolutionary Biology*, **8**, 43.

Christoffels, A., Koh, E.G.L., Chia, J.-m., Brenner, S., Aparicio, S.*, et al.* (2004) Fugu Genome Analysis Provides Evidence for a Whole-Genome Duplication Early During the Evolution of Ray-Finned Fishes, *Molecular Biology and Evolution*, **21**, 1146-1151.

Conant, G.C. and Wolfe, K.H. (2008) Turning a hobby into a job: How duplicated genes find new functions, *Nat Rev Genet*, **9**, 938-950.

de Souza, F.v.S.J., Bumaschny, V.F., Low, M.J. and Rubinstein, M. (2005) Subfunctionalization of Expression and Peptide Domains Following the Ancient Duplication of the Proopiomelanocortin Gene in Teleost Fishes, *Molecular Biology and Evolution*, **22**, 2417-2427.

Escriva, H., Bertrand, S.p., Germain, P., Robinson-Rechavi, M., Umbhauer, M.*, et al.* (2006) Neofunctionalization in Vertebrates: The Example of Retinoic Acid Receptors, *PLoS Genet*, **2**, e102.

Farre, D. and Alba, M.M. (2010) Heterogeneous Patterns of Gene-Expression Diversification in Mammalian Gene Duplicates, *Mol Biol Evol*, **27**, 325-335.

Finger, J.H., Smith, C.M., Hayamizu, T.F., McCright, I.J., Eppig, J.T.*, et al.* (2011) The mouse Gene Expression Database (GXD): 2011 update, *Nucleic Acids Research*, **39**, D835-D841.

Flicek, P., Amode, M.R., Barrell, D., Beal, K., Brent, S.*, et al.* (2011) Ensembl 2011, *Nucleic Acids Research*, **39**, D800-D806.

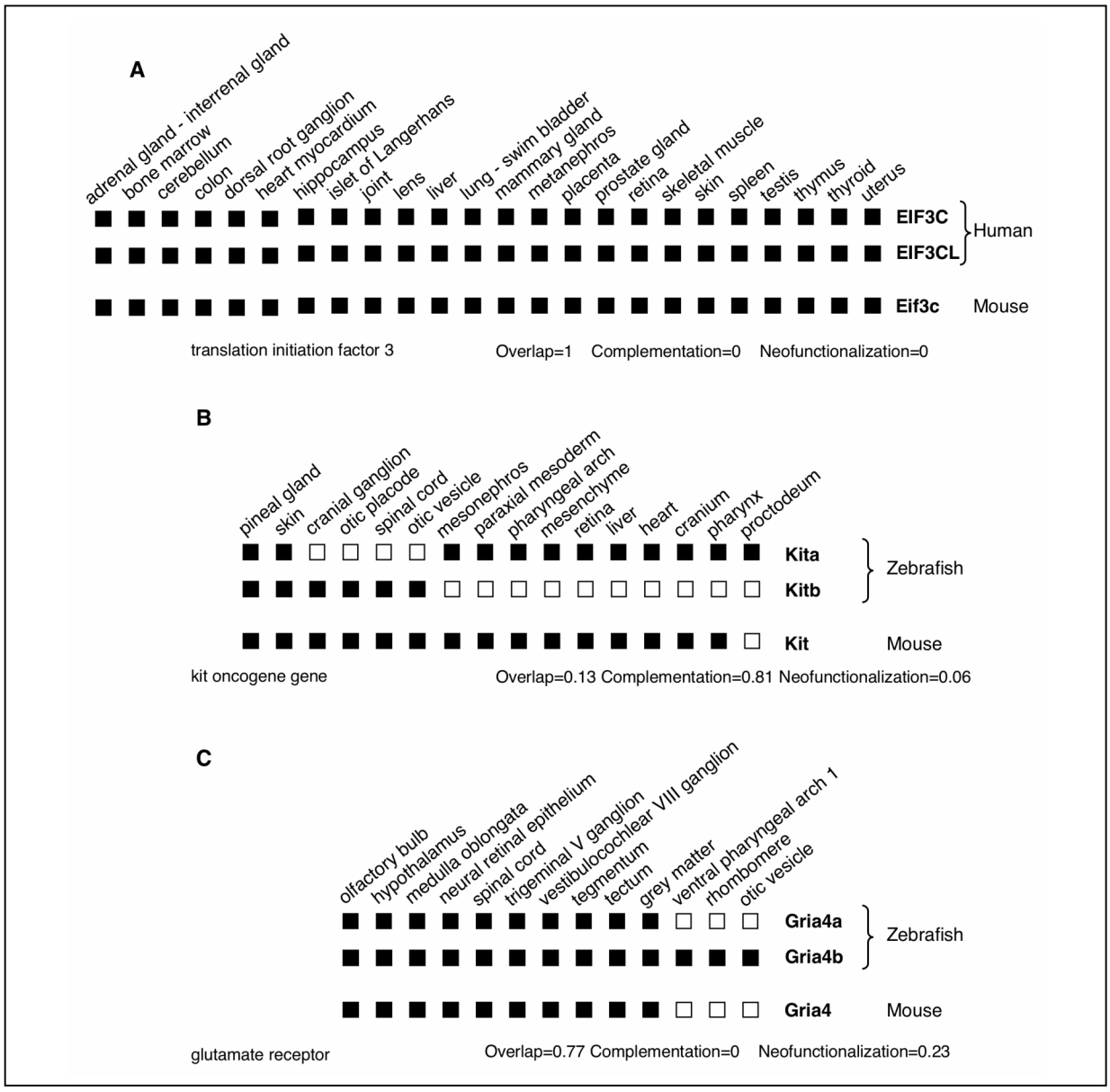
Force, A., Lynch, M., Pickett, F.B., Amores, A., Yan, Y.-l., *et al.* (1999) Preservation of Duplicate Genes by Complementary, Degenerative Mutations, *Genetics*, **151**, 1531-1545.
Freilich, S., Massingham, T., Blanc, E., Goldovsky, L. and Thornton, J. (2006) Relating tissue specialization to the differentiation of expression of singleton and duplicate mouse proteins, *Genome Biology*, **7**, R89.
Furlong, R.F. and Holland, P.W.H. (2002) Were vertebrates octoploid?, *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, **357**, 531-544.
Ganko, E.W., Meyers, B.C. and Vision, T.J. (2007) Divergence in Expression between Duplicated Genes in Arabidopsis, *Molecular Biology and Evolution*, **24**, 2298-2309.
Gout, J.-F.o., Kahn, D., Duret, L. and Paramecium Post-Genomics, C. (2010) The Relationship among Gene Expression, the Evolution of Gene Dosage, and the Rate of Protein Evolution, *PLoS Genet*, **6**, e1000944.
Hakes, L., Pinney, J., Lovell, S., Oliver, S. and Robertson, D. (2007) All duplicates are not equal: the difference between small-scale and genome duplication, *Genome Biology*, **8**, R209.
He, X. and Zhang, J. (2005) Rapid Subfunctionalization Accompanied by Prolonged and Substantial Neofunctionalization in Duplicate Gene Evolution, *Genetics*, **169**, 1157-1164.
Hellsten, U., Khokha, M., Grammer, T., Harland, R., Richardson, P., *et al.* (2007) Accelerated gene evolution and subfunctionalization in the pseudotetraploid frog Xenopus laevis, *BMC Biology*, **5**, 31.
Hughes, T. and Liberles, D. (2007) The Pattern of Evolution of Smaller-Scale Gene Duplicates in Mammalian Genomes is More Consistent with Neo- than Subfunctionalisation, *Journal of Molecular Evolution*, **65**, 574-588.
Huminiecki, L. and Wolfe, K.H. (2004) Divergence of Spatial Gene Expression Profiles Following Species-Specific Gene Duplications in Human and Mouse, *Genome Research*, **14**, 1870-1879.
Innan, H. and Kondrashov, F. (2010) The evolution of gene duplications: classifying and distinguishing between models, *Nat Rev Genet*, **11**, 97-108.
Jaillon, O., Aury, J.-M., Brunet, F., Petit, J.-L., Stange-Thomann, N., *et al.* (2004) Genome duplication in the teleost fish Tetraodon nigroviridis reveals the early vertebrate proto-karyotype, *Nature*, **431**, 946-957.
Jeffery, J.E., Bininda-Emonds, O.R.P., Coates, M.I. and Richardson, M.K. (2005) A New Technique for Identifying Sequence Heterochrony, *Systematic Biology*, **54**, 230-240.
Kassahn, K.S., Dang, V.T., Wilkins, S.J., Perkins, A.C. and Ragan, M.A. (2009) Evolution of gene function and regulatory control after whole-genome duplication: Comparative analyses in vertebrates, *Genome Research*, **19**, 1404-1418.
Kleinjan, D.A., Bancewicz, R.M., Gautier, P., Dahm, R., Schonthaler, H.B., *et al.* (2008) Subfunctionalization of duplicated zebrafish pax6 genes by cis-regulatory divergence, *PLoS Genet*, **4**, e29.
Kondrashov, F., Rogozin, I., Wolf, Y. and Koonin, E. (2002) Selection in the evolution of gene duplications, *Genome Biology*, **3**, 1-9.
Kondrashov, F.A. and Kondrashov, A.S. (2006) Role of selection in fixation of gene duplications, *Journal of Theoretical Biology*, **239**, 141-151.
Liu, W.-m., Mei, R., Di, X., Ryder, T.B., Hubbell, E., *et al.* (2002) Analysis of high density expression microarrays with signed-rank call algorithms, *Bioinformatics*, **18**, 1593-1599.
Lynch, M. and Conery, J.S. (2000) The Evolutionary Fate and Consequences of Duplicate Genes, *Science*, **290**, 1151-1155.
Lynch, M. and Conery, J.S. (2003) The evolutionary demography of duplicate genes, *Journal of Structural and Functional Genomics*, **3**, 35-44.
Lynch, M. and Force, A. (2000) The Probability of Duplicate Gene Preservation by Subfunctionalization, *Genetics*, **154**, 459-473.

Lynch, M. and Katju, V. (2004) The altered evolutionary trajectories of gene duplicates, *Trends in Genetics*, **20**, 544-549.
Lynch, M., O'Hely, M., Walsh, B. and Force, A. (2001) The Probability of Preservation of a Newly Arisen Gene Duplicate, *Genetics*, **159**, 1789-1804.
MacCarthy, T. and Bergman, A. (2007) The limits of subfunctionalization, *BMC Evolutionary Biology*, **7**, 213.
Maere, S., De Bodt, S., Raes, J., Casneuf, T., Van Montagu, M.*, et al.* (2005) Modeling gene and genome duplications in eukaryotes, *Proceedings of the National Academy of Sciences of the United States of America*, **102**, 5454-5459.
Makova, K.D. and Li, W.-H. (2003) Divergence in the Spatial Pattern of Gene Expression Between Human Duplicate Genes, *Genome Research*, **13**, 1638-1645.
McClintock, J.M., Carlson, R., Mann, D.M. and Prince, V.E. (2001) Consequences of Hox gene duplication in the vertebrates: an investigation of the zebrafish Hox paralogue group 1 genes, *Development*, **128**, 2471-2484.
Morin, R.D., Chang, E., Petrescu, A., Liao, N., Griffith, M.*, et al.* (2006) Sequencing and analysis of 10,967 full-length cDNA clones from Xenopus laevis and Xenopus tropicalis reveals post-tetraploidization transcriptome remodeling, *Genome Research*, **16**, 796-803.
Nuzhdin, S.V., Wayne, M.L., Harmon, K.L. and McIntyre, L.M. (2004) Common Pattern of Evolution of Gene Expression Level and Protein Sequence in Drosophila, *Molecular Biology and Evolution*, **21**, 1308-1317.
Ohno, S. (1970) *Evolution by Gene Duplication*. Springer-Verlag.
Parkinson, H., Sarkans, U., Kolesnikov, N., Abeygunawardena, N., Burdett, T.*, et al.* (2011) ArrayExpress update - an archive of microarray and high-throughput sequencing-based functional genomics experiments, *Nucleic Acids Research*, **39**, D1002-D1004.
Parmentier, G., Bastian, F.B. and Robinson-Rechavi, M. (2010) Homolonto: generating homology relationships by pairwise alignment of ontologies and application to vertebrate anatomy, *Bioinformatics*, **26**, 1766-1771.
Pontius, J.U., Wagner, L. and Schuler, G.D. (2003) UniGene: a unified view of the transcriptome. In McEntyre, J. and Ostell, J. (eds), *The NCBI Handbook.* National Center for Biotechnology Information (US), Bethesda (MD).
Putnam, N.H., Butts, T., Ferrier, D.E.K., Furlong, R.F., Hellsten, U.*, et al.* (2008) The amphioxus genome and the evolution of the chordate karyotype, *Nature*, **453**, 1064-1071.
Qian, W., Liao, B.-Y., Chang, A.Y.-F. and Zhang, J. (2010) Maintenance of duplicate genes and their functional redundancy by reduced expression, *Trends in Genetics*, **26**, 425-430.
Schuster, E., Blanc, E., Partridge, L. and Thornton, J. (2007) Correcting for sequence biases in present/absent calls, *Genome Biology*, **8**, R125.
Sémon, M. and Wolfe, K.H. (2007) Consequences of genome duplication, *Current Opinion in Genetics & Development*, **17**, 505-512.
Sémon, M. and Wolfe, K.H. (2008) Preferential subfunctionalization of slow-evolving genes after allopolyploidization in Xenopus laevis, *Proceedings of the National Academy of Sciences*, **105**, 8333-8338.
Shiu, S.-H., Byrnes, J.K., Pan, R., Zhang, P. and Li, W.-H. (2006) Role of positive selection in the retention of duplicate genes in mammalian genomes, *Proceedings of the National Academy of Sciences of the United States of America*, **103**, 2232-2236.
Smedley, D., Haider, S., Ballester, B., Holland, R., London, D.*, et al.* (2009) BioMart - biological queries made easy, *BMC Genomics*, **10**, 22.
Studer, R.A. and Robinson-Rechavi, M. (2009) How confident can we be that orthologs are similar, but paralogs differ?, *Trends in Genetics*, **25**, 210-216.

Vilella, A.J., Severin, J., Ureta-Vidal, A., Heng, L., Durbin, R., *et al.* (2009) EnsemblCompara GeneTrees: Complete, duplication-aware phylogenetic trees in vertebrates, *Genome Research*, **19**, 327-335.
Woolfe, A. and Elgar, G. (2007) Comparative genomics using Fugu reveals insights into regulatory subfunctionalization, *Genome Biol*, **8**, R53.
Wu, Z., Irizarry, R.A., Gentleman, R., Martinez-Murillo, F. and Spencer, F. (2004) A Model-Based Background Adjustment for Oligonucleotide Expression Arrays, *Journal of the American Statistical Association*, **99**, 909-917.
Zhang, J. (2003) Evolution by gene duplication: an update, *Trends in Ecology & Evolution*, **18**, 292-298.

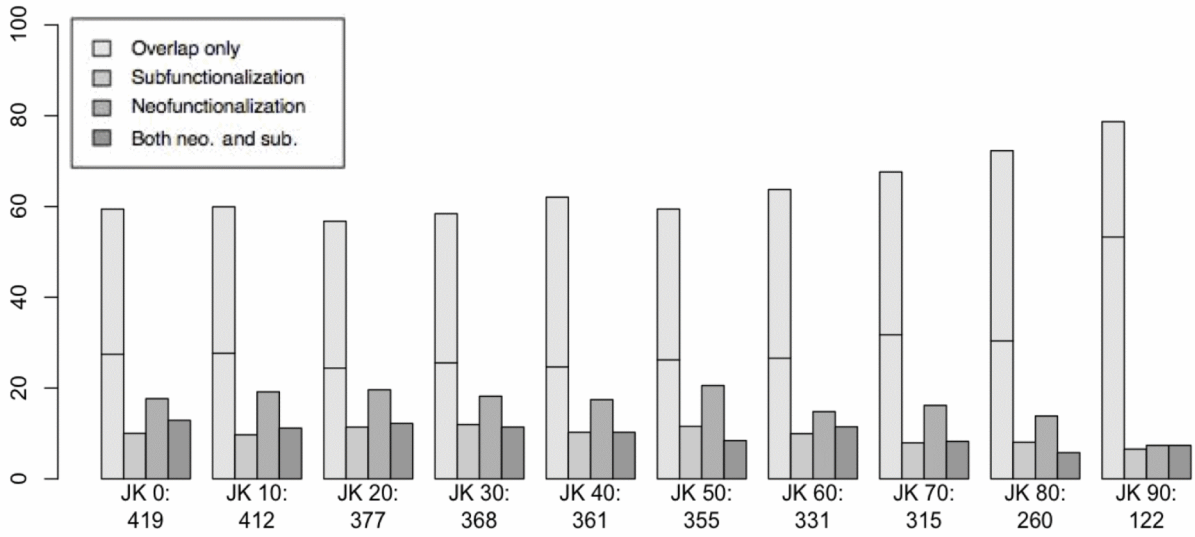
6 Supplementary figures

6.1 Supplementary figure S1



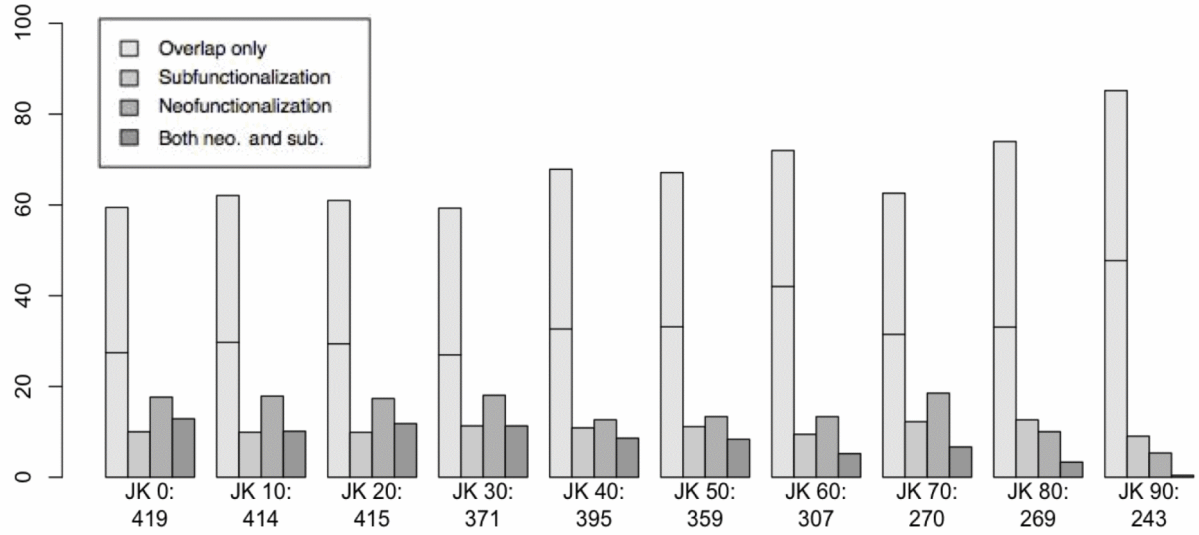
Supplementary Figure S1: examples of comparison of expression patterns, spatial-only analyses.
We adopted the representation formalism used in (Farre and Alba, 2010). The examples are the same than in Fig. 1, but for spatial-only analyses. Filled boxes represent anatomical structures with expression. White boxes represent conditions with absence of expression. The two first lines correspond to expression patterns of the duplicates in one species, the third line to the expression pattern of the singleton ortholog in another species.

6.2 Supplementary figure S2



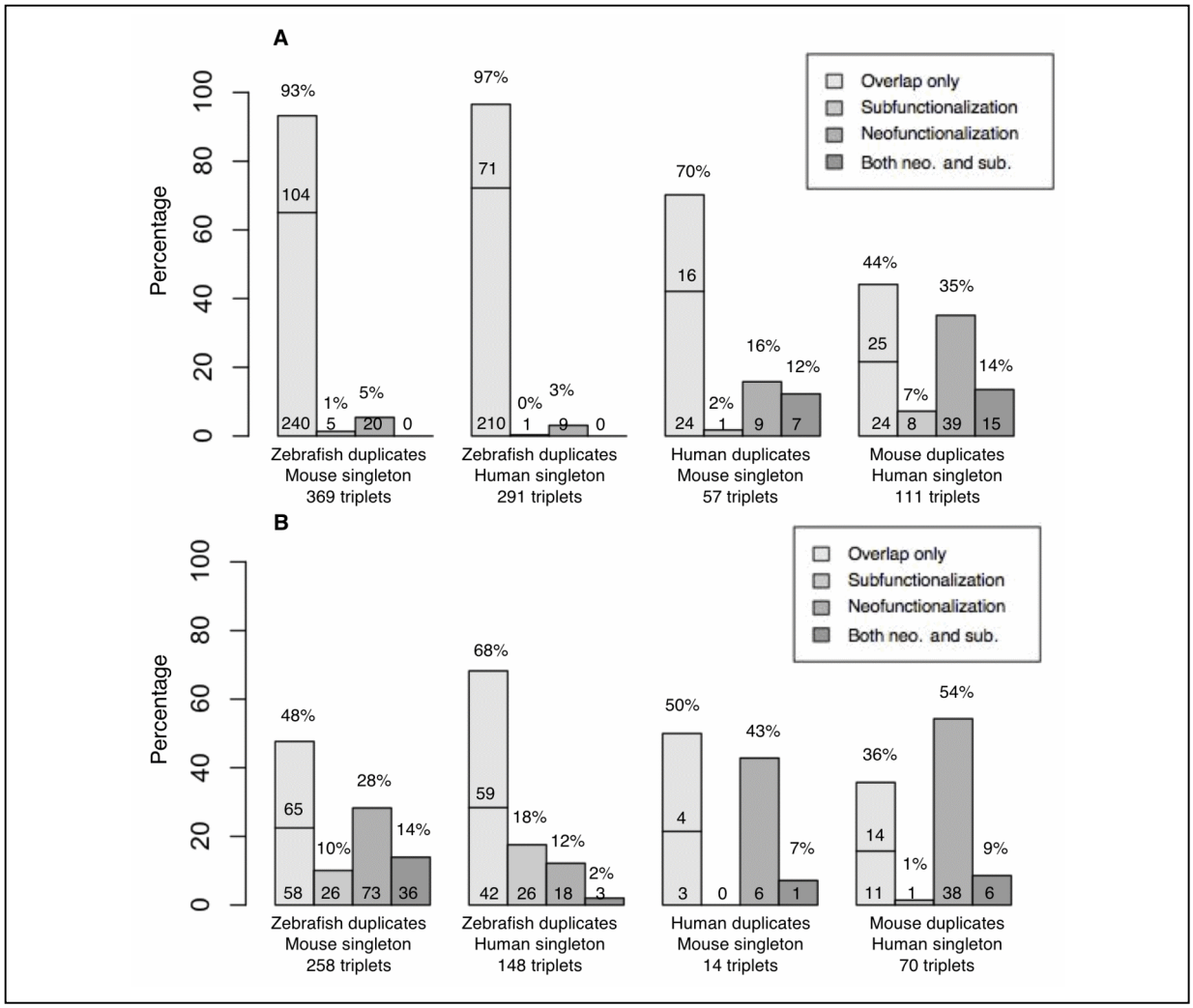
Supplementary Figure S2: Jackknife on expression data.
We successively removed from 10 to 90% of the data, randomly, with a 10% step. Barplots represent percentages of triplets exhibiting overlap only, subfunctionalization, neofunctionalization, or both neo- and subfunctionalization. For the category "overlap only", the bar is split in two parts: the bottom bar represents proportion of triplets with complete overlap (overlap score = 1), the upper bar represents the remaining triplets with overlap only (overlap score < 1, complementation score = 0, neofunctionalization score = 0).
JK0: standard spatial analysis on zebrafish duplicates with mouse singletons. JK10, …, JK90: 10% of data removed, …, 90% of data removed. Numbers below represent the count of triplets that could be studied.

6.3 Supplementary figure S3



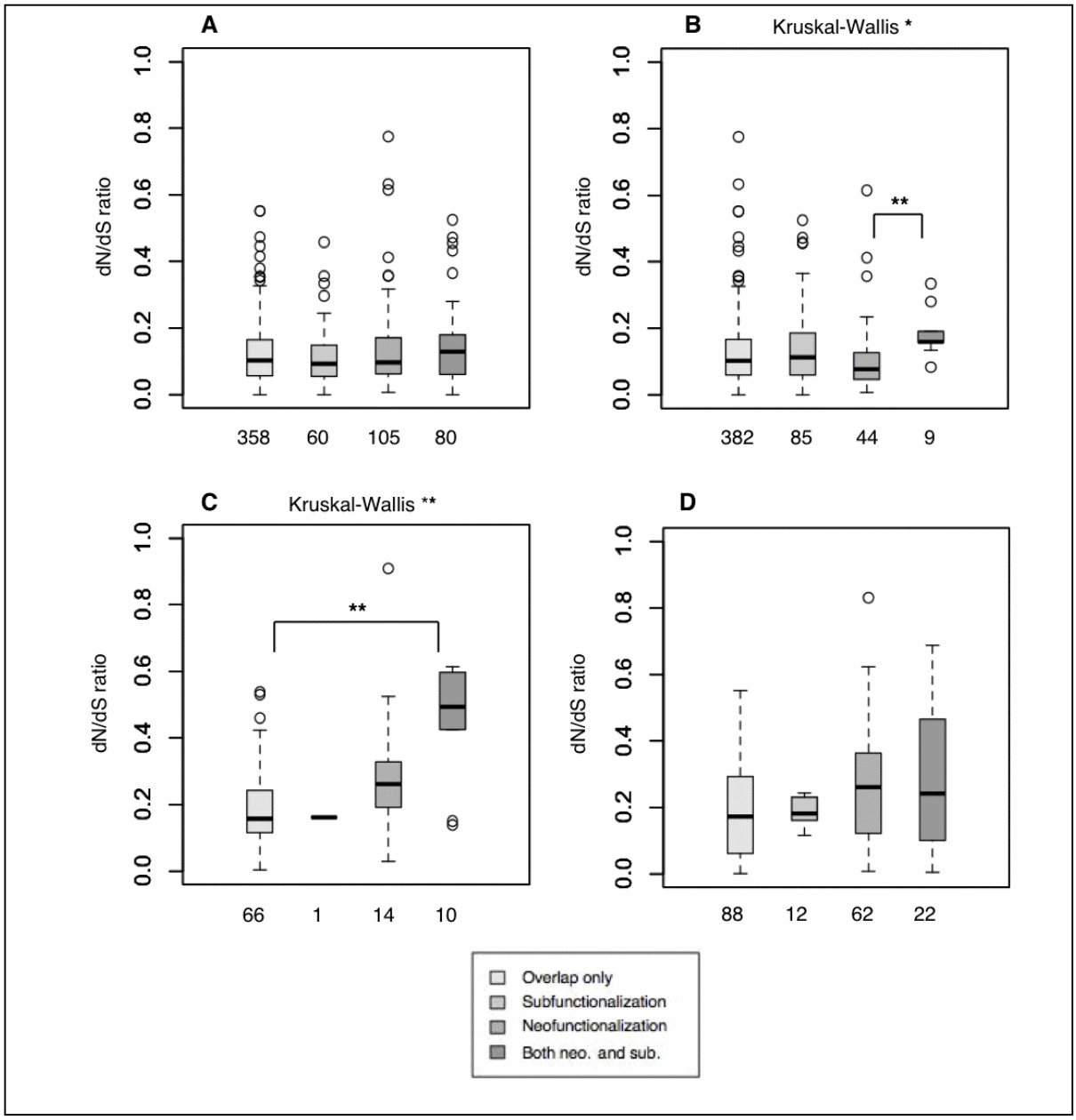
Supplementary Figure S3: Jackknife on mappings between species-specific anatomical structures.
We successively removed from 10 to 90% of the mappings between species-specific anatomical structures, randomly, with a 10% step. Barplots represent percentages of triplets exhibiting overlap only, subfunctionalization, neofunctionalization, or both neo- and subfunctionalization. For the category "overlap only", the bar is split in two parts: the bottom bar represents proportion of triplets with complete overlap (overlap score = 1), the upper bar represents the remaining triplets with overlap only (overlap score < 1, complementation score = 0, neofunctionalization score = 0).
JK0: standard spatial analysis on zebrafish duplicates with mouse singletons. JK10, …, JK90: 10% of mappings removed, …, 90% of mappings removed. Numbers below represent the count of triplets that could be studied.

6.4 Supplementary figure S4



Supplementary Figure S4: Use of different parameters to assess expression or absence of expression.
A: Expression vs No Expression. **B:** High quality data only. Barplots represent percentages of triplets exhibiting overlap only, subfunctionalization, neofunctionalization, or both neo- and subfunctionalization. For the category "overlap only", the bar is split in two parts: the bottom bar represents proportion of triplets with complete overlap (overlap score = 1), the upper bar represents the remaining triplets with overlap only (overlap score < 1, complementation score = 0, neofunctionalization score = 0). Below numbers represent total number of triplets that could be studied for each analysis.

6.5 Supplementary figure S5



Supplementary Figure S5: Relationships between evolution of sequences and of expression patterns.
Boxplots of dN/dS ratios of duplicated genes depending on their pattern of neo- and subfunctionalization. **A:** zebrafish duplicates with mouse singletons 1; **B:** zebrafish duplicates with human singletons; 1 **C:** human duplicates with human singletons; **D:** mouse duplicates with human singletons. Numbers below each category represent count of duplicates with dN/dS information. Duplicates with dN/dS greater than 1 are not displayed but taken into account for all counts and computations (1 for A and B, 3 for D).
Results for Wilcoxon tests and Kruskal-Wallis tests indicated when Kruskal-Wallis test is significant.
**: corrected p-values ≤ 0.01, *: corrected p-values ≤ 0.05

7 Supplementary information

7.1 Online supplementary material

Online supplementary material: we provide a web-interface to browse all results, and related raw data at http://bioinfo.unil.ch/supdata/Bastian_2011/html/.

7.2 Spatial analysis: increase in the precision of localization of expression

In our spatial-only analysis, we have pooled expression data from all developmental stages indifferently. This allowed to increase the precision of the descriptions of spatial expression patterns.

To observe this trend, we can study the level of the anatomical structures used in our analyses. The level of a structure represents the precision of its description. It is the number of parent tissues, that separate the structure from the root of the representation of the anatomy. For instance, “neural plate” has a maximum of 4 parent structures that separate it from the root: “neural plate” *is_a* “neuroectoderm”, *part_of* “embryonic ectoderm”, *part_of* “embryo”, *part_of* “whole organism”. The level of “neural plate” is thus 4.

In both spatio-temporal and spatial analyses, we denoted a highly significant negative correlation between the mean overlap score of triplets, and the precision of the structures used to study them (two-sided Spearman’s correlation test, p-values $< 3.9\ 10^{-4}$): this denotes the fact that there are more chances to consider all three genes of a triplets expressed in a non-granular structure, such as “whole organism”, than in a very precise structure, such as “cochlear duct epithelium”. Thanks to the increased precision in the spatial-only analysis, the correlation with overlap scores is reduced ($\rho = -0.34$ for spatio-temporal analysis, -0.15 for spatial-only analysis). The mean overlap score is also significantly reduced between the two analyses (wilcoxon test, p-value: $6.24\ 10^{-9}$), while still remaining high (mean overlap score for spatio-temporal analysis: 0.72; spatial-only analysis: 0.64).

7.3 Number of repetitions used for Bonferroni corrections

Test	Repetitions	Motivation
Fisher tests on the proportions of triplets "neofunctionalization only" vs. triplets "subfunctionalization only"	4	Test performed for the 4 types of triplets
Fisher tests on classes structures between standard analyses and analyses using high quality data only.	4	Test performed for the 4 types of triplets
Wilcoxon tests on dN/dS ratios between duplicates "overlap only" vs. the union of other categories	4	Test performed for the 4 types of triplets
Spearman correlation tests between dN/dS ratios and metrics (neofunctionalization, subfunctionalization, overlap)	12	Correlation to 3 metrics were tested, for the 4 types of triplets

8 Supplementary tables

All sup. tables are available at: http://bioinfo.unil.ch/supdata/Bastian_PhD_thesis/index.html

8.1 Supplementary table 1

The supplementary table 1 is extremely long, and is provided as online material. It is also proposed as multiple tables in Appendix 3.

8.2 Supplementary table 2

List of Homologous Organs Groups (HOGs) used in this study, with counts of triplets using each of them in the different analyses, and with the mapping to species-specific anatomical structures.

A: Count of triplets of zebrafish duplicates using mouse singletons, that have expression in this HOG

B: Count of triplets of zebrafish duplicates using human singletons, that have expression in this HOG

C: Count of triplets of human duplicates using mouse singletons, that have expression in this HOG

D: Count of triplets of mouse duplicates using human singletons, that have expression in this HOG

Homologous Organs Groups (HOGs)		Spatial-only analyses				Spatio-temporal analyses				Mapping to species-specific anatomical structures		
HOG ID	HOG name	A	B	C	D	A	B	C	D	human	mouse	zebrafish
HOG:0000229	retina	309	310	25	80	298	210	23	71	EHDAA:4745 retina; EV:0100348 retina	EMAPA:17168 retina; MA:0000276 retina	ZFA:0001071 presumptive neural retina; ZFA:0000152 retina
HOG:0000257	liver	248	241	36	91	193	182	30	81	EHDAA:1530 hepatic diverticulum; EHDAA:2185 liver; EV:0100089 liver	EMAPA:16565 hepatic diverticulum; EMAPA:16846 liver; EMAPA:16847 hepatic primordium; MA:0000358 liver	ZFA:0000124 liver primordium; ZFA:0000123 liver
HOG:0000276	heart	281	266	15	18	232	207	15	48	EHDAA:420 heart; EHDAA:424 early primitive heart tube; EHDAA:436 primitive heart tube; EV:0100018 heart	EMAPA:16105 heart; EMAPA:16208 early primitive heart tube; EMAPA:16215 primitive heart tube; MA:0000072 heart	ZFA:0000028 heart primordium; ZFA:0000115 heart rudiment; ZFA:0000149 primitive heart tube; ZFA:0000360 heart tube; ZFA:0000114 heart
HOG:0000157	brain	244	239	4	4	289	240	24	31	EHDAA:300 future brain; EHDAA:830 future brain; EHDAA:2629 brain; EV:0100164 brain	EMAPA:16089 future brain; EMAPA:16471 future brain; EMAPA:16894 brain;	ZFA:0000146 presumptive brain; ZFA:0000008 brain

											MA:0000168 brain	
HOG:0000671	whole organism	0	0	0	0	354	307	13	29	EHDAA:1 human; EV:0100000 Anatomical System; EV:0100016 whole body	EMAPA:25765 mouse; MA:0000001 mouse anatomy	ZFA:0100000 zebrafish anatomical entity; ZFA:0001094 whole organism
HOG:0000723	renal system	119	168	0	1	94	67	0	0	EHDAA:5889 renal or urinary system; EV:0100095 urinary system	EMAPA:17366 renal/urinary system; MA:0000325 renal/urinary system	ZFA:0000163 renal system
HOG:0000170	mesenchyme	218	0	0	0	216	0	0	0	EHDAA:177 mesenchyme; EV:0100007 mesenchyma	EMAPA:16097 mesenchyme	ZFA:0000393 mesenchyme
HOG:0000252	testis	54	50	39	96	33	30	30	89	EHDAA:8134 testis; EV:0100102 testis	EMAPA:17972 testis; MA:0000411 testis	ZFA:0000598 testis
HOG:0001674	sensory system	180	0	0	0	234	0	0	0	NA	MA:0002442 sensory organ system	ZFA:0000282 sensory system
HOG:0000559	presomitic mesoderm	189	0	0	0	191	0	0	0	EHDAA:374 unsegmented mesenchyme; EHDAA:389 unsegmented mesenchyme	EMAPA:16189 unsegmented mesenchyme; EMAPA:16752 unsegmented mesenchyme	ZFA:0000053 presumptive segmental plate; ZFA:0000279 segmental plate
HOG:0000251	ovary	57	60	28	80	27	29	22	72	EHDAA:8112 ovary; EV:0100111 ovary	EMAPA:17962 ovary; MA:0000384 ovary	ZFA:0000403 ovary
HOG:0000287	olfactory organ	101	103	15	68	27	0	14	34	EHDAA:1502 nose; EV:0100037 nose	EMAPA:16542 nose; MA:0000281 nose	ZFA:0000047 peripheral olfactory organ
HOG:0000601	spinal cord	49	64	15	63	49	7	11	49	EHDAA:344 future spinal cord; EHDAA:898 future spinal cord; EHDAA:2851 spinal cord; EV:0100316 spinal cord	EMAPA:16092 future spinal cord; EMAPA:16525 future spinal cord; EMAPA:16755 future spinal cord; EMAPA:17577 spinal cord; EMAPA:17700 spinal cord; MA:0000216 spinal cord	ZFA:0000417 presumptive spinal cord; ZFA:0000075 spinal cord
HOG:0000860	skin	37	62	27	40	27	12	24	73	EHDAA:6518 skin; EV:0100152 skin	EMAPA:17525 skin; EMAPA:18051 skin; EMAPA:18056 skin; EMAPA:18059 skin; EMAPA:18062 skin; EMAPA:18067 skin; EMAPA:18072 skin; EMAPA:18077 skin; EMAPA:18082 skin; EMAPA:18087 skin; EMAPA:18090 skin; EMAPA:18093 skin; EMAPA:18096 skin; EMAPA:18099 skin; EMAPA:18103 rest of skin; EMAPA:18108 skin; EMAPA:18113 skin; EMAPA:18118 skin; EMAPA:18123 skin;	ZFA:0000368 integument

											EMAPA:18128 skin; EMAPA:18131 skin; EMAPA:18134 skin; EMAPA:18137 skin; EMAPA:18140 skin; EMAPA:18148 skin; EMAPA:18151 skin; EMAPA:18156 skin; EMAPA:18159 skin; EMAPA:18199 rest of skin; EMAPA:18486 skin; EMAPA:18504 skin; MA:0000151 skin	
HOG:0000275	eye	33	20	11	4	125	67	10	4	EHDAA:936 eye; EV:0100336 visual apparatus	EMAPA:16198 eye; MA:0000261 eye	ZFA:0000107 eye
HOG:0000024	cerebellum	21	18	23	73	13	7	18	64	EHDAA:2689 cerebellum primordium; EHDAA:3514 cerebellum primordium; EHDAA:5494 cerebellum primordium; EHDAA:6608 cerebellum primordium; EHDAA:7584 cerebellum primordium; EV:0100293 cerebellum	EMAPA:17074 cerebellum primordium; EMAPA:17787 cerebellum; MA:0000198 cerebellum	ZFA:0001440 rhombic lip; ZFA:0000100 cerebellum
HOG:0000310	lung - swim bladder	3	4	45	86	3	3	26	61	EHDAA:1554 lung; EHDAA:2193 lung; EV:0100042 lung	EMAPA:16728 lung; MA:0000415 lung	ZFA:0000076 swim bladder
HOG:0001266	placenta	0	0	38	59	0	0	38	59	EV:0100119 placenta	MA:0000386 placenta	NA
HOG:0000039	metanephros	0	0	34	51	0	0	18	83	EHDAA:3077 metanephros; EHDAA:5899 metanephros; EV:0100096 kidney	EMAPA:17207 metanephros; EMAPA:17373 metanephros; MA:0000368 kidney	NA
HOG:0000398	mammary gland	0	0	21	75	0	0	21	68	EHDAA:6512 mammary gland; EV:0100125 mammary gland	EMAPA:17759 mammary gland; MA:0000145 mammary gland	NA
HOG:0001261	prostate gland	0	0	34	64	0	0	24	60	EV:0100104 prostate	EMAPA:19287 prostate gland; MA:0000404 prostate gland	NA
HOG:0000179	hypothalamus	13	12	15	64	12	3	13	46	EHDAA:5434 hypothalamus; EV:0100225 hypothalamus	EMAPA:17536 hypothalamus; MA:0000173 hypothalamus	ZFA:0000032 hypothalamus
HOG:0001284	adipose tissue	0	0	25	66	0	0	20	64	EV:0100381 adipose tissue	MA:0000009 adipose tissue	NA
HOG:0001177	hippocampus	0	0	27	74	0	0	21	51	EV:0100180 hippocampus	EMAPA:19039 hippocampus; EMAPA:19148 hippocampus; MA:0000191 hippocampus	NA
HOG:0000120	spleen	0	0	29	69	0	0	18	54	EHDAA:2991 splenic primordium; EV:0100055 spleen	EMAPA:18659 splenic primordium; EMAPA:18535 spleen	ZFA:0000436 spleen

											primordium; EMAPA:18767 spleen; MA:0000141 spleen	
HOG:0000098	endocrine system	64	77	1	0	12	10	3	0	EV:0100128 endocrine system	MA:0000012 endocrine system	ZFA:0001158 endocrine system
HOG:0000648	colon	0	0	25	64	0	0	22	54	EV:0100079 colon	EMAPA:18939 colon; MA:0000335 colon	NA
HOG:0000069	midbrain	32	67	0	5	42	5	0	3	EHDAA:302 future mesencephalon; EHDAA:832 future mesencephalon; EHDAA:1941 mesencephalon; EHDAA:2661 mesencephalon; EHDAA:3682 midbrain; EV:0100242 midbrain	EMAPA:16140 future midbrain; EMAPA:16472 future midbrain; EMAPA:16974 midbrain; MA:0000207 midbrain	ZFA:0000148 presumptive midbrain; ZFA:0000128 midbrain
HOG:0000222	dorsal root ganglion	1	0	21	65	1	0	19	45	EHDAA:2887 dorsal root ganglion; EV:0100373 spinal ganglion	EMAPA:16668 dorsal root ganglion; EMAPA:18372 dorsal root ganglion; MA:0000231 spinal ganglion; MA:0000232 dorsal root ganglion	ZFA:0000200 dorsal root ganglion
HOG:0000143	hypophysis	7	6	20	46	7	1	18	43	EHDAA:997 pituitary; EHDAA:2171 pituitary; EHDAA:4465 pituitary; EV:0100132 pituitary gland	EMAPA:16573 pituitary; EMAPA:16647 pituitary; EMAPA:16724 pituitary; EMAPA:16898 pituitary; MA:0000176 pituitary gland	ZFA:0000118 hypophysis
HOG:0000318	diencephalon	31	51	0	3	57	3	0	2	EHDAA:844 future diencephalon; EHDAA:1957 diencephalon; EHDAA:2633 diencephalon; EHDAA:3460 diencephalon; EV:0100194 diencephalon	EMAPA:16514 future diencephalon; EMAPA:16641 diencephalon; EMAPA:16896 diencephalon; MA:0000171 diencephalon	ZFA:0000574 presumptive diencephalon; ZFA:0000101 diencephalon
HOG:0001137	uterus	0	0	19	54	0	0	18	54	EV:0100113 uterus	MA:0000389 uterus	NA
HOG:0000740	urinary bladder	0	0	13	66	0	0	12	52	EHDAA:9316 bladder; EV:0100098 bladder	EMAPA:18321 bladder; MA:0000380 urinary bladder	NA
HOG:0000435	heart ventricle	2	2	10	60	2	0	10	55	EHDAA:472 primitive ventricle; EHDAA:806 primitive ventricle; EHDAA:1900 ventricle; EV:0100020 ventricle	EMAPA:16233 primitive ventricle; EMAPA:16350 primitive ventricle; EMAPA:17331 ventricle; MA:0000091 heart ventricle	ZFA:0000009 cardiac ventricle
HOG:0000182	reproductive system	59	70	0	1	1	8	1	0	EHDAA:5911 reproductive system; EV:0100100 reproductive system	EMAPA:17381 reproductive system; MA:0000326 reproductive system	ZFA:0000632 reproductive system
HOG:0000646	islet of Langerhans	0	0	28	53	0	0	15	44	EV:0100130 islets of Langerhans	EMAPA:19246 islets of Langerhans; EMAPA:19247 islets of	NA

											Langerhans; EMAPA:19248 islets of Langerhans; MA:0000127 pancreatic islet	
HOG:0000319	skeletal muscle	0	0	24	31	0	0	24	60	EV:0100377 skeletal muscle	MA:0000165 set of skeletal muscles	NA
HOG:0000253	thymus	1	1	21	55	0	0	14	43	EHDAA:2957 thymus primordium; EHDAA:9107 thymus; EV:0100138 thymus	EMAPA:17523 thymus primordium; EMAPA:18536 thymus primordium; EMAPA:18768 thymus; MA:0000142 thymus	ZFA:0001077 thymus primordium; ZFA:0001078 thymus
HOG:0001141	adrenal gland - interrenal gland	2	1	14	53	1	0	13	49	EV:0100135 adrenal gland	EMAPA:18426 adrenal gland; MA:0000116 adrenal gland	ZFA:0001346 interrenal primordium; ZFA:0001345 interrenal gland
HOG:0001218	bone marrow	0	0	19	52	0	0	15	45	EV:0100046 bone marrow	MA:0000134 bone marrow	NA
HOG:0000224	blood	5	5	21	44	5	0	14	33	EHDAA:418 blood; EV:0100047 blood	EMAPA:16332 blood; MA:0000059 blood	ZFA:0000568 presumptive blood; ZFA:0000007 blood
HOG:0001273	lymph node	0	0	12	53	0	0	12	49	EV:0100050 lymph node	MA:0000139 lymph node	NA
HOG:0001457	brainstem	10	7	5	42	1	0	8	53	EV:0100241 brain stem	MA:0000169 brainstem	ZFA:0001707 brainstem
HOG:0001573	substantia nigra	0	0	17	45	0	0	17	45	EV:0100247 substantia nigra	MA:0000210 substantia nigra	NA
HOG:0001753	forelimb - pectoral fin	63	0	0	0	59	0	0	0	EHDAA:6196 upper limb; EV:0100014 upper limb	EMAPA:17412 forelimb; MA:0000025 forelimb	ZFA:0001161 pectoral fin
HOG:0000053	jejunum	0	0	18	52	0	0	13	38	EV:0100074 jejunum	EMAPA:18666 jejunum; EMAPA:18932 jejunum; MA:0000340 jejunum	NA
HOG:0001175	corpus striatum	0	0	9	59	0	0	8	45	EHDAA:4475 future corpus striatum; EV:0100184 corpus striatum	EMAPA:17549 corpus striatum; MA:0000891 striatum	NA
HOG:0001523	aorta	0	0	13	56	0	0	13	39	EV:0100027 aorta	EMAPA:18601 aorta; MA:0000062 aorta	NA
HOG:0000462	pharynx	39	44	0	1	27	3	0	0	EHDAA:2935 pharynx; EV:0100065 pharynx	EMAPA:16706 pharynx; EMAPA:18838 pharynx; MA:0000432 pharynx	ZFA:0000056 pharynx
HOG:0000033	olfactory bulb	11	9	2	39	4	2	2	38	EV:0100173 olfactory bulb	MA:0000194 olfactory bulb	ZFA:0000402 olfactory bulb
HOG:0000191	somite	54	0	0	0	53	0	0	0	EHDAA:366 somite; EHDAA:699 somite	EMAPA:16172 somite; EMAPA:16184 somite; EMAPA:16860 somite	ZFA:0000155 somite
HOG:0001277	amygdala	0	0	8	46	0	0	8	45	EV:0100189 amygdala	MA:0000887 amygdala	NA
HOG:0000052	duodenum	0	0	7	46	0	0	7	46	EHDAA:3818 duodenum; EHDAA:3925 duodenum; EV:0100073 duodenum	EMAPA:17178 duodenum; EMAPA:17193 duodenum; EMAPA:18661 duodenum; EMAPA:18852 duodenum; MA:0000338 duodenum	NA
HOG:0001766	embryo	0	0	1	1	0	0	18	82	EHDAA:38 embryo	EMAPA:16039 embryo	NA

HOG:0001379	seminal vesicle	0	0	13	35	0	0	13	35	EV:0100106 seminal vesicle	EMAPA:19180 seminal vesicle; MA:0000410 seminal vesicle	NA
HOG:0000308	parotid gland	0	0	11	36	0	0	11	36	EHDAA:9234 parotid gland primordium; EV:0100060 parotid gland	EMAPA:18537 parotid; MA:0001585 parotid gland	NA
HOG:0000070	hindbrain	40	1	0	0	50	2	0	0	EHDAA:316 future rhombencephalon; EHDAA:854 future rhombencephalon; EHDAA:1983 rhombencephalon; EHDAA:2679 rhombencephalon; EHDAA:3502 hindbrain	EMAPA:16148 future rhombencephalon; EMAPA:16478 future rhombencephalon; EMAPA:16916 hindbrain; MA:0000195 hindbrain	ZFA:0000569 presumptive hindbrain; ZFA:0000029 hindbrain
HOG:0000412	alimentary system	10	16	3	0	23	30	2	5	EHDAA:514 alimentary system; EV:0100056 alimentary system	EMAPA:16246 alimentary system; MA:0002431 digestive system	ZFA:0000339 digestive system
HOG:0001247	immune system	46	0	0	0	42	0	0	0	NA	MA:0002711 immune system	ZFA:0001159 immune system
HOG:0000283	telencephalon	39	0	0	0	48	0	0	0	EHDAA:1969 future telencephalon; EHDAA:2647 future telencephalon; EHDAA:3484 telencephalon	EMAPA:16652 telencephalon; EMAPA:16910 telencephalon; MA:0000183 telencephalon	ZFA:0000571 presumptive telencephalon; ZFA:0000079 telencephalon
HOG:0000114	paraxial mesoderm	43	0	0	0	43	0	0	0	EHDAA:364 paraxial mesenchyme; EHDAA:387 paraxial mesenchyme	EMAPA:16171 paraxial mesenchyme; EMAPA:16183 paraxial mesenchyme; EMAPA:16751 paraxial mesenchyme	ZFA:0000591 presumptive paraxial mesoderm; ZFA:0000255 paraxial mesoderm
HOG:0000284	inner ear	53	24	0	0	4	1	0	1	EHDAA:504 inner ear; EV:0100361 internal ear	EMAPA:16194 inner ear; MA:0000237 inner ear	ZFA:0000217 inner ear
HOG:0001265	epididymis	0	0	11	50	0	0	11	10	EV:0100103 epididymis	EMAPA:19290 epididymis; MA:0000397 epididymis	NA
HOG:0000038	mesonephros	78	0	0	0	3	0	0	0	EHDAA:1581 mesonephros; EHDAA:5891 mesonephros; EHDAA:9322 degenerating mesonephros	EMAPA:16744 mesonephros; EMAPA:17369 mesonephros; EMAPA:17946 degenerating mesonephros	ZFA:0000529 kidney
HOG:0000050	pancreas	10	9	4	21	9	0	8	17	EHDAA:2151 pancreas primordium; EHDAA:6881 pancreas; EV:0100092 pancreas	EMAPA:17066 pancreas primordium; EMAPA:17503 pancreas; EMAPA:18816 pancreas; MA:0000120 pancreas	ZFA:0000254 pancreas primordium; ZFA:0000140 pancreas
HOG:0000713	diaphragm	0	0	4	38	0	0	4	32	EHDAA:4104 future diaphragm; EV:0100376 diaphragm	EMAPA:17701 diaphragm; MA:0001904 diaphragm	NA
HOG:0000108	dermis	1	1	6	39	0	0	3	26	EHDAA:6524 future dermis; EV:0100154 dermis	EMAPA:18412 dermis; EMAPA:17527 dermis; EMAPA:18405 dermis;	ZFA:0001119 dermis

											EMAPA:18052 dermis; EMAPA:18057 dermis; EMAPA:18060 dermis; EMAPA:18063 dermis; EMAPA:18068 dermis; EMAPA:18073 dermis; EMAPA:18078 dermis; EMAPA:18083 dermis; EMAPA:18088 dermis; EMAPA:18091 dermis; EMAPA:18094 dermis; EMAPA:18097 dermis; EMAPA:18100 dermis; EMAPA:18104 dermis; EMAPA:18109 dermis; EMAPA:18114 dermis; EMAPA:18119 dermis; EMAPA:18124 dermis; EMAPA:18129 dermis; EMAPA:18132 dermis; EMAPA:18135 dermis; EMAPA:18138 dermis; EMAPA:18141 dermis; EMAPA:18146 dermis; EMAPA:18149 dermis; EMAPA:18152 dermis; EMAPA:18157 dermis; EMAPA:18160 dermis; EMAPA:18201 dermis; EMAPA:18487 dermis; EMAPA:18505 dermis; MA:0000152 dermis	
HOG:0000076	cranial ganglion	38	0	0	0	36	0	0	0	EHDAA:920 cranial	EMAPA:16659 cranial; MA:0000214 cranial ganglion	ZFA:0000013 cranial ganglion
HOG:0000102	ciliary body	0	0	7	29	0	0	7	29	EV:0100346 ciliary body	EMAPA:19065 ciliary body; MA:0000264 ciliary body	ZFA:0001203 ciliary zone
HOG:0001148	otic vesicle	33	0	0	0	37	0	0	0	EHDAA:2110 otocyst	EMAPA:16669 otocyst	ZFA:0000051 otic vesicle
HOG:0000175	heart atrium	3	2	14	48	2	0	0	0	EHDAA:456 common atrial chamber; EHDAA:786 common atrial chamber; EHDAA:1265 atrium; EHDAA:1267 common atrial chamber; EV:0100019 atrium	EMAPA:16225 common atrial chamber; EMAPA:16342 common atrial chamber; EMAPA:16688 atrium; EMAPA:16689 common atrial chamber; MA:0000073 heart atrium	ZFA:0000471 atrium
HOG:0000155	pharyngeal arch	28	1	0	0	36	1	0	0	EHDAA:571 branchial arch	EMAPA:16117 branchial arch	ZFA:0001306 pharyngeal arch
HOG:0000647	ileum	0	0	5	33	0	0	4	24	EV:0100075 ileum	MA:0000339 ileum	NA
HOG:0000419	tongue	0	0	10	23	0	0	9	21	EHDAA:2939 future tongue; EHDAA:9132 tongue; EV:0100058 tongue	EMAPA:17185 tongue; EMAPA:18870 tongue; MA:0000347 tongue	NA
HOG:0000156	ganglion	2	44	1	3	11	0	0	0	EHDAA:918 ganglion; EHDAA:2885 ganglion;	EMAPA:16658 ganglion; EMAPA:16667 ganglion;	ZFA:0000190 ganglion

										EHDAA:3759 primordial ganglia; EHDAA:4650 ganglion; EHDAA:5609 ganglion; EV:0100372 ganglion	EMAPA:17157 ganglion; EMAPA:18221 ganglion; EMAPA:18371 ganglion; MA:0002406 ganglion	
HOG:0000722	cerebral cortex	0	0	9	12	0	0	14	26	EHDAA:5452 cerebral cortex; EV:0100166 cerebral cortex	EMAPA:17544 cerebral cortex; MA:0000185 cerebral cortex	NA
HOG:0000371	trachea	0	0	13	20	0	0	11	16	EHDAA:1007 tracheal diverticulum; EHDAA:1574 tracheal diverticulum; EHDAA:2211 primitive trachea; EHDAA:3066 trachea; EV:0100040 trachea	EMAPA:16740 tracheal diverticulum; EMAPA:16853 trachea; MA:0000441 trachea	NA
HOG:0000307	neural tube	29	0	0	0	30	0	0	0	EHDAA:908 neural tube; EHDAA:2857 neural tube	EMAPA:16164 neural tube; EMAPA:16530 neural tube; EMAPA:16757 neural tube	ZFA:0001135 neural tube
HOG:0001138	vagina	0	0	13	15	0	0	13	15	EV:0100117 vagina	EMAPA:18986 vagina; MA:0000394 vagina	NA
HOG:0000051	pineal gland	31	6	0	11	4	0	0	0	EHDAA:7511 pineal gland; EHDAA:9931 epiphysis; EV:0100131 pineal gland; EV:0100221 pineal body	EMAPA:18544 pineal primordium; EMAPA:18778 pineal gland; MA:0000175 pineal gland	ZFA:0000019 epiphysis
HOG:0000376	salivary gland	0	0	3	23	0	0	3	22	EHDAA:7975 salivary gland; EV:0100059 salivary gland	EMAPA:17751 salivary gland; MA:0000346 salivary gland	NA
HOG:0000315	viscerocranium	30	0	0	0	20	0	0	0	EHDAA:8349 viscerocranium	EMAPA:18022 viscerocranium; MA:0000318 viscerocranium	ZFA:0001216 splanchnocranium
HOG:0001190	bone	0	0	5	18	0	0	6	21	EV:0100140 bone	MA:0001459 bone	ZFA:0001514 bone
HOG:0000083	heart myocardium	0	0	9	18	0	0	5	16	EHDAA:430 myocardium; EV:0100022 myocardium	EMAPA:16211 cardiac muscle; MA:0000080 myocardium layer	ZFA:0001319 myocardium
HOG:0000450	oesophagus	0	0	8	18	0	0	7	15	EHDAA:2925 oesophagus; EV:0100069 oesophagus	EMAPA:16833 oesophagus; EMAPA:18860 oesophagus; MA:0000352 esophagus	ZFA:0000204 esophagus
HOG:0000672	rhombomere	24	0	0	0	24	0	0	0	EHDAA:318 pro-rhombomere a; EHDAA:326 pro-rhombomere b; EHDAA:332 pro-rhombomere c; EHDAA:338 pro-rhombomere d; EHDAA:856 pro-rhombomere a; EHDAA:866 pro-rhombomere b; EHDAA:876 pro-	EMAPA:16149 anterior pro-rhombomere; EMAPA:16157 posterior pro-rhombomere; EMAPA:16290 rhombomere 01; EMAPA:16293 rhombomere 02; EMAPA:16297 rhombomere 03; EMAPA:16301 rhombomere 04; EMAPA:16305	ZFA:0001207 presumptive rhombomere 1; ZFA:0001208 presumptive rhombomere 2; ZFA:0001209 presumptive rhombomere 7; ZFA:0001210 presumptive rhombomere 6; ZFA:0001211

			rhombomere c; EHDAA:886 pro-rhombomere d; EHDAA:1373 rhombomere 01; EHDAA:1383 rhombomere 02; EHDAA:1393 rhombomere 03; EHDAA:1408 rhombomere 04; EHDAA:1423 rhombomere 05; EHDAA:1433 rhombomere 06; EHDAA:1443 rhombomere 07; EHDAA:1991 rhombomere 01; EHDAA:2003 rhombomere 02; EHDAA:2015 rhombomere 03; EHDAA:2025 rhombomere 04; EHDAA:2037 rhombomere 05; EHDAA:2047 rhombomere 06; EHDAA:2059 rhombomere 07; EHDAA:2071 rhombomere 08; EHDAA:2703 rhombomere 01; EHDAA:2715 rhombomere 02; EHDAA:2743 rhombomere 03; EHDAA:2755 rhombomere 04; EHDAA:2767 rhombomere 05; EHDAA:2779 rhombomere 06; EHDAA:2791 rhombomere 07; EHDAA:2805 rhombomere 08; EHDAA:3532 rhombomere 01; EHDAA:3546 rhombomere 02; EHDAA:3586 rhombomere 03; EHDAA:3600 rhombomere 04;	rhombomere 05; EMAPA:16480 rhombomere 01; EMAPA:16484 rhombomere 02; EMAPA:16488 rhombomere 03; EMAPA:16492 rhombomere 04; EMAPA:16496 rhombomere 05; EMAPA:16500 rhombomere 06; EMAPA:16504 rhombomere 07; EMAPA:16508 rhombomere 08; EMAPA:16918 rhombomere 01; EMAPA:16925 rhombomere 02; EMAPA:16932 rhombomere 03; EMAPA:16939 rhombomere 04; EMAPA:16946 rhombomere 05; EMAPA:16953 rhombomere 06; EMAPA:16960 rhombomere 07; EMAPA:16967 rhombomere 08; EMAPA:17092 rhombomere 01; EMAPA:17099 rhombomere 02; EMAPA:17106 rhombomere 03; EMAPA:17113 rhombomere 04; EMAPA:17120 rhombomere 05; EMAPA:17127 rhombomere 06; EMAPA:17134 rhombomere 07; EMAPA:17141 rhombomere 08	presumptive rhombomere 5; ZFA:0001212 presumptive rhombomere 4; ZFA:0001213 presumptive rhombomere 3; ZFA:0001214 presumptive rhombomere 8; ZFA:0001064 rhombomere

										EHDAA:3614 rhombomere 05; EHDAA:3628 rhombomere 06; EHDAA:3642 rhombomere 07; EHDAA:3658 rhombomere 08		
HOG:0000169	lens	14	8	2	9	4	0	2	8	EHDAA:9045 lens; EV:0100343 lens	EMAPA:17838 lens; MA:0000275 lens	ZFA:0000035 lens
HOG:0001245	muscle	10	11	3	4	0	0	5	13	EV:0100146 muscle	MA:0002888 musculature	ZFA:0005145 muscle
HOG:0001624	hematopoietic system	6	3	0	2	0	0	14	21	EV:0100045 hematological system	MA:0002434 hematopoietic system	ZFA:0005023 hematopoietic system
HOG:0000418	thyroid	1	0	13	12	1	0	11	6	EHDAA:952 thyroid primordium; EHDAA:2136 thyroid; EHDAA:2963 thyroid; EV:0100133 thyroid	EMAPA:16361 thyroid primordium; EMAPA:16558 thyroid primordium; EMAPA:17068 thyroid; EMAPA:18827 thyroid; MA:0000129 thyroid gland	ZFA:0001081 thyroid primordium; ZFA:0001072 thyroid follicle
HOG:0001268	hair follicle	0	0	8	31	0	0	0	0	EV:0100156 hair follicle	EMAPA:18771 follicle; MA:0000154 hair follicle	NA
HOG:0001367	tegmentum	29	0	0	0	10	0	0	0	NA	EMAPA:18215 tegmentum; MA:0000212 midbrain tegmentum	ZFA:0000160 tegmentum
HOG:0000181	medulla oblongata	6	7	7	3	5	1	6	1	EHDAA:7576 medulla oblongata; EV:0100275 medulla oblongata	EMAPA:17550 medulla oblongata; MA:0000206 medulla oblongata	ZFA:0000545 medulla oblongata
HOG:0000408	stomach	0	0	3	9	0	0	5	18	EHDAA:2981 stomach; EV:0100070 stomach	EMAPA:17021 stomach; EMAPA:18889 stomach; MA:0000353 stomach	NA
HOG:0000005	brain ventricular system	7	9	1	8	0	0	1	8	EV:0100306 ventricular system	MA:0000818 brain ventricle	ZFA:0001261 ventricular system
HOG:0000077	epidermis	21	0	0	1	11	0	0	1	EV:0100153 epidermis	EMAPA:18413 epidermis; EMAPA:17528 epidermis; EMAPA:18406 epidermis; EMAPA:18053 epidermis; EMAPA:18058 epidermis; EMAPA:18061 epidermis; EMAPA:18064 epidermis; EMAPA:18069 epidermis; EMAPA:18074 epidermis; EMAPA:18079 epidermis; EMAPA:18084	ZFA:0000105 epidermis

											epidermis; EMAPA:18089 epidermis; EMAPA:18092 epidermis; EMAPA:18095 epidermis; EMAPA:18098 epidermis; EMAPA:18101 epidermis; EMAPA:18105 epidermis; EMAPA:18110 epidermis; EMAPA:18115 epidermis; EMAPA:18120 epidermis; EMAPA:18125 epidermis; EMAPA:18130 epidermis; EMAPA:18133 epidermis; EMAPA:18136 epidermis; EMAPA:18139 epidermis; EMAPA:18142 epidermis; EMAPA:18147 epidermis; EMAPA:18150 epidermis; EMAPA:18153 epidermis; EMAPA:18158 epidermis; EMAPA:18161 epidermis; EMAPA:18202 epidermis; EMAPA:18488 epidermis; EMAPA:18506 epidermis; MA:0000153 epidermis	
HOG:0001242	metanephric glomerulus	0	0	4	30	0	0	0	0	EV:0100386 glomerus	EMAPA:18324 glomeruli; MA:0001657 glomerulus	NA
HOG:0000055	small intestine	0	0	3	13	0	0	4	13	EV:0100072 small intestine	MA:0000337 small intestine	NA
HOG:0000535	neural retinal epithelium	13	0	0	0	19	0	0	0	EHDAA:4751 neural retinal epithelium	EMAPA:17171 neural retinal epithelium; EMAPA:18590 neural retina; MA:0000277	ZFA:0000046 retinal neural layer

											neural retinal epithelium	
HOG:0001176	pons	0	0	11	17	0	0	4	0	EV:0100253 pons	EMAPA:17563 pons; MA:0000204 pons	NA
HOG:0001359	uterine cervix	0	0	11	6	0	0	8	6	EV:0100114 cervix	MA:0000392 uterine cervix	NA
HOG:0000235	otic placode	13	0	0	0	14	0	0	0	EHDAA:506 otic placode	EMAPA:16195 otic placode	ZFA:0000138 otic placode
HOG:0000309	gut	8	3	0	1	12	0	0	1	EHDAA:518 gut	EMAPA:16247 gut; MA:0000917 gut	ZFA:0000112 gut
HOG:0000657	thalamus	5	7	1	5	2	1	1	3	EHDAA:3470 future thalamus; EV:0100195 thalamus	EMAPA:17540 thalamus; MA:0000179 thalamus	ZFA:0001215 thalamus
HOG:0000383	forebrain	11	0	0	0	13	0	0	0	EHDAA:310 future prosencephalon; EHDAA:840 future prosencephalon; EHDAA:1955 prosencephalon; EHDAA:2631 future forebrain; EHDAA:3458 forebrain	EMAPA:16144 future prosencephalon; EMAPA:16512 prosencephalon; EMAPA:16640 future forebrain; EMAPA:16895 forebrain; MA:0000170 forebrain	ZFA:0000062 presumptive forebrain; ZFA:0000109 forebrain
HOG:0000727	penis	0	0	7	5	0	0	7	5	EHDAA:9368 penis; EV:0100107 penis	EMAPA:18682 penis; MA:0000408 penis	NA
HOG:0000082	archinephric duct	11	0	0	0	12	0	0	0	EHDAA:1590 nephric duct; EHDAA:8108 nephric duct; EHDAA:8128 nephric duct	EMAPA:16369 presumptive nephric duct; EMAPA:16577 nephric duct; EMAPA:17377 nephric duct; EMAPA:17970 mesonephric duct	ZFA:0000546 mesonephric duct; ZFA:0000150 pronephric duct
HOG:0000202	respiratory system	2	2	1	2	8	6	0	2	EHDAA:1003 future respiratory system; EHDAA:2191 respiratory system; EV:0100036 respiratory system	EMAPA:16727 respiratory system; MA:0000327 respiratory system	ZFA:0000272 respiratory system
HOG:0000691	cochlea	0	0	0	14	0	0	0	9	EHDAA:4704 cochlear; EV:0100363 cochlea	EMAPA:17597 cochlea; MA:0000240 cochlea	NA
HOG:0001388	tectum	20	0	0	0	3	0	0	0	NA	EMAPA:19051 tectum; MA:0000211 tectum	ZFA:0000445 optic tectum
HOG:0001559	caecum	0	0	5	5	0	0	8	5	EHDAA:3901 caecum; EV:0100397 cecum	MA:0000334 cecum	NA
HOG:0000054	large intestine	0	0	2	8	0	0	0	12	EV:0100077 large intestine	EMAPA:19252 large intestine; MA:0000333 large intestine	NA
HOG:0000302	cardiovascular system	0	3	0	1	14	2	0	2	EHDAA:394 cardiovascular system; EV:0100017 cardiovascular system	EMAPA:16104 cardiovascular system; MA:0000010 cardiovascular system	ZFA:0000010 cardiovascular system
HOG:0000694	trigeminal V ganglion	13	0	0	0	8	0	0	0	EHDAA:924 trigeminal V preganglion; EHDAA:2101 trigeminal V ganglion	EMAPA:16663 trigeminal V preganglion; EMAPA:16797 trigeminal V; MA:0001080 trigeminal V ganglion	ZFA:0000295 trigeminal ganglion
HOG:0000316	intraembryonic coelom	19	0	0	0	1	0	0	0	EHDAA:251 intraembryonic coelom	EMAPA:16088 intraembryonic coelom	ZFA:0001438 coelom
HOG:0000334	cranium	12	0	0	0	8	0	0	0	EHDAA:6017 cranium	EMAPA:17680 cranium; MA:0000316 cranium	ZFA:0000737 cranium

HOG:0000337	hindlimb	0	0	0	16	0	0	0	4	EHDAA:6082 lower limb; EV:0100015 lower limb	EMAPA:17458 hindlimb; MA:0000026 hindlimb	NA
HOG:0000397	gonad	12	0	0	0	8	0	0	0	EHDAA:5915 gonad primordium	EMAPA:17204 gonad primordium; EMAPA:17383 gonad primordium; EMAPA:17648 gonad; MA:0002420 gonad	ZFA:0001262 gonad primordium; ZFA:0000413 gonad
HOG:0001743	vein	8	11	0	0	0	0	0	0	EV:0100031 vein	MA:0000067 vein	ZFA:0000082 vein
HOG:0001754	forelimb - pectoral fin bud	9	0	0	0	10	0	0	0	EHDAA:1699 upper limb bud	EMAPA:16406 forelimb bud	ZFA:0000141 pectoral fin bud
HOG:0000330	ear	2	7	0	2	3	2	0	2	EHDAA:502 ear; EV:0100353 auditory apparatus	EMAPA:16193 ear; MA:0000236 ear	ZFA:0001138 vestibuloauditory system
HOG:0000056	intestine	6	7	0	0	2	0	0	2	EV:0100071 intestine	MA:0000328 intestine	ZFA:0001338 intestine
HOG:0000402	nervous system	1	2	0	0	5	8	1	0	EHDAA:826 nervous system; EV:0100162 nervous system	EMAPA:16469 nervous system; EMAPA:16753 nervous system; MA:0000016 nervous system	ZFA:0000396 nervous system
HOG:0000178	epithalamus	4	0	0	0	12	0	0	0	EHDAA:5421 epithalamus; EV:0100220 epithalamus	EMAPA:17532 epithalamus; MA:0000172 epithalamus	ZFA:0000509 epithalamus
HOG:0000399	peripheral nervous system	1	2	2	0	6	1	4	0	EHDAA:2881 peripheral nervous system; EV:0100335 peripheral nervous system	EMAPA:16665 peripheral nervous system; EMAPA:18370 peripheral nervous system; MA:0000218 peripheral nervous system	ZFA:0000142 peripheral nervous system
HOG:0000726	female reproductive system	0	0	1	3	0	0	3	9	EHDAA:8104 female; EV:0100110 female reproductive system	EMAPA:17959 female; MA:0000381 female reproductive system	NA
HOG:0000199	notochord	7	0	0	0	7	0	0	0	EHDAA:1241 notochord; EHDAA:6009 notochord; EV:0100002 notochord	EMAPA:16191 notochord	ZFA:0000135 notochord
HOG:0000201	tail bud	6	0	0	0	8	0	0	0	EHDAA:1595 tail bud	EMAPA:16580 tail bud	ZFA:0000077 tail bud
HOG:0001276	joint	0	0	6	4	0	0	3	1	EV:0100142 joint	EMAPA:19204 joint; MA:0000319 joint	ZFA:0001596 joint
HOG:0001275	musculoskeletal system	0	0	0	1	0	0	6	5	EHDAA:5019 skeletal muscular system; EV:0100139 musculoskeletal system	MA:0002418 musculoskeletal system	NA
HOG:0000154	embryonic endoderm	7	0	0	0	3	0	0	0	EHDAA:94 endoderm; EV:0100005 endoderm	EMAPA:16062 endoderm	ZFA:0000416 presumptive endoderm; ZFA:0000017 endoderm
HOG:0001526	metanephric tubule	0	0	3	7	0	0	0	0	EV:0100387 renal tubule	MA:0000377 renal tubule	NA
HOG:0001251	artery	2	7	0	0	0	0	0	0	EV:0100026 artery	MA:0000064 artery	ZFA:0000005 artery
HOG:0000165	optic vesicle	4	0	0	0	4	0	0	0	EHDAA:1496 optic vesicle	EMAPA:16540 optic vesicle	ZFA:0000050 optic vesicle
HOG:0000223	optic stalk	4	0	0	0	4	0	0	0	EHDAA:3804 optic stalk	EMAPA:16678 optic stalk	ZFA:0000137 optic stalk
HOG:0001254	skeletal system	4	0	0	0	4	0	0	0	EHDAA:5035 skeleton	EMAPA:17213 skeleton; MA:0000018 skeletal	ZFA:0000434 skeletal system

											system	
HOG:0000186	olfactory placode	3	0	0	0	4	0	0	0	EHDAA:1504 olfactory placode	EMAPA:16543 olfactory placode	ZFA:0000048 olfactory placode
HOG:0000288	chondrocranium	4	0	0	0	3	0	0	0	EHDAA:6019 chondrocranium	EMAPA:17681 chondrocranium; MA:0000317 chondrocranium	ZFA:0001424 chondrocranium
HOG:0000725	male reproductive system	0	0	0	0	0	0	3	4	EHDAA:8124 male; EV:0100101 male reproductive system	EMAPA:17968 male; MA:0000396 male reproductive system	NA
HOG:0001224	brain ventricular zone	6	0	0	0	1	0	0	0	NA	MA:0000819 brain ventricular zone	ZFA:0001083 ventricular zone
HOG:0000101	iris	0	0	0	4	0	0	0	2	EV:0100345 iris	EMAPA:19154 iris; MA:0000273 iris	ZFA:0001238 iris
HOG:0000293	central nervous system	0	1	0	0	3	1	0	1	EHDAA:828 central nervous system; EV:0100163 central nervous system	EMAPA:16470 central nervous system; EMAPA:16754 central nervous system; MA:0000167 central nervous system	ZFA:0000012 central nervous system
HOG:0000536	pigmented retinal epithelium	4	0	0	0	2	0	0	0	EHDAA:4753 pigmented retinal epithelium	EMAPA:17172 pigmented retinal epithelium; MA:0000279 pigmented retinal epithelium	ZFA:0000064 presumptive retinal pigmented epithelium; ZFA:0000144 retinal pigmented epithelium
HOG:0001306	appendix	0	0	4	1	0	0	0	1	EHDAA:6902 future appendix; EV:0100076 vermiform appendix; EV:0100080 appendix	MA:0001540 appendix	NA
HOG:0001476	lacrimal gland	0	0	0	3	0	0	0	3	EV:0100339 lacrimal gland	MA:0001296 lacrimal gland	NA
HOG:0001768	grey matter	4	0	0	0	2	0	0	0	NA	MA:0001112 grey matter	ZFA:0001681 grey matter
HOG:0000152	embryonic mesoderm	0	0	0	0	5	0	0	0	EHDAA:183 mesoderm; EV:0100006 mesoderm	EMAPA:16071 mesoderm	ZFA:0001377 presumptive mesoderm; ZFA:0000041 mesoderm
HOG:0000403	integumental system	0	0	0	2	0	0	0	3	EHDAA:6508 integumental system; EV:0100151 dermal system	EMAPA:17524 integumental system; MA:0000014 integumental system	NA
HOG:0000696	vestibulocochlear VIII ganglion	3	0	0	0	2	0	0	0	EHDAA:5557 vestibulocochlear VIII ganglion; EHDAA:6641 vestibulocochlear VIII ganglion	EMAPA:16982 acoustic ganglion VIII; EMAPA:17570 vestibulo-cochlear VIII ganglion complex; EMAPA:17571 vestibulocochlear VIII; MA:0001084 vestibulocochlear VIII ganglion	ZFA:0000588 statoacoustic (VIII) ganglion
HOG:0000719	metanephric nephron	0	0	0	5	0	0	0	0	EHDAA:10439 primitive nephrons; EV:0100384 nephron	EMAPA:17954 nephrons; MA:0000375 nephron	NA
HOG:0001135	ductus deferens	0	0	0	5	0	0	0	0	EV:0100105 vas deferens	EMAPA:18681 ductus deferens; MA:0000413	NA

											vas deferens	
HOG:0001167	retinal inner nuclear layer	3	0	0	0	2	0	0	0	NA	EMAPA:19155 inner nuclear layer; MA:0001311 retina inner nuclear layer	ZFA:0000119 retinal inner nuclear layer
HOG:0001202	primitive streak - blastopore - germ ring	4	0	0	0	1	0	0	0	EHDAA:185 primitive streak	EMAPA:16072 primitive streak	ZFA:0000111 germ ring
HOG:0001248	circulatory system	4	0	0	0	1	0	0	0	NA	MA:0002718 vascular system	ZFA:0005076 primordial vasculature; ZFA:0001079 blood vasculature
HOG:0000139	proctodeum	3	0	0	0	1	0	0	0	EHDAA:5737 anal pit; EV:0100082 anus	EMAPA:17350 anal pit; MA:0000331 anus	ZFA:0000066 proctodeum
HOG:0000264	dorsal aorta	3	0	0	0	1	0	0	0	EHDAA:402 dorsal aorta	EMAPA:16204 dorsal aorta; EMAPA:18606 dorsal aorta; MA:0000476 dorsal aorta	ZFA:0000014 dorsal aorta
HOG:0000643	telencephalic ventricle	0	0	1	1	0	0	1	1	EHDAA:1981 telencephalic vesicle; EHDAA:2659 telencephalic vesicle; EHDAA:3490 lateral ventricle; EHDAA:6564 lateral ventricles; EV:0100307 lateral ventricle	EMAPA:16653 telencephalic vesicle; EMAPA:16914 lateral ventricle; MA:0000192 lateral ventricle	ZFA:0000696 telencephalic ventricle
HOG:0000812	mouth	2	0	0	0	2	0	0	0	EHDAA:544 stomatodaeum	EMAPA:16263 stomatodaeum; MA:0002474 mouth	ZFA:0000547 mouth; ZFA:0001290 stomodeum
HOG:0001064	apical ectodermal ridge forelimb	2	0	0	0	2	0	0	0	EHDAA:3195 apical ectodermal ridge; EHDAA:4186 apical ectodermal ridge; EHDAA:5194 apical ectodermal ridge; EHDAA:6284 apical ectodermal ridge	EMAPA:16778 apical ectodermal ridge; EMAPA:17247 apical ectodermal ridge	ZFA:0000085 apical ectodermal ridge pectoral fin bud
HOG:0001136	oviduct	0	0	1	1	0	0	1	1	EV:0100112 uterine tube	EMAPA:18984 oviduct; MA:0000385 oviduct	NA
HOG:0001639	cerebral hemisphere	0	0	1	0	0	0	1	2	EV:0100165 cerebrum	MA:0000133 cerebral hemisphere	NA
HOG:0001696	basal ganglia	0	0	1	1	0	0	1	1	EV:0100182 basal nuclei	MA:0000184 basal ganglia	NA
HOG:0000153	embryonic ectoderm	1	0	0	0	2	0	0	0	EHDAA:132 ectoderm; EV:0100003 ectoderm	EMAPA:16069 ectoderm	ZFA:0001376 presumptive ectoderm; ZFA:0000016 ectoderm
HOG:0000296	pharyngeal arch 1	1	0	0	0	2	0	0	0	EHDAA:573 1st arch	EMAPA:16118 1st arch	ZFA:0001612 pharyngeal arch 1
HOG:0000543	optic II nerve	1	1	0	1	0	0	0	0	EHDAA:6776 optic nerve; EHDAA:7670 optic II; EV:0100351 optic nerve	EMAPA:17575 optic II; EMAPA:17846 optic nerve; MA:0001097 optic II nerve	ZFA:0000435 cranial nerve II
HOG:0001166	retinal ganglion	3	0	0	0	0	0	0	0	NA	MA:0001310 retina ganglion cell layer	ZFA:0000024 retinal ganglion cell layer

	cell layer											
HOG:0001644	head	1	0	0	0	2	0	0	0	NA	MA:0000023 head	ZFA:0001114 head
HOG:0001761	lymphatic system	0	0	3	0	0	0	0	0	EHDAA:8665 lymphatic system; EV:0100048 lymphoreticular system	EMAPA:18248 lymphatic system; MA:0002435 lymphoid system	ZFA:0000385 lymphatic system
HOG:0001764	white matter	3	0	0	0	0	0	0	0	NA	MA:0001135 white matter	ZFA:0001682 white matter
HOG:0000049	endocrine pancreas	1	1	0	0	0	0	0	0	EV:0100129 endocrine pancreas	MA:0001582 endocrine pancreas	ZFA:0001260 endocrine pancreas
HOG:0000166	lens placode	1	0	0	0	1	0	0	0	EHDAA:2896 lens placode	EMAPA:16672 lens placode	ZFA:0000122 lens placode
HOG:0000249	Meckel's cartilage	1	0	0	0	1	0	0	0	EHDAA:7985 Meckel's cartilage	EMAPA:17635 Meckel's cartilage; EMAPA:17907 Meckel's cartilage; MA:0001580 meckel's cartilage	ZFA:0001205 Meckel's cartilage
HOG:0000294	liver and biliary system	0	0	1	0	0	0	0	1	EHDAA:2177 liver and biliary system; EV:0100088 liver and biliary system	EMAPA:16840 liver and biliary system; MA:0000324 hepatobiliary system	ZFA:0000036 liver and biliary system
HOG:0000297	pharyngeal arch 2	1	0	0	0	1	0	0	0	EHDAA:611 2nd arch	EMAPA:16272 2nd arch	ZFA:0001611 pharyngeal arch 2
HOG:0000396	autonomic nervous system	1	0	0	0	1	0	0	0	EHDAA:3755 autonomic	EMAPA:16984 autonomic; MA:0000219 autonomic nervous system	ZFA:0001574 autonomic nervous system
HOG:0000510	ventral pharyngeal arch 1	2	0	0	0	0	0	0	0	EHDAA:583 mandibular component; EHDAA:5859 mandibular process	EMAPA:16382 mandibular component; EMAPA:17355 mandibular process	ZFA:0001273 ventral mandibular arch
HOG:0000702	glossopharyngeal IX ganglion	1	0	0	0	1	0	0	0	EHDAA:1479 glossopharyngeal IX preganglion; EHDAA:2826 glossopharyngeal IX ganglion	EMAPA:16661 glossopharyngeal IX preganglion; EMAPA:16795 glossopharyngeal IX; MA:0001077 glossopharyngeal IX ganglion	ZFA:0001301 glossopharyngeal ganglion
HOG:0000707	facial VII ganglion	1	0	0	0	1	0	0	0	EHDAA:5555 facial VII ganglion; EHDAA:6632 facial VII ganglion	EMAPA:16983 facial ganglion VII; EMAPA:17569 facial VII; MA:0001076 facial VII ganglion	ZFA:0001291 facial ganglion
HOG:0000782	floor plate diencephalon	1	0	0	0	1	0	0	0	EHDAA:846 floor plate; EHDAA:1963 floor plate; EHDAA:2639 floor plate; EHDAA:3468 floor plate	EMAPA:16516 floor plate; EMAPA:16645 floor plate; EMAPA:16903 floor plate; EMAPA:18545 floorplate	ZFA:0000871 floor plate diencephalic region
HOG:0000787	floor plate spinal cord	1	0	0	0	1	0	0	0	NA	EMAPA:17578 floor plate; EMAPA:18573 floorplate	ZFA:0000890 floor plate spinal cord region
HOG:0001019	floor plate hindbrain	1	0	0	0	1	0	0	0	EHDAA:320 floor plate; EHDAA:328 floor plate; EHDAA:334 floor plate; EHDAA:340 floor plate; EHDAA:858 floor plate;	EMAPA:16150 floor plate; EMAPA:16154 floor plate; EMAPA:16158 floor plate; EMAPA:16287	ZFA:0001258 floor plate rhombomere region

										EHDAA:868 floor plate; EHDAA:878 floor plate; EHDAA:888 floor plate; EHDAA:1375 floor plate; EHDAA:1385 floor plate; EHDAA:1395 floor plate; EHDAA:1410 floor plate; EHDAA:1425 floor plate; EHDAA:1435 floor plate; EHDAA:1445 floor plate; EHDAA:1993 floor plate; EHDAA:2005 floor plate; EHDAA:2017 floor plate; EHDAA:2027 floor plate; EHDAA:2039 floor plate; EHDAA:2049 floor plate; EHDAA:2061 floor plate; EHDAA:2073 floor plate; EHDAA:2705 floor plate; EHDAA:2717 floor plate; EHDAA:2745 floor plate; EHDAA:2757 floor plate; EHDAA:2769 floor plate; EHDAA:2781 floor plate; EHDAA:2793 floor plate; EHDAA:2807 floor plate; EHDAA:3534 floor plate; EHDAA:3548 floor plate; EHDAA:3588 floor plate; EHDAA:3602 floor plate; EHDAA:3616 floor plate; EHDAA:3630 floor plate; EHDAA:3644 floor plate; EHDAA:3660 floor plate	floor plate; EMAPA:16291 floor plate; EMAPA:16294 floor plate; EMAPA:16298 floor plate; EMAPA:16302 floor plate; EMAPA:16306 floor plate; EMAPA:16481 floor plate; EMAPA:16485 floor plate; EMAPA:16489 floor plate; EMAPA:16493 floor plate; EMAPA:16497 floor plate; EMAPA:16501 floor plate; EMAPA:16505 floor plate; EMAPA:16509 floor plate; EMAPA:16919 floor plate; EMAPA:16926 floor plate; EMAPA:16933 floor plate; EMAPA:16940 floor plate; EMAPA:16947 floor plate; EMAPA:16954 floor plate; EMAPA:16961 floor plate; EMAPA:16968 floor plate; EMAPA:17093 floor plate; EMAPA:17100 floor plate; EMAPA:17107 floor plate; EMAPA:17114 floor plate; EMAPA:17121 floor plate; EMAPA:17128 floor plate; EMAPA:17135 floor plate; EMAPA:17142 floor plate	
HOG:0001156	pectoral girdle	2	0	0	0	0	0	0	0	NA	MA:0000292 pectoral girdle bone	ZFA:0000407 pectoral girdle
HOG:0001170	retinal outer nuclear layer	1	0	0	0	1	0	0	0	NA	EMAPA:19157 outer nuclear layer; MA:0001315 retina outer nuclear layer	ZFA:0001464 retinal outer nuclear layer
HOG:0001207	cartilage	0	1	0	0	0	1	0	0	EV:0100141 cartilage	MA:0000104 cartilage	ZFA:0001501 cartilage
HOG:0001428	dorsal pancreatic bud	1	0	0	0	1	0	0	0	EHDAA:2153 dorsal bud	EMAPA:17067 dorsal bud	ZFA:0001370 posterior pancreatic bud
HOG:0001536	ovary follicle	1	0	0	0	1	0	0	0	NA	MA:0001707 ovary follicle	ZFA:0001110 ovarian follicle
HOG:0001756	ventricular	2	0	0	0	0	0	0	0	NA	EMAPA:17768 choroid	ZFA:0001075

	system choroid fissure										fissure	choroidal fissure
HOG:0000006	fourth ventricle	1	0	0	0	0	0	0	0	EHDAA:896 rhombencephalic vesicle; EHDAA:1363 4th ventricle; EHDAA:1985 4th ventricle; EHDAA:2681 4th ventricle; EHDAA:3504 4th ventricle; EV:0100310 fourth ventricle	EMAPA:16479 4th ventricle; EMAPA:16917 4th ventricle; MA:0000196 fourth ventricle	ZFA:0000110 fourth ventricle
HOG:0000111	posterior cardinal vein	1	0	0	0	0	0	0	0	EHDAA:1316 posterior; EHDAA:7455 remnant of posterior	EMAPA:16357 posterior	ZFA:0000477 posterior cardinal vein
HOG:0000238	semicircular duct	1	0	0	0	0	0	0	0	NA	MA:0000251 semicircular duct	ZFA:0000431 semicircular canal
HOG:0000246	anterior semicircular duct	1	0	0	0	0	0	0	0	EHDAA:7790 superior semicircular canal	EMAPA:17299 superior semicircular canal; MA:0001211 anterior semicircular duct	ZFA:0000314 anterior semicircular canal; ZFA:0000469 otic vesicle anterior protrusion
HOG:0000247	lateral semicircular duct	1	0	0	0	0	0	0	0	EHDAA:7778 lateral semicircular canal	EMAPA:17821 lateral semicircular canal; MA:0001213 lateral semicircular duct	ZFA:0000232 otic vesicle lateral protrusion; ZFA:0000220 lateral semicircular canal
HOG:0000248	posterior semicircular duct	1	0	0	0	0	0	0	0	EHDAA:7784 posterior semicircular canal	EMAPA:17296 posterior semicircular canal; MA:0001214 posterior semicircular duct	ZFA:0000262 posterior semicircular canal; ZFA:0000412 otic vesicle posterior protrusion
HOG:0000280	oral region	0	0	0	0	1	0	0	0	EHDAA:542 oral region	EMAPA:16262 oral region; MA:0000341 oral region	ZFA:0000590 oral region
HOG:0000286	urogenital system	0	0	0	1	0	0	0	0	EHDAA:1013 urogenital system; EV:0100094 urogenital system	EMAPA:16367 urogenital system	NA
HOG:0000655	choroid fissure - optic fissure	1	0	0	0	0	0	0	0	EHDAA:4747 choroid fissure	MA:0001305 choroid fissure	ZFA:0001284 optic fissure
HOG:0000777	roof plate spinal cord	1	0	0	0	0	0	0	0	NA	EMAPA:17586 roof plate	ZFA:0001177 roof plate spinal cord region
HOG:0000783	floor plate telencephalon	0	0	0	0	1	0	0	0	EHDAA:1973 floor plate; EHDAA:2651 floor plate; EHDAA:3486 floor plate	EMAPA:16655 floor plate	ZFA:0000914 floor plate telencephalic region
HOG:0001165	retinal photoreceptor layer	1	0	0	0	0	0	0	0	NA	MA:0001308 retina photoreceptor layer	ZFA:0000143 retinal photoreceptor layer
HOG:0001264	urethra	0	0	1	0	0	0	0	0	EV:0100099 urethra	EMAPA:18692 urethra; MA:0000379 urethra	NA

8.3 Supplementary table 3

For readability, supplementary table 3 has been split in 3 tables in this manuscript.

Supplementary table 3-A

List of metastages used in this study with mappings to human developmental stages

Metastage ID	Metastage name	Metastage description	Human stage iD	Human stage name	Human stage description
BilaDO:0000005	zygote	A zygote is a cell that is the result of fertilization. [wikipedia:12/07]	HsapDO:0000003	CarnegieStage01	Fertilized oocyte, pronuclei. Day 1. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
BilaDO:0000006	cleavage	In embryology, cleavage is the division of cells in the early embryo. [wikipedia:12/07]	HsapDO:0000004	cleavage	
			HsapDO:0000005	CarnegieStage02	Cell division with reduction in cytoplasmic volume, formation of inner and outer cell mass. Days 2-3. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
BilaDO:0000007	blastula	The blastula consists of a spherical layer of around 128 cells surrounding a central fluid-filled cavity called the blastocoel. [wikipedia:12/07]	HsapDO:0000006	blastula	
			HsapDO:0000007	CarnegieStage03	Loss of zona pellucida, free blastocyst. Days 4-5. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000008	CarnegieStage04	Attaching blastocyst. Days 6-7. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000009	CarnegieStage05	Implantation. Days 7-12. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000031	CarnegieStage05a	Implantation 1/3. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000032	CarnegieStage05b	Implantation 2/3. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000033	CarnegieStage05c	Implantation 3/3. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
BilaDO:0000008	gastrula	Gastrulation is a phase during which the morphology of the embryo is dramatically restructured by cell migration.	HsapDO:0000010	gastrula	

		The purpose of gastrulation is to position the three embryonic germ layers, the endoderm, ectoderm and mesoderm. [wikipedia:12/07]			
			HsapDO:0000011	CarnegieStage06	Extraembryonic mesoderm, primitive streak. Days 13-15. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000034	CarnegieStage06a	Extraembryonic mesoderm, primitive streak 1/2. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000035	CarnegieStage06b	Extraembryonic mesoderm, primitive streak 2/2. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
BilaDO:0000009	neurula	Neurulation is the development of the nervous system in the vertebrates, at the thickened area above the notochord in ectoderm. [wikipedia:02/09]	HsapDO:0000012	neurula	
			HsapDO:0000013	CarnegieStage07	Gastrulation, notochordal process. Days 15-17. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000014	CarnegieStage08	Primitive pit, notochordal canal. Days 17-19. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
BilaDO:0000010	organogenesis	In animal development, organogenesis is the process by which the ectoderm, endoderm, and mesoderm develop into the internal organs of the organism. [wikipedia:12/07]	HsapDO:0000015	organogenesis	
			HsapDO:0000016	CarnegieStage09	Somite Number 1-3. Neural folds, cardiac primordium, head fold. Days 19-21. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000017	CarnegieStage10	Somite Number 4-12. Neural fold fuses. Days 22-23. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000018	CarnegieStage11	Somite Number 13-20. Rostral neuropore closes. Days 23-26. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000019	CarnegieStage12	Somite Number 21-29. Caudal neuropore closes. Days 26-30. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000020	CarnegieStage13	Somite Number 30. Leg buds, lens placode, pharyngeal arches. Days 28-32. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000021	CarnegieStage14	Lens pit, optic cup. Days 31-35.

					[http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000022	CarnegieStage15	Lens vesicle, nasal pit, hand plate. Days 35-38. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000023	CarnegieStage16	Nasal pits moved ventrally, auricular hillocks, foot plate. Days 37-42. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000024	CarnegieStage17	Finger rays. Days 42-44. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000025	CarnegieStage18	Ossification commences. Days 44-48. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000026	CarnegieStage19	Straightening of trunk. Days 48-51. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000027	CarnegieStage20	Upper limbs longer and bent at elbow. Days 51-53. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000028	CarnegieStage21	Hands and feet turned inward. Days 53-54. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000029	CarnegieStage22	Eyelids, external ears. Days 54-56. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
			HsapDO:0000030	CarnegieStage23	Rounded head, body and limbs. Days 56-60. [http://embryology.med.unsw.edu.au/wwwhuman/Stages/CStages.htm\\:01/08]
BilaDO:0000003	post-embryonic development	Following the embryonic stages of development and before adult stage. [wikipedia:12/07]	HsapDO:0000036	post-embryonic development	
			HsapDO:0000037	fetus	
			HsapDO:0000038	infant	0-1 year. [MRR_lab:curator]
			HsapDO:0000039	child	2-12 years. [MRR_lab:curator]
			HsapDO:0000040	toddler	2-3 years. [MRR_lab:curator]
			HsapDO:0000041	adolescent	13-17 years. [MRR_lab:curator]
BilaDO:0000004	adult	Adulthood is the time when physical maturation is complete. [wikipedia:12/07]	HsapDO:0000042	adult	18-69 years. [MRR_lab:curator]
			HsapDO:0000043	elderly	70-99 years. [MRR_lab:curator]

Supplementary table 3-B

List of metastages used in this study with mappings to mouse developmental stages

Metastage ID	Metastage name	Metastage description	Mouse stage ID	Mouse stage name	Mouse stage description
BilaDO:0000005	zygote	A zygote is a cell that is the result of fertilization. [wikipedia:12/07]	MmusDO:0000003	TheilerStage01	One-cell egg. 0-1 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
BilaDO:0000006	cleavage	In embryology, cleavage is the division of cells in the early embryo. [wikipedia:12/07]	MmusDO:0000004	cleavage	
			MmusDO:0000005	TheilerStage02	Dividing egg. 1 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000006	TheilerStage03	Morula. 2 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
BilaDO:0000007	blastula	The blastula consists of a spherical layer of around 128 cells surrounding a central fluid-filled cavity called the blastocoel. [wikipedia:12/07]	MmusDO:0000007	blastula	
			MmusDO:0000008	TheilerStage04	Blastocyst (ICM apparent). 3 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000009	TheilerStage05	Blastocyst (zona-free). 4 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000010	TheilerStage06	Attachment of blastocyst. 4.5 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000011	TheilerStage07	Implantation and formation of egg cylinder. 5 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000012	TheilerStage08	Differentiation of egg cylinder. 6 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
BilaDO:0000008	gastrula	Gastrulation is a phase during which the morphology of the embryo is dramatically restructured by cell migration. The purpose of gastrulation is to position the three embryonic germ layers, the endoderm, ectoderm and mesoderm. [wikipedia:12/07]	MmusDO:0000013	gastrula	
			MmusDO:0000014	TheilerStage09	Advanced endometrial reaction. 6.5 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy

					/new/\\:01/08]
			MmusDO:0000015	TheilerStage10	Amnion. 7 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
BilaDO:0000009	neurula	Neurulation is the development of the nervous system in the vertebrates, at the thickened area above the notochord in ectoderm. [wikipedia:02/09]	MmusDO:0000016	neurula	
			MmusDO:0000017	TheilerStage11	Neural plate, presomite stage. 7.5 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
BilaDO:0000010	organogenesis	In animal development, organogenesis is the process by which the ectoderm, endoderm, and mesoderm develop into the internal organs of the organism. [wikipedia:12/07]	MmusDO:0000018	organogenesis	
			MmusDO:0000019	TheilerStage12	First somites. 8 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000020	TheilerStage13	Turning of the embryo. 8.5 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000021	TheilerStage14	Formation and closure of anterior neuropore. 9 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000022	TheilerStage15	Formation of posterior neuropore; forelimb bud. 9.5 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000023	TheilerStage16	Closure of posterior neuropore; hind limb bud and tail bud. 10 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000024	TheilerStage17	Deep lens indentation. 10.5 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000025	TheilerStage18	Closure of lens vesicle. 11 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000026	TheilerStage19	Lens vesicle completely separated from surface. 11.5 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000027	TheilerStage20	Earliest signs of fingers. 12 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000028	TheilerStage21	Anterior footplate indented. 13 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:000002	TheilerStage22	Fingers separate distally. 14 dpc.

			9		[http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
BilaDO:0000003	post-embryonic development	Following the embryonic stages of development and before adult stage. [wikipedia:12/07]	MmusDO:0000030	post-embryonic development	
			MmusDO:0000031	fetus	
			MmusDO:0000032	TheilerStage23	Toes separate. 15 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000033	TheilerStage24	Reposition of umbilical hernia. 16 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000034	TheilerStage25	Skin wrinkled. 17 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000035	TheilerStage26	Long whiskers. 18 dpc. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000036	TheilerStage27	Newborn mouse. [http://genex.hgu.mrc.ac.uk/Databases/Anatomy/new/\\:01/08]
			MmusDO:0000038	infant	1-4 weeks. [MRR_lab:curator]
			MmusDO:0000039	adolescent	4-6 weeks. [MRR_lab:curator]
BilaDO:0000004	adult	Adulthood is the time when physical maturation is complete. [wikipedia:12/07]	MmusDO:0000040	adult	> 6 weeks. [MRR_lab:curator]

Supplementary table 3-C

List of metastages used in this study with mappings to zebrafish developmental stages

Metastage ID	Metastage name	Metastage description	Zebrafish stage ID	Zebrafish stage name
BilaDO:0000005	zygote	A zygote is a cell that is the result of fertilization. [wikipedia:12/07]	DrerDO:0000003	Zygote:1-cell
BilaDO:0000006	cleavage	In embryology, cleavage is the division of cells in the early embryo. [wikipedia:12/07]	DrerDO:0000047	Cleavage
			DrerDO:0000004	Cleavage:2-cell
			DrerDO:0000005	Cleavage:4-cell
			DrerDO:0000006	Cleavage:8-cell
			DrerDO:0000007	Cleavage:16-cell
			DrerDO:0000008	Cleavage:32-cell
			DrerDO:0000009	Cleavage:64-cell
BilaDO:0000007	blastula	The blastula consists of a spherical layer of around 128 cells surrounding a central fluid-filled cavity called the blastocoel. [wikipedia:12/07]	DrerDO:0000048	Blastula
			DrerDO:0000010	Blastula:128-cell
			DrerDO:0000011	Blastula:256-cell
			DrerDO:0000012	Blastula:512-cell
			DrerDO:0000013	Blastula:1k-cell
			DrerDO:0000014	Blastula:High
			DrerDO:0000015	Blastula:Oblong
			DrerDO:0000016	Blastula:Sphere
			DrerDO:0000017	Blastula:Dome
			DrerDO:0000018	Blastula:30%-epiboly
BilaDO:0000008	gastrula	Gastrulation is a phase during which the morphology of the embryo is dramatically restructured by cell migration. The purpose of gastrulation is to position the three embryonic germ layers, the endoderm, ectoderm and mesoderm. [wikipedia:12/07]	DrerDO:0000049	Gastrula
			DrerDO:0000019	Gastrula:50%-epiboly
			DrerDO:0000020	Gastrula:Germ-ring
			DrerDO:0000021	Gastrula:Shield
			DrerDO:0000022	Gastrula:75%-epiboly
BilaDO:0000009	neurula	Neurulation is the development of the nervous system in the vertebrates, at the thickened area above the notochord in ectoderm. [wikipedia:02/09]	DrerDO:0000050	Neurula
			DrerDO:0000023	Gastrula:90%-epiboly
			DrerDO:0000024	Gastrula:Bud
BilaDO:0000010	organogenesis	In animal development, organogenesis is the process by which the ectoderm, endoderm, and mesoderm develop into the internal organs of the organism. [wikipedia:12/07]	DrerDO:0000051	Segmentation
			DrerDO:0000025	Segmentation:1-4 somites
			DrerDO:0000026	Segmentation:5-9 somites
			DrerDO:0000027	Segmentation:10-13 somites

			DrerDO:0000028	Segmentation:14-19 somites
			DrerDO:0000029	Segmentation:20-25 somites
			DrerDO:0000030	Segmentation:26+ somites
			DrerDO:0000052	Pharyngula
			DrerDO:0000031	Pharyngula:Prim-5
			DrerDO:0000032	Pharyngula:Prim-15
			DrerDO:0000033	Pharyngula:Prim-25
			DrerDO:0000034	Pharyngula:High-pec
			DrerDO:0000053	Hatching
			DrerDO:0000035	Hatching:Long-pec
			DrerDO:0000036	Hatching:Pec-fin
BilaDO:0000003	post-embryonic development	Following the embryonic stages of development and before adult stage. [wikipedia:12/07]	DrerDO:0000046	Post-embryonic development
			DrerDO:0000054	Larval
			DrerDO:0000037	Larval:Protruding-mouth
			DrerDO:0000038	Larval:Day 4
			DrerDO:0000039	Larval:Day 5
			DrerDO:0000040	Larval:Day 6
			DrerDO:0000041	Larval:Days 7-13
			DrerDO:0000042	Larval:Days 14-20
			DrerDO:0000043	Larval:Days 21-29
			DrerDO:0000055	Juvenile
			DrerDO:0000044	Juvenile:Days 30-44
			DrerDO:0000045	Juvenile:Days 45-89
BilaDO:0000004	adult	Adulthood is the time when physical maturation is complete. [wikipedia:12/07]	DrerDO:0000056	Adult

8.4 Supplementary table 4

For readability, supplementary table 4 has been split in two tables in this manuscript.

Supplementary table 4-A

GO terms associated with triplets “overlap only”

Zebrafish duplicates - mouse singletons

Enrichment in Biological Process

GO.ID	Term	Annotated	Significant	Expected	p	FDR
GO:0006886	intracellular protein transport	23	22	13.73	770E-07	0.226457

Depletion in Cellular Component

GO.ID	Term	Annotated	Significant	Expected	p	FDR
GO:0005576	extracellular region	42	11	24.62	0.00077	0.23632
GO:0030424	axon	16	3	9.38	0.00112	0.23632

Zebrafish duplicates - human singletons

Depletion in Cellular Component

GO.ID	Term	Annotated	Significant	Expected	p	FDR
GO:0016021	integral to membrane	99	57	71.77	0.0001	0.0397
GO:0044459	plasma membrane part	65	36	47.12	0.00076	0.15086

Depletion in Molecular Function

GO.ID	Term	Annotated	Significant	Expected	p	FDR
GO:0005509	calcium ion binding	20	7	14.5	0.00034	0.22168

Mouse duplicates - human singletons

Depletion in Cellular Component

GO.ID	Term	Annotated	Significant	Expected	p	FDR
GO:0016021	integral to membrane	32	4	13.33	260E-07	0.00546

Supplementary table 4-B

GO terms associated with triplets “neofunctionalization only”

Zebrafish duplicates - human singletons

Enrichment in Molecular Function

GO.ID	Term	Annotated	Significant	Expected	p	FDR
GO:0005509	calcium ion binding	20	9	1.99	260E-07	0.016952

Mouse duplicates - human singletons

Enrichment in Molecular Function

GO.ID	Term	Annotated	Significant	Expected	p	FDR
GO:0004872	receptor activity	9	8	2.97	490E-06	0.14406

Enrichment in Cellular Component

GO.ID	Term	Annotated	Significant	Expected	p	FDR
GO:0016021	integral to membrane	32	20	11.67	230E-06	0.0483

Discussion

Bgee is under continuous development, and has clear implementation plans, in order to connect with our targeted audience, and meet the expectations we have for this resource. I will present how future improvements could address the needs in the field of evolutionary transcriptomics.

1 Future plans for Bgee

1.1 Addition of more species

An important aspect of future plans of Bgee is to add more species in the database. A limitation is the need for precise species-specific ontologies, developed by experts in anatomy and development of model species. The number of such ontologies increases at a rather slow rate, and this is a limiting factor for the development of Bgee.

The most challenging aim is to add more distant species. Relations between anatomies of different species are to date only based on true historical homology (Roux and Robinson-Rechavi, 2010). Drosophila has already been added in Bgee, but only few homology relationships exist between insects and vertebrates, thus the comparisons between these species are limited. Adding to the database other types of relations, such as homoplasy, would allow to perform more meaningful queries between distant species. This will require important modifications to the database schema, and to the code dealing with multi-species comparisons using the Homologous Organs Groups.

1.2 Adding RNA-Seq data

Another aspect of future plans is to add more data sources and data types, and notably, RNA-Seq data. This point is difficult to address, as this field is not mature yet, both regarding analyses of expression, and storage of the data. We first need official and central repositories to emerge, as it was the case for microarrays (GEO (Barrett, Troup*, et al.*, 2011), ArrayExpress (Parkinson, Sarkans*, et al.*, 2011), CIBEX (Ikeo, Ishi-i*, et al.*)). An important recent step has been achieved by ArrayExpress, which now proposes High-Throughput Sequencing data on their website. They also encourage the use of the MINSEQE guidelines[32], that could be as essential for RNA-Seq submissions as MIAME (Brazma, Hingamp*, et al.*, 2001) has been for microarrays.

We do not have the capacities required to scale our infrastructure and applications for handling RNA-Seq raw data, as we do for other data types. We will rely on emerging central repositories, and our capabilities will be restricted by the possibilities they will offer: will it

[32] http://www.mged.org/minseqe/

be possible to retrieve all reads mapped to a gene in an experiment? Will it be possible to query this information through web-services? Will it be possible to retrieve sequences of all reads? With quality information? This emerging field will probably evolve significantly in the next few years, and integrating these data into Bgee promises ever more entertaining SQL optimizations.

1.3 Annotating experimental conditions

Bgee is currently focused on the study of the evolution of gene expression. But, as presented in the Introduction, Bgee could evolve to become a centralized service for gene expression data, thanks to its main strengths: integration of various data types, and high quality annotations. This involves broadening the scope beyond "normal" experimental conditions, to integrate data from various treatments, strains, or conditions. This would be facilitated by the Experimental Factor Ontology (Malone, Holloway*, et al.*, 2010), used to annotate experimental conditions in the Gene Expression Atlas (Kapushesky, Emam*, et al.*, 2010). Bgee could use annotations already performed on Affymetrix data by the Gene Expression Atlas team, and annotate experiments for other data types. Obviously, our annotations would then be available for reuse by other resources. This would open new opportunities, and would allow for instance to compare gene expression patterns between different mouse strains, with high resolution at the anatomy level, or to visualize effects of a Knock-Out on the different anatomical structures of an organism.

1.4 Improving user interfaces

Bgee suffers from poorly-designed user interfaces. This limits our potential audience. Current users of Bgee are mostly bioinformaticians using direct data download. All interfaces of Bgee should be made clearer, with more summarized information. For instance, comparisons of expression patterns between homologous genes could be proposed in a similar way to that used for my analysis of evolution of expression after duplication (Chapter 5). This approach allows to identify only the most precise and independent organs, shared by different species, with comparable expression data. This results in overviews of expression patterns which are easily understandable and meaningful (see, e.g., online supplementary material of the chapter 5). This is a good example of what all interfaces should look like: more summarized information, with better design.

1.5 Implementation plan

Bgee requires a constant effort to (i) curate new expression data; (ii) update the database from a variety of sources (of which some have always changed their format or implementation); (iii) optimize database queries, in response to changes in the distribution of the data. Beyond these needs, if funding supports of Bgee remain constant, the new functionalities described above will be implemented with the following schedule in the next years:

Year 1: On the programmatic side, the priority will be the integration of over-expression and non-expression into the web interface, allowing relevant queries and visualizing this information. Another priority will be the improvement of interface usability, which will require usability studies, reflexion on how representing complex data, and reflexion on graphical design. This step is a prerequesite to any further improvements of Bgee, as it will never reach its targeted audience (notably, wet-lab biologists) without these modifications.

Year 2: On the programmatic side, the priority will be modification of the database structure and of the query tools, in relation to one big issue, the inclusion of relations other than homology.

On the data management side, the priority will be the addition of RNA-seq. For this, we will need to benchmark and define the relevant statistical criteria for expression, over-expression, and non-expression; to define a robust pipeline to retrieve data from relevant data sources; and to perform new data curation.

On the data curation side, the priority will be the addition of more diverse species. Probably arthropods (insects, crustaceans, etc), although the choice will be made according to data availability and user demand at that point.

Later plans: One future priority will be the development of new web tools for integrative queries. Another important challenge will be the integration of experimental factors of interest, such as physiological states We will continue the addition of more species, with probably a priority on nematodes.

2 Use of Bgee

Bgee is now mature regarding the data content and structure. There are two important aspects for the database durability: maintaining good relations with other resources, in order to enhance collaborations and gain visibility; and meeting users expectation, to become a database routinely used in scientific publications.

2.1 Relations with other resources

Bgee is used as a data source by other resources, that want to integrate high quality expression information, without dealing with complex transcriptomics data:

neXtProt[33]: a new human-centric knowledgebase. Our human expression data are directly visualized on their website (e.g. data for DLX-5[34]). They also use our annotated organs as a guide to build their human anatomical ontology.

PROSITE (Sigrist, Cerutti, *et al.*, 2010): PROSITE is a database of protein domains. They are currently integrating to their search engine (ScanProsite) a simplified dataset of expression data and homologous organs from Bgee.

The following resources consider Bgee as a valuable tool, and provide links to it:

AnAge (De Magalhaes and Costa, 2009): AnAge is a curated database of ageing and life history in animals, including extensive longevity records, primarily developed for comparative biology studies. They provide cross references to Bgee, to use the information about developmental stages displayed on our website.

UniprotKB (The UniProt Consortium, 2011) UniprotKB provides cross-references to Bgee, for proteins corresponding to genes with expression data in our database.

UBERON (Haendel, Gkoutos, *et al.*, 2009): UBERON is a project similar to our HOG ontology, trying to provide a multi-species ontology, but regardless of the types of the mappings (i.e., not homology-strict). The UBERON ontology provides references to our HOG ontology.

[33] www.nextprot.org

[34] http://www.nextprot.org/db/entry/NX_P56178/expression

2.2 Use in scientific publications

Although Bgee is relatively recent, and has not yet been published in a biology journal, it has received 11 citations in the scientific literature, of which 5 outside our group (Dahdul, Lundberg*, et al.*, 2010; Dimitrieva and Anisimova, 2010; Gross, Hartung*, et al.*, 2010; Huerta-Cepas, Dopazo*, et al.*, 2011; Kearse, Chen*, et al.*, 2011). A good example of an advanced use, already possible today through direct data download by bioinformaticians, is the study from Huerta-Cepas and colleagues (2011): notably using Bgee (both expression data and mapping between species), they compare spatial expression of human-mouse paralogs, and human-mouse orthologs. They showed that gene duplication leads to increased levels of tissue specificity. Of note, they pre-selected 44 independent homologous structures in Bgee to perform their analysis. After discussing with the first author, it appeared that a better presentation of the data in Bgee, or the availability of more powerful analytics tools, would have allowed him to use the same type of approach that I used in chapter 5, and to not pre-select tissues. As an example of the type of use which we expect to increase with more biology users, Kearse *et al.* (2011) used Bgee to compare their experimental results for RpL22e in fly with the homologous expression in vertebrates. Again, it is clear that we need to make our interfaces more user-friendly to see this type of use increase.

3 Evolutionary biology

A major purpose of Bgee is to answer unresolved question in evolutionary biology. It has already been a major component of four published studies in evolutionary biology (Comte, Roux*, et al.*, 2010; Huerta-Cepas, Dopazo*, et al.*, 2011; Roux and Robinson-Rechavi, 2008; Roux and Robinson-Rechavi, 2011), plus the study presented in chapter 5. Publishing such papers relying entirely on Bgee should serve as proof of principle of its potential, and bring more evolutionary biologists to consider its use. There are many more questions that Bgee can answer. Adding more species, and developing new mappings between distant species, will increase its possibilities, and reach a broader audience, from different model species communities.

4 Concluding remarks

The development of the Bgee database has involved many people over the years. Our ambitions are high, because we believe that Bgee addresses a clear need in comparative

transcriptomics, and is unique in providing an answer to it. We intend to build on our two strengths: high quality data and ontology curation; and a solid grounding in evolutionary biology. This grounding in evolutionary biology provides us with a unique approach for organizing expression data. In the future, this will allow us to provide user views such as expression mapped to phylogenies, or explicit coding of convergence or parallelism between non homologous expression patterns.

Bgee is now at a pivotal point: it can fall into the dark, as most databases do (Wren, 2008); or it can evolve, avoiding the strong purifying selection acting on newly arisen databases. Our "big hairy audacious goal"[35] is that Bgee will put evolutionary transcriptomics at the centre of biological research, as Ensembl has done for comparative genomics.

[35] http://en.wikipedia.org/wiki/Big_Hairy_Audacious_Goal

5 References

Barrett, T., Troup, D.B., Wilhite, S.E., Ledoux, P., Evangelista, C.*, et al.* (2011) NCBI GEO: archive for functional genomics data sets‚Äî10 years on, *Nucleic Acids Research*, **39**, D1005-D1010.

Brazma, A., Hingamp, P., Quackenbush, J., Sherlock, G., Spellman, P.*, et al.* (2001) Minimum information about a microarray experiment (MIAME)-toward standards for microarray data, *Nature genetics*, **29**, 365-371.

Comte, A., Roux, J. and Robinson-Rechavi, M. (2010) Molecular signaling in zebrafish development and the vertebrate phylotypic period, *Evolution & Development*, **12**, 144-156.

Dahdul, W.M., Lundberg, J.G., Midford, P.E., Balhoff, J.P., Lapp, H.*, et al.* (2010) The Teleost Anatomy Ontology: Anatomical Representation for the Genomics Age, *Syst Biol*, syq013.

De Magalhaes, J.P. and Costa, J. (2009) A database of vertebrate longevity records and their relation to other life-history traits, *Journal of Evolutionary Biology*, **22**, 1770-1774.

Dimitrieva, S. and Anisimova, M. (2010) *PANDITplus: toward better integration of evolutionary view on molecular sequences with supplementary bioinformatics resources*. 2010.

Gross, A., Hartung, M., Kirsten, T. and Rahm, E. (2010) On Matching Large Life Science Ontologies in Parallel. In Lambrix, P. and Kemp, G. (eds), *Data Integration in the Life Sciences*. Springer Berlin / Heidelberg, pp. 35-49.

Haendel, M., Gkoutos, G., Lewis, S. and Mungall, C. (2009) Uberon: towards a comprehensive multi-species anatomy ontology. *International Conference on Biomedical Ontology*. Buffalo (NY), USA.

Huerta-Cepas, J., Dopazo, J.n., Huynen, M.A. and Gabald√≥n, T. (2011) Evidence for short-time divergence and long-time conservation of tissue-specific expression after gene duplication, *Briefings in Bioinformatics*.

Ikeo, K., Ishi-i, J., Tamura, T., Gojobori, T. and Tateno, Y. CIBEX: Center for Information Biology gene EXpression database, *Comptes Rendus Biologies*, **326**, 1079-1082.

Kapushesky, M., Emam, I., Holloway, E., Kurnosov, P., Zorin, A.*, et al.* (2010) Gene Expression Atlas at the European Bioinformatics Institute, *Nucleic Acids Research*, **38**, D690-D698.

Kearse, M.G., Chen, A.S. and Ware, V.C. (2011) Expression of ribosomal protein L22e family members in Drosophila melanogaster: rpL22-like is differentially expressed and alternatively spliced, *Nucleic Acids Research*, **39**, 2701-2716.

Malone, J., Holloway, E., Adamusiak, T., Kapushesky, M., Zheng, J.*, et al.* (2010) Modeling sample variables with an Experimental Factor Ontology, *Bioinformatics*, **26**, 1112-1118.

Parkinson, H., Sarkans, U., Kolesnikov, N., Abeygunawardena, N., Burdett, T.*, et al.* (2011) ArrayExpress update - an archive of microarray and high-throughput sequencing-based functional genomics experiments, *Nucleic Acids Research*, **39**, D1002-D1004.

Roux, J. and Robinson-Rechavi, M. (2008) Developmental Constraints on Vertebrate Genome Evolution, *PLoS Genet*, **4**, e1000311.

Roux, J. and Robinson-Rechavi, M. (2010) An ontology to clarify homology-related concepts, *Trends in Genetics*, **26**, 99-102.

Roux, J. and Robinson-Rechavi, M. (2011) Age-dependent gain of alternative splice forms and biased duplication explain the relation between splicing and duplication, *Genome Research*, **21**, 357-363.
Sigrist, C.J.A., Cerutti, L., de Castro, E., Langendijk-Genevaux, P.S., Bulliard, V.*, et al.* (2010) PROSITE, a protein domain database for functional characterization and annotation, *Nucleic Acids Research*, **38**, D161-D166.
The UniProt Consortium (2011) Ongoing and future developments at the Universal Protein Resource, *Nucleic Acids Research*, **39**, D214-D219.
Wren, J.D. (2008) URL decay in MEDLINE, a 4-year follow-up study, *Bioinformatics*, **24**, 1381-1385.

Appendices

1 Appendix 1: Bgee pipeline documentation

Description of the different steps of the Bgee pipeline, from the wiki of our lab.

Update Bgee data

From Mrrwiki

Contents

Introduction

This document is here to make future updates of Bgee easier. This checklist will help to keep Bgee up-to-date. Many sources of data are present in Bgee, taken from different sources and databases. This increases the risk of problem/bugs/errors when running an automated pipeline.

Here are the different steps to follow:

To do for the bgee_v10 pipeline run

- request a postgreSQL account to MGI: "The MGI Public Ad Hoc PostgreSQL Server is available for running custom SQL queries against the MGI database. If you currently have a Sybase account, it will be supported only until Sept 23, 2011. Contact MGI User Support (mgi-help@informatics.jax.org) to request a PostgreSQL account. You will receive a login, password, and connection parameters."
- Add an chip filtering step. E.g. "The quality of the CEL files was evalu- ated individually using the R simpleaffy package and four quality control measurements were produced: average background (AvgBg), scale factors (sfs), percent present (PP) and RNA degradation slope (RNAdeg)" (methods in http://genomebiology.com/content/11/12/R124), or see also https://www.genevestigator.com/userdocs/manual/qc.html
- Modify insert_in_situ_mgi.pl accordingly

- request for a new term in the drosophila developmental ontology: "unknown" (this is the only term we added to this ontology, if they add it then we don't need to change identifiers of the ontology because we modified it)
- Check the mouse, zebrafish, and Xenopus developmental ontologies (some exhibit the same problem than the former human developmental ontology)
- It seems that there is a missing metastage as compared to 4DXpress: http://4dx.embl.de/4DXpress/reg/all/view/stage.do?stageID=7 ("juvenile or larval stage", preceeded by "organogenesis" and followed by "adult"). Should we add it, we'd need to recheck the mapping to species-specific developmental stages.
- do such a page: http://www.panditplus.org/show.php?in=&show=version
- recode extra/pipeline/pipeline/insert_metastages.pl so that, in the same way than insert_stages.pl, leftBound and rightBound are computed before the insertion, so that we don't need to update the table after the insertion (we've changed metaStageLeftBound and metaStageRightBound to "not null", so we cannot just insert metastages with no values specified for leftBound and rightBound)
- Remove insert_xref_zebrafish_miRNA.pl if ensembl provides all miRNA Xref for Zebrafish
- Make a script to find which annotations have changed since the last pipeline run (based on launch_diff_analysis.pl).
- Relaunch the analysis of the whole microarray dataset for differential expression
- for the gene name search box in basic search expression: remove the limitation of 3 letters minimum, allow for searching for IDs and not names only, and when selecting a gene, tick automaticly the corresponding species in the form.
- In Ensembl 62, some attributes to query Ensembl via perl-biomart have changed, notably regarding GeneOntology. For this reason, the insertion of the mappings between gene and GO terms (table geneToGeneOntologyTerm) has failed in Bgee_v09. We've made some temporary changes to the script insert_genes.pl (see below). You have to check if these changes are still required, or if Ensembl reintroduced the old attributes (go_biological_process_id, go_cellular_component_id, go_molecular_function_id)

```
$xml = '<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE Query>
<Query  virtualSchemaName = "default" formatter = "TSV" header = "0" uniqueRows = "1" count = "" datasetConfigVersion = "0.7" >
<Dataset name = "'.$species[5].'_gene_ensembl" interface = "default" >
<Filter name = "with_go" excluded = "0"/>
<Attribute name = "ensembl_gene_id" />
<Attribute name = "go_id" />
</Dataset>
</Query>';
```

```
$all_data = send_biomart_query($xml);
@res_rows = split(/\n/, $all_data);
$all_data = ();
```

```
print "\tFilling geneToGeneOntologyTerm table...\n";
my %go;
foreach my $res_row (sort @res_rows) {
  #split each line of results
  my @data = split(/\t/, $res_row);
```

```
  if ((defined $data[1]) and ($data[1] ne )){ $go{$data[0]}->{$data[1]}++}
}
```

```
#insertion into bgee
foreach my $gene (keys %go){
  foreach my $go_id (keys %{$go{$gene}}){
    $ins->execute($gene,$go_id);
    $ins->finish;
  }
}
```

To do for the bgee_v09 pipeline run

- The script insert_geneName_zebrafish_miRNA.pl may not be needed anymore (if Ensembl is providing geneNames for zebrafish miRNA genes).
- Some parts of the script insert_xref_zebrafish_miRNA.pl may not be needed anymore: it should be possible starting from e61 to have the mapping Ensembl ID -> mirBase Accession from Biomart for zebrafish (used to be the only species where it was not possible to get it). Warning: this script also inserts the mapping Ensembl ID -> ZFIN ID for miRNA genes and this will still be needed most probably.
- ~~Modify the script inserting data sources into the table `dataSource`, to provide a `xRefUrl` for the data source miRBase: `http://www.mirbase.org/cgi-bin/mirna_entry.pl?acc=`~~
- ~~Change the IDs of our developmental ontologies, so that there is not a mix of e.g. "OGES:" and "EV:". Provide our own IDs (erase IDs from the original ontologies, and instead provide xrefs to the original ontologies)~~
- REMOVE all innodb tables in order to be able to clean the endless innodb log file => Hmm, disagreed! --Fbastian 11:58, 23 July 2010 (UTC)

Check if innodb index are properly done from foreign keys

Before everything

```
This can be done locally.
```

- `svn update` to get the last version of the project.
- Check with `svn status` if something uncommitted remains.
- Keep a stable (freezed) release as a separated branch.

  `svn copy https://svn.vital-it.ch/svn/BGee/trunk/bgee/ https://svn.vital-it.ch/svn/BGee/tags/bgee_vXX/`
- Edit `bgee/extra/sql/bgee.sql` with new bgee database name (bgee_vXX e.g. bgee_v09_ens62).
- Edit `bgee/extra/pipeline/pipeline/script_global.sh` with new bgee database name (bgee_vXX e.g. bgee_v09_ens62)
- For a new dataSource, insert it into the dataSource table.

Ontologies

Checklist

```
This can be done locally.
```

- Download the latest version of the anatomy/development ontologies from OBO foundry and put them in `bgee/extra/pipeline/OBO_ontologies/`
  - Mouse adult gross anatomy (http://www.obofoundry.org/cgi-bin/detail.cgi?id=adult_mouse_anatomy)
  - Zebrafish anatomy (http://www.obofoundry.org/cgi-bin/detail.cgi?id=zebrafish_anatomy)
  - Xenopus Anatomy (http://www.obofoundry.org/cgi-bin/detail.cgi?id=xenopus_anatomy)
  - Drosophila melanogaster (http://obo.cvs.sourceforge.net/*checkout*/obo/obo/ontology/anatomy/gross_anatomy/animal_gross_anatomy/fly/fly_anatomy.obo) (+ Drosophila development (http://www.obofoundry.org/cgi-bin/detail.cgi?id=fly_development) , only used to check if no major change was made to the developmental ontology, see Remarks)
- These ontologies are usually not updated
  - Mouse anatomy modified by Aitken (http://www.aiai.ed.ac.uk/resources/bioinf/context-plus-mouse.obo)
  - Human anatomy modified by Aitken (http://www.aiai.ed.ac.uk/resources/bioinf/context-plus-human.obo)
  - Human adult anatomy eVoc 2.7 (http://www.obofoundry.org/cgi-bin/detail.cgi?id=evoc) Only **anatomicalsystem.obo** file is required in the tarball. Rename it to **evoc_anatomicalsystem.obo**.
- Check that they are in UNIX format (end-of-line is `\n`). Use `od -c filename` for example.

Usually only xenopus ontology uses `\r\n`. Use `perl -i -pe 's/(\r\n|\r)/\n/g;' *.obo` to check all OBO files.

- Check that the `.obo` file is ending with a blank line (specification of OBO format).

Use `tail -n1 *.obo` to check this.

- If changes have been made to an ontology, check its corresponding `.pattern` file. This is important since it is the only guarantee that the parsing of the ontology will be correct.
- Check that no change was made on developmental stages. If it is the case, modify the files `bgee/download/stages.obo` and `bgee/download/stage_association.obo`. Be careful that in `stages.obo`, the stages have to be ordered since it is the only way to create the interval representation and display them in the right order in Bgee.
- Modify `bgee/extra/pipeline/pipeline/insert_modifs.sql` if some changes have to be made on the ontologies (start/end stages, 'unknown' organ, etc)
- Download the latest version of the Gene Ontology (http://geneontology.org/ontology/gene_ontology_edit.obo) .

```
svn commit if this part was done locally.
```

Pipeline

```
This is done on devbioinfo server, as bgee user. The project is in /var/bgee/
```

Go to `bgee/extra/pipeline/pipeline`:

- Edit `bgee/extra/pipeline/pipeline/db_connections.pl` with the new bgee database name (bgee_vXX).
- Initialize the new database

  ```
  mysql -u root -p < ../../sql/bgee.sql
  ```
  Do NOT initialize the bgeeAdministration database (conserved from release to release)!
- Insert species infos (mouse, human, zebrafish, xenopus)

  ```
  perl insert_species.pl
  ```
- Insert metastages

  ```
  perl insert_metastages.pl ../OBO_ontologies/meta_stages.pattern
  ```
- Set the constraints of the database

  ```
  mysql -u root -p bgee_vXX < ../../sql/bgeeConstraint.sql
  ```
- Insert stages infos from OBO files

  ```
  perl insert_stages.pl ../OBO_ontologies/xenopus_stages.pattern
  perl insert_stages.pl ../OBO_ontologies/mouse_stages.pattern
  perl insert_stages.pl ../OBO_ontologies/human_stages.pattern
  perl insert_stages.pl ../OBO_ontologies/zebrafish_stages.pattern
  perl insert_stages.pl ../OBO_ontologies/fly_development.pattern
  ```
- Insert organs infos from OBO files

  ```
  perl insert_organs.pl ../OBO_ontologies/adult_mouse_anatomy.pattern
  perl insert_organs.pl ../OBO_ontologies/context-plus-mouse.pattern
  perl insert_organs.pl ../OBO_ontologies/evoc_anatomicalsystem.pattern
  perl insert_organs.pl ../OBO_ontologies/context-plus-human.pattern
  perl insert_organs.pl ../OBO_ontologies/xenopus_anatomy.pattern
  perl insert_organs.pl ../OBO_ontologies/zebrafish_anatomy.pattern
  perl insert_organs.pl ../OBO_ontologies/fly_anatomy.pattern
  perl insert_organDescendants.pl
  ```
- Insert gene ontology annotations

  ```
  perl insert_go_terms.pl
  ```

Remarks/Warnings

- Inferred relationships
- Warning with `insert_organs.pl` when inferring the new relationships (the same relation is sometimes inferred several times from different paths).

```
DBD::mysql::st execute failed: Duplicate entry 'ZFA:0009000-ZFA:0009082' for key 1 at insert_organs.pl line 387.
DBD::mysql::st execute failed: Duplicate entry 'ZFA:0009000-ZFA:0009087' for key 1 at insert_organs.pl line 387.
```

TO DO: Change the array with a hash to suppress this problem.

- Warning with drosohila organs due to problems in the OBO file. I reported them to the OBOfoundry tracker but they are not yet corrected.
  - FBbt:00002779 has 2 identical synonyms
  - FBbt:00004158 is_a FBbt:00004159, but also part_of...

- Warning with drosohila organs due case insensitivity of MySQL (e.g. 'ko' and 'KO' are considered identical strings)

```
DBD::mysql::st execute failed: Duplicate entry 'FBbt:00002779-ko' for key 1 at insert_organs.pl line 239, <IN> line 23920.
```
This happens for ~10 insertions of synonyms

Genes, cross-references, gene families

Checklist

```
This is done on devbioinfo server.
```

- Update Ensembl perl API on the server to the new version. See [1] (http://www.ensembl.org/info/docs/webcode/install/build.html) for details... Or ask Sebastien [[2] (http://wiki.isb-sib.ch/mrrwiki/How_to_update_Selectome#Install_Ensembl_API)]
- Check that biomart is updated to the new Ensembl version (Either on Biomart (http://www.biomart.org) or Ensembl (http://www.ensembl.org) server) and edit `bgee/extra/pipeline/pipeline/db_connections.pl` accordingly (in subroutine `send_biomart_query`).

Pipeline

- Insert all infos on genes

```
perl insert_genes.pl xenopus
perl insert_genes.pl zebrafish
perl insert_genes.pl mouse
perl insert_genes.pl human
perl insert_genes.pl fruitfly
perl insert_geneName_zebrafish_miRNA.pl
perl insert_xref_zebrafish_miRNA.pl
```

- Insert homology groups (Ensembl families and Gene Trees orthologs). The gene trees are inserted with the taxonomic depth indicated as argument (117571=Euteleostomi, 33213=Bilateria and includes drosophila)

```
perl insert_families.pl
perl insert_orthologs.pl 117571
perl insert_orthologs.pl 33213
perl insert_miRNA_families.pl
```

- Fill geneToTerm table

`perl insert_geneToTerm.pl` (takes 12H)

- Insert ponctual modifications

```
mysql -u root -p bgee_vXX < insert_modifs.sql
```

- Save an intermediate dump

```
mysqldump -u root -p --no-create-info --no-create-db --triggers=false bgee_vXX > dump_genes.sql
```

Remarks/Warnings

- In `insert_genes.pl`, the URL where we download the cross-links to 4DXpress depends on the date it was created (e.g. `http://4dx.embl.de/bgee/ensIds_2009_03.txt`). Frederic asked Thorsten to change that: we'll have to modify the script when it's done.

- There can be sometimes problems with the API connection that is lost (problem on Ensembl side). Just rerun the script, it usually works fine.

```
DBD::mysql::st execute failed: Lost connection to MySQL server during query at /usr/local/ensembl/ensembl-compara/modules//Bio/EnsEMBL
/Compara/DBSQL/MemberAdaptor.pm line 662.
```

- In `insert_orthologs.pl`, warning of perl when the recursion is going deep:

```
Deep recursion on subroutine "Bio::EnsEMBL::Compara::NestedSet::_recursive_get_all_leaves" at /usr/local/Ensembl/ensembl-compara/modules
//Bio/EnsEMBL/Compara/NestedSet.pm line 1508.
```

- MySQL insertion by `insert_geneToTerm.pl` can return some duplicates because of case un-sensitiveness.

Affymetrix

Checklist

- Convert `annotation.xls` to text files affymetrixChip, microarrayExperiment and chipType (In TSV format (TAB delimiter and without text delimiter), without file extension) (if doing this from Excel, be careful with the end-of-line characters).
  - Put them in bgee/extra/pipeline/Affymetrix/

- Raw data verification(`.cel` files)
  - Download the latest version of the folder

```
bgee/extra/pipeline/curation/Affymetrix/cel_data/ from the annotators computers (Anne's computer, bgee account, evodevo password, backed-up on Fred's computer)
to
bgee/extra/pipeline/Affymetrix/cel_data/.
```

  - Once it is done, remove them from the annotators computers to not re-process them next time !

- Raw data with only 1 `.cel` file
  - It's not possible in that case to use gcRMA
  - Normalization with MAS5: use `bgee/extra/pipeline/Affymetrix/bioconductor/affy_analysis_mas5.R`. Warning, this not an automatic script as it is used for very few experiments. You have to open the script and run it line by line into R.

- Processed data ~~split and~~ verification (MAS5)
  - Download the latest version of the folder `bgee/extra/pipeline/curation/Affymetrix/processed_mas5/` on the annotators computers.
  - ~~Put them in the `bgee/extra/pipeline/Affymetrix/processed_mas5/not_separated/` folder.~~
  - ~~In `bgee/extra/pipeline/pipeline/`:~~

    ```
    perl separate_affy_processed_mas5.pl
    ```

  - ~~Be careful, some processed data have a blank column instead of probeset IDs. This is frequent and is due to ArrayExpress. The experiments should be removed and put in "not_included for now" (or the probeset column should be taken from somewhere else, because we know the chip type, but no guarantee that the probesets are in the same order, so it's dirty).~~
  - Put them in the `bgee/extra/pipeline/Affymetrix/processed_mas5/` folder.

```
The data structure changed in ArrayExpress for processed data. It should work as indicated now. After the pipeline, remove the striked text (describing the old way of tre
```

- In `bgee/extra/pipeline/pipeline/` check that there is no problem left with the annotation:

  `perl check_affy_curation.pl before` (before normalization, to detect problems in the annotation and files. Be careful, the script should be able to connect to the database, and it should be run on the computer having all the data. It checks a lot of small common mistakes by the annotators)

- Raw data normalization
  - Send these folders to vital-IT/devbioinfo using `rsync`. For example:

    ```
    rsync -Wav -essh --exclude '*.gz' ~/work/bgee/extra/pipeline/Affymetrix/cel_data/ jroux@dee-serv02.vital-it.ch:/scratch
    /frt/yearly/jroux/pipeline/Affymetrix/cel_data/
    rsync -Wav -essh ~/work/bgee/extra/pipeline/Affymetrix/bioconductor/ jroux@dee-serv02.vital-it.ch:/scratch/frt/yearly/jroux
    /pipeline/Affymetrix/bioconductor/
    rsync -Wv -essh ~/work/bgee/extra/pipeline/Affymetrix/* jroux@dee-serv02.vital-it.ch:/scratch/frt/yearly/jroux/pipeline
    /Affymetrix/
    ```

  - Send also the last version of the scripts to Vital-IT. For example:

    ```
    rsync -Wv -essh ~/work/bgee/extra/pipeline/pipeline/*.pl jroux@dee-serv02.vital-it.ch:/scratch/frt/yearly/jroux/pipeline
    /pipeline/
    ```

    Or `svn update` on devbioinfo.
  - Connect to vital-IT

    `cd /scratch/frt/yearly/jroux/pipeline/pipeline/` or alias `bgee`

    `mkdir /scratch/frt/yearly/jroux/pipeline/Affymetrix/processed_schuster/`

    `perl launch_affy_analysis.pl` (or `perl launch_affy_analysis.pl EXP_ID` if you want to analyse only one experiment).
  - Check normalization process by looking if some ***.out.PROB** files exist in **bgee/extra/pipeline/Affymetrix/bioconductor/out/** AND if **all *.out** files contains a line with **proc.time**() at the end.

```
ls -l *.out.PROB
grep -H -c 'proc.time' *.out | grep ':0'
```

  - When calculations are finished, download the data produced:

    ```
    rsync -Wav -essh /scratch/frt/yearly/jroux/pipeline/Affymetrix/bioconductor/ admin@130.223.48.XX:~/work/bgee/extra/pipeline
    /Affymetrix/bioconductor/
    rsync -Wav -essh /scratch/frt/yearly/jroux/pipeline/Affymetrix/processed_schuster/ admin@130.223.48.XX:~/work/bgee/extra
    /pipeline/Affymetrix/processed_schuster/
    ```

```
Warning! Be careful that all files you transfer are not dated from more than a year ago (or they will be removed by cron, even in the middle of the calculations).
Also the folder /scratch/frt/yearly will disappear at one point.
```

- In `bgee/extra/pipeline/pipeline/` check that there is no problem with the normalized files:

  `perl check_affy_curation.pl after` (after normalization)

- You can compress the cel files already used. In the subdirectory cel_data/:

  ```
  find . ! -name \*.gz -type f -exec gzip -9 {} \;
  ```

Potential problems

- When normalizing:
  - The annotation package for the chipType is missing and it can't be automatically installed on vital-IT (no permission) -> ask Li Long to install it. The List of all annotations packages is here (http://www.bioconductor.org/packages/2.2/ChipName.html) . Another option is to do the normalization on another computer (yours or devbioinfo) where you have the rights to install the required packages.
  - The annotation file asks you to normalize an experiment with only 1 chip. This is not possible with gcRMA -> has to be done with mas5 (use `bgee/extra/pipeline/Affymetrix/bioconductor/affy_analysis_mas5.R`). Put the results in processed_mas5/ folder and change the normalization and detection method in affymetrixChip (usually from 2 and 2 to 1 and 1). Examples of error messages:

```
> data.gcrma <- gcrma(data, affinity.info=ai, type="affinities")
Adjusting for optical effect.Done.
Error in model.frame(formula, rownames, variables, varnames, extras, extranames,  :
```

```
    variable lengths differ (found for 'x')
> data.gcrma <- gcrma(data, affinity.info=ai, type="affinities")
Adjusting for optical effect.Done.
Error in model.frame.default(formula = y ~ x, drop.unused.levels = TRUE) :
variable lengths differ (found for 'x')
Calls: gcrma ... lm -> eval -> eval -> model.frame -> model.frame.default
```

-
  - Annotations errors. A problem hapens if the annotators put the wrong chip type. This is often the case when multiple chip types are used in the same experiment. Sometimes the mistake is present in ArrayExpress! -> You can have a look at the chip type directly in the header of the CEL file.
  - Corrupted files. Usually there is nothing to do... You can remove the problematic chip from the experiment in the annotation file.
  - Custom chips: the annotation package does not exist in bioconductor (encode chips for example)
  - Memory problems: shouldn't occur on vital-IT (216Go memory)
  - Other problems may be solved using the bioconductor mailing list (http://dir.gmane.org/gmane.science.biology.informatics.conductor) usually.
- With processed data (processed_mas5):
  - Annotation problems: the name in the annotation file does not correspond to the name of the files in the experiment folder.
  - Corrupted files: sometimes the exported files on ArrayExpress do not include the probeIds. The first column if the downloaded files is empty -> find the list of probes from another experiment using the same chip, or contact AE so that they correct their file.
  - Corrupted files: sometimes files don't have the correct number of lines (probes). This is mysterious and is probably due to a bad submission to AE.

Pipeline

- Transfer the processed data on the machine where the pipeline is run

```
rsync -Wav -essh extra/pipeline/Affymetrix/processed_schuster/ bgee@devbioinfo:/var/bgee/extra/pipeline/Affymetrix/processed_schuster/
rsync -Wav -essh extra/pipeline/Affymetrix/processed_mas5/ bgee@devbioinfo:/var/bgee/extra/pipeline/Affymetrix/processed_mas5/
```

- Fill the affymetrixProbeset, expression and noExpression tables. If you use the "mysql" option it will insert directly into the database, but this is too slow (many days compared to 3 hours with "file" for bgee_v07):

```
perl create_files_affy.pl both file
```

- Sort the files (affymetrixProbeset.tsv, expression.tsv & noExpression.tsv) (supposed to be faster to insert primary keys)

```
sort -k1 -T /var/tmp affymetrixProbeset.tsv > temp_file
mv temp_file affymetrixProbeset.tsv
```

this takes more than 2 hours AND at least 3 times affymetrixProbeset.tsv size as free disk space to sort it.

- Load the files into MySQL. This is faster with no constraints so you have to re-initiate the database:

```
mysqldump -u root -p --no-create-info --triggers=false bgee_v09_ens62 > dump_v09_affymetrixChip.sql
mysql -u root -p < ../../sql/bgee.sql
mysql -u root -p bgee_v09_ens62 < dump_v09_affymetrixChip.sql

mysql -u root -p bgee_v09_ens62 -e "load data infile '$PWD/expression.tsv' into table expression; SHOW WARNINGS"
mysql -u root -p bgee_v09_ens62 -e "load data infile '$PWD/noExpression.tsv' into table noExpression; SHOW WARNINGS"
mysql -u root -p bgee_v09_ens62 -e "load data infile '$PWD/affymetrixProbeset.tsv' into table affymetrixProbeset; SHOW WARNINGS"
```

This is taking more than 1 hour (bgee_v08)

If you want to use nohup, you have to paste the MySQL root password to `-p => -pxxxx` in order to use nohup in a non-interactive way !

- Load the constraints

```
mysql -u root -p bgee_v09_ens62 < ../../sql/bgeeConstraint.sql
```

```
⧗
This is long! (43 hours with bgee_v09)
```

- Save an intermediate dump

```
mysqldump -u root -p --no-create-info --triggers=false bgee_vXX > dump_affy.sql
```

Remarks/Warnings

- Because many folders (for cel files) downloaded in Arrayexpress finish by ".raw" or ".raw.1", you can rename them using:

```
for i in *.raw; do mv $i ${i/.raw/}; done
```

- Insert one condition only:

```
perl create_files_affy.pl <expr/no_expr/both> <mysql/file> <organId> <stageId>
```

- The old scripts to do the insertion are not up-to-date any more (and couln't be used anyway because they were too long). They are removed from the SVN:

```
perl insert_affy.pl <present/absent/both>
perl update_affymetrixProbeset.pl
perl insert_expression_affy.pl <expr/no_expr/both>
perl update_expression_affy.pl <organId> <stageId>
```

- This script use to check that no problem occured during the insertion. But it is slow and not up-to-date !

```
perl check_affy_inserted.pl
```

- Warnings for `create_files_affy.pl` are harmless:

```
"Warning! The mapping in the .out file is outdated (515 probesets are no longer mapped)"
Means custom mapping for some arrays (Su et al.) for which some gene id have changed in ensembl.

"Warning! Some expression calls are not standart (2)"
Means these probsets have different calls than current Present/Absent/MArginal.

All these probsets with warnings are not included in Bgee
```

- The script :`check_affy_curation.pl` could be modified to signal when an experiment is both in the annotation file and the "not_included" or "not_included_for_now" files.
- Data files (.cel) and MAS5 are stored locally on my computer and are not on the svn -> find a solution?
- Consensus concerning probeset quality (when multiple probesets are present for the same genes):

Pst/High	Pst/Low	Abs/High	Abs/Low	Consensus
1	1	0	0	Pst/High
1	0	0	0	Pst/High
1	1	1	1	Pst/Low
1	1	1	0	Pst/Low
1	1	0	1	Pst/Low
1	0	1	1	Pst/Low
1	0	1	0	Pst/Low
1	0	0	1	Pst/Low
0	1	1	1	Pst/Bronze (not inserted)
0	1	1	0	Pst/Bronze (not inserted)
0	1	0	1	Pst/Bronze (not inserted)
0	1	0	0	Pst/Low
0	0	1	0	Abs/High
0	0	1	1	Abs/High
0	0	0	1	Abs/Low (not inserted)
0	0	0	0	Not possible

- Note that in some cases the probesets are inserted in affymetrixProbeset table, but nothing is inserted into the expression/noExpression tables. This is the case for:
  - Consensus Abs/Low (Abs seen only by mas5)
  - Consensus Pst/Bronze (no probeset Pst/High is seen for this gene/stage/organ)
  - Pre-filtering: probesets that are never Pst/High on the whole dataset with gcRMA, and never Pst(/Low) with mas5. Detection flags are always absent or marginal.
- Note: the same consensus table is used for in situ data

ESTs

Checklist

```
This can be done locally.
```

- Annotation files (`annotation_libs_....txt`) are located in `bgee/extra/pipeline/curation/EST/`.
- Download the latest version of Mm.data (ftp://ftp.ncbi.nih.gov/repository/UniGene/Mus_musculus/Mm.data.gz) , Hs.data (ftp://ftp.ncbi.nih.gov/repository/UniGene/Homo_sapiens/Hs.data.gz) , Dr.data (ftp://ftp.ncbi.nih.gov/repository/UniGene/Danio_rerio/Dr.data.gz) , Str.data (ftp://ftp.ncbi.nih.gov/repository/UniGene/Xenopus_tropicalis/Str.data.gz) , Dm.data (ftp://ftp.ncbi.nih.gov/repository/UniGene/Drosophila_melanogaster/Dm.data.gz) and uncompress them.
- Download the latest version of library.report (ftp://ftp.ncbi.nih.gov/repository/UniLib/library.report) .
- Put them in `bgee/extra/pipeline/EST_NCBI/`.
- Synchromize them with the server:

```
rsync -Wav -essh ~/work/bgee/extra/pipeline/EST_NCBI/*.data bgee@devbioinfo:/var/bgee/extra/pipeline/EST_NCBI/
rsync -Wav -essh ~/work/bgee/extra/pipeline/EST_NCBI/library.report bgee@devbioinfo:/var/bgee/extra/pipeline/EST_NCBI/
```

- For the script insert_miRNA_est.pl:
  - Check that the file `organs_correspondances.csv` (manually curated) exists and that it's placed in `../curation/miRNA/`.
  - Download the latest version of S.xls (http://www.mirz.unibas.ch/cloningprofiles/resources/S.xls) , save it as a `tsv` (keep the name as `S.csv`) and place it in `../miRNA/EST_smiRNAdb/`. Remove from this file the whole section concerning Rat librairies (some have the same name than human librairies and the file is a mess to parse).
  - Download the latest version of the files Report_x.csv (http://www.mirz.unibas.ch/cloningprofiles/) (check Downloads section) and place them in `../miRNA/EST_smiRNAdb/`.
- For the mapping between Flybase genes and UniGene clusters
  - Go in `bgee/extra/pipeline/EST_NCBI/mapping/`
  - Download `dmel_all_cdna.fasta` from biomart (Use the same release than previously !!!)

    Dataset name = "dmelanogaster_gene_ensembl"
    Filter (Gene type) = "protein_coding"
    Under the "Sequences" category:
    Attribute = "ensembl_gene_id"
    Attribute = "ensembl_transcript_id"
    Attribute name = "cDNA sequences"

- Download from Unigene the file Dm.seq.uniq (ftp://ftp.ncbi.nih.gov/repository/UniGene/Drosophila_melanogaster/Dm.seq.uniq.gz)

```
perl change_fasta_headers.pl Dm.seq.uniq > Dm.seq.uniq_new_headers
formatdb -p F -i dmel_all_cdna.fasta -n my_db
blastall -p blastn -F F -m8 -d my_db -i ./Dm.seq.uniq_new_headers -a 4 -e 1e-10 -o dmel_cdna.results
perl extract_results.pl
```

Pipeline

This is done on devbioinfo server.

- Insert normal EST libraries and their stage and organ. Indicate the mapping file if it is not available from Biomart.

```
perl insert_est.pl mouse
perl insert_est.pl human
perl insert_est.pl zebrafish
perl insert_est.pl xenopus
perl insert_est.pl fruitfly ../EST_NCBI/mapping/mapping_dmel_unigene_ensembl.txt
perl insert_miRNA_est.pl fruitfly
perl insert_miRNA_est.pl human
perl insert_miRNA_est.pl mouse
perl insert_miRNA_est.pl zebrafish
```

- Fill expression table and update the field estData (quality) in EST table

`perl insert_expression_est.pl` (Be careful, this has to be done after the insertion of affymetrix data into expression table).

- Save an intermediate dump

```
mysqldump -u root -p --no-create-info --triggers=false bgee_vXX > dump_EST.sql
```

Remarks/Warnings

- TO DO: script to check that all annotations are corresponding to stages/organs present in Bgee.
- TO DO: script to check that no space has been inserted by mistake (before or after a tab especially) in the annotation file.
- `insert_miRNA_est.pl` can return warnings (mainly for human and mouse) due to MySQL uppercase/lowercase un-sensitiveness. E.g.
  - DBD::mysql::st execute failed: Duplicate entry 'mmu-mi12-38' for key 1 at insert_miRNA_est.pl line 132, <IN> line 183.

In-situ

Checklist zebrafish

- Update the mapping OBO Ids to ZFIN Ids for organs and stages. In `bgee/extra/pipeline/In_situ/ZFIN/`:
  - `perl mk_organs_correspondance.pl`
  - `perl mk_stages_correspondance.pl`

Checklist mouse

- Connect to the database MGI with SQuirreLSQL Client (http://www.squirrelsql.org/) (increased memory) or any other client if you manage (good luck!)

`cd /Applications/SQuirreL/`
`java -Xmx512m -Xms256m -jar squirrel-sql.jar` to install SQuirreLSQL Client.
Add Sybase plugin during the installation process
Unzip the Sybase driver Media:jconnect60.zip (See jConnect (http://www.sybase.com/products/allproductsa-z/softwaredeveloperkit/jconnect) if you need an update)
Once the installation is complete, run squirrelsql (`squirrel-sql.sh`) and select the *Drivers* tab
Modify the driver *Sybase Adaptive Server Anywhere*:
Add an *Extra Class Path* to jConnect-6_0/classes/*.jar (directory previously unzipped)
Then, click on *List Drivers* and select **com.sybase.jdbc3.jdbc.SybDriver** as *Class Name*.
Click *OK* to finish. *Sybase Adaptive Server Anywhere* driver should be activated now.
Go back to *Aliases* tab, and create a new alias with these parameters:
URL: jdbc:sybase:Tds:gondor.informatics.jax.org:4025/mgd
user: jroux
pwd: JR0ux01
Increase memory for squirrelsql (2GB is good), tables you will retrieve are very large !

- Load the following tables and save them (right click) into tab delimited .csv files. Be careful to download them on the same day (regular updates are made on MGI).

Un-select **Limit rows** checkbox and run following SQL commands !!!
Save result table as *table_name*.csv , with *Include column headers*, *Export CSV file*, *Use tab character*, Line separator: LF (\n), Charset: UTF-8, and *Export complete table* by clicking in the result table and selecting **Export CSV / MS Excel / XML ...**

```
SELECT * FROM ACC_Accession WHERE (_LogicalDB_key=60 OR _LogicalDB_key=83) AND _MGIType_key=2
SELECT * FROM ALL_Allele
SELECT * FROM GXD_AlleleGenotype
SELECT * FROM GXD_Genotype
SELECT * FROM GXD_Assay
SELECT _Specimen_key, _Assay_key, _Genotype_key FROM GXD_Specimen
SELECT _Result_key, _Specimen_key, _Strength_key, _Pattern_key FROM GXD_InSituResult
SELECT * FROM GXD_ISResultStructure
SELECT * FROM GXD_Structure
```

Copy these files in bgee/extra/pipeline/In_situ/MGI

Checklist drosophila

- You have to install the BDGP database
- Download the dump here (ftp://ftp.fruitfly.org/pub/exgomysqldump/archive/current/) , put it in `bgee/extra/pipeline/In_situ/BDGP` and load it:

```
mysql -u root -p -e "create database exgo_200703 character set utf8"
mysql -u root -p exgo_200703 < exgopub-20070309.dump
```

Pipeline

```
perl insert_in_situ_zfin.pl both
perl insert_in_situ_mgi.pl both
perl insert_in_situ_bdgp.pl
perl insert_in_situ_xenbase.pl
perl insert_expression_in_situ.pl both
```
(Be careful, this has to be done after the insertion of affymetrix data into expression table).

Remarks/Warnings

- Some fields are not downloaded in MGI tables because they contain "\n" and the exported files are corrupted because of that.
- Some Xenbase warnings may be due to out dated mapping between ensembl genes used by xenbase and current ensembl version
- In case of missing data in the publications (e.g. "skeletal muscle" part_of "hindlimb" or part_of "forelimb"), MGI curators create a new term in the ontology "skeletal muscle", at the same level than "hindlimb" and "forelimb" (i.e. children of "limb"). These new terms are not in the Edimburgh ontology (EMAP)... In our logic these data should be mapped to the upper level "limb". For now we didn't integrate these problematic data.
- MGI stores only normal conditions (http://www.informatics.jax.org/mgihome/homepages/tabContents/GXD_Curators.shtml) expression data (wild-type and mutants, but no treatment, etc)
- Quality codes in MGI:

code	quality	percentage of the expression results	quality in Bgee
-2	Not Applicable	0	Not included
-1	Not Specified	0	Not included
1	Absent	31	Not included
2	Present	42	High
3	Ambiguous	1.8	Low
4	Trace	0.2	Low
5	Weak	14	Low
6	Moderate	1.2	High
7	Strong	10	High
8	Very strong	0.15	High

- Quality codes in ZFIN:

Thisse stars	quality	quality in Bgee
*	Probe is difficult to use. General basal level of expression with more intense labeling in particular structure	Low
**	Weak expression pattern	Low
***	Moderate expression pattern.	High
****	Nice strong expression pattern	High
*****	Simple to use, intense expression pattern restricted to a few structures	High
No star	(Experiments not made by Thisse)	High

Clean the noExpression table

- A line in the table noExpression must be removed if there is expression of the same gene, in the organ itself or a substructure of the organ, during the same developmental stage or during a child stage. This is done independently for each data type (e.g. a report of in situ expression in one organ/stage does not affect a report of noExpression with affymetrix data in the same organ/stage).
- Use the script `bgee/extra/pipeline/pipeline/check_noExpression.pl` to take care of this step.
- Check that everything went fine with the following SQL commands (none of them should return any results):

```
select distinct noExpressionId, t5.expressionId from noExpression as t1 inner join stage as t3 on t1.stageId = t3.stageId inner join stage as t4 on t4.leftBound >= t3.
select distinct noExpressionId, t5.expressionId from noExpression as t1 inner join organDescendants as t2 on t1.organId = t2.organAllParentId inner join stage as t3 on
select distinct noExpressionId, t5.expressionId from noExpression as t1 inner join stage as t3 on t1.stageId = t3.stageId inner join stage as t4 on t4.leftBound >= t3.
select distinct noExpressionId, t5.expressionId from noExpression as t1 inner join organDescendants as t2 on t1.organId = t2.organAllParentId inner join stage as t3 on
```

- NOTE: this step requires the table organDescendants to be filled (at the previous step).

- Old way to do it, when the cleaning was not done independently for each data type (Fred):

```
This can be done in several step. The noExpressionIds to delete can be inserted into a temp table before deletion. For instance:
* create a temp table
create table test.noExpressionIdToDelete(noExpressionId bigint unsigned not null);
* get noExpressionId related to an expression in a subtructure of the organ, during the same developmental stage or during a child stage
insert into test.noExpressionIdToDelete select distinct noExpressionId from noExpression as t1 inner join organDescendants as t2 on t1.organId = t2.organAllParentId inne
* get noExpressionId related to an expression in the organ itself, during the same developmental stage or during a child stage ===
insert into test.noExpressionIdToDelete select distinct noExpressionId from noExpression as t1 inner join stage as t3 on t1.stageId = t3.stageId inner join stage as t4 o
* delete the noExpressionIds
delete t1 from noExpression as t1 inner join test.noExpressionIdToDelete as t2 on t1.noExpressionId = t2.noExpressionId;
* Note: should we delete only noExpression with expression from the same data type, instead of any data types?
```

Differential Expression Affymetrix

Checklist

- You can do this analysis on your local computer (not really demanding). Be careful that you have all the data then.
- Launch differential analysis

  ```
  perl launch_diff_analysis.pl
  ```
  Check results in extra/pipeline/Affymetrix/bioconductor/differential/ with `grep -H -c 'proc.time' *.out | grep ':0'`

- Send data to the server devbioinfo using `rsync`:

  ```
  rsync -Wav -essh ~/work/bgee/extra/pipeline/Affymetrix/processed_differential/ bgee@devbioinfo:/var/bgee/extra/pipeline/Affymetrix/processed_differential/
  rsync -Wav -essh ~/work/bgee/extra/pipeline/Affymetrix/bioconductor/ bgee@devbioinfo:/var/bgee/extra/pipeline/Affymetrix/bioconductor/
  ```

- From time to time it should be good to relaunch the analysis of the whole microarray dataset (since the annotations may have changed). If you do so, please keep a backup copy of the folders `/extra/pipeline/Affymetrix/processed_differential/`, `/extra/pipeline/Affymetrix/bioconductor/differential/` and `/extra/pipeline/Affymetrix/bioconductor/targets/`, this will be useful to know what was inserted in previous versions of the database. When this is done, you can empty these 3 folders and relaunch the analysis using `perl launch_diff_analysis.pl`

Pipeline

- Fill the deaAffymetrixProbesetSummary table

  ```
  perl insert_diff_affy.pl
  ```

- Fill the differentialExpression table

  ```
  perl insert_diff_expression_affy.pl
  ```

Remarks/Warnings

- It is possible to launch the scripts on one experiment/condition only:

  ```
  perl launch_diff_analysis.pl <expId>
  perl insert_diff_affy.pl <expId> <chipTypeId>
  perl insert_diff_expression_affy.pl <organId> <stageId>
  ```

- Data files are stored locally on my computer and are not on the svn -> find a solution?

Gene synonyms generation

Execute the following SQL command:

```
INSERT INTO geneNameSynonym (geneId, geneNameSynonym)
  SELECT DISTINCT t1.geneId, t1.XRefName from geneXRef as t1
    INNER JOIN gene as t2 on t1.geneId = t2.geneId
    INNER JOIN dataSource as t3 ON t1.dataSourceId = t3.dataSourceId
    WHERE (dataSourceName = 'UniprotKB/TrEMBL' or dataSourceName = 'UniprotKB/Swiss-prot' or
    dataSourceName = 'ZFIN' or dataSourceName = 'MGI' or dataSourceName = 'FlyBase' or dataSourceName = 'Xenbase') and XRefName != "" and t1.XRefName != t2.geneName;
```

warning ! If you retrieve xref from a new data source, add it to the previous query

Check for errors in annotation by Bgee curators

Execute the following SQL command:

```
SELECT DISTINCT t0.organId, t0.stageId, if(t0.estData != 'no data', 'yes', 'no') AS estData,
  if(t0.affymetrixData != 'no data', 'yes', 'no') AS affymetrixData, if(t0.inSituData != 'no data', 'yes', 'no') AS inSituData
  FROM expression as t0 INNER JOIN stage as t10 on t0.stageId = t10.stageId
  WHERE t10.stageName != 'unknown' and not exists
    (SELECT 1 FROM organ as t1 INNER JOIN stage as t2 on t1.startStageId = t2.stageId
       INNER JOIN stage as t2bis on t2.leftBound <= t2bis.rightBound and t2.speciesId = t2bis.speciesId
       INNER JOIN stage as t3 on t1.endStageId = t3.stageId
       INNER JOIN stage as t3bis on t3.rightBound >= t3bis.leftBound and t3.speciesId = t3bis.speciesId
       WHERE t1.organId = t0.organId and t2bis.stageId = t0.stageId and t3bis.stageId = t0.stageId)
     and (t0.estData != 'no data' or t0.affymetrixData != 'no data');
```

You will get a list of "impossible" annotations: the annotated organ does not exist at the annotated stage. You can see if the error is an annotation of EST data, Affymetrix data, or both. You have then to retrieve the libraries and chips with such annotation (e.g. `select estLibraryId from estLibrary where organId = 'EHDAA:38' and stageId = 'XUO:0000152'`). These errors should then be corrected for the next pipeline run.

warning ! If you add a new data source (e.g. for RNASeq data), you'll have to modify the query (e.g. "`if(t0.estData != 'no data', 'yes', 'no') as estData`" and "`t0.estData != 'no data'`")

To do after the pipeline run

- Make statistics of the db. See Update_Bgee_data#Global stats

```
This is very important for error detection!
```

Save a final dump and open Champagne bottle :p

```
mysqldump -u root -p --no-create-info --triggers=false bgee_vXX > dump_vXX.sql
gzip -9 dump_vXX.sql
```

!!! Don't forget to redo the stats (table at the end)!!! It can help to detect big bugs !!!

FOR ALL THE FOLLOWING!!

```
This has to be done on every server you'll use to generate the data, including yours.
```

- you must first update the project with the last version ("svn update" while in the root directory of the Bgee project)
- you must then recompile the classes using the fresh versions of the java files ("ant" while in the root directory of the Bgee project)
- check in the constructor of the class src.model.Parameters that the default values for the arguments used to connect to the database are correct (dblogin, dbpassword, dbase, ...). Recompile the class if needed ("ant ...).
- check in META-INF/Parameters.yaml that the same arguments are correct.
- Go to the directory WEB-INF/classes and create a directory "logs" (mkidr logs). This directory will be used when you launch classes directly from the directory WEB-INF/classes
- Edit the file `extra/pipeline/pipeline/db_connections.pl` to edit the information of connection to the database e.g.

```
# # on devbioinfo.unil.ch
 sub bgee_connection {
  my $dbname='bgee_v09_ens62';
  my $host='localhost';
  my $user='root';
  my $pwd='xxxxxxxx';
  my $bgee = DBI->connect("dbi:mysql:database=$dbname;host=$host","$user","$pwd") or die $DBI::errstr;
  return $bgee;
 }
```

HOGs

```
This has to be done on a server with the last version of the database, with absolutly all the data generated
(at this point, should be the development server, but it also could be your local computer).
```

This section describes the insertion of the HOGs into the database, and the generation of the relationships amongst them. It uses the class `extra/insert_hog/InsertHog`. The parameters are ([] are optionnal): database login, database password, database name, path to the transitiveGroups file, "vertebrates only?", "CARO compliant?", path to the custom relationships file, [If CARO compliant=0, path to the caro_to_nonCaro file], ontology coverage, within-ontology agreement, inter-ontology agreement, "for curation or for real ?", non-trusted ontologies list.

- NOTE: these classes use the following tables in the database: author, homologousOrgansGroup, hogXRef, hogNameSynonym, organ, organRelationship, hogRelationship
- WARNING: if you used Excel to generate the text files transitiveGroups.txt and custom_HOG_relationships.txt, check for unrecognised chars and text fields quoted multiple times.

Generate a CARO-compliant vertebrates-only ontology

- locate the file containing the homology relationships, and the file containing the custom relationships between HOGs. Currently located at extra/pipeline/curation /HOG/transitiveGroups.txt and extra/pipeline/curation/HOG/custom_HOG_relationships_caro_vertebrates.txt
- go into the directory WEB-INF/classes/ and launch the class `extra.insert_hog.InsertHog`, e.g.:

```
java -classpath ../lib/mysql-connector-java.jar:. extra/insert_hog/InsertHog usr pwd bgee_vXX ../../extra/pipeline/curation/HOG/transitiveGroups.txt 1 1 ../../extra/pi
```

Check if any error occurs in the out file (e.g. insertion failed, update failed, ...). Some classic warnings you could see are about organs mapped to several HOGs, or organs present in the transitiveGroups.txt file, but that dont exist anymore.

- Move this out file to the proper directory (`bgee/extra/pipeline/curation/HOG`), so that annotators have access to it:

```
mv algoOut_caro_vertebrates_bgee_vXX.txt ../../extra/pipeline/curation/HOG/algoOut_caro_vertebrates_bgee_vXX.txt
```

- generate xrefs to other ontologies using already-existing mappings to species-specific ontologies:
  - You need to download the OBO files containing mappings between species-specific ontologies and the ontology you want to generate xrefs for. For instance, get the zebrafish anatomy ontology to get xrefs to TAO, e.g.:

```
wget http://obo.cvs.sourceforge.net/viewvc/obo/obo/ontology/anatomy/gross_anatomy/animal_gross_anatomy/fish/zebrafish_anatomy.obo
```

  - Use the class `extra/insert_hog/GenerateXRef` to generate xrefs. The parameters are: database login, database password, database name, location of the OBO file to use, namespace of the ontology that we want xrefs to, ontologies used to do the linkage present in terms(=1) or xrefs(=2) of the OBO file?, namespace of the linkage ontology 1, [namespace of the linkage ontology 2, ...]. E.g.:

```
java -classpath ../lib/mysql-connector-java.jar:. extra/insert_hog/GenerateXRef usr pwd bgee_vXX zebrafish_anatomy.obo TAO 1 ZFA
```

- Generate the download files:
  - go to the directory extra/pipeline/curation/HOG/ and launch the script generating the download files (note: this script takes one argument, representing the path where to store the files):

```
cd extra/pipeline/curation/HOG/
perl create_HOG_obo_file.pl ./
```

  - open the generated file HOG.obo.
    - Modify the version number
    - Modify xref declarations (see [OBO format http://www.geneontology.org/GO.format.obo-1_4.shtml]): treat-xrefs-as-equivalent, treat-xrefs-as-genus-differentia, ...

- Change the identifier into VHOG:... For instance in vi:

```
:%s/OG:/VHOG:/g
```

- Change the `namespace-id-rule` accordingly
- Change the name of the organ_association.txt file:

```
:%s/organ_association.txt/organ_association_vHOG.txt/g
```

- Change the name of the root of the ontology, for instance in vi if the name is `HOG anatomical entity` (but check before, the name is currently vHOG anatomical entity):

```
:%s/HOG anat/vHOG anat/g
```

- open the generated file `organ_association.txt`
  - Change the IDs into VHOG, e.g. in vi:

```
:%s/OG:/VHOG:/g
```

- Change the name of the file HOG.obo

```
:%s/HOG\.obo/vHOG\.obo/g
```

- Give a proper name to the HOG.obo file and organ_association.txt. Commit the modifications so that annotators have acces to the new generated files:

```
mv HOG.obo HOG_caro_vertebrates_bgee_vXX.obo
mv organ_association.txt organ_association_caro_vertebrates_bgee_vXX.txt
svn commit
```

- You now have to wait for the feedback from annotators. If they change anything, you have to relaunch this part of the pipeline. You can move to the next step only once this one is totally finished.

Generate a non-CARO all-species ontology for the Bgee database

- locate the file containing the homology relationships, the file containing the custom relationships between HOGs, and the file containing the modifications to do to the CARO ontology. Currently located at `extra/pipeline/curation/HOG/transitiveGroups.txt`, `extra/pipeline/curation/HOG/custom_HOG_relationships_caro_vertebrates.txt`, and `extra/pipeline/curation/HOG/caroToNonCaroModificationsFile.txt`
- go into the directory WEB-INF/classes/ and launch the class `extra.insert_hog.InsertHog`, e.g.:

```
java -classpath ../lib/mysql-connector-java.jar:. extra/insert_hog/InsertHog usr pwd bgee_vXX ../../extra/pipeline/curation/HOG/transitiveGroups.txt 0 0 ../../extra/pi
```

Check if any error occurs in the out file (e.g. insertion failed, update failed, ...). Some classic warnings you could see are about organs mapped to several HOGs, or organs present in the transitiveGroups.txt file, but that dont exist anymore.

- Move this out file to the proper directory (`bgee/extra/pipeline/curation/HOG`), so that annotators have access to it:

```
mv algoOut_nonCaro_allSpecies_bgee_vXX.txt ../../extra/pipeline/curation/HOG/algoOut_nonCaro_allSpecies_bgee_vXX.txt
```

- generate xrefs to other ontologies using already-existing mappings to species-specific ontologies:
  - You need to download the OBO files containing mappings between species-specific ontologies and the ontology you want to generate xrefs for. For instance, get the zebrafish anatomy ontology to get xrefs to TAO, e.g.:

```
wget http://obo.cvs.sourceforge.net/viewvc/obo/obo/ontology/anatomy/gross_anatomy/animal_gross_anatomy/fish/zebrafish_anatomy.obo
```

- Use the class `extra/insert_hog/GenerateXRef` to generate xrefs. The parameters are: database login, database password, database name, location of the OBO file to use, namespace of the ontology that we want xrefs to, ontologies used to do the linkage present in terms(=1) or xrefs(=2) of the OBO file?, namespace of the linkage ontology 1, [namespace of the linkage ontology 2, ...]. E.g.:

```
java -classpath ../lib/mysql-connector-java.jar:. extra/insert_hog/GenerateXRef usr pwd bgee_vXX zebrafish_anatomy.obo TAO 1 ZFA
```

- Generate the download files:
  - go to the directory extra/pipeline/curation/HOG/ and launch the script generating the download files (note: this script takes one argument, representing the path where to store the files):

```
cd extra/pipeline/curation/HOG/
perl create_HOG_obo_file.pl ./
```

- open the generated file HOG.obo.
  - Add the version number
  - Check xref declarations (see [OBO format http://www.geneontology.org/GO.format.obo-1_4.shtml]): treat-xrefs-as-equivalent, treat-xrefs-as-genus-differentia, ...
  - Change the identifier into HOG (if it is not already), for instance in vi:

```
:%s/OG:/HOG:/g
```

- Change the namespace-id-rule accordingly
- Change the default namespace accordingly

- Open the generated file organ_association.txt
  - Change the IDs into HOG (if it is not already), e.g. in vi:

```
:%s/OG:/HOG:/g
```

-
  - Move the HOG.obo file and organ_association.txt to the proper directory (`bgee/extra/pipeline/curation/HOG`) with a proper name. Commit the modifications so that annotators have acces to the new generated files:

```
mv HOG.obo HOG_nonCaro_allSpecies_bgee_vXX.obo
mv organ_association.txt organ_association_nonCaro_allSpecies_bgee_vXX.txt
svn commit
```

- You now have to wait for the feedback from annotators. If they change anything, you have to relaunch this part of the pipeline. You can move to the next step only once this one is totally finished.

Release

- The files HOG and organ_association have then to be put in the correct directory to be available for download (currently `/srv/www/htdocs/bgee.unil.ch/download/`, see section "release on the server")

(But the CARO-compliant vertebrates-only ontology has to always be at the same location ('cause submitted to OBO Foundry))

```
cp HOG_caro_vertebrates_bgee_vXX.obo /srv/www/htdocs/bgee.unil.ch/download/vHOG.obo
cp organ_association_caro_vertebrates_bgee_vXX.txt /srv/www/htdocs/bgee.unil.ch/download/organ_association_vHOG.txt
cp HOG_nonCaro_allSpecies_bgee_vXX.obo /srv/www/htdocs/bgee.unil.ch/download/OG_bgee_vXX.obo
cp organ_association_nonCaro_allSpecies_bgee_vXX.txt /srv/www/htdocs/bgee.unil.ch/download/organ_association_bgee_vXX.txt
```

- Update the database to define "frequentlyUsedHog", to select HOGs that will be displayed by default on the "Easy search" tool, e.g.

```
mysql -u root -p bgee_vXX
update homologousOrgansGroup set frequentlyUsedHog = 1 where hogId = 'OG:0000182' or hogId = 'OG:0000202' or hogId = 'OG:0000302' or hogId = 'OG:0000402' or hogId = 'O
```

Organs and Hogs descendants

```
This has to be done on a server with the last version of the database, with absolutly all the data generated
(at this point, should be the development server, but it also could be your local computer).
```

Check that the table `organDescendants` is filled (perl script of the pipeline).

You now need to fill the tables `hogDescendants`, using the table `hogRelationship`

- go into the directory WEB-INF/classes/
- launch the class extra.organ.HogDescendants, e.g.

```
java -classpath ../lib/mysql-connector-java.jar:. extra/organ/HogDescendants usr pwd bgee_vXX
```

Organs mapped to HOG

For the moment, this step is not required anymore.

Old task(just for the records):

```
   This has to be done on a server with the last version of the database, with absolutly all the data generated
   (at this point, should be the development server, but it also could be your local computer).

  You now need to fill the table organMappedToHog, with a script using notably the table hogRelationship, filled at the previous step.

  * go into the directory WEB-INF/classes/
  * launch the class extra.insert_hog.GenerateOrgansMappedToHog, e.g.
      java -classpath ../lib/mysql-connector-java.jar:. extra/insert_hog/GenerateOrgansMappedToHog
```

globalExpression

```
This has to be done on a server with the last version of the database, with absolutly all the data generated
(at this point, should be the development server, but it also could be your local computer).
```

You now need to fill the table `globalExpression`, with a script using the tables `expression` and `organDescendants`.

The aim is to fill a table containing, for an organ, all the expression information for this organ but also for all its child organs. The script also generates a junction table to the expression table, `globalExpressionToExpression`

The arguments are: databaseName, user, password, [[debuglevel] or [port host]], path where to store the temp files (absolute path with about 5 Go free)

Note: if you see that that it takes too long to delete the table (`delete from globalExpression`), just drop the table and create it again (without forgetting the constrains!).

- go into the directory WEB-INF/classes/
- launch the class extra.generate_global_expression.NewGenerateGlobalExpression with extra memory, e.g.

```
java -Xmx40g -classpath ../lib/mysql-connector-java.jar:. extra/generate_global_expression/NewGenerateGlobalExpression bgee_vXX usr pwd /var/tmp/
```

- This script takes about 1 hour to fill the table, but requires a large amount of memeroy.
- Old way to do it (Balazs), in case you have low memeroy:

```
globalExpression
 This has to be done on a server with the last version of the database, with absolutly all the data generated
 (at this point, should be the development server, but it also could be your local computer).

You now need to fill the table globalExpression, with a script using the tables expression and organDescendants.

The aim is to fill a table containing, for an organ, all the expression information for this organ but also for all its child organs. The script also generates a junct

The script needs some entry arguments to run properly, e.g. the database's name, the user, the password. The port and the host are set to default to 3306 and 127.0.0.1

Note: if you see that that it takes too long to delete the table (delete from globalExpression), just drop the table and create it again (without forgetting the const

* go into the directory WEB-INF/classes/
* launch the class extra.generate_global_expression.GenerateGlobalExpression, e.g.
java -classpath ../lib/mysql-connector-java.jar:. extra/generate_global_expression/GenerateGlobalExpression bgee_vXX [usr] [pwd]
* This script takes about 12 (!) hours to fill the table.
```

hogExpression

```
This has to be done on a server with the last version of the database, with absolutly all the data generated
(at this point, should be the development server, but it also could be your local computer).
```

You now need to fill the table `hogExpression`, with a script using the tables `globalExpression`, `globalExpressionToExpression`, `homologousOrgansGroup`, `organ`, `organDescendants`, `hogDescendants`, `metaStage`, `stage`. So make sure to have successfully run the previous steps of this part of the pipeline.

The aim of the table `hogExpression` is to compute all the expression data for a HOG. The script also generates a junction table to the expression table, `hogExpressionToExpression`

The arguments are: database's name, user, password, [[debuglevel] or [port host]], path where to store the temp files (absolute path with about 2 Go free)

- go into the directory WEB-INF/classes/
- launch the class extra.generate_global_expression.NewGenerateHogExpression, e.g.

```
java -classpath ../lib/mysql-connector-java.jar:. extra/generate_global_expression/NewGenerateHogExpression bgee_vXX usr pwd /var/tmp/
```

- This script takes about 4 hours to fill the table.
- Old way to do it (Balazs):

```
hogExpression

The script needs some entry arguments to run properly, e.g. the database's name, the user, the password. The port and the host are set to default to 3306 and 127.0.0.1

* go into the directory WEB-INF/classes/
* launch the class extra.generate_global_expression.GenerateHogExpression, e.g.
java -classpath ../lib/mysql-connector-java.jar:. extra/generate_global_expression/GenerateHogExpression bgee_vXX [usr] [pwd]
* This script takes about 36 (!) hours to fill the table.
```

hogExpressionSummary

```
This has to be done on a server with the last version of the database, with absolutly all the data generated
(at this point, should be the development server, but it also could be your local computer).
```

You now need to fill the table `hogExpressionSummary`.

The aim of this table is to compute whether it exists some expression data for a species, in a HOG (to be able to distinguish between "expression", "no expression", or "no data").

- go into the directory WEB-INF/classes/
- launch the class extra.insert_hog.GenerateHogExpressionSummary, e.g.

```
java -classpath ../lib/mysql-connector-java.jar:. extra/insert_hog/GenerateHogExpressionSummary usr pwd bgee_vXX
```

- This script is not well optimized, and this takes about three hours.

Modifications of the source code

- If a new data source has been added, you might need to do some modification in the java source code. Notably, the methods generating URL to retrieve original expression data (such as on this page: http://bgee.unil.ch/bgee/bgee?page=expression&action=data&gene_id=ENSMUSG00000038253), in the class `src.view.html.HtmlExpression.class`.

For instance, if you added an new in situ hybridizations database, you need to modify the methods `view.html.HtmlExpression.getInSituExperimentUrl(String, String)` and `view.html.HtmlExpression.displayInSituSpot(Collection<InSituSpot>)`. For a new EST database, the methods `view.html.HtmlExpression.getEstLibraryUrl(String, String)` and `view.html.HtmlExpression.getEstUrl(String, String)`. For a new microarray database, the method `view.html.HtmlExpression.getAffymetrixExperimentUrl(String, String)`

- Modify the text in `view.html.HtmlDocumentation` and `view.html.HtmlStatic` to reflect the modifications of Bgee (new datasources, new data types, ...). For instance, in `view.html.HtmlDocumentation`, modify the Ensembl version, i.e.

this.writeln("
Bgee is currently based on genomes from [Ensembl release 62] (13 April 2011).
");

- Check in the database, in the table geneBioType, the IDs of "miRNAs" and "protein_coding". Change the field DataTypeTO.MIRNA and DataTypeTO.PROTEINCODING accordingly.

Release on the server

- Insert a detailed news in the table bgeeAdministration.news, and a summary news in the table bgeeAdministration.shortNews. In the table shortNews, there is only one line (as we do not need to display previous summarized news).

- Generate a dump file

```
This has to be done on a server with the last version of the database, with absolutely all the data generated
(at this point, it should be the development server, but it also could be your local computer).
```

Generate a SQL dump file of the data only (no creation of any tables, triggers, ... e.g. mysqldump -u root -p --no-create-info --no-create-db --triggers=false bgee_vXX > dump_bgee_vXX.sql).

- Before updating the MySQL server and the Bgee application, think to save the current Bgee application

```
svn cp https://svn.vital-it.ch/svn/BGee/trunk/bgee/   https://svn.vital-it.ch/svn/BGee/tags/bgee_vXX/
```

- Load the data into the production server ('cause you didn't generate the data directly on the prod server, right? ;))

```
This has to be done on the production server
```

- - copy all the required files on the server: extra/sql/bgee.sql, extra/sql/bgeeIndex.sql, extra/sql/bgeeConstraint.sql (could be done using svn), and of course the dump file you generated.
  - modify the file extra/sql/bgee.sql in order to use the correct name of the new database (bgee_vXX)
  - use the extra/sql/bgee.sql file to create the database and the tables

```
mysql -u root -p < extra/sql/bgee.sql
```

- - load the data into the database using the dump file you generated previously

```
mysql -u root -p bgee_vXX < dump_bgee_vXX.sql
```

- - use the extra/sql/bgeeIndex.sql file to create the indexes. Generating indexes AFTER data loading is faster than before data loading.

```
mysql -u root -p bgee_vXX < extra/sql/bgeeIndex.sql
```

- - use the extra/sql/bgeeConstraint.sql file to create the foreign key constraints. It should be done after the indexes creation to avoid generating redundant indexes (as foreign key constraints require indexes and create them if needed). And it should also be done after the data loading into the database, as the data has been already generated using these contraints and thus are coherent (but these constraints are still required for the indexes they generate).

```
mysql -u root -p bgee_vXX < extra/sql/bgeeConstraint.sql
```

- - give select permission on the new database to the bgee user, e.g.:

```
grant select on bgee_vXX.* to 'bgee'@'localhost';
flush privileges;
```

OR

```
grant select on bgee_vXX.* to 'bgee'@'127.0.0.1';
flush privileges;
```

- - Important remark: altering a table after data insertion, to add indexes and foreign key constraints, can fail if the table is very large, with the error 1206: "ERROR 1206 (HY000): The total number of locks exceeds the lock table size". To solve this problem, you have to increase the buffer pool size (see comments here for instance (http://bugs.mysql.com/bug.php?id=9975)), or you have to insert the data AFTER indexes and foreign key constraints generation. You'd rather increase the buffer pool size.

- Generate data files available for download

```
This has to be done on a server with the last version of the database, with absolutly all the data generated
(at this point, could be the production server, but could also be the development server or your local computer).
The generated file has to be put, and the database modified, on the production server
```

- - create a new directory in download/, named as the database release (e.g. mkdir download/bgee_vXX) - denoted as 'pathToStoreTheFiles' below.
  - go into the directory WEB-INF/classes/
  - launch the class to generate the data files (e.g.: java -classpath ../lib/mysql-connector-java.jar:. extra/generate_data_files/GenerateDataFiles usr pdw bdd pathToStoreTheFiles
  - Warning: pathToStoreTheFiles must be an absolute path, not a relative one (e.g. '/var/bgee/download/bgee_vxx/' and not '../../download/bgee_vxx')
  - Note that the file affymetrixProbesets is generated at a previous step of the pipeline, and is present in the directory extra/pipeline/pipeline/. All other files are generated here.
  - If exists, remove from this directory the file "generatedHtml.txt"
  - tar gz the directory (e.g. tar -zcvf bgee_vXX.tar.gz bgee_vXX/).
  - copy bgee_vXX.tar.gz to its final repository: `/srv/www/htdocs/bgee.unil.ch/download/`
  - remove bgee_vXX/ directory
  - update the download table in the bgeeAdministration database. The downloadId will determine the display order on the download webpage (e.g. insert into download (downloadId, downloadName, downloadDescription, downloadPath, downloadSize, freelyAvailable) values (1, 'Bgee Release XX as TSV files', 'This archive contains the full content of the Bgee database Realease XX as TSV files. A description of these files can be found in the <a

href="?page=documentation#sectionTSVDataFiles">documentation section. Note that some files are very large once uncompressed (> 2 Go)', 'bgee_vXX.tar.gz', 357, 1))

- Generate the UniProt/SwissProt mapping

```
This has to be done on a server with the last version of the database, with absolutly all the data generated
(at this point, could be the production server, but could also be the development server or your local computer).
The generated file has to be put on the ftp server (publicly available from ftp://lausanne.isb-sib.ch/pub/databases/Bgee/ (NOW !)ftp://ludwig-sun1.unil.ch/pub/databases/B
```

- - check in the class src.extra.generate_data_files.GenerateUniprotXRef that the final static variables TREMBLID and SWISSPROTID are correct (currently 3 and 4). They must correspond to the SwissProt dataSourceId and trembl dataSourceId in the dataSource table. Recompile the class if needed.
  - go into the directory WEB-INF/classes/
  - launch the class to generate the mapping file (e.g. java -classpath ../lib/mysql-connector-java.jar:. extra/generate_data_files/GenerateUniprotXRef ../../download/)
  - Put the generated mapping file to `/db/ftp/pub/databases/Bgee/`, available from the Vital-IT frontal (prd.vital-it.ch)

- Generate PROSITE data

```
This has to be done on a server with the last version of the database, with absolutly all the data generated
(at this point, could be the production server, but could also be the development server or your local computer).
The generated file has to be put on the ftp server (publicly available from ftp://lausanne.isb-sib.ch/pub/databases/Bgee/
```

- - check in the class src.extra.generate_data_files.GeneratePrositeData that the final static variables TREMBLID and SWISSPROTID are correct (currently 3 and 4). They must correspond to the SwissProt dataSourceId and trembl dataSourceId in the dataSource table. Recompile the class if needed.
  - create a directory where to store the generated files (e.g.: mkdir /var/bgee_v09/PROSITEBgeeData)
  - go into the directory WEB-INF/classes/
  - launch the class to generate the data. The parameters are: "location where to store the files", speciesIdToUse1[, speciesIdToUse2, ...]. The parameters for connecting to the database are set in Parameters.java and Parameters.yaml, so make sure they are correct.

```
java -classpath ../lib/mysql-connector-java.jar:. extra/generate_data_files/GeneratePrositeData /var/bgee_v09/PROSITEBgeeData/ 7955 9606 10090 8364
```

- - Go to the directory, and zip its content, e.g.:

```
zip -9 PROSITEBgeeData.zip *
```

- - Move the zip in another folder to delete this one
  - Put the generated file to `/db/ftp/pub/databases/Bgee/`, available from the Vital-IT frontal (prd.vital-it.ch)

- Generate the 4DXpress mapping

```
This has to be done on a server with the last version of the database, with absolutly all the data generated
(at this point, could be the production server, but could also be the development server or your local computer).
The generated file has to be put on the ftp server (publicly available from ftp://lausanne.isb-sib.ch/pub/databases/Bgee/ (NOW !)ftp://ludwig-sun1.unil.ch/pub/databases/B
```

- - go into the directory WEB-INF/classes/
  - launch the class to generate the mapping file (e.g. java -classpath ../lib/mysql-connector-java.jar:. extra/generate_data_files/Generate4DXpressXRef ../../download/)
  - Put the generated mapping file to `/db/ftp/pub/databases/Bgee/`, available from the Vital-IT frontal (prd.vital-it.ch)

- Generate the neXtProt data file

```
This has to be done on a server with the last version of the database, with absolutly all the data generated
(at this point, could be the production server, but could also be the development server or your local computer).
The generated file has to be put on the ftp server (publicly available from ftp://lausanne.isb-sib.ch/pub/databases/Bgee/ (NOW !)ftp://ludwig-sun1.unil.ch/pub/databases/B
```

- - go into the directory WEB-INF/classes/
  - launch the class to generate the file. The parameters are: usr, pwd, databaseName (i.e. bgee_vXX), path where to store the file (e.g. ../../download/), Bgee release number, human genome build, e.g.:

```
java -classpath ../lib/mysql-connector-java.jar:../lib/commons-lang.jar:. extra/generate_data_files/GenerateNextProtData usr pwd bgee_v09_ens62 ../../download/ 08 60.3
```

- - zip the generated XML file (e.g. zip -9 -r neXtProtBgeeData.zip neXtProtBgeeData.xml). Avoid gzip for Windows compatibility. (`-9` for the best compression !)
  - Put the generated file to `/db/ftp/pub/databases/Bgee/`, available from the Vital-IT frontal (prd.vital-it.ch)

- update the database statistics displayed on the "about" webpage

```
This has to be done on a server with the last version of the database, with absolutly all the data generated
(at this point, could be the production server, but could also be the development server or your local computer).
```

- - go into the directory WEB-INF/classes/
  - launch the class to calculate the statistics, species by species (e.g. java -classpath ../lib/mysql-connector-java.jar:. extra/stat/DatabaseStats user password bgee_vXX)

affymetrixProbeset		31380415	25339322	54674536	168330474	241683478	285249148	291'759'824
inSituExperiment				15958	17025	30693	38222	41'460
inSituEvidence				84057	85917	126627	248546	257'744
inSituSpot				402021	496071	540415	1063547	1'098'157
expression					6459784	8569393	8512875	8'623'058
noExpression					2957794	3299875	3731531 (before conflicts are removed) 3559711 (after conflicts are removed)	3'747'503 (before conflic removed) 3'569'176 (after conflicts removed)
differentialExpression					959255	1034435	1194818	1'234'390
globalExpression						25648235 globalExpressionToExpression: 73599719 distinct organId: 4290	25872162 globalExpressionToExpression: 72982160 distinct organId: 4908	26'179'493 globalExpressionToExpr 72'905'949 distinct organId: 4'954
hogExpression						10801884 hogExpressionToExpression: 44775501	13465934 hogExpressionToExpression: 74561817	13'610'770 hogExpressionToExpres: 74'751'912
miRNAs geneToGeneFamily*					1266	1029***	1392	1'410
miRNAs EST**					23719	413***	23083	22'954
miRNAs in situ spots					195	172***	26627	12'918

* SELECT COUNT(*) FROM geneToGeneFamily as t1 INNER JOIN gene as t2 ON t1.geneId = t2.geneId INNER JOIN geneBioType as t3 ON t2.geneBioTypeId = t3.geneBioTypeId WHERE t3.geneBioTypeName='miRNA';

SELECT speciesId, COUNT(t1.geneId) FROM geneToGeneFamily as t1 INNER JOIN gene as t2 ON t1.geneId = t2.geneId INNER JOIN geneBioType as t3 ON t2.geneBioTypeId = t3.geneBioTypeId WHERE t3.geneBioTypeName='miRNA' GROUP BY speciesId;

** SELECT COUNT(*) FROM expressedSequenceTag as t1 INNER JOIN gene as t2 ON t1.geneId = t2.geneId INNER JOIN geneBioType as t3 ON t2.geneBioTypeId = t3.geneBioTypeId WHERE t3.geneBioTypeName='miRNA';

> SELECT speciesId, COUNT(estId) FROM expressedSequenceTag as t1 INNER JOIN gene as t2 ON t1.geneId = t2.geneId INNER JOIN geneBioType as t3 ON t2.geneBioTypeId = t3.geneBioTypeId WHERE t3.geneBioTypeName='miRNA' GROUP BY speciesId;
>
> SELECT speciesId, COUNT(inSituSpotId) FROM inSituSpot as t1 INNER JOIN gene as t2 ON t1.geneId = t2.geneId INNER JOIN geneBioType as t3 ON t2.geneBioTypeId = t3.geneBioTypeId WHERE t3.geneBioTypeName='miRNA' GROUP BY speciesId;

*** In bgee_v07, zebrafish miRNA genes were not mapped to families (problem on geneName mapping), very few miRNA ESTs were inserted (unknown reason) and mouse in situ hybridization for miRNA were not inserted (mapping problem?).

- Other useful queries:

```
SELECT COUNT(geneId) FROM geneXRef;
```

```
SELECT t2.dataSourceName, COUNT(geneId) FROM geneXRef as t1 INNER JOIN dataSource as t2 ON t1.dataSourceId = t2.dataSourceId GROUP BY t1.dataSourceId;
```

Check that the insertion of XRefs from ZFIN for zebrafish miRNAs / from MGI for mouse miRNAs were successful:

```
SELECT COUNT(*) FROM geneXRef as t1 INNER JOIN gene as t2 ON t1.geneId = t2.geneId INNER JOIN geneBioType as t3 ON t2.geneBioTypeId = t3.geneBioTypeId
   INNER JOIN dataSource as t4 ON t1.dataSourceId=t4.dataSourceId WHERE t3.geneBioTypeName='miRNA' and t4.dataSourceName='ZFIN';
```

```
SELECT COUNT(*) FROM geneXRef as t1 INNER JOIN gene as t2 ON t1.geneId = t2.geneId INNER JOIN geneBioType as t3 ON t2.geneBioTypeId = t3.geneBioTypeId
   INNER JOIN dataSource as t4 ON t1.dataSourceId=t4.dataSourceId WHERE t3.geneBioTypeName='miRNA' and t4.dataSourceName='MGI';
```


- This page was last modified on August 9, 2011, at 20:48.

2 Appendix 2: guidelines for curators

Guidelines for our curators, from the wiki of our lab.

Annotation

From Mrrwiki

Contents

SVN

Svn (subversion) is a versioning system, i.e. it saves every modification of files in a project. It means that you can always go back and restart on unmodified code, at any point. It is really useful when several people work on a same project, because they can access the last modifications you made on the project.

Check the Svn page to know how to install it.

Curators have to start their session with `svn update` (to get the last version of the project) and finish it with `svn commit` (to send their modifications on the project).

An account has been created specially for curators: `bgeeannot`

Annotation of expression data

Expression data needs to be annotated with a developmental stage and an anatomical structure in order to be included in BGee (http://bgee.unil.ch) .

This section aims at describing how to annotate the expression data. This is supposed to make the handling of the process easier for new annotators.

It can also be used as a place to write down some pragmatic choices we have made in the annotated data and that are likely to come again in new data (for example: "do we annotate fasted mice as normal condition?").

General considerations

- It is really important, when annotating an experiment, that the annotated anatomical structure DOES exist at the annotated developmental stage. For instance, if you are annotating an experiment performed on a mouse adult brain, you might want to annotate it by using the organ EMAPA:16894: brain (http://bgee.unil.ch/bgee/bgee?page=anatomy&action=organ_details&organ_id=EMAPA%3A16894) . But this organ only exists until Theiler Stage 26 (as we use separate ontologies for embryo and adult mouse), so you would be WRONG. Instead, you should annotate this experiment with the organ MA:0000168: brain (http://bgee.unil.ch/bgee/bgee?page=anatomy&action=organ_details&organ_id=MA%3A0000168) , which exists at the adult developmental stage.

- If the experiment is a mix of different stages or structures, it must be annotated with the stage or structure that is higher in the ontology and includes the different stages or structures. For example: a mouse experiment that mixes Theiler Stages 11 (XUO:0000055) and 15 (XUO:0000059) must be annotated with embryo (OGES:000022) see the mouse developmental stages ontology (http://bgee.unil.ch/bgee/bgee?page=anatomy&action=stages&all_stages=on&&species_id=10090) . An adult mouse experiment that mixes stomach (MA:0000353) and intestine (MA:0000328) must be annotated with gastrointestinal system (MA:0000323) see the adult mouse anatomical ontology (http://bgee.unil.ch/bgee/bgee?page=anatomy&action=organs&stage_id=OGES%3A000027) .

- If the structure does not exist in the ontology, annotate the experiment with the structure that includes the missing structure. For example: An adult human experiment that samples the left heart ventricle must be annotated with ventricle (EV:0100020) as the adult human ontology does not have right and left heart ventricle terms.

- The file "**Dvlpmt_stage_time_correspondances.doc**" on the svn contains correspondances between developmental stages and time for mouse, human and drosophila. When annotating, it is faster to consult this file than checking on BGEE for each experiment to what time does a specific stage corresponds.

- Some developmental stages overlap. For example: Mouse Theiler Stage 27 newborn mouse (http://bgee.unil.ch/bgee/bgee?page=anatomy&action=organs&stage_id=XUO%3A0000071) corresponds to 1-7 days post-natal and mouse infant stage (http://bgee.unil.ch/bgee/bgee?page=anatomy&action=organs&stage_id=OGES%3A000025) corresponds to 1-4 weeks. When stages overlap, in order to be coherent with previous annotations, always annotate the experiment with the earliest stage. In the previous example, an experiment that samples 1 week (7

days) post-natal mouse must be annotated with Theiler stage 27.

Affymetrix data

Note that we are looking for expression data only, that means material type has to be 'total_RNA' [1] (http://www.ebi.ac.uk/microarray-as/ae/files/E-GEOD-20291/E-GEOD-20291.sdrf.txt) and not 'genomic DNA'[2] (http://www.ebi.ac.uk/microarray-as/ae/files/E-GEOD-12896/E-GEOD-12896.sdrf.txt)

- Images make the following text clearer so check the "***how_to_annotate_expr_data_step_by_step*.ppt**" file on the Svn.
- The experiments that have not been annotated yet (black) are in the "***annotation*.xls**" file in the tabs bearing the name of the organisms (Mouse, Homo, Danio and Droso). The web address leads you to the experiment page in Arrayexpress (http://www.ebi.ac.uk/microarray-as/ae/) .
- The colour code in the "***annotation*.xls**" file is:
  - Black - Experiments not yet annotated
  - Red - Experiments not included
  - Orange - Experiments not included for now
  - Blue - Experiments partially included, only some samples were "**normal**"
  - Green - Experiments totally included, only "**normal**" samples
- For each experiment check that there are samples with "**normal**" conditions (no knock-out or mutation, no cancer, no treatment...). You'll find the information for the experiment samples in the description and in the ".sdrf.txt" file. In the description they don't always mention if they used controls (wild-type, untreated...) so always look at the ".sdrf.txt" file.

  > BE CAREFUL: what is called control does not always correspond to "**normal**" conditions (heterozygotes, floxed mice, vehicle (PBS, saline, oil...) treated, untreated mutant, sham operated, GFP-expressing...)

- The ".sdrf.txt" file generally contains all the information on the experiment samples: "**normality**", organ, developmental stage, chip type, raw data and processed data file names... If some information is missing (usually developmental stage) check the publication if it is available. Otherwise annotate with the stage unknown.
- If the experiment has "**normal**" samples and the raw data is available:
  - Download the **raw data** (the ".cel.tar.gz" file containing the ".CEL" files)
  - Create a new directory in "cel_data/", that you name with the experiment ID (e.g. "E-TABM-33"). Be careful to **remove spaces in file names**!
  - Remove the ".CEL" files that correspond to "**anormal**" samples.
- If the experiment has "**normal**" samples but only the processed data is available (only MAS5 normalization):
  - Click ArrayExpress Advanced Interface
  - Click Retrieve data
  - Tick in "EXPERIMENTAL CONDITIONS" the samples that correspond to "**normal**" ones.
  - Tick in "QUANTITATION TYPES": "ABS_CALL" and "VALUE" (or similar).
  - Tick in "DESIGN ELEMENT PROPERTIES": "CompositeSequencename".
  - Click "Export Data" and when the file is created, click "Download data matrix >>"
  - Store this file in the directory "processed_mas5".
- Add the experiment ID, name and description in the tab "**microarrayExperiment**" of the

"***annotation*.xls**" file. Separator between experiments = '//'.

- Add the Chip type in the tab "**chipType**" of the "***annotation*.xls**" file (if it is not already present). This describes which microarray platform was used.
  - Put the organism on which the experiment was done (can be different from the organism the chip was designed for, e.g. hybridization of chimp RNA on human chip).
  - Annotate the name of xref table of the database martdb (Ensembl). This can be found on the biomart website (when you export the query filtering for genes only with a probe on that chip). If no xref of the chip is available in Ensembl, a mapping file between affy IDs and Ensembl IDs has to be provided. It has to be put in the "annotations" directory and has to be a ".out" file. Put the name of the file in "chipType" in this case.

- Manual annotation in the tab "affymetrixChip" of the "***annotation*.xls**" file (add new lines for new samples):
  - The first column is filled with the ".CEL" file name or the processed data file name that has this format GSExxxxGSMxxxx_Norm
  - The second with the experiment ID
  - The third with the chip ID
  - The fourth and fifth (normalization method and detection method) with "2" and "2" for raw data / with "1" and "1" for processed data
  - The sixth and seventh with the organ and stage IDs for each sample. Be sure that the organ ID exists at the annotated stage!

- Some experiments are described as Superseries see an example in ArrayExpress (http://www.ebi.ac.uk/microarray-as/ae/browse.html?keywords=E-GEOD-4067&detailedview=on) . They are composed of several other experiments. Be careful not to annotate twice the same experiment (once on its own and once as part of the Superseries)! Annotate only the experiment on its own and add the Superseries in the "not_included" file.

- Special case: Raw data is available but only one ".CEL" file of the experiment will be annotated. Then directly download and annotate the processed data as it's not possible to normalize only one file. If the processed data is not available, download and annotate the ".CEL" file anyway but type "1" and "1" in the fourth and fifth column of the "***annotation*.xls**" file.

- If the experiment should not be included (only "**anormal**" samples), add its ID to the "not_included" file, as well as a short description why it can't be included. Note that "not_included" may also contain experiments with not enough information about samples (treatment, age...) and not possible (or even useful) to contact the authors.

- If the experiment should be included, but for any reason the insertion is not possible (future development of BGee or of the ontologies, only processed data is available but ABS_CALL is not available...), store the experiment ID and a description of the problem in "not_included_for_now" file. Note that "not_included_for_now" may also contain experiments with not enough information about samples (treatment, age...) but may be useful to contact the authors because sample seems interesting.

- In other cases: Ask Julien (http://www.unil.ch/dee/page38327.html)

EST data

- Take each UniGene (http://www.ncbi.nlm.nih.gov/sites/entrez?db=unigene) EST library from the file "libs_to_annotate_*species*".
- Check that the condition is **normal**. To get more informations, you may need to refer to the file library.report (ftp://ftp.ncbi.nih.gov/repository/UniLib/) where all details on the UniGene library are displayed. Be careful that in this file, the library ID is not the number just after the ">", but the number

after "dbEST lib id: ".

- Fill the file "annotation_libs_*species*.txt":
  - First column is the library ID.
  - Second is the stage ID.
  - Third is the organ ID.
  - Fourth is the libary name.
- If the library can't be included ("anormal"), add its ID to the "not_included" file, as well as a short description why it can't be included. If it could be included, but for any reason the insertion is not possible, store the library ID and a description of the problem in "not_included_for_now" file.
- The file "not_annotated_libs_*species*.txt" contains the library ID and number of sequences for unannotated librairies. Most of them were not annotated because they have a small number of sequences.

Data "normality"

Experiments:

In some cases we had to make a choice whether including or not an experiment. Here are some choices we have made, to serve as a guide if the same cases appear again:

Experiment	Include into Bgee?	Comments	Example
Cell lines (3T3-L1, Hela, MCF-7) and cell cultures	No		
Fasted animals	Yes	If the fastening time is reasonable	E-GEOD-7137 (http://www.ebi.ac.uk/arrayexpress/experiments/E-GEOD-7137)
Low or high fat diet for short time	Yes	If the diet time is short (3 days), can be considered as part of the wild life variability for animals	E-GEOD-8524 (http://www.ebi.ac.uk/arrayexpress/experiments/E-GEOD-8524)
Mammary glands from virgin, pregnant and lactating females	Yes	From all types of females	E-TABM-199 (http://www.ebi.ac.uk/arrayexpress/experiments/E-TABM-199)
Oocytes at different stages of maturation	Yes	Without including the info on the stage (except for Drosophila where the different maturation stages are present in the ontology)	E-GEOD-3351 (http://www.ebi.ac.uk/arrayexpress/experiments/E-GEOD-3351)
Placenta and extraembryonic components during development	Yes	Be careful whether to put it in the adult or the embryo!	E-GEOD-7674 (http://www.ebi.ac.uk/arrayexpress/experiments/E-GEOD-7674)

Injury	No		
Animals selected for their behaviour (e.g. fear)	Yes	Part of the natural variability	E-GEOD-4035 (http://www.ebi.ac.uk/arrayexpress/experiments/E-GEOD-4035)
Animals from different strains (e.g. C57BL/6, BALB/c...)	Yes	Part of the natural variability	
Intestinal germ free animals	No	Normal animals have an intestinal flora	E-GEOD-5156 (http://www.ebi.ac.uk/arrayexpress/experiments/E-GEOD-5156)
Removal of the eye (monocular enucleation) or cochlea on one side; the eye, visual cortex or cochlea on the other side were analysed	No		E-GEOD-4265 (http://www.ebi.ac.uk/arrayexpress/experiments/E-GEOD-4265)
Cell types (T-cells, stem cells...)	Yes	Should be included only if enough precision in the ontologies (e.g. T-cell in zebrafish (http://bgee.unil.ch/bgee/bgee?page=anatomy&action=organ_details&organ_id=ZFA%3A0009046)). If not enough precision in the ontology, store the experiment ID in the "not_included_for_now" file	
Polysomal RNA only hybridized	No	Method that pellets the polyribosomes while leaving the mono and non-polysomal mRNA fractions in the supernatant.	E-GEOD-3962 (http://www.ebi.ac.uk/arrayexpress/experiments/E-GEOD-3962)
Anesthesia	No	Similar to drug treatment (but sometimes anesthesia is simply not described, and should be accepted for human?)	
Human post-mortem tissues	Yes	Mainly the simple way to get human tissues	
Light impulse to stress the animals	Yes	Stress is probably usual for lab animals	
Killed by cervical dislocation or decapitation	Yes	Common for Mouse	
Killed by inhalants (CO2)	Yes	Common for Mouse	

Killed by exsanguination under CO2 anesthesia	No	Used for mouse lung retrieval	
Killed by intravenous anesthetic	No	Note that method of killing is sometimes simply not described	
Killed by intracardiac or intraperitoneal injection	No	Note that method of killing is sometimes simply not described	

Technologies: Some microarray technologies are not (yet) taken into account in Bgee

Technology	Include into Bgee?	Comments	Example
ChIP-chip (Chromatin immunoprecipitation)	No	ChIP-on-chip (http://www.chiponchip.org/)	E-TABM-736 (http://www.ebi.ac.uk/arrayexpress/experiments/E-TABM-736)
RIP-Chip (RNA-binding protein immunoprecipitation-microarray)	No	Technologies for purifying endogenously formed RBP-mRNA complexes from cellular extracts	E-GEOD-12239 (http://www.ebi.ac.uk/arrayexpress/experiments/E-GEOD-12239)
RNA-Seq (microarrays and transcriptome sequencing)	No	A recently developed approach to transcriptome profiling that uses deep-sequencing technologies, see RNA-Seq: a revolutionary tool for transcriptomics. (http://www.ncbi.nlm.nih.gov/pubmed/19015660)	E-GEOD-13744 (http://www.ebi.ac.uk/microarray-as/ae/browse.html?keywords=E-GEOD-13744)
Exon array (GeneChip Whole Transcript(WT) Sense Target (ST) Labelling Assay	No	With probes designed to detect each individual exon for known or predicted genes, useful for detecting different splicing isoforms, see Analysis of Affymetrix Exon Arrays (http://www.ki.informatik.hu-berlin.de/wbi/research/publications/2010/tr_exonarrayanalysis.pdf)	E-GEOD-17757 (http://www.ebi.ac.uk/microarray-as/ae/browse.html?keywords=E-GEOD-17757)
Tiling array (a subtype of microarray chips)	No	For gene expression of previously unidentified genes. Used mainly for ChIP-chip.	E-GEOD-23220 (http://www.ebi.ac.uk/microarray-as/ae/browse.html?keywords=E-GEOD-23220)

Tips from the expert

- Some experience sample gastrocnemius AND soleus muscle TOGETHER. Do not annotate it with MA:0000015: muscle organ (http://bgee.unil.ch/bgee/bgee?page=anatomy&action=organ_details&organ_id=MA%3A0000015&organ_children=on) but with MA:0002400: triceps surae (http://bgee.unil.ch/bgee/bgee?page=anatomy&action=organ_details&organ_id=MA%3A0002400&organ_children=on) which is a term given by some anatomists to the gastrocnemius and soleus muscle together.

- The term umbilical cord does not exist in the mouse ontologies. Annotate it with MA:0000381: female reproductive system (http://bgee.unil.ch/bgee/bgee?page=anatomy&action=organ_details&organ_id=MA%3A0000381&organ_children=on) and adult stage!
- The term otic vesicle does not exist as such in the mouse and human embryo ontologies, it exists as EMAPA:16669: otocyst (http://bgee.unil.ch/bgee/bgee?page=anatomy&action=organ_details&organ_id=EMAPA%3A16669&organ_children=on) and EHDAA:2110: otocyst (http://bgee.unil.ch/bgee/bgee?page=anatomy&action=organ_details&organ_id=EHDAA%3A2110&organ_children=on)
- NOD mouse = Non-Obese Diabetic mouse
- Drosophila: if the sample concerns the entire organism, select the structure FBbt:00007001: anatomical structure
- Drosophila is a holometabolous insect with 4 development stages: egg (24h->)larva (5 days->)pupa (5 days->) adult. The larva stage is sub-divised into two steps: larva + 24h and larva + 48h
- Drosophila: unfertilised eggs are annotated with development stage FBdv:00005287 (unfertilized egg stage) and the structure FBbt:00007001: anatomical structure E-MEXP-2580 (http://www.ebi.ac.uk/arrayexpress/experiments/E-MEXP-2580)
- Drosophila: stage 14 oocytes are annotated with development stage FBdv:00005369 (adult stage) and the female reproductive system structure FBbt:00005283: stage S14 oocyte E-MEXP-2746 (http://www.ebi.ac.uk/microarray-as/ae/browse.html?keywords=E-MEXP-2746)
- Drosophila: cycles and stages, see here (http://www.sdbonline.org/fly/aimain/2stages.htm)
- Mouse: the stages can be described as E15.5 (example) that means 15.5 dpc (days post-coitum, days after fertilization), you have to use the corresponding TheilerStage (in this example E15.5 is still related to TheilerStage23 (15dpc)).
- Mouse: stages and number of cells, see here (http://genex.hgu.mrc.ac.uk/Databases/Anatomy/MAstaging.shtml)
- Zebrafish: follow this link (http://en.wikipedia.org/wiki/Zebrafish#Wild-Type_strains) for listed wild-types
- Zebrafish: follow this link (http://zfin.org/zf_info/zfbook/stages/stages.html) for matching hpf (=hours post fertilization) and development stages
- Zebrafish: whole embryo samples are reported on ZFA:0001094 (whole organism); no Affymetrix chips annotation on ZFA:0000037 (anatomical structure)

Curation of relations between organs

This section aims at describing how to curate relations between organs for BGee (http://bgee.unil.ch) . This is supposed to make the handling of the process easier for new curators.

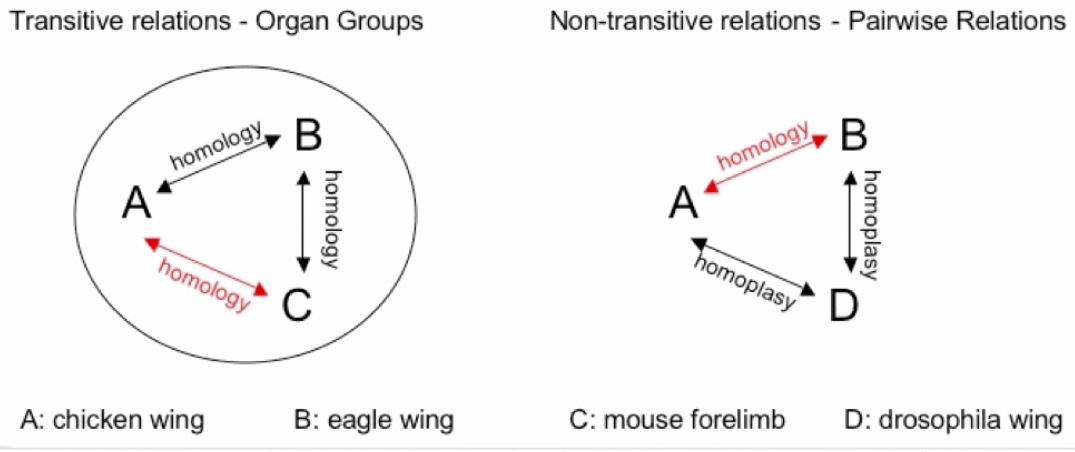
Julien has developed an ontology of homology and related concepts in biology (http://bgee.unil.ch/bgee/download/homology_ontology.obo) that describes relations that can exist between organs (homology, homoplasy/analogy, functional equivalence...). It is such relations that the curators have to create between organs.

The relations can be divided in two different types:

- Transitive relations (example: homology): We have three elements (A, B and C). If the relation holds between the first (A) and second (B) elements and between the second (B) and third (C) elements, the relation NECESSARILY holds between the first (A) and third (C) elements. As such relations hold between all the elements, we can group the organs linked by transitive relations into Organ Groups (OG).

- Non-transitive relations (example: homoplasy/analogy): We have three elements (A, B and D). If the relation holds between the second (B) and the third (D) elements and between the third (D) and the first (A) elements, the relation does NOT necessarily hold between the first (A) and second (B) elements. As such relations do not hold between all the elements, we cannot group the organs linked by

non-transitive relations but have to form pairwise relations between the organs.



Consequently, the relations between organs are curated in two separate files:

Files

here description of format only, for significance of each line, see further in the page

nonTransitiveRelations.xls

The "***nonTransitiveRelations.xls***" file contains the pairwise relations.

The format is (\t = tabulation char):

organid1 \t organ name1 \t organid2 or OGid \t organ name2 or OG name \t HOMid \t HOMname \t confidence code \t reference(s) \t note

TransitiveGroups.xls

The "***TransitiveGroups.xls***" file contains the Organ Groups - OGs.

The format is (\t = tabulation char):

//

id \t OG:+7 digits

name \t free text

description \t free text (optional)

synonym \t free text (optional) \t synonym type \t synonym source

synonym \t free text (optional) \t synonym type \t synonym source

...

xref \t ID of the xref (optional)

...

HOMid \t HOM:+7 digits \t HOM name

actionForCARO \t keep or delete (optional)

actionForNonCARO \t keep or delete (optional)

member \t organ ID \t organ name \t confidence code \t reference(s)

member \t organ ID \t organ name \t confidence code \t reference(s)

...

note \t free text (optional)

//

How to annotate

- Every OG has an OGid. OGs whose organs are related by homology (Homologous Organ Groups - HOG) also have a HOGid (HOG:+7 digits identical to the OGid 7 digits). Create new OGids from the last ids. Do not try to use missing numbers between OGids as they might have been used before and that could create confusion.

- Every OG has a name.
  - Give precise names so there is no confusion about what a OG designates (for example: name the OG medial nasal process ectoderm and NOT just ectoderm).
  - Avoid giving identical names to several OGs.
  - Try to make the name as general as possible so it covers the structures of the different organisms (for example: forearm (human) and lower arm (mouse) are in a OG named forelimb zeugopodium). Alternatively use the mouse names as these terms are less medical than the human ones.
  - OGs can contain completely different structures (for example: lung and swimm bladder, limb and fin...) which renders the naming of the OG difficult. In these cases, you should use a composite name, separating the words by hyphen (for example: lung - swim bladder or limb - fin...).
  - Some organ names can be written with or without a hyphen (for example: tubo-tympanic or tubotympanic recess). In these cases write the OG name without the hyphen in order to be coherent with previous OGs.

- OG should have a description.
  - When relevant, the description should be taken from one of the organs included in the OG (zebrafish, xenopus and drosophila ontology are the only ones with description) and the reference for the description is then the organ id. When the description has to be modified to fit for all organisms, it should be precised that it was adapted from such organ. Example: for hindbrain - "The most posterior of the three principal regions of the brain." [adapted from ZFA:0000029].
  - When irrelevant or absent, you can add descriptions from anatomical dictionaries, articles, books... Always cite the reference. Precise when it was not taken directly but adapted from the reference.

    Example of reference from book for a description:
    "The quadriceps is a collective term for the rectus femoris and the three heads of the vastus (lateralis, medialis, intermedius)." [see Kardong KV, Vertebrates: Comparative Anatomy,

Function, Evolution, Fourth Edition (2006) McGraw-Hill, p.391]

- When they exist, synonyms should be present. You will find synonyms in the various ontologies (mouse and human embryo do not have synonyms). Synonyms found in dictionaries, articles and books should also be added. It is unnecessary to add plural synonyms that simply add a 's'.

  The type of the synonyms should be precised. See http://www.geneontology.org/GO.format.obo-1_2.shtml for more details. Synonyms can be:

  EXACT
  An alias in which the alias exhibits true synonymy. Example: ornithine cycle for urea cycle [OBO Format Metamodel]
  RELATED
  An alias in which the alias is related to the primary class name, but not necessarily broader or narrower. Example: virulence for pathogenesis
  NARROW
  An alias in which the alias is narrower than the primary class name. Example: pyrimidine-dimer repair for photoreactive repair
  BROAD
  An alias in which the alias is broader than the primary class name. Example: cell division for cytokinesis

- NB: 'PLURAL' can be add to the type if the term is really different in the plural. Example: meninges is the EXACT PLURAL for meninx

- The source of the synonym should be noted. It will be the id of the organ from which the synonym was taken or a book, article reference.

- The Homology Ontology term id (HOMid) and name come from the ontology of homology and related concepts in biology (http://bgee.unil.ch/bgee/download/homology_ontology.obo) developed by Julien. They describe which relation (historical homology, serial homology, functional equivalence...) exists between the organs of the group. The same organs can be linked by different relations (historical homology and functional equivalence). In this case you must create a different OG for each relation as the references for each organ will be different for each relation.

Confidence level

- We assign confidence code to each organ. It describes how confident we are this organ belongs to this OG with this HOMid relationship.

  The confidence codes are:
  OB obvious (general knowledge, no need for reference. Valid mostly for close species)
  WE well-established (add a reference stating explicitly about the relation, can be textbook example)
  DE debated (add the references and choose a consensus)
  UN uncertain (uncertainty of the relation for example if no reference was found. Could also be used if the uncertainty is claimed explicitly in the reference or if the curator judges that the reference has not enough value)
  IN inferred (deduced by Bgee curator from references which do not discuss this mapping explicitely; or personnal communication from experts [≈ non traceable author statement])
  HO Homolonto software = not manually curated (code automatically applied by Bgee, not used by curators)

Note 1: some WE are in fact 'obvious' with textbook references or a single literature reference (but mostly

without explicit description)

Note 2: we try to avoid OB, so changing OB into WE by adding a reference

References

- Each organ also has book, article or internet reference(s) that state that this organ has such a relation with other organs of the group.
  - To be coherent references should follow these models:
    - Book:
      - Liem KF, Bemis WE, Walker WF, Grande L, Functional Anatomy of the Vertebrates: An Evolutionary Perspective, Third Edition (2001) Orlando Fla.: Harcourt College Publishers, p.275
    - Article:
      - Shimeld SM and Holland PW, Vertebrate innovations. PNAS (2000) 97(9): 4449-4452
      - Graham A, The development and evolution of the pharyngeal arches. J Anat (2001) 199: 133-141
      - Maximino C, Evolutionary Changes in the Complexity of the Tectum of Nontetrapods: A Cladistic Approach. PLoS ONE (2008) 3(10): e3582
      - Mess A, Carter AM, Evolution of the placenta during the early radiation of placental mammals. Comparative Biochemistry and Physiology-Part A: Molecular and Integrative Physiology (2007) 148: 769-779

Note: the reference rules of Wikipedia might be useful to keep in mind: generic (http://en.wikipedia.org/wiki/Template:Citation) , journal article (http://en.wikipedia.org/wiki/Template:Cite_journal) , book (http://en.wikipedia.org/wiki/Template:Cite_book)

ISBN reference

(ISBN-13)

une seule paire de crochet a la fin de la ligne. Ca fait : [xrefId "notes optionnelles", xrefIdEventuelles "notes optionnelles]

Les xrefs sont separees par une virgule, tu peux en mettre autant que tu veux.

http://oboformat.googlecode.com/svn/trunk/doc/obo-syntax.html#2.6

- Kardong KV, Vertebrates: Comparative Anatomy, Function, Evolution, Fourth Edition (2006) Boston etc.: McGraw-Hill
  - ISBN:978-0072528305
- Liem KF, Bemis WE, Walker WF, Grande L, Functional Anatomy of the Vertebrates: An Evolutionary Perspective, Third Edition (2001) Orlando Fla.: Harcourt College Publishers
  - ISBN:978-0030223693
- Gilbert SF, Developmental Biology, Eighth Edition (2006) Sunderland Mass.: Sinauer Associates
  - ISBN:978-0878932504
- Romer AS, Vertebrate body, Fourth Edition (1970) Philadelphia etc.: WB Saunders
  - ISBN:978-0721676678
- Hildebrand M, Analysis of vertebrate structure, Second Edition (1983) New York etc.: J. Wiley & Sons
  - ISBN:978-0471090588
- Schmidt-Rhaesa A, The evolution of organ systems (2007) Oxford: Oxford University Press
  - ISBN:978-0198566694
- Butler AB, Hodos W, Comparative vertebrate neuroanatomy: Evolution and Adaptation, Second

Edition (2005) New York: J. Wiley & Sons
    - ISBN:978-0471210054
- Paul WE, Fundamental Immunology, Sixth Edition (2008) Philadelphia etc.: Lippincott Williams and Wilkins
    - ISBN:978-0781765190
- Stevens CE and Hume ID, Comparative physiology of the vertebrate digestive system, Second edition (2004) Cambridge University Press
    - ISBN:978-0521617147
- Ruppert EE, Fox RS, Barnes RD, Invertebrate zoology: a functional evolutionary approach. Seventh Edition (2003) USA: Thomson Brooks/Cole
    - ISBN:978-0030259821
- Colbert EH, Evolution of the vertebrates: a history of the backboned animals through time, Fifth Edition (2001) New York: J. Wiley & Sons
    - ISBN:978-0471384618
- Kapoor BG, Bhavna Khanna, Ichthyology Handbook (2004) Narosa Publishing House
    - ISBN:978-3540428541
- Dorian AF, Elsevier's encyclopaedic dictionary of medicine, Part B: Anatomy (1988) Amsterdam etc.: Elsevier
    - ISBN:978-0828893114

```
syntax example
[ISBN:978-0878932504 "Gilbert SF, Developmental Biology (2006) p.558"]
```

DOI reference

example

- DOI:10.1146/annurev.pp.39.060188.001135

If DOI is not available (check deeply before...it is sometimes available on the journal web page, and not directly on the NCBI-PubMed search page), use PMID.)

example

- PMID:11567064

```
syntax example
[DOI:10.1016/j.ydbio.2005.04.035 "Yee NS, Lorent K, Pack M, Exocrine pancreas development in zebrafish. Devel
or
[PMID:11567064]
```

Note

- Any specific characteristic of an OG :
    - why a structure in one species was included
    - why a structure in one species was NOT included
    - why several structures were included (serial homology, no general term in one ontology)
    - ...

  should be added under note in order to keep track of what has been done.

Tips for the curation of the relations

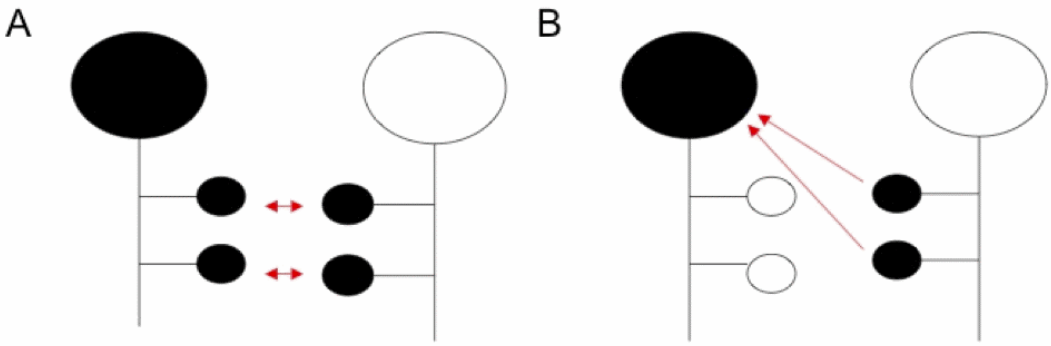
- Basic search in Bgee will search for the term in organ names, synonyms and descriptions.
- Organs do not necessarily have the same name in the different ontologies.

  Watch out for synonyms!
- You might have to try searching for only part of the organ name, especially for mouse and human (embryo) species.

  Example: in mouse you find the structure cranial ganglion under the term cranial that is a child of the term ganglion
- Presumptive, primitive, future, primordium, degenerating structures... have to be included under the OG of the fully formed organ.

  Example: the structure "cerebellum primordium" is included in the OG "cerebellum"
- Always try to be as precise as possible.

  Example: there are many different endoderm terms: embryonic, extraembryonic, midgut endoderm, thyroid endoderm... and if possible there should be a OG for each of them
- Some organs that have identical name but are part of a different structure may still be the same organ. They may be part of different structures because the structures had not developed yet (for example: in human embryo ontology the apical ectodermal ridge is first part of the limb bud, then the hand/footplate and finally the digital region) or because they migrate during development (for example: germ cells).
- An organ can be member of only one HOG (Homologous Organ Groups).
- Specific case - right/left part of an organ, substructures of an organ, specific tissue types (endoderm)



The spheres correspond to organs in an ontology, the lines to their relationships

Black: existence, white: absence, red arrows: homology relationship

Case A)

Ontology1: precise and general terms exist

Ontology2: precise terms exist but the general term does not exist

Create OG for the precise terms.

EXAMPLE:
Ontology1:

- HOG:0000309 gut
  - HOG:0000285 foregut
  - HOG:0000290 midgut
  - HOG:0000459 hindgut

Ontology2:

- FBbt:00005379 foregut
- FBbt:00005383 midgut
- FBbt:00005384 hindgut

(FBbt gut does not exist)
see OG:0000285 (foregut) and OG:0000290 (midgut) and OG:0001709 (hindgut)

Case B)

Ontology1: precise terms do not exist but the general term exists

Ontology2: precise terms exist but the general term does not exist

In this case the precise terms have to be included in the OG of the general term.

- For organ tissues (epithelium, mesenchyme...), components of the circulatory system or regions of the brain, the homology relationships are uncertain (is it really homologous? which type of homology?...) so OGs containing such structures were attributed the HOMid and name: HOM:0000000 similarity *with an OB evidence code* [has to be replaced to UN uncertain (ANiknejad 15:17, 15 January 2010 (UTC))] until a reference is found.

- Some authors conclude from the same set of genes expressed in a structure that the structure was already present in the ancestor (historical homology) but some are cautious and rather conclude the regulatory network was present in the ancestor (deep homology). Furthermore, Erwin and Davidson (The last common bilaterian ancestor (2004) Devlpmt 129: 3021-3032) argue that "differentiation gene batteries and body parts are not the same thing, and it cannot safely be assumed that the PDA possessed a full range of complex body parts homologous to those of extant Bilateria. [...] we think the true homologies in some of these cases lie at the level of cell-specification processes, not morphogenesis." So whenever it seems the authors are not cautious enough it is better to use a UN confidence code.

Possibilities discussed and on the way to be used during Bgee annotation process (June 2010)

- In some cases a structure in one species has split into three different structures in two other species (for example: the adductor mandibulae complex is a single structure in zebrafish but it has divided into the temporalis, masseter, pterygoideus, tensor tympani and tensor veli palati in mammals (see Liem, Functional Anatomy of the Vertebrates: An Evolutionary Perspective, p.333-334 + Table 10-4 and Diogo R, Hinits Y and Hughes SM, Development of mandibular, hyoid and hypobranchial muscles in the zebrafish: homologies and evolution of these muscles within bony fishes and tetrapods. BMC Developmental Biology (2008) 8(24) doi:10.1186/1471-213X-8-24). So individual muscles are

homologous between human and mouse but all these muscles are homologous with the zebrafish one. It is the case where an organ belongs to several OGs. It is necessary to create three OGs for mammal muscles and the zebrafish muscle belongs to the three OGs.

- An OG is a member of another OG in some cases (see also below Special cases for historical homology OG).

For instance there is a problem of confidence in the homology relationships:

- - you are sure that 2 structures in 2 species of fishes are homologous
  - you are sure that 2 structures in two mammal species are homologous
  - you are NOT sure that these structures are homologous between fishes and mammals.

  So:
  - the structures A (fishes) and B (fishes) are part of the OG 1 with an "OB" confidence
  - the structures C (mammals) and D (mammals) are part of the OG 2 with an "OB" confidence.
  - the OG 1 and 2 are part of the OG 3 with the "DE" confidence.

  So basically, the OGs 1 2 and 3 describe the same homologous structures, but with different confidence level.

- *In the case where all ontologies have precise terms but no general terms; this would lead to have a LOT of OGs with no parent, at the root of the OG ontology. It can be boring for a display on the website. So in this case, and only this case (a lot of OGs with no parents at all) we could create a "fake" OG named after the general term and containing no structure that would have part_of relationships with the OGs for the precise terms.* **-->will be modified making HOG.obo file Caro compliant**

- *This would also be nice if as usually in the ontologies, the general term has a complete and precise definition (see ZFA:0000045 (http://bgee.unil.ch/bgee/bgee?page=anatomy&action=organ_details&organ_id=ZFA%3A0000045&organ_children=on)) and the precise term just have a definition that says it's part of this structure (see ZFA:0000812 (http://bgee.unil.ch/bgee/bgee?page=anatomy&action=organ_details&organ_id=ZFA%3A0000812&organ_children=on)). So if it's not possible to form an OG:general term there will be no precise definition.* **-->will be modified making HOG.obo file Caro compliant**

Special cases for historical homology OG

- it is possible to create several times the 'same' OG (same name and same HOMid, but of course different OGid) with different members to make reference to different 'ancestor'
  - example 1: OG:0001718 refers to the bilaterian ancestor and OG:0000285 refers to the vertebrate ancestor

id OG:0001718

name foregut

HOMid HOM:0000007 historical homology

member OG:0000285 foregut DE

member FBbt:00005379 foregut DE

// id OG:0000285

name foregut

HOMid HOM:0000007 historical homology

member EHDAA:520 foregut WE

member XAO:0000232 foregut WE

member EMAPA:16548 foregut WE

member MA:0001526 foregut WE

member EMAPA:16248 foregut diverticulum WE

//

- example 2: to avoid re-listing the members of an already existing OG

id OG:0001717

name testis-ovary

HOMid HOM:0000008 biological homology

member OG:0000252 testis WE

member OG:0000251 ovary WE

- - caution: not accepted to have an OG that contains one OG and several organs --> organs have to be grouped into another OG and this OGid reported in the considered OG

See also Special OG examples

OG relationships pipelines

Note:

Since January 2011, we have two pipelines of organ groups relationship curation, one to create a CARO compliant vertebrates-only ontology (for OBOFoundry), the other to create a non-CARO all-species ontology (for Bgee release). Both pipelines use the same transitiveGroups.txt file, but depending on the pipeline the algorithm is reading the file differently. Actually transitiveGroups.txt (TransitiveGroups.xls) file may contain the following lines as part of OG format (see CARO compliant pipeline below):

- actionForCARO
  - keep or delete
- actionForNonCARO
  - keep or delete

Description of CARO and non-CARO pipelines

CARO compliant pipeline

The customized file for the relationships is on the svn:

- /HOG/custom_HOG_relationships_caro_vertebrates.txt

(associated .xls file is custom_HOG_relationships_caro_vertebrates.xls)

It is currently set for managing the creation of a

- Vertebrate CARO compliant ontology (available at http://obofoundry.org/cgi-bin/detail.cgi?id=vHOG)

CARO compliance involves the creation of 'junk' OGs in the transitiveGroups.txt (such as 'immaterial anatomical entity').

'Junk' OGs do not have neither HOMid nor members, so they need the 'actionForCARO keep' tag to be considered by the algorithm (by default, the algorithm removes all terms with no members or containing only one species).

A xref line allows to associate CARO term with the OG.

non-CARO pipeline

The customized file for the relationships is on the svn:

- /HOG/caroToNonCaroModificationsFile.txt

It is currently set for managing the creation of the

- Bgee historical homology ontology, on all species present into the database

The idea of the algorithm is to make annotators work easier, by avoiding to get two totally different ontologies to manage. Here is explained how the algorithm works, so annotators know how to manage it:

The algorithm tries first to build the previous "CARO vertebrates-only" ontology (always keeping the term with 'actionForCARO keep', even if they have no members or contain only one species). The difference is that it also keeps terms with 'actionForNonCARO keep', even if they have no members or contain only one species. (the algorithm still removes terms not tagged, while having no members or containing only one species) Then the algorithm will properly removed the unnecessary terms, i.e. all not-yet-removed terms with no members or containing only one species, without the tag 'actionForNonCARO keep', and terms with the tag 'actionForNonCARO delete' (should never exists). "Properly removed" means that children of a term to delete will become children of all parents of the term, by a proper relation (defined using the OBOFoundry composition rules).

So you should really be aware that this second pipeline is kind of a hybrid, and it could be sometimes misleading: it first builds the CARO ontology (but not exactly the same, c.f. 'actionForNonCARO keep'), then remove the unnecessary terms, to generate a weird "half-CARO" ontology, so you have less modifications to do.

Annotation on the output of the algorithm

Note: each output of the algorithm gives 2 files

- a .obo file, wich you can read as a text file or visualize with OBOedit (http://oboedit.org /?page=download)
- a txt file, which lists all the warning and generates lists of relationships to manually curate

obo file

This is the output of the algorithm that defines your ontology.

txt file

This is the output txt file of the algorithm that lists and comments all the non-automatically generated relationships. This file is used to modify and to complete the custom_HOG_relationships_caro_vertebrates.xls

- open the txt file with xls

```
This HOG is present in the file custom_HOG_relationships_caro_vertebrates.txt, but it doesn't exist: OG:00016
```

- check the TransitiveGroups.xls file
- the above comment appears also when none of the OG's members are considered in the ontology (for instance, the group contains only Zebrafish and Drosophila members and you are working on the Caro vertebrate ontology)

```
Searched for cycles
```

- done twice to avoid any cyles

```
4 "update" or "delete" in the curation file do not correspond to any relations generated by the algorithm. Re
```

- follow instructions and modify custom_HOG_relationships_caro_vertebrates.xls

```
Relation types still undefined:
```

- copy and paste into custom_HOG_relationships_caro_vertebrates.xls ('sorted_and_corrected' sheet)
- define the relation type (is_a/part_of/all) and give a status (delete/update)

Caution:

-
  - if you decide to 'delete' a relationship still undefined, put 'all' as relation type
  - check the new descent_HOG_name list, if a descent is present more than once, be careful attributing 'part_of' relationships (cycles), and remember that a term of the ontology has only ONE 'is_a' relationship

Tips: use the .obo file of the ontology to check what is already automatically generated by the algorithm.

```
145 potentially redundant relations:
```

The list contains as well the 'undefined' relationships already in the 'Relation types still undefined:', so don't worry, the number of potentially redundant relations is less...(you will see that in the next output)

```
HOGs with multiple is_a relationships (a HOG should have one and only one is_a relation, you should remove un
```

- follow the instructions (caution: 'remove unnecessary relations'= put 'delete' status

```
HOGs with no parents at all:
```

- should be only the root of the ontology

```
HOGs with no is_a relationships (don't bother if there still are undefined relations):
```

- this list will be smaller in the next output of the algorithm, once you have defined new relationships
- we aim at having one 'is_a' relationship by OG, anyway there is still a lot of OGs without 'is_a' relationship

```
Hogs with no part_of relationships (don't bother if there still are undefined relations):
```

- this list will be smaller in the next output of the algorithm, once you have defined new relationships

Export the xls file into txt file

At each new release of Bgee, you need to export the xls file into a txt file, for the developers to integrate your work into the database.

Please use OpenOffice instead of Excel to do it. Excel generates too many weird things during the export, add quotes around every text area, etc.

- Open your xls file in OpenOffice
- File > save as
- file type: choose "text CSV (.csv)"
- Click "save as"
- Confirm that you want to export in text file
- Choose the appropriate chars encoding (UTF-8 for instance)
- Choose {tab} as field separator
- leave empty the text separator (no quotes nor single quotes)
- save the file

Annotation benchmarks

January 2010, Bgee 06

- 1'011 HOG Historical homology
- 502 without references (unannotated)

NB: information from the TransitiveGroups.xls available on January 2010

```
<50% unannotated
>50% annotated
```

April 2010, Bgee 07

- 1'005 OGs Historical homology
- 460 unannotated

```
>45% unannotated
>54% annotated
```

January 2011, Bgee 08

- 1'105 OGs Historical homology
- 140 OGs whithout references (unannotated)

```
<13% unannotated
>87% annotated
```

Juin 2011, Bgee 09 (in progress)

- 1'165 OGs Historical homology
- 89 OGs whithout references (unannotated)

```
<8% unannotated
>92% annotated
```

Where to find informations

- Books
  - For metazoan organ system evolution:
    - Schmidt-Rhaesa A, The evolution of organ systems (2007) Oxford University Press, 385p.
  - For vertebrate anatomy and evolution:
    - Kardong Kenneth V, Vertebrates: Comparative Anatomy, Function, Evolution, Fourth Edition (2006) McGraw-Hill, 782p.
    - Karel F. Liem et al., Functional Anatomy of the Vertebrates: An Evolutionary Perspective, Third Edition (2001) Orlando Fla.: Harcourt College Publishers, 703p.
  - For mouse development:
    - Kaufman M.H. & Bard JBL, The anatomical basis of mouse development (1999) Academic Press, San Diego, p.291

- Other multi-species ontologies
  - Uberon
  - MIAA
  - Bilaterian ontology

- Single species anatomical ontologies (in definition field often)
  - ZFIN
  - Teleost
  - Xenopus
  - Mosquito

- Articles that may be worth looking at:
  - mammals ears (http://www.sciencemag.org/cgi/content/full/326/5950/243)
  - dental and gnathic features in primates (http://www.nature.com/nature/journal/v461/n7267/full/nature08429.html)
  - article about how they do curation at the Rat database (http://www.ploscompbiol.org/article/info%3Adoi%2F10.1371%2Fjournal.pcbi.1000582)
  - mushroom bodies (http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VRT-4Y4NM9K-7&_user=10&_rdoc=1&_fmt=&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=1e01b3320f898813b066f3cae1feadb1) . I also have seen a talk of Detlev Arendt (EMBL) that was seeing expresseion of homologous genes in some parts of the vertebrate brain (deep homology).

- CNS evolution (http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VRT-4WYTJG8-9&_user=10&_rdoc=1&_fmt=&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=b7bb36d7908896fa6d8adc270a3d83d9)

Organ system specialists

- CNS
  - Wassef M. (France)
  - Puelles L. (Spain)
  - Holland LZ. (lzholland@ucsd.edu), amphioxus specialist
  - Glenn Northcutt R., PhD Professor (rgnorthcutt@ucsd.edu), California (San Diego) (thanks to Linda Z. Holland)

Dr. Northcutt is a leader in comparative vertebrate neurobiology. The Northcutt laboratory conducts research work in three major areas: comparative neurobiology of vertebrate forebrain organization and cranial nerves, development and evolution of the lateral line system, and development of the gustatory system.

- Fish reproduction
  - Manfred Schartl (D)

- Zebrafish cardiac conduction
  - Neil C. Chi at UCSD
  - David Milan at Massachusetts General Hospital.

- Amphibian gonadal development
  - Maria Ogielska (Chair of Vertebrate Zoology, Wrozlaw-University, Poland)
    - ogielska@biol.uni.wroc.pl

- Insect brain, homologies insect-vertebrate nervous systems
  - Heinrich Reichert (Basel) [3] (http://www.biozentrum.unibas.ch/reichert/index.html)

- Germ layers (and evo-devo, neural crest cells, cartilage and bones evolution)
  - Brian K Hall at Dalhousie University, Faculty of Sciences
    - brian.hall@dal.ca

- Miscellaneous
  - Noden DN, PhD Professor of Embryology and Animal Development (dmn2@cornell.edu), development of vertebrate craniofacial muscles, blood vessels, and skeletal tissues (thanks to Linda Z. Holland)
  - Philippe Janvier, Palaeozoic vertebrates specialist, Museum National de l'Histoire Naturelle, Paris

Ontology contact

- ZFA
  - Ceri Van Slyke (van_slyke@zfin.org)

- XAO
  - Peter Vize (pvize@ucalgary.ca)

Retrieve new experiments from ArrayExpress

- Go to: bgee/extra/pipeline/curation/Affymetrix/get_new_experiments/

- Retrieve xml files with all experiments for the different species

```
wget http://www.ebi.ac.uk/microarray-as/ae/xml/experiments?species=Homo+sapiens
```

- Rename the file in "Homo_sapiens.xml"
- Repeat the same procedure for the other species in Bgee
- Check the xml files, they should be larger than the previous ones
- `svn update` to get the last version of the file annotation.xls
- From annotation.xls, copy and replace each file (present on the svn) "microarrayExperiment", "not_included" and "not_included_for_now" with the updated content. These 3 files should contain all experiments already included into Bgee
- `./change_end_of_line.sh` to change \r to \n in the files
- `perl parse_experiments_xml_new.pl Homo_sapiens.xml` to create a file Homo_sapiens.out with new experiments. Some warnings can appear ("... element has non-unique value in 'name' key ..."), this is not important for us (as we can store only one name in Bgee).

- Append this file to the tab "Homo sapiens" (where all experiments are listed) in annotation.xls
- Repeat this for other species.

To do

- Review all existing OGs to see if other HOMids can be applied to them (such as functional equivalence)

- **Some structures that are known to be historically homologous have references relating to similarities in development and thus defining them as biologically homologous (eye structures, inner ear structures...). It would be good to rather find a reference for historical homology.**

- Add references. It should be easier to find references for OGs with historical homology HOM name and OB evidence code.

- Add descriptions

- It would be nice to make a decision tree like for GO annotation [4] (http://www.geneontology.org /GO.evidence.tree.shtml) or to use the one already existing in obo format [5] (http://obo.cvs.sourceforge.net/*checkout*/obo/obo/ontology/evidence_code.obo)

- This page was last modified on August 4, 2011, at 14:42.

3 Appendix 3: supplementary table 1 of chapter 5

This table has been split into 7 distinct tables to be included in these appendices. It is available online at: http://bioinfo.unil.ch/supdata/Bastian_PhD_thesis/index.html .

3.1 Supplementary table of triplets of zebrafish duplicates with mouse singletons, with results of expression patterns comparisons

Zebrafish duplicate 1 Ensembl ID	Zebrafish duplicate 2 Ensembl ID	Mouse singleton Ensembl ID	Mouse singleton Ensembl name	Spatio-temporal analysis	Spatial-only analysis	Expression vs. No Expression	High quality data
ENSDARG00000001686	ENSDARG00000078973	ENSMUSG00000089917	Uckl1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000006600	ENSDARG00000011408	ENSMUSG00000066568	Lsm14a	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000007812	ENSDARG00000001549	ENSMUSG00000027109	Sp3	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000008057	ENSDARG00000013979	ENSMUSG00000024425	Ndfip1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000008109	ENSDARG00000030053	ENSMUSG00000055762	Eef1d	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000008370	ENSDARG00000006125	ENSMUSG00000025162	Csnk1d	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000009087	ENSDARG00000036628	ENSMUSG00000024610	Cd74	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000009881	ENSDARG00000086881	ENSMUSG00000053560	Ier2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000011609	ENSDARG00000030583	ENSMUSG00000039275	Foxk2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000012553	ENSDARG00000087346	ENSMUSG00000068798	Rap1a	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000012591	ENSDARG00000035054	ENSMUSG00000027835	Pdcd10	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000012818	ENSDARG00000013582	ENSMUSG00000046707	Csnk2a2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000014794	ENSDARG00000071691	ENSMUSG00000030884	Uqcrc2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000015823	ENSDARG00000055433	ENSMUSG00000031988	Vps26b	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000016255	ENSDARG00000007323	ENSMUSG00000038467	Chmp4b	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000017010	ENSDARG00000010279	ENSMUSG00000040188	Scamp2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000018602	ENSDARG00000007257	ENSMUSG00000017831	Rab5a	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000018898	ENSDARG00000002271	ENSMUSG00000024750	Zfand5	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000019644	ENSDARG00000071076	ENSMUSG00000030246	Ldhb	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000019949	ENSDARG00000075954	ENSMUSG00000070436	Serpinh1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000023921	ENSDARG00000010745	ENSMUSG00000031701	Dnaja2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000030236	ENSDARG00000043555	ENSMUSG00000032328	Tmem30a	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000030441	ENSDARG00000034201	ENSMUSG00000020089	Ppa1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000031907	ENSDARG00000019362	ENSMUSG00000006498	Ptbp1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000032532	ENSDARG00000039880	ENSMUSG00000007656	Arpp19	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000035066	ENSDARG00000038780	ENSMUSG00000020923	Ubtf	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000036236	ENSDARG00000007959	ENSMUSG00000029776	Hibadh	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000036715	ENSDARG00000023279	ENSMUSG00000005625	Psmd4	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000037860	ENSDARG00000045230	ENSMUSG00000036751	Cox6b1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000039034	ENSDARG00000035715	ENSMUSG00000047945	Marcksl1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000039650	ENSDARG00000043448	ENSMUSG00000026223	Itm2c	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000042837	ENSDARG00000015790	ENSMUSG00000032412	Atp1b3	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000052789	ENSDARG00000035869	ENSMUSG00000037458	Azin1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000052842	ENSDARG00000007409	ENSMUSG00000021868	Ppif	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000056623	ENSDARG00000071018	ENSMUSG00000013663	Pten	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000058044	ENSDARG00000029663	ENSMUSG00000020149	Rab1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000060150	ENSDARG00000005134	ENSMUSG00000017428	Psmd11	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000067975	ENSDARG00000044092	ENSMUSG00000054428	Atpif1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000078113	ENSDARG00000068940	ENSMUSG00000050856	Atp5k	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000079251	ENSDARG00000077329	ENSMUSG00000051790	Nlgn2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000089550	ENSDARG00000089610	ENSMUSG00000052534	Pbx1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000090697	ENSDARG00000002549	ENSMUSG00000022336	Eif3e	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000031317	ENSDARG00000007682	ENSMUSG00000016344	Ppdpf	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000053301	ENSDARG00000091756	ENSMUSG00000068154	Insm1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000011127	ENSDARG00000028664	ENSMUSG00000021037	Ahsa1	Overlap only	Overlap only	Overlap only	Subfunctiona
ENSDARG00000032970	ENSDARG00000022509	ENSMUSG00000031818	Cox4i1	Overlap only	Overlap only	Overlap only	Subfunctiona
ENSDARG00000011141	ENSDARG00000059311	ENSMUSG00000029168	Dpysl5	Overlap only	Overlap only	Overlap only	Neofunctiona
ENSDARG00000036848	ENSDARG00000061120	ENSMUSG00000038178	Slc43a2	Overlap only	Overlap only	Overlap only	Neofunctiona
ENSDARG00000037361	ENSDARG00000005254	ENSMUSG00000079111	Kdelr2	Overlap only	Overlap only	Overlap only	Neofunctiona
ENSDARG00000052928	ENSDARG00000073734	ENSMUSG00000044147	Arf6	Overlap only	Overlap only	Overlap only	Neofunctiona
ENSDARG00000067741	ENSDARG00000002994	ENSMUSG00000003752	Itpkc	Overlap only	Overlap only	Overlap only	Neofunctiona
ENSDARG00000026611	ENSDARG00000025428	ENSMUSG00000053113	Socs3	Overlap only	Subfunctiona	Overlap only	Overlap only
ENSDARG00000041394	ENSDARG00000015831	ENSMUSG00000005483	Dnajb1	Overlap only	Neofunctiona	Overlap only	Overlap only
ENSDARG00000012194	ENSDARG00000036496	ENSMUSG00000028603	Scp2	Overlap only	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000068478	ENSDARG00000076836	ENSMUSG00000075706	Gpx4	Overlap only	Neofunctiona	Overlap only	Neofunctiona

ENSDARG00000055398	ENSDARG00000091481	ENSMUSG00000050295	Foxc1	Overlap only	Both neo-	Overlap only	Neofunctiona
ENSDARG00000007671	ENSDARG00000054771	ENSMUSG00000055737	Ghr	Subfunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000038159	ENSDARG00000007369	ENSMUSG00000055799	Tcf7l1	Subfunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000009418	ENSDARG00000029764	ENSMUSG00000005583	Mef2c	Subfunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000032369	ENSDARG00000076440	ENSMUSG00000002803	Btbd6	Subfunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000034700	ENSDARG00000045971	ENSMUSG00000023951	Vegfa	Subfunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000058992	ENSDARG00000013704	ENSMUSG00000015714	Lass2	Subfunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000016238	ENSDARG00000077044	ENSMUSG00000035199	Arl6ip5	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000057093	ENSDARG00000003098	ENSMUSG00000042207	Kdm5b	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000004702	ENSDARG00000006275	ENSMUSG00000051495	Irf2bp2	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000029439	ENSDARG00000005122	ENSMUSG00000029467	Atp2a2	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000059391	ENSDARG00000011934	ENSMUSG00000019528	Gyg	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000026882	ENSDARG00000007818	ENSMUSG00000035863	Palm	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000057770	ENSDARG00000011929	ENSMUSG00000031425	Plp1	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000045240	ENSDARG00000036073	ENSMUSG00000056216	Cebpg	Subfunctiona	Subfunctiona	Overlap only	Both neo-
ENSDARG00000003820	ENSDARG00000009594	ENSMUSG00000021775	Nr1d2	Subfunctiona	Subfunctiona	Overlap only	Both neo-
ENSDARG00000063309	ENSDARG00000023443	ENSMUSG00000024812	Tjp2	Subfunctiona	Subfunctiona	Subfunctiona	Overlap only
ENSDARG00000018174	ENSDARG00000017294	ENSMUSG00000032562	Gnai2	Subfunctiona	Both neo-	Overlap only	Neofunctiona
ENSDARG00000012405	ENSDARG00000035809	ENSMUSG00000001506	Col1a1	Subfunctiona	Both neo-	Overlap only	Neofunctiona
ENSDARG00000039576	ENSDARG00000015559	ENSMUSG00000022816	Fstl1	Subfunctiona	Both neo-	Overlap only	Both neo-
ENSDARG00000011824	ENSDARG00000071015	ENSMUSG00000042613	Pbxip1	Subfunctiona	Both neo-	Overlap only	Both neo-
ENSDARG00000042677	ENSDARG00000031075	ENSMUSG00000032076	Cadm1	Subfunctiona	Both neo-	Overlap only	Both neo-
ENSDARG00000028173	ENSDARG00000052330	ENSMUSG00000028962	Slc4a2	Subfunctiona	Both neo-	Overlap only	Both neo-
ENSDARG00000038267	ENSDARG00000027600	ENSMUSG00000028273	Pdlim5	Subfunctiona	Both neo-	Overlap only	Both neo-
ENSDARG00000008170	ENSDARG00000016016	ENSMUSG00000020476	Dbnl	Neofunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000017339	ENSDARG00000069054	ENSMUSG00000026473	Glul	Neofunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000026821	ENSDARG00000035949	ENSMUSG00000029571	Tmem106b	Neofunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000006003	ENSDARG00000034956	ENSMUSG00000028654	Mycl1	Neofunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000007693	ENSDARG00000005481	ENSMUSG00000021025	Nfkbia	Neofunctiona	Overlap only	Overlap only	Neofunctiona
ENSDARG00000001676	ENSDARG00000005739	ENSMUSG00000031342	Gpm6b	Neofunctiona	Subfunctiona	Overlap only	Neofunctiona
ENSDARG00000008788	ENSDARG00000044526	ENSMUSG00000016179	Camk1g	Neofunctiona	Subfunctiona	Overlap only	Neofunctiona
ENSDARG00000010420	ENSDARG00000032849	ENSMUSG00000005125	Ndrg1	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000042029	ENSDARG00000061774	ENSMUSG00000035478	Mbd3	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000056490	ENSDARG00000056483	ENSMUSG00000070003	Ssbp4	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000070475	ENSDARG00000052856	ENSMUSG00000028790	Khdrbs1	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000054274	ENSDARG00000036121	ENSMUSG00000049100	Pcdh10	Neofunctiona	Neofunctiona	Neofunctiona	Neofunctiona
ENSDARG00000038666	ENSDARG00000014947	ENSMUSG00000020429	Igfbp1	Neofunctiona	Neofunctiona	Neofunctiona	Neofunctiona
ENSDARG00000012504	ENSDARG00000045808	ENSMUSG00000039194	Rlbp1	Neofunctiona	Neofunctiona	Neofunctiona	Neofunctiona
ENSDARG00000076900	ENSDARG00000037783	ENSMUSG00000031445	Proz	Neofunctiona	Neofunctiona	Neofunctiona	Neofunctiona
ENSDARG00000003142	ENSDARG00000069440	ENSMUSG00000055639	Dach1	Neofunctiona	Both neo-	Overlap only	Neofunctiona
ENSDARG00000077383	ENSDARG00000002632	ENSMUSG00000021866	Anxa11	Neofunctiona	Both neo-	Overlap only	Neofunctiona
ENSDARG00000034705	ENSDARG00000009311	ENSMUSG00000005716	Pvalb	Neofunctiona	Both neo-	Overlap only	Neofunctiona
ENSDARG00000041062	ENSDARG00000036344	ENSMUSG00000003657	Calb2	Both neo-	Overlap only	Overlap only	Overlap only
ENSDARG00000057853	ENSDARG00000036577	ENSMUSG00000024121	Atp6v0c	Both neo-	Overlap only	Overlap only	Neofunctiona
ENSDARG00000035650	ENSDARG00000031086	ENSMUSG00000021262	Evl	Both neo-	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000038190	ENSDARG00000010953	ENSMUSG00000018736	Ndel1	Both neo-	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000026531	ENSDARG00000058538	ENSMUSG00000022636	Alcam	Both neo-	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000043257	ENSDARG00000069752	ENSMUSG00000001270	Ckb	Both neo-	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000062174	ENSDARG00000009738	ENSMUSG00000017412	Cacnb4	Both neo-	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000052765	ENSDARG00000070173	ENSMUSG00000033981	Gria2	Both neo-	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000040565	ENSDARG00000035327	ENSMUSG00000030399	Ckm	Both neo-	Neofunctiona	Neofunctiona	Neofunctiona
ENSDARG00000004621	ENSDARG00000055455	ENSMUSG00000031517	Gpm6a	Both neo-	Both neo-	Overlap only	Neofunctiona
ENSDARG00000019613	ENSDARG00000008310	ENSMUSG00000032599	Ip6k2	Both neo-	Both neo-	Overlap only	Both neo-
ENSDARG00000009014	ENSDARG00000026165	ENSMUSG00000027966	Col11a1	Both neo-	Both neo-	Overlap only	Both neo-
ENSDARG00000043581	ENSDARG00000069991	ENSMUSG00000036390	Gadd45a	Both neo-	Both neo-	Overlap only	Both neo-
ENSDARG00000004588	ENSDARG00000043235	ENSMUSG00000076431	Sox4	Both neo-	Both neo-	Overlap only	Both neo-
ENSDARG00000032724	ENSDARG00000060457	ENSMUSG00000018217	Pmp22	Both neo-	Both neo-	Overlap only	Both neo-
ENSDARG00000037116	ENSDARG00000055100	ENSMUSG00000061353	Cxcl12	Both neo-	Both neo-	Overlap only	Both neo-
ENSDARG00000013144	ENSDARG00000076833	ENSMUSG00000026576	Atp1b1	Both neo-	Both neo-	Overlap only	Both neo-
ENSDARG00000019815	ENSDARG00000006526	ENSMUSG00000026193	Fn1	Both neo-	Both neo-	Overlap only	Both neo-
ENSDARG00000044808	ENSDARG00000013730	ENSMUSG00000060961	Slc4a4	Both neo-	Both neo-	Overlap only	Both neo-
ENSDARG00000011239	ENSDARG00000017710	ENSMUSG00000037166	Ppp1r14a	Both neo-	Both neo-	Overlap only	Both neo-
ENSDARG00000020364	ENSDARG00000021366	ENSMUSG00000069805	Fbp1	Both neo-	Both neo-	Overlap only	Both neo-
ENSDARG00000030289	ENSDARG00000013168	ENSMUSG00000027276	Jag1	Both neo-	Both neo-	Subfunctiona	Neofunctiona
ENSDARG00000070360	ENSDARG00000070404	ENSMUSG00000042106	6230427J0	Both neo-	Both neo-	Subfunctiona	Both neo-
ENSDARG00000013605	ENSDARG00000034424	ENSMUSG00000041329	Atp1b2	Both neo-	Both neo-	Neofunctiona	Both neo-
ENSDARG00000022437	ENSDARG00000036080	ENSMUSG00000037706	Cd81	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000000394	ENSDARG00000035734	ENSMUSG00000037236	Matr3	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000001241	ENSDARG00000032175	ENSMUSG00000002524	Puf60	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000004754	ENSDARG00000018989	ENSMUSG00000020361	Hspa4	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000008548	ENSDARG00000026482	ENSMUSG00000041225	Arhgap12	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000011783	ENSDARG00000053668	ENSMUSG00000025862	Stag2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000016763	ENSDARG00000043973	ENSMUSG00000039967	Zfp292	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000018882	ENSDARG00000007915	ENSMUSG00000024789	Jak2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000019081	ENSDARG00000028336	ENSMUSG00000011382	Dhdh	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000021996	ENSDARG00000006624	ENSMUSG00000022052	Ppp2r2a	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000025789	ENSDARG00000063535	ENSMUSG00000063870	Chd4	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000027423	ENSDARG00000034434	ENSMUSG00000005533	Igf1r	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000030368	ENSDARG00000003213	ENSMUSG00000063273	Naa15	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000031240	ENSDARG00000017338	ENSMUSG00000036333	Kidins220	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000033614	ENSDARG00000044251	ENSMUSG00000029333	Rasgef1b	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000035986	ENSDARG00000016481	ENSMUSG00000024539	Ptpn2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000036685	ENSDARG00000036510	ENSMUSG00000026349	Ccnt2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000037260	ENSDARG00000039784	ENSMUSG00000036822	Topors	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000041735	ENSDARG00000074248	ENSMUSG00000038079	Als2cr4	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000042489	ENSDARG00000020964	ENSMUSG00000030753	Prkrir	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000053804	ENSDARG00000013830	ENSMUSG00000039050	Osbpl2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000054304	ENSDARG00000024598	ENSMUSG00000057156	Homez	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000054442	ENSDARG00000004189	ENSMUSG00000018666	Cbx1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000056856	ENSDARG00000034062	ENSMUSG00000004535	Tax1bp1	Overlap only	Overlap only	Overlap only	Overlap only

ENSDARG00000059870	ENSDARG00000062954	ENSMUSG00000068917	Clk2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000060316	ENSDARG00000016773	ENSMUSG00000032578	Cish	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000060586	ENSDARG00000061587	ENSMUSG00000033411	Ctdspl2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000062469	ENSDARG00000062082	ENSMUSG00000027177	Hipk3	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000067626	ENSDARG00000071658	ENSMUSG00000051391	Ywhag	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000073848	ENSDARG00000006299	ENSMUSG00000031511	Arhgef7	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000074287	ENSDARG00000018976	ENSMUSG00000021036	Sptlc2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000076742	ENSDARG00000021488	ENSMUSG00000017132	Cyth1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000077623	ENSDARG00000088440	ENSMUSG00000037926	Ssh2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000090156	ENSDARG00000040039	ENSMUSG00000009291	Pttg1ip	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000006074	ENSDARG00000022213	ENSMUSG00000026558	Uck2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000032919	ENSDARG00000034933	ENSMUSG00000053768	Chchd3	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000009081	ENSDARG00000028099	ENSMUSG00000059013	Sh2d3c	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000040988	ENSDARG00000025012	ENSMUSG00000023456	Tpi1	Overlap only	Overlap only	Overlap only	Subfunctiona
ENSDARG00000010052	ENSDARG00000013087	ENSMUSG00000027634	Ndrg3	Overlap only	Overlap only	Overlap only	Neofunctiona
ENSDARG00000062376	ENSDARG00000062581	ENSMUSG00000031302	Nlgn3	Overlap only	Overlap only	Overlap only	Neofunctiona
ENSDARG00000032737	ENSDARG00000037498	ENSMUSG00000001986	Gria3	Overlap only	Subfunctiona	Overlap only	Overlap only
ENSDARG00000055505	ENSDARG00000058424	ENSMUSG00000025856	Pdgfa	Overlap only	Subfunctiona	Overlap only	Overlap only
ENSDARG00000043932	ENSDARG00000030106	ENSMUSG00000022044	Stmn4	Overlap only	Subfunctiona	Overlap only	Overlap only
ENSDARG00000004377	ENSDARG00000009142	ENSMUSG00000021285	Ppp1r13b	Overlap only	Neofunctiona	Overlap only	NA
ENSDARG00000030514	ENSDARG00000003854	ENSMUSG00000018796	Acsl1	Subfunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000009208	ENSDARG00000070651	ENSMUSG00000021948	Prkcd	Subfunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000019302	ENSDARG00000041051	ENSMUSG00000008035	Mid1ip1	Subfunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000033733	ENSDARG00000022531	ENSMUSG00000020902	Ntn1	Subfunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000005993	ENSDARG00000010511	ENSMUSG00000038943	Prc1	Subfunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000003191	ENSDARG00000003933	ENSMUSG00000032294	Pkm2	Subfunctiona	Overlap only	Overlap only	Subfunctiona
ENSDARG00000030340	ENSDARG00000005776	ENSMUSG00000020444	Guk1	Subfunctiona	Subfunctiona	Overlap only	NA
ENSDARG00000014962	ENSDARG00000057456	ENSMUSG00000022092	Ppp3cc	Subfunctiona	Subfunctiona	Overlap only	Overlap only
ENSDARG00000059244	ENSDARG00000056664	ENSMUSG00000030881	Arfip2	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000068629	ENSDARG00000038288	ENSMUSG00000025510	Cd151	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000029761	ENSDARG00000056892	ENSMUSG00000038388	Mpp6	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000045694	ENSDARG00000040649	ENSMUSG00000036158	Prickle1	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000035820	ENSDARG00000038363	ENSMUSG00000025496	Drd4	Subfunctiona	Subfunctiona	Overlap only	Neofunctiona
ENSDARG00000002412	ENSDARG00000058356	ENSMUSG00000006390	Elovl1	Subfunctiona	Neofunctiona	Overlap only	Both neo-
ENSDARG00000002235	ENSDARG00000008388	ENSMUSG00000000957	Mmp14	Subfunctiona	Both neo-	Overlap only	Both neo-
ENSDARG00000042210	ENSDARG00000019235	ENSMUSG00000028883	Sema3a	Neofunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000014233	ENSDARG00000032606	ENSMUSG00000018398	sep.08	Neofunctiona	Overlap only	Overlap only	Neofunctiona
ENSDARG00000077556	ENSDARG00000075597	ENSMUSG00000047787	Flrt1	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000070537	ENSDARG00000033234	ENSMUSG00000027500	Stmn2	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000031049	ENSDARG00000056084	ENSMUSG00000040972	Igsf21	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000023058	ENSDARG00000042904	ENSMUSG00000048756	Foxo3	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000037496	ENSDARG00000059368	ENSMUSG00000025892	Gria4	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000039615	ENSDARG00000003399	ENSMUSG00000025219	Fgf8	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000053248	ENSDARG00000011862	ENSMUSG00000034336	Ina	Neofunctiona	Neofunctiona	Neofunctiona	Overlap only
ENSDARG00000089464	ENSDARG00000074030	ENSMUSG00000010505	Myt1	Neofunctiona	Neofunctiona	Neofunctiona	Neofunctiona
ENSDARG00000045444	ENSDARG00000038569	ENSMUSG00000036904	Fzd8	Neofunctiona	Both neo-	Overlap only	Neofunctiona
ENSDARG00000034165	ENSDARG00000035899	ENSMUSG00000049556	Lingo1	Both neo-	Overlap only	Overlap only	Neofunctiona
ENSDARG00000034893	ENSDARG00000056783	ENSMUSG00000037992	Rara	Both neo-	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000089288	ENSDARG00000045524	ENSMUSG00000002900	Lamb1	Both neo-	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000017704	ENSDARG00000023362	ENSMUSG00000026751	Nr5a1	Both neo-	Neofunctiona	Neofunctiona	Neofunctiona
ENSDARG00000005108	ENSDARG00000003091	ENSMUSG00000021638	Ocln	Both neo-	Both neo-	Overlap only	Subfunctiona
ENSDARG00000014059	ENSDARG00000043716	ENSMUSG00000041378	Cldn5	Both neo-	Both neo-	Overlap only	Neofunctiona
ENSDARG00000062338	ENSDARG00000078416	ENSMUSG00000026872	Zeb2	Both neo-	Both neo-	Overlap only	Neofunctiona
ENSDARG00000041150	ENSDARG00000001127	ENSMUSG00000030500	Slc17a6	Both neo-	Both neo-	Overlap only	Neofunctiona
ENSDARG00000074639	ENSDARG00000061848	ENSMUSG00000028339	Col15a1	Both neo-	Both neo-	Overlap only	Both neo-
ENSDARG00000020219	ENSDARG00000010791	ENSMUSG00000014773	Dll1	Both neo-	Both neo-	Overlap only	Both neo-
ENSDARG00000002336	ENSDARG00000004232	ENSMUSG00000003436	Dll3	Both neo-	Both neo-	Neofunctiona	Both neo-
ENSDARG00000003910	ENSDARG00000053884	ENSMUSG00000034297	Med13	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000004154	ENSDARG00000011515	ENSMUSG00000049686	Orai1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000004771	ENSDARG00000037100	ENSMUSG00000031508	Ankrd10	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000010641	ENSDARG00000020114	ENSMUSG00000027397	Slc20a1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000011407	ENSDARG00000069093	ENSMUSG00000022483	Col2a1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000011583	ENSDARG00000045768	ENSMUSG00000020038	Cry1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000012458	ENSDARG00000055383	ENSMUSG00000022507	1810013L2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000013274	ENSDARG00000077012	ENSMUSG00000028156	Eif4e	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000015015	ENSDARG00000056656	ENSMUSG00000027217	Tspan18	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000016187	ENSDARG00000025718	ENSMUSG00000024560	Cxxc1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000016263	ENSDARG00000087417	ENSMUSG00000034075	Zdhhc5	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000019842	ENSDARG00000007135	ENSMUSG00000035632	Cnot3	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000020123	ENSDARG00000032426	ENSMUSG00000026489	Adck3	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000021193	ENSDARG00000035598	ENSMUSG00000004530	Coro1c	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000021380	ENSDARG00000009273	ENSMUSG00000020525	Ppm1d	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000022768	ENSDARG00000037589	ENSMUSG00000027573	2310003C2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000026582	ENSDARG00000035596	ENSMUSG00000025825	Iscu	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000030267	ENSDARG00000071583	ENSMUSG00000016503	Gtf3a	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000031560	ENSDARG00000073997	ENSMUSG00000004865	Srpk1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000031770	ENSDARG00000070371	ENSMUSG00000038909	Myst2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000034189	ENSDARG00000027500	ENSMUSG00000036737	Oxsr1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000035458	ENSDARG00000020574	ENSMUSG00000030730	Atp2a1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000039681	ENSDARG00000045814	ENSMUSG00000022437	Samm50	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000040184	ENSDARG00000026723	ENSMUSG00000032423	Syncrip	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000041317	ENSDARG00000056059	ENSMUSG00000022391	Rangap1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000041602	ENSDARG00000005870	ENSMUSG00000026766	Mmadhc	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000045927	ENSDARG00000035905	ENSMUSG00000050144	Slc25a44	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000052099	ENSDARG00000018478	ENSMUSG00000026272	Agxt	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000052438	ENSDARG00000070076	ENSMUSG00000020152	Actr2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000052851	ENSDARG00000044225	ENSMUSG00000022200	Golph3	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000053326	ENSDARG00000010002	ENSMUSG00000034781	Gna11	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000053571	ENSDARG00000042827	ENSMUSG00000057134	Ado	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000054272	ENSDARG00000009346	ENSMUSG00000027184	Caprin1	Overlap only	Overlap only	Overlap only	NA

ENSDARG00000055540	ENSDARG00000029075	ENSMUSG00000025648	Pfkfb4	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000056252	ENSDARG00000029402	ENSMUSG00000068747	Sort1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000059653	ENSDARG00000078133	ENSMUSG00000054611	Kdm2a	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000060065	ENSDARG00000088318	ENSMUSG00000028433	Ubap2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000060297	ENSDARG00000062577	ENSMUSG00000058230	Grlf1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000067605	ENSDARG00000020405	ENSMUSG00000006024	Napa	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000070145	ENSDARG00000003169	ENSMUSG00000045095	Magi1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000074020	ENSDARG00000076009	ENSMUSG00000023022	Lima1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000076810	ENSDARG00000005754	ENSMUSG00000033295	Ptprf	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000077178	ENSDARG00000055350	ENSMUSG00000036817	Sun1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000078772	ENSDARG00000077297	ENSMUSG00000017119	Nbr1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000092112	ENSDARG00000036721	ENSMUSG00000002984	Tomm40	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000032865	ENSDARG00000042128	ENSMUSG00000040276	Pacsin1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000003991	ENSDARG00000042018	ENSMUSG00000008136	Fhl2	Overlap only	Overlap only	Overlap only	Neofunctiona
ENSDARG00000034710	ENSDARG00000017312	ENSMUSG00000039704	Lmbrd2	Overlap only	Neofunctiona	Overlap only	NA
ENSDARG00000062948	ENSDARG00000059466	ENSMUSG00000029636	Wasf3	Overlap only	Neofunctiona	Neofunctiona	NA
ENSDARG00000031622	ENSDARG00000038446	ENSMUSG00000025969	Nrp2	Overlap only	Both neo-	Overlap only	Neofunctiona
ENSDARG00000006395	ENSDARG00000039266	ENSMUSG00000010608	Rbm25	Subfunctiona	Overlap only	Overlap only	NA
ENSDARG00000011157	ENSDARG00000042308	ENSMUSG00000004568	Arhgef18	Subfunctiona	Overlap only	Overlap only	NA
ENSDARG00000036107	ENSDARG00000070000	ENSMUSG00000038393	Txnip	Subfunctiona	Overlap only	Overlap only	NA
ENSDARG00000008697	ENSDARG00000057671	ENSMUSG00000024140	Epas1	Subfunctiona	Overlap only	Overlap only	NA
ENSDARG00000075261	ENSDARG00000061226	ENSMUSG00000017466	Timp2	Subfunctiona	Overlap only	Overlap only	NA
ENSDARG00000077671	ENSDARG00000011506	ENSMUSG00000021608	Lpcat1	Subfunctiona	Overlap only	Overlap only	NA
ENSDARG00000017441	ENSDARG00000014196	ENSMUSG00000061816	Myl1	Subfunctiona	Subfunctiona	Overlap only	Overlap only
ENSDARG00000016676	ENSDARG00000036058	ENSMUSG00000031748	Gnao1	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000002787	ENSDARG00000069006	ENSMUSG00000032280	Tle3	Subfunctiona	Subfunctiona	Subfunctiona	NA
ENSDARG00000026166	ENSDARG00000024537	ENSMUSG00000029163	Emilin1	Subfunctiona	Both neo-	Overlap only	Both neo-
ENSDARG00000043317	ENSDARG00000056133	ENSMUSG00000005672	Kit	Subfunctiona	Both neo-	Overlap only	Both neo-
ENSDARG00000006982	ENSDARG00000056697	ENSMUSG00000048450	Msx1	Subfunctiona	Both neo-	Overlap only	Both neo-
ENSDARG00000017128	ENSDARG00000006112	ENSMUSG00000048612	Myof	Neofunctiona	Overlap only	Overlap only	NA
ENSDARG00000039117	ENSDARG00000038401	ENSMUSG00000022389	Tef	Neofunctiona	Overlap only	Overlap only	NA
ENSDARG00000021065	ENSDARG00000011065	ENSMUSG00000057897	Camk2b	Neofunctiona	Overlap only	Overlap only	Subfunctiona
ENSDARG00000006901	ENSDARG00000091726	ENSMUSG00000020473	Aebp1	Neofunctiona	Neofunctiona	Overlap only	NA
ENSDARG00000019098	ENSDARG00000026070	ENSMUSG00000027215	Cd82	Neofunctiona	Neofunctiona	Overlap only	NA
ENSDARG00000019702	ENSDARG00000057661	ENSMUSG00000017390	Aldoc	Neofunctiona	Neofunctiona	Overlap only	NA
ENSDARG00000036082	ENSDARG00000029432	ENSMUSG00000040046	Tph1	Neofunctiona	Neofunctiona	Overlap only	NA
ENSDARG00000032714	ENSDARG00000021352	ENSMUSG00000020524	Gria1	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000009461	ENSDARG00000056819	ENSMUSG00000038227	Hoxa9	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000000161	ENSDARG00000054973	ENSMUSG00000020640	Itsn2	Neofunctiona	Neofunctiona	Neofunctiona	NA
ENSDARG00000031782	ENSDARG00000006060	ENSMUSG00000019866	Aim1	Neofunctiona	Neofunctiona	Neofunctiona	NA
ENSDARG00000034643	ENSDARG00000059158	ENSMUSG00000032643	Fhl3	Neofunctiona	Neofunctiona	Neofunctiona	NA
ENSDARG00000040295	ENSDARG00000086370	ENSMUSG00000002985	Apoe	Neofunctiona	Neofunctiona	Neofunctiona	NA
ENSDARG00000044655	ENSDARG00000061173	ENSMUSG00000031995	St14	Neofunctiona	Neofunctiona	Neofunctiona	NA
ENSDARG00000062116	ENSDARG00000071673	ENSMUSG00000047409	Ctdspl	Neofunctiona	Neofunctiona	Neofunctiona	NA
ENSDARG00000013613	ENSDARG00000013976	ENSMUSG00000055114	Anxa13	Neofunctiona	Neofunctiona	Neofunctiona	NA
ENSDARG00000055565	ENSDARG00000079906	ENSMUSG00000057914	Cacnb2	Neofunctiona	Both neo-	Overlap only	Neofunctiona
ENSDARG00000032808	ENSDARG00000077523	ENSMUSG00000035517	Tdrd7	Both neo-	Overlap only	Overlap only	NA
ENSDARG00000002642	ENSDARG00000067958	ENSMUSG00000003200	Sh3gl1	Both neo-	Overlap only	Overlap only	NA
ENSDARG00000045540	ENSDARG00000069654	ENSMUSG00000036561	Ppp6r2	Both neo-	Overlap only	Overlap only	NA
ENSDARG00000053535	ENSDARG00000004930	ENSMUSG00000033060	Lmo7	Both neo-	Neofunctiona	Overlap only	NA
ENSDARG00000007220	ENSDARG00000056181	ENSMUSG00000039542	Ncam1	Both neo-	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000041348	ENSDARG00000009852	ENSMUSG00000032274	Cyp19a1	Both neo-	Both neo-	NA	Both neo-
ENSDARG00000004861	ENSDARG00000011696	ENSMUSG00000026610	Esrrg	Both neo-	Both neo-	Overlap only	NA
ENSDARG00000056633	ENSDARG00000035056	ENSMUSG00000031137	Fgf13	Both neo-	Both neo-	Overlap only	Neofunctiona
ENSDARG00000055373	ENSDARG00000011163	ENSMUSG00000034684	Sema3f	Both neo-	Both neo-	Overlap only	Neofunctiona
ENSDARG00000003971	ENSDARG00000053499	ENSMUSG00000032318	Isl2	Both neo-	Both neo-	Overlap only	Both neo-
ENSDARG00000035084	ENSDARG00000055291	ENSMUSG00000073639	Rab18	NA	Overlap only	Overlap only	Overlap only
ENSDARG00000009567	ENSDARG00000039256	ENSMUSG00000026207	Speg	Overlap only	Overlap only	NA	Overlap only
ENSDARG00000026329	ENSDARG00000017748	ENSMUSG00000039831	Arhgap29	Overlap only	Overlap only	NA	Neofunctiona
ENSDARG00000051912	ENSDARG00000012609	ENSMUSG00000030895	Hpx	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000056765	ENSDARG00000056744	ENSMUSG00000062478	Ctrc	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000060081	ENSDARG00000060106	ENSMUSG00000035403	Crb2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000026109	ENSDARG00000026907	ENSMUSG00000081534	Slc48a1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000062674	ENSDARG00000020252	ENSMUSG00000038187	Btbd10	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000074245	ENSDARG00000074332	ENSMUSG00000040761	Spen	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000053254	ENSDARG00000002589	ENSMUSG00000030672	Mylpf	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000004836	ENSDARG00000042948	ENSMUSG00000000826	Dnajc5	Overlap only	Overlap only	Overlap only	Neofunctiona
ENSDARG00000002748	ENSDARG00000000189	ENSMUSG00000038777	Sema6c	Overlap only	Overlap only	Overlap only	Neofunctiona
ENSDARG00000092810	ENSDARG00000043281	ENSMUSG00000038781	Stap2	Subfunctiona	Overlap only	Overlap only	NA
ENSDARG00000076030	ENSDARG00000001881	ENSMUSG00000003352	Cacnb3	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000046019	ENSDARG00000056995	ENSMUSG00000042821	Snai1	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000009727	ENSDARG00000094792	ENSMUSG00000023277	Twf2	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000079011	ENSDARG00000069415	ENSMUSG00000025064	Col17a1	Subfunctiona	Subfunctiona	Overlap only	Both neo-
ENSDARG00000070220	ENSDARG00000076262	ENSMUSG00000052621	Pou3f2	Subfunctiona	Both neo-	Overlap only	Overlap only
ENSDARG00000020450	ENSDARG00000070626	ENSMUSG00000053395	Cacng8	Neofunctiona	Neofunctiona	NA	NA
ENSDARG00000079396	ENSDARG00000071230	ENSMUSG00000035653	Lrfn5	Neofunctiona	Neofunctiona	NA	Neofunctiona
ENSDARG00000010563	ENSDARG00000003974	ENSMUSG00000026771	Spopl	Neofunctiona	Neofunctiona	Overlap only	NA
ENSDARG00000034181	ENSDARG00000016454	ENSMUSG00000021055	Esr2	Neofunctiona	Neofunctiona	Overlap only	NA
ENSDARG00000039684	ENSDARG00000078690	ENSMUSG00000054021	Sirt5	Neofunctiona	Neofunctiona	Overlap only	NA
ENSDARG00000003732	ENSDARG00000037833	ENSMUSG00000035158	Mitf	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000008723	ENSDARG00000022254	ENSMUSG00000052889	Prkcb	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000039051	ENSDARG00000005139	ENSMUSG00000032523	Hhatl	Neofunctiona	Both neo-	NA	Neofunctiona
ENSDARG00000057223	ENSDARG00000089790	ENSMUSG00000048915	Efna5	Neofunctiona	Both neo-	Overlap only	Neofunctiona
ENSDARG00000032859	ENSDARG00000040280	ENSMUSG00000072568	Fam84b	NA	Overlap only	Overlap only	NA
ENSDARG00000034522	ENSDARG00000031343	ENSMUSG00000032549	Rab6b	NA	Overlap only	Overlap only	NA
ENSDARG00000041165	ENSDARG00000029036	ENSMUSG00000019832	Rab32	NA	Overlap only	Overlap only	NA
ENSDARG00000044295	ENSDARG00000006508	ENSMUSG00000024867	Pip5k1b	NA	Overlap only	Overlap only	NA
ENSDARG00000052254	ENSDARG00000068920	ENSMUSG00000049606	Zfp644	NA	Overlap only	Overlap only	NA
ENSDARG00000003216	ENSDARG00000053625	ENSMUSG00000032231	Anxa2	Overlap only	Overlap only	NA	NA
ENSDARG00000017311	ENSDARG00000025027	ENSMUSG00000027883	Gpsm2	Overlap only	Overlap only	NA	NA

ENSDARG00000018865	ENSDARG00000088663	ENSMUSG00000001143	Lman2l	Overlap only	Overlap only	NA	NA
ENSDARG00000034497	ENSDARG00000045801	ENSMUSG00000030019	Fbxl14	Overlap only	Overlap only	NA	Overlap only
ENSDARG00000041323	ENSDARG00000068477	ENSMUSG00000042109	Csdc2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000014179	ENSDARG00000060797	ENSMUSG00000033065	Pfkm	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000015681	ENSDARG00000029501	ENSMUSG00000057177	Gsk3a	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000053453	ENSDARG00000010957	ENSMUSG00000017314	Mpp2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000053753	ENSDARG00000039203	ENSMUSG00000026150	Mff	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000058128	ENSDARG00000028740	ENSMUSG00000031207	Msn	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000078452	ENSDARG00000055101	ENSMUSG00000004070	Hmox2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000001804	ENSDARG00000057060	ENSMUSG00000014177	Fam18b	Overlap only	Overlap only	Overlap only	Subfunctiona
ENSDARG00000015025	ENSDARG00000007149	ENSMUSG00000031391	L1cam	Overlap only	Neofunctiona	NA	NA
ENSDARG00000039528	ENSDARG00000044954	ENSMUSG00000025020	Slit1	Overlap only	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000002696	ENSDARG00000004358	ENSMUSG00000023439	Gnb3	Overlap only	Both neo-	NA	Neofunctiona
ENSDARG00000015901	ENSDARG00000015230	ENSMUSG00000028134	Ptbp2	Subfunctiona	Overlap only	NA	NA
ENSDARG00000056998	ENSDARG00000001634	ENSMUSG00000041734	Kirrel	Subfunctiona	Overlap only	Overlap only	NA
ENSDARG00000014651	ENSDARG00000055075	ENSMUSG00000024236	Svil	Subfunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000074635	ENSDARG00000079009	ENSMUSG00000015243	Abca1	Subfunctiona	Subfunctiona	Overlap only	Both neo-
ENSDARG00000032578	ENSDARG00000028148	ENSMUSG00000004231	Pax2	Subfunctiona	Both neo-	Overlap only	Neofunctiona
ENSDARG00000041660	ENSDARG00000037159	ENSMUSG00000050511	Oprd1	Neofunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000055080	ENSDARG00000036386	ENSMUSG00000033760	Rbm4b	Neofunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000027740	ENSDARG00000004015	ENSMUSG00000024256	Adcyap1	Neofunctiona	Neofunctiona	NA	Overlap only
ENSDARG00000052470	ENSDARG00000031422	ENSMUSG00000039323	Igfbp2	Neofunctiona	Neofunctiona	NA	Neofunctiona
ENSDARG00000013317	ENSDARG00000055518	ENSMUSG00000032648	Pygm	Neofunctiona	Neofunctiona	NA	Neofunctiona
ENSDARG00000016934	ENSDARG00000010727	ENSMUSG00000034714	Ttyh2	Neofunctiona	Neofunctiona	Overlap only	NA
ENSDARG00000055481	ENSDARG00000011298	ENSMUSG00000052414	Atf7	Neofunctiona	Neofunctiona	Overlap only	NA
ENSDARG00000007609	ENSDARG00000036254	ENSMUSG00000038203	Hoxa13	Neofunctiona	Neofunctiona	Overlap only	Overlap only
ENSDARG00000009045	ENSDARG00000007009	ENSMUSG00000038210	Hoxa11	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000018032	ENSDARG00000005775	ENSMUSG00000023033	Scn8a	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000036036	ENSDARG00000020708	ENSMUSG00000027239	Mdk	Neofunctiona	Neofunctiona	Overlap only	Both neo-
ENSDARG00000058656	ENSDARG00000005221	ENSMUSG00000026208	Des	Neofunctiona	Both neo-	NA	NA
ENSDARG00000052764	ENSDARG00000038508	ENSMUSG00000031492	Chrnb3	Both neo-	Overlap only	Overlap only	NA
ENSDARG00000001710	ENSDARG00000037998	ENSMUSG00000059714	Flot1	Both neo-	Overlap only	Overlap only	Overlap only
ENSDARG00000029596	ENSDARG00000058158	ENSMUSG00000060913	Trim55	NA	NA	NA	NA
ENSDARG00000041609	ENSDARG00000003544	ENSMUSG00000020262	Adarb1	NA	Overlap only	NA	Overlap only
ENSDARG00000030326	ENSDARG00000018787	ENSMUSG00000027954	Efna1	NA	Neofunctiona	Overlap only	NA
ENSDARG00000030547	ENSDARG00000004218	ENSMUSG00000054855	Rnd1	NA	Neofunctiona	Overlap only	NA
ENSDARG00000030630	ENSDARG00000035909	ENSMUSG00000028655	Mfsd2a	NA	Neofunctiona	Overlap only	NA
ENSDARG00000052654	ENSDARG00000000151	ENSMUSG00000058756	Thra	Overlap only	Overlap only	NA	NA
ENSDARG00000075752	ENSDARG00000061862	ENSMUSG00000000631	Myo18a	Overlap only	Overlap only	NA	NA
ENSDARG00000076448	ENSDARG00000061383	ENSMUSG00000038224	Serpinf2	Overlap only	Overlap only	NA	NA
ENSDARG00000092060	ENSDARG00000024894	ENSMUSG00000018263	Tbx5	Overlap only	Overlap only	NA	Overlap only
ENSDARG00000002037	ENSDARG00000023840	ENSMUSG00000026409	Pfkfb2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000006283	ENSDARG00000014113	ENSMUSG00000029684	Wasl	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000008807	ENSDARG00000052129	ENSMUSG00000026278	Bok	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000009136	ENSDARG00000054858	ENSMUSG00000026510	Trp53bp2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000017397	ENSDARG00000036251	ENSMUSG00000032481	Smarcc1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000025728	ENSDARG00000027828	ENSMUSG00000026959	Grin1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000035122	ENSDARG00000019208	ENSMUSG00000026933	Camsap1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000037403	ENSDARG00000068992	ENSMUSG00000015656	Hspa8	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000042791	ENSDARG00000061915	ENSMUSG00000041890	Git2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000045064	ENSDARG00000060149	ENSMUSG00000025085	Ablim1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000070863	ENSDARG00000069981	ENSMUSG00000032482	Cspg5	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000016293	ENSDARG00000076215	ENSMUSG00000039646	Vasn	Overlap only	Subfunctiona	NA	NA
ENSDARG00000044098	ENSDARG00000042826	ENSMUSG00000037868	Egr2	Overlap only	Subfunctiona	NA	Overlap only
ENSDARG00000007786	ENSDARG00000079122	ENSMUSG00000050043	Tmx2	Overlap only	Neofunctiona	Overlap only	NA
ENSDARG00000011886	ENSDARG00000017634	ENSMUSG00000006007	Pdc	Overlap only	Neofunctiona	Overlap only	NA
ENSDARG00000007990	ENSDARG00000031420	ENSMUSG00000016458	Wt1	Overlap only	Both neo-	NA	Overlap only
ENSDARG00000008263	ENSDARG00000023768	ENSMUSG00000059149	Mfsd4	Subfunctiona	Overlap only	NA	NA
ENSDARG00000017554	ENSDARG00000037059	ENSMUSG00000057193	Slc44a2	Subfunctiona	Subfunctiona	NA	NA
ENSDARG00000074369	ENSDARG00000076856	ENSMUSG00000037016	Frem2	Subfunctiona	Subfunctiona	NA	Both neo-
ENSDARG00000078954	ENSDARG00000002006	ENSMUSG00000039656	Rxrb	Subfunctiona	Subfunctiona	Subfunctiona	NA
ENSDARG00000062129	ENSDARG00000062222	ENSMUSG00000029070	Mxra8	Subfunctiona	Neofunctiona	NA	NA
ENSDARG00000062262	ENSDARG00000011876	ENSMUSG00000031616	Ednra	Neofunctiona	Overlap only	NA	Neofunctiona
ENSDARG00000037790	ENSDARG00000071601	ENSMUSG00000029618	Ocm	Neofunctiona	Neofunctiona	Neofunctiona	NA
ENSDARG00000040725	ENSDARG00000040503	ENSMUSG00000059334	Zfp36l3	Neofunctiona	Neofunctiona	Neofunctiona	NA
ENSDARG00000044895	ENSDARG00000010294	ENSMUSG00000041559	Fmod	Both neo-	Subfunctiona	NA	Both neo-
ENSDARG00000058488	ENSDARG00000033706	ENSMUSG00000020178	Adora2a	Both neo-	Both neo-	NA	Both neo-
ENSDARG00000056617	ENSDARG00000057074	ENSMUSG00000031174	Rpgr	NA	Overlap only	NA	NA
ENSDARG00000003994	ENSDARG00000029239	ENSMUSG00000062542	Syt9	NA	Overlap only	Overlap only	NA
ENSDARG00000005343	ENSDARG00000039497	ENSMUSG00000032878	Ccdc85a	NA	Overlap only	Overlap only	NA
ENSDARG00000020847	ENSDARG00000015174	ENSMUSG00000019302	Atp6v0a1	NA	Overlap only	Overlap only	NA
ENSDARG00000035175	ENSDARG00000038981	ENSMUSG00000027777	Schip1	NA	Overlap only	Overlap only	NA
ENSDARG00000036593	ENSDARG00000046010	ENSMUSG00000029475	Kdm2b	NA	Overlap only	Overlap only	NA
ENSDARG00000037748	ENSDARG00000037393	ENSMUSG00000027075	Slc43a1	NA	Overlap only	Overlap only	NA
ENSDARG00000038855	ENSDARG00000041900	ENSMUSG00000028419	Chmp5	NA	Overlap only	Overlap only	NA
ENSDARG00000042115	ENSDARG00000034685	ENSMUSG00000051703	Tmem198	NA	Overlap only	Overlap only	NA
ENSDARG00000052782	ENSDARG00000052769	ENSMUSG00000028020	Glrb	NA	Overlap only	Overlap only	NA
ENSDARG00000061551	ENSDARG00000074222	ENSMUSG00000038807	Rap1gap2	NA	Overlap only	Overlap only	NA
ENSDARG00000004455	ENSDARG00000024139	ENSMUSG00000005950	P2rx5	NA	Neofunctiona	NA	NA
ENSDARG00000086585	ENSDARG00000077818	ENSMUSG00000060275	Nrg2	NA	Both neo-	NA	NA
ENSDARG00000006420	ENSDARG00000077188	ENSMUSG00000054843	Atrnl1	Overlap only	NA	NA	NA
ENSDARG00000011703	ENSDARG00000003631	ENSMUSG00000029238	Clock	Overlap only	NA	NA	NA
ENSDARG00000011948	ENSDARG00000071524	ENSMUSG00000005534	Insr	Overlap only	NA	NA	NA
ENSDARG00000018260	ENSDARG00000063230	ENSMUSG00000008999	Bmp7	Overlap only	NA	NA	NA
ENSDARG00000025319	ENSDARG00000011370	ENSMUSG00000019843	Fyn	Overlap only	NA	NA	NA
ENSDARG00000044016	ENSDARG00000042141	ENSMUSG00000033577	Myo6	Overlap only	NA	NA	NA
ENSDARG00000060036	ENSDARG00000036894	ENSMUSG00000028029	Aimp1	Overlap only	NA	NA	NA
ENSDARG00000062416	ENSDARG00000060319	ENSMUSG00000046480	Scn4b	Overlap only	NA	NA	NA
ENSDARG00000071562	ENSDARG00000034105	ENSMUSG00000045636	Mtus1	Overlap only	NA	NA	NA
ENSDARG00000077207	ENSDARG00000074597	ENSMUSG00000035342	Lzts2	Overlap only	NA	NA	NA

ENSDARG00000004729	ENSDARG00000019457	ENSMUSG00000000134	Tcfe3	Overlap only	Neofunctiona	NA	NA
ENSDARG00000003020	ENSDARG00000069402	ENSMUSG00000049939	Lrrc4	Neofunctiona	NA	NA	NA
ENSDARG00000053479	ENSDARG00000005510	ENSMUSG00000051279	Gdf6	Neofunctiona	Neofunctiona	NA	NA
ENSDARG00000037266	ENSDARG00000012311	ENSMUSG00000028116	Myoz2	NA	NA	NA	NA
ENSDARG00000013695	ENSDARG00000028048	ENSMUSG00000053773	Rdh8	NA	NA	NA	NA
ENSDARG00000044253	ENSDARG00000017703	ENSMUSG00000055725	Paqr3	NA	NA	NA	NA
ENSDARG00000005883	ENSDARG00000075904	ENSMUSG00000031706	Rfx1	NA	Overlap only	NA	NA
ENSDARG00000006240	ENSDARG00000038352	ENSMUSG00000031808	Slc27a1	NA	Overlap only	NA	NA
ENSDARG00000016809	ENSDARG00000014134	ENSMUSG00000005469	Prkaca	NA	Overlap only	NA	NA
ENSDARG00000017023	ENSDARG00000019001	ENSMUSG00000041323	Ak7	NA	Overlap only	NA	NA
ENSDARG00000020944	ENSDARG00000025091	ENSMUSG00000052397	Ezr	NA	Overlap only	NA	NA
ENSDARG00000037917	ENSDARG00000012824	ENSMUSG00000001507	Itga3	NA	Overlap only	NA	NA
ENSDARG00000058327	ENSDARG00000010047	ENSMUSG00000035239	Neu3	NA	Overlap only	NA	NA
ENSDARG00000059805	ENSDARG00000074533	ENSMUSG00000032519	Slc25a38	NA	Overlap only	NA	NA
ENSDARG00000061651	ENSDARG00000025076	ENSMUSG00000021636	Marveld2	NA	Overlap only	NA	NA
ENSDARG00000070319	ENSDARG00000053855	ENSMUSG00000017639	Rab11fip4	NA	Overlap only	NA	NA
ENSDARG00000089885	ENSDARG00000017773	ENSMUSG00000009378	Slc16a12	NA	Overlap only	NA	NA
ENSDARG00000034588	ENSDARG00000008797	ENSMUSG00000001027	Scn4a	NA	Subfunctiona	NA	NA
ENSDARG00000029204	ENSDARG00000056151	ENSMUSG00000005994	Tyrp1	NA	Neofunctiona	NA	NA
ENSDARG00000007788	ENSDARG00000012684	ENSMUSG00000019943	Atp2b1	Overlap only	NA	NA	NA
ENSDARG00000009196	ENSDARG00000044254	ENSMUSG00000029484	Anxa3	Overlap only	NA	NA	NA
ENSDARG00000011466	ENSDARG00000042902	ENSMUSG00000038302	Lace1	Overlap only	NA	NA	NA
ENSDARG00000012574	ENSDARG00000061525	ENSMUSG00000025060	Slk	Overlap only	NA	NA	NA
ENSDARG00000014137	ENSDARG00000012866	ENSMUSG00000039361	Picalm	Overlap only	NA	NA	NA
ENSDARG00000014840	ENSDARG00000038018	ENSMUSG00000023978	Prph2	Overlap only	NA	NA	NA
ENSDARG00000015252	ENSDARG00000015374	ENSMUSG00000028538	St3gal3	Overlap only	NA	NA	NA
ENSDARG00000015968	ENSDARG00000014430	ENSMUSG00000025340	Rabgef1	Overlap only	NA	NA	NA
ENSDARG00000019179	ENSDARG00000052896	ENSMUSG00000041044	Lrit1	Overlap only	NA	NA	NA
ENSDARG00000024759	ENSDARG00000012671	ENSMUSG00000041324	Inhba	Overlap only	NA	NA	NA
ENSDARG00000033411	ENSDARG00000019990	ENSMUSG00000029544	Cabp1	Overlap only	NA	NA	NA
ENSDARG00000035676	ENSDARG00000087443	ENSMUSG00000028788	Ptp4a2	Overlap only	NA	NA	NA
ENSDARG00000037285	ENSDARG00000013963	ENSMUSG00000025389	Mip	Overlap only	NA	NA	NA
ENSDARG00000041295	ENSDARG00000015445	ENSMUSG00000004613	Lim2	Overlap only	NA	NA	NA
ENSDARG00000044362	ENSDARG00000034453	ENSMUSG00000002058	Unc119	Overlap only	NA	NA	NA
ENSDARG00000044475	ENSDARG00000032380	ENSMUSG00000074006	Omp	Overlap only	NA	NA	NA
ENSDARG00000045156	ENSDARG00000037925	ENSMUSG00000020599	Rgs9	Overlap only	NA	NA	NA
ENSDARG00000045803	ENSDARG00000015349	ENSMUSG00000030605	Mfge8	Overlap only	NA	NA	NA
ENSDARG00000051748	ENSDARG00000070408	ENSMUSG00000000184	Ccnd2	Overlap only	NA	NA	NA
ENSDARG00000051798	ENSDARG00000013596	ENSMUSG00000022387	Brd1	Overlap only	NA	NA	NA
ENSDARG00000052417	ENSDARG00000038281	ENSMUSG00000018931	Gm16515	Overlap only	NA	NA	NA
ENSDARG00000053246	ENSDARG00000055043	ENSMUSG00000027173	Depdc7	Overlap only	NA	NA	NA
ENSDARG00000053875	ENSDARG00000041141	ENSMUSG00000000724	Cryba1	Overlap only	NA	NA	NA
ENSDARG00000056743	ENSDARG00000038658	ENSMUSG00000028348	Murc	Overlap only	NA	NA	NA
ENSDARG00000060697	ENSDARG00000062962	ENSMUSG00000006307	Wbp7	Overlap only	NA	NA	NA
ENSDARG00000063295	ENSDARG00000001014	ENSMUSG00000022443	Myh9	Overlap only	NA	NA	NA
ENSDARG00000068822	ENSDARG00000068013	ENSMUSG00000091207	AL646020.	Overlap only	NA	NA	NA
ENSDARG00000069910	ENSDARG00000006816	ENSMUSG00000067995	Gtf2f2	Overlap only	NA	NA	NA
ENSDARG00000070835	ENSDARG00000095002	ENSMUSG00000017300	Tnnc2	Overlap only	NA	NA	NA
ENSDARG00000071159	ENSDARG00000070746	ENSMUSG00000040848	Sft2d2	Overlap only	NA	NA	NA
ENSDARG00000078507	ENSDARG00000052910	ENSMUSG00000012282	Wnt8a	Overlap only	NA	NA	NA
ENSDARG00000039399	ENSDARG00000058231	ENSMUSG00000025041	Nt5c2	Subfunctiona	NA	NA	NA
ENSDARG00000078671	ENSDARG00000071011	ENSMUSG00000090071	Cdk5r2	Subfunctiona	NA	NA	NA
ENSDARG00000009477	ENSDARG00000033184	ENSMUSG00000032601	Prkar2a	Neofunctiona	NA	NA	NA
ENSDARG00000025302	ENSDARG00000056267	ENSMUSG00000032064	Dixdc1	Neofunctiona	NA	NA	NA
ENSDARG00000061096	ENSDARG00000018345	ENSMUSG00000032380	Dapk2	Neofunctiona	NA	NA	NA
ENSDARG00000077219	ENSDARG00000059950	ENSMUSG00000026748	Plxdc2	Both neo-	NA	NA	NA
ENSDARG00000000369	ENSDARG00000017537	ENSMUSG00000006542	Prkag3	NA	NA	NA	NA
ENSDARG00000000370	ENSDARG00000019426	ENSMUSG00000022263	Trio	NA	NA	NA	NA
ENSDARG00000001452	ENSDARG00000057644	ENSMUSG00000025473	Adam8	NA	NA	NA	NA
ENSDARG00000001712	ENSDARG00000006568	ENSMUSG00000037610	Kcnmb2	NA	NA	NA	NA
ENSDARG00000001803	ENSDARG00000010296	ENSMUSG00000001901	Kcnh6	NA	NA	NA	NA
ENSDARG00000001880	ENSDARG00000051981	ENSMUSG00000041488	Stx3	NA	NA	NA	NA
ENSDARG00000001933	ENSDARG00000012625	ENSMUSG00000028944	Prkag2	NA	NA	NA	NA
ENSDARG00000002013	ENSDARG00000035308	ENSMUSG00000020176	Grb10	NA	NA	NA	NA
ENSDARG00000002483	ENSDARG00000044827	ENSMUSG00000030093	Wnt7a	NA	NA	NA	NA
ENSDARG00000002546	ENSDARG00000007245	ENSMUSG00000006575	Rundc3a	NA	NA	NA	NA
ENSDARG00000002576	ENSDARG00000028485	ENSMUSG00000005649	Cabp5	NA	NA	NA	NA
ENSDARG00000002614	ENSDARG00000024642	ENSMUSG00000028126	Pip5k1a	NA	NA	NA	NA
ENSDARG00000002635	ENSDARG00000014081	ENSMUSG00000019856	Fam184a	NA	NA	NA	NA
ENSDARG00000002656	ENSDARG00000029234	ENSMUSG00000019790	Stxbp5	NA	NA	NA	NA
ENSDARG00000002682	ENSDARG00000019525	ENSMUSG00000037287	Tbcel	NA	NA	NA	NA
ENSDARG00000002771	ENSDARG00000005966	ENSMUSG00000068323	Slc4a5	NA	NA	NA	NA
ENSDARG00000002898	ENSDARG00000060626	ENSMUSG00000025357	Dgka	NA	NA	NA	NA
ENSDARG00000002917	ENSDARG00000069095	ENSMUSG00000044005	Gls2	NA	NA	NA	NA
ENSDARG00000003022	ENSDARG00000063651	ENSMUSG00000029674	Limk1	NA	NA	NA	NA
ENSDARG00000003303	ENSDARG00000058476	ENSMUSG00000014813	Stc1	NA	NA	NA	NA
ENSDARG00000003326	ENSDARG00000039240	ENSMUSG00000040373	Cacng5	NA	NA	NA	NA
ENSDARG00000003533	ENSDARG00000077403	ENSMUSG00000068196	Col8a1	NA	NA	NA	NA
ENSDARG00000003779	ENSDARG00000062415	ENSMUSG00000022240	Ctnnd2	NA	NA	NA	NA
ENSDARG00000003836	ENSDARG00000078744	ENSMUSG00000036026	Tmem63b	NA	NA	NA	NA
ENSDARG00000003899	ENSDARG00000029039	ENSMUSG00000036304	Zdhhc23	NA	NA	NA	NA
ENSDARG00000004026	ENSDARG00000069598	ENSMUSG00000074939	Chrm5	NA	NA	NA	NA
ENSDARG00000004322	ENSDARG00000076079	ENSMUSG00000045288	Ush1g	NA	NA	NA	NA
ENSDARG00000004592	ENSDARG00000045383	ENSMUSG00000044067	Gpr22	NA	NA	NA	NA
ENSDARG00000004597	ENSDARG00000014792	ENSMUSG00000047085	Lrrc4b	NA	NA	NA	NA
ENSDARG00000004618	ENSDARG00000068217	ENSMUSG00000029428	Stx2	NA	NA	NA	NA
ENSDARG00000004643	ENSDARG00000044447	ENSMUSG00000021803	Cdhr1	NA	NA	NA	NA
ENSDARG00000004648	ENSDARG00000020102	ENSMUSG00000051401	Kctd16	NA	NA	NA	NA
ENSDARG00000004830	ENSDARG00000069774	ENSMUSG00000061981	Flot2	NA	NA	NA	NA
ENSDARG00000005002	ENSDARG00000017835	ENSMUSG00000011158	Brf1	NA	NA	NA	NA

ENSDARG00000005141	ENSDARG00000027963	ENSMUSG00000032936	Camkv	NA	NA	NA	NA
ENSDARG00000005271	ENSDARG00000016062	ENSMUSG00000042677	Zc3h12a	NA	NA	NA	NA
ENSDARG00000005364	ENSDARG00000074647	ENSMUSG00000035745	Grin3b	NA	NA	NA	NA
ENSDARG00000005377	ENSDARG00000058937	ENSMUSG00000022132	Cldn10	NA	NA	NA	NA
ENSDARG00000005397	ENSDARG00000063711	ENSMUSG00000036989	Trim3	NA	NA	NA	NA
ENSDARG00000005485	ENSDARG00000027799	ENSMUSG00000026668	Ucma	NA	NA	NA	NA
ENSDARG00000005549	ENSDARG00000014680	ENSMUSG00000048897	Zfp710	NA	NA	NA	NA
ENSDARG00000005578	ENSDARG00000008200	ENSMUSG00000001891	Ugp2	NA	NA	NA	NA
ENSDARG00000005625	ENSDARG00000012741	ENSMUSG00000028826	Tmem57	NA	NA	NA	NA
ENSDARG00000005626	ENSDARG00000019709	ENSMUSG00000039960	Rhou	NA	NA	NA	NA
ENSDARG00000005670	ENSDARG00000043026	ENSMUSG00000090100	Ttbk2	NA	NA	NA	NA
ENSDARG00000005673	ENSDARG00000021013	ENSMUSG00000028128	F3	NA	NA	NA	NA
ENSDARG00000005679	ENSDARG00000077953	ENSMUSG00000019487	Trip10	NA	NA	NA	NA
ENSDARG00000005716	ENSDARG00000021480	ENSMUSG00000038463	Olfml2b	NA	NA	NA	NA
ENSDARG00000006079	ENSDARG00000056774	ENSMUSG00000026424	Gpr37l1	NA	NA	NA	NA
ENSDARG00000006202	ENSDARG00000036993	ENSMUSG00000018166	Erbb3	NA	NA	NA	NA
ENSDARG00000006272	ENSDARG00000004721	ENSMUSG00000021112	Mpp5	NA	NA	NA	NA
ENSDARG00000006385	ENSDARG00000075870	ENSMUSG00000033088	Triobp	NA	NA	NA	NA
ENSDARG00000006396	ENSDARG00000091662	ENSMUSG00000020598	Nrcam	NA	NA	NA	NA
ENSDARG00000006560	ENSDARG00000055374	ENSMUSG00000021356	Irf4	NA	NA	NA	NA
ENSDARG00000006640	ENSDARG00000019428	ENSMUSG00000032446	Eomes	NA	NA	NA	NA
ENSDARG00000006757	ENSDARG00000068888	ENSMUSG00000075307	Kbtbd10	NA	NA	NA	NA
ENSDARG00000006862	ENSDARG00000008639	ENSMUSG00000026585	Kifap3	NA	NA	NA	NA
ENSDARG00000006891	ENSDARG00000029511	ENSMUSG00000043673	Kcns3	NA	NA	NA	NA
ENSDARG00000006923	ENSDARG00000037905	ENSMUSG00000034656	Cacna1a	NA	NA	NA	NA
ENSDARG00000006978	ENSDARG00000044615	ENSMUSG00000004085	B230120H2	NA	NA	NA	NA
ENSDARG00000006983	ENSDARG00000034668	ENSMUSG00000028137	Celf3	NA	NA	NA	NA
ENSDARG00000006990	ENSDARG00000074886	ENSMUSG00000030284	Creld1	NA	NA	NA	NA
ENSDARG00000007179	ENSDARG00000058853	ENSMUSG00000015305	Sash1	NA	NA	NA	NA
ENSDARG00000007195	ENSDARG00000004150	ENSMUSG00000023192	Grm2	NA	NA	NA	NA
ENSDARG00000007289	ENSDARG00000052555	ENSMUSG00000039208	Metrnl	NA	NA	NA	NA
ENSDARG00000007356	ENSDARG00000086070	ENSMUSG00000031603	Fgf20	NA	NA	NA	NA
ENSDARG00000007412	ENSDARG00000001437	ENSMUSG00000028645	Slc2a1	NA	NA	NA	NA
ENSDARG00000007430	ENSDARG00000088563	ENSMUSG00000079466	Prdm12	NA	NA	NA	NA
ENSDARG00000007654	ENSDARG00000038991	ENSMUSG00000034187	Nsf	NA	NA	NA	NA
ENSDARG00000007678	ENSDARG00000034473	ENSMUSG00000036565	Ttyh3	NA	NA	NA	NA
ENSDARG00000007808	ENSDARG00000015989	ENSMUSG00000025157	Zdhhc16	NA	NA	NA	NA
ENSDARG00000007856	ENSDARG00000055578	ENSMUSG00000045287	Rtn4rl1	NA	NA	NA	NA
ENSDARG00000007950	ENSDARG00000036086	ENSMUSG00000032243	Itga11	NA	NA	NA	NA
ENSDARG00000008100	ENSDARG00000051730	ENSMUSG00000030495	Slc7a10	NA	NA	NA	NA
ENSDARG00000008191	ENSDARG00000056740	ENSMUSG00000028347	Tmeff1	NA	NA	NA	NA
ENSDARG00000008209	ENSDARG00000006212	ENSMUSG00000061911	Myt1l	NA	NA	NA	NA
ENSDARG00000008767	ENSDARG00000042484	ENSMUSG00000034771	Tle2	NA	NA	NA	NA
ENSDARG00000008772	ENSDARG00000052360	ENSMUSG00000020722	Cacng1	NA	NA	NA	NA
ENSDARG00000008912	ENSDARG00000040625	ENSMUSG00000030376	Slc8a2	NA	NA	NA	NA
ENSDARG00000008948	ENSDARG00000078718	ENSMUSG00000034579	Pla2g3	NA	NA	NA	NA
ENSDARG00000009023	ENSDARG00000086326	ENSMUSG00000014496	Ankrd28	NA	NA	NA	NA
ENSDARG00000009351	ENSDARG00000045856	ENSMUSG00000000183	Fgf6	NA	NA	NA	NA
ENSDARG00000009372	ENSDARG00000028066	ENSMUSG00000043670	Diras1	NA	NA	NA	NA
ENSDARG00000009524	ENSDARG00000024827	ENSMUSG00000047747	Rnf150	NA	NA	NA	NA
ENSDARG00000009621	ENSDARG00000032565	ENSMUSG00000019146	Cacng2	NA	NA	NA	NA
ENSDARG00000009782	ENSDARG00000006281	ENSMUSG00000018830	Myh11	NA	NA	NA	NA
ENSDARG00000009901	ENSDARG00000014587	ENSMUSG00000031170	Slc38a5	NA	NA	NA	NA
ENSDARG00000009903	ENSDARG00000087722	ENSMUSG00000031090	Nadsyn1	NA	NA	NA	NA
ENSDARG00000010155	ENSDARG00000062991	ENSMUSG00000058835	Abi1	NA	NA	NA	NA
ENSDARG00000010158	ENSDARG00000070080	ENSMUSG00000027799	Nbea	NA	NA	NA	NA
ENSDARG00000010231	ENSDARG00000057032	ENSMUSG00000030402	Ppm1n	NA	NA	NA	NA
ENSDARG00000010255	ENSDARG00000003219	ENSMUSG00000075411	Bin2	NA	NA	NA	NA
ENSDARG00000010376	ENSDARG00000077812	ENSMUSG00000089774	Slc5a3	NA	NA	NA	NA
ENSDARG00000010385	ENSDARG00000035683	ENSMUSG00000020486	sep.04	NA	NA	NA	NA
ENSDARG00000010655	ENSDARG00000076011	ENSMUSG00000037826	Ppm1k	NA	NA	NA	NA
ENSDARG00000010785	ENSDARG00000063430	ENSMUSG00000040152	Thbs1	NA	NA	NA	NA
ENSDARG00000010816	ENSDARG00000079231	ENSMUSG00000069072	Slc7a14	NA	NA	NA	NA
ENSDARG00000010958	ENSDARG00000058267	ENSMUSG00000029276	Glmn	NA	NA	NA	NA
ENSDARG00000010977	ENSDARG00000045628	ENSMUSG00000002059	Rab34	NA	NA	NA	NA
ENSDARG00000011029	ENSDARG00000054680	ENSMUSG00000029205	Chrna9	NA	NA	NA	NA
ENSDARG00000011188	ENSDARG00000079944	ENSMUSG00000052155	Acvr2a	NA	NA	NA	NA
ENSDARG00000011259	ENSDARG00000061399	ENSMUSG00000030523	Trpm1	NA	NA	NA	NA
ENSDARG00000011571	ENSDARG00000011473	ENSMUSG00000059588	Calcrl	NA	NA	NA	NA
ENSDARG00000011855	ENSDARG00000077686	ENSMUSG00000057230	Aak1	NA	NA	NA	NA
ENSDARG00000011932	ENSDARG00000007601	ENSMUSG00000039671	Zmynd8	NA	NA	NA	NA
ENSDARG00000012071	ENSDARG00000003025	ENSMUSG00000033544	Angptl1	NA	NA	NA	NA
ENSDARG00000012125	ENSDARG00000029898	ENSMUSG00000067220	Cnga1	NA	NA	NA	NA
ENSDARG00000012269	ENSDARG00000062084	ENSMUSG00000029862	Clcn1	NA	NA	NA	NA
ENSDARG00000012482	ENSDARG00000063299	ENSMUSG00000061601	Pclo	NA	NA	NA	NA
ENSDARG00000012496	ENSDARG00000003900	ENSMUSG00000091735	Gpr62	NA	NA	NA	NA
ENSDARG00000012586	ENSDARG00000075041	ENSMUSG00000036053	Fmnl2	NA	NA	NA	NA
ENSDARG00000012588	ENSDARG00000036114	ENSMUSG00000021518	Ptdss1	NA	NA	NA	NA
ENSDARG00000012823	ENSDARG00000060849	ENSMUSG00000061689	Dlgap4	NA	NA	NA	NA
ENSDARG00000013047	ENSDARG00000043902	ENSMUSG00000028280	Gabrr1	NA	NA	NA	NA
ENSDARG00000013072	ENSDARG00000051962	ENSMUSG00000031790	Mmp15	NA	NA	NA	NA
ENSDARG00000013221	ENSDARG00000002411	ENSMUSG00000031842	Pde4c	NA	NA	NA	NA
ENSDARG00000013222	ENSDARG00000020981	ENSMUSG00000027957	Slc35a3	NA	NA	NA	NA
ENSDARG00000013245	ENSDARG00000029751	ENSMUSG00000047731	D19Wsu16	NA	NA	NA	NA
ENSDARG00000013360	ENSDARG00000007302	ENSMUSG00000030638	Sh3gl3	NA	NA	NA	NA
ENSDARG00000013460	ENSDARG00000059139	ENSMUSG00000044177	Wfikkn2	NA	NA	NA	NA
ENSDARG00000013669	ENSDARG00000069101	ENSMUSG00000027438	Napb	NA	NA	NA	NA
ENSDARG00000013685	ENSDARG00000054050	ENSMUSG00000049598	Vsig8	NA	NA	NA	NA
ENSDARG00000013690	ENSDARG00000074680	ENSMUSG00000041670	Rims1	NA	NA	NA	NA
ENSDARG00000013813	ENSDARG00000016396	ENSMUSG00000028439	2310028H2	NA	NA	NA	NA

ENSDARG00000013921	ENSDARG00000056001	ENSMUSG00000056602	Fry	NA	NA	NA	NA
ENSDARG00000014105	ENSDARG00000074328	ENSMUSG00000024897	Apba1	NA	NA	NA	NA
ENSDARG00000014169	ENSDARG00000025206	ENSMUSG00000026452	Syt2	NA	NA	NA	NA
ENSDARG00000014320	ENSDARG00000056045	ENSMUSG00000042638	Gucy2c	NA	NA	NA	NA
ENSDARG00000014439	ENSDARG00000076025	ENSMUSG00000040479	Dgkz	NA	NA	NA	NA
ENSDARG00000014477	ENSDARG00000074958	ENSMUSG00000044933	Sstr3	NA	NA	NA	NA
ENSDARG00000014655	ENSDARG00000074149	ENSMUSG00000030102	Itpr1	NA	NA	NA	NA
ENSDARG00000014674	ENSDARG00000032079	ENSMUSG00000032883	Acsl3	NA	NA	NA	NA
ENSDARG00000014675	ENSDARG00000032485	ENSMUSG00000028039	Efna3	NA	NA	NA	NA
ENSDARG00000014907	ENSDARG00000032831	ENSMUSG00000006205	Htra1	NA	NA	NA	NA
ENSDARG00000014910	ENSDARG00000025285	ENSMUSG00000031934	Panx1	NA	NA	NA	NA
ENSDARG00000014973	ENSDARG00000073713	ENSMUSG00000059857	Ntng1	NA	NA	NA	NA
ENSDARG00000014995	ENSDARG00000041071	ENSMUSG00000051256	Jagn1	NA	NA	NA	NA
ENSDARG00000015184	ENSDARG00000062667	ENSMUSG00000052373	Mpp3	NA	NA	NA	NA
ENSDARG00000015552	ENSDARG00000032221	ENSMUSG00000066043	Phactr4	NA	NA	NA	NA
ENSDARG00000015566	ENSDARG00000005394	ENSMUSG00000020661	Dnmt3a	NA	NA	NA	NA
ENSDARG00000015589	ENSDARG00000058357	ENSMUSG00000022237	Ankrd33b	NA	NA	NA	NA
ENSDARG00000015731	ENSDARG00000036147	ENSMUSG00000055489	Ano5	NA	NA	NA	NA
ENSDARG00000015803	ENSDARG00000052818	ENSMUSG00000049323	Smcr8	NA	NA	NA	NA
ENSDARG00000015854	ENSDARG00000089929	ENSMUSG00000021919	Chat	NA	NA	NA	NA
ENSDARG00000015891	ENSDARG00000021151	ENSMUSG00000041836	Ptpre	NA	NA	NA	NA
ENSDARG00000016048	ENSDARG00000006491	ENSMUSG00000029314	Agpat9	NA	NA	NA	NA
ENSDARG00000016348	ENSDARG00000005350	ENSMUSG00000023026	Dip2b	NA	NA	NA	NA
ENSDARG00000016439	ENSDARG00000041874	ENSMUSG00000041313	Slc7a1	NA	NA	NA	NA
ENSDARG00000016470	ENSDARG00000026406	ENSMUSG00000027712	Anxa5	NA	NA	NA	NA
ENSDARG00000016667	ENSDARG00000018967	ENSMUSG00000024462	Gabbr1	NA	NA	NA	NA
ENSDARG00000016718	ENSDARG00000026325	ENSMUSG00000000901	Mmp11	NA	NA	NA	NA
ENSDARG00000016742	ENSDARG00000060601	ENSMUSG00000021719	Rgs7bp	NA	NA	NA	NA
ENSDARG00000016788	ENSDARG00000013207	ENSMUSG00000024238	Zeb1	NA	NA	NA	NA
ENSDARG00000016866	ENSDARG00000025846	ENSMUSG00000039157	Fam102a	NA	NA	NA	NA
ENSDARG00000016963	ENSDARG00000068572	ENSMUSG00000032902	Slc16a1	NA	NA	NA	NA
ENSDARG00000016999	ENSDARG00000004328	ENSMUSG00000050966	Lin28a	NA	NA	NA	NA
ENSDARG00000017162	ENSDARG00000079500	ENSMUSG00000020668	Kif3c	NA	NA	NA	NA
ENSDARG00000017211	ENSDARG00000075821	ENSMUSG00000053646	Plxnb1	NA	NA	NA	NA
ENSDARG00000017360	ENSDARG00000028524	ENSMUSG00000004098	Col5a3	NA	NA	NA	NA
ENSDARG00000017649	ENSDARG00000023542	ENSMUSG00000026312	Cdh7	NA	NA	NA	NA
ENSDARG00000017880	ENSDARG00000076181	ENSMUSG00000079056	Kcnip3	NA	NA	NA	NA
ENSDARG00000018047	ENSDARG00000006235	ENSMUSG00000012076	Brms1l	NA	NA	NA	NA
ENSDARG00000018105	ENSDARG00000038716	ENSMUSG00000007122	Casq1	NA	NA	NA	NA
ENSDARG00000018130	ENSDARG00000070316	ENSMUSG00000017686	Rhot1	NA	NA	NA	NA
ENSDARG00000018530	ENSDARG00000002552	ENSMUSG00000016528	Mapkapk2	NA	NA	NA	NA
ENSDARG00000018566	ENSDARG00000018820	ENSMUSG00000068699	Flnc	NA	NA	NA	NA
ENSDARG00000018619	ENSDARG00000031387	ENSMUSG00000008206	Lass4	NA	NA	NA	NA
ENSDARG00000018750	ENSDARG00000031751	ENSMUSG00000027931	Npr1	NA	NA	NA	NA
ENSDARG00000018782	ENSDARG00000019103	ENSMUSG00000033326	Kdm4a	NA	NA	NA	NA
ENSDARG00000018935	ENSDARG00000079586	ENSMUSG00000007653	Gabrb2	NA	NA	NA	NA
ENSDARG00000018997	ENSDARG00000077736	ENSMUSG00000033615	Cplx1	NA	NA	NA	NA
ENSDARG00000019125	ENSDARG00000039052	ENSMUSG00000074001	Kbtbd5	NA	NA	NA	NA
ENSDARG00000019335	ENSDARG00000007097	ENSMUSG00000067071	Hes6	NA	NA	NA	NA
ENSDARG00000019405	ENSDARG00000062880	ENSMUSG00000064293	Cntn4	NA	NA	NA	NA
ENSDARG00000019541	ENSDARG00000055642	ENSMUSG00000022546	Gpt	NA	NA	NA	NA
ENSDARG00000019601	ENSDARG00000078322	ENSMUSG00000032332	Col12a1	NA	NA	NA	NA
ENSDARG00000019622	ENSDARG00000035994	ENSMUSG00000037386	Rims2	NA	NA	NA	NA
ENSDARG00000019658	ENSDARG00000036816	ENSMUSG00000008496	Pou2f2	NA	NA	NA	NA
ENSDARG00000019686	ENSDARG00000019861	ENSMUSG00000039899	Fgl2	NA	NA	NA	NA
ENSDARG00000020000	ENSDARG00000030104	ENSMUSG00000036206	Sh3bp4	NA	NA	NA	NA
ENSDARG00000020176	ENSDARG00000003251	ENSMUSG00000051390	Zbtb22	NA	NA	NA	NA
ENSDARG00000020178	ENSDARG00000017673	ENSMUSG00000021047	Nova1	NA	NA	NA	NA
ENSDARG00000020224	ENSDARG00000051936	ENSMUSG00000030304	Ergic2	NA	NA	NA	NA
ENSDARG00000020228	ENSDARG00000087519	ENSMUSG00000058239	Usf2	NA	NA	NA	NA
ENSDARG00000020270	ENSDARG00000069937	ENSMUSG00000033335	Dnm2	NA	NA	NA	NA
ENSDARG00000020395	ENSDARG00000075608	ENSMUSG00000038244	Mical2	NA	NA	NA	NA
ENSDARG00000020443	ENSDARG00000043410	ENSMUSG00000035067	Xkr6	NA	NA	NA	NA
ENSDARG00000020493	ENSDARG00000058421	ENSMUSG00000067242	Lgi1	NA	NA	NA	NA
ENSDARG00000020610	ENSDARG00000031920	ENSMUSG00000026414	Tnnt2	NA	NA	NA	NA
ENSDARG00000020845	ENSDARG00000078842	ENSMUSG00000055322	Tns1	NA	NA	NA	NA
ENSDARG00000020871	ENSDARG00000051814	ENSMUSG00000068748	Ptprz1	NA	NA	NA	NA
ENSDARG00000020872	ENSDARG00000014022	ENSMUSG00000003847	Nfat5	NA	NA	NA	NA
ENSDARG00000020924	ENSDARG00000061579	ENSMUSG00000017774	Myo1c	NA	NA	NA	NA
ENSDARG00000021389	ENSDARG00000014246	ENSMUSG00000002799	Jag2	NA	NA	NA	NA
ENSDARG00000021846	ENSDARG00000015091	ENSMUSG00000034586	C630004H	NA	NA	NA	NA
ENSDARG00000021882	ENSDARG00000078003	ENSMUSG00000022124	Fbxl3	NA	NA	NA	NA
ENSDARG00000022045	ENSDARG00000059601	ENSMUSG00000027254	Mtap1a	NA	NA	NA	NA
ENSDARG00000022309	ENSDARG00000076673	ENSMUSG00000054889	Dsp	NA	NA	NA	NA
ENSDARG00000022668	ENSDARG00000005414	ENSMUSG00000004837	Grap	NA	NA	NA	NA
ENSDARG00000022772	ENSDARG00000053487	ENSMUSG00000020435	Osbp2	NA	NA	NA	NA
ENSDARG00000022858	ENSDARG00000071107	ENSMUSG00000022382	Wnt7b	NA	NA	NA	NA
ENSDARG00000022895	ENSDARG00000056603	ENSMUSG00000031139	Mcf2	NA	NA	NA	NA
ENSDARG00000023210	ENSDARG00000094201	ENSMUSG00000037553	Zdhhc18	NA	NA	NA	NA
ENSDARG00000023318	ENSDARG00000061778	ENSMUSG00000028354	Fmn2	NA	NA	NA	NA
ENSDARG00000023527	ENSDARG00000012649	ENSMUSG00000024515	Smad4	NA	NA	NA	NA
ENSDARG00000023624	ENSDARG00000038012	ENSMUSG00000022408	Fam83f	NA	NA	NA	NA
ENSDARG00000023683	ENSDARG00000010933	ENSMUSG00000031142	Cacna1f	NA	NA	NA	NA
ENSDARG00000023878	ENSDARG00000031413	ENSMUSG00000063410	Stk24	NA	NA	NA	NA
ENSDARG00000023886	ENSDARG00000026855	ENSMUSG00000041460	Cacna2d4	NA	NA	NA	NA
ENSDARG00000024167	ENSDARG00000023236	ENSMUSG00000058248	Kcnh1	NA	NA	NA	NA
ENSDARG00000024189	ENSDARG00000025024	ENSMUSG00000045731	Pnoc	NA	NA	NA	NA
ENSDARG00000024365	ENSDARG00000006368	ENSMUSG00000007888	Crlf1	NA	NA	NA	NA
ENSDARG00000024560	ENSDARG00000012881	ENSMUSG00000006574	Slc4a1	NA	NA	NA	NA
ENSDARG00000024847	ENSDARG00000031678	ENSMUSG00000026042	Col5a2	NA	NA	NA	NA

ENSDARG00000024865	ENSDARG00000028118	ENSMUSG00000050272	Dscam	NA	NA	NA	NA
ENSDARG00000024966	ENSDARG00000023914	ENSMUSG00000030397	Mark4	NA	NA	NA	NA
ENSDARG00000025013	ENSDARG00000035178	ENSMUSG00000024697	Gna14	NA	NA	NA	NA
ENSDARG00000025089	ENSDARG00000075310	ENSMUSG00000025185	Loxl4	NA	NA	NA	NA
ENSDARG00000025189	ENSDARG00000037926	ENSMUSG00000052560	Cpne8	NA	NA	NA	NA
ENSDARG00000025299	ENSDARG00000045706	ENSMUSG00000030352	Tspan9	NA	NA	NA	NA
ENSDARG00000025325	ENSDARG00000040085	ENSMUSG00000031971	1700054N0	NA	NA	NA	NA
ENSDARG00000025615	ENSDARG00000029308	ENSMUSG00000047040	Prr15l	NA	NA	NA	NA
ENSDARG00000025671	ENSDARG00000017742	ENSMUSG00000000617	Grm6	NA	NA	NA	NA
ENSDARG00000025974	ENSDARG00000076916	ENSMUSG00000052539	Magi3	NA	NA	NA	NA
ENSDARG00000026248	ENSDARG00000034940	ENSMUSG00000008932	Slc1a7	NA	NA	NA	NA
ENSDARG00000026333	ENSDARG00000036952	ENSMUSG00000042631	Xkr7	NA	NA	NA	NA
ENSDARG00000026634	ENSDARG00000068157	ENSMUSG00000036893	Ehmt1	NA	NA	NA	NA
ENSDARG00000026926	ENSDARG00000019752	ENSMUSG00000071648	Rom1	NA	NA	NA	NA
ENSDARG00000027153	ENSDARG00000030750	ENSMUSG00000074991	Gabrr3	NA	NA	NA	NA
ENSDARG00000027345	ENSDARG00000088742	ENSMUSG00000032092	Mpzl2	NA	NA	NA	NA
ENSDARG00000027497	ENSDARG00000088789	ENSMUSG00000053693	Mast1	NA	NA	NA	NA
ENSDARG00000027564	ENSDARG00000052405	ENSMUSG00000074923	Pak6	NA	NA	NA	NA
ENSDARG00000027867	ENSDARG00000042186	ENSMUSG00000021223	Papln	NA	NA	NA	NA
ENSDARG00000027957	ENSDARG00000062542	ENSMUSG00000022523	Fgf12	NA	NA	NA	NA
ENSDARG00000027966	ENSDARG00000076073	ENSMUSG00000054702	Ap1s3	NA	NA	NA	NA
ENSDARG00000028067	ENSDARG00000025468	ENSMUSG00000022051	Bnip3l	NA	NA	NA	NA
ENSDARG00000028071	ENSDARG00000028053	ENSMUSG00000022098	Bmp1	NA	NA	NA	NA
ENSDARG00000028257	ENSDARG00000056281	ENSMUSG00000034445	Cybasc3	NA	NA	NA	NA
ENSDARG00000028348	ENSDARG00000010192	ENSMUSG00000004872	Pax3	NA	NA	NA	NA
ENSDARG00000028412	ENSDARG00000003259	ENSMUSG00000024529	Lox	NA	NA	NA	NA
ENSDARG00000028521	ENSDARG00000031013	ENSMUSG00000045532	C1ql1	NA	NA	NA	NA
ENSDARG00000028552	ENSDARG00000010144	ENSMUSG00000035835	BC005764	NA	NA	NA	NA
ENSDARG00000028725	ENSDARG00000027638	ENSMUSG00000045875	Adra1a	NA	NA	NA	NA
ENSDARG00000028776	ENSDARG00000069159	ENSMUSG00000030559	Rab38	NA	NA	NA	NA
ENSDARG00000028857	ENSDARG00000075376	ENSMUSG00000042216	Sgsm1	NA	NA	NA	NA
ENSDARG00000028878	ENSDARG00000059058	ENSMUSG00000032528	Vipr1	NA	NA	NA	NA
ENSDARG00000028896	ENSDARG00000002231	ENSMUSG00000052151	Ppap2c	NA	NA	NA	NA
ENSDARG00000029057	ENSDARG00000029982	ENSMUSG00000036151	Tm6sf2	NA	NA	NA	NA
ENSDARG00000029457	ENSDARG00000042552	ENSMUSG00000026407	Cacna1s	NA	NA	NA	NA
ENSDARG00000029474	ENSDARG00000060116	ENSMUSG00000030272	Camk1	NA	NA	NA	NA
ENSDARG00000029493	ENSDARG00000010097	ENSMUSG00000031138	F9	NA	NA	NA	NA
ENSDARG00000029590	ENSDARG00000059534	ENSMUSG00000025318	Jph3	NA	NA	NA	NA
ENSDARG00000029881	ENSDARG00000060053	ENSMUSG00000038319	Kcnh2	NA	NA	NA	NA
ENSDARG00000029994	ENSDARG00000055577	ENSMUSG00000045613	Chrm2	NA	NA	NA	NA
ENSDARG00000030012	ENSDARG00000095170	ENSMUSG00000026305	Lrrfip1	NA	NA	NA	NA
ENSDARG00000030157	ENSDARG00000021265	ENSMUSG00000038670	Mybpc2	NA	NA	NA	NA
ENSDARG00000030292	ENSDARG00000059438	ENSMUSG00000038296	Galntl4	NA	NA	NA	NA
ENSDARG00000030311	ENSDARG00000033104	ENSMUSG00000060332	Tmc2	NA	NA	NA	NA
ENSDARG00000030411	ENSDARG00000087437	ENSMUSG00000038135	Crygn	NA	NA	NA	NA
ENSDARG00000030832	ENSDARG00000020581	ENSMUSG00000062372	Otof	NA	NA	NA	NA
ENSDARG00000030932	ENSDARG00000067548	ENSMUSG00000021732	Fgf10	NA	NA	NA	NA
ENSDARG00000030933	ENSDARG00000068714	ENSMUSG00000018334	Ksr1	NA	NA	NA	NA
ENSDARG00000031219	ENSDARG00000005600	ENSMUSG00000052430	Bmpr1b	NA	NA	NA	NA
ENSDARG00000031383	ENSDARG00000040278	ENSMUSG00000022357	Klhl38	NA	NA	NA	NA
ENSDARG00000031489	ENSDARG00000044132	ENSMUSG00000021390	Ogn	NA	NA	NA	NA
ENSDARG00000031548	ENSDARG00000033589	ENSMUSG00000005958	Ephb3	NA	NA	NA	NA
ENSDARG00000031651	ENSDARG00000054447	ENSMUSG00000023942	Slc29a1	NA	NA	NA	NA
ENSDARG00000031845	ENSDARG00000042551	ENSMUSG00000020646	Mboat2	NA	NA	NA	NA
ENSDARG00000032083	ENSDARG00000038974	ENSMUSG00000022048	Dpysl2	NA	NA	NA	NA
ENSDARG00000032493	ENSDARG00000087701	ENSMUSG00000056486	Chn1	NA	NA	NA	NA
ENSDARG00000033251	ENSDARG00000040482	ENSMUSG00000029822	Osbpl3	NA	NA	NA	NA
ENSDARG00000033296	ENSDARG00000074563	ENSMUSG00000039904	Gpr37	NA	NA	NA	NA
ENSDARG00000033320	ENSDARG00000042794	ENSMUSG00000020088	Sar1a	NA	NA	NA	NA
ENSDARG00000033446	ENSDARG00000036787	ENSMUSG00000024339	Tap2	NA	NA	NA	NA
ENSDARG00000033544	ENSDARG00000029124	ENSMUSG00000033453	Adamts15	NA	NA	NA	NA
ENSDARG00000033635	ENSDARG00000060702	ENSMUSG00000035528	Npffr2	NA	NA	NA	NA
ENSDARG00000033804	ENSDARG00000016977	ENSMUSG00000028136	Snx27	NA	NA	NA	NA
ENSDARG00000034373	ENSDARG00000028236	ENSMUSG00000045672	Col27a1	NA	NA	NA	NA
ENSDARG00000034493	ENSDARG00000070543	ENSMUSG00000059003	Grin2a	NA	NA	NA	NA
ENSDARG00000034555	ENSDARG00000067785	ENSMUSG00000052062	Pard3b	NA	NA	NA	NA
ENSDARG00000034604	ENSDARG00000018881	ENSMUSG00000040694	Apobec2	NA	NA	NA	NA
ENSDARG00000034714	ENSDARG00000014239	ENSMUSG00000025366	Esyt1	NA	NA	NA	NA
ENSDARG00000034808	ENSDARG00000022109	ENSMUSG00000053519	Kcnip1	NA	NA	NA	NA
ENSDARG00000034930	ENSDARG00000057792	ENSMUSG00000051056	Gja10	NA	NA	NA	NA
ENSDARG00000035273	ENSDARG00000045753	ENSMUSG00000036019	Tmtc2	NA	NA	NA	NA
ENSDARG00000035452	ENSDARG00000015134	ENSMUSG00000020785	Camkk1	NA	NA	NA	NA
ENSDARG00000035533	ENSDARG00000016025	ENSMUSG00000030043	Tacr1	NA	NA	NA	NA
ENSDARG00000035538	ENSDARG00000035565	ENSMUSG00000038023	Atp6v0a2	NA	NA	NA	NA
ENSDARG00000035895	ENSDARG00000069739	ENSMUSG00000001334	Fndc5	NA	NA	NA	NA
ENSDARG00000035910	ENSDARG00000000567	ENSMUSG00000041483	Zfp281	NA	NA	NA	NA
ENSDARG00000036017	ENSDARG00000034907	ENSMUSG00000037348	Paqr7	NA	NA	NA	NA
ENSDARG00000036031	ENSDARG00000013843	ENSMUSG00000072214	sep.05	NA	NA	NA	NA
ENSDARG00000036065	ENSDARG00000012407	ENSMUSG00000020346	Mgat1	NA	NA	NA	NA
ENSDARG00000036139	ENSDARG00000016337	ENSMUSG00000032401	Lctl	NA	NA	NA	NA
ENSDARG00000036152	ENSDARG00000001259	ENSMUSG00000030498	Gas2	NA	NA	NA	NA
ENSDARG00000036175	ENSDARG00000062720	ENSMUSG00000051375	Pcdh1	NA	NA	NA	NA
ENSDARG00000036243	ENSDARG00000056793	ENSMUSG00000063568	Jazf1	NA	NA	NA	NA
ENSDARG00000036295	ENSDARG00000031461	ENSMUSG00000042532	Golga7b	NA	NA	NA	NA
ENSDARG00000036457	ENSDARG00000046079	ENSMUSG00000078815	Cacng6	NA	NA	NA	NA
ENSDARG00000036463	ENSDARG00000067678	ENSMUSG00000001739	Cldn15	NA	NA	NA	NA
ENSDARG00000036541	ENSDARG00000017367	ENSMUSG00000020282	Rhbdf1	NA	NA	NA	NA
ENSDARG00000036815	ENSDARG00000018259	ENSMUSG00000040907	Atp1a3	NA	NA	NA	NA
ENSDARG00000036826	ENSDARG00000063576	ENSMUSG00000014498	Ankrd52	NA	NA	NA	NA
ENSDARG00000037337	ENSDARG00000091683	ENSMUSG00000044629	Cnrip1	NA	NA	NA	NA

ENSDARG00000037357	ENSDARG00000040657	ENSMUSG00000041895	Wipi1	NA	NA	NA	NA
ENSDARG00000037373	ENSDARG00000021539	ENSMUSG00000028664	Ephb2	NA	NA	NA	NA
ENSDARG00000037415	ENSDARG00000014280	ENSMUSG00000003279	Dlgap1	NA	NA	NA	NA
ENSDARG00000037495	ENSDARG00000052012	ENSMUSG00000050896	Rtn4rl2	NA	NA	NA	NA
ENSDARG00000037533	ENSDARG00000040683	ENSMUSG00000024313	Mep1b	NA	NA	NA	NA
ENSDARG00000037558	ENSDARG00000017086	ENSMUSG00000031204	Asb12	NA	NA	NA	NA
ENSDARG00000037587	ENSDARG00000044278	ENSMUSG00000056296	Synpr	NA	NA	NA	NA
ENSDARG00000037593	ENSDARG00000020982	ENSMUSG00000030020	Prickle2	NA	NA	NA	NA
ENSDARG00000037607	ENSDARG00000074902	ENSMUSG00000061411	8430427H1	NA	NA	NA	NA
ENSDARG00000037794	ENSDARG00000045164	ENSMUSG00000059991	Nptx2	NA	NA	NA	NA
ENSDARG00000037859	ENSDARG00000058557	ENSMUSG00000004371	Il11	NA	NA	NA	NA
ENSDARG00000037861	ENSDARG00000013295	ENSMUSG00000003153	Slc2a3	NA	NA	NA	NA
ENSDARG00000037904	ENSDARG00000024004	ENSMUSG00000015968	Cacna1d	NA	NA	NA	NA
ENSDARG00000038025	ENSDARG00000087181	ENSMUSG00000053411	Cbx7	NA	NA	NA	NA
ENSDARG00000038119	ENSDARG00000073684	ENSMUSG00000037813	D630003M	NA	NA	NA	NA
ENSDARG00000038131	ENSDARG00000053918	ENSMUSG00000015605	Srf	NA	NA	NA	NA
ENSDARG00000038219	ENSDARG00000036156	ENSMUSG00000075415	Fnbp1	NA	NA	NA	NA
ENSDARG00000038239	ENSDARG00000042887	ENSMUSG00000031691	Tnpo2	NA	NA	NA	NA
ENSDARG00000038373	ENSDARG00000019418	ENSMUSG00000041695	Kcnj2	NA	NA	NA	NA
ENSDARG00000038574	ENSDARG00000017470	ENSMUSG00000050711	Scg2	NA	NA	NA	NA
ENSDARG00000038634	ENSDARG00000070810	ENSMUSG00000032532	Cck	NA	NA	NA	NA
ENSDARG00000038826	ENSDARG00000058603	ENSMUSG00000042686	Jph1	NA	NA	NA	NA
ENSDARG00000038918	ENSDARG00000071640	ENSMUSG00000021478	Drd1a	NA	NA	NA	NA
ENSDARG00000038957	ENSDARG00000031506	ENSMUSG00000034258	Mfsd7c	NA	NA	NA	NA
ENSDARG00000038968	ENSDARG00000087474	ENSMUSG00000040899	Ccr6	NA	NA	NA	NA
ENSDARG00000039234	ENSDARG00000045957	ENSMUSG00000021886	Gpr65	NA	NA	NA	NA
ENSDARG00000039238	ENSDARG00000074669	ENSMUSG00000020723	Cacng4	NA	NA	NA	NA
ENSDARG00000039265	ENSDARG00000015003	ENSMUSG00000031389	Arhgap4	NA	NA	NA	NA
ENSDARG00000039453	ENSDARG00000071877	ENSMUSG00000033044	Dhrs7c	NA	NA	NA	NA
ENSDARG00000039577	ENSDARG00000022841	ENSMUSG00000059456	Ptk2b	NA	NA	NA	NA
ENSDARG00000039901	ENSDARG00000023600	ENSMUSG00000028488	Sh3gl2	NA	NA	NA	NA
ENSDARG00000039932	ENSDARG00000038011	ENSMUSG00000018008	Cyth4	NA	NA	NA	NA
ENSDARG00000039943	ENSDARG00000011797	ENSMUSG00000046694	Fam46b	NA	NA	NA	NA
ENSDARG00000039963	ENSDARG00000091660	ENSMUSG00000048373	Fgfbp1	NA	NA	NA	NA
ENSDARG00000039987	ENSDARG00000018773	ENSMUSG00000015501	Hivep2	NA	NA	NA	NA
ENSDARG00000039999	ENSDARG00000077691	ENSMUSG00000020805	Slc13a5	NA	NA	NA	NA
ENSDARG00000040065	ENSDARG00000069450	ENSMUSG00000057123	Gja5	NA	NA	NA	NA
ENSDARG00000040133	ENSDARG00000078729	ENSMUSG00000079355	Ccrl1	NA	NA	NA	NA
ENSDARG00000040137	ENSDARG00000020133	ENSMUSG00000034271	Jdp2	NA	NA	NA	NA
ENSDARG00000040248	ENSDARG00000016545	ENSMUSG00000026853	Crat	NA	NA	NA	NA
ENSDARG00000040274	ENSDARG00000018743	ENSMUSG00000040722	Scamp5	NA	NA	NA	NA
ENSDARG00000040334	ENSDARG00000037121	ENSMUSG00000053907	Mat2a	NA	NA	NA	NA
ENSDARG00000040474	ENSDARG00000004405	ENSMUSG00000038301	Snx10	NA	NA	NA	NA
ENSDARG00000040543	ENSDARG00000040898	ENSMUSG00000000544	Gpa33	NA	NA	NA	NA
ENSDARG00000040627	ENSDARG00000069139	ENSMUSG00000022935	Grik1	NA	NA	NA	NA
ENSDARG00000040684	ENSDARG00000057975	ENSMUSG00000026173	Plcd4	NA	NA	NA	NA
ENSDARG00000040705	ENSDARG00000062812	ENSMUSG00000026103	Gls	NA	NA	NA	NA
ENSDARG00000041115	ENSDARG00000088589	ENSMUSG00000063651	Cnfn	NA	NA	NA	NA
ENSDARG00000041162	ENSDARG00000026796	ENSMUSG00000019828	Grm1	NA	NA	NA	NA
ENSDARG00000041173	ENSDARG00000011317	ENSMUSG00000050541	Adra1b	NA	NA	NA	NA
ENSDARG00000041516	ENSDARG00000044422	ENSMUSG00000061393	Acvr2b	NA	NA	NA	NA
ENSDARG00000041864	ENSDARG00000043035	ENSMUSG00000079110	Capn3	NA	NA	NA	NA
ENSDARG00000042021	ENSDARG00000006409	ENSMUSG00000022610	Mapk12	NA	NA	NA	NA
ENSDARG00000042055	ENSDARG00000023053	ENSMUSG00000026483	Fam129a	NA	NA	NA	NA
ENSDARG00000042081	ENSDARG00000088096	ENSMUSG00000050824	Sstr5	NA	NA	NA	NA
ENSDARG00000042114	ENSDARG00000058820	ENSMUSG00000024381	Bin1	NA	NA	NA	NA
ENSDARG00000042145	ENSDARG00000002330	ENSMUSG00000028201	Lhx8	NA	NA	NA	NA
ENSDARG00000042338	ENSDARG00000042561	ENSMUSG00000031861	Lpar2	NA	NA	NA	NA
ENSDARG00000042350	ENSDARG00000030614	ENSMUSG00000035864	Syt1	NA	NA	NA	NA
ENSDARG00000042379	ENSDARG00000030914	ENSMUSG00000039886	Tmem120a	NA	NA	NA	NA
ENSDARG00000042811	ENSDARG00000017542	ENSMUSG00000036585	Fgf1	NA	NA	NA	NA
ENSDARG00000042859	ENSDARG00000014599	ENSMUSG00000006641	Slc5a6	NA	NA	NA	NA
ENSDARG00000042947	ENSDARG00000069133	ENSMUSG00000026100	Mstn	NA	NA	NA	NA
ENSDARG00000042954	ENSDARG00000011049	ENSMUSG00000023393	Slc17a9	NA	NA	NA	NA
ENSDARG00000042974	ENSDARG00000002230	ENSMUSG00000031144	Syp	NA	NA	NA	NA
ENSDARG00000042988	ENSDARG00000063158	ENSMUSG00000037996	Slc24a2	NA	NA	NA	NA
ENSDARG00000043059	ENSDARG00000070721	ENSMUSG00000022479	Vdr	NA	NA	NA	NA
ENSDARG00000043220	ENSDARG00000069117	ENSMUSG00000034402	Kcnh5	NA	NA	NA	NA
ENSDARG00000043313	ENSDARG00000009026	ENSMUSG00000032826	Ank2	NA	NA	NA	NA
ENSDARG00000043396	ENSDARG00000009949	ENSMUSG00000038552	Fndc4	NA	NA	NA	NA
ENSDARG00000043406	ENSDARG00000013422	ENSMUSG00000054640	Slc8a1	NA	NA	NA	NA
ENSDARG00000043661	ENSDARG00000070567	ENSMUSG00000054423	Cadps	NA	NA	NA	NA
ENSDARG00000043701	ENSDARG00000043180	ENSMUSG00000023019	Gpd1	NA	NA	NA	NA
ENSDARG00000043746	ENSDARG00000062693	ENSMUSG00000066392	Nrxn3	NA	NA	NA	NA
ENSDARG00000043907	ENSDARG00000069662	ENSMUSG00000042826	Fgf11	NA	NA	NA	NA
ENSDARG00000044015	ENSDARG00000042723	ENSMUSG00000022103	Gfra2	NA	NA	NA	NA
ENSDARG00000044161	ENSDARG00000074583	ENSMUSG00000041078	Grid1	NA	NA	NA	NA
ENSDARG00000044175	ENSDARG00000033956	ENSMUSG00000049112	Oxtr	NA	NA	NA	NA
ENSDARG00000044179	ENSDARG00000056150	ENSMUSG00000040043	Rbms2	NA	NA	NA	NA
ENSDARG00000044271	ENSDARG00000017901	ENSMUSG00000052698	Tln2	NA	NA	NA	NA
ENSDARG00000044441	ENSDARG00000077201	ENSMUSG00000024388	Myo7b	NA	NA	NA	NA
ENSDARG00000044456	ENSDARG00000058162	ENSMUSG00000035246	Pcyt1b	NA	NA	NA	NA
ENSDARG00000044632	ENSDARG00000061937	ENSMUSG00000030761	Myo7a	NA	NA	NA	NA
ENSDARG00000044775	ENSDARG00000069408	ENSMUSG00000036587	Fut7	NA	NA	NA	NA
ENSDARG00000045006	ENSDARG00000060123	ENSMUSG00000021745	Ptprg	NA	NA	NA	NA
ENSDARG00000045023	ENSDARG00000056458	ENSMUSG00000062252	Lhfpl5	NA	NA	NA	NA
ENSDARG00000045036	ENSDARG00000039704	ENSMUSG00000041598	Cdc42ep4	NA	NA	NA	NA
ENSDARG00000045070	ENSDARG00000056767	ENSMUSG00000020689	Itgb3	NA	NA	NA	NA
ENSDARG00000045087	ENSDARG00000037916	ENSMUSG00000048895	Cdk5r1	NA	NA	NA	NA
ENSDARG00000045129	ENSDARG00000062796	ENSMUSG00000001555	Fkbp10	NA	NA	NA	NA

ENSDARG00000045200	ENSDARG00000040490	ENSMUSG00000027001	Dusp19	NA	NA	NA	NA
ENSDARG00000045204	ENSDARG00000078760	ENSMUSG00000021991	Cacna2d3	NA	NA	NA	NA
ENSDARG00000045316	ENSDARG00000068480	ENSMUSG00000041020	Mtap7d2	NA	NA	NA	NA
ENSDARG00000045415	ENSDARG00000075850	ENSMUSG00000024524	Gnal	NA	NA	NA	NA
ENSDARG00000045632	ENSDARG00000061769	ENSMUSG00000030046	Bmp10	NA	NA	NA	NA
ENSDARG00000045708	ENSDARG00000078875	ENSMUSG00000054136	Adm2	NA	NA	NA	NA
ENSDARG00000045758	ENSDARG00000068231	ENSMUSG00000061414	Efcab4b	NA	NA	NA	NA
ENSDARG00000045789	ENSDARG00000007461	ENSMUSG00000020121	Srgap1	NA	NA	NA	NA
ENSDARG00000045799	ENSDARG00000035891	ENSMUSG00000030607	Acan	NA	NA	NA	NA
ENSDARG00000045864	ENSDARG00000045634	ENSMUSG00000029683	Lmod2	NA	NA	NA	NA
ENSDARG00000045956	ENSDARG00000062849	ENSMUSG00000033854	Kcnk10	NA	NA	NA	NA
ENSDARG00000052045	ENSDARG00000078258	ENSMUSG00000006344	Ggt5	NA	NA	NA	NA
ENSDARG00000052142	ENSDARG00000018968	ENSMUSG00000000532	Acvr1b	NA	NA	NA	NA
ENSDARG00000052155	ENSDARG00000032188	ENSMUSG00000007476	Lrrc8a	NA	NA	NA	NA
ENSDARG00000052386	ENSDARG00000046085	ENSMUSG00000022744	Cldnd1	NA	NA	NA	NA
ENSDARG00000052631	ENSDARG00000020072	ENSMUSG00000021702	Thbs4	NA	NA	NA	NA
ENSDARG00000052642	ENSDARG00000045145	ENSMUSG00000022494	Shisa9	NA	NA	NA	NA
ENSDARG00000052658	ENSDARG00000011122	ENSMUSG00000038582	Pptc7	NA	NA	NA	NA
ENSDARG00000052708	ENSDARG00000000474	ENSMUSG00000026418	Tnni1	NA	NA	NA	NA
ENSDARG00000052734	ENSDARG00000059301	ENSMUSG00000021670	Hmgcr	NA	NA	NA	NA
ENSDARG00000052748	ENSDARG00000052702	ENSMUSG00000058626	Capn11	NA	NA	NA	NA
ENSDARG00000052787	ENSDARG00000076632	ENSMUSG00000015335	Zdhhc12	NA	NA	NA	NA
ENSDARG00000052898	ENSDARG00000043466	ENSMUSG00000049265	Kcnk3	NA	NA	NA	NA
ENSDARG00000052966	ENSDARG00000057206	ENSMUSG00000020936	Nmt1	NA	NA	NA	NA
ENSDARG00000052982	ENSDARG00000014057	ENSMUSG00000023267	Gabrr2	NA	NA	NA	NA
ENSDARG00000053179	ENSDARG00000056091	ENSMUSG00000062127	Cttnbp2nl	NA	NA	NA	NA
ENSDARG00000053186	ENSDARG00000010154	ENSMUSG00000050666	E130203B1	NA	NA	NA	NA
ENSDARG00000053425	ENSDARG00000056532	ENSMUSG00000023232	Serinc2	NA	NA	NA	NA
ENSDARG00000053449	ENSDARG00000035832	ENSMUSG00000017311	Pyy	NA	NA	NA	NA
ENSDARG00000053454	ENSDARG00000013647	ENSMUSG00000030075	Cntn3	NA	NA	NA	NA
ENSDARG00000053559	ENSDARG00000034753	ENSMUSG00000032324	Tspan3	NA	NA	NA	NA
ENSDARG00000053586	ENSDARG00000093420	ENSMUSG00000025958	Creb1	NA	NA	NA	NA
ENSDARG00000053724	ENSDARG00000029989	ENSMUSG00000029778	Adcyap1r1	NA	NA	NA	NA
ENSDARG00000053746	ENSDARG00000011281	ENSMUSG00000044252	Osbpl1a	NA	NA	NA	NA
ENSDARG00000053859	ENSDARG00000089691	ENSMUSG00000050671	Ism2	NA	NA	NA	NA
ENSDARG00000054002	ENSDARG00000029419	ENSMUSG00000020737	Hn1	NA	NA	NA	NA
ENSDARG00000054036	ENSDARG00000038300	ENSMUSG00000029474	Rnf34	NA	NA	NA	NA
ENSDARG00000054196	ENSDARG00000009482	ENSMUSG00000034224	Slc38a8	NA	NA	NA	NA
ENSDARG00000054641	ENSDARG00000037183	ENSMUSG00000032265	Fam46a	NA	NA	NA	NA
ENSDARG00000054844	ENSDARG00000078241	ENSMUSG00000019996	Mtap7	NA	NA	NA	NA
ENSDARG00000054894	ENSDARG00000036428	ENSMUSG00000040212	Emp3	NA	NA	NA	NA
ENSDARG00000055045	ENSDARG00000017905	ENSMUSG00000031628	Casp3	NA	NA	NA	NA
ENSDARG00000055120	ENSDARG00000067570	ENSMUSG00000021939	Ctsb	NA	NA	NA	NA
ENSDARG00000055123	ENSDARG00000007151	ENSMUSG00000037624	Kcnk2	NA	NA	NA	NA
ENSDARG00000055160	ENSDARG00000075903	ENSMUSG00000063765	Chadl	NA	NA	NA	NA
ENSDARG00000055317	ENSDARG00000011549	ENSMUSG00000001076	C1ql4	NA	NA	NA	NA
ENSDARG00000055377	ENSDARG00000092921	ENSMUSG00000032192	Gnb5	NA	NA	NA	NA
ENSDARG00000055412	ENSDARG00000091260	ENSMUSG00000044951	Mylk4	NA	NA	NA	NA
ENSDARG00000055502	ENSDARG00000071150	ENSMUSG00000005442	Cic	NA	NA	NA	NA
ENSDARG00000055855	ENSDARG00000037933	ENSMUSG00000062785	Kcnc3	NA	NA	NA	NA
ENSDARG00000056021	ENSDARG00000068892	ENSMUSG00000036169	Sostdc1	NA	NA	NA	NA
ENSDARG00000056125	ENSDARG00000088546	ENSMUSG00000046916	Myct1	NA	NA	NA	NA
ENSDARG00000056156	ENSDARG00000074697	ENSMUSG00000015094	Npdc1	NA	NA	NA	NA
ENSDARG00000056206	ENSDARG00000071395	ENSMUSG00000021820	Camk2g	NA	NA	NA	NA
ENSDARG00000056226	ENSDARG00000090903	ENSMUSG00000035041	Creb3l3	NA	NA	NA	NA
ENSDARG00000056228	ENSDARG00000057125	ENSMUSG00000027695	Pld1	NA	NA	NA	NA
ENSDARG00000056250	ENSDARG00000040874	ENSMUSG00000025026	Add3	NA	NA	NA	NA
ENSDARG00000056347	ENSDARG00000043835	ENSMUSG00000031840	Rab3a	NA	NA	NA	NA
ENSDARG00000056394	ENSDARG00000009217	ENSMUSG00000000538	Tom1l2	NA	NA	NA	NA
ENSDARG00000056619	ENSDARG00000010654	ENSMUSG00000050730	Arhgap42	NA	NA	NA	NA
ENSDARG00000056625	ENSDARG00000067730	ENSMUSG00000031997	Trpc6	NA	NA	NA	NA
ENSDARG00000056762	ENSDARG00000057706	ENSMUSG00000079625	Tm4sf19	NA	NA	NA	NA
ENSDARG00000056910	ENSDARG00000061099	ENSMUSG00000026442	Nfasc	NA	NA	NA	NA
ENSDARG00000056913	ENSDARG00000052057	ENSMUSG00000029718	Pcolce	NA	NA	NA	NA
ENSDARG00000056934	ENSDARG00000077945	ENSMUSG00000046240	Hepacam	NA	NA	NA	NA
ENSDARG00000057016	ENSDARG00000013858	ENSMUSG00000033502	Cdc14a	NA	NA	NA	NA
ENSDARG00000057025	ENSDARG00000006602	ENSMUSG00000022041	Chrna2	NA	NA	NA	NA
ENSDARG00000057121	ENSDARG00000042172	ENSMUSG00000079105	C7	NA	NA	NA	NA
ENSDARG00000057169	ENSDARG00000062661	ENSMUSG00000028125	Abca4	NA	NA	NA	NA
ENSDARG00000057286	ENSDARG00000051819	ENSMUSG00000031015	Swap70	NA	NA	NA	NA
ENSDARG00000057352	ENSDARG00000059052	ENSMUSG00000021265	Slc25a29	NA	NA	NA	NA
ENSDARG00000057419	ENSDARG00000017398	ENSMUSG00000028360	Slc44a5	NA	NA	NA	NA
ENSDARG00000057433	ENSDARG00000039220	ENSMUSG00000039037	St6galnac5	NA	NA	NA	NA
ENSDARG00000057437	ENSDARG00000060345	ENSMUSG00000022548	Apod	NA	NA	NA	NA
ENSDARG00000057527	ENSDARG00000031756	ENSMUSG00000030557	Mef2a	NA	NA	NA	NA
ENSDARG00000057568	ENSDARG00000012426	ENSMUSG00000022055	Nefl	NA	NA	NA	NA
ENSDARG00000057790	ENSDARG00000029370	ENSMUSG00000040183	Ankrd6	NA	NA	NA	NA
ENSDARG00000057940	ENSDARG00000057907	ENSMUSG00000038914	Dido1	NA	NA	NA	NA
ENSDARG00000058064	ENSDARG00000035553	ENSMUSG00000047797	Gjb1	NA	NA	NA	NA
ENSDARG00000058103	ENSDARG00000006865	ENSMUSG00000018595	Glra4	NA	NA	NA	NA
ENSDARG00000058178	ENSDARG00000055066	ENSMUSG00000021969	Zdhhc20	NA	NA	NA	NA
ENSDARG00000058230	ENSDARG00000018399	ENSMUSG00000020516	Rps6kb1	NA	NA	NA	NA
ENSDARG00000058243	ENSDARG00000019304	ENSMUSG00000027525	Phactr3	NA	NA	NA	NA
ENSDARG00000058323	ENSDARG00000090534	ENSMUSG00000006301	Tmbim1	NA	NA	NA	NA
ENSDARG00000058392	ENSDARG00000014588	ENSMUSG00000021536	Adcy2	NA	NA	NA	NA
ENSDARG00000058460	ENSDARG00000076401	ENSMUSG00000066189	Cacng3	NA	NA	NA	NA
ENSDARG00000058646	ENSDARG00000077047	ENSMUSG00000026204	Ptprn	NA	NA	NA	NA
ENSDARG00000058649	ENSDARG00000012367	ENSMUSG00000042766	Trim46	NA	NA	NA	NA
ENSDARG00000058692	ENSDARG00000021664	ENSMUSG00000007989	Fzd3	NA	NA	NA	NA
ENSDARG00000058736	ENSDARG00000075058	ENSMUSG00000020428	Gabra6	NA	NA	NA	NA

ENSDARG00000058800	ENSDARG00000052954	ENSMUSG00000008601	Rab25	NA	NA	NA	NA
ENSDARG00000058848	ENSDARG00000002285	ENSMUSG00000004567	Mcoln1	NA	NA	NA	NA
ENSDARG00000058960	ENSDARG00000001771	ENSMUSG00000027788	Otol1	NA	NA	NA	NA
ENSDARG00000058987	ENSDARG00000013479	ENSMUSG00000020740	Gga3	NA	NA	NA	NA
ENSDARG00000059054	ENSDARG00000020876	ENSMUSG00000038967	Pdk2	NA	NA	NA	NA
ENSDARG00000059081	ENSDARG00000017213	ENSMUSG00000033491	Prss35	NA	NA	NA	NA
ENSDARG00000059090	ENSDARG00000069806	ENSMUSG00000047904	Sstr2	NA	NA	NA	NA
ENSDARG00000059123	ENSDARG00000034080	ENSMUSG00000010660	Plcd1	NA	NA	NA	NA
ENSDARG00000059202	ENSDARG00000003754	ENSMUSG00000027858	Tspan2	NA	NA	NA	NA
ENSDARG00000059236	ENSDARG00000035415	ENSMUSG00000039942	Ptger4	NA	NA	NA	NA
ENSDARG00000059308	ENSDARG00000022795	ENSMUSG00000030245	Golt1b	NA	NA	NA	NA
ENSDARG00000059363	ENSDARG00000034541	ENSMUSG00000032440	Tgfbr2	NA	NA	NA	NA
ENSDARG00000059484	ENSDARG00000060627	ENSMUSG00000000915	Hip1r	NA	NA	NA	NA
ENSDARG00000059598	ENSDARG00000079062	ENSMUSG00000079003	Samd1	NA	NA	NA	NA
ENSDARG00000059677	ENSDARG00000073695	ENSMUSG00000033207	Mamdc2	NA	NA	NA	NA
ENSDARG00000059678	ENSDARG00000074894	ENSMUSG00000046312	AI464131	NA	NA	NA	NA
ENSDARG00000059680	ENSDARG00000037747	ENSMUSG00000029581	Fscn1	NA	NA	NA	NA
ENSDARG00000059685	ENSDARG00000078136	ENSMUSG00000040389	Wdr47	NA	NA	NA	NA
ENSDARG00000059773	ENSDARG00000057448	ENSMUSG00000038453	Srcin1	NA	NA	NA	NA
ENSDARG00000059806	ENSDARG00000015290	ENSMUSG00000025240	Sacm1l	NA	NA	NA	NA
ENSDARG00000059818	ENSDARG00000005470	ENSMUSG00000074657	Kif5a	NA	NA	NA	NA
ENSDARG00000059822	ENSDARG00000062618	ENSMUSG00000042529	Kcnj12	NA	NA	NA	NA
ENSDARG00000059888	ENSDARG00000063079	ENSMUSG00000028842	Eif2c3	NA	NA	NA	NA
ENSDARG00000059910	ENSDARG00000090897	ENSMUSG00000066129	Kndc1	NA	NA	NA	NA
ENSDARG00000059960	ENSDARG00000056805	ENSMUSG00000029055	Plch2	NA	NA	NA	NA
ENSDARG00000059965	ENSDARG00000062173	ENSMUSG00000041570	Camsap1l1	NA	NA	NA	NA
ENSDARG00000060016	ENSDARG00000060705	ENSMUSG00000021488	Nsd1	NA	NA	NA	NA
ENSDARG00000060025	ENSDARG00000061506	ENSMUSG00000006476	Nelf	NA	NA	NA	NA
ENSDARG00000060034	ENSDARG00000079878	ENSMUSG00000050405	Tmem151b	NA	NA	NA	NA
ENSDARG00000060096	ENSDARG00000077871	ENSMUSG00000034412	Tbc1d10a	NA	NA	NA	NA
ENSDARG00000060236	ENSDARG00000088164	ENSMUSG00000044716	Dok7	NA	NA	NA	NA
ENSDARG00000060237	ENSDARG00000079840	ENSMUSG00000063142	Kcnma1	NA	NA	NA	NA
ENSDARG00000060248	ENSDARG00000011830	ENSMUSG00000022788	Fgd4	NA	NA	NA	NA
ENSDARG00000060303	ENSDARG00000063133	ENSMUSG00000026904	Slc4a10	NA	NA	NA	NA
ENSDARG00000060452	ENSDARG00000078116	ENSMUSG00000041592	Sdk2	NA	NA	NA	NA
ENSDARG00000060458	ENSDARG00000045137	ENSMUSG00000037346	Hrh4	NA	NA	NA	NA
ENSDARG00000060459	ENSDARG00000077489	ENSMUSG00000040490	Lrfn2	NA	NA	NA	NA
ENSDARG00000060520	ENSDARG00000063011	ENSMUSG00000029338	Antxr2	NA	NA	NA	NA
ENSDARG00000060584	ENSDARG00000060102	ENSMUSG00000032702	Kank1	NA	NA	NA	NA
ENSDARG00000060675	ENSDARG00000068710	ENSMUSG00000005397	Nid1	NA	NA	NA	NA
ENSDARG00000060723	ENSDARG00000061560	ENSMUSG00000030987	Stim1	NA	NA	NA	NA
ENSDARG00000060725	ENSDARG00000059699	ENSMUSG00000040697	Dnajc16	NA	NA	NA	NA
ENSDARG00000060756	ENSDARG00000070894	ENSMUSG00000025277	Abhd6	NA	NA	NA	NA
ENSDARG00000060805	ENSDARG00000060326	ENSMUSG00000019261	Mtap1s	NA	NA	NA	NA
ENSDARG00000060860	ENSDARG00000053568	ENSMUSG00000032322	Pstpip1	NA	NA	NA	NA
ENSDARG00000060929	ENSDARG00000075183	ENSMUSG00000028677	Rnf220	NA	NA	NA	NA
ENSDARG00000060933	ENSDARG00000016483	ENSMUSG00000018126	Baiap2l2	NA	NA	NA	NA
ENSDARG00000060954	ENSDARG00000076747	ENSMUSG00000030126	Tmcc1	NA	NA	NA	NA
ENSDARG00000061011	ENSDARG00000074752	ENSMUSG00000003949	Hlf	NA	NA	NA	NA
ENSDARG00000061030	ENSDARG00000008247	ENSMUSG00000018377	Vezf1	NA	NA	NA	NA
ENSDARG00000061047	ENSDARG00000078068	ENSMUSG00000032131	Abcg4	NA	NA	NA	NA
ENSDARG00000061082	ENSDARG00000090308	ENSMUSG00000040640	Erc2	NA	NA	NA	NA
ENSDARG00000061089	ENSDARG00000061131	ENSMUSG00000022629	Kif21a	NA	NA	NA	NA
ENSDARG00000061093	ENSDARG00000079378	ENSMUSG00000048537	Phldb1	NA	NA	NA	NA
ENSDARG00000061101	ENSDARG00000079931	ENSMUSG00000031993	Snx19	NA	NA	NA	NA
ENSDARG00000061143	ENSDARG00000073999	ENSMUSG00000046985	Tapt1	NA	NA	NA	NA
ENSDARG00000061191	ENSDARG00000077499	ENSMUSG00000015745	Plekho1	NA	NA	NA	NA
ENSDARG00000061255	ENSDARG00000060130	ENSMUSG00000003518	Dusp3	NA	NA	NA	NA
ENSDARG00000061282	ENSDARG00000013780	ENSMUSG00000003316	Glg1	NA	NA	NA	NA
ENSDARG00000061342	ENSDARG00000079342	ENSMUSG00000060487	Samd5	NA	NA	NA	NA
ENSDARG00000061479	ENSDARG00000090496	ENSMUSG00000032625	Thsd7a	NA	NA	NA	NA
ENSDARG00000061641	ENSDARG00000077086	ENSMUSG00000045034	Ankrd34b	NA	NA	NA	NA
ENSDARG00000061665	ENSDARG00000090115	ENSMUSG00000020331	Hcn2	NA	NA	NA	NA
ENSDARG00000061688	ENSDARG00000074329	ENSMUSG00000000325	Arvcf	NA	NA	NA	NA
ENSDARG00000061725	ENSDARG00000086505	ENSMUSG00000031833	Mast3	NA	NA	NA	NA
ENSDARG00000061732	ENSDARG00000006301	ENSMUSG00000026014	Raph1	NA	NA	NA	NA
ENSDARG00000061736	ENSDARG00000077582	ENSMUSG00000069601	Ank3	NA	NA	NA	NA
ENSDARG00000061757	ENSDARG00000060315	ENSMUSG00000026721	Rabgap1l	NA	NA	NA	NA
ENSDARG00000061758	ENSDARG00000060148	ENSMUSG00000053617	Sh3pxd2a	NA	NA	NA	NA
ENSDARG00000061804	ENSDARG00000060340	ENSMUSG00000050390	C77080	NA	NA	NA	NA
ENSDARG00000061835	ENSDARG00000063372	ENSMUSG00000064310	Zpld1	NA	NA	NA	NA
ENSDARG00000061852	ENSDARG00000062171	ENSMUSG00000027848	Olfml3	NA	NA	NA	NA
ENSDARG00000061956	ENSDARG00000075436	ENSMUSG00000030616	Sytl2	NA	NA	NA	NA
ENSDARG00000061970	ENSDARG00000067815	ENSMUSG00000051067	Lingo3	NA	NA	NA	NA
ENSDARG00000061976	ENSDARG00000036626	ENSMUSG00000001227	Sema6b	NA	NA	NA	NA
ENSDARG00000061977	ENSDARG00000029168	ENSMUSG00000036528	Ppfibp2	NA	NA	NA	NA
ENSDARG00000062000	ENSDARG00000059751	ENSMUSG00000032724	Abtb2	NA	NA	NA	NA
ENSDARG00000062024	ENSDARG00000061817	ENSMUSG00000014602	Kif1a	NA	NA	NA	NA
ENSDARG00000062030	ENSDARG00000045427	ENSMUSG00000052229	Gpr17	NA	NA	NA	NA
ENSDARG00000062106	ENSDARG00000015506	ENSMUSG00000005148	Klf5	NA	NA	NA	NA
ENSDARG00000062113	ENSDARG00000044146	ENSMUSG00000046079	Lrrc8d	NA	NA	NA	NA
ENSDARG00000062134	ENSDARG00000087247	ENSMUSG00000028931	Kcnab2	NA	NA	NA	NA
ENSDARG00000062156	ENSDARG00000071095	ENSMUSG00000035258	Abi3bp	NA	NA	NA	NA
ENSDARG00000062199	ENSDARG00000062020	ENSMUSG00000031822	Gse1	NA	NA	NA	NA
ENSDARG00000062220	ENSDARG00000060813	ENSMUSG00000045659	Plekha7	NA	NA	NA	NA
ENSDARG00000062341	ENSDARG00000074617	ENSMUSG00000039474	Wfs1	NA	NA	NA	NA
ENSDARG00000062372	ENSDARG00000019596	ENSMUSG00000053510	Nrd1	NA	NA	NA	NA
ENSDARG00000062396	ENSDARG00000078901	ENSMUSG00000024219	Anks1	NA	NA	NA	NA
ENSDARG00000062401	ENSDARG00000073856	ENSMUSG00000046556	Zfp319	NA	NA	NA	NA
ENSDARG00000062445	ENSDARG00000036094	ENSMUSG00000032405	Pias1	NA	NA	NA	NA

ENSDARG00000062449	ENSDARG00000029671	ENSMUSG00000026469	Xpr1	NA	NA	NA	NA
ENSDARG00000062462	ENSDARG00000063144	ENSMUSG00000053550	Shisa7	NA	NA	NA	NA
ENSDARG00000062552	ENSDARG00000069441	ENSMUSG00000033446	Lpar6	NA	NA	NA	NA
ENSDARG00000062633	ENSDARG00000009930	ENSMUSG00000064115	Cadm2	NA	NA	NA	NA
ENSDARG00000062754	ENSDARG00000040069	ENSMUSG00000032564	Cpne4	NA	NA	NA	NA
ENSDARG00000062799	ENSDARG00000060587	ENSMUSG00000025372	Baiap2	NA	NA	NA	NA
ENSDARG00000062823	ENSDARG00000076724	ENSMUSG00000041720	Pi4ka	NA	NA	NA	NA
ENSDARG00000062900	ENSDARG00000062450	ENSMUSG00000028098	Rnf115	NA	NA	NA	NA
ENSDARG00000062942	ENSDARG00000017108	ENSMUSG00000047976	Kcna1	NA	NA	NA	NA
ENSDARG00000062955	ENSDARG00000061362	ENSMUSG00000029270	Fam69a	NA	NA	NA	NA
ENSDARG00000062967	ENSDARG00000051892	ENSMUSG00000045246	Kcng4	NA	NA	NA	NA
ENSDARG00000062976	ENSDARG00000062108	ENSMUSG00000038271	Iffo1	NA	NA	NA	NA
ENSDARG00000062986	ENSDARG00000040002	ENSMUSG00000036833	Pnpla7	NA	NA	NA	NA
ENSDARG00000063006	ENSDARG00000070624	ENSMUSG00000069806	Cacng7	NA	NA	NA	NA
ENSDARG00000063018	ENSDARG00000062889	ENSMUSG00000060568	Fam78b	NA	NA	NA	NA
ENSDARG00000063040	ENSDARG00000063255	ENSMUSG00000020042	Btbd11	NA	NA	NA	NA
ENSDARG00000063293	ENSDARG00000062343	ENSMUSG00000036902	Neto2	NA	NA	NA	NA
ENSDARG00000063313	ENSDARG00000076015	ENSMUSG00000030214	Plbd1	NA	NA	NA	NA
ENSDARG00000063332	ENSDARG00000063054	ENSMUSG00000022623	Shank3	NA	NA	NA	NA
ENSDARG00000063361	ENSDARG00000063008	ENSMUSG00000063455	D630045J1	NA	NA	NA	NA
ENSDARG00000063420	ENSDARG00000002031	ENSMUSG00000016831	Tox4	NA	NA	NA	NA
ENSDARG00000063538	ENSDARG00000078117	ENSMUSG00000061751	Kalrn	NA	NA	NA	NA
ENSDARG00000063544	ENSDARG00000003776	ENSMUSG00000026737	Pip4k2a	NA	NA	NA	NA
ENSDARG00000063555	ENSDARG00000087330	ENSMUSG00000030678	Maz	NA	NA	NA	NA
ENSDARG00000063568	ENSDARG00000078060	ENSMUSG00000024743	Syt7	NA	NA	NA	NA
ENSDARG00000063594	ENSDARG00000077095	ENSMUSG00000008730	Hipk1	NA	NA	NA	NA
ENSDARG00000063682	ENSDARG00000061904	ENSMUSG00000034295	Fhod3	NA	NA	NA	NA
ENSDARG00000067566	ENSDARG00000094708	ENSMUSG00000056370	Sftpb	NA	NA	NA	NA
ENSDARG00000067591	ENSDARG00000024890	ENSMUSG00000043991	Pura	NA	NA	NA	NA
ENSDARG00000067634	ENSDARG00000030532	ENSMUSG00000059495	Arhgef12	NA	NA	NA	NA
ENSDARG00000067683	ENSDARG00000012490	ENSMUSG00000004347	Pde1c	NA	NA	NA	NA
ENSDARG00000067701	ENSDARG00000093552	ENSMUSG00000049173	Myoz3	NA	NA	NA	NA
ENSDARG00000067720	ENSDARG00000018492	ENSMUSG00000039081	Zfp503	NA	NA	NA	NA
ENSDARG00000067725	ENSDARG00000077430	ENSMUSG00000091530	AC122350.	NA	NA	NA	NA
ENSDARG00000067820	ENSDARG00000005783	ENSMUSG00000002341	Ncan	NA	NA	NA	NA
ENSDARG00000067927	ENSDARG00000061405	ENSMUSG00000035104	Fam176a	NA	NA	NA	NA
ENSDARG00000067999	ENSDARG00000070781	ENSMUSG00000068615	Gjd2	NA	NA	NA	NA
ENSDARG00000068008	ENSDARG00000010433	ENSMUSG00000033389	Arhgap44	NA	NA	NA	NA
ENSDARG00000068232	ENSDARG00000063376	ENSMUSG00000040380	Cbln3	NA	NA	NA	NA
ENSDARG00000068242	ENSDARG00000042107	ENSMUSG00000031789	Cngb1	NA	NA	NA	NA
ENSDARG00000068296	ENSDARG00000018726	ENSMUSG00000025790	Slco3a1	NA	NA	NA	NA
ENSDARG00000068397	ENSDARG00000076292	ENSMUSG00000037003	Tenc1	NA	NA	NA	NA
ENSDARG00000068483	ENSDARG00000071596	ENSMUSG00000050321	Neto1	NA	NA	NA	NA
ENSDARG00000068705	ENSDARG00000062168	ENSMUSG00000029569	Tmem168	NA	NA	NA	NA
ENSDARG00000068849	ENSDARG00000060830	ENSMUSG00000046761	Fam83h	NA	NA	NA	NA
ENSDARG00000068890	ENSDARG00000088634	ENSMUSG00000020431	Adcy1	NA	NA	NA	NA
ENSDARG00000068918	ENSDARG00000006609	ENSMUSG00000035027	Map2k2	NA	NA	NA	NA
ENSDARG00000069030	ENSDARG00000062448	ENSMUSG00000022245	Skor1	NA	NA	NA	NA
ENSDARG00000069265	ENSDARG00000069245	ENSMUSG00000020583	Matn3	NA	NA	NA	NA
ENSDARG00000069318	ENSDARG00000033516	ENSMUSG00000020658	Efr3b	NA	NA	NA	NA
ENSDARG00000069388	ENSDARG00000056920	ENSMUSG00000045377	Tmem88	NA	NA	NA	NA
ENSDARG00000069467	ENSDARG00000033845	ENSMUSG00000034275	Igsf9b	NA	NA	NA	NA
ENSDARG00000069589	ENSDARG00000074503	ENSMUSG00000028857	Tmem222	NA	NA	NA	NA
ENSDARG00000069674	ENSDARG00000027687	ENSMUSG00000027341	5730494N0	NA	NA	NA	NA
ENSDARG00000069701	ENSDARG00000089957	ENSMUSG00000039252	Lgi2	NA	NA	NA	NA
ENSDARG00000069742	ENSDARG00000004260	ENSMUSG00000032030	Cul5	NA	NA	NA	NA
ENSDARG00000069745	ENSDARG00000090686	ENSMUSG00000042195	Slc35f2	NA	NA	NA	NA
ENSDARG00000069748	ENSDARG00000069717	ENSMUSG00000035547	Capn5	NA	NA	NA	NA
ENSDARG00000069765	ENSDARG00000063713	ENSMUSG00000067629	Syngap1	NA	NA	NA	NA
ENSDARG00000069787	ENSDARG00000004875	ENSMUSG00000025572	Tmc6	NA	NA	NA	NA
ENSDARG00000069829	ENSDARG00000059154	ENSMUSG00000028646	Rragc	NA	NA	NA	NA
ENSDARG00000069994	ENSDARG00000091783	ENSMUSG00000029675	Eln	NA	NA	NA	NA
ENSDARG00000070056	ENSDARG00000075694	ENSMUSG00000042429	Adora1	NA	NA	NA	NA
ENSDARG00000070100	ENSDARG00000079095	ENSMUSG00000024883	Rin1	NA	NA	NA	NA
ENSDARG00000070171	ENSDARG00000086098	ENSMUSG00000028967	Errfi1	NA	NA	NA	NA
ENSDARG00000070314	ENSDARG00000086391	ENSMUSG00000029761	Cald1	NA	NA	NA	NA
ENSDARG00000070412	ENSDARG00000037101	ENSMUSG00000039431	Mtmr7	NA	NA	NA	NA
ENSDARG00000070479	ENSDARG00000068883	ENSMUSG00000020577	Tspan13	NA	NA	NA	NA
ENSDARG00000070507	ENSDARG00000062183	ENSMUSG00000027748	Trpc4	NA	NA	NA	NA
ENSDARG00000070571	ENSDARG00000078155	ENSMUSG00000041605	5730559C1	NA	NA	NA	NA
ENSDARG00000070575	ENSDARG00000070952	ENSMUSG00000029861	Fam131b	NA	NA	NA	NA
ENSDARG00000070590	ENSDARG00000035883	ENSMUSG00000054958	Nt5c1a	NA	NA	NA	NA
ENSDARG00000070620	ENSDARG00000086207	ENSMUSG00000002771	Grin2d	NA	NA	NA	NA
ENSDARG00000070726	ENSDARG00000012297	ENSMUSG00000026114	Cnga3	NA	NA	NA	NA
ENSDARG00000070787	ENSDARG00000059067	ENSMUSG00000001552	Jup	NA	NA	NA	NA
ENSDARG00000070919	ENSDARG00000061466	ENSMUSG00000024008	Cpne5	NA	NA	NA	NA
ENSDARG00000070941	ENSDARG00000090833	ENSMUSG00000023046	Igfbp6	NA	NA	NA	NA
ENSDARG00000070956	ENSDARG00000025904	ENSMUSG00000031708	Tecr	NA	NA	NA	NA
ENSDARG00000070971	ENSDARG00000062909	ENSMUSG00000030530	Furin	NA	NA	NA	NA
ENSDARG00000070973	ENSDARG00000036272	ENSMUSG00000025127	Gcgr	NA	NA	NA	NA
ENSDARG00000070995	ENSDARG00000063352	ENSMUSG00000026113	Inpp4a	NA	NA	NA	NA
ENSDARG00000071031	ENSDARG00000079116	ENSMUSG00000032382	Snx1	NA	NA	NA	NA
ENSDARG00000071091	ENSDARG00000071298	ENSMUSG00000046159	Chrm3	NA	NA	NA	NA
ENSDARG00000071217	ENSDARG00000069500	ENSMUSG00000053465	Hs6st3	NA	NA	NA	NA
ENSDARG00000071493	ENSDARG00000039174	ENSMUSG00000027965	Olfm3	NA	NA	NA	NA
ENSDARG00000071637	ENSDARG00000008329	ENSMUSG00000023017	Accn2	NA	NA	NA	NA
ENSDARG00000073699	ENSDARG00000031483	ENSMUSG00000026147	Col9a1	NA	NA	NA	NA
ENSDARG00000073707	ENSDARG00000074480	ENSMUSG00000025658	Cnksr2	NA	NA	NA	NA
ENSDARG00000073756	ENSDARG00000062058	ENSMUSG00000017756	Slc12a7	NA	NA	NA	NA
ENSDARG00000073769	ENSDARG00000021590	ENSMUSG00000040003	Magi2	NA	NA	NA	NA

ENSDARG00000073792	ENSDARG00000076592	ENSMUSG00000036646	Man1b1	NA	NA	NA	NA
ENSDARG00000073822	ENSDARG00000016551	ENSMUSG00000034312	Iqsec1	NA	NA	NA	NA
ENSDARG00000073861	ENSDARG00000078388	ENSMUSG00000014303	Glis2	NA	NA	NA	NA
ENSDARG00000073918	ENSDARG00000075046	ENSMUSG00000008482	Rnf151	NA	NA	NA	NA
ENSDARG00000073970	ENSDARG00000001414	ENSMUSG00000032776	Mctp2	NA	NA	NA	NA
ENSDARG00000074018	ENSDARG00000077868	ENSMUSG00000000202	Btbd17	NA	NA	NA	NA
ENSDARG00000074073	ENSDARG00000074521	ENSMUSG00000055407	Mtap6	NA	NA	NA	NA
ENSDARG00000074075	ENSDARG00000025672	ENSMUSG00000033420	Antxr1	NA	NA	NA	NA
ENSDARG00000074153	ENSDARG00000076987	ENSMUSG00000033214	Slitrk5	NA	NA	NA	NA
ENSDARG00000074173	ENSDARG00000060181	ENSMUSG00000030236	Slco1b2	NA	NA	NA	NA
ENSDARG00000074229	ENSDARG00000075849	ENSMUSG00000046574	Prr12	NA	NA	NA	NA
ENSDARG00000074275	ENSDARG00000079060	ENSMUSG00000037736	Limch1	NA	NA	NA	NA
ENSDARG00000074308	ENSDARG00000091128	ENSMUSG00000046807	AI646023	NA	NA	NA	NA
ENSDARG00000074321	ENSDARG00000063649	ENSMUSG00000002249	Tead3	NA	NA	NA	NA
ENSDARG00000074358	ENSDARG00000073716	ENSMUSG00000027408	Cpxm1	NA	NA	NA	NA
ENSDARG00000074372	ENSDARG00000078141	ENSMUSG00000048988	Elfn1	NA	NA	NA	NA
ENSDARG00000074381	ENSDARG00000063695	ENSMUSG00000025555	Farp1	NA	NA	NA	NA
ENSDARG00000074396	ENSDARG00000059574	ENSMUSG00000025380	Fscn2	NA	NA	NA	NA
ENSDARG00000074403	ENSDARG00000022518	ENSMUSG00000027674	Pex5l	NA	NA	NA	NA
ENSDARG00000074419	ENSDARG00000061685	ENSMUSG00000032338	Hcn4	NA	NA	NA	NA
ENSDARG00000074457	ENSDARG00000037140	ENSMUSG00000025271	Pfkfb1	NA	NA	NA	NA
ENSDARG00000074526	ENSDARG00000007184	ENSMUSG00000066687	Zbtb16	NA	NA	NA	NA
ENSDARG00000074535	ENSDARG00000069970	ENSMUSG00000045083	Lingo2	NA	NA	NA	NA
ENSDARG00000074599	ENSDARG00000076496	ENSMUSG00000030064	Frmd4b	NA	NA	NA	NA
ENSDARG00000074636	ENSDARG00000078327	ENSMUSG00000072825	AW555464	NA	NA	NA	NA
ENSDARG00000074638	ENSDARG00000094738	ENSMUSG00000032818	Loxhd1	NA	NA	NA	NA
ENSDARG00000074663	ENSDARG00000076184	ENSMUSG00000021770	Samd8	NA	NA	NA	NA
ENSDARG00000074681	ENSDARG00000062427	ENSMUSG00000022843	Clcn2	NA	NA	NA	NA
ENSDARG00000074777	ENSDARG00000059093	ENSMUSG00000031543	Ank1	NA	NA	NA	NA
ENSDARG00000074826	ENSDARG00000077427	ENSMUSG00000045281	Gpr20	NA	NA	NA	NA
ENSDARG00000074843	ENSDARG00000079889	ENSMUSG00000033149	Phldb2	NA	NA	NA	NA
ENSDARG00000074854	ENSDARG00000095348	ENSMUSG00000005696	Sh2d1a	NA	NA	NA	NA
ENSDARG00000074897	ENSDARG00000068168	ENSMUSG00000028940	Hes2	NA	NA	NA	NA
ENSDARG00000074905	ENSDARG00000017446	ENSMUSG00000039145	Camk1d	NA	NA	NA	NA
ENSDARG00000074924	ENSDARG00000077559	ENSMUSG00000039697	Ncoa7	NA	NA	NA	NA
ENSDARG00000074976	ENSDARG00000018856	ENSMUSG00000027797	Dclk1	NA	NA	NA	NA
ENSDARG00000074979	ENSDARG00000078401	ENSMUSG00000023025	Larp4	NA	NA	NA	NA
ENSDARG00000074984	ENSDARG00000062347	ENSMUSG00000029651	Mtus2	NA	NA	NA	NA
ENSDARG00000075026	ENSDARG00000075450	ENSMUSG00000061013	Mkx	NA	NA	NA	NA
ENSDARG00000075054	ENSDARG00000002816	ENSMUSG00000021708	Rasgrf2	NA	NA	NA	NA
ENSDARG00000075141	ENSDARG00000077080	ENSMUSG00000008734	Gprc5b	NA	NA	NA	NA
ENSDARG00000075147	ENSDARG00000087745	ENSMUSG00000028584	Lrrc38	NA	NA	NA	NA
ENSDARG00000075152	ENSDARG00000040027	ENSMUSG00000040875	Osbpl10	NA	NA	NA	NA
ENSDARG00000075180	ENSDARG00000079272	ENSMUSG00000021361	Tmem14c	NA	NA	NA	NA
ENSDARG00000075192	ENSDARG00000087253	ENSMUSG00000026775	Yme1l1	NA	NA	NA	NA
ENSDARG00000075209	ENSDARG00000071233	ENSMUSG00000006675	P4htm	NA	NA	NA	NA
ENSDARG00000075227	ENSDARG00000004445	ENSMUSG00000049583	Grm5	NA	NA	NA	NA
ENSDARG00000075265	ENSDARG00000039145	ENSMUSG00000021822	Plau	NA	NA	NA	NA
ENSDARG00000075271	ENSDARG00000074307	ENSMUSG00000041992	Rapgef5	NA	NA	NA	NA
ENSDARG00000075328	ENSDARG00000075673	ENSMUSG00000036591	Arhgap21	NA	NA	NA	NA
ENSDARG00000075382	ENSDARG00000009209	ENSMUSG00000060681	Slc9a6	NA	NA	NA	NA
ENSDARG00000075394	ENSDARG00000059826	ENSMUSG00000042401	Crtac1	NA	NA	NA	NA
ENSDARG00000075455	ENSDARG00000063311	ENSMUSG00000038916	6330407J2	NA	NA	NA	NA
ENSDARG00000075519	ENSDARG00000055713	ENSMUSG00000055805	Fmnl1	NA	NA	NA	NA
ENSDARG00000075600	ENSDARG00000076735	ENSMUSG00000021763	BC067074	NA	NA	NA	NA
ENSDARG00000075648	ENSDARG00000061471	ENSMUSG00000052133	Sema5b	NA	NA	NA	NA
ENSDARG00000075803	ENSDARG00000073881	ENSMUSG00000034591	Slc41a2	NA	NA	NA	NA
ENSDARG00000075831	ENSDARG00000054343	ENSMUSG00000022180	Slc7a8	NA	NA	NA	NA
ENSDARG00000075846	ENSDARG00000043993	ENSMUSG00000025221	Kcnip2	NA	NA	NA	NA
ENSDARG00000075858	ENSDARG00000086224	ENSMUSG00000079157	Fam155a	NA	NA	NA	NA
ENSDARG00000075865	ENSDARG00000077349	ENSMUSG00000063434	Sorcs3	NA	NA	NA	NA
ENSDARG00000075924	ENSDARG00000079872	ENSMUSG00000049044	Rapgef4	NA	NA	NA	NA
ENSDARG00000075930	ENSDARG00000091328	ENSMUSG00000036545	Adamts2	NA	NA	NA	NA
ENSDARG00000075942	ENSDARG00000079622	ENSMUSG00000027238	Frmd5	NA	NA	NA	NA
ENSDARG00000075980	ENSDARG00000073768	ENSMUSG00000050854	Tmem125	NA	NA	NA	NA
ENSDARG00000075986	ENSDARG00000077459	ENSMUSG00000048330	Ric3	NA	NA	NA	NA
ENSDARG00000076001	ENSDARG00000009442	ENSMUSG00000034902	Pip5k1c	NA	NA	NA	NA
ENSDARG00000076076	ENSDARG00000076068	ENSMUSG00000003575	Crtc1	NA	NA	NA	NA
ENSDARG00000076096	ENSDARG00000020239	ENSMUSG00000020593	Lpin1	NA	NA	NA	NA
ENSDARG00000076111	ENSDARG00000022550	ENSMUSG00000036197	Gxylt1	NA	NA	NA	NA
ENSDARG00000076143	ENSDARG00000073909	ENSMUSG00000033526	Ppip5k1	NA	NA	NA	NA
ENSDARG00000076174	ENSDARG00000031817	ENSMUSG00000027993	Trim2	NA	NA	NA	NA
ENSDARG00000076220	ENSDARG00000079414	ENSMUSG00000000632	Sez6	NA	NA	NA	NA
ENSDARG00000076265	ENSDARG00000077229	ENSMUSG00000034863	Ano8	NA	NA	NA	NA
ENSDARG00000076268	ENSDARG00000076873	ENSMUSG00000029419	Gm996	NA	NA	NA	NA
ENSDARG00000076281	ENSDARG00000062687	ENSMUSG00000059742	Kcnh7	NA	NA	NA	NA
ENSDARG00000076302	ENSDARG00000078016	ENSMUSG00000039982	Dtx4	NA	NA	NA	NA
ENSDARG00000076404	ENSDARG00000060871	ENSMUSG00000021596	Mctp1	NA	NA	NA	NA
ENSDARG00000076416	ENSDARG00000076371	ENSMUSG00000045180	Shroom2	NA	NA	NA	NA
ENSDARG00000076431	ENSDARG00000079366	ENSMUSG00000038976	Ppp1r9b	NA	NA	NA	NA
ENSDARG00000076434	ENSDARG00000021255	ENSMUSG00000063506	Arhgap22	NA	NA	NA	NA
ENSDARG00000076541	ENSDARG00000074394	ENSMUSG00000025784	Clec3b	NA	NA	NA	NA
ENSDARG00000076546	ENSDARG00000036159	ENSMUSG00000038760	Trhr	NA	NA	NA	NA
ENSDARG00000076591	ENSDARG00000015931	ENSMUSG00000033419	Snap91	NA	NA	NA	NA
ENSDARG00000076595	ENSDARG00000088143	ENSMUSG00000025207	Sema4g	NA	NA	NA	NA
ENSDARG00000076615	ENSDARG00000027192	ENSMUSG00000028051	Hcn3	NA	NA	NA	NA
ENSDARG00000076620	ENSDARG00000079719	ENSMUSG00000007950	Abhd8	NA	NA	NA	NA
ENSDARG00000076644	ENSDARG00000062906	ENSMUSG00000047298	Kcnv2	NA	NA	NA	NA
ENSDARG00000076712	ENSDARG00000063436	ENSMUSG00000029608	Rph3a	NA	NA	NA	NA
ENSDARG00000076821	ENSDARG00000061249	ENSMUSG00000024049	Myom1	NA	NA	NA	NA

ENSDARG00000076826	ENSDARG00000024744	ENSMUSG00000061576	Dpp6	NA	NA	NA	NA
ENSDARG00000076829	ENSDARG00000060768	ENSMUSG00000040351	Ankib1	NA	NA	NA	NA
ENSDARG00000076854	ENSDARG00000059935	ENSMUSG00000042861	Kcna10	NA	NA	NA	NA
ENSDARG00000076861	ENSDARG00000071250	ENSMUSG00000001420	Tmem79	NA	NA	NA	NA
ENSDARG00000076868	ENSDARG00000079542	ENSMUSG00000016128	Stard13	NA	NA	NA	NA
ENSDARG00000076960	ENSDARG00000074160	ENSMUSG00000023909	Paqr4	NA	NA	NA	NA
ENSDARG00000076962	ENSDARG00000077284	ENSMUSG00000035314	Gdpd5	NA	NA	NA	NA
ENSDARG00000076996	ENSDARG00000060618	ENSMUSG00000033365	Ipo13	NA	NA	NA	NA
ENSDARG00000077038	ENSDARG00000003877	ENSMUSG00000042323	Pbrm1	NA	NA	NA	NA
ENSDARG00000077039	ENSDARG00000076639	ENSMUSG00000001946	Esam	NA	NA	NA	NA
ENSDARG00000077040	ENSDARG00000074589	ENSMUSG00000001768	Rin2	NA	NA	NA	NA
ENSDARG00000077061	ENSDARG00000078605	ENSMUSG00000019464	Ptger1	NA	NA	NA	NA
ENSDARG00000077083	ENSDARG00000045788	ENSMUSG00000020123	Avpr1a	NA	NA	NA	NA
ENSDARG00000077103	ENSDARG00000062352	ENSMUSG00000028064	Sema4a	NA	NA	NA	NA
ENSDARG00000077124	ENSDARG00000077545	ENSMUSG00000035390	Brsk1	NA	NA	NA	NA
ENSDARG00000077134	ENSDARG00000079665	ENSMUSG00000045967	Gpr158	NA	NA	NA	NA
ENSDARG00000077177	ENSDARG00000063583	ENSMUSG00000033352	Map2k4	NA	NA	NA	NA
ENSDARG00000077187	ENSDARG00000074839	ENSMUSG00000032343	Impg1	NA	NA	NA	NA
ENSDARG00000077192	ENSDARG00000044528	ENSMUSG00000025557	Slc15a1	NA	NA	NA	NA
ENSDARG00000077226	ENSDARG00000008350	ENSMUSG00000032187	Smarca4	NA	NA	NA	NA
ENSDARG00000077228	ENSDARG00000063035	ENSMUSG00000059146	Ntrk3	NA	NA	NA	NA
ENSDARG00000077237	ENSDARG00000074522	ENSMUSG00000037674	Rfx7	NA	NA	NA	NA
ENSDARG00000077275	ENSDARG00000013293	ENSMUSG00000025776	Crispld1	NA	NA	NA	NA
ENSDARG00000077313	ENSDARG00000079933	ENSMUSG00000029650	Slc46a3	NA	NA	NA	NA
ENSDARG00000077326	ENSDARG00000021820	ENSMUSG00000079020	Slc45a4	NA	NA	NA	NA
ENSDARG00000077352	ENSDARG00000061520	ENSMUSG00000006731	B4galnt1	NA	NA	NA	NA
ENSDARG00000077399	ENSDARG00000061243	ENSMUSG00000032020	Ubash3b	NA	NA	NA	NA
ENSDARG00000077531	ENSDARG00000075892	ENSMUSG00000024392	Bag6	NA	NA	NA	NA
ENSDARG00000077560	ENSDARG00000078149	ENSMUSG00000020734	Grin2c	NA	NA	NA	NA
ENSDARG00000077606	ENSDARG00000063359	ENSMUSG00000036412	Arsi	NA	NA	NA	NA
ENSDARG00000077630	ENSDARG00000070683	ENSMUSG00000030772	Dkk3	NA	NA	NA	NA
ENSDARG00000077726	ENSDARG00000078525	ENSMUSG00000023087	Ccrn4l	NA	NA	NA	NA
ENSDARG00000077740	ENSDARG00000073917	ENSMUSG00000051950	B3galtl	NA	NA	NA	NA
ENSDARG00000077749	ENSDARG00000077948	ENSMUSG00000034235	Usp54	NA	NA	NA	NA
ENSDARG00000077775	ENSDARG00000089549	ENSMUSG00000022296	Baalc	NA	NA	NA	NA
ENSDARG00000077826	ENSDARG00000079765	ENSMUSG00000068263	Ccdc48	NA	NA	NA	NA
ENSDARG00000077844	ENSDARG00000061070	ENSMUSG00000057337	Chst3	NA	NA	NA	NA
ENSDARG00000077881	ENSDARG00000076233	ENSMUSG00000030077	Chl1	NA	NA	NA	NA
ENSDARG00000077888	ENSDARG00000019185	ENSMUSG00000055717	Slain1	NA	NA	NA	NA
ENSDARG00000077906	ENSDARG00000078817	ENSMUSG00000025427	Rnf165	NA	NA	NA	NA
ENSDARG00000077996	ENSDARG00000075960	ENSMUSG00000059674	Cdh24	NA	NA	NA	NA
ENSDARG00000078022	ENSDARG00000056689	ENSMUSG00000025241	Fyco1	NA	NA	NA	NA
ENSDARG00000078052	ENSDARG00000076299	ENSMUSG00000050700	Emilin3	NA	NA	NA	NA
ENSDARG00000078061	ENSDARG00000082979	ENSMUSG00000026987	Baz2b	NA	NA	NA	NA
ENSDARG00000078142	ENSDARG00000074531	ENSMUSG00000020859	Spag9	NA	NA	NA	NA
ENSDARG00000078151	ENSDARG00000075764	ENSMUSG00000003378	Grik5	NA	NA	NA	NA
ENSDARG00000078187	ENSDARG00000075815	ENSMUSG00000017740	Slc12a5	NA	NA	NA	NA
ENSDARG00000078202	ENSDARG00000060018	ENSMUSG00000045767	B230219D2	NA	NA	NA	NA
ENSDARG00000078222	ENSDARG00000077477	ENSMUSG00000025375	Aatk	NA	NA	NA	NA
ENSDARG00000078259	ENSDARG00000078063	ENSMUSG00000024191	Bnip1	NA	NA	NA	NA
ENSDARG00000078272	ENSDARG00000060846	ENSMUSG00000009075	Cabp7	NA	NA	NA	NA
ENSDARG00000078373	ENSDARG00000063037	ENSMUSG00000003123	Lipe	NA	NA	NA	NA
ENSDARG00000078378	ENSDARG00000030173	ENSMUSG00000026942	Traf2	NA	NA	NA	NA
ENSDARG00000078430	ENSDARG00000025920	ENSMUSG00000002489	Tiam1	NA	NA	NA	NA
ENSDARG00000078440	ENSDARG00000063681	ENSMUSG00000032740	Ccdc88a	NA	NA	NA	NA
ENSDARG00000078485	ENSDARG00000075539	ENSMUSG00000027457	Snph	NA	NA	NA	NA
ENSDARG00000078486	ENSDARG00000077855	ENSMUSG00000058446	Znrf2	NA	NA	NA	NA
ENSDARG00000078578	ENSDARG00000059886	ENSMUSG00000037750	BC017647	NA	NA	NA	NA
ENSDARG00000078599	ENSDARG00000074255	ENSMUSG00000039478	Efha2	NA	NA	NA	NA
ENSDARG00000078603	ENSDARG00000061968	ENSMUSG00000066952	Myo1h	NA	NA	NA	NA
ENSDARG00000078615	ENSDARG00000076499	ENSMUSG00000039701	Usp53	NA	NA	NA	NA
ENSDARG00000078618	ENSDARG00000076338	ENSMUSG00000006127	Inpp5k	NA	NA	NA	NA
ENSDARG00000078640	ENSDARG00000079252	ENSMUSG00000038893	Fam117a	NA	NA	NA	NA
ENSDARG00000078696	ENSDARG00000077293	ENSMUSG00000039376	Synpo2l	NA	NA	NA	NA
ENSDARG00000078722	ENSDARG00000079483	ENSMUSG00000049550	Clip1	NA	NA	NA	NA
ENSDARG00000078755	ENSDARG00000079671	ENSMUSG00000044667	D3Bwg056	NA	NA	NA	NA
ENSDARG00000078797	ENSDARG00000013153	ENSMUSG00000036661	Dennd3	NA	NA	NA	NA
ENSDARG00000078831	ENSDARG00000076874	ENSMUSG00000032540	Abhd5	NA	NA	NA	NA
ENSDARG00000078878	ENSDARG00000055437	ENSMUSG00000047343	A530098C1	NA	NA	NA	NA
ENSDARG00000078953	ENSDARG00000004633	ENSMUSG00000010080	Epn3	NA	NA	NA	NA
ENSDARG00000078981	ENSDARG00000075956	ENSMUSG00000028246	6230409E1	NA	NA	NA	NA
ENSDARG00000079029	ENSDARG00000077461	ENSMUSG00000030986	Dhx32	NA	NA	NA	NA
ENSDARG00000079167	ENSDARG00000074604	ENSMUSG00000037652	Phc3	NA	NA	NA	NA
ENSDARG00000079184	ENSDARG00000075571	ENSMUSG00000037933	Bicd2	NA	NA	NA	NA
ENSDARG00000079235	ENSDARG00000062040	ENSMUSG00000028457	Atp8b5	NA	NA	NA	NA
ENSDARG00000079286	ENSDARG00000042329	ENSMUSG00000009681	Bcr	NA	NA	NA	NA
ENSDARG00000079324	ENSDARG00000076320	ENSMUSG00000054662	Ano9	NA	NA	NA	NA
ENSDARG00000079348	ENSDARG00000030376	ENSMUSG00000030209	Grin2b	NA	NA	NA	NA
ENSDARG00000079369	ENSDARG00000060534	ENSMUSG00000021054	Sgpp1	NA	NA	NA	NA
ENSDARG00000079374	ENSDARG00000077506	ENSMUSG00000030516	Tjp1	NA	NA	NA	NA
ENSDARG00000079443	ENSDARG00000078247	ENSMUSG00000019772	Vip	NA	NA	NA	NA
ENSDARG00000079484	ENSDARG00000079098	ENSMUSG00000058740	Kcnt1	NA	NA	NA	NA
ENSDARG00000079491	ENSDARG00000063282	ENSMUSG00000047959	Kcna3	NA	NA	NA	NA
ENSDARG00000079496	ENSDARG00000074357	ENSMUSG00000003452	Bicd1	NA	NA	NA	NA
ENSDARG00000079561	ENSDARG00000074655	ENSMUSG00000042616	Oscp1	NA	NA	NA	NA
ENSDARG00000079572	ENSDARG00000052957	ENSMUSG00000020937	Plcd3	NA	NA	NA	NA
ENSDARG00000079613	ENSDARG00000057586	ENSMUSG00000024565	Sall3	NA	NA	NA	NA
ENSDARG00000079716	ENSDARG00000059812	ENSMUSG00000042557	Sin3a	NA	NA	NA	NA
ENSDARG00000079731	ENSDARG00000073859	ENSMUSG00000060012	Kif13b	NA	NA	NA	NA
ENSDARG00000079790	ENSDARG00000053381	ENSMUSG00000021759	Ppap2a	NA	NA	NA	NA

ENSDARG00000079822	ENSDARG00000079161	ENSMUSG00000032589	Bsn	NA	NA	NA	NA
ENSDARG00000079850	ENSDARG00000070025	ENSMUSG00000036862	Dchs1	NA	NA	NA	NA
ENSDARG00000079858	ENSDARG00000088227	ENSMUSG00000026347	Tmem163	NA	NA	NA	NA
ENSDARG00000079876	ENSDARG00000079556	ENSMUSG00000045912	C2cd4c	NA	NA	NA	NA
ENSDARG00000079879	ENSDARG00000060073	ENSMUSG00000007880	Arid1a	NA	NA	NA	NA
ENSDARG00000079895	ENSDARG00000057353	ENSMUSG00000024937	Ehbp1l1	NA	NA	NA	NA
ENSDARG00000079898	ENSDARG00000077938	ENSMUSG00000056481	Cd248	NA	NA	NA	NA
ENSDARG00000079972	ENSDARG00000076640	ENSMUSG00000027544	Nfatc2	NA	NA	NA	NA
ENSDARG00000079977	ENSDARG00000070227	ENSMUSG00000059493	Nhs	NA	NA	NA	NA
ENSDARG00000080000	ENSDARG00000076381	ENSMUSG00000003528	Slc25a1	NA	NA	NA	NA
ENSDARG00000086013	ENSDARG00000019301	ENSMUSG00000020823	Sec14l1	NA	NA	NA	NA
ENSDARG00000086104	ENSDARG00000071685	ENSMUSG00000025938	Slco5a1	NA	NA	NA	NA
ENSDARG00000086109	ENSDARG00000087341	ENSMUSG00000059921	Unc5c	NA	NA	NA	NA
ENSDARG00000086142	ENSDARG00000061798	ENSMUSG00000034255	Arhgap27	NA	NA	NA	NA
ENSDARG00000086158	ENSDARG00000060022	ENSMUSG00000046318	Ccbe1	NA	NA	NA	NA
ENSDARG00000086274	ENSDARG00000017391	ENSMUSG00000028456	Unc13b	NA	NA	NA	NA
ENSDARG00000086411	ENSDARG00000022415	ENSMUSG00000028676	Srsf10	NA	NA	NA	NA
ENSDARG00000086499	ENSDARG00000070831	ENSMUSG00000039316	Rftn1	NA	NA	NA	NA
ENSDARG00000086762	ENSDARG00000040485	ENSMUSG00000029821	Dfna5	NA	NA	NA	NA
ENSDARG00000086775	ENSDARG00000070545	ENSMUSG00000070544	Top1	NA	NA	NA	NA
ENSDARG00000086808	ENSDARG00000037042	ENSMUSG00000037697	Ddhd1	NA	NA	NA	NA
ENSDARG00000086965	ENSDARG00000059997	ENSMUSG00000051111	Sv2c	NA	NA	NA	NA
ENSDARG00000087059	ENSDARG00000057378	ENSMUSG00000021792	5730469M1	NA	NA	NA	NA
ENSDARG00000087086	ENSDARG00000079722	ENSMUSG00000043857	Mgat5b	NA	NA	NA	NA
ENSDARG00000087196	ENSDARG00000039949	ENSMUSG00000074971	Fibin	NA	NA	NA	NA
ENSDARG00000087260	ENSDARG00000028943	ENSMUSG00000033763	Mtss1l	NA	NA	NA	NA
ENSDARG00000087394	ENSDARG00000015959	ENSMUSG00000021217	Tshz3	NA	NA	NA	NA
ENSDARG00000087446	ENSDARG00000089090	ENSMUSG00000039533	Mmd2	NA	NA	NA	NA
ENSDARG00000087517	ENSDARG00000005544	ENSMUSG00000062098	Btbd3	NA	NA	NA	NA
ENSDARG00000087599	ENSDARG00000005479	ENSMUSG00000031561	Odz3	NA	NA	NA	NA
ENSDARG00000087646	ENSDARG00000025921	ENSMUSG00000022952	Runx1	NA	NA	NA	NA
ENSDARG00000087687	ENSDARG00000090990	ENSMUSG00000069763	Tmem100	NA	NA	NA	NA
ENSDARG00000087741	ENSDARG00000008473	ENSMUSG00000021898	Asb14	NA	NA	NA	NA
ENSDARG00000087780	ENSDARG00000040719	ENSMUSG00000023800	Tiam2	NA	NA	NA	NA
ENSDARG00000087983	ENSDARG00000090953	ENSMUSG00000000159	Igsf5	NA	NA	NA	NA
ENSDARG00000088026	ENSDARG00000091140	ENSMUSG00000046207	Pik3r6	NA	NA	NA	NA
ENSDARG00000088072	ENSDARG00000060632	ENSMUSG00000020905	Usp43	NA	NA	NA	NA
ENSDARG00000088121	ENSDARG00000086702	ENSMUSG00000046634	Pkd1l1	NA	NA	NA	NA
ENSDARG00000088124	ENSDARG00000054510	ENSMUSG00000045730	Adrb2	NA	NA	NA	NA
ENSDARG00000088137	ENSDARG00000088937	ENSMUSG00000031298	Gpr64	NA	NA	NA	NA
ENSDARG00000088437	ENSDARG00000075715	ENSMUSG00000061531	Fam23a	NA	NA	NA	NA
ENSDARG00000088466	ENSDARG00000038894	ENSMUSG00000024614	Tmx3	NA	NA	NA	NA
ENSDARG00000088521	ENSDARG00000001767	ENSMUSG00000024891	Slc29a2	NA	NA	NA	NA
ENSDARG00000088630	ENSDARG00000074244	ENSMUSG00000040964	Arhgef10l	NA	NA	NA	NA
ENSDARG00000088813	ENSDARG00000090468	ENSMUSG00000042717	Ppp1r3a	NA	NA	NA	NA
ENSDARG00000088842	ENSDARG00000038862	ENSMUSG00000092083	AC132603.	NA	NA	NA	NA
ENSDARG00000088898	ENSDARG00000069766	ENSMUSG00000060371	Caln1	NA	NA	NA	NA
ENSDARG00000089134	ENSDARG00000056680	ENSMUSG00000020303	Stc2	NA	NA	NA	NA
ENSDARG00000089190	ENSDARG00000077073	ENSMUSG00000035168	Tanc1	NA	NA	NA	NA
ENSDARG00000089233	ENSDARG00000040535	ENSMUSG00000036356	Csgalnact1	NA	NA	NA	NA
ENSDARG00000089322	ENSDARG00000051827	ENSMUSG00000074259	Gramd2	NA	NA	NA	NA
ENSDARG00000089334	ENSDARG00000053498	ENSMUSG00000022122	Ednrb	NA	NA	NA	NA
ENSDARG00000089348	ENSDARG00000071325	ENSMUSG00000035640	Dos	NA	NA	NA	NA
ENSDARG00000089545	ENSDARG00000043673	ENSMUSG00000040867	Begain	NA	NA	NA	NA
ENSDARG00000089641	ENSDARG00000063218	ENSMUSG00000027784	Ppm1l	NA	NA	NA	NA
ENSDARG00000089647	ENSDARG00000013623	ENSMUSG00000021771	Vdac2	NA	NA	NA	NA
ENSDARG00000089805	ENSDARG00000052494	ENSMUSG00000037892	Pcdh18	NA	NA	NA	NA
ENSDARG00000089817	ENSDARG00000043864	ENSMUSG00000032336	Nptn	NA	NA	NA	NA
ENSDARG00000089853	ENSDARG00000014313	ENSMUSG00000022890	Atp5j	NA	NA	NA	NA
ENSDARG00000089856	ENSDARG00000088825	ENSMUSG00000029516	Cit	NA	NA	NA	NA
ENSDARG00000089858	ENSDARG00000088979	ENSMUSG00000034903	Cobll1	NA	NA	NA	NA
ENSDARG00000089871	ENSDARG00000088405	ENSMUSG00000033960	9430020K0	NA	NA	NA	NA
ENSDARG00000089887	ENSDARG00000055479	ENSMUSG00000018620	Mmp20	NA	NA	NA	NA
ENSDARG00000089893	ENSDARG00000013346	ENSMUSG00000040651	D14Abb1e	NA	NA	NA	NA
ENSDARG00000089914	ENSDARG00000025535	ENSMUSG00000006169	Clint1	NA	NA	NA	NA
ENSDARG00000090106	ENSDARG00000016480	ENSMUSG00000070570	Slc17a7	NA	NA	NA	NA
ENSDARG00000090188	ENSDARG00000074270	ENSMUSG00000049164	Zfp518a	NA	NA	NA	NA
ENSDARG00000090292	ENSDARG00000089193	ENSMUSG00000039717	Ralyl	NA	NA	NA	NA
ENSDARG00000090340	ENSDARG00000062929	ENSMUSG00000042377	Fam83g	NA	NA	NA	NA
ENSDARG00000090375	ENSDARG00000078989	ENSMUSG00000038763	Alpk3	NA	NA	NA	NA
ENSDARG00000090402	ENSDARG00000067723	ENSMUSG00000064289	Tank	NA	NA	NA	NA
ENSDARG00000090514	ENSDARG00000075433	ENSMUSG00000031461	Myom2	NA	NA	NA	NA
ENSDARG00000090524	ENSDARG00000079472	ENSMUSG00000021675	F2rl2	NA	NA	NA	NA
ENSDARG00000090585	ENSDARG00000019341	ENSMUSG00000034220	Gpc1	NA	NA	NA	NA
ENSDARG00000090631	ENSDARG00000076974	ENSMUSG00000074818	Pdzd7	NA	NA	NA	NA
ENSDARG00000090669	ENSDARG00000037576	ENSMUSG00000039358	Drd5	NA	NA	NA	NA
ENSDARG00000090760	ENSDARG00000061021	ENSMUSG00000051000	Fam160a1	NA	NA	NA	NA
ENSDARG00000090933	ENSDARG00000078102	ENSMUSG00000037126	Psd	NA	NA	NA	NA
ENSDARG00000090937	ENSDARG00000077964	ENSMUSG00000025239	Limd1	NA	NA	NA	NA
ENSDARG00000091027	ENSDARG00000023713	ENSMUSG00000004655	Aqp1	NA	NA	NA	NA
ENSDARG00000091053	ENSDARG00000069419	ENSMUSG00000005580	Adcy9	NA	NA	NA	NA
ENSDARG00000091059	ENSDARG00000056395	ENSMUSG00000045518	Onecut3	NA	NA	NA	NA
ENSDARG00000091163	ENSDARG00000087907	ENSMUSG00000040280	Ndufa4l2	NA	NA	NA	NA
ENSDARG00000091173	ENSDARG00000074515	ENSMUSG00000056073	Grik2	NA	NA	NA	NA
ENSDARG00000091238	ENSDARG00000010583	ENSMUSG00000025812	Pard3	NA	NA	NA	NA
ENSDARG00000091359	ENSDARG00000059475	ENSMUSG00000044433	2310057J1	NA	NA	NA	NA
ENSDARG00000091406	ENSDARG00000089276	ENSMUSG00000070330	Gm12581	NA	NA	NA	NA
ENSDARG00000091509	ENSDARG00000090963	ENSMUSG00000078958	Atp6ap1l	NA	NA	NA	NA
ENSDARG00000091540	ENSDARG00000031126	ENSMUSG00000042988	Notum	NA	NA	NA	NA
ENSDARG00000091550	ENSDARG00000061196	ENSMUSG00000024053	Emilin2	NA	NA	NA	NA

ENSDARG00000091623	ENSDARG00000086535	ENSMUSG00000054409	Tmem74	NA	NA	NA	NA
ENSDARG00000091637	ENSDARG00000031020	ENSMUSG00000025417	Pip4k2c	NA	NA	NA	NA
ENSDARG00000091902	ENSDARG00000052376	ENSMUSG00000051650	B3gnt2	NA	NA	NA	NA
ENSDARG00000092081	ENSDARG00000058875	ENSMUSG00000007440	Pcdha1	NA	NA	NA	NA
ENSDARG00000092154	ENSDARG00000087939	ENSMUSG00000040813	Tex264	NA	NA	NA	NA
ENSDARG00000092553	ENSDARG00000042521	ENSMUSG00000016319	Slc25a5	NA	NA	NA	NA
ENSDARG00000092610	ENSDARG00000077944	ENSMUSG00000031447	Lamp1	NA	NA	NA	NA
ENSDARG00000093021	ENSDARG00000077470	ENSMUSG00000015484	Fam163a	NA	NA	NA	NA
ENSDARG00000093091	ENSDARG00000075792	ENSMUSG00000040797	Iqsec3	NA	NA	NA	NA
ENSDARG00000093357	ENSDARG00000079581	ENSMUSG00000054976	9430031J1	NA	NA	NA	NA
ENSDARG00000093359	ENSDARG00000078542	ENSMUSG00000034570	Inpp5j	NA	NA	NA	NA
ENSDARG00000093401	ENSDARG00000027657	ENSMUSG00000049796	Crh	NA	NA	NA	NA
ENSDARG00000093515	ENSDARG00000026137	ENSMUSG00000033720	Sfxn5	NA	NA	NA	NA
ENSDARG00000094052	ENSDARG00000060751	ENSMUSG00000061288	Taok3	NA	NA	NA	NA
ENSDARG00000094243	ENSDARG00000062109	ENSMUSG00000039154	Shd	NA	NA	NA	NA
ENSDARG00000094255	ENSDARG00000090698	ENSMUSG00000040485	Lrrc52	NA	NA	NA	NA
ENSDARG00000094377	ENSDARG00000079978	ENSMUSG00000038605	Samd10	NA	NA	NA	NA
ENSDARG00000094510	ENSDARG00000088248	ENSMUSG00000051343	Rab11fip5	NA	NA	NA	NA
ENSDARG00000094665	ENSDARG00000061498	ENSMUSG00000021768	Dusp13	NA	NA	NA	NA
ENSDARG00000094908	ENSDARG00000078527	ENSMUSG00000044505	Lingo4	NA	NA	NA	NA
ENSDARG00000095378	ENSDARG00000073891	ENSMUSG00000021943	Gdf10	NA	NA	NA	NA
ENSDARG00000095603	ENSDARG00000076103	ENSMUSG00000010825	Grid2ip	NA	NA	NA	NA
ENSDARG00000095614	ENSDARG00000062346	ENSMUSG00000004110	Cacna1e	NA	NA	NA	NA

3.2 Supplementary table of triplets of zebrafish duplicates with human singletons, with results of expression patterns comparisons

Zebrafish duplicate 1 Ensembl ID	Zebrafish duplicate 2 Ensembl ID	Human singleton Ensembl ID	Human singleton Ensembl name	Spatio-temporal analysis	Spatial-only analysis	Expression vs. No Expression	High quality data
ENSDARG00000001686	ENSDARG00000078973	ENSG00000198276	UCKL1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000006600	ENSDARG00000011408	ENSG00000105216	LSM14A	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000007812	ENSDARG00000001549	ENSG00000172845	SP3	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000008057	ENSDARG00000013979	ENSG00000131507	NDFIP1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000008109	ENSDARG00000030053	ENSG00000104529	EEF1D	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000008370	ENSDARG00000006125	ENSG00000141551	CSNK1D	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000009087	ENSDARG00000036628	ENSG00000019582	CD74	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000009881	ENSDARG00000086881	ENSG00000160888	IER2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000011609	ENSDARG00000030583	ENSG00000141568	FOXK2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000012553	ENSDARG00000087346	ENSG00000116473	RAP1A	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000012591	ENSDARG00000035054	ENSG00000114209	PDCD10	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000012818	ENSDARG00000013582	ENSG00000070770	CSNK2A2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000014794	ENSDARG00000071691	ENSG00000140740	UQCRC2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000015823	ENSDARG00000055433	ENSG00000151502	VPS26B	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000016255	ENSDARG00000007323	ENSG00000101421	CHMP4B	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000017010	ENSDARG00000010279	ENSG00000140497	SCAMP2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000018602	ENSDARG00000007257	ENSG00000144566	RAB5A	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000018898	ENSDARG00000002271	ENSG00000107372	ZFAND5	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000019644	ENSDARG00000071076	ENSG00000111716	LDHB	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000019949	ENSDARG00000075954	ENSG00000149257	SERPINH1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000023921	ENSDARG00000010745	ENSG00000069345	DNAJA2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000030236	ENSDARG00000043555	ENSG00000112697	TMEM30A	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000030441	ENSDARG00000034201	ENSG00000180817	PPA1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000031907	ENSDARG00000019362	ENSG00000011304	PTBP1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000032532	ENSDARG00000039880	ENSG00000128989	ARPP19	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000035066	ENSDARG00000038780	ENSG00000108312	UBTF	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000036236	ENSDARG00000007959	ENSG00000106049	HIBADH	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000036715	ENSDARG00000023279	ENSG00000159352	PSMD4	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000037860	ENSDARG00000045230	ENSG00000126267	COX6B1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000039034	ENSDARG00000035715	ENSG00000175130	MARCKSL1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000039650	ENSDARG00000043448	ENSG00000135916	ITM2C	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000042837	ENSDARG00000015790	ENSG00000069849	ATP1B3	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000052789	ENSDARG00000035869	ENSG00000155096	AZIN1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000052842	ENSDARG00000007409	ENSG00000108179	PPIF	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000056623	ENSDARG00000071018	ENSG00000171862	PTEN	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000058044	ENSDARG00000029663	ENSG00000138069	RAB1A	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000060150	ENSDARG00000005134	ENSG00000108671	PSMD11	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000067975	ENSDARG00000044092	ENSG00000130770	ATPIF1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000078113	ENSDARG00000068940	ENSG00000169020	ATP5I	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000079251	ENSDARG00000077329	ENSG00000169992	NLGN2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000089550	ENSDARG00000089610	ENSG00000185630	PBX1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000090697	ENSDARG00000002549	ENSG00000104408	EIF3E	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000031317	ENSDARG00000007682	ENSG00000125534	PPDPF	Subfunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000053301	ENSDARG00000091756	ENSG00000173404	INSM1	Neofunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000011127	ENSDARG00000028664	ENSG00000100591	AHSA1	Overlap only	Overlap only	Overlap only	Subfunctiona
ENSDARG00000032970	ENSDARG00000022509	ENSG00000131143	COX4I1	Overlap only	Overlap only	Overlap only	Subfunctiona
ENSDARG00000011141	ENSDARG00000059311	ENSG00000157851	DPYSL5	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000036848	ENSDARG00000061120	ENSG00000167703	SLC43A2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000037361	ENSDARG00000005254	ENSG00000136240	KDELR2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000052928	ENSDARG00000073734	ENSG00000165527	ARF6	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000067741	ENSDARG00000002994	ENSG00000086544	ITPKC	Overlap only	Overlap only	Overlap only	Neofunctiona
ENSDARG00000026611	ENSDARG00000025428	ENSG00000184557	SOCS3	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000041394	ENSDARG00000015831	ENSG00000132002	DNAJB1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000012194	ENSDARG00000036496	ENSG00000116171	SCP2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000068478	ENSDARG00000076836	ENSG00000167468	GPX4	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000055398	ENSDARG00000091481	ENSG00000054598	FOXC1	Overlap only	Subfunctiona	Overlap only	Overlap only
ENSDARG00000007671	ENSDARG00000054771	ENSG00000112964	GHR	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000038159	ENSDARG00000007369	ENSG00000152284	TCF7L1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000009418	ENSDARG00000029764	ENSG00000081189	MEF2C	Overlap only	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000032369	ENSDARG00000076440	ENSG00000184887	BTBD6	Subfunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000034700	ENSDARG00000045971	ENSG00000112715	VEGFA	Subfunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000058992	ENSDARG00000013704	ENSG00000143418	LASS2	Subfunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000016238	ENSDARG00000077044	ENSG00000144746	ARL6IP5	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000057093	ENSDARG00000003098	ENSG00000117139	KDM5B	Overlap only	Subfunctiona	Overlap only	Overlap only
ENSDARG00000004702	ENSDARG00000006275	ENSG00000168264	IRF2BP2	Overlap only	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000029439	ENSDARG00000005122	ENSG00000174437	ATP2A2	Overlap only	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000059391	ENSDARG00000011934	ENSG00000163754	GYG1	Overlap only	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000026882	ENSDARG00000007818	ENSG00000099864	PALM	Overlap only	Both neo-	Overlap only	Subfunctiona
ENSDARG00000057770	ENSDARG00000011929	ENSG00000123560	PLP1	Neofunctiona	Subfunctiona	Overlap only	Neofunctiona
ENSDARG00000045240	ENSDARG00000036073	ENSG00000153879	CEBPG	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000003820	ENSDARG00000009594	ENSG00000174738	NR1D2	Overlap only	Subfunctiona	Overlap only	Overlap only
ENSDARG00000063309	ENSDARG00000023443	ENSG00000119139	TJP2	Subfunctiona	Subfunctiona	Subfunctiona	Overlap only
ENSDARG00000018174	ENSDARG00000017294	ENSG00000114353	GNAI2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000012405	ENSDARG00000035809	ENSG00000108821	COL1A1	Overlap only	Subfunctiona	Overlap only	Overlap only
ENSDARG00000039576	ENSDARG00000015559	ENSG00000163430	FSTL1	Overlap only	Overlap only	Overlap only	Neofunctiona
ENSDARG00000011824	ENSDARG00000071015	ENSG00000163346	PBXIP1	Overlap only	Subfunctiona	Overlap only	Overlap only

ENSDARG00000042677	ENSDARG00000031075	ENSG00000182985	CADM1	Overlap only	Subfunctiona	Overlap only	Overlap only
ENSDARG00000028173	ENSDARG00000052330	ENSG00000164889	SLC4A2	Overlap only	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000038267	ENSDARG00000027600	ENSG00000163110	PDLIM5	Overlap only	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000008170	ENSDARG00000016016	ENSG00000136279	DBNL	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000017339	ENSDARG00000069054	ENSG00000135821	GLUL	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000026821	ENSDARG00000035949	ENSG00000106460	TMEM106B	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000006003	ENSDARG00000034956	ENSG00000116990	MYCL1	Neofunctiona	Overlap only	Overlap only	Neofunctiona
ENSDARG00000007693	ENSDARG00000005481	ENSG00000100906	NFKBIA	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000001676	ENSDARG00000005739	ENSG00000046653	GPM6B	Overlap only	Subfunctiona	Overlap only	Overlap only
ENSDARG00000008788	ENSDARG00000044526	ENSG00000008118	CAMK1G	Overlap only	Both neo-	Neofunctiona	Neofunctiona
ENSDARG00000010420	ENSDARG00000032849	ENSG00000104419	NDRG1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000042029	ENSDARG00000061774	ENSG00000071655	MBD3	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000056490	ENSDARG00000056483	ENSG00000130511	SSBP4	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000070475	ENSDARG00000052856	ENSG00000121774	KHDRBS1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000054274	ENSDARG00000036121	ENSG00000138650	PCDH10	Overlap only	Neofunctiona	Neofunctiona	Neofunctiona
ENSDARG00000038666	ENSDARG00000014947	ENSG00000146678	IGFBP1	Neofunctiona	Overlap only	Overlap only	Neofunctiona
ENSDARG00000012504	ENSDARG00000045808	ENSG00000140522	RLBP1	Neofunctiona	Neofunctiona	Neofunctiona	Neofunctiona
ENSDARG00000076900	ENSDARG00000037783	ENSG00000126231	PROZ	Neofunctiona	Neofunctiona	Neofunctiona	Neofunctiona
ENSDARG00000003142	ENSDARG00000069440	ENSG00000165659	DACH1	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000077383	ENSDARG00000002632	ENSG00000122359	ANXA11	Overlap only	Subfunctiona	Overlap only	Overlap only
ENSDARG00000034705	ENSDARG00000009311	ENSG00000100362	PVALB	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000041062	ENSDARG00000036344	ENSG00000172137	CALB2	Overlap only	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000057853	ENSDARG00000036577	ENSG00000185883	ATP6V0C	Subfunctiona	Overlap only	Overlap only	Overlap only
ENSDARG00000035650	ENSDARG00000031086	ENSG00000196405	EVL	Overlap only	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000038190	ENSDARG00000010953	ENSG00000166579	NDEL1	Overlap only	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000026531	ENSDARG00000058538	ENSG00000170017	ALCAM	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000043257	ENSDARG00000069752	ENSG00000166165	CKB	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000062174	ENSDARG00000009738	ENSG00000182389	CACNB4	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000052765	ENSDARG00000070173	ENSG00000120251	GRIA2	Neofunctiona	Neofunctiona	Overlap only	Neofunctiona
ENSDARG00000040565	ENSDARG00000035327	ENSG00000104879	CKM	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000004621	ENSDARG00000055455	ENSG00000150625	GPM6A	Overlap only	Subfunctiona	Overlap only	Overlap only
ENSDARG00000019613	ENSDARG00000008310	ENSG00000068745	IP6K2	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000009014	ENSDARG00000026165	ENSG00000060718	COL11A1	Overlap only	Overlap only	Overlap only	Subfunctiona
ENSDARG00000043581	ENSDARG00000069991	ENSG00000116717	GADD45A	Overlap only	Subfunctiona	Overlap only	Overlap only
ENSDARG00000004588	ENSDARG00000043235	ENSG00000124766	SOX4	Overlap only	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000032724	ENSDARG00000060457	ENSG00000109099	PMP22	Overlap only	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000037116	ENSDARG00000055100	ENSG00000107562	CXCL12	Overlap only	Both neo-	Overlap only	Both neo-
ENSDARG00000013144	ENSDARG00000076833	ENSG00000143153	ATP1B1	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000019815	ENSDARG00000006526	ENSG00000115414	FN1	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000044808	ENSDARG00000013730	ENSG00000080493	SLC4A4	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000011239	ENSDARG00000017710	ENSG00000167641	PPP1R14A	Subfunctiona	Both neo-	Overlap only	Subfunctiona
ENSDARG00000020364	ENSDARG00000021366	ENSG00000165140	FBP1	Neofunctiona	Overlap only	Overlap only	Neofunctiona
ENSDARG00000030289	ENSDARG00000013168	ENSG00000101384	JAG1	Subfunctiona	Subfunctiona	Overlap only	Overlap only
ENSDARG00000070360	ENSDARG00000070404	ENSG00000185614	C3orf54	Overlap only	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000013605	ENSDARG00000034424	ENSG00000129244	ATP1B2	Overlap only	Both neo-	Overlap only	Both neo-
ENSDARG00000022437	ENSDARG00000036080	ENSG00000110651	CD81	Overlap only	Overlap only	NA	Overlap only
ENSDARG00000000394	ENSDARG00000035734	ENSG00000015479	MATR3	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000001241	ENSDARG00000032175	ENSG00000179950	PUF60	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000004754	ENSDARG00000018989	ENSG00000170606	HSPA4	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000008548	ENSDARG00000026482	ENSG00000165322	ARHGAP12	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000011783	ENSDARG00000053668	ENSG00000101972	STAG2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000016763	ENSDARG00000043973	ENSG00000188994	ZNF292	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000018882	ENSDARG00000007915	ENSG00000096968	JAK2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000019081	ENSDARG00000028336	ENSG00000104808	DHDH	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000021996	ENSDARG00000006624	ENSG00000221914	PPP2R2A	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000025789	ENSDARG00000063535	ENSG00000111642	CHD4	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000027423	ENSDARG00000034434	ENSG00000140443	IGF1R	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000030368	ENSDARG00000003213	ENSG00000164134	NAA15	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000031240	ENSDARG00000017338	ENSG00000134313	KIDINS220	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000033614	ENSDARG00000044251	ENSG00000138670	RASGEF1B	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000035986	ENSDARG00000016481	ENSG00000175354	PTPN2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000036685	ENSDARG00000036510	ENSG00000082258	CCNT2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000037260	ENSDARG00000039784	ENSG00000197579	TOPORS	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000041735	ENSDARG00000074248	ENSG00000155755	ALS2CR4	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000042489	ENSDARG00000020964	ENSG00000137492	PRKRIR	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000053804	ENSDARG00000013830	ENSG00000130703	OSBPL2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000054304	ENSDARG00000024598	ENSG00000215271	HOMEZ	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000054442	ENSDARG00000004189	ENSG00000108468	CBX1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000056856	ENSDARG00000034062	ENSG00000106052	TAX1BP1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000059870	ENSDARG00000062954	ENSG00000176444	CLK2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000060316	ENSDARG00000016773	ENSG00000114737	CISH	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000060586	ENSDARG00000061587	ENSG00000137770	CTDSPL2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000062469	ENSDARG00000062082	ENSG00000110422	HIPK3	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000067626	ENSDARG00000071658	ENSG00000170027	YWHAG	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000073848	ENSDARG00000006299	ENSG00000102606	ARHGEF7	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000074287	ENSDARG00000018976	ENSG00000100596	SPTLC2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000076742	ENSDARG00000021488	ENSG00000108669	CYTH1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000077623	ENSDARG00000088440	ENSG00000141298	SSH2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000090156	ENSDARG00000040039	ENSG00000183255	PTTG1IP	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000006074	ENSDARG00000022213	ENSG00000143179	UCK2	Neofunctiona	Overlap only	Overlap only	NA
ENSDARG00000032919	ENSDARG00000034933	ENSG00000106554	CHCHD3	Neofunctiona	Overlap only	Overlap only	NA
ENSDARG00000009081	ENSDARG00000028099	ENSG00000095370	SH2D3C	Neofunctiona	Neofunctiona	Neofunctiona	NA
ENSDARG00000040988	ENSDARG00000025012	ENSG00000111669	TPI1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000010052	ENSDARG00000013087	ENSG00000101079	NDRG3	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000062376	ENSDARG00000062581	ENSG00000196338	NLGN3	Overlap only	Neofunctiona	Overlap only	NA
ENSDARG00000032737	ENSDARG00000037498	ENSG00000125675	GRIA3	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000055505	ENSDARG00000058424	ENSG00000197461	PDGFA	Overlap only	Subfunctiona	Overlap only	NA
ENSDARG00000043932	ENSDARG00000030106	ENSG00000015592	STMN4	Overlap only	Neofunctiona	Overlap only	NA
ENSDARG00000004377	ENSDARG00000009142	ENSG00000088808	PPP1R13B	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000030514	ENSDARG00000003854	ENSG00000151726	ACSL1	NA	Overlap only	Overlap only	Overlap only

ENSDARG00000009208	ENSDARG00000070651	ENSG00000163932	PRKCD	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000019302	ENSDARG00000041051	ENSG00000165175	MID1IP1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000033733	ENSDARG00000022531	ENSG00000065320	NTN1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000005993	ENSDARG00000010511	ENSG00000198901	PRC1	Subfunctiona	Overlap only	Overlap only	NA
ENSDARG00000003191	ENSDARG00000003933	ENSG00000067225	PKM2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000030340	ENSDARG00000005776	ENSG00000143774	GUK1	Overlap only	Subfunctiona	Overlap only	Overlap only
ENSDARG00000014962	ENSDARG00000057456	ENSG00000120910	PPP3CC	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000059244	ENSDARG00000056664	ENSG00000132254	ARFIP2	Overlap only	Subfunctiona	NA	Subfunctiona
ENSDARG00000068629	ENSDARG00000038288	ENSG00000177697	CD151	Overlap only	Subfunctiona	NA	Subfunctiona
ENSDARG00000029761	ENSDARG00000056892	ENSG00000105926	MPP6	Overlap only	Subfunctiona	Overlap only	NA
ENSDARG00000045694	ENSDARG00000040649	ENSG00000139174	PRICKLE1	Subfunctiona	Subfunctiona	Overlap only	NA
ENSDARG00000035820	ENSDARG00000038363	ENSG00000069696	DRD4	Neofunctiona	Neofunctiona	NA	Neofunctiona
ENSDARG00000002412	ENSDARG00000058356	ENSG00000066322	ELOVL1	NA	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000002235	ENSDARG00000008388	ENSG00000157227	MMP14	Subfunctiona	Subfunctiona	Overlap only	NA
ENSDARG00000042210	ENSDARG00000019235	ENSG00000075213	SEMA3A	Neofunctiona	Overlap only	Overlap only	NA
ENSDARG00000014233	ENSDARG00000032606	ENSG00000164402	sep.08	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000077556	ENSDARG00000075597	ENSG00000126500	FLRT1	NA	Overlap only	Overlap only	Overlap only
ENSDARG00000070537	ENSDARG00000033234	ENSG00000104435	STMN2	NA	Neofunctiona	Overlap only	Overlap only
ENSDARG00000031049	ENSDARG00000056084	ENSG00000117154	IGSF21	Overlap only	Overlap only	NA	Overlap only
ENSDARG00000023058	ENSDARG00000042904	ENSG00000118689	FOXO3	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000037496	ENSDARG00000059368	ENSG00000152578	GRIA4	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000039615	ENSDARG00000003399	ENSG00000107831	FGF8	Overlap only	Neofunctiona	Overlap only	NA
ENSDARG00000053248	ENSDARG00000011862	ENSG00000148798	INA	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000089464	ENSDARG00000074030	ENSG00000196132	MYT1	Neofunctiona	Overlap only	Overlap only	NA
ENSDARG00000045444	ENSDARG00000038569	ENSG00000177283	FZD8	Subfunctiona	Subfunctiona	Overlap only	NA
ENSDARG00000034165	ENSDARG00000035899	ENSG00000169783	LINGO1	NA	Overlap only	Overlap only	Overlap only
ENSDARG00000034893	ENSDARG00000056783	ENSG00000131759	RARA	Overlap only	Subfunctiona	Overlap only	NA
ENSDARG00000089288	ENSDARG00000045524	ENSG00000091136	LAMB1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000017704	ENSDARG00000023362	ENSG00000136931	NR5A1	Neofunctiona	Neofunctiona	Neofunctiona	NA
ENSDARG00000005108	ENSDARG00000003091	ENSG00000197822	OCLN	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000014059	ENSDARG00000043716	ENSG00000184113	CLDN5	Overlap only	Subfunctiona	NA	Subfunctiona
ENSDARG00000062338	ENSDARG00000078416	ENSG00000169554	ZEB2	Subfunctiona	Subfunctiona	NA	Subfunctiona
ENSDARG00000041150	ENSDARG00000001127	ENSG00000091664	SLC17A6	Both neo-	Neofunctiona	NA	Neofunctiona
ENSDARG00000074639	ENSDARG00000061848	ENSG00000204291	COL15A1	NA	Subfunctiona	Overlap only	Overlap only
ENSDARG00000020219	ENSDARG00000010791	ENSG00000198719	DLL1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000002336	ENSDARG00000004232	ENSG00000090932	DLL3	Neofunctiona	Neofunctiona	Neofunctiona	NA
ENSDARG00000003910	ENSDARG00000053884	ENSG00000108510	MED13	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000004154	ENSDARG00000011515	ENSG00000182500	ORAI1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000004771	ENSDARG00000037100	ENSG00000088448	ANKRD10	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000010641	ENSDARG00000020114	ENSG00000144136	SLC20A1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000011407	ENSDARG00000069093	ENSG00000139219	COL2A1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000011583	ENSDARG00000045768	ENSG00000008405	CRY1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000012458	ENSDARG00000055383	ENSG00000182831	C16orf72	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000013274	ENSDARG00000077012	ENSG00000151247	EIF4E	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000015015	ENSDARG00000056656	ENSG00000157570	TSPAN18	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000016187	ENSDARG00000025718	ENSG00000154832	CXXC1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000016263	ENSDARG00000087417	ENSG00000156599	ZDHHC5	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000019842	ENSDARG00000007135	ENSG00000088038	CNOT3	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000020123	ENSDARG00000032426	ENSG00000163050	ADCK3	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000021193	ENSDARG00000035598	ENSG00000110880	CORO1C	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000021380	ENSDARG00000009273	ENSG00000170836	PPM1D	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000022768	ENSDARG00000037589	ENSG00000101193	C20orf11	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000026582	ENSDARG00000035596	ENSG00000136003	ISCU	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000030267	ENSDARG00000071583	ENSG00000122034	GTF3A	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000031560	ENSDARG00000073997	ENSG00000096063	SRPK1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000031770	ENSDARG00000070371	ENSG00000136504	MYST2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000034189	ENSDARG00000027500	ENSG00000172939	OXSR1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000035458	ENSDARG00000020574	ENSG00000196296	ATP2A1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000039681	ENSDARG00000045814	ENSG00000100347	SAMM50	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000040184	ENSDARG00000026723	ENSG00000135316	SYNCRIP	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000041317	ENSDARG00000056059	ENSG00000100401	RANGAP1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000041602	ENSDARG00000005870	ENSG00000168288	MMADHC	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000045927	ENSDARG00000035905	ENSG00000160785	SLC25A44	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000052099	ENSDARG00000018478	ENSG00000172482	AGXT	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000052438	ENSDARG00000070076	ENSG00000138071	ACTR2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000052851	ENSDARG00000044225	ENSG00000113384	GOLPH3	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000053326	ENSDARG00000010002	ENSG00000088256	GNA11	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000053571	ENSDARG00000042827	ENSG00000181915	ADO	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000054272	ENSDARG00000009346	ENSG00000135387	CAPRIN1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000055540	ENSDARG00000029075	ENSG00000114268	PFKFB4	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000056252	ENSDARG00000029402	ENSG00000134243	SORT1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000059653	ENSDARG00000078133	ENSG00000173120	KDM2A	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000060065	ENSDARG00000088318	ENSG00000137073	UBAP2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000060297	ENSDARG00000062577	ENSG00000160007	GRLF1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000067605	ENSDARG00000020405	ENSG00000105402	NAPA	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000070145	ENSDARG00000003169	ENSG00000151276	MAGI1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000074020	ENSDARG00000076009	ENSG00000050405	LIMA1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000076810	ENSDARG00000005754	ENSG00000142949	PTPRF	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000077178	ENSDARG00000055350	ENSG00000164828	SUN1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000078772	ENSDARG00000077297	ENSG00000188554	NBR1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000092112	ENSDARG00000036721	ENSG00000130204	TOMM40	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000032865	ENSDARG00000042128	ENSG00000124507	PACSIN1	Overlap only	Overlap only	NA	NA
ENSDARG00000003991	ENSDARG00000042018	ENSG00000115641	FHL2	NA	Overlap only	NA	Overlap only
ENSDARG00000034710	ENSDARG00000017312	ENSG00000164187	LMBRD2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000062948	ENSDARG00000059466	ENSG00000132970	WASF3	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000031622	ENSDARG00000038446	ENSG00000118257	NRP2	Overlap only	Both neo-	NA	NA
ENSDARG00000006395	ENSDARG00000039266	ENSG00000119707	RBM25	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000011157	ENSDARG00000042308	ENSG00000104880	ARHGEF18	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000036107	ENSDARG00000070000	ENSG00000117289	TXNIP	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000008697	ENSDARG00000057671	ENSG00000116016	EPAS1	Subfunctiona	Overlap only	Overlap only	NA

ENSDARG00000075261	ENSDARG00000061226	ENSG00000035862	TIMP2	Subfunctiona	Overlap only	Overlap only	NA
ENSDARG00000077671	ENSDARG00000011506	ENSG00000153395	LPCAT1	Subfunctiona	Overlap only	Overlap only	NA
ENSDARG00000017441	ENSDARG00000014196	ENSG00000168530	MYL1	Neofunctiona	Neofunctiona	NA	NA
ENSDARG00000016676	ENSDARG00000036058	ENSG00000087258	GNAO1	NA	Subfunctiona	Overlap only	NA
ENSDARG00000002787	ENSDARG00000069006	ENSG00000140332	TLE3	Subfunctiona	Overlap only	Overlap only	NA
ENSDARG00000026166	ENSDARG00000024537	ENSG00000138080	EMILIN1	NA	Subfunctiona	NA	Subfunctiona
ENSDARG00000043317	ENSDARG00000056133	ENSG00000157404	KIT	NA	Subfunctiona	Overlap only	NA
ENSDARG00000006982	ENSDARG00000056697	ENSG00000163132	MSX1	Overlap only	Neofunctiona	NA	NA
ENSDARG00000017128	ENSDARG00000006112	ENSG00000138119	MYOF	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000039117	ENSDARG00000038401	ENSG00000167074	TEF	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000021065	ENSDARG00000011065	ENSG00000058404	CAMK2B	Overlap only	Overlap only	NA	NA
ENSDARG00000006901	ENSDARG00000091726	ENSG00000106624	AEBP1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000019098	ENSDARG00000026070	ENSG00000085117	CD82	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000019702	ENSDARG00000057661	ENSG00000109107	ALDOC	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000036082	ENSDARG00000029432	ENSG00000129167	TPH1	Neofunctiona	Neofunctiona	Neofunctiona	NA
ENSDARG00000032714	ENSDARG00000021352	ENSG00000155511	GRIA1	NA	Overlap only	Overlap only	NA
ENSDARG00000009461	ENSDARG00000056819	ENSG00000078399	HOXA9	Overlap only	Overlap only	NA	NA
ENSDARG00000000161	ENSDARG00000054973	ENSG00000198399	ITSN2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000031782	ENSDARG00000006060	ENSG00000112297	AIM1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000034643	ENSDARG00000059158	ENSG00000183386	FHL3	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000040295	ENSDARG00000086370	ENSG00000130203	APOE	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000044655	ENSDARG00000061173	ENSG00000149418	ST14	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000062116	ENSDARG00000071673	ENSG00000144677	CTDSPL	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000013613	ENSDARG00000013976	ENSG00000104537	ANXA13	Overlap only	Neofunctiona	Overlap only	NA
ENSDARG00000055565	ENSDARG00000079906	ENSG00000165995	CACNB2	Overlap only	Subfunctiona	NA	NA
ENSDARG00000032808	ENSDARG00000077523	ENSG00000196116	TDRD7	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000002642	ENSDARG00000067958	ENSG00000141985	SH3GL1	Subfunctiona	Overlap only	Overlap only	NA
ENSDARG00000045540	ENSDARG00000069654	ENSG00000100239	PPP6R2	Subfunctiona	Overlap only	Overlap only	NA
ENSDARG00000053535	ENSDARG00000004930	ENSG00000136153	LMO7	Overlap only	Neofunctiona	Overlap only	NA
ENSDARG00000007220	ENSDARG00000056181	ENSG00000149294	NCAM1	Overlap only	Neofunctiona	NA	NA
ENSDARG00000041348	ENSDARG00000009852	ENSG00000137869	CYP19A1	Neofunctiona	Both neo-	NA	Neofunctiona
ENSDARG00000004861	ENSDARG00000011696	ENSG00000196482	ESRRG	Subfunctiona	Subfunctiona	Overlap only	NA
ENSDARG00000056633	ENSDARG00000035056	ENSG00000129682	FGF13	NA	Subfunctiona	NA	Overlap only
ENSDARG00000055373	ENSDARG00000011163	ENSG00000001617	SEMA3F	NA	Subfunctiona	Overlap only	NA
ENSDARG00000003971	ENSDARG00000053499	ENSG00000159556	ISL2	NA	Neofunctiona	Overlap only	NA
ENSDARG00000035084	ENSDARG00000055291	ENSG00000099246	RAB18	NA	Overlap only	Overlap only	NA
ENSDARG00000009567	ENSDARG00000039256	ENSG00000072195	SPEG	NA	Overlap only	NA	Overlap only
ENSDARG00000026329	ENSDARG00000017748	ENSG00000137962	ARHGAP29	NA	Overlap only	NA	Overlap only
ENSDARG00000051912	ENSDARG00000012609	ENSG00000110169	HPX	NA	Overlap only	Overlap only	NA
ENSDARG00000056765	ENSDARG00000056744	ENSG00000162438	CTRC	NA	Overlap only	Overlap only	NA
ENSDARG00000060081	ENSDARG00000060106	ENSG00000148204	CRB2	NA	Neofunctiona	Overlap only	NA
ENSDARG00000026109	ENSDARG00000026907	ENSG00000211584	SLC48A1	Overlap only	Overlap only	NA	NA
ENSDARG00000062674	ENSDARG00000020252	ENSG00000148925	BTBD10	Overlap only	Overlap only	NA	NA
ENSDARG00000074245	ENSDARG00000074332	ENSG00000065526	SPEN	Overlap only	Overlap only	NA	NA
ENSDARG00000053254	ENSDARG00000002589	ENSG00000180209	MYLPF	NA	Neofunctiona	NA	NA
ENSDARG00000004836	ENSDARG00000042948	ENSG00000101152	DNAJC5	NA	Overlap only	NA	NA
ENSDARG00000002748	ENSDARG00000000189	ENSG00000143434	SEMA6C	NA	Neofunctiona	NA	NA
ENSDARG00000092810	ENSDARG00000043281	ENSG00000178078	STAP2	NA	Neofunctiona	Overlap only	NA
ENSDARG00000076030	ENSDARG00000001881	ENSG00000167535	CACNB3	NA	Overlap only	NA	NA
ENSDARG00000046019	ENSDARG00000056995	ENSG00000124216	SNAI1	NA	Neofunctiona	NA	NA
ENSDARG00000009727	ENSDARG00000094792	ENSG00000247596	TWF2	Overlap only	NA	NA	NA
ENSDARG00000079011	ENSDARG00000069415	ENSG00000065618	COL17A1	NA	Both neo-	NA	NA
ENSDARG00000070220	ENSDARG00000076262	ENSG00000184486	POU3F2	NA	Neofunctiona	NA	NA
ENSDARG00000020450	ENSDARG00000070626	ENSG00000142408	CACNG8	Neofunctiona	Neofunctiona	Neofunctiona	NA
ENSDARG00000079396	ENSDARG00000071230	ENSG00000165379	LRFN5	NA	Neofunctiona	NA	Neofunctiona
ENSDARG00000010563	ENSDARG00000003974	ENSG00000144228	SPOPL	Overlap only	Overlap only	NA	NA
ENSDARG00000034181	ENSDARG00000016454	ENSG00000140009	ESR2	Overlap only	Overlap only	NA	NA
ENSDARG00000039684	ENSDARG00000078690	ENSG00000124523	SIRT5	Overlap only	Overlap only	NA	NA
ENSDARG00000003732	ENSDARG00000037833	ENSG00000187098	MITF	NA	Overlap only	NA	NA
ENSDARG00000008723	ENSDARG00000022254	ENSG00000166501	PRKCB	NA	Overlap only	NA	NA
ENSDARG00000039051	ENSDARG00000005139	ENSG00000010282	HHATL	Neofunctiona	Neofunctiona	NA	NA
ENSDARG00000057223	ENSDARG00000089790	ENSG00000184349	EFNA5	NA	Overlap only	NA	NA
ENSDARG00000005161	ENSDARG00000012987	ENSG00000105220	GPI	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000069708	ENSDARG00000012627	ENSG00000099804	CDC34	Overlap only	Overlap only	Overlap only	Overlap only
ENSDARG00000056653	ENSDARG00000071498	ENSG00000022267	FHL1	Overlap only	Overlap only	Overlap only	Both neo-
ENSDARG00000069843	ENSDARG00000053542	ENSG00000178695	KCTD12	Subfunctiona	Subfunctiona	Overlap only	Subfunctiona
ENSDARG00000032859	ENSDARG00000040280	ENSG00000168672	FAM84B	NA	Overlap only	Overlap only	NA
ENSDARG00000034522	ENSDARG00000031343	ENSG00000154917	RAB6B	NA	Overlap only	Overlap only	NA
ENSDARG00000041165	ENSDARG00000029036	ENSG00000118508	RAB32	NA	Overlap only	Overlap only	NA
ENSDARG00000044295	ENSDARG00000006508	ENSG00000107242	PIP5K1B	NA	Overlap only	Overlap only	NA
ENSDARG00000052254	ENSDARG00000068920	ENSG00000122482	ZNF644	NA	Overlap only	Overlap only	NA
ENSDARG00000003216	ENSDARG00000053625	ENSG00000182718	ANXA2	Overlap only	Overlap only	NA	NA
ENSDARG00000017311	ENSDARG00000025027	ENSG00000121957	GPSM2	Overlap only	Overlap only	NA	NA
ENSDARG00000018865	ENSDARG00000088663	ENSG00000114988	LMAN2L	Overlap only	Overlap only	NA	NA
ENSDARG00000034497	ENSDARG00000045801	ENSG00000171823	FBXL14	NA	Neofunctiona	NA	NA
ENSDARG00000041323	ENSDARG00000068477	ENSG00000172346	CSDC2	NA	Overlap only	NA	NA
ENSDARG00000014179	ENSDARG00000060797	ENSG00000152556	PFKM	Overlap only	NA	NA	NA
ENSDARG00000015681	ENSDARG00000029501	ENSG00000105723	GSK3A	Overlap only	NA	NA	NA
ENSDARG00000053453	ENSDARG00000010957	ENSG00000108852	MPP2	Overlap only	NA	NA	NA
ENSDARG00000053753	ENSDARG00000039203	ENSG00000168958	MFF	Overlap only	NA	NA	NA
ENSDARG00000058128	ENSDARG00000028740	ENSG00000147065	MSN	Overlap only	NA	NA	NA
ENSDARG00000078452	ENSDARG00000055101	ENSG00000103415	HMOX2	Overlap only	NA	NA	NA
ENSDARG00000015025	ENSDARG00000007149	ENSG00000198910	L1CAM	Overlap only	Overlap only	NA	NA
ENSDARG00000039528	ENSDARG00000044954	ENSG00000187122	SLIT1	NA	NA	NA	NA
ENSDARG00000002696	ENSDARG00000004358	ENSG00000111664	GNB3	NA	Subfunctiona	NA	NA
ENSDARG00000015901	ENSDARG00000015230	ENSG00000117569	PTBP2	Overlap only	Overlap only	NA	NA
ENSDARG00000056998	ENSDARG00000001634	ENSG00000183853	KIRREL	NA	Overlap only	NA	NA
ENSDARG00000074635	ENSDARG00000079009	ENSG00000165029	ABCA1	NA	NA	NA	NA
ENSDARG00000032578	ENSDARG00000028148	ENSG00000075891	PAX2	NA	NA	NA	NA
ENSDARG00000041660	ENSDARG00000037159	ENSG00000116329	OPRD1	NA	NA	NA	NA

ENSDARG00000027740	ENSDARG00000004015	ENSG00000141433	ADCYAP1	NA	Neofunctiona	NA	NA
ENSDARG00000052470	ENSDARG00000031422	ENSG00000115457	IGFBP2	NA	Overlap only	NA	NA
ENSDARG00000013317	ENSDARG00000055518	ENSG00000068976	PYGM	Overlap only	NA	NA	NA
ENSDARG00000016934	ENSDARG00000010727	ENSG00000141540	TTYH2	NA	Overlap only	NA	NA
ENSDARG00000055481	ENSDARG00000011298	ENSG00000170653	ATF7	NA	Overlap only	NA	NA
ENSDARG00000007609	ENSDARG00000036254	ENSG00000106031	HOXA13	NA	NA	NA	NA
ENSDARG00000009045	ENSDARG00000007009	ENSG00000005073	HOXA11	NA	NA	NA	NA
ENSDARG00000018032	ENSDARG00000005775	ENSG00000196876	SCN8A	NA	NA	NA	NA
ENSDARG00000036036	ENSDARG00000020708	ENSG00000110492	MDK	NA	NA	NA	NA
ENSDARG00000058656	ENSDARG00000005221	ENSG00000175084	DES	Overlap only	Subfunctiona	NA	NA
ENSDARG00000052764	ENSDARG00000038508	ENSG00000147432	CHRNB3	Neofunctiona	NA	NA	NA
ENSDARG00000001710	ENSDARG00000037998	ENSG00000137312	FLOT1	NA	NA	NA	NA
ENSDARG00000007714	ENSDARG00000013990	ENSG00000140367	UBE2Q2	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000025071	ENSDARG00000055999	ENSG00000112983	BRD8	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000025397	ENSDARG00000059360	ENSG00000112081	SRSF3	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000037675	ENSDARG00000014329	ENSG00000181163	NPM1	Overlap only	Overlap only	Overlap only	NA
ENSDARG00000029596	ENSDARG00000058158	ENSG00000147573	TRIM55	Neofunctiona	Overlap only	Overlap only	NA
ENSDARG00000041609	ENSDARG00000003544	ENSG00000197381	ADARB1	NA	Overlap only	NA	NA
ENSDARG00000030326	ENSDARG00000018787	ENSG00000169242	EFNA1	NA	Overlap only	NA	NA
ENSDARG00000030547	ENSDARG00000004218	ENSG00000172602	RND1	NA	Overlap only	NA	NA
ENSDARG00000030630	ENSDARG00000035909	ENSG00000168389	MFSD2A	NA	Overlap only	NA	NA
ENSDARG00000052654	ENSDARG00000000151	ENSG00000126351	THRA	NA	Overlap only	NA	NA
ENSDARG00000075752	ENSDARG00000061862	ENSG00000196535	MYO18A	NA	Overlap only	NA	NA
ENSDARG00000076448	ENSDARG00000061383	ENSG00000167711	SERPINF2	Overlap only	NA	NA	NA
ENSDARG00000092060	ENSDARG00000024894	ENSG00000089225	TBX5	NA	NA	NA	NA
ENSDARG00000002037	ENSDARG00000023840	ENSG00000123836	PFKFB2	NA	NA	NA	NA
ENSDARG00000006283	ENSDARG00000014113	ENSG00000106299	WASL	NA	NA	NA	NA
ENSDARG00000008807	ENSDARG00000052129	ENSG00000176720	BOK	NA	NA	NA	NA
ENSDARG00000009136	ENSDARG00000054858	ENSG00000143514	TP53BP2	NA	NA	NA	NA
ENSDARG00000017397	ENSDARG00000036251	ENSG00000173473	SMARCC1	NA	NA	NA	NA
ENSDARG00000025728	ENSDARG00000027828	ENSG00000176884	GRIN1	NA	NA	NA	NA
ENSDARG00000035122	ENSDARG00000019208	ENSG00000130559	CAMSAP1	NA	NA	NA	NA
ENSDARG00000037403	ENSDARG00000068992	ENSG00000109971	HSPA8	NA	NA	NA	NA
ENSDARG00000042791	ENSDARG00000061915	ENSG00000139436	GIT2	NA	NA	NA	NA
ENSDARG00000045064	ENSDARG00000060149	ENSG00000099204	ABLIM1	NA	NA	NA	NA
ENSDARG00000070863	ENSDARG00000069981	ENSG00000114646	CSPG5	NA	NA	NA	NA
ENSDARG00000016293	ENSDARG00000076215	ENSG00000168140	VASN	NA	Subfunctiona	NA	NA
ENSDARG00000044098	ENSDARG00000042826	ENSG00000122877	EGR2	NA	NA	NA	NA
ENSDARG00000011886	ENSDARG00000017634	ENSG00000116703	PDC	NA	NA	NA	NA
ENSDARG00000008263	ENSDARG00000023768	ENSG00000174514	MFSD4	NA	Overlap only	NA	NA
ENSDARG00000017554	ENSDARG00000037059	ENSG00000129353	SLC44A2	NA	Subfunctiona	NA	NA
ENSDARG00000074369	ENSDARG00000076856	ENSG00000150893	FREM2	NA	NA	NA	NA
ENSDARG00000078954	ENSDARG00000002006	ENSG00000204231	RXRB	NA	NA	NA	NA
ENSDARG00000062129	ENSDARG00000062222	ENSG00000162576	MXRA8	NA	Subfunctiona	NA	NA
ENSDARG00000062262	ENSDARG00000011876	ENSG00000151617	EDNRA	NA	NA	NA	NA
ENSDARG00000044895	ENSDARG00000010294	ENSG00000122176	FMOD	NA	NA	NA	NA
ENSDARG00000058488	ENSDARG00000033706	ENSG00000128271	ADORA2A	NA	NA	NA	NA
ENSDARG00000056617	ENSDARG00000057074	ENSG00000156313	RPGR	NA	Overlap only	NA	NA
ENSDARG00000003994	ENSDARG00000029239	ENSG00000170743	SYT9	NA	NA	NA	NA
ENSDARG00000005343	ENSDARG00000039497	ENSG00000055813	CCDC85A	NA	NA	NA	NA
ENSDARG00000020847	ENSDARG00000015174	ENSG00000033627	ATP6V0A1	NA	NA	NA	NA
ENSDARG00000036593	ENSDARG00000046010	ENSG00000089094	KDM2B	NA	NA	NA	NA
ENSDARG00000037748	ENSDARG00000037393	ENSG00000149150	SLC43A1	NA	NA	NA	NA
ENSDARG00000038855	ENSDARG00000041900	ENSG00000086065	CHMP5	NA	NA	NA	NA
ENSDARG00000042115	ENSDARG00000034685	ENSG00000188760	TMEM198	NA	NA	NA	NA
ENSDARG00000052782	ENSDARG00000052769	ENSG00000109738	GLRB	NA	NA	NA	NA
ENSDARG00000061551	ENSDARG00000074222	ENSG00000132359	RAP1GAP2	NA	NA	NA	NA
ENSDARG00000004455	ENSDARG00000024139	ENSG00000083454	P2RX5	NA	Subfunctiona	NA	NA
ENSDARG00000086585	ENSDARG00000077818	ENSG00000158458	NRG2	NA	Subfunctiona	NA	NA
ENSDARG00000006420	ENSDARG00000077188	ENSG00000107518	ATRNL1	Overlap only	NA	NA	NA
ENSDARG00000011703	ENSDARG00000003631	ENSG00000134852	CLOCK	Overlap only	NA	NA	NA
ENSDARG00000011948	ENSDARG00000071524	ENSG00000171105	INSR	Overlap only	NA	NA	NA
ENSDARG00000018260	ENSDARG00000063230	ENSG00000101144	BMP7	Overlap only	NA	NA	NA
ENSDARG00000025319	ENSDARG00000011370	ENSG00000010810	FYN	Overlap only	NA	NA	NA
ENSDARG00000044016	ENSDARG00000042141	ENSG00000196586	MYO6	Overlap only	NA	NA	NA
ENSDARG00000060036	ENSDARG00000036894	ENSG00000164022	AIMP1	Overlap only	NA	NA	NA
ENSDARG00000062416	ENSDARG00000060319	ENSG00000177098	SCN4B	Overlap only	NA	NA	NA
ENSDARG00000071562	ENSDARG00000034105	ENSG00000129422	MTUS1	Overlap only	NA	NA	NA
ENSDARG00000077207	ENSDARG00000074597	ENSG00000107816	LZTS2	Overlap only	NA	NA	NA
ENSDARG00000004729	ENSDARG00000019457	ENSG00000068323	TFE3	NA	NA	NA	NA
ENSDARG00000003020	ENSDARG00000069402	ENSG00000128594	LRRC4	Neofunctiona	NA	NA	NA
ENSDARG00000053479	ENSDARG00000005510	ENSG00000156466	GDF6	NA	NA	NA	NA
ENSDARG00000044457	ENSDARG00000020746	ENSG00000162676	GFI1	NA	Overlap only	NA	NA
ENSDARG00000037266	ENSDARG00000012311	ENSG00000172399	MYOZ2	NA	Subfunctiona	NA	NA
ENSDARG00000013695	ENSDARG00000028048	ENSG00000080511	RDH8	NA	Neofunctiona	NA	NA
ENSDARG00000044253	ENSDARG00000017703	ENSG00000163291	PAQR3	Overlap only	NA	NA	NA
ENSDARG00000005883	ENSDARG00000075904	ENSG00000132005	RFX1	NA	NA	NA	NA
ENSDARG00000006240	ENSDARG00000038352	ENSG00000130304	SLC27A1	NA	NA	NA	NA
ENSDARG00000017023	ENSDARG00000019001	ENSG00000140057	AK7	NA	NA	NA	NA
ENSDARG00000020944	ENSDARG00000025091	ENSG00000092820	EZR	NA	NA	NA	NA
ENSDARG00000037917	ENSDARG00000012824	ENSG00000005884	ITGA3	NA	NA	NA	NA
ENSDARG00000058327	ENSDARG00000010047	ENSG00000162139	NEU3	NA	NA	NA	NA
ENSDARG00000059805	ENSDARG00000074533	ENSG00000144659	SLC25A38	NA	NA	NA	NA
ENSDARG00000061651	ENSDARG00000025076	ENSG00000152939	MARVELD2	NA	NA	NA	NA
ENSDARG00000070319	ENSDARG00000053855	ENSG00000131242	RAB11FIP4	NA	NA	NA	NA
ENSDARG00000089885	ENSDARG00000017773	ENSG00000152779	SLC16A12	NA	NA	NA	NA
ENSDARG00000034588	ENSDARG00000008797	ENSG00000007314	SCN4A	NA	NA	NA	NA
ENSDARG00000029204	ENSDARG00000056151	ENSG00000107165	TYRP1	NA	NA	NA	NA
ENSDARG00000007788	ENSDARG00000012684	ENSG00000070961	ATP2B1	NA	NA	NA	NA
ENSDARG00000009196	ENSDARG00000044254	ENSG00000138772	ANXA3	NA	NA	NA	NA

ENSDARG00000011466	ENSDARG00000042902	ENSG00000135537	LACE1	NA	NA	NA	NA
ENSDARG00000012574	ENSDARG00000061525	ENSG00000065613	SLK	NA	NA	NA	NA
ENSDARG00000014137	ENSDARG00000012866	ENSG00000073921	PICALM	NA	NA	NA	NA
ENSDARG00000014840	ENSDARG00000038018	ENSG00000112619	PRPH2	NA	NA	NA	NA
ENSDARG00000015252	ENSDARG00000015374	ENSG00000126091	ST3GAL3	NA	NA	NA	NA
ENSDARG00000019179	ENSDARG00000052896	ENSG00000148602	LRIT1	NA	NA	NA	NA
ENSDARG00000024759	ENSDARG00000012671	ENSG00000122641	INHBA	NA	NA	NA	NA
ENSDARG00000033411	ENSDARG00000019990	ENSG00000157782	CABP1	NA	NA	NA	NA
ENSDARG00000035676	ENSDARG00000087443	ENSG00000184007	PTP4A2	NA	NA	NA	NA
ENSDARG00000037285	ENSDARG00000013963	ENSG00000135517	MIP	NA	NA	NA	NA
ENSDARG00000041295	ENSDARG00000015445	ENSG00000105370	LIM2	NA	NA	NA	NA
ENSDARG00000044362	ENSDARG00000034453	ENSG00000109103	UNC119	NA	NA	NA	NA
ENSDARG00000044475	ENSDARG00000032380	ENSG00000254550	OMP	NA	NA	NA	NA
ENSDARG00000045156	ENSDARG00000037925	ENSG00000108370	RGS9	NA	NA	NA	NA
ENSDARG00000045803	ENSDARG00000015349	ENSG00000140545	MFGE8	NA	NA	NA	NA
ENSDARG00000051748	ENSDARG00000070408	ENSG00000118971	CCND2	NA	NA	NA	NA
ENSDARG00000051798	ENSDARG00000013596	ENSG00000100425	BRD1	NA	NA	NA	NA
ENSDARG00000053246	ENSDARG00000055043	ENSG00000121690	DEPDC7	NA	NA	NA	NA
ENSDARG00000053875	ENSDARG00000041141	ENSG00000108255	CRYBA1	NA	NA	NA	NA
ENSDARG00000056743	ENSDARG00000038658	ENSG00000170681	MURC	NA	NA	NA	NA
ENSDARG00000060697	ENSDARG00000062962	ENSG00000105663	AD000671.1	NA	NA	NA	NA
ENSDARG00000063295	ENSDARG00000001014	ENSG00000100345	MYH9	NA	NA	NA	NA
ENSDARG00000068822	ENSDARG00000068013	ENSG00000146676	PURB	NA	NA	NA	NA
ENSDARG00000069910	ENSDARG00000006816	ENSG00000188342	GTF2F2	NA	NA	NA	NA
ENSDARG00000070835	ENSDARG00000095002	ENSG00000101470	TNNC2	NA	NA	NA	NA
ENSDARG00000071159	ENSDARG00000070746	ENSG00000213064	SFT2D2	NA	NA	NA	NA
ENSDARG00000078507	ENSDARG00000052910	ENSG00000061492	WNT8A	NA	NA	NA	NA
ENSDARG00000039399	ENSDARG00000058231	ENSG00000076685	NT5C2	NA	NA	NA	NA
ENSDARG00000078671	ENSDARG00000071011	ENSG00000171450	CDK5R2	NA	NA	NA	NA
ENSDARG00000009477	ENSDARG00000033184	ENSG00000114302	PRKAR2A	NA	NA	NA	NA
ENSDARG00000025302	ENSDARG00000056267	ENSG00000150764	DIXDC1	NA	NA	NA	NA
ENSDARG00000061096	ENSDARG00000018345	ENSG00000035664	DAPK2	NA	NA	NA	NA
ENSDARG00000077219	ENSDARG00000059950	ENSG00000120594	PLXDC2	NA	NA	NA	NA
ENSDARG00000000369	ENSDARG00000017537	ENSG00000115592	PRKAG3	NA	NA	NA	NA
ENSDARG00000000370	ENSDARG00000019426	ENSG00000038382	TRIO	NA	NA	NA	NA
ENSDARG00000001712	ENSDARG00000006568	ENSG00000197584	KCNMB2	NA	NA	NA	NA
ENSDARG00000001803	ENSDARG00000010296	ENSG00000173826	KCNH6	NA	NA	NA	NA
ENSDARG00000001880	ENSDARG00000051981	ENSG00000166900	STX3	NA	NA	NA	NA
ENSDARG00000001933	ENSDARG00000012625	ENSG00000106617	PRKAG2	NA	NA	NA	NA
ENSDARG00000002013	ENSDARG00000035308	ENSG00000106070	GRB10	NA	NA	NA	NA
ENSDARG00000002483	ENSDARG00000044827	ENSG00000154764	WNT7A	NA	NA	NA	NA
ENSDARG00000002546	ENSDARG00000007245	ENSG00000108309	RUNDC3A	NA	NA	NA	NA
ENSDARG00000002576	ENSDARG00000028485	ENSG00000105507	CABP5	NA	NA	NA	NA
ENSDARG00000002614	ENSDARG00000024642	ENSG00000143398	PIP5K1A	NA	NA	NA	NA
ENSDARG00000002635	ENSDARG00000014081	ENSG00000111879	FAM184A	NA	NA	NA	NA
ENSDARG00000002656	ENSDARG00000029234	ENSG00000164506	STXBP5	NA	NA	NA	NA
ENSDARG00000002682	ENSDARG00000019525	ENSG00000154114	TBCEL	NA	NA	NA	NA
ENSDARG00000002771	ENSDARG00000005966	ENSG00000188687	SLC4A5	NA	NA	NA	NA
ENSDARG00000002898	ENSDARG00000060626	ENSG00000065357	DGKA	NA	NA	NA	NA
ENSDARG00000002917	ENSDARG00000069095	ENSG00000135423	GLS2	NA	NA	NA	NA
ENSDARG00000003022	ENSDARG00000063651	ENSG00000106683	LIMK1	NA	NA	NA	NA
ENSDARG00000003303	ENSDARG00000058476	ENSG00000159167	STC1	NA	NA	NA	NA
ENSDARG00000003326	ENSDARG00000039240	ENSG00000075429	CACNG5	NA	NA	NA	NA
ENSDARG00000003533	ENSDARG00000077403	ENSG00000144810	COL8A1	NA	NA	NA	NA
ENSDARG00000003779	ENSDARG00000062415	ENSG00000169862	CTNND2	NA	NA	NA	NA
ENSDARG00000003836	ENSDARG00000078744	ENSG00000137216	TMEM63B	NA	NA	NA	NA
ENSDARG00000003899	ENSDARG00000029039	ENSG00000184307	ZDHHC23	NA	NA	NA	NA
ENSDARG00000004026	ENSDARG00000069598	ENSG00000184984	CHRM5	NA	NA	NA	NA
ENSDARG00000004322	ENSDARG00000076079	ENSG00000182040	USH1G	NA	NA	NA	NA
ENSDARG00000004592	ENSDARG00000045383	ENSG00000172209	GPR22	NA	NA	NA	NA
ENSDARG00000004597	ENSDARG00000014792	ENSG00000131409	LRRC4B	NA	NA	NA	NA
ENSDARG00000004618	ENSDARG00000068217	ENSG00000111450	STX2	NA	NA	NA	NA
ENSDARG00000004643	ENSDARG00000044447	ENSG00000148600	CDHR1	NA	NA	NA	NA
ENSDARG00000004648	ENSDARG00000020102	ENSG00000183775	KCTD16	NA	NA	NA	NA
ENSDARG00000004830	ENSDARG00000069774	ENSG00000132589	FLOT2	NA	NA	NA	NA
ENSDARG00000005002	ENSDARG00000017835	ENSG00000185024	BRF1	NA	NA	NA	NA
ENSDARG00000005141	ENSDARG00000027963	ENSG00000164076	CAMKV	NA	NA	NA	NA
ENSDARG00000005271	ENSDARG00000016062	ENSG00000163874	ZC3H12A	NA	NA	NA	NA
ENSDARG00000005364	ENSDARG00000074647	ENSG00000116032	GRIN3B	NA	NA	NA	NA
ENSDARG00000005377	ENSDARG00000058937	ENSG00000134873	CLDN10	NA	NA	NA	NA
ENSDARG00000005397	ENSDARG00000063711	ENSG00000110171	TRIM3	NA	NA	NA	NA
ENSDARG00000005485	ENSDARG00000027799	ENSG00000165623	UCMA	NA	NA	NA	NA
ENSDARG00000005549	ENSDARG00000014680	ENSG00000140548	ZNF710	NA	NA	NA	NA
ENSDARG00000005578	ENSDARG00000008200	ENSG00000169764	UGP2	NA	NA	NA	NA
ENSDARG00000005625	ENSDARG00000012741	ENSG00000204178	TMEM57	NA	NA	NA	NA
ENSDARG00000005626	ENSDARG00000019709	ENSG00000116574	RHOU	NA	NA	NA	NA
ENSDARG00000005670	ENSDARG00000043026	ENSG00000128881	TTBK2	NA	NA	NA	NA
ENSDARG00000005673	ENSDARG00000021013	ENSG00000117525	F3	NA	NA	NA	NA
ENSDARG00000005679	ENSDARG00000077953	ENSG00000125733	TRIP10	NA	NA	NA	NA
ENSDARG00000005716	ENSDARG00000021480	ENSG00000162745	OLFML2B	NA	NA	NA	NA
ENSDARG00000006079	ENSDARG00000056774	ENSG00000170075	GPR37L1	NA	NA	NA	NA
ENSDARG00000006202	ENSDARG00000036993	ENSG00000065361	ERBB3	NA	NA	NA	NA
ENSDARG00000006272	ENSDARG00000004721	ENSG00000072415	MPP5	NA	NA	NA	NA
ENSDARG00000006356	ENSDARG00000090189	ENSG00000187714	SLC18A3	NA	NA	NA	NA
ENSDARG00000006385	ENSDARG00000075870	ENSG00000100106	TRIOBP	NA	NA	NA	NA
ENSDARG00000006396	ENSDARG00000091662	ENSG00000091129	NRCAM	NA	NA	NA	NA
ENSDARG00000006560	ENSDARG00000055374	ENSG00000137265	IRF4	NA	NA	NA	NA
ENSDARG00000006640	ENSDARG00000019428	ENSG00000163508	EOMES	NA	NA	NA	NA
ENSDARG00000006757	ENSDARG00000068888	ENSG00000239474	KBTBD10	NA	NA	NA	NA
ENSDARG00000006862	ENSDARG00000008639	ENSG00000075945	KIFAP3	NA	NA	NA	NA

ENSDARG00000006891	ENSDARG00000029511	ENSG00000170745	KCNS3	NA	NA	NA	NA
ENSDARG00000006923	ENSDARG00000037905	ENSG00000141837	CACNA1A	NA	NA	NA	NA
ENSDARG00000006978	ENSDARG00000044615	ENSG00000091436	AC013461.1	NA	NA	NA	NA
ENSDARG00000006983	ENSDARG00000034668	ENSG00000159409	CELF3	NA	NA	NA	NA
ENSDARG00000006990	ENSDARG00000074886	ENSG00000163703	CRELD1	NA	NA	NA	NA
ENSDARG00000007179	ENSDARG00000058853	ENSG00000111961	SASH1	NA	NA	NA	NA
ENSDARG00000007195	ENSDARG00000004150	ENSG00000164082	GRM2	NA	NA	NA	NA
ENSDARG00000007289	ENSDARG00000052555	ENSG00000176845	METRNL	NA	NA	NA	NA
ENSDARG00000007356	ENSDARG00000086070	ENSG00000078579	FGF20	NA	NA	NA	NA
ENSDARG00000007412	ENSDARG00000001437	ENSG00000117394	SLC2A1	NA	NA	NA	NA
ENSDARG00000007430	ENSDARG00000088563	ENSG00000130711	PRDM12	NA	NA	NA	NA
ENSDARG00000007654	ENSDARG00000038991	ENSG00000073969	NSF	NA	NA	NA	NA
ENSDARG00000007678	ENSDARG00000034473	ENSG00000136295	TTYH3	NA	NA	NA	NA
ENSDARG00000007808	ENSDARG00000015989	ENSG00000171307	ZDHHC16	NA	NA	NA	NA
ENSDARG00000007856	ENSDARG00000055578	ENSG00000185924	RTN4RL1	NA	NA	NA	NA
ENSDARG00000007950	ENSDARG00000036086	ENSG00000137809	ITGA11	NA	NA	NA	NA
ENSDARG00000008100	ENSDARG00000051730	ENSG00000130876	SLC7A10	NA	NA	NA	NA
ENSDARG00000008209	ENSDARG00000006212	ENSG00000186487	MYT1L	NA	NA	NA	NA
ENSDARG00000008767	ENSDARG00000042484	ENSG00000065717	TLE2	NA	NA	NA	NA
ENSDARG00000008772	ENSDARG00000052360	ENSG00000108878	CACNG1	NA	NA	NA	NA
ENSDARG00000008912	ENSDARG00000040625	ENSG00000118160	SLC8A2	NA	NA	NA	NA
ENSDARG00000008948	ENSDARG00000078718	ENSG00000100078	PLA2G3	NA	NA	NA	NA
ENSDARG00000009023	ENSDARG00000086326	ENSG00000206560	ANKRD28	NA	NA	NA	NA
ENSDARG00000009351	ENSDARG00000045856	ENSG00000111241	FGF6	NA	NA	NA	NA
ENSDARG00000009372	ENSDARG00000028066	ENSG00000176490	DIRAS1	NA	NA	NA	NA
ENSDARG00000009524	ENSDARG00000024827	ENSG00000170153	RNF150	NA	NA	NA	NA
ENSDARG00000009621	ENSDARG00000032565	ENSG00000166862	CACNG2	NA	NA	NA	NA
ENSDARG00000009782	ENSDARG00000006281	ENSG00000133392	MYH11	NA	NA	NA	NA
ENSDARG00000009901	ENSDARG00000014587	ENSG00000017483	SLC38A5	NA	NA	NA	NA
ENSDARG00000009903	ENSDARG00000087722	ENSG00000172890	NADSYN1	NA	NA	NA	NA
ENSDARG00000010155	ENSDARG00000062991	ENSG00000136754	ABI1	NA	NA	NA	NA
ENSDARG00000010158	ENSDARG00000070080	ENSG00000172915	NBEA	NA	NA	NA	NA
ENSDARG00000010231	ENSDARG00000057032	ENSG00000213889	PPM1N	NA	NA	NA	NA
ENSDARG00000010255	ENSDARG00000003219	ENSG00000110934	BIN2	NA	NA	NA	NA
ENSDARG00000010376	ENSDARG00000077812	ENSG00000198743	SLC5A3	NA	NA	NA	NA
ENSDARG00000010385	ENSDARG00000035683	ENSG00000108387	sep.04	NA	NA	NA	NA
ENSDARG00000010655	ENSDARG00000076011	ENSG00000163644	PPM1K	NA	NA	NA	NA
ENSDARG00000010785	ENSDARG00000063430	ENSG00000137801	THBS1	NA	NA	NA	NA
ENSDARG00000010816	ENSDARG00000079231	ENSG00000013293	SLC7A14	NA	NA	NA	NA
ENSDARG00000010958	ENSDARG00000058267	ENSG00000174842	GLMN	NA	NA	NA	NA
ENSDARG00000010977	ENSDARG00000045628	ENSG00000109113	RAB34	NA	NA	NA	NA
ENSDARG00000011029	ENSDARG00000054680	ENSG00000174343	CHRNA9	NA	NA	NA	NA
ENSDARG00000011188	ENSDARG00000079944	ENSG00000121989	ACVR2A	NA	NA	NA	NA
ENSDARG00000011259	ENSDARG00000061399	ENSG00000134160	TRPM1	NA	NA	NA	NA
ENSDARG00000011571	ENSDARG00000011473	ENSG00000064989	CALCRL	NA	NA	NA	NA
ENSDARG00000011683	ENSDARG00000074528	ENSG00000099256	PRTFDC1	NA	NA	NA	NA
ENSDARG00000011855	ENSDARG00000077686	ENSG00000115977	AAK1	NA	NA	NA	NA
ENSDARG00000011932	ENSDARG00000007601	ENSG00000101040	ZMYND8	NA	NA	NA	NA
ENSDARG00000012071	ENSDARG00000003025	ENSG00000116194	ANGPTL1	NA	NA	NA	NA
ENSDARG00000012125	ENSDARG00000029898	ENSG00000198515	CNGA1	NA	NA	NA	NA
ENSDARG00000012269	ENSDARG00000062084	ENSG00000188037	CLCN1	NA	NA	NA	NA
ENSDARG00000012482	ENSDARG00000063299	ENSG00000186472	PCLO	NA	NA	NA	NA
ENSDARG00000012496	ENSDARG00000003900	ENSG00000180929	GPR62	NA	NA	NA	NA
ENSDARG00000012586	ENSDARG00000075041	ENSG00000157827	FMNL2	NA	NA	NA	NA
ENSDARG00000012588	ENSDARG00000036114	ENSG00000156471	PTDSS1	NA	NA	NA	NA
ENSDARG00000012823	ENSDARG00000060849	ENSG00000080845	DLGAP4	NA	NA	NA	NA
ENSDARG00000013047	ENSDARG00000043902	ENSG00000146276	GABRR1	NA	NA	NA	NA
ENSDARG00000013072	ENSDARG00000051962	ENSG00000102996	MMP15	NA	NA	NA	NA
ENSDARG00000013221	ENSDARG00000002411	ENSG00000105650	PDE4C	NA	NA	NA	NA
ENSDARG00000013222	ENSDARG00000020981	ENSG00000117620	SLC35A3	NA	NA	NA	NA
ENSDARG00000013245	ENSDARG00000029751	ENSG00000166272	C10orf26	NA	NA	NA	NA
ENSDARG00000013360	ENSDARG00000007302	ENSG00000140600	SH3GL3	NA	NA	NA	NA
ENSDARG00000013460	ENSDARG00000059139	ENSG00000173714	WFIKKN2	NA	NA	NA	NA
ENSDARG00000013669	ENSDARG00000069101	ENSG00000125814	NAPB	NA	NA	NA	NA
ENSDARG00000013685	ENSDARG00000054050	ENSG00000243284	VSIG8	NA	NA	NA	NA
ENSDARG00000013690	ENSDARG00000074680	ENSG00000079841	RIMS1	NA	NA	NA	NA
ENSDARG00000013813	ENSDARG00000016396	ENSG00000164970	C9orf25	NA	NA	NA	NA
ENSDARG00000013921	ENSDARG00000056001	ENSG00000073910	FRY	NA	NA	NA	NA
ENSDARG00000014105	ENSDARG00000074328	ENSG00000107282	APBA1	NA	NA	NA	NA
ENSDARG00000014169	ENSDARG00000025206	ENSG00000143858	SYT2	NA	NA	NA	NA
ENSDARG00000014320	ENSDARG00000056045	ENSG00000070019	GUCY2C	NA	NA	NA	NA
ENSDARG00000014439	ENSDARG00000076025	ENSG00000149091	DGKZ	NA	NA	NA	NA
ENSDARG00000014477	ENSDARG00000074958	ENSG00000183473	SSTR3	NA	NA	NA	NA
ENSDARG00000014655	ENSDARG00000074149	ENSG00000150995	ITPR1	NA	NA	NA	NA
ENSDARG00000014674	ENSDARG00000032079	ENSG00000123983	ACSL3	NA	NA	NA	NA
ENSDARG00000014907	ENSDARG00000032831	ENSG00000166033	HTRA1	NA	NA	NA	NA
ENSDARG00000014910	ENSDARG00000025285	ENSG00000110218	PANX1	NA	NA	NA	NA
ENSDARG00000014973	ENSDARG00000073713	ENSG00000162631	NTNG1	NA	NA	NA	NA
ENSDARG00000014995	ENSDARG00000041071	ENSG00000171135	JAGN1	NA	NA	NA	NA
ENSDARG00000015184	ENSDARG00000062667	ENSG00000161647	MPP3	NA	NA	NA	NA
ENSDARG00000015552	ENSDARG00000032221	ENSG00000204138	PHACTR4	NA	NA	NA	NA
ENSDARG00000015566	ENSDARG00000005394	ENSG00000119772	DNMT3A	NA	NA	NA	NA
ENSDARG00000015589	ENSDARG00000058357	ENSG00000164236	ANKRD33B	NA	NA	NA	NA
ENSDARG00000015731	ENSDARG00000036147	ENSG00000171714	ANO5	NA	NA	NA	NA
ENSDARG00000015803	ENSDARG00000052818	ENSG00000176994	SMCR8	NA	NA	NA	NA
ENSDARG00000015854	ENSDARG00000089929	ENSG00000070748	CHAT	NA	NA	NA	NA
ENSDARG00000015891	ENSDARG00000021151	ENSG00000132334	PTPRE	NA	NA	NA	NA
ENSDARG00000016048	ENSDARG00000006491	ENSG00000138678	AGPAT9	NA	NA	NA	NA
ENSDARG00000016348	ENSDARG00000005350	ENSG00000066084	DIP2B	NA	NA	NA	NA
ENSDARG00000016439	ENSDARG00000041874	ENSG00000139514	SLC7A1	NA	NA	NA	NA

ENSDARG00000016470	ENSDARG00000026406	ENSG00000164111	ANXA5	NA	NA	NA	NA
ENSDARG00000016667	ENSDARG00000018967	ENSG00000204681	GABBR1	NA	NA	NA	NA
ENSDARG00000016718	ENSDARG00000026325	ENSG00000099953	MMP11	NA	NA	NA	NA
ENSDARG00000016742	ENSDARG00000060601	ENSG00000186479	RGS7BP	NA	NA	NA	NA
ENSDARG00000016788	ENSDARG00000013207	ENSG00000148516	ZEB1	NA	NA	NA	NA
ENSDARG00000016866	ENSDARG00000025846	ENSG00000167106	FAM102A	NA	NA	NA	NA
ENSDARG00000016963	ENSDARG00000068572	ENSG00000155380	SLC16A1	NA	NA	NA	NA
ENSDARG00000016999	ENSDARG00000004328	ENSG00000131914	LIN28A	NA	NA	NA	NA
ENSDARG00000017162	ENSDARG00000079500	ENSG00000084731	KIF3C	NA	NA	NA	NA
ENSDARG00000017211	ENSDARG00000075821	ENSG00000164050	PLXNB1	NA	NA	NA	NA
ENSDARG00000017360	ENSDARG00000028524	ENSG00000080573	COL5A3	NA	NA	NA	NA
ENSDARG00000017649	ENSDARG00000023542	ENSG00000081138	CDH7	NA	NA	NA	NA
ENSDARG00000017880	ENSDARG00000076181	ENSG00000115041	KCNIP3	NA	NA	NA	NA
ENSDARG00000018047	ENSDARG00000006235	ENSG00000100916	BRMS1L	NA	NA	NA	NA
ENSDARG00000018105	ENSDARG00000038716	ENSG00000143318	CASQ1	NA	NA	NA	NA
ENSDARG00000018130	ENSDARG00000070316	ENSG00000126858	RHOT1	NA	NA	NA	NA
ENSDARG00000018530	ENSDARG00000002552	ENSG00000162889	MAPKAPK2	NA	NA	NA	NA
ENSDARG00000018566	ENSDARG00000018820	ENSG00000128591	FLNC	NA	NA	NA	NA
ENSDARG00000018619	ENSDARG00000031387	ENSG00000090661	LASS4	NA	NA	NA	NA
ENSDARG00000018750	ENSDARG00000031751	ENSG00000169418	NPR1	NA	NA	NA	NA
ENSDARG00000018782	ENSDARG00000019103	ENSG00000066135	KDM4A	NA	NA	NA	NA
ENSDARG00000018935	ENSDARG00000079586	ENSG00000145864	GABRB2	NA	NA	NA	NA
ENSDARG00000018997	ENSDARG00000077736	ENSG00000168993	CPLX1	NA	NA	NA	NA
ENSDARG00000019125	ENSDARG00000039052	ENSG00000157119	KBTBD5	NA	NA	NA	NA
ENSDARG00000019335	ENSDARG00000007097	ENSG00000144485	HES6	NA	NA	NA	NA
ENSDARG00000019405	ENSDARG00000062880	ENSG00000144619	CNTN4	NA	NA	NA	NA
ENSDARG00000019541	ENSDARG00000055642	ENSG00000167701	GPT	NA	NA	NA	NA
ENSDARG00000019601	ENSDARG00000078322	ENSG00000111799	COL12A1	NA	NA	NA	NA
ENSDARG00000019622	ENSDARG00000035994	ENSG00000176406	RIMS2	NA	NA	NA	NA
ENSDARG00000019658	ENSDARG00000036816	ENSG00000028277	POU2F2	NA	NA	NA	NA
ENSDARG00000019686	ENSDARG00000019861	ENSG00000127951	FGL2	NA	NA	NA	NA
ENSDARG00000020000	ENSDARG00000030104	ENSG00000130147	SH3BP4	NA	NA	NA	NA
ENSDARG00000020176	ENSDARG00000003251	ENSG00000236104	ZBTB22	NA	NA	NA	NA
ENSDARG00000020178	ENSDARG00000017673	ENSG00000139910	NOVA1	NA	NA	NA	NA
ENSDARG00000020224	ENSDARG00000051936	ENSG00000087502	ERGIC2	NA	NA	NA	NA
ENSDARG00000020228	ENSDARG00000087519	ENSG00000105698	USF2	NA	NA	NA	NA
ENSDARG00000020270	ENSDARG00000069937	ENSG00000079805	DNM2	NA	NA	NA	NA
ENSDARG00000020395	ENSDARG00000075608	ENSG00000133816	MICAL2	NA	NA	NA	NA
ENSDARG00000020443	ENSDARG00000043410	ENSG00000171044	XKR6	NA	NA	NA	NA
ENSDARG00000020493	ENSDARG00000058421	ENSG00000108231	LGI1	NA	NA	NA	NA
ENSDARG00000020610	ENSDARG00000031920	ENSG00000118194	TNNT2	NA	NA	NA	NA
ENSDARG00000020845	ENSDARG00000078842	ENSG00000079308	TNS1	NA	NA	NA	NA
ENSDARG00000020871	ENSDARG00000051814	ENSG00000106278	PTPRZ1	NA	NA	NA	NA
ENSDARG00000020872	ENSDARG00000014022	ENSG00000102908	NFAT5	NA	NA	NA	NA
ENSDARG00000020924	ENSDARG00000061579	ENSG00000197879	MYO1C	NA	NA	NA	NA
ENSDARG00000021389	ENSDARG00000014246	ENSG00000184916	JAG2	NA	NA	NA	NA
ENSDARG00000021846	ENSDARG00000015091	ENSG00000167861	C17orf28	NA	NA	NA	NA
ENSDARG00000021882	ENSDARG00000078003	ENSG00000005812	FBXL3	NA	NA	NA	NA
ENSDARG00000022045	ENSDARG00000059601	ENSG00000166963	MAP1A	NA	NA	NA	NA
ENSDARG00000022309	ENSDARG00000076673	ENSG00000096696	DSP	NA	NA	NA	NA
ENSDARG00000022772	ENSDARG00000053487	ENSG00000184792	OSBP2	NA	NA	NA	NA
ENSDARG00000022858	ENSDARG00000071107	ENSG00000188064	WNT7B	NA	NA	NA	NA
ENSDARG00000022895	ENSDARG00000056603	ENSG00000101977	MCF2	NA	NA	NA	NA
ENSDARG00000023210	ENSDARG00000094201	ENSG00000204160	ZDHHC18	NA	NA	NA	NA
ENSDARG00000023318	ENSDARG00000061778	ENSG00000155816	FMN2	NA	NA	NA	NA
ENSDARG00000023527	ENSDARG00000012649	ENSG00000141646	SMAD4	NA	NA	NA	NA
ENSDARG00000023624	ENSDARG00000038012	ENSG00000133477	FAM83F	NA	NA	NA	NA
ENSDARG00000023683	ENSDARG00000010933	ENSG00000102001	CACNA1F	NA	NA	NA	NA
ENSDARG00000023878	ENSDARG00000031413	ENSG00000102572	STK24	NA	NA	NA	NA
ENSDARG00000023886	ENSDARG00000026855	ENSG00000151062	CACNA2D4	NA	NA	NA	NA
ENSDARG00000024167	ENSDARG00000023236	ENSG00000143473	KCNH1	NA	NA	NA	NA
ENSDARG00000024189	ENSDARG00000025024	ENSG00000168081	PNOC	NA	NA	NA	NA
ENSDARG00000024365	ENSDARG00000006368	ENSG00000006016	CRLF1	NA	NA	NA	NA
ENSDARG00000024560	ENSDARG00000012881	ENSG00000004939	SLC4A1	NA	NA	NA	NA
ENSDARG00000024847	ENSDARG00000031678	ENSG00000204262	COL5A2	NA	NA	NA	NA
ENSDARG00000024865	ENSDARG00000028118	ENSG00000171587	DSCAM	NA	NA	NA	NA
ENSDARG00000024966	ENSDARG00000023914	ENSG00000007047	MARK4	NA	NA	NA	NA
ENSDARG00000025013	ENSDARG00000035178	ENSG00000156049	GNA14	NA	NA	NA	NA
ENSDARG00000025089	ENSDARG00000075310	ENSG00000138131	LOXL4	NA	NA	NA	NA
ENSDARG00000025189	ENSDARG00000037926	ENSG00000139117	CPNE8	NA	NA	NA	NA
ENSDARG00000025299	ENSDARG00000045706	ENSG00000011105	TSPAN9	NA	NA	NA	NA
ENSDARG00000025325	ENSDARG00000040085	ENSG00000154429	C1orf96	NA	NA	NA	NA
ENSDARG00000025615	ENSDARG00000029308	ENSG00000167183	PRR15L	NA	NA	NA	NA
ENSDARG00000025671	ENSDARG00000017742	ENSG00000113262	GRM6	NA	NA	NA	NA
ENSDARG00000025974	ENSDARG00000076916	ENSG00000081026	MAGI3	NA	NA	NA	NA
ENSDARG00000026248	ENSDARG00000034940	ENSG00000162383	SLC1A7	NA	NA	NA	NA
ENSDARG00000026333	ENSDARG00000036952	ENSG00000101321	XKR7	NA	NA	NA	NA
ENSDARG00000026634	ENSDARG00000068157	ENSG00000181090	EHMT1	NA	NA	NA	NA
ENSDARG00000026926	ENSDARG00000019752	ENSG00000149489	ROM1	NA	NA	NA	NA
ENSDARG00000027345	ENSDARG00000088742	ENSG00000149573	MPZL2	NA	NA	NA	NA
ENSDARG00000027497	ENSDARG00000088789	ENSG00000105613	MAST1	NA	NA	NA	NA
ENSDARG00000027564	ENSDARG00000052405	ENSG00000137843	PAK6	NA	NA	NA	NA
ENSDARG00000027867	ENSDARG00000042186	ENSG00000100767	PAPLN	NA	NA	NA	NA
ENSDARG00000027957	ENSDARG00000062542	ENSG00000114279	FGF12	NA	NA	NA	NA
ENSDARG00000027966	ENSDARG00000076073	ENSG00000152056	AP1S3	NA	NA	NA	NA
ENSDARG00000028067	ENSDARG00000025468	ENSG00000104765	BNIP3L	NA	NA	NA	NA
ENSDARG00000028071	ENSDARG00000028053	ENSG00000168487	BMP1	NA	NA	NA	NA
ENSDARG00000028257	ENSDARG00000056281	ENSG00000162144	CYBASC3	NA	NA	NA	NA
ENSDARG00000028348	ENSDARG00000010192	ENSG00000135903	PAX3	NA	NA	NA	NA
ENSDARG00000028412	ENSDARG00000003259	ENSG00000113083	LOX	NA	NA	NA	NA

ENSDARG00000028521	ENSDARG00000031013	ENSG00000131094	C1QL1	NA	NA	NA	NA
ENSDARG00000028552	ENSDARG00000010144	ENSG00000129951	MIR3187	NA	NA	NA	NA
ENSDARG00000028725	ENSDARG00000027638	ENSG00000120907	ADRA1A	NA	NA	NA	NA
ENSDARG00000028776	ENSDARG00000069159	ENSG00000123892	RAB38	NA	NA	NA	NA
ENSDARG00000028857	ENSDARG00000075376	ENSG00000167037	SGSM1	NA	NA	NA	NA
ENSDARG00000028878	ENSDARG00000059058	ENSG00000114812	VIPR1	NA	NA	NA	NA
ENSDARG00000028896	ENSDARG00000002231	ENSG00000141934	PPAP2C	NA	NA	NA	NA
ENSDARG00000029057	ENSDARG00000029982	ENSG00000213996	TM6SF2	NA	NA	NA	NA
ENSDARG00000029457	ENSDARG00000042552	ENSG00000081248	CACNA1S	NA	NA	NA	NA
ENSDARG00000029474	ENSDARG00000060116	ENSG00000134072	CAMK1	NA	NA	NA	NA
ENSDARG00000029493	ENSDARG00000010097	ENSG00000101981	F9	NA	NA	NA	NA
ENSDARG00000029590	ENSDARG00000059534	ENSG00000154118	JPH3	NA	NA	NA	NA
ENSDARG00000029881	ENSDARG00000060053	ENSG00000055118	KCNH2	NA	NA	NA	NA
ENSDARG00000029994	ENSDARG00000055577	ENSG00000181072	CHRM2	NA	NA	NA	NA
ENSDARG00000030012	ENSDARG00000095170	ENSG00000124831	LRRFIP1	NA	NA	NA	NA
ENSDARG00000030157	ENSDARG00000021265	ENSG00000086967	MYBPC2	NA	NA	NA	NA
ENSDARG00000030292	ENSDARG00000059438	ENSG00000110328	GALNTL4	NA	NA	NA	NA
ENSDARG00000030311	ENSDARG00000033104	ENSG00000149488	TMC2	NA	NA	NA	NA
ENSDARG00000030411	ENSDARG00000087437	ENSG00000127377	CRYGN	NA	NA	NA	NA
ENSDARG00000030758	ENSDARG00000044629	ENSG00000138472	GUCA1C	NA	NA	NA	NA
ENSDARG00000030782	ENSDARG00000008414	ENSG00000130201	EXOC3L2	NA	NA	NA	NA
ENSDARG00000030832	ENSDARG00000020581	ENSG00000115155	OTOF	NA	NA	NA	NA
ENSDARG00000030932	ENSDARG00000067548	ENSG00000070193	FGF10	NA	NA	NA	NA
ENSDARG00000030933	ENSDARG00000068714	ENSG00000141068	KSR1	NA	NA	NA	NA
ENSDARG00000031219	ENSDARG00000005600	ENSG00000138696	BMPR1B	NA	NA	NA	NA
ENSDARG00000031383	ENSDARG00000040278	ENSG00000175946	KLHL38	NA	NA	NA	NA
ENSDARG00000031489	ENSDARG00000044132	ENSG00000106809	OGN	NA	NA	NA	NA
ENSDARG00000031548	ENSDARG00000033589	ENSG00000182580	EPHB3	NA	NA	NA	NA
ENSDARG00000031651	ENSDARG00000054447	ENSG00000112759	SLC29A1	NA	NA	NA	NA
ENSDARG00000031845	ENSDARG00000042551	ENSG00000143797	MBOAT2	NA	NA	NA	NA
ENSDARG00000032083	ENSDARG00000038974	ENSG00000092964	DPYSL2	NA	NA	NA	NA
ENSDARG00000032493	ENSDARG00000087701	ENSG00000128656	CHN1	NA	NA	NA	NA
ENSDARG00000033251	ENSDARG00000040482	ENSG00000070882	OSBPL3	NA	NA	NA	NA
ENSDARG00000033296	ENSDARG00000074563	ENSG00000170775	GPR37	NA	NA	NA	NA
ENSDARG00000033320	ENSDARG00000042794	ENSG00000079332	SAR1A	NA	NA	NA	NA
ENSDARG00000033544	ENSDARG00000029124	ENSG00000166106	ADAMTS15	NA	NA	NA	NA
ENSDARG00000033635	ENSDARG00000060702	ENSG00000056291	NPFFR2	NA	NA	NA	NA
ENSDARG00000033804	ENSDARG00000016977	ENSG00000143376	SNX27	NA	NA	NA	NA
ENSDARG00000034373	ENSDARG00000028236	ENSG00000196739	COL27A1	NA	NA	NA	NA
ENSDARG00000034493	ENSDARG00000070543	ENSG00000183454	GRIN2A	NA	NA	NA	NA
ENSDARG00000034555	ENSDARG00000067785	ENSG00000116117	PARD3B	NA	NA	NA	NA
ENSDARG00000034604	ENSDARG00000018881	ENSG00000124701	APOBEC2	NA	NA	NA	NA
ENSDARG00000034714	ENSDARG00000014239	ENSG00000139641	ESYT1	NA	NA	NA	NA
ENSDARG00000034808	ENSDARG00000022109	ENSG00000182132	KCNIP1	NA	NA	NA	NA
ENSDARG00000034930	ENSDARG00000057792	ENSG00000135355	GJA10	NA	NA	NA	NA
ENSDARG00000035273	ENSDARG00000045753	ENSG00000179104	TMTC2	NA	NA	NA	NA
ENSDARG00000035452	ENSDARG00000015134	ENSG00000004660	CAMKK1	NA	NA	NA	NA
ENSDARG00000035533	ENSDARG00000016025	ENSG00000115353	TACR1	NA	NA	NA	NA
ENSDARG00000035538	ENSDARG00000035565	ENSG00000185344	ATP6V0A2	NA	NA	NA	NA
ENSDARG00000035895	ENSDARG00000069739	ENSG00000160097	FNDC5	NA	NA	NA	NA
ENSDARG00000035910	ENSDARG00000000567	ENSG00000162702	ZNF281	NA	NA	NA	NA
ENSDARG00000036017	ENSDARG00000034907	ENSG00000182749	PAQR7	NA	NA	NA	NA
ENSDARG00000036031	ENSDARG00000013843	ENSG00000184702	sep.05	NA	NA	NA	NA
ENSDARG00000036065	ENSDARG00000012407	ENSG00000131446	MGAT1	NA	NA	NA	NA
ENSDARG00000036139	ENSDARG00000016337	ENSG00000188501	LCTL	NA	NA	NA	NA
ENSDARG00000036152	ENSDARG00000001259	ENSG00000148935	GAS2	NA	NA	NA	NA
ENSDARG00000036175	ENSDARG00000062720	ENSG00000156453	PCDH1	NA	NA	NA	NA
ENSDARG00000036243	ENSDARG00000056793	ENSG00000153814	JAZF1	NA	NA	NA	NA
ENSDARG00000036295	ENSDARG00000031461	ENSG00000155265	GOLGA7B	NA	NA	NA	NA
ENSDARG00000036457	ENSDARG00000046079	ENSG00000130433	CACNG6	NA	NA	NA	NA
ENSDARG00000036463	ENSDARG00000067678	ENSG00000106404	CLDN15	NA	NA	NA	NA
ENSDARG00000036541	ENSDARG00000017367	ENSG00000007384	RHBDF1	NA	NA	NA	NA
ENSDARG00000036815	ENSDARG00000018259	ENSG00000105409	ATP1A3	NA	NA	NA	NA
ENSDARG00000036826	ENSDARG00000063576	ENSG00000139645	ANKRD52	NA	NA	NA	NA
ENSDARG00000037337	ENSDARG00000091683	ENSG00000119865	CNRIP1	NA	NA	NA	NA
ENSDARG00000037357	ENSDARG00000040657	ENSG00000070540	WIPI1	NA	NA	NA	NA
ENSDARG00000037373	ENSDARG00000021539	ENSG00000133216	EPHB2	NA	NA	NA	NA
ENSDARG00000037415	ENSDARG00000014280	ENSG00000170579	DLGAP1	NA	NA	NA	NA
ENSDARG00000037422	ENSDARG00000007129	ENSG00000063127	SLC6A16	NA	NA	NA	NA
ENSDARG00000037495	ENSDARG00000052012	ENSG00000186907	RTN4RL2	NA	NA	NA	NA
ENSDARG00000037533	ENSDARG00000040683	ENSG00000141434	MEP1B	NA	NA	NA	NA
ENSDARG00000037558	ENSDARG00000017086	ENSG00000198881	ASB12	NA	NA	NA	NA
ENSDARG00000037587	ENSDARG00000044278	ENSG00000163630	SYNPR	NA	NA	NA	NA
ENSDARG00000037593	ENSDARG00000020982	ENSG00000163637	PRICKLE2	NA	NA	NA	NA
ENSDARG00000037607	ENSDARG00000074902	ENSG00000197183	C20orf112	NA	NA	NA	NA
ENSDARG00000037794	ENSDARG00000045164	ENSG00000106236	NPTX2	NA	NA	NA	NA
ENSDARG00000037859	ENSDARG00000058557	ENSG00000095752	IL11	NA	NA	NA	NA
ENSDARG00000037904	ENSDARG00000024004	ENSG00000157388	CACNA1D	NA	NA	NA	NA
ENSDARG00000038025	ENSDARG00000087181	ENSG00000100307	CBX7	NA	NA	NA	NA
ENSDARG00000038119	ENSDARG00000073684	ENSG00000149633	KIAA1755	NA	NA	NA	NA
ENSDARG00000038131	ENSDARG00000053918	ENSG00000112658	SRF	NA	NA	NA	NA
ENSDARG00000038219	ENSDARG00000036156	ENSG00000187239	FNBP1	NA	NA	NA	NA
ENSDARG00000038239	ENSDARG00000042887	ENSG00000105576	TNPO2	NA	NA	NA	NA
ENSDARG00000038373	ENSDARG00000019418	ENSG00000123700	KCNJ2	NA	NA	NA	NA
ENSDARG00000038574	ENSDARG00000017470	ENSG00000171951	SCG2	NA	NA	NA	NA
ENSDARG00000038634	ENSDARG00000070810	ENSG00000187094	CCK	NA	NA	NA	NA
ENSDARG00000038826	ENSDARG00000058603	ENSG00000104369	JPH1	NA	NA	NA	NA
ENSDARG00000038918	ENSDARG00000071640	ENSG00000184845	DRD1	NA	NA	NA	NA
ENSDARG00000038957	ENSDARG00000031506	ENSG00000119686	AC007182.1	NA	NA	NA	NA
ENSDARG00000038968	ENSDARG00000087474	ENSG00000112486	CCR6	NA	NA	NA	NA

ENSDARG00000039234	ENSDARG00000045957	ENSG00000140030	GPR65	NA	NA	NA	NA
ENSDARG00000039238	ENSDARG00000074669	ENSG00000075461	CACNG4	NA	NA	NA	NA
ENSDARG00000039265	ENSDARG00000015003	ENSG00000089820	ARHGAP4	NA	NA	NA	NA
ENSDARG00000039453	ENSDARG00000071877	ENSG00000184544	DHRS7C	NA	NA	NA	NA
ENSDARG00000039577	ENSDARG00000022841	ENSG00000120899	PTK2B	NA	NA	NA	NA
ENSDARG00000039901	ENSDARG00000023600	ENSG00000107295	SH3GL2	NA	NA	NA	NA
ENSDARG00000039932	ENSDARG00000038011	ENSG00000100055	CYTH4	NA	NA	NA	NA
ENSDARG00000039943	ENSDARG00000011797	ENSG00000158246	FAM46B	NA	NA	NA	NA
ENSDARG00000039963	ENSDARG00000091660	ENSG00000137440	FGFBP1	NA	NA	NA	NA
ENSDARG00000039987	ENSDARG00000018773	ENSG00000010818	HIVEP2	NA	NA	NA	NA
ENSDARG00000039999	ENSDARG00000077691	ENSG00000141485	SLC13A5	NA	NA	NA	NA
ENSDARG00000040065	ENSDARG00000069450	ENSG00000143140	GJA5	NA	NA	NA	NA
ENSDARG00000040133	ENSDARG00000078729	ENSG00000129048	CCRL1	NA	NA	NA	NA
ENSDARG00000040137	ENSDARG00000020133	ENSG00000140044	JDP2	NA	NA	NA	NA
ENSDARG00000040248	ENSDARG00000016545	ENSG00000095321	CRAT	NA	NA	NA	NA
ENSDARG00000040274	ENSDARG00000018743	ENSG00000198794	SCAMP5	NA	NA	NA	NA
ENSDARG00000040334	ENSDARG00000037121	ENSG00000168906	MAT2A	NA	NA	NA	NA
ENSDARG00000040430	ENSDARG00000053375	ENSG00000221890	NPTXR	NA	NA	NA	NA
ENSDARG00000040474	ENSDARG00000004405	ENSG00000086300	SNX10	NA	NA	NA	NA
ENSDARG00000040543	ENSDARG00000040898	ENSG00000143167	GPA33	NA	NA	NA	NA
ENSDARG00000040627	ENSDARG00000069139	ENSG00000171189	GRIK1	NA	NA	NA	NA
ENSDARG00000040684	ENSDARG00000057975	ENSG00000115556	PLCD4	NA	NA	NA	NA
ENSDARG00000040705	ENSDARG00000062812	ENSG00000115419	GLS	NA	NA	NA	NA
ENSDARG00000041115	ENSDARG00000088589	ENSG00000105427	CNFN	NA	NA	NA	NA
ENSDARG00000041162	ENSDARG00000026796	ENSG00000152822	GRM1	NA	NA	NA	NA
ENSDARG00000041173	ENSDARG00000011317	ENSG00000170214	ADRA1B	NA	NA	NA	NA
ENSDARG00000041516	ENSDARG00000044422	ENSG00000114739	ACVR2B	NA	NA	NA	NA
ENSDARG00000041864	ENSDARG00000043035	ENSG00000092529	CAPN3	NA	NA	NA	NA
ENSDARG00000042021	ENSDARG00000006409	ENSG00000188130	MAPK12	NA	NA	NA	NA
ENSDARG00000042055	ENSDARG00000023053	ENSG00000135842	FAM129A	NA	NA	NA	NA
ENSDARG00000042081	ENSDARG00000088096	ENSG00000162009	SSTR5	NA	NA	NA	NA
ENSDARG00000042114	ENSDARG00000058820	ENSG00000136717	BIN1	NA	NA	NA	NA
ENSDARG00000042145	ENSDARG00000002330	ENSG00000162624	LHX8	NA	NA	NA	NA
ENSDARG00000042338	ENSDARG00000042561	ENSG00000064547	LPAR2	NA	NA	NA	NA
ENSDARG00000042350	ENSDARG00000030614	ENSG00000067715	SYT1	NA	NA	NA	NA
ENSDARG00000042811	ENSDARG00000017542	ENSG00000113578	FGF1	NA	NA	NA	NA
ENSDARG00000042859	ENSDARG00000014599	ENSG00000138074	SLC5A6	NA	NA	NA	NA
ENSDARG00000042947	ENSDARG00000069133	ENSG00000138379	MSTN	NA	NA	NA	NA
ENSDARG00000042954	ENSDARG00000011049	ENSG00000101194	SLC17A9	NA	NA	NA	NA
ENSDARG00000042974	ENSDARG00000002230	ENSG00000102003	SYP	NA	NA	NA	NA
ENSDARG00000042988	ENSDARG00000063158	ENSG00000155886	SLC24A2	NA	NA	NA	NA
ENSDARG00000043037	ENSDARG00000016818	ENSG00000118777	ABCG2	NA	NA	NA	NA
ENSDARG00000043059	ENSDARG00000070721	ENSG00000111424	VDR	NA	NA	NA	NA
ENSDARG00000043220	ENSDARG00000069117	ENSG00000140015	KCNH5	NA	NA	NA	NA
ENSDARG00000043313	ENSDARG00000009026	ENSG00000145362	ANK2	NA	NA	NA	NA
ENSDARG00000043396	ENSDARG00000009949	ENSG00000115226	FNDC4	NA	NA	NA	NA
ENSDARG00000043406	ENSDARG00000013422	ENSG00000183023	SLC8A1	NA	NA	NA	NA
ENSDARG00000043661	ENSDARG00000070567	ENSG00000163618	CADPS	NA	NA	NA	NA
ENSDARG00000043701	ENSDARG00000043180	ENSG00000167588	GPD1	NA	NA	NA	NA
ENSDARG00000043746	ENSDARG00000062693	ENSG00000021645	NRXN3	NA	NA	NA	NA
ENSDARG00000043907	ENSDARG00000069662	ENSG00000161958	FGF11	NA	NA	NA	NA
ENSDARG00000044015	ENSDARG00000042723	ENSG00000168546	GFRA2	NA	NA	NA	NA
ENSDARG00000044161	ENSDARG00000074583	ENSG00000182771	GRID1	NA	NA	NA	NA
ENSDARG00000044175	ENSDARG00000033956	ENSG00000180914	OXTR	NA	NA	NA	NA
ENSDARG00000044179	ENSDARG00000056150	ENSG00000076067	RBMS2	NA	NA	NA	NA
ENSDARG00000044271	ENSDARG00000017901	ENSG00000171914	TLN2	NA	NA	NA	NA
ENSDARG00000044441	ENSDARG00000077201	ENSG00000169994	MYO7B	NA	NA	NA	NA
ENSDARG00000044456	ENSDARG00000058162	ENSG00000102230	PCYT1B	NA	NA	NA	NA
ENSDARG00000044632	ENSDARG00000061937	ENSG00000137474	MYO7A	NA	NA	NA	NA
ENSDARG00000044775	ENSDARG00000069408	ENSG00000180549	FUT7	NA	NA	NA	NA
ENSDARG00000045006	ENSDARG00000060123	ENSG00000144724	PTPRG	NA	NA	NA	NA
ENSDARG00000045023	ENSDARG00000056458	ENSG00000197753	LHFPL5	NA	NA	NA	NA
ENSDARG00000045036	ENSDARG00000039704	ENSG00000179604	CDC42EP4	NA	NA	NA	NA
ENSDARG00000045087	ENSDARG00000037916	ENSG00000176749	CDK5R1	NA	NA	NA	NA
ENSDARG00000045129	ENSDARG00000062796	ENSG00000141756	FKBP10	NA	NA	NA	NA
ENSDARG00000045200	ENSDARG00000040490	ENSG00000162999	DUSP19	NA	NA	NA	NA
ENSDARG00000045204	ENSDARG00000078760	ENSG00000157445	CACNA2D3	NA	NA	NA	NA
ENSDARG00000045316	ENSDARG00000068480	ENSG00000184368	MAP7D2	NA	NA	NA	NA
ENSDARG00000045415	ENSDARG00000075850	ENSG00000141404	GNAL	NA	NA	NA	NA
ENSDARG00000045632	ENSDARG00000061769	ENSG00000163217	BMP10	NA	NA	NA	NA
ENSDARG00000045692	ENSDARG00000088062	ENSG00000134283	PPHLN1	NA	NA	NA	NA
ENSDARG00000045708	ENSDARG00000078875	ENSG00000128165	ADM2	NA	NA	NA	NA
ENSDARG00000045758	ENSDARG00000068231	ENSG00000130038	EFCAB4B	NA	NA	NA	NA
ENSDARG00000045789	ENSDARG00000007461	ENSG00000196935	SRGAP1	NA	NA	NA	NA
ENSDARG00000045799	ENSDARG00000035891	ENSG00000157766	ACAN	NA	NA	NA	NA
ENSDARG00000045864	ENSDARG00000045634	ENSG00000170807	LMOD2	NA	NA	NA	NA
ENSDARG00000045956	ENSDARG00000062849	ENSG00000100433	KCNK10	NA	NA	NA	NA
ENSDARG00000051746	ENSDARG00000015623	ENSG00000093072	CECR1	NA	NA	NA	NA
ENSDARG00000052045	ENSDARG00000078258	ENSG00000099998	GGT5	NA	NA	NA	NA
ENSDARG00000052142	ENSDARG00000018968	ENSG00000135503	ACVR1B	NA	NA	NA	NA
ENSDARG00000052155	ENSDARG00000032188	ENSG00000136802	LRRC8A	NA	NA	NA	NA
ENSDARG00000052386	ENSDARG00000046085	ENSG00000080822	CLDND1	NA	NA	NA	NA
ENSDARG00000052631	ENSDARG00000020072	ENSG00000113296	THBS4	NA	NA	NA	NA
ENSDARG00000052642	ENSDARG00000045145	ENSG00000237515	SHISA9	NA	NA	NA	NA
ENSDARG00000052658	ENSDARG00000011122	ENSG00000196850	PPTC7	NA	NA	NA	NA
ENSDARG00000052708	ENSDARG00000000474	ENSG00000159173	TNNI1	NA	NA	NA	NA
ENSDARG00000052734	ENSDARG00000059301	ENSG00000113161	HMGCR	NA	NA	NA	NA
ENSDARG00000052748	ENSDARG00000052702	ENSG00000137225	CAPN11	NA	NA	NA	NA
ENSDARG00000052787	ENSDARG00000076632	ENSG00000160446	ZDHHC12	NA	NA	NA	NA
ENSDARG00000052898	ENSDARG00000043466	ENSG00000171303	KCNK3	NA	NA	NA	NA

ENSDARG00000052966	ENSDARG00000057206	ENSG00000136448	NMT1	NA	NA	NA	NA
ENSDARG00000052982	ENSDARG00000014057	ENSG00000111886	GABRR2	NA	NA	NA	NA
ENSDARG00000053179	ENSDARG00000056091	ENSG00000143079	CTTNBP2NL	NA	NA	NA	NA
ENSDARG00000053186	ENSDARG00000010154	ENSG00000165633	C10orf72	NA	NA	NA	NA
ENSDARG00000053425	ENSDARG00000056532	ENSG00000168528	SERINC2	NA	NA	NA	NA
ENSDARG00000053449	ENSDARG00000035832	ENSG00000131096	PYY	NA	NA	NA	NA
ENSDARG00000053454	ENSDARG00000013647	ENSG00000113805	CNTN3	NA	NA	NA	NA
ENSDARG00000053559	ENSDARG00000034753	ENSG00000140391	TSPAN3	NA	NA	NA	NA
ENSDARG00000053586	ENSDARG00000093420	ENSG00000118260	CREB1	NA	NA	NA	NA
ENSDARG00000053724	ENSDARG00000029989	ENSG00000078549	ADCYAP1R1	NA	NA	NA	NA
ENSDARG00000053746	ENSDARG00000011281	ENSG00000141447	OSBPL1A	NA	NA	NA	NA
ENSDARG00000053859	ENSDARG00000089691	ENSG00000100593	ISM2	NA	NA	NA	NA
ENSDARG00000054002	ENSDARG00000029419	ENSG00000189159	HN1	NA	NA	NA	NA
ENSDARG00000054036	ENSDARG00000038300	ENSG00000170633	RNF34	NA	NA	NA	NA
ENSDARG00000054196	ENSDARG00000009482	ENSG00000166558	SLC38A8	NA	NA	NA	NA
ENSDARG00000054641	ENSDARG00000037183	ENSG00000112773	FAM46A	NA	NA	NA	NA
ENSDARG00000054844	ENSDARG00000078241	ENSG00000135525	MAP7	NA	NA	NA	NA
ENSDARG00000054894	ENSDARG00000036428	ENSG00000142227	EMP3	NA	NA	NA	NA
ENSDARG00000055045	ENSDARG00000017905	ENSG00000164305	CASP3	NA	NA	NA	NA
ENSDARG00000055120	ENSDARG00000067570	ENSG00000164733	CTSB	NA	NA	NA	NA
ENSDARG00000055123	ENSDARG00000007151	ENSG00000082482	KCNK2	NA	NA	NA	NA
ENSDARG00000055160	ENSDARG00000075903	ENSG00000100399	CHADL	NA	NA	NA	NA
ENSDARG00000055317	ENSDARG00000011549	ENSG00000186897	C1QL4	NA	NA	NA	NA
ENSDARG00000055377	ENSDARG00000092921	ENSG00000069966	GNB5	NA	NA	NA	NA
ENSDARG00000055412	ENSDARG00000091260	ENSG00000145949	MYLK4	NA	NA	NA	NA
ENSDARG00000055463	ENSDARG00000057054	ENSG00000183423	LRIT3	NA	NA	NA	NA
ENSDARG00000055502	ENSDARG00000071150	ENSG00000079432	CIC	NA	NA	NA	NA
ENSDARG00000055534	ENSDARG00000020602	ENSG00000114124	GRK7	NA	NA	NA	NA
ENSDARG00000055855	ENSDARG00000037933	ENSG00000131398	KCNC3	NA	NA	NA	NA
ENSDARG00000056021	ENSDARG00000068892	ENSG00000171243	SOSTDC1	NA	NA	NA	NA
ENSDARG00000056125	ENSDARG00000088546	ENSG00000120279	MYCT1	NA	NA	NA	NA
ENSDARG00000056156	ENSDARG00000074697	ENSG00000107281	NPDC1	NA	NA	NA	NA
ENSDARG00000056206	ENSDARG00000071395	ENSG00000148660	CAMK2G	NA	NA	NA	NA
ENSDARG00000056226	ENSDARG00000090903	ENSG00000060566	CREB3L3	NA	NA	NA	NA
ENSDARG00000056228	ENSDARG00000057125	ENSG00000075651	PLD1	NA	NA	NA	NA
ENSDARG00000056250	ENSDARG00000040874	ENSG00000148700	ADD3	NA	NA	NA	NA
ENSDARG00000056347	ENSDARG00000043835	ENSG00000105649	RAB3A	NA	NA	NA	NA
ENSDARG00000056394	ENSDARG00000009217	ENSG00000175662	TOM1L2	NA	NA	NA	NA
ENSDARG00000056619	ENSDARG00000010654	ENSG00000165895	ARHGAP42	NA	NA	NA	NA
ENSDARG00000056625	ENSDARG00000067730	ENSG00000137672	TRPC6	NA	NA	NA	NA
ENSDARG00000056762	ENSDARG00000057706	ENSG00000145107	TM4SF19	NA	NA	NA	NA
ENSDARG00000056910	ENSDARG00000061099	ENSG00000163531	NFASC	NA	NA	NA	NA
ENSDARG00000056913	ENSDARG00000052057	ENSG00000106333	PCOLCE	NA	NA	NA	NA
ENSDARG00000056934	ENSDARG00000077945	ENSG00000165478	HEPACAM	NA	NA	NA	NA
ENSDARG00000057016	ENSDARG00000013858	ENSG00000079335	CDC14A	NA	NA	NA	NA
ENSDARG00000057025	ENSDARG00000006602	ENSG00000120903	CHRNA2	NA	NA	NA	NA
ENSDARG00000057121	ENSDARG00000042172	ENSG00000112936	C7	NA	NA	NA	NA
ENSDARG00000057169	ENSDARG00000062661	ENSG00000198691	ABCA4	NA	NA	NA	NA
ENSDARG00000057286	ENSDARG00000051819	ENSG00000133789	SWAP70	NA	NA	NA	NA
ENSDARG00000057352	ENSDARG00000059052	ENSG00000197119	SLC25A29	NA	NA	NA	NA
ENSDARG00000057419	ENSDARG00000017398	ENSG00000137968	SLC44A5	NA	NA	NA	NA
ENSDARG00000057433	ENSDARG00000039220	ENSG00000117069	ST6GALNAC5	NA	NA	NA	NA
ENSDARG00000057437	ENSDARG00000060345	ENSG00000189058	APOD	NA	NA	NA	NA
ENSDARG00000057527	ENSDARG00000031756	ENSG00000068305	MEF2A	NA	NA	NA	NA
ENSDARG00000057568	ENSDARG00000012426	ENSG00000256228	AC107373.1	NA	NA	NA	NA
ENSDARG00000057790	ENSDARG00000029370	ENSG00000135299	ANKRD6	NA	NA	NA	NA
ENSDARG00000057940	ENSDARG00000057907	ENSG00000101191	DIDO1	NA	NA	NA	NA
ENSDARG00000058064	ENSDARG00000035553	ENSG00000169562	GJB1	NA	NA	NA	NA
ENSDARG00000058103	ENSDARG00000006865	ENSG00000188828	GLRA4	NA	NA	NA	NA
ENSDARG00000058178	ENSDARG00000055066	ENSG00000180776	ZDHHC20	NA	NA	NA	NA
ENSDARG00000058230	ENSDARG00000018399	ENSG00000108443	RPS6KB1	NA	NA	NA	NA
ENSDARG00000058243	ENSDARG00000019304	ENSG00000087495	PHACTR3	NA	NA	NA	NA
ENSDARG00000058323	ENSDARG00000090534	ENSG00000135926	TMBIM1	NA	NA	NA	NA
ENSDARG00000058392	ENSDARG00000014588	ENSG00000078295	ADCY2	NA	NA	NA	NA
ENSDARG00000058460	ENSDARG00000076401	ENSG00000006116	CACNG3	NA	NA	NA	NA
ENSDARG00000058646	ENSDARG00000077047	ENSG00000054356	PTPRN	NA	NA	NA	NA
ENSDARG00000058649	ENSDARG00000012367	ENSG00000163462	TRIM46	NA	NA	NA	NA
ENSDARG00000058692	ENSDARG00000021664	ENSG00000104290	FZD3	NA	NA	NA	NA
ENSDARG00000058736	ENSDARG00000075058	ENSG00000145863	GABRA6	NA	NA	NA	NA
ENSDARG00000058800	ENSDARG00000052954	ENSG00000132698	RAB25	NA	NA	NA	NA
ENSDARG00000058848	ENSDARG00000002285	ENSG00000090674	MCOLN1	NA	NA	NA	NA
ENSDARG00000058960	ENSDARG00000001771	ENSG00000182447	OTOL1	NA	NA	NA	NA
ENSDARG00000058987	ENSDARG00000013479	ENSG00000125447	GGA3	NA	NA	NA	NA
ENSDARG00000059054	ENSDARG00000020876	ENSG00000005882	PDK2	NA	NA	NA	NA
ENSDARG00000059081	ENSDARG00000017213	ENSG00000146250	PRSS35	NA	NA	NA	NA
ENSDARG00000059090	ENSDARG00000069806	ENSG00000180616	SSTR2	NA	NA	NA	NA
ENSDARG00000059123	ENSDARG00000034080	ENSG00000187091	PLCD1	NA	NA	NA	NA
ENSDARG00000059202	ENSDARG00000003754	ENSG00000134198	TSPAN2	NA	NA	NA	NA
ENSDARG00000059236	ENSDARG00000035415	ENSG00000171522	PTGER4	NA	NA	NA	NA
ENSDARG00000059308	ENSDARG00000022795	ENSG00000111711	GOLT1B	NA	NA	NA	NA
ENSDARG00000059363	ENSDARG00000034541	ENSG00000163513	TGFBR2	NA	NA	NA	NA
ENSDARG00000059484	ENSDARG00000060627	ENSG00000130787	HIP1R	NA	NA	NA	NA
ENSDARG00000059598	ENSDARG00000079062	ENSG00000141858	SAMD1	NA	NA	NA	NA
ENSDARG00000059677	ENSDARG00000073695	ENSG00000165072	MAMDC2	NA	NA	NA	NA
ENSDARG00000059678	ENSDARG00000074894	ENSG00000164976	KIAA1161	NA	NA	NA	NA
ENSDARG00000059680	ENSDARG00000037747	ENSG00000075618	FSCN1	NA	NA	NA	NA
ENSDARG00000059685	ENSDARG00000078136	ENSG00000085433	WDR47	NA	NA	NA	NA
ENSDARG00000059773	ENSDARG00000057448	ENSG00000017373	SRCIN1	NA	NA	NA	NA
ENSDARG00000059806	ENSDARG00000015290	ENSG00000211456	SACM1L	NA	NA	NA	NA
ENSDARG00000059818	ENSDARG00000005470	ENSG00000155980	KIF5A	NA	NA	NA	NA

ENSDARG00000059822	ENSDARG00000062618	ENSG00000184185	KCNJ12	NA	NA	NA	NA
ENSDARG00000059888	ENSDARG00000063079	ENSG00000126070	EIF2C3	NA	NA	NA	NA
ENSDARG00000059910	ENSDARG00000090897	ENSG00000171798	KNDC1	NA	NA	NA	NA
ENSDARG00000059960	ENSDARG00000056805	ENSG00000149527	PLCH2	NA	NA	NA	NA
ENSDARG00000059965	ENSDARG00000062173	ENSG00000118200	CAMSAP1L1	NA	NA	NA	NA
ENSDARG00000060016	ENSDARG00000060705	ENSG00000165671	NSD1	NA	NA	NA	NA
ENSDARG00000060025	ENSDARG00000061506	ENSG00000165802	NELF	NA	NA	NA	NA
ENSDARG00000060034	ENSDARG00000079878	ENSG00000178233	TMEM151B	NA	NA	NA	NA
ENSDARG00000060236	ENSDARG00000088164	ENSG00000175920	DOK7	NA	NA	NA	NA
ENSDARG00000060237	ENSDARG00000079840	ENSG00000156113	KCNMA1	NA	NA	NA	NA
ENSDARG00000060248	ENSDARG00000011830	ENSG00000139132	FGD4	NA	NA	NA	NA
ENSDARG00000060303	ENSDARG00000063133	ENSG00000144290	SLC4A10	NA	NA	NA	NA
ENSDARG00000060452	ENSDARG00000078116	ENSG00000069188	SDK2	NA	NA	NA	NA
ENSDARG00000060458	ENSDARG00000045137	ENSG00000134489	HRH4	NA	NA	NA	NA
ENSDARG00000060459	ENSDARG00000077489	ENSG00000156564	LRFN2	NA	NA	NA	NA
ENSDARG00000060520	ENSDARG00000063011	ENSG00000163297	ANTXR2	NA	NA	NA	NA
ENSDARG00000060584	ENSDARG00000060102	ENSG00000107104	KANK1	NA	NA	NA	NA
ENSDARG00000060675	ENSDARG00000068710	ENSG00000116962	NID1	NA	NA	NA	NA
ENSDARG00000060723	ENSDARG00000061560	ENSG00000167323	STIM1	NA	NA	NA	NA
ENSDARG00000060725	ENSDARG00000059699	ENSG00000116138	DNAJC16	NA	NA	NA	NA
ENSDARG00000060756	ENSDARG00000070894	ENSG00000163686	ABHD6	NA	NA	NA	NA
ENSDARG00000060805	ENSDARG00000060326	ENSG00000130479	MAP1S	NA	NA	NA	NA
ENSDARG00000060860	ENSDARG00000053568	ENSG00000140368	PSTPIP1	NA	NA	NA	NA
ENSDARG00000060929	ENSDARG00000075183	ENSG00000187147	RNF220	NA	NA	NA	NA
ENSDARG00000060933	ENSDARG00000016483	ENSG00000128298	BAIAP2L2	NA	NA	NA	NA
ENSDARG00000060954	ENSDARG00000076747	ENSG00000172765	TMCC1	NA	NA	NA	NA
ENSDARG00000061011	ENSDARG00000074752	ENSG00000108924	HLF	NA	NA	NA	NA
ENSDARG00000061030	ENSDARG00000008247	ENSG00000136451	VEZF1	NA	NA	NA	NA
ENSDARG00000061047	ENSDARG00000078068	ENSG00000172350	ABCG4	NA	NA	NA	NA
ENSDARG00000061082	ENSDARG00000090308	ENSG00000187672	ERC2	NA	NA	NA	NA
ENSDARG00000061089	ENSDARG00000061131	ENSG00000139116	KIF21A	NA	NA	NA	NA
ENSDARG00000061093	ENSDARG00000079378	ENSG00000019144	PHLDB1	NA	NA	NA	NA
ENSDARG00000061101	ENSDARG00000079931	ENSG00000120451	SNX19	NA	NA	NA	NA
ENSDARG00000061143	ENSDARG00000073999	ENSG00000169762	TAPT1	NA	NA	NA	NA
ENSDARG00000061191	ENSDARG00000077499	ENSG00000023902	PLEKHO1	NA	NA	NA	NA
ENSDARG00000061255	ENSDARG00000060130	ENSG00000108861	DUSP3	NA	NA	NA	NA
ENSDARG00000061282	ENSDARG00000013780	ENSG00000090863	GLG1	NA	NA	NA	NA
ENSDARG00000061342	ENSDARG00000079342	ENSG00000203727	SAMD5	NA	NA	NA	NA
ENSDARG00000061479	ENSDARG00000090496	ENSG00000005108	THSD7A	NA	NA	NA	NA
ENSDARG00000061641	ENSDARG00000077086	ENSG00000189127	ANKRD34B	NA	NA	NA	NA
ENSDARG00000061688	ENSDARG00000074329	ENSG00000099889	ARVCF	NA	NA	NA	NA
ENSDARG00000061725	ENSDARG00000086505	ENSG00000099308	MAST3	NA	NA	NA	NA
ENSDARG00000061732	ENSDARG00000006301	ENSG00000173166	RAPH1	NA	NA	NA	NA
ENSDARG00000061736	ENSDARG00000077582	ENSG00000151150	ANK3	NA	NA	NA	NA
ENSDARG00000061757	ENSDARG00000060315	ENSG00000152061	RABGAP1L	NA	NA	NA	NA
ENSDARG00000061758	ENSDARG00000060148	ENSG00000107957	SH3PXD2A	NA	NA	NA	NA
ENSDARG00000061804	ENSDARG00000060340	ENSG00000162522	KIAA1522	NA	NA	NA	NA
ENSDARG00000061835	ENSDARG00000063372	ENSG00000170044	ZPLD1	NA	NA	NA	NA
ENSDARG00000061852	ENSDARG00000062171	ENSG00000116774	OLFML3	NA	NA	NA	NA
ENSDARG00000061956	ENSDARG00000075436	ENSG00000137501	SYTL2	NA	NA	NA	NA
ENSDARG00000061970	ENSDARG00000067815	ENSG00000220008	LINGO3	NA	NA	NA	NA
ENSDARG00000061976	ENSDARG00000036626	ENSG00000167680	SEMA6B	NA	NA	NA	NA
ENSDARG00000061977	ENSDARG00000029168	ENSG00000166387	PPFIBP2	NA	NA	NA	NA
ENSDARG00000062000	ENSDARG00000059751	ENSG00000166016	ABTB2	NA	NA	NA	NA
ENSDARG00000062024	ENSDARG00000061817	ENSG00000130294	KIF1A	NA	NA	NA	NA
ENSDARG00000062030	ENSDARG00000045427	ENSG00000144230	GPR17	NA	NA	NA	NA
ENSDARG00000062106	ENSDARG00000015506	ENSG00000102554	KLF5	NA	NA	NA	NA
ENSDARG00000062113	ENSDARG00000044146	ENSG00000171492	LRRC8D	NA	NA	NA	NA
ENSDARG00000062134	ENSDARG00000087247	ENSG00000069424	KCNAB2	NA	NA	NA	NA
ENSDARG00000062156	ENSDARG00000071095	ENSG00000154175	ABI3BP	NA	NA	NA	NA
ENSDARG00000062199	ENSDARG00000062020	ENSG00000131149	KIAA0182	NA	NA	NA	NA
ENSDARG00000062220	ENSDARG00000060813	ENSG00000166689	PLEKHA7	NA	NA	NA	NA
ENSDARG00000062341	ENSDARG00000074617	ENSG00000109501	WFS1	NA	NA	NA	NA
ENSDARG00000062372	ENSDARG00000019596	ENSG00000078618	NRD1	NA	NA	NA	NA
ENSDARG00000062396	ENSDARG00000078901	ENSG00000064999	ANKS1A	NA	NA	NA	NA
ENSDARG00000062401	ENSDARG00000073856	ENSG00000166188	ZNF319	NA	NA	NA	NA
ENSDARG00000062445	ENSDARG00000036094	ENSG00000033800	PIAS1	NA	NA	NA	NA
ENSDARG00000062449	ENSDARG00000029671	ENSG00000143324	XPR1	NA	NA	NA	NA
ENSDARG00000062462	ENSDARG00000063144	ENSG00000187902	SHISA7	NA	NA	NA	NA
ENSDARG00000062552	ENSDARG00000069441	ENSG00000139679	LPAR6	NA	NA	NA	NA
ENSDARG00000062633	ENSDARG00000009930	ENSG00000175161	CADM2	NA	NA	NA	NA
ENSDARG00000062754	ENSDARG00000040069	ENSG00000196353	CPNE4	NA	NA	NA	NA
ENSDARG00000062799	ENSDARG00000060587	ENSG00000175866	BAIAP2	NA	NA	NA	NA
ENSDARG00000062823	ENSDARG00000076724	ENSG00000241973	PI4KA	NA	NA	NA	NA
ENSDARG00000062900	ENSDARG00000062450	ENSG00000121848	RNF115	NA	NA	NA	NA
ENSDARG00000062942	ENSDARG00000017108	ENSG00000111262	KCNA1	NA	NA	NA	NA
ENSDARG00000062955	ENSDARG00000061362	ENSG00000154511	FAM69A	NA	NA	NA	NA
ENSDARG00000062967	ENSDARG00000051892	ENSG00000168418	KCNG4	NA	NA	NA	NA
ENSDARG00000062976	ENSDARG00000062108	ENSG00000010295	IFFO1	NA	NA	NA	NA
ENSDARG00000062986	ENSDARG00000040002	ENSG00000130653	PNPLA7	NA	NA	NA	NA
ENSDARG00000063006	ENSDARG00000070624	ENSG00000105605	CACNG7	NA	NA	NA	NA
ENSDARG00000063018	ENSDARG00000062889	ENSG00000188859	FAM78B	NA	NA	NA	NA
ENSDARG00000063040	ENSDARG00000063255	ENSG00000151136	BTBD11	NA	NA	NA	NA
ENSDARG00000063293	ENSDARG00000062343	ENSG00000171208	NETO2	NA	NA	NA	NA
ENSDARG00000063313	ENSDARG00000076015	ENSG00000121316	PLBD1	NA	NA	NA	NA
ENSDARG00000063332	ENSDARG00000063054	ENSG00000251322	SHANK3	NA	NA	NA	NA
ENSDARG00000063361	ENSDARG00000063008	ENSG00000122778	KIAA1549	NA	NA	NA	NA
ENSDARG00000063420	ENSDARG00000002031	ENSG00000092203	TOX4	NA	NA	NA	NA
ENSDARG00000063538	ENSDARG00000078117	ENSG00000160145	KALRN	NA	NA	NA	NA
ENSDARG00000063544	ENSDARG00000003776	ENSG00000150867	PIP4K2A	NA	NA	NA	NA

ENSDARG00000063555	ENSDARG00000087330	ENSG00000103495	MAZ	NA	NA	NA	NA
ENSDARG00000063568	ENSDARG00000078060	ENSG00000011347	SYT7	NA	NA	NA	NA
ENSDARG00000063594	ENSDARG00000077095	ENSG00000163349	HIPK1	NA	NA	NA	NA
ENSDARG00000063682	ENSDARG00000061904	ENSG00000134775	FHOD3	NA	NA	NA	NA
ENSDARG00000067566	ENSDARG00000094708	ENSG00000168878	SFTPB	NA	NA	NA	NA
ENSDARG00000067591	ENSDARG00000024890	ENSG00000185129	PURA	NA	NA	NA	NA
ENSDARG00000067634	ENSDARG00000030532	ENSG00000196914	ARHGEF12	NA	NA	NA	NA
ENSDARG00000067683	ENSDARG00000012490	ENSG00000154678	PDE1C	NA	NA	NA	NA
ENSDARG00000067701	ENSDARG00000093552	ENSG00000164591	MYOZ3	NA	NA	NA	NA
ENSDARG00000067720	ENSDARG00000018492	ENSG00000165655	ZNF503	NA	NA	NA	NA
ENSDARG00000067725	ENSDARG00000077430	ENSG00000171217	CLDN20	NA	NA	NA	NA
ENSDARG00000067820	ENSDARG00000005783	ENSG00000130287	NCAN	NA	NA	NA	NA
ENSDARG00000067908	ENSDARG00000079636	ENSG00000151327	FAM177A1	NA	NA	NA	NA
ENSDARG00000067927	ENSDARG00000061405	ENSG00000115363	FAM176A	NA	NA	NA	NA
ENSDARG00000067999	ENSDARG00000070781	ENSG00000159248	GJD2	NA	NA	NA	NA
ENSDARG00000068008	ENSDARG00000010433	ENSG00000006740	ARHGAP44	NA	NA	NA	NA
ENSDARG00000068232	ENSDARG00000063376	ENSG00000139899	CBLN3	NA	NA	NA	NA
ENSDARG00000068242	ENSDARG00000042107	ENSG00000070729	CNGB1	NA	NA	NA	NA
ENSDARG00000068296	ENSDARG00000018726	ENSG00000176463	SLCO3A1	NA	NA	NA	NA
ENSDARG00000068397	ENSDARG00000076292	ENSG00000111077	TENC1	NA	NA	NA	NA
ENSDARG00000068483	ENSDARG00000071596	ENSG00000166342	NETO1	NA	NA	NA	NA
ENSDARG00000068705	ENSDARG00000062168	ENSG00000146802	TMEM168	NA	NA	NA	NA
ENSDARG00000068849	ENSDARG00000060830	ENSG00000180921	FAM83H	NA	NA	NA	NA
ENSDARG00000068890	ENSDARG00000088634	ENSG00000164742	ADCY1	NA	NA	NA	NA
ENSDARG00000068918	ENSDARG00000006609	ENSG00000126934	MAP2K2	NA	NA	NA	NA
ENSDARG00000069030	ENSDARG00000062448	ENSG00000188779	SKOR1	NA	NA	NA	NA
ENSDARG00000069265	ENSDARG00000069245	ENSG00000132031	MATN3	NA	NA	NA	NA
ENSDARG00000069318	ENSDARG00000033516	ENSG00000084710	EFR3B	NA	NA	NA	NA
ENSDARG00000069388	ENSDARG00000056920	ENSG00000167874	TMEM88	NA	NA	NA	NA
ENSDARG00000069467	ENSDARG00000033845	ENSG00000080854	IGSF9B	NA	NA	NA	NA
ENSDARG00000069589	ENSDARG00000074503	ENSG00000186501	TMEM222	NA	NA	NA	NA
ENSDARG00000069674	ENSDARG00000027687	ENSG00000089063	C20orf30	NA	NA	NA	NA
ENSDARG00000069701	ENSDARG00000089957	ENSG00000153012	LGI2	NA	NA	NA	NA
ENSDARG00000069742	ENSDARG00000004260	ENSG00000166266	CUL5	NA	NA	NA	NA
ENSDARG00000069745	ENSDARG00000090686	ENSG00000110660	SLC35F2	NA	NA	NA	NA
ENSDARG00000069748	ENSDARG00000069717	ENSG00000149260	CAPN5	NA	NA	NA	NA
ENSDARG00000069765	ENSDARG00000063713	ENSG00000197283	SYNGAP1	NA	NA	NA	NA
ENSDARG00000069787	ENSDARG00000004875	ENSG00000141524	TMC6	NA	NA	NA	NA
ENSDARG00000069829	ENSDARG00000059154	ENSG00000116954	RRAGC	NA	NA	NA	NA
ENSDARG00000069830	ENSDARG00000086453	ENSG00000131233	GJA9	NA	NA	NA	NA
ENSDARG00000069994	ENSDARG00000091783	ENSG00000049540	ELN	NA	NA	NA	NA
ENSDARG00000070056	ENSDARG00000075694	ENSG00000163485	ADORA1	NA	NA	NA	NA
ENSDARG00000070100	ENSDARG00000079095	ENSG00000174791	RIN1	NA	NA	NA	NA
ENSDARG00000070171	ENSDARG00000086098	ENSG00000116285	ERRFI1	NA	NA	NA	NA
ENSDARG00000070314	ENSDARG00000086391	ENSG00000122786	CALD1	NA	NA	NA	NA
ENSDARG00000070412	ENSDARG00000037101	ENSG00000003987	MTMR7	NA	NA	NA	NA
ENSDARG00000070479	ENSDARG00000068883	ENSG00000106537	TSPAN13	NA	NA	NA	NA
ENSDARG00000070507	ENSDARG00000062183	ENSG00000133107	TRPC4	NA	NA	NA	NA
ENSDARG00000070571	ENSDARG00000078155	ENSG00000163362	C1orf106	NA	NA	NA	NA
ENSDARG00000070575	ENSDARG00000070952	ENSG00000159784	FAM131B	NA	NA	NA	NA
ENSDARG00000070590	ENSDARG00000035883	ENSG00000116981	NT5C1A	NA	NA	NA	NA
ENSDARG00000070620	ENSDARG00000086207	ENSG00000105464	GRIN2D	NA	NA	NA	NA
ENSDARG00000070726	ENSDARG00000012297	ENSG00000144191	CNGA3	NA	NA	NA	NA
ENSDARG00000070787	ENSDARG00000059067	ENSG00000173801	JUP	NA	NA	NA	NA
ENSDARG00000070919	ENSDARG00000061466	ENSG00000124772	CPNE5	NA	NA	NA	NA
ENSDARG00000070941	ENSDARG00000090833	ENSG00000167779	IGFBP6	NA	NA	NA	NA
ENSDARG00000070956	ENSDARG00000025904	ENSG00000099797	TECR	NA	NA	NA	NA
ENSDARG00000070971	ENSDARG00000062909	ENSG00000140564	FURIN	NA	NA	NA	NA
ENSDARG00000070973	ENSDARG00000036272	ENSG00000215644	GCGR	NA	NA	NA	NA
ENSDARG00000070995	ENSDARG00000063352	ENSG00000040933	INPP4A	NA	NA	NA	NA
ENSDARG00000071031	ENSDARG00000079116	ENSG00000028528	SNX1	NA	NA	NA	NA
ENSDARG00000071091	ENSDARG00000071298	ENSG00000133019	CHRM3	NA	NA	NA	NA
ENSDARG00000071217	ENSDARG00000069500	ENSG00000185352	HS6ST3	NA	NA	NA	NA
ENSDARG00000071493	ENSDARG00000039174	ENSG00000118733	OLFM3	NA	NA	NA	NA
ENSDARG00000071637	ENSDARG00000008329	ENSG00000110881	ACCN2	NA	NA	NA	NA
ENSDARG00000073699	ENSDARG00000031483	ENSG00000112280	COL9A1	NA	NA	NA	NA
ENSDARG00000073707	ENSDARG00000074480	ENSG00000149970	CNKSR2	NA	NA	NA	NA
ENSDARG00000073756	ENSDARG00000062058	ENSG00000113504	SLC12A7	NA	NA	NA	NA
ENSDARG00000073769	ENSDARG00000021590	ENSG00000187391	MAGI2	NA	NA	NA	NA
ENSDARG00000073792	ENSDARG00000076592	ENSG00000177239	MAN1B1	NA	NA	NA	NA
ENSDARG00000073822	ENSDARG00000016551	ENSG00000144711	IQSEC1	NA	NA	NA	NA
ENSDARG00000073861	ENSDARG00000078388	ENSG00000126603	GLIS2	NA	NA	NA	NA
ENSDARG00000073918	ENSDARG00000075046	ENSG00000179580	RNF151	NA	NA	NA	NA
ENSDARG00000073970	ENSDARG00000001414	ENSG00000140563	MCTP2	NA	NA	NA	NA
ENSDARG00000074018	ENSDARG00000077868	ENSG00000204347	BTBD17	NA	NA	NA	NA
ENSDARG00000074073	ENSDARG00000074521	ENSG00000171533	MAP6	NA	NA	NA	NA
ENSDARG00000074075	ENSDARG00000025672	ENSG00000169604	ANTXR1	NA	NA	NA	NA
ENSDARG00000074153	ENSDARG00000076987	ENSG00000165300	SLITRK5	NA	NA	NA	NA
ENSDARG00000074229	ENSDARG00000075849	ENSG00000126464	PRR12	NA	NA	NA	NA
ENSDARG00000074275	ENSDARG00000079060	ENSG00000064042	LIMCH1	NA	NA	NA	NA
ENSDARG00000074308	ENSDARG00000091128	ENSG00000178026	C22orf36	NA	NA	NA	NA
ENSDARG00000074321	ENSDARG00000063649	ENSG00000007866	TEAD3	NA	NA	NA	NA
ENSDARG00000074358	ENSDARG00000073716	ENSG00000088882	CPXM1	NA	NA	NA	NA
ENSDARG00000074381	ENSDARG00000063695	ENSG00000152767	FARP1	NA	NA	NA	NA
ENSDARG00000074396	ENSDARG00000059574	ENSG00000186765	FSCN2	NA	NA	NA	NA
ENSDARG00000074403	ENSDARG00000022518	ENSG00000114757	PEX5L	NA	NA	NA	NA
ENSDARG00000074419	ENSDARG00000061685	ENSG00000138622	HCN4	NA	NA	NA	NA
ENSDARG00000074457	ENSDARG00000037140	ENSG00000158571	PFKFB1	NA	NA	NA	NA
ENSDARG00000074526	ENSDARG00000007184	ENSG00000109906	ZBTB16	NA	NA	NA	NA
ENSDARG00000074535	ENSDARG00000069970	ENSG00000174482	LINGO2	NA	NA	NA	NA

ENSDARG00000074599	ENSDARG00000076496	ENSG00000114541	FRMD4B	NA	NA	NA	NA
ENSDARG00000074636	ENSDARG00000078327	ENSG00000099814	KIAA0284	NA	NA	NA	NA
ENSDARG00000074638	ENSDARG00000094738	ENSG00000167210	LOXHD1	NA	NA	NA	NA
ENSDARG00000074663	ENSDARG00000076184	ENSG00000156671	SAMD8	NA	NA	NA	NA
ENSDARG00000074681	ENSDARG00000062427	ENSG00000114859	CLCN2	NA	NA	NA	NA
ENSDARG00000074777	ENSDARG00000059093	ENSG00000029534	ANK1	NA	NA	NA	NA
ENSDARG00000074826	ENSDARG00000077427	ENSG00000204882	GPR20	NA	NA	NA	NA
ENSDARG00000074843	ENSDARG00000079889	ENSG00000144824	PHLDB2	NA	NA	NA	NA
ENSDARG00000074854	ENSDARG00000095348	ENSG00000183918	SH2D1A	NA	NA	NA	NA
ENSDARG00000074897	ENSDARG00000068168	ENSG00000069812	HES2	NA	NA	NA	NA
ENSDARG00000074905	ENSDARG00000017446	ENSG00000183049	CAMK1D	NA	NA	NA	NA
ENSDARG00000074924	ENSDARG00000077559	ENSG00000111912	NCOA7	NA	NA	NA	NA
ENSDARG00000074976	ENSDARG00000018856	ENSG00000133083	DCLK1	NA	NA	NA	NA
ENSDARG00000074979	ENSDARG00000078401	ENSG00000161813	LARP4	NA	NA	NA	NA
ENSDARG00000074984	ENSDARG00000062347	ENSG00000132938	MTUS2	NA	NA	NA	NA
ENSDARG00000075026	ENSDARG00000075450	ENSG00000150051	MKX	NA	NA	NA	NA
ENSDARG00000075054	ENSDARG00000002816	ENSG00000113319	RASGRF2	NA	NA	NA	NA
ENSDARG00000075141	ENSDARG00000077080	ENSG00000167191	GPRC5B	NA	NA	NA	NA
ENSDARG00000075147	ENSDARG00000087745	ENSG00000162494	LRRC38	NA	NA	NA	NA
ENSDARG00000075152	ENSDARG00000040027	ENSG00000144645	OSBPL10	NA	NA	NA	NA
ENSDARG00000075192	ENSDARG00000087253	ENSG00000136758	YME1L1	NA	NA	NA	NA
ENSDARG00000075209	ENSDARG00000071233	ENSG00000178467	P4HTM	NA	NA	NA	NA
ENSDARG00000075227	ENSDARG00000004445	ENSG00000168959	GRM5	NA	NA	NA	NA
ENSDARG00000075265	ENSDARG00000039145	ENSG00000122861	PLAU	NA	NA	NA	NA
ENSDARG00000075271	ENSDARG00000074307	ENSG00000136237	RAPGEF5	NA	NA	NA	NA
ENSDARG00000075328	ENSDARG00000075673	ENSG00000107863	ARHGAP21	NA	NA	NA	NA
ENSDARG00000075382	ENSDARG00000009209	ENSG00000198689	SLC9A6	NA	NA	NA	NA
ENSDARG00000075394	ENSDARG00000059826	ENSG00000095713	CRTAC1	NA	NA	NA	NA
ENSDARG00000075519	ENSDARG00000055713	ENSG00000184922	FMNL1	NA	NA	NA	NA
ENSDARG00000075648	ENSDARG00000061471	ENSG00000082684	SEMA5B	NA	NA	NA	NA
ENSDARG00000075803	ENSDARG00000073881	ENSG00000136052	SLC41A2	NA	NA	NA	NA
ENSDARG00000075831	ENSDARG00000054343	ENSG00000092068	SLC7A8	NA	NA	NA	NA
ENSDARG00000075846	ENSDARG00000043993	ENSG00000120049	KCNIP2	NA	NA	NA	NA
ENSDARG00000075858	ENSDARG00000086224	ENSG00000204442	FAM155A	NA	NA	NA	NA
ENSDARG00000075865	ENSDARG00000077349	ENSG00000156395	SORCS3	NA	NA	NA	NA
ENSDARG00000075924	ENSDARG00000079872	ENSG00000091428	RAPGEF4	NA	NA	NA	NA
ENSDARG00000075930	ENSDARG00000091328	ENSG00000087116	ADAMTS2	NA	NA	NA	NA
ENSDARG00000075942	ENSDARG00000079622	ENSG00000171877	FRMD5	NA	NA	NA	NA
ENSDARG00000075980	ENSDARG00000073768	ENSG00000179178	TMEM125	NA	NA	NA	NA
ENSDARG00000075986	ENSDARG00000077459	ENSG00000166405	RIC3	NA	NA	NA	NA
ENSDARG00000076001	ENSDARG00000009442	ENSG00000186111	PIP5K1C	NA	NA	NA	NA
ENSDARG00000076076	ENSDARG00000076068	ENSG00000105662	CRTC1	NA	NA	NA	NA
ENSDARG00000076096	ENSDARG00000020239	ENSG00000134324	LPIN1	NA	NA	NA	NA
ENSDARG00000076111	ENSDARG00000022550	ENSG00000151233	GXYLT1	NA	NA	NA	NA
ENSDARG00000076143	ENSDARG00000073909	ENSG00000168781	PPIP5K1	NA	NA	NA	NA
ENSDARG00000076174	ENSDARG00000031817	ENSG00000109654	TRIM2	NA	NA	NA	NA
ENSDARG00000076220	ENSDARG00000079414	ENSG00000063015	SEZ6	NA	NA	NA	NA
ENSDARG00000076265	ENSDARG00000077229	ENSG00000074855	ANO8	NA	NA	NA	NA
ENSDARG00000076268	ENSDARG00000076873	ENSG00000232434	C9orf172	NA	NA	NA	NA
ENSDARG00000076281	ENSDARG00000062687	ENSG00000184611	KCNH7	NA	NA	NA	NA
ENSDARG00000076302	ENSDARG00000078016	ENSG00000110042	DTX4	NA	NA	NA	NA
ENSDARG00000076309	ENSDARG00000074815	ENSG00000101825	MXRA5	NA	NA	NA	NA
ENSDARG00000076404	ENSDARG00000060871	ENSG00000175471	MCTP1	NA	NA	NA	NA
ENSDARG00000076416	ENSDARG00000076371	ENSG00000146950	SHROOM2	NA	NA	NA	NA
ENSDARG00000076434	ENSDARG00000021255	ENSG00000128805	ARHGAP22	NA	NA	NA	NA
ENSDARG00000076541	ENSDARG00000074394	ENSG00000163815	CLEC3B	NA	NA	NA	NA
ENSDARG00000076546	ENSDARG00000036159	ENSG00000174417	TRHR	NA	NA	NA	NA
ENSDARG00000076591	ENSDARG00000015931	ENSG00000065609	SNAP91	NA	NA	NA	NA
ENSDARG00000076595	ENSDARG00000088143	ENSG00000095539	SEMA4G	NA	NA	NA	NA
ENSDARG00000076615	ENSDARG00000027192	ENSG00000143630	HCN3	NA	NA	NA	NA
ENSDARG00000076620	ENSDARG00000079719	ENSG00000127220	ABHD8	NA	NA	NA	NA
ENSDARG00000076644	ENSDARG00000062906	ENSG00000168263	KCNV2	NA	NA	NA	NA
ENSDARG00000076712	ENSDARG00000063436	ENSG00000089169	RPH3A	NA	NA	NA	NA
ENSDARG00000076821	ENSDARG00000061249	ENSG00000101605	MYOM1	NA	NA	NA	NA
ENSDARG00000076826	ENSDARG00000024744	ENSG00000130226	DPP6	NA	NA	NA	NA
ENSDARG00000076829	ENSDARG00000060768	ENSG00000001629	ANKIB1	NA	NA	NA	NA
ENSDARG00000076854	ENSDARG00000059935	ENSG00000143105	KCNA10	NA	NA	NA	NA
ENSDARG00000076861	ENSDARG00000071250	ENSG00000163472	TMEM79	NA	NA	NA	NA
ENSDARG00000076868	ENSDARG00000079542	ENSG00000133121	STARD13	NA	NA	NA	NA
ENSDARG00000076960	ENSDARG00000074160	ENSG00000162073	PAQR4	NA	NA	NA	NA
ENSDARG00000076962	ENSDARG00000077284	ENSG00000158555	GDPD5	NA	NA	NA	NA
ENSDARG00000076964	ENSDARG00000017154	ENSG00000149679	CABLES2	NA	NA	NA	NA
ENSDARG00000076970	ENSDARG00000010764	ENSG00000102796	DHRS12	NA	NA	NA	NA
ENSDARG00000076996	ENSDARG00000060618	ENSG00000117408	IPO13	NA	NA	NA	NA
ENSDARG00000077038	ENSDARG00000003877	ENSG00000163939	PBRM1	NA	NA	NA	NA
ENSDARG00000077039	ENSDARG00000076639	ENSG00000149564	ESAM	NA	NA	NA	NA
ENSDARG00000077040	ENSDARG00000074589	ENSG00000132669	RIN2	NA	NA	NA	NA
ENSDARG00000077061	ENSDARG00000078605	ENSG00000160951	PTGER1	NA	NA	NA	NA
ENSDARG00000077083	ENSDARG00000045788	ENSG00000166148	AVPR1A	NA	NA	NA	NA
ENSDARG00000077103	ENSDARG00000062352	ENSG00000196189	SEMA4A	NA	NA	NA	NA
ENSDARG00000077124	ENSDARG00000077545	ENSG00000160469	BRSK1	NA	NA	NA	NA
ENSDARG00000077134	ENSDARG00000079665	ENSG00000151025	GPR158	NA	NA	NA	NA
ENSDARG00000077177	ENSDARG00000063583	ENSG00000065559	MAP2K4	NA	NA	NA	NA
ENSDARG00000077187	ENSDARG00000074839	ENSG00000112706	IMPG1	NA	NA	NA	NA
ENSDARG00000077192	ENSDARG00000044528	ENSG00000088386	SLC15A1	NA	NA	NA	NA
ENSDARG00000077226	ENSDARG00000008350	ENSG00000127616	SMARCA4	NA	NA	NA	NA
ENSDARG00000077228	ENSDARG00000063035	ENSG00000140538	NTRK3	NA	NA	NA	NA
ENSDARG00000077237	ENSDARG00000074522	ENSG00000181827	RFX7	NA	NA	NA	NA
ENSDARG00000077244	ENSDARG00000060847	ENSG00000139718	SETD1B	NA	NA	NA	NA
ENSDARG00000077275	ENSDARG00000013293	ENSG00000121005	CRISPLD1	NA	NA	NA	NA

ENSDARG00000077313	ENSDARG00000079933	ENSG00000139508	SLC46A3	NA	NA	NA	NA
ENSDARG00000077326	ENSDARG00000021820	ENSG00000022567	SLC45A4	NA	NA	NA	NA
ENSDARG00000077352	ENSDARG00000061520	ENSG00000135454	B4GALNT1	NA	NA	NA	NA
ENSDARG00000077399	ENSDARG00000061243	ENSG00000154127	UBASH3B	NA	NA	NA	NA
ENSDARG00000077531	ENSDARG00000075892	ENSG00000204463	BAG6	NA	NA	NA	NA
ENSDARG00000077560	ENSDARG00000078149	ENSG00000161509	GRIN2C	NA	NA	NA	NA
ENSDARG00000077606	ENSDARG00000063359	ENSG00000183876	ARSI	NA	NA	NA	NA
ENSDARG00000077630	ENSDARG00000070683	ENSG00000050165	DKK3	NA	NA	NA	NA
ENSDARG00000077645	ENSDARG00000074600	ENSG00000155269	GPR78	NA	NA	NA	NA
ENSDARG00000077726	ENSDARG00000078525	ENSG00000151014	CCRN4L	NA	NA	NA	NA
ENSDARG00000077740	ENSDARG00000073917	ENSG00000187676	B3GALTL	NA	NA	NA	NA
ENSDARG00000077749	ENSDARG00000077948	ENSG00000166348	USP54	NA	NA	NA	NA
ENSDARG00000077775	ENSDARG00000089549	ENSG00000164929	BAALC	NA	NA	NA	NA
ENSDARG00000077844	ENSDARG00000061070	ENSG00000122863	CHST3	NA	NA	NA	NA
ENSDARG00000077881	ENSDARG00000076233	ENSG00000134121	CHL1	NA	NA	NA	NA
ENSDARG00000077888	ENSDARG00000019185	ENSG00000139737	SLAIN1	NA	NA	NA	NA
ENSDARG00000077906	ENSDARG00000078817	ENSG00000141622	RNF165	NA	NA	NA	NA
ENSDARG00000077996	ENSDARG00000075960	ENSG00000139880	CDH24	NA	NA	NA	NA
ENSDARG00000078022	ENSDARG00000056689	ENSG00000163820	FYCO1	NA	NA	NA	NA
ENSDARG00000078052	ENSDARG00000076299	ENSG00000183798	EMILIN3	NA	NA	NA	NA
ENSDARG00000078061	ENSDARG00000082979	ENSG00000123636	BAZ2B	NA	NA	NA	NA
ENSDARG00000078142	ENSDARG00000074531	ENSG00000008294	SPAG9	NA	NA	NA	NA
ENSDARG00000078151	ENSDARG00000075764	ENSG00000105737	GRIK5	NA	NA	NA	NA
ENSDARG00000078187	ENSDARG00000075815	ENSG00000124140	SLC12A5	NA	NA	NA	NA
ENSDARG00000078202	ENSDARG00000060018	ENSG00000181904	C5orf24	NA	NA	NA	NA
ENSDARG00000078222	ENSDARG00000077477	ENSG00000181409	AATK	NA	NA	NA	NA
ENSDARG00000078259	ENSDARG00000078063	ENSG00000113734	BNIP1	NA	NA	NA	NA
ENSDARG00000078272	ENSDARG00000060846	ENSG00000100314	CABP7	NA	NA	NA	NA
ENSDARG00000078373	ENSDARG00000063037	ENSG00000079435	LIPE	NA	NA	NA	NA
ENSDARG00000078378	ENSDARG00000030173	ENSG00000127191	TRAF2	NA	NA	NA	NA
ENSDARG00000078430	ENSDARG00000025920	ENSG00000156299	TIAM1	NA	NA	NA	NA
ENSDARG00000078440	ENSDARG00000063681	ENSG00000115355	CCDC88A	NA	NA	NA	NA
ENSDARG00000078485	ENSDARG00000075539	ENSG00000101298	SNPH	NA	NA	NA	NA
ENSDARG00000078486	ENSDARG00000077855	ENSG00000180233	ZNRF2	NA	NA	NA	NA
ENSDARG00000078578	ENSDARG00000059886	ENSG00000173065	C17orf63	NA	NA	NA	NA
ENSDARG00000078599	ENSDARG00000074255	ENSG00000155970	EFHA2	NA	NA	NA	NA
ENSDARG00000078603	ENSDARG00000061968	ENSG00000174527	MYO1H	NA	NA	NA	NA
ENSDARG00000078615	ENSDARG00000076499	ENSG00000145390	USP53	NA	NA	NA	NA
ENSDARG00000078618	ENSDARG00000076338	ENSG00000132376	INPP5K	NA	NA	NA	NA
ENSDARG00000078640	ENSDARG00000079252	ENSG00000121104	FAM117A	NA	NA	NA	NA
ENSDARG00000078696	ENSDARG00000077293	ENSG00000166317	SYNPO2L	NA	NA	NA	NA
ENSDARG00000078722	ENSDARG00000079483	ENSG00000130779	CLIP1	NA	NA	NA	NA
ENSDARG00000078755	ENSDARG00000079671	ENSG00000117600	RP4-788L13.1	NA	NA	NA	NA
ENSDARG00000078797	ENSDARG00000013153	ENSG00000105339	DENND3	NA	NA	NA	NA
ENSDARG00000078831	ENSDARG00000076874	ENSG00000011198	ABHD5	NA	NA	NA	NA
ENSDARG00000078878	ENSDARG00000055437	ENSG00000139780	C13orf39	NA	NA	NA	NA
ENSDARG00000078953	ENSDARG00000004633	ENSG00000049283	EPN3	NA	NA	NA	NA
ENSDARG00000078981	ENSDARG00000075956	ENSG00000146267	C6orf168	NA	NA	NA	NA
ENSDARG00000079029	ENSDARG00000077461	ENSG00000089876	DHX32	NA	NA	NA	NA
ENSDARG00000079167	ENSDARG00000074604	ENSG00000173889	PHC3	NA	NA	NA	NA
ENSDARG00000079184	ENSDARG00000075571	ENSG00000185963	BICD2	NA	NA	NA	NA
ENSDARG00000079286	ENSDARG00000042329	ENSG00000186716	BCR	NA	NA	NA	NA
ENSDARG00000079324	ENSDARG00000076320	ENSG00000185101	ANO9	NA	NA	NA	NA
ENSDARG00000079348	ENSDARG00000030376	ENSG00000150086	GRIN2B	NA	NA	NA	NA
ENSDARG00000079369	ENSDARG00000060534	ENSG00000126821	SGPP1	NA	NA	NA	NA
ENSDARG00000079374	ENSDARG00000077506	ENSG00000104067	TJP1	NA	NA	NA	NA
ENSDARG00000079443	ENSDARG00000078247	ENSG00000146469	VIP	NA	NA	NA	NA
ENSDARG00000079484	ENSDARG00000079098	ENSG00000107147	KCNT1	NA	NA	NA	NA
ENSDARG00000079491	ENSDARG00000063282	ENSG00000177272	KCNA3	NA	NA	NA	NA
ENSDARG00000079496	ENSDARG00000074357	ENSG00000151746	BICD1	NA	NA	NA	NA
ENSDARG00000079561	ENSDARG00000074655	ENSG00000116885	OSCP1	NA	NA	NA	NA
ENSDARG00000079572	ENSDARG00000052957	ENSG00000161714	PLCD3	NA	NA	NA	NA
ENSDARG00000079613	ENSDARG00000057586	ENSG00000151514	SALL3	NA	NA	NA	NA
ENSDARG00000079716	ENSDARG00000059812	ENSG00000169375	SIN3A	NA	NA	NA	NA
ENSDARG00000079731	ENSDARG00000073859	ENSG00000197892	KIF13B	NA	NA	NA	NA
ENSDARG00000079790	ENSDARG00000053381	ENSG00000067113	PPAP2A	NA	NA	NA	NA
ENSDARG00000079822	ENSDARG00000079161	ENSG00000164061	BSN	NA	NA	NA	NA
ENSDARG00000079850	ENSDARG00000070025	ENSG00000166341	DCHS1	NA	NA	NA	NA
ENSDARG00000079858	ENSDARG00000088227	ENSG00000152128	TMEM163	NA	NA	NA	NA
ENSDARG00000079876	ENSDARG00000079556	ENSG00000183186	C2CD4C	NA	NA	NA	NA
ENSDARG00000079879	ENSDARG00000060073	ENSG00000117713	ARID1A	NA	NA	NA	NA
ENSDARG00000079895	ENSDARG00000057353	ENSG00000173442	EHBP1L1	NA	NA	NA	NA
ENSDARG00000079898	ENSDARG00000077938	ENSG00000174807	CD248	NA	NA	NA	NA
ENSDARG00000079972	ENSDARG00000076640	ENSG00000101096	NFATC2	NA	NA	NA	NA
ENSDARG00000079977	ENSDARG00000070227	ENSG00000188158	NHS	NA	NA	NA	NA
ENSDARG00000080000	ENSDARG00000076381	ENSG00000100075	SLC25A1	NA	NA	NA	NA
ENSDARG00000086013	ENSDARG00000019301	ENSG00000129657	SEC14L1	NA	NA	NA	NA
ENSDARG00000086104	ENSDARG00000071685	ENSG00000137571	SLCO5A1	NA	NA	NA	NA
ENSDARG00000086109	ENSDARG00000087341	ENSG00000182168	UNC5C	NA	NA	NA	NA
ENSDARG00000086142	ENSDARG00000061798	ENSG00000159314	ARHGAP27	NA	NA	NA	NA
ENSDARG00000086158	ENSDARG00000060022	ENSG00000183287	CCBE1	NA	NA	NA	NA
ENSDARG00000086274	ENSDARG00000017391	ENSG00000198722	UNC13B	NA	NA	NA	NA
ENSDARG00000086450	ENSDARG00000013004	ENSG00000139372	TDG	NA	NA	NA	NA
ENSDARG00000086499	ENSDARG00000070831	ENSG00000131378	RFTN1	NA	NA	NA	NA
ENSDARG00000086762	ENSDARG00000040485	ENSG00000105928	DFNA5	NA	NA	NA	NA
ENSDARG00000086775	ENSDARG00000070545	ENSG00000198900	TOP1	NA	NA	NA	NA
ENSDARG00000086808	ENSDARG00000037042	ENSG00000100523	DDHD1	NA	NA	NA	NA
ENSDARG00000086965	ENSDARG00000059997	ENSG00000122012	SV2C	NA	NA	NA	NA
ENSDARG00000087059	ENSDARG00000057378	ENSG00000122378	C10orf58	NA	NA	NA	NA
ENSDARG00000087086	ENSDARG00000079722	ENSG00000167889	MGAT5B	NA	NA	NA	NA

ENSDARG00000087196	ENSDARG00000039949	ENSG00000176971	FIBIN	NA	NA	NA	NA
ENSDARG00000087260	ENSDARG00000028943	ENSG00000132613	MTSS1L	NA	NA	NA	NA
ENSDARG00000087394	ENSDARG00000015959	ENSG00000121297	TSHZ3	NA	NA	NA	NA
ENSDARG00000087446	ENSDARG00000089090	ENSG00000136297	MMD2	NA	NA	NA	NA
ENSDARG00000087517	ENSDARG00000005544	ENSG00000132640	BTBD3	NA	NA	NA	NA
ENSDARG00000087599	ENSDARG00000005479	ENSG00000218336	ODZ3	NA	NA	NA	NA
ENSDARG00000087646	ENSDARG00000025921	ENSG00000159216	RUNX1	NA	NA	NA	NA
ENSDARG00000087687	ENSDARG00000090990	ENSG00000166292	TMEM100	NA	NA	NA	NA
ENSDARG00000087741	ENSDARG00000008473	ENSG00000239388	ASB14	NA	NA	NA	NA
ENSDARG00000087780	ENSDARG00000040719	ENSG00000146426	TIAM2	NA	NA	NA	NA
ENSDARG00000087983	ENSDARG00000090953	ENSG00000183067	IGSF5	NA	NA	NA	NA
ENSDARG00000088072	ENSDARG00000060632	ENSG00000154914	USP43	NA	NA	NA	NA
ENSDARG00000088121	ENSDARG00000086702	ENSG00000158683	PKD1L1	NA	NA	NA	NA
ENSDARG00000088124	ENSDARG00000054510	ENSG00000169252	ADRB2	NA	NA	NA	NA
ENSDARG00000088137	ENSDARG00000088937	ENSG00000173698	GPR64	NA	NA	NA	NA
ENSDARG00000088466	ENSDARG00000038894	ENSG00000166479	TMX3	NA	NA	NA	NA
ENSDARG00000088521	ENSDARG00000001767	ENSG00000174669	SLC29A2	NA	NA	NA	NA
ENSDARG00000088630	ENSDARG00000074244	ENSG00000074964	ARHGEF10L	NA	NA	NA	NA
ENSDARG00000088813	ENSDARG00000090468	ENSG00000154415	PPP1R3A	NA	NA	NA	NA
ENSDARG00000088842	ENSDARG00000038862	ENSG00000182674	KCNB2	NA	NA	NA	NA
ENSDARG00000088898	ENSDARG00000069766	ENSG00000183166	CALN1	NA	NA	NA	NA
ENSDARG00000089134	ENSDARG00000056680	ENSG00000113739	STC2	NA	NA	NA	NA
ENSDARG00000089190	ENSDARG00000077073	ENSG00000115183	TANC1	NA	NA	NA	NA
ENSDARG00000089233	ENSDARG00000040535	ENSG00000147408	CSGALNACT1	NA	NA	NA	NA
ENSDARG00000089322	ENSDARG00000051827	ENSG00000175318	GRAMD2	NA	NA	NA	NA
ENSDARG00000089334	ENSDARG00000053498	ENSG00000136160	EDNRB	NA	NA	NA	NA
ENSDARG00000089348	ENSDARG00000071325	ENSG00000099625	C19orf26	NA	NA	NA	NA
ENSDARG00000089545	ENSDARG00000043673	ENSG00000183092	BEGAIN	NA	NA	NA	NA
ENSDARG00000089641	ENSDARG00000063218	ENSG00000163590	PPM1L	NA	NA	NA	NA
ENSDARG00000089647	ENSDARG00000013623	ENSG00000165637	VDAC2	NA	NA	NA	NA
ENSDARG00000089805	ENSDARG00000052494	ENSG00000189184	PCDH18	NA	NA	NA	NA
ENSDARG00000089817	ENSDARG00000043864	ENSG00000156642	NPTN	NA	NA	NA	NA
ENSDARG00000089853	ENSDARG00000014313	ENSG00000154723	ATP5J	NA	NA	NA	NA
ENSDARG00000089856	ENSDARG00000088825	ENSG00000122966	CIT	NA	NA	NA	NA
ENSDARG00000089858	ENSDARG00000088979	ENSG00000082438	COBLL1	NA	NA	NA	NA
ENSDARG00000089871	ENSDARG00000088405	ENSG00000165757	KIAA1462	NA	NA	NA	NA
ENSDARG00000089887	ENSDARG00000055479	ENSG00000137674	MMP20	NA	NA	NA	NA
ENSDARG00000089893	ENSDARG00000013346	ENSG00000163946	C3orf63	NA	NA	NA	NA
ENSDARG00000089914	ENSDARG00000025535	ENSG00000113282	CLINT1	NA	NA	NA	NA
ENSDARG00000090106	ENSDARG00000016480	ENSG00000104888	SLC17A7	NA	NA	NA	NA
ENSDARG00000090292	ENSDARG00000089193	ENSG00000184672	RALYL	NA	NA	NA	NA
ENSDARG00000090314	ENSDARG00000088204	ENSG00000234965	SHISA8	NA	NA	NA	NA
ENSDARG00000090340	ENSDARG00000062929	ENSG00000188522	FAM83G	NA	NA	NA	NA
ENSDARG00000090375	ENSDARG00000078989	ENSG00000136383	ALPK3	NA	NA	NA	NA
ENSDARG00000090402	ENSDARG00000067723	ENSG00000136560	TANK	NA	NA	NA	NA
ENSDARG00000090514	ENSDARG00000075433	ENSG00000036448	MYOM2	NA	NA	NA	NA
ENSDARG00000090524	ENSDARG00000079472	ENSG00000164220	F2RL2	NA	NA	NA	NA
ENSDARG00000090585	ENSDARG00000019341	ENSG00000063660	GPC1	NA	NA	NA	NA
ENSDARG00000090631	ENSDARG00000076974	ENSG00000186862	PDZD7	NA	NA	NA	NA
ENSDARG00000090669	ENSDARG00000037576	ENSG00000169676	DRD5	NA	NA	NA	NA
ENSDARG00000090760	ENSDARG00000061021	ENSG00000164142	FAM160A1	NA	NA	NA	NA
ENSDARG00000090933	ENSDARG00000078102	ENSG00000059915	PSD	NA	NA	NA	NA
ENSDARG00000090937	ENSDARG00000077964	ENSG00000144791	LIMD1	NA	NA	NA	NA
ENSDARG00000091053	ENSDARG00000069419	ENSG00000162104	ADCY9	NA	NA	NA	NA
ENSDARG00000091059	ENSDARG00000056395	ENSG00000205922	ONECUT3	NA	NA	NA	NA
ENSDARG00000091163	ENSDARG00000087907	ENSG00000185633	NDUFA4L2	NA	NA	NA	NA
ENSDARG00000091173	ENSDARG00000074515	ENSG00000164418	GRIK2	NA	NA	NA	NA
ENSDARG00000091238	ENSDARG00000010583	ENSG00000148498	PARD3	NA	NA	NA	NA
ENSDARG00000091359	ENSDARG00000059475	ENSG00000076826	KIAA1543	NA	NA	NA	NA
ENSDARG00000091509	ENSDARG00000090963	ENSG00000205464	ATP6AP1L	NA	NA	NA	NA
ENSDARG00000091540	ENSDARG00000031126	ENSG00000185269	NOTUM	NA	NA	NA	NA
ENSDARG00000091550	ENSDARG00000061196	ENSG00000132205	EMILIN2	NA	NA	NA	NA
ENSDARG00000091623	ENSDARG00000086535	ENSG00000164841	TMEM74	NA	NA	NA	NA
ENSDARG00000091637	ENSDARG00000031020	ENSG00000166908	PIP4K2C	NA	NA	NA	NA
ENSDARG00000091902	ENSDARG00000052376	ENSG00000170340	B3GNT2	NA	NA	NA	NA
ENSDARG00000092081	ENSDARG00000058875	ENSG00000243232	PCDHAC2	NA	NA	NA	NA
ENSDARG00000092154	ENSDARG00000087939	ENSG00000164081	TEX264	NA	NA	NA	NA
ENSDARG00000092158	ENSDARG00000003860	ENSG00000122565	CBX3	NA	NA	NA	NA
ENSDARG00000092610	ENSDARG00000077944	ENSG00000185896	LAMP1	NA	NA	NA	NA
ENSDARG00000093021	ENSDARG00000077470	ENSG00000143340	FAM163A	NA	NA	NA	NA
ENSDARG00000093091	ENSDARG00000075792	ENSG00000120645	IQSEC3	NA	NA	NA	NA
ENSDARG00000093357	ENSDARG00000079581	ENSG00000144460	KIAA1486	NA	NA	NA	NA
ENSDARG00000093359	ENSDARG00000078542	ENSG00000185133	INPP5J	NA	NA	NA	NA
ENSDARG00000093401	ENSDARG00000027657	ENSG00000147571	CRH	NA	NA	NA	NA
ENSDARG00000093411	ENSDARG00000027419	ENSG00000128683	GAD1	NA	NA	NA	NA
ENSDARG00000093515	ENSDARG00000026137	ENSG00000144040	SFXN5	NA	NA	NA	NA
ENSDARG00000094052	ENSDARG00000060751	ENSG00000135090	TAOK3	NA	NA	NA	NA
ENSDARG00000094243	ENSDARG00000062109	ENSG00000105251	SHD	NA	NA	NA	NA
ENSDARG00000094255	ENSDARG00000090698	ENSG00000162763	LRRC52	NA	NA	NA	NA
ENSDARG00000094377	ENSDARG00000079978	ENSG00000130590	SAMD10	NA	NA	NA	NA
ENSDARG00000094510	ENSDARG00000088248	ENSG00000135631	RAB11FIP5	NA	NA	NA	NA
ENSDARG00000094665	ENSDARG00000061498	ENSG00000079393	DUSP13	NA	NA	NA	NA
ENSDARG00000094908	ENSDARG00000078527	ENSG00000213171	LINGO4	NA	NA	NA	NA
ENSDARG00000095378	ENSDARG00000073891	ENSG00000107623	GDF10	NA	NA	NA	NA
ENSDARG00000095603	ENSDARG00000076103	ENSG00000215045	GRID2IP	NA	NA	NA	NA
ENSDARG00000095614	ENSDARG00000062346	ENSG00000198216	CACNA1E	NA	NA	NA	NA

3.3 Supplementary table of zebrafish duplicates, with 1-to-1 orthologs in fugu and tetraodon, and with dN/dS values between these orthologs

Zebrafish duplicate 1 Ensembl ID	Fugu 1-to-1 ortholog to duplicate 1	Tetraodon 1-to-1 ortholog to duplicate 1	dN between orthologs to duplicate 1 in Fugu and Tetraodon	dS between orthologs to duplicate 1 in Fugu and Tetraodon
ENSDARG00000001686	ENSTRUG00000003694	ENSTNIG00000012491	0.0257	0.464
ENSDARG00000006600	ENSTRUG00000004046	NA	NA	NA
ENSDARG00000007812	ENSTRUG00000015246	ENSTNIG00000017208	0.0709	0.5179
ENSDARG00000008057	ENSTRUG00000008999	ENSTNIG00000018205	0.0509	0.4802
ENSDARG00000008109	ENSTRUG00000013449	ENSTNIG00000018628	0.1367	0.6169
ENSDARG00000008370	NA	ENSTNIG00000013992	NA	NA
ENSDARG00000009087	ENSTRUG00000007005	ENSTNIG00000007463	0.1819	0.5785
ENSDARG00000009881	ENSTRUG00000010441	ENSTNIG00000011311	0.0805	0.4059
ENSDARG00000011609	ENSTRUG00000003203	ENSTNIG00000010237	0.0798	0.5723
ENSDARG00000012553	ENSTRUG00000006645	ENSTNIG00000012479	0	0.2636
ENSDARG00000012591	ENSTRUG00000015882	ENSTNIG00000017195	0	0.2071
ENSDARG00000012818	ENSTRUG00000012041	NA	NA	NA
ENSDARG00000014794	ENSTRUG00000016072	ENSTNIG00000017979	0.0504	0.3187
ENSDARG00000015823	ENSTRUG00000003226	ENSTNIG00000016183	0.0039	0.3798
ENSDARG00000016255	ENSTRUG00000005853	ENSTNIG00000012012	0.0402	0.7048
ENSDARG00000017010	ENSTRUG00000016531	ENSTNIG00000009578	0.0957	0.9286
ENSDARG00000018602	NA	ENSTNIG00000009196	NA	NA
ENSDARG00000018898	ENSTRUG00000001654	ENSTNIG00000004321	0.0734	0.6122
ENSDARG00000019644	ENSTRUG00000010689	ENSTNIG00000007239	0.0288	0.3484
ENSDARG00000019949	ENSTRUG00000001559	NA	NA	NA
ENSDARG00000023921	ENSTRUG00000009459	ENSTNIG00000011892	0.0095	0.9517
ENSDARG00000030236	ENSTRUG00000009973	ENSTNIG00000016880	0.0956	0.5714
ENSDARG00000030441	ENSTRUG00000006960	ENSTNIG00000008634	0.07	0.525
ENSDARG00000031907	ENSTRUG00000010168	NA	NA	NA
ENSDARG00000032532	ENSTRUG00000008875	NA	NA	NA
ENSDARG00000035066	ENSTRUG00000016692	ENSTNIG00000004271	0.0428	0.5615
ENSDARG00000036236	ENSTRUG00000018235	ENSTNIG00000009206	0.1212	0.5506
ENSDARG00000036715	ENSTRUG00000009274	ENSTNIG00000017570	0.0686	0.4149
ENSDARG00000037860	NA	ENSTNIG00000008121	NA	NA
ENSDARG00000039034	ENSTRUG00000012289	ENSTNIG00000008924	0.1001	0.9476
ENSDARG00000039650	ENSTRUG00000008709	ENSTNIG00000015236	0.0462	0.6518
ENSDARG00000042837	ENSTRUG00000017963	ENSTNIG00000001635	0.2064	0.7382
ENSDARG00000052789	ENSTRUG00000010029	ENSTNIG00000005306	0.0668	0.3453
ENSDARG00000052842	ENSTRUG00000013768	ENSTNIG00000013153	0.0385	0.3796
ENSDARG00000056623	NA	ENSTNIG00000005984	NA	NA
ENSDARG00000058044	ENSTRUG00000004287	NA	NA	NA
ENSDARG00000060150	ENSTRUG00000007262	ENSTNIG00000011164	0.0064	0.4762
ENSDARG00000067975	ENSTRUG00000008805	ENSTNIG00000017577	0.0708	0.2605
ENSDARG00000078113	NA	ENSTNIG00000009134	NA	NA
ENSDARG00000079251	ENSTRUG00000007038	ENSTNIG00000010776	0.0174	0.2772
ENSDARG00000089550	NA	NA	NA	NA
ENSDARG00000090697	ENSTRUG00000005064	ENSTNIG00000015446	0.1108	0.4592
ENSDARG00000031317	ENSTRUG00000005031	ENSTNIG00000001517	0.0394	0.3708
ENSDARG00000053301	ENSTRUG00000007119	ENSTNIG00000000943	0.0256	0.2385
ENSDARG00000011127	ENSTRUG00000006057	ENSTNIG00000012397	0.0379	0.5629
ENSDARG00000032970	ENSTRUG00000018241	ENSTNIG00000000609	0.1421	0.5037
ENSDARG00000011141	ENSTRUG00000009449	ENSTNIG00000019291	0.0278	0.4088
ENSDARG00000036848	ENSTRUG00000011859	ENSTNIG00000009969	0.0343	0.3998
ENSDARG00000037361	ENSTRUG00000006050	ENSTNIG00000010239	0.816	1.5904
ENSDARG00000052928	NA	ENSTNIG00000019582	NA	NA
ENSDARG00000067741	ENSTRUG00000009596	ENSTNIG00000007730	0.0258	0.6065
ENSDARG00000026611	NA	ENSTNIG00000004816	NA	NA
ENSDARG00000041394	ENSTRUG00000005217	ENSTNIG00000014090	0.0399	0.4141
ENSDARG00000012194	ENSTRUG00000012802	ENSTNIG00000006953	0.0213	0.4009
ENSDARG00000068478	ENSTRUG00000018245	ENSTNIG00000013186	0.0337	0.2205
ENSDARG00000055398	NA	ENSTNIG00000001080	NA	NA
ENSDARG00000007671	ENSTRUG00000013005	ENSTNIG00000001787	0.2263	0.8979
ENSDARG00000038159	ENSTRUG00000018634	ENSTNIG00000013604	0.1101	0.5403
ENSDARG00000009418	ENSTRUG00000000877	ENSTNIG00000015441	0.0087	0.2409
ENSDARG00000032369	ENSTRUG00000008962	ENSTNIG00000012385	0.0325	0.6314
ENSDARG00000034700	ENSTRUG00000015230	ENSTNIG00000009142	0.0589	0.2679
ENSDARG00000058992	ENSTRUG00000014385	ENSTNIG00000008063	0.0342	0.3633
ENSDARG00000016238	ENSTRUG00000012296	ENSTNIG00000012561	0.0217	0.1984
ENSDARG00000057093	ENSTRUG00000013308	ENSTNIG00000007074	0.0582	0.3588
ENSDARG00000004702	ENSTRUG00000002487	ENSTNIG00000016653	0.0212	0.3356
ENSDARG00000029439	ENSTRUG00000015616	ENSTNIG00000011446	0.0091	0.3467
ENSDARG00000059391	ENSTRUG00000017735	ENSTNIG00000012755	0.0837	0.4053

ENSDARG00000026882	ENSTRUG00000008119	NA	NA	NA
ENSDARG00000057770	ENSTRUG00000008916	ENSTNIG00000008976	0.1241	0.5873
ENSDARG00000045240	NA	NA	NA	NA
ENSDARG00000003820	ENSTRUG00000009180	NA	NA	NA
ENSDARG00000063309	ENSTRUG00000012412	NA	NA	NA
ENSDARG00000018174	ENSTRUG00000007037	ENSTNIG00000014613	0.0164	0.7159
ENSDARG00000012405	ENSTRUG00000013913	ENSTNIG00000011168	0.0576	0.1265
ENSDARG00000039576	ENSTRUG00000001760	ENSTNIG00000013936	0.075	0.4681
ENSDARG00000011824	ENSTRUG00000006435	ENSTNIG00000018332	0.5524	1.0923
ENSDARG00000042677	ENSTRUG00000007218	ENSTNIG00000016187	0.1071	0.5375
ENSDARG00000028173	NA	NA	NA	NA
ENSDARG00000038267	ENSTRUG00000005717	ENSTNIG00000015802	0.0384	0.3011
ENSDARG00000008170	ENSTRUG00000018633	ENSTNIG00000013603	0.1736	0.5905
ENSDARG00000017339	NA	NA	NA	NA
ENSDARG00000026821	NA	NA	NA	NA
ENSDARG00000006003	ENSTRUG00000011538	ENSTNIG00000017476	0.068	0.537
ENSDARG00000007693	ENSTRUG00000005076	ENSTNIG00000003921	0.0661	0.5255
ENSDARG00000001676	ENSTRUG00000008825	ENSTNIG00000013958	0.0436	0.3796
ENSDARG00000008788	ENSTRUG00000005125	NA	NA	NA
ENSDARG00000010420	ENSTRUG00000010966	ENSTNIG00000009635	0.0531	0.3425
ENSDARG00000042029	NA	ENSTNIG00000010627	NA	NA
ENSDARG00000056490	ENSTRUG00000015567	ENSTNIG00000017202	0.0207	0.2947
ENSDARG00000070475	ENSTRUG00000010001	ENSTNIG00000013071	0.0372	0.3233
ENSDARG00000054274	ENSTRUG00000013565	ENSTNIG00000012372	0.0278	0.3564
ENSDARG00000038666	NA	ENSTNIG00000000894	NA	NA
ENSDARG00000012504	ENSTRUG00000016880	ENSTNIG00000009543	0.0313	0.6024
ENSDARG00000076900	ENSTRUG00000005303	ENSTNIG00000006588	0.1838	0.4459
ENSDARG00000003142	ENSTRUG00000011286	ENSTNIG00000014984	0.0972	0.4242
ENSDARG00000077383	ENSTRUG00000005504	ENSTNIG00000008630	0.0315	0.354
ENSDARG00000034705	NA	ENSTNIG00000018837	NA	NA
ENSDARG00000041062	NA	ENSTNIG00000007000	NA	NA
ENSDARG00000057853	ENSTRUG00000014516	ENSTNIG00000012801	0.0089	0.2705
ENSDARG00000035650	ENSTRUG00000012665	ENSTNIG00000017332	0.0716	0.2935
ENSDARG00000038190	ENSTRUG00000010536	ENSTNIG00000010427	0.0246	0.3478
ENSDARG00000026531	ENSTRUG00000000595	ENSTNIG00000000596	0.2977	0.6501
ENSDARG00000043257	ENSTRUG00000016321	ENSTNIG00000004799	0.0172	0.5825
ENSDARG00000062174	ENSTRUG00000006633	ENSTNIG00000014461	0.0079	0.3314
ENSDARG00000052765	ENSTRUG00000015959	NA	NA	NA
ENSDARG00000040565	ENSTRUG00000006969	ENSTNIG00000018982	0.0232	0.5696
ENSDARG00000004621	ENSTRUG00000010464	ENSTNIG00000014109	0.0446	0.3973
ENSDARG00000019613	ENSTRUG00000008746	ENSTNIG00000014610	0.0259	0.4174
ENSDARG00000009014	ENSTRUG00000000434	ENSTNIG00000014876	0.0564	0.3034
ENSDARG00000043581	ENSTRUG00000006833	ENSTNIG00000006973	0.0475	0.3118
ENSDARG00000004588	ENSTRUG00000011266	ENSTNIG00000009265	0.0067	0.3096
ENSDARG00000032724	ENSTRUG00000000987	ENSTNIG00000010424	0.0353	0.2641
ENSDARG00000037116	ENSTRUG00000013517	NA	NA	NA
ENSDARG00000013144	ENSTRUG00000004970	ENSTNIG00000013777	0.0889	0.6529
ENSDARG00000019815	ENSTRUG00000001374	ENSTNIG00000017053	0.0494	0.3529
ENSDARG00000044808	ENSTRUG00000018460	ENSTNIG00000007486	0.0388	0.4958
ENSDARG00000011239	ENSTRUG00000007053	ENSTNIG00000014242	0.0876	0.556
ENSDARG00000020364	ENSTRUG00000018578	ENSTNIG00000013448	0.0193	0.4368
ENSDARG00000030289	NA	NA	NA	NA
ENSDARG00000070360	ENSTRUG00000007378	ENSTNIG00000014612	0.1059	0.5822
ENSDARG00000013605	ENSTRUG00000005213	ENSTNIG00000004825	0.2177	1.7506
ENSDARG00000022437	ENSTRUG00000013015	ENSTNIG00000013678	0.0648	0.3122
ENSDARG00000000394	NA	ENSTNIG00000003166	NA	NA
ENSDARG00000001241	ENSTRUG00000005420	ENSTNIG00000013675	0.0037	0.1409
ENSDARG00000004754	ENSTRUG00000008366	NA	NA	NA
ENSDARG00000008548	ENSTRUG00000006634	ENSTNIG00000007969	0.0341	0.4408
ENSDARG00000011783	ENSTRUG00000014972	ENSTNIG00000011795	0.028	0.3023
ENSDARG00000016763	ENSTRUG00000005901	ENSTNIG00000017298	0.0728	0.3596
ENSDARG00000018882	ENSTRUG00000016857	ENSTNIG00000015572	0.0669	0.4068
ENSDARG00000019081	NA	NA	NA	NA
ENSDARG00000021996	ENSTRUG00000000495	ENSTNIG00000005350	0.0407	0.9323
ENSDARG00000025789	ENSTRUG00000007202	ENSTNIG00000008031	0.0182	0.4036
ENSDARG00000027423	ENSTRUG00000005173	ENSTNIG00000019227	0.039	0.3527
ENSDARG00000030368	ENSTRUG00000015036	ENSTNIG00000012342	0.0421	0.6816
ENSDARG00000031240	ENSTRUG00000014349	ENSTNIG00000017309	0.0238	0.3151
ENSDARG00000033614	NA	ENSTNIG00000016709	NA	NA
ENSDARG00000035986	ENSTRUG00000006188	ENSTNIG00000009147	0.0797	0.4456
ENSDARG00000036685	ENSTRUG00000007764	ENSTNIG00000007563	0.0704	0.2825
ENSDARG00000037260	ENSTRUG00000003917	ENSTNIG00000018039	0.148	0.6824
ENSDARG00000041735	ENSTRUG00000016941	ENSTNIG00000003776	0.2933	1.5838
ENSDARG00000042489	ENSTRUG00000005307	NA	NA	NA
ENSDARG00000053804	ENSTRUG00000005892	ENSTNIG00000012483	0.0344	0.4948
ENSDARG00000054304	ENSTRUG00000005126	NA	NA	NA
ENSDARG00000054442	ENSTRUG00000012203	ENSTNIG00000010097	0.0049	0.5197
ENSDARG00000056856	ENSTRUG00000015394	ENSTNIG00000018429	0.159	0.5626
ENSDARG00000059870	ENSTRUG00000014806	ENSTNIG00000008067	0.0804	0.5707
ENSDARG00000060316	ENSTRUG00000013763	ENSTNIG00000014769	0.0529	0.3794
ENSDARG00000060586	ENSTRUG00000010767	ENSTNIG00000013692	0.0302	0.3191
ENSDARG00000062469	ENSTRUG00000001835	NA	NA	NA
ENSDARG00000067626	NA	NA	NA	NA
ENSDARG00000073848	ENSTRUG00000017333	ENSTNIG00000014507	0.0365	0.3173
ENSDARG00000074287	ENSTRUG00000018026	ENSTNIG00000009698	0.0103	0.3719
ENSDARG00000076742	ENSTRUG00000011477	ENSTNIG00000009776	0.0159	0.4009
ENSDARG00000077623	NA	ENSTNIG00000016162	NA	NA
ENSDARG00000090156	NA	ENSTNIG00000017213	NA	NA
ENSDARG00000006074	NA	NA	NA	NA
ENSDARG00000032919	ENSTRUG00000016055	NA	NA	NA

ENSDARG00000009081	ENSTRUG00000007730	ENSTNIG00000016729	0.3173	1.0832
ENSDARG00000040988	ENSTRUG00000008984	ENSTNIG00000003478	0.0161	0.363
ENSDARG00000010052	ENSTRUG00000009677	ENSTNIG00000014957	0.0563	0.5641
ENSDARG00000062376	ENSTRUG00000015428	ENSTNIG00000011792	0.0083	0.2714
ENSDARG00000032737	ENSTRUG00000015213	ENSTNIG00000011793	0.0077	0.2109
ENSDARG00000055505	ENSTRUG00000017346	ENSTNIG00000018844	0.1008	0.6396
ENSDARG00000043932	ENSTRUG00000004274	ENSTNIG00000002571	0.0867	0.9073
ENSDARG00000004377	ENSTRUG00000012456	ENSTNIG00000003062	0.1238	0.6021
ENSDARG00000030514	ENSTRUG00000017576	ENSTNIG00000018054	0.109	0.3959
ENSDARG00000009208	ENSTRUG00000010650	NA	NA	NA
ENSDARG00000019302	NA	NA	NA	NA
ENSDARG00000033733	ENSTRUG00000013263	ENSTNIG00000005478	0.0268	0.4382
ENSDARG00000005993	ENSTRUG00000014588	ENSTNIG00000018783	0.0481	0.5683
ENSDARG00000003191	ENSTRUG00000004651	ENSTNIG00000013713	0.0159	0.4698
ENSDARG00000030340	ENSTRUG00000014441	NA	NA	NA
ENSDARG00000014962	ENSTRUG00000006318	ENSTNIG00000018865	0.021	1.1144
ENSDARG00000059244	ENSTRUG00000009061	ENSTNIG00000016275	0.0126	0.2743
ENSDARG00000068629	ENSTRUG00000016437	ENSTNIG00000009586	0.0393	0.4247
ENSDARG00000029761	ENSTRUG00000006945	ENSTNIG00000017759	0.0224	0.5397
ENSDARG00000045694	ENSTRUG00000016741	ENSTNIG00000018501	0.0323	0.3825
ENSDARG00000035820	ENSTRUG00000012466	NA	NA	NA
ENSDARG00000002412	ENSTRUG00000007647	ENSTNIG00000015263	0.0483	0.3759
ENSDARG00000002235	ENSTRUG00000008020	NA	NA	NA
ENSDARG00000042210	ENSTRUG00000013994	ENSTNIG00000019200	0.0322	0.342
ENSDARG00000014233	ENSTRUG00000006162	ENSTNIG00000008939	0.0106	0.4366
ENSDARG00000077556	ENSTRUG00000000834	ENSTNIG00000000332	0.047	0.3673
ENSDARG00000070537	ENSTRUG00000014525	ENSTNIG00000017786	0.0753	1.0742
ENSDARG00000031049	ENSTRUG00000006952	NA	NA	NA
ENSDARG00000023058	ENSTRUG00000004868	ENSTNIG00000019314	0.0413	0.6328
ENSDARG00000037496	NA	NA	NA	NA
ENSDARG00000039615	ENSTRUG00000014840	ENSTNIG00000003830	0.0084	0.3055
ENSDARG00000053248	ENSTRUG00000014528	ENSTNIG00000012087	0.1132	0.6378
ENSDARG00000089464	ENSTRUG00000002124	ENSTNIG00000003105	0.1131	0.634
ENSDARG00000045444	NA	NA	NA	NA
ENSDARG00000034165	ENSTRUG00000016122	ENSTNIG00000008459	0.009	0.3135
ENSDARG00000034893	NA	ENSTNIG00000011157	NA	NA
ENSDARG00000089288	ENSTRUG00000007734	ENSTNIG00000013748	0.0546	0.5809
ENSDARG00000017704	NA	ENSTNIG00000010588	NA	NA
ENSDARG00000005108	ENSTRUG00000018564	ENSTNIG00000013533	0.0697	0.5344
ENSDARG00000014059	ENSTRUG00000018609	ENSTNIG00000013579	0.0321	0.3157
ENSDARG00000062338	ENSTRUG00000017311	ENSTNIG00000005793	0.2329	0.9423
ENSDARG00000041150	ENSTRUG00000017277	ENSTNIG00000009404	0.021	0.3752
ENSDARG00000074639	ENSTRUG00000017871	ENSTNIG00000013618	0.2056	0.5634
ENSDARG00000020219	ENSTRUG00000006183	ENSTNIG00000005347	0.1198	0.6758
ENSDARG00000002336	NA	NA	NA	NA
ENSDARG00000003910	ENSTRUG00000007405	ENSTNIG00000003289	0.0288	0.3794
ENSDARG00000004154	ENSTRUG00000010189	ENSTNIG00000009086	0.0153	0.6022
ENSDARG00000004771	ENSTRUG00000010032	ENSTNIG00000013917	0.2014	0.4255
ENSDARG00000010641	ENSTRUG00000010138	ENSTNIG00000009119	0.2668	0.817
ENSDARG00000011407	ENSTRUG00000010345	ENSTNIG00000014825	0.0362	0.2748
ENSDARG00000011583	NA	NA	NA	NA
ENSDARG00000012458	ENSTRUG00000012950	ENSTNIG00000008278	0.0359	0.3863
ENSDARG00000013274	ENSTRUG00000000960	ENSTNIG00000005642	0.0221	0.388
ENSDARG00000015015	ENSTRUG00000017052	NA	NA	NA
ENSDARG00000016187	ENSTRUG00000005220	NA	NA	NA
ENSDARG00000016263	ENSTRUG00000008381	ENSTNIG00000019681	0.0262	0.4408
ENSDARG00000019842	ENSTRUG00000007248	ENSTNIG00000005663	0.0641	0.4484
ENSDARG00000020123	ENSTRUG00000014182	ENSTNIG00000010950	0.0182	0.3915
ENSDARG00000021193	ENSTRUG00000011491	ENSTNIG00000009074	0.0105	0.3578
ENSDARG00000021380	ENSTRUG00000007635	ENSTNIG00000014392	0.0582	0.3165
ENSDARG00000022768	ENSTRUG00000005472	ENSTNIG00000017881	0.0084	0.2747
ENSDARG00000026582	ENSTRUG00000011436	ENSTNIG00000009075	0.027	0.5698
ENSDARG00000030267	ENSTRUG00000007067	ENSTNIG00000006308	0.0759	0.5234
ENSDARG00000031560	ENSTRUG00000008180	ENSTNIG00000006793	0.0813	0.3327
ENSDARG00000031770	ENSTRUG00000016561	ENSTNIG00000012858	0.0048	0.3316
ENSDARG00000034189	ENSTRUG00000009412	ENSTNIG00000007922	0.0207	0.3307
ENSDARG00000035458	ENSTRUG00000006333	ENSTNIG00000018939	0.022	0.2422
ENSDARG00000039681	ENSTRUG00000008882	ENSTNIG00000002696	0.0243	0.4973
ENSDARG00000040184	ENSTRUG00000014766	ENSTNIG00000002821	0.0207	0.6685
ENSDARG00000041317	ENSTRUG00000008041	ENSTNIG00000005099	0.0863	0.4297
ENSDARG00000041602	ENSTRUG00000011556	ENSTNIG00000010360	0.066	0.4339
ENSDARG00000045927	ENSTRUG00000015947	ENSTNIG00000008451	0.0126	0.3434
ENSDARG00000052099	ENSTRUG00000011397	ENSTNIG00000003261	0.1078	0.457
ENSDARG00000052438	NA	NA	NA	NA
ENSDARG00000052851	NA	NA	NA	NA
ENSDARG00000053326	ENSTRUG00000015938	ENSTNIG00000017192	0.0034	0.1707
ENSDARG00000053571	ENSTRUG00000012216	ENSTNIG00000018681	0.0546	0.4809
ENSDARG00000054272	ENSTRUG00000017061	ENSTNIG00000016043	0.0463	0.2782
ENSDARG00000055540	ENSTRUG00000010555	ENSTNIG00000007096	0.0168	0.3726
ENSDARG00000056252	ENSTRUG00000004017	ENSTNIG00000015137	0.0516	0.3425
ENSDARG00000059653	ENSTRUG00000005339	ENSTNIG00000003239	0.0916	0.592
ENSDARG00000060065	ENSTRUG00000005653	NA	NA	NA
ENSDARG00000060297	ENSTRUG00000014756	ENSTNIG00000011798	0.007	0.4529
ENSDARG00000067605	NA	NA	NA	NA
ENSDARG00000070145	ENSTRUG00000012813	NA	NA	NA
ENSDARG00000074020	NA	NA	NA	NA
ENSDARG00000076810	ENSTRUG00000008928	ENSTNIG00000004718	0.0688	0.5507
ENSDARG00000077178	ENSTRUG00000003138	ENSTNIG00000003578	0.0549	0.3425
ENSDARG00000078772	ENSTRUG00000004447	ENSTNIG00000004210	0.1077	0.4914
ENSDARG00000092112	ENSTRUG00000004364	ENSTNIG00000006409	0.0543	0.3327

ENSDARG00000032865	ENSTRUG00000011060	ENSTNIG00000012576	0.0099	0.1555
ENSDARG00000003991	ENSTRUG00000008468	ENSTNIG00000017175	0.0574	0.6568
ENSDARG00000034710	ENSTRUG00000008373	ENSTNIG00000015795	0.1603	0.4479
ENSDARG00000062948	ENSTRUG00000016893	ENSTNIG00000010028	0.0482	0.2267
ENSDARG00000031622	ENSTRUG00000009236	ENSTNIG00000014531	0.076	0.4759
ENSDARG00000006395	ENSTRUG00000017964	ENSTNIG00000012222	0.032	0.4576
ENSDARG00000011157	ENSTRUG00000007257	ENSTNIG00000014906	0.1604	0.7812
ENSDARG00000036107	ENSTRUG00000003416	ENSTNIG00000005009	0.0575	0.9972
ENSDARG00000008697	NA	ENSTNIG00000019821	NA	NA
ENSDARG00000075261	ENSTRUG00000011232	ENSTNIG00000009774	0.0554	0.3236
ENSDARG00000077671	ENSTRUG00000011318	NA	NA	NA
ENSDARG00000017441	ENSTRUG00000008767	ENSTNIG00000008325	0.0176	0.2955
ENSDARG00000016676	NA	NA	NA	NA
ENSDARG00000002787	ENSTRUG00000015125	ENSTNIG00000008436	0.0205	0.3921
ENSDARG00000026166	ENSTRUG00000005686	ENSTNIG00000010227	0.232	0.8395
ENSDARG00000043317	ENSTRUG00000015193	ENSTNIG00000017656	0.0537	0.3461
ENSDARG00000006982	NA	ENSTNIG00000010999	NA	NA
ENSDARG00000017128	ENSTRUG00000010522	ENSTNIG00000008653	0.0782	0.3987
ENSDARG00000039117	ENSTRUG00000017028	ENSTNIG00000012940	0.1278	0.7279
ENSDARG00000021065	ENSTRUG00000018591	ENSTNIG00000013568	0.024	0.3195
ENSDARG00000006901	ENSTRUG00000005739	ENSTNIG00000004922	0.0642	0.45
ENSDARG00000019098	ENSTRUG00000017050	ENSTNIG00000016039	0.0397	0.4485
ENSDARG00000019702	ENSTRUG00000017142	ENSTNIG00000009974	0.0249	0.4107
ENSDARG00000036082	NA	NA	NA	NA
ENSDARG00000032714	ENSTRUG00000000702	ENSTNIG00000007666	0.0278	0.3468
ENSDARG00000009461	ENSTRUG00000015974	ENSTNIG00000001582	0.0312	0.2912
ENSDARG00000000161	ENSTRUG00000015752	ENSTNIG00000016308	0.0236	0.4334
ENSDARG00000031782	ENSTRUG00000002591	ENSTNIG00000000890	0.1074	0.4148
ENSDARG00000034643	ENSTRUG00000009493	ENSTNIG00000006814	0.0358	0.4256
ENSDARG00000040295	ENSTRUG00000000934	ENSTNIG00000006406	0.3149	0.4062
ENSDARG00000044655	ENSTRUG00000013632	ENSTNIG00000002566	0.1224	0.8056
ENSDARG00000062116	ENSTRUG00000008918	ENSTNIG00000007924	0.0211	0.4889
ENSDARG00000013613	ENSTRUG00000005702	ENSTNIG00000007889	0.0434	0.4887
ENSDARG00000055565	ENSTRUG00000008881	ENSTNIG00000018655	0.012	0.3602
ENSDARG00000032808	ENSTRUG00000015667	ENSTNIG00000018065	0.2228	0.4038
ENSDARG00000002642	ENSTRUG00000002216	ENSTNIG00000010690	0.0082	0.4522
ENSDARG00000045540	ENSTRUG00000006924	ENSTNIG00000000032	0.0179	0.5887
ENSDARG00000053535	ENSTRUG00000017236	ENSTNIG00000009433	0.4916	0.8
ENSDARG00000007220	ENSTRUG00000007164	ENSTNIG00000016188	0.0734	0.4295
ENSDARG00000041348	ENSTRUG00000016986	ENSTNIG00000009520	0.0561	0.4194
ENSDARG00000004861	ENSTRUG00000001481	ENSTNIG00000017714	0.0093	0.2237
ENSDARG00000056633	ENSTRUG00000007939	NA	NA	NA
ENSDARG00000055373	ENSTRUG00000014242	ENSTNIG00000007335	0.0111	0.3208
ENSDARG00000003971	ENSTRUG00000008697	ENSTNIG00000008382	0.0081	0.2855
ENSDARG00000035084	ENSTRUG00000004283	ENSTNIG00000007882	0.0322	0.4271
ENSDARG00000009567	ENSTRUG00000003675	ENSTNIG00000008876	0.0247	0.3389
ENSDARG00000026329	ENSTRUG00000009200	ENSTNIG00000008740	0.049	0.4404
ENSDARG00000051912	ENSTRUG00000002894	ENSTNIG00000013289	0.0963	0.6036
ENSDARG00000056765	ENSTRUG00000014497	NA	NA	NA
ENSDARG00000060081	ENSTRUG00000001637	ENSTNIG00000010591	0.0803	0.6107
ENSDARG00000026109	ENSTRUG00000011336	ENSTNIG00000001291	0.3752	1.1268
ENSDARG00000062674	ENSTRUG00000008803	ENSTNIG00000005489	0.0476	0.6596
ENSDARG00000074245	ENSTRUG00000001017	ENSTNIG00000010907	0.0799	0.4256
ENSDARG00000053254	ENSTRUG00000008394	ENSTNIG00000014927	0.0068	0.4884
ENSDARG00000004836	ENSTRUG00000004022	NA	NA	NA
ENSDARG00000002748	ENSTRUG00000003699	ENSTNIG00000005386	0.1212	0.7868
ENSDARG00000092810	ENSTRUG00000006357	ENSTNIG00000015335	0.0167	0.3206
ENSDARG00000076030	ENSTRUG00000015617	ENSTNIG00000015098	0.0178	0.3015
ENSDARG00000046019	ENSTRUG00000000419	ENSTNIG00000003865	0.027	0.5213
ENSDARG00000009727	NA	ENSTNIG00000014674	NA	NA
ENSDARG00000079011	ENSTRUG00000008948	ENSTNIG00000013322	0.1361	0.4072
ENSDARG00000070220	ENSTRUG00000015061	ENSTNIG00000016300	0.0089	0.2647
ENSDARG00000020450	ENSTRUG00000006483	NA	NA	NA
ENSDARG00000079396	ENSTRUG00000010599	ENSTNIG00000010739	0.0181	0.2936
ENSDARG00000010563	NA	NA	NA	NA
ENSDARG00000034181	ENSTRUG00000006761	ENSTNIG00000012382	0.0966	0.6118
ENSDARG00000039684	NA	ENSTNIG00000012314	NA	NA
ENSDARG00000003732	ENSTRUG00000001600	ENSTNIG00000007360	0.0335	0.5242
ENSDARG00000008723	ENSTRUG00000009582	ENSTNIG00000005453	0.007	0.3193
ENSDARG00000039051	ENSTRUG00000008732	ENSTNIG00000007925	0.0352	0.46
ENSDARG00000057223	ENSTRUG00000015156	ENSTNIG00000016669	0.0512	0.3595
ENSDARG00000005161	ENSTRUG00000015872	ENSTNIG00000010519	0.0327	0.3202
ENSDARG00000069708	ENSTRUG00000005720	ENSTNIG00000015462	0.0082	0.4795
ENSDARG00000056653	ENSTRUG00000010547	NA	NA	NA
ENSDARG00000069843	ENSTRUG00000010608	ENSTNIG00000014991	0.0279	0.469
ENSDARG00000032859	ENSTRUG00000007744	NA	NA	NA
ENSDARG00000034522	NA	NA	NA	NA
ENSDARG00000041165	NA	ENSTNIG00000019308	NA	NA
ENSDARG00000044295	NA	NA	NA	NA
ENSDARG00000052254	NA	NA	NA	NA
ENSDARG00000003216	ENSTRUG00000011041	ENSTNIG00000008392	0.037	0.282
ENSDARG00000017311	ENSTRUG00000014852	ENSTNIG00000015297	0.0311	0.5098
ENSDARG00000018865	ENSTRUG00000018670	ENSTNIG00000009032	0.0351	0.3926
ENSDARG00000034497	ENSTRUG00000012497	NA	NA	NA
ENSDARG00000041323	ENSTRUG00000017020	ENSTNIG00000012937	0.0358	0.4599
ENSDARG00000014179	ENSTRUG00000015992	ENSTNIG00000015110	0.0269	0.5827
ENSDARG00000015681	ENSTRUG00000006315	ENSTNIG00000003519	0.0332	0.4712
ENSDARG00000053453	ENSTRUG00000010753	ENSTNIG00000011154	0.0231	0.4207
ENSDARG00000053753	NA	NA	NA	NA
ENSDARG00000058128	ENSTRUG00000012243	NA	NA	NA

ENSDARG00000078452	ENSTRUG00000006994	ENSTNIG00000009746	0.0209	0.506
ENSDARG00000001804	NA	ENSTNIG00000009784	NA	NA
ENSDARG00000015025	ENSTRUG00000010688	ENSTNIG00000003492	0.1324	0.5206
ENSDARG00000039528	ENSTRUG00000006451	NA	NA	NA
ENSDARG00000002696	ENSTRUG00000000211	ENSTNIG00000004096	0.0157	0.3665
ENSDARG00000015901	NA	NA	NA	NA
ENSDARG00000056998	ENSTRUG00000001963	ENSTNIG00000005830	0.0828	0.3936
ENSDARG00000014651	ENSTRUG00000003440	NA	NA	NA
ENSDARG00000074635	ENSTRUG00000015743	ENSTNIG00000018062	0.022	0.4023
ENSDARG00000032578	ENSTRUG00000011987	ENSTNIG00000019400	0.0104	0.1216
ENSDARG00000041660	ENSTRUG00000010376	ENSTNIG00000014036	0.0779	0.9683
ENSDARG00000055080	ENSTRUG00000013328	ENSTNIG00000000316	0.0366	0.3492
ENSDARG00000027740	ENSTRUG00000010059	ENSTNIG00000018649	0.0366	0.156
ENSDARG00000052470	ENSTRUG00000013702	ENSTNIG00000008344	0.0344	0.4344
ENSDARG00000013317	ENSTRUG00000013364	NA	NA	NA
ENSDARG00000016934	ENSTRUG00000017969	ENSTNIG00000014453	0.0574	0.6315
ENSDARG00000055481	ENSTRUG00000007560	ENSTNIG00000014570	0.0591	0.3199
ENSDARG00000007609	NA	ENSTNIG00000009207	NA	NA
ENSDARG00000009045	ENSTRUG00000015981	ENSTNIG00000001767	0.0245	0.3274
ENSDARG00000018032	NA	ENSTNIG00000013615	NA	NA
ENSDARG00000036036	NA	NA	NA	NA
ENSDARG00000058656	ENSTRUG00000013833	NA	NA	NA
ENSDARG00000052764	ENSTRUG00000006363	ENSTNIG00000012037	0.0151	0.3444
ENSDARG00000001710	ENSTRUG00000004775	ENSTNIG00000018187	0.0292	0.4429
ENSDARG00000007714	ENSTRUG00000003621	ENSTNIG00000011965	0.0504	0.52
ENSDARG00000025071	ENSTRUG00000005613	ENSTNIG00000002972	0.1461	0.5718
ENSDARG00000025397	NA	ENSTNIG00000014643	NA	NA
ENSDARG00000037675	ENSTRUG00000008105	ENSTNIG00000013057	0.0634	0.309
ENSDARG00000029596	NA	ENSTNIG00000004908	NA	NA
ENSDARG00000041609	ENSTRUG00000006297	ENSTNIG00000014498	0.0247	0.3645
ENSDARG00000030326	ENSTRUG00000010820	ENSTNIG00000017558	0.0307	0.4135
ENSDARG00000030547	ENSTRUG00000000426	NA	NA	NA
ENSDARG00000030630	ENSTRUG00000011635	ENSTNIG00000000180	0.097	0.4906
ENSDARG00000052654	ENSTRUG00000003867	ENSTNIG00000003353	0.0012	0.4884
ENSDARG00000075752	ENSTRUG00000010843	ENSTNIG00000011837	0.0499	0.3101
ENSDARG00000076448	ENSTRUG00000005191	NA	NA	NA
ENSDARG00000092060	ENSTRUG00000016260	ENSTNIG00000015908	0.0462	0.437
ENSDARG00000002037	ENSTRUG00000011040	ENSTNIG00000003857	0.047	0.9203
ENSDARG00000006283	ENSTRUG00000016634	ENSTNIG00000018486	0.0865	0.588
ENSDARG00000008807	ENSTRUG00000007558	ENSTNIG00000015262	0.0299	0.4829
ENSDARG00000009136	ENSTRUG00000012198	ENSTNIG00000008659	0.0301	0.3591
ENSDARG00000017397	ENSTRUG00000002300	ENSTNIG00000003672	0.0366	0.4337
ENSDARG00000025728	ENSTRUG00000013382	ENSTNIG00000006046	0.0286	0.8166
ENSDARG00000035122	ENSTRUG00000016586	ENSTNIG00000015593	0.0504	0.3402
ENSDARG00000037403	NA	NA	NA	NA
ENSDARG00000042791	ENSTRUG00000013096	ENSTNIG00000009062	0.0253	0.3789
ENSDARG00000045064	ENSTRUG00000014662	ENSTNIG00000012806	0.1023	0.3761
ENSDARG00000070863	ENSTRUG00000009631	ENSTNIG00000006435	0.1774	0.4994
ENSDARG00000016293	ENSTRUG00000006723	NA	NA	NA
ENSDARG00000044098	ENSTRUG00000012225	ENSTNIG00000018682	0.0696	0.7458
ENSDARG00000007786	ENSTRUG00000008236	ENSTNIG00000019533	0.0116	0.4263
ENSDARG00000011886	NA	NA	NA	NA
ENSDARG00000007990	ENSTRUG00000006559	ENSTNIG00000013806	0.031	0.2647
ENSDARG00000008263	ENSTRUG00000013327	ENSTNIG00000012550	0.0649	0.3928
ENSDARG00000017554	NA	NA	NA	NA
ENSDARG00000074369	ENSTRUG00000008677	ENSTNIG00000016271	0.033	0.3436
ENSDARG00000078954	ENSTRUG00000008509	ENSTNIG00000018176	0.0717	0.643
ENSDARG00000062129	ENSTRUG00000013997	ENSTNIG00000012542	0.0744	0.5419
ENSDARG00000062262	ENSTRUG00000017482	ENSTNIG00000011251	0.1137	0.6017
ENSDARG00000037790	ENSTRUG00000010231	ENSTNIG00000011947	0.0459	0.3104
ENSDARG00000040725	NA	NA	NA	NA
ENSDARG00000044895	ENSTRUG00000005359	ENSTNIG00000007291	0.0778	0.4551
ENSDARG00000058488	ENSTRUG00000003097	ENSTNIG00000005324	0.1785	56.0463
ENSDARG00000056617	NA	NA	NA	NA
ENSDARG00000003994	ENSTRUG00000008469	ENSTNIG00000013815	0.0392	0.3907
ENSDARG00000005343	ENSTRUG00000013723	ENSTNIG00000012075	0.03	0.3703
ENSDARG00000020847	ENSTRUG00000015258	ENSTNIG00000011704	0.0192	0.3967
ENSDARG00000035175	ENSTRUG00000004730	ENSTNIG00000007705	0.0279	0.6462
ENSDARG00000036593	ENSTRUG00000005276	ENSTNIG00000006287	0.0207	0.7022
ENSDARG00000037748	NA	NA	NA	NA
ENSDARG00000038855	ENSTRUG00000011216	ENSTNIG00000018642	0.0122	0.6903
ENSDARG00000042115	ENSTRUG00000013769	ENSTNIG00000016447	0.0163	0.43
ENSDARG00000052782	NA	NA	NA	NA
ENSDARG00000061551	NA	NA	NA	NA
ENSDARG00000004455	ENSTRUG00000000923	ENSTNIG00000008535	0.0643	0.7097
ENSDARG00000086585	ENSTRUG00000006829	ENSTNIG00000004640	0.0446	0.2389
ENSDARG00000006420	ENSTRUG00000011106	ENSTNIG00000018902	0.0794	0.4008
ENSDARG00000011703	ENSTRUG00000015488	ENSTNIG00000017652	0.0537	0.3834
ENSDARG00000011948	ENSTRUG00000007600	ENSTNIG00000014905	0.0434	0.6765
ENSDARG00000018260	ENSTRUG00000011215	ENSTNIG00000007091	0.066	0.3637
ENSDARG00000025319	ENSTRUG00000003538	ENSTNIG00000005722	0.0996	0.4096
ENSDARG00000044016	ENSTRUG00000015100	ENSTNIG00000002816	0.0622	0.7445
ENSDARG00000060036	ENSTRUG00000007708	ENSTNIG00000018027	0.0377	0.2958
ENSDARG00000062416	ENSTRUG00000001355	ENSTNIG00000006815	0.0495	0.3303
ENSDARG00000071562	ENSTRUG00000009546	ENSTNIG00000004213	0.1683	0.5432
ENSDARG00000077207	ENSTRUG00000004530	ENSTNIG00000014425	0.0754	0.7855
ENSDARG00000004729	ENSTRUG00000005584	ENSTNIG00000019469	0.0989	0.9049
ENSDARG00000003020	ENSTRUG00000013375	NA	NA	NA
ENSDARG00000053479	ENSTRUG00000004399	ENSTNIG00000006883	0.0315	0.2661
ENSDARG00000044457	ENSTRUG00000000415	ENSTNIG00000000651	0.137	0.8922

ENSDARG00000037266	ENSTRUG00000014201	ENSTNIG00000012362	0.1659	0.5959
ENSDARG00000013695	ENSTRUG00000014748	ENSTNIG00000008261	0.0772	0.7849
ENSDARG00000044253	ENSTRUG00000004286	ENSTNIG00000013227	0.0178	0.5413
ENSDARG00000005883	ENSTRUG00000012387	ENSTNIG00000003294	0.0343	0.224
ENSDARG00000006240	ENSTRUG00000014236	ENSTNIG00000018546	0.0329	0.3208
ENSDARG00000016809	ENSTRUG00000005663	ENSTNIG00000014041	0.0137	0.3425
ENSDARG00000017023	ENSTRUG00000008091	ENSTNIG00000006199	0.1959	0.5544
ENSDARG00000020944	ENSTRUG00000008111	ENSTNIG00000010533	0.0552	0.8127
ENSDARG00000037917	NA	ENSTNIG00000005130	NA	NA
ENSDARG00000058327	NA	NA	NA	NA
ENSDARG00000059805	NA	NA	NA	NA
ENSDARG00000061651	ENSTRUG00000005540	ENSTNIG00000004546	0.0851	0.8283
ENSDARG00000070319	ENSTRUG00000011924	ENSTNIG00000003236	0.0294	0.4377
ENSDARG00000089885	ENSTRUG00000004915	ENSTNIG00000010375	0.0937	0.3256
ENSDARG00000034588	ENSTRUG00000000432	ENSTNIG00000005129	0.0892	0.3751
ENSDARG00000029204	ENSTRUG00000012615	ENSTNIG00000011318	0.0263	0.7566
ENSDARG00000007788	ENSTRUG00000001560	ENSTNIG00000016067	0.0287	0.3723
ENSDARG00000009196	ENSTRUG00000001925	ENSTNIG00000016714	0.0778	0.4342
ENSDARG00000011466	ENSTRUG00000004950	ENSTNIG00000019315	0.0183	0.5849
ENSDARG00000012574	ENSTRUG00000009332	ENSTNIG00000014161	0.0703	0.3809
ENSDARG00000014137	ENSTRUG00000005633	ENSTNIG00000016174	0.0169	0.2714
ENSDARG00000014840	ENSTRUG00000004626	ENSTNIG00000013386	0.0182	0.4738
ENSDARG00000015252	ENSTRUG00000007567	ENSTNIG00000006978	0.0492	0.3552
ENSDARG00000015968	ENSTRUG00000005529	ENSTNIG00000007717	0.0629	0.5547
ENSDARG00000019179	ENSTRUG00000009508	ENSTNIG00000008647	0.0229	0.3052
ENSDARG00000024759	NA	ENSTNIG00000014168	NA	NA
ENSDARG00000033411	ENSTRUG00000011218	ENSTNIG00000009080	0.1418	1.1994
ENSDARG00000035676	ENSTRUG00000015716	ENSTNIG00000001611	0.0149	0.3285
ENSDARG00000037285	ENSTRUG00000015688	NA	NA	NA
ENSDARG00000041295	ENSTRUG00000004856	ENSTNIG00000012095	0	0.2799
ENSDARG00000044362	ENSTRUG00000012195	ENSTNIG00000016130	0.0237	0.3382
ENSDARG00000044475	ENSTRUG00000006040	NA	NA	NA
ENSDARG00000045156	ENSTRUG00000017994	ENSTNIG00000014458	0.047	0.4897
ENSDARG00000045803	ENSTRUG00000015729	ENSTNIG00000010392	0.1252	0.9387
ENSDARG00000051748	ENSTRUG00000001816	ENSTNIG00000008809	0.0167	0.2101
ENSDARG00000051798	ENSTRUG00000016114	ENSTNIG00000010401	0.1222	1.0236
ENSDARG00000052417	ENSTRUG00000006864	ENSTNIG00000011256	0.1634	0.5612
ENSDARG00000053246	ENSTRUG00000001266	NA	NA	NA
ENSDARG00000053875	ENSTRUG00000012111	ENSTNIG00000016129	0.0145	0.2212
ENSDARG00000056743	ENSTRUG00000017439	ENSTNIG00000000292	0.0804	1.1875
ENSDARG00000060697	ENSTRUG00000015234	ENSTNIG00000018468	0.0597	0.4085
ENSDARG00000063295	ENSTRUG00000004910	ENSTNIG00000014117	0.0751	0.6431
ENSDARG00000068822	ENSTRUG00000018581	NA	NA	NA
ENSDARG00000069910	ENSTRUG00000017183	ENSTNIG00000010292	0.2707	0.9954
ENSDARG00000070835	ENSTRUG00000004150	NA	NA	NA
ENSDARG00000071159	NA	ENSTNIG00000000090	NA	NA
ENSDARG00000078507	ENSTRUG00000006709	ENSTNIG00000017057	0.0358	0.4602
ENSDARG00000039399	ENSTRUG00000001182	NA	NA	NA
ENSDARG00000078671	NA	ENSTNIG00000001286	NA	NA
ENSDARG00000009477	NA	NA	NA	NA
ENSDARG00000025302	ENSTRUG00000006613	ENSTNIG00000016191	0.1142	0.444
ENSDARG00000061096	ENSTRUG00000010609	ENSTNIG00000003435	0.0858	0.6672
ENSDARG00000077219	NA	ENSTNIG00000005636	NA	NA
ENSDARG00000000369	ENSTRUG00000007613	ENSTNIG00000015647	0.0472	0.3595
ENSDARG00000000370	NA	ENSTNIG00000019124	NA	NA
ENSDARG00000001452	ENSTRUG00000013948	ENSTNIG00000016539	0.1256	0.4576
ENSDARG00000001712	NA	NA	NA	NA
ENSDARG00000001803	ENSTRUG00000009514	ENSTNIG00000014933	0.0512	0.584
ENSDARG00000001880	ENSTRUG00000013797	ENSTNIG00000013138	0.014	0.3706
ENSDARG00000001933	ENSTRUG00000005433	ENSTNIG00000015228	0.04	0.4498
ENSDARG00000002013	ENSTRUG00000013116	ENSTNIG00000009253	0.0495	0.368
ENSDARG00000002483	ENSTRUG00000008597	ENSTNIG00000017935	0.006	0.1951
ENSDARG00000002546	ENSTRUG00000001646	ENSTNIG00000018928	0.0426	0.3191
ENSDARG00000002576	ENSTRUG00000008562	ENSTNIG00000015214	0.0151	0.263
ENSDARG00000002614	NA	ENSTNIG00000017571	NA	NA
ENSDARG00000002635	ENSTRUG00000017364	ENSTNIG00000014511	0.0145	0.3318
ENSDARG00000002656	ENSTRUG00000018383	ENSTNIG00000012252	0.0686	0.3915
ENSDARG00000002682	ENSTRUG00000006818	ENSTNIG00000014359	0.0342	0.8301
ENSDARG00000002771	ENSTRUG00000007729	ENSTNIG00000018868	0.0314	0.57
ENSDARG00000002898	ENSTRUG00000012452	ENSTNIG00000007082	0.0739	0.4276
ENSDARG00000002917	NA	NA	NA	NA
ENSDARG00000003022	ENSTRUG00000010715	ENSTNIG00000003310	0.0771	0.4454
ENSDARG00000003303	ENSTRUG00000002135	ENSTNIG00000019446	0.0696	0.6807
ENSDARG00000003326	ENSTRUG00000000752	ENSTNIG00000014130	0.0834	0.6549
ENSDARG00000003533	ENSTRUG00000012571	ENSTNIG00000010265	0.1042	0.4106
ENSDARG00000003779	NA	ENSTNIG00000017608	NA	NA
ENSDARG00000003836	ENSTRUG00000010221	ENSTNIG00000016625	0.0333	0.4154
ENSDARG00000003899	ENSTRUG00000000900	ENSTNIG00000012724	0.1056	0.3914
ENSDARG00000004026	NA	ENSTNIG00000017444	NA	NA
ENSDARG00000004322	ENSTRUG00000012280	ENSTNIG00000009782	0.063	0.4645
ENSDARG00000004592	ENSTRUG00000010205	ENSTNIG00000007247	0.0591	0.9387
ENSDARG00000004597	ENSTRUG00000005710	ENSTNIG00000002646	0.0173	0.6081
ENSDARG00000004618	ENSTRUG00000009162	ENSTNIG00000000082	0.1341	0.3939
ENSDARG00000004643	ENSTRUG00000009404	ENSTNIG00000008646	0.0335	0.3648
ENSDARG00000004648	ENSTRUG00000007820	ENSTNIG00000008947	0.0391	0.3933
ENSDARG00000004830	ENSTRUG00000000514	ENSTNIG00000008530	0.0084	0.6769
ENSDARG00000005002	ENSTRUG00000016217	ENSTNIG00000004803	0.0587	0.4288
ENSDARG00000005141	ENSTRUG00000014152	ENSTNIG00000007334	0.0526	0.4914
ENSDARG00000005271	NA	NA	NA	NA
ENSDARG00000005364	ENSTRUG00000011772	ENSTNIG00000006658	0.0558	0.4796

ENSDARG00000005377	ENSTRUG00000004199	ENSTNIG00000019488	0.0465	0.3315
ENSDARG00000005397	ENSTRUG00000005754	ENSTNIG00000009935	0.0152	0.5733
ENSDARG00000005485	ENSTRUG00000016930	NA	NA	NA
ENSDARG00000005549	ENSTRUG00000002213	ENSTNIG00000011367	0.022	0.7228
ENSDARG00000005578	ENSTRUG00000008604	ENSTNIG00000002732	0.0372	0.9094
ENSDARG00000005625	ENSTRUG00000011058	ENSTNIG00000009268	0.0166	0.2444
ENSDARG00000005626	ENSTRUG00000000596	ENSTNIG00000000639	0.1174	1.0871
ENSDARG00000005670	ENSTRUG00000009875	NA	NA	NA
ENSDARG00000005673	ENSTRUG00000003042	ENSTNIG00000004579	0.5123	4.949
ENSDARG00000005679	ENSTRUG00000007309	ENSTNIG00000018562	0.0234	0.3416
ENSDARG00000005716	ENSTRUG00000006413	ENSTNIG00000010683	0.1483	0.5385
ENSDARG00000006079	ENSTRUG00000009206	ENSTNIG00000003020	0.1806	1.5229
ENSDARG00000006202	ENSTRUG00000011645	ENSTNIG00000014596	0.0903	0.5171
ENSDARG00000006272	ENSTRUG00000009068	NA	NA	NA
ENSDARG00000006356	NA	ENSTNIG00000008649	NA	NA
ENSDARG00000006385	ENSTRUG00000007320	ENSTNIG00000010837	0.0678	0.606
ENSDARG00000006396	ENSTRUG00000016787	ENSTNIG00000018509	0.0411	0.4169
ENSDARG00000006560	ENSTRUG00000011568	ENSTNIG00000005370	0.1058	0.427
ENSDARG00000006640	ENSTRUG00000005361	ENSTNIG00000017582	0.0226	0.3982
ENSDARG00000006757	ENSTRUG00000011704	ENSTNIG00000013264	0.0518	0.5174
ENSDARG00000006862	ENSTRUG00000005998	ENSTNIG00000005488	0.037	0.3276
ENSDARG00000006891	ENSTRUG00000006579	NA	NA	NA
ENSDARG00000006923	ENSTRUG00000007330	ENSTNIG00000011310	0.0509	0.444
ENSDARG00000006978	ENSTRUG00000017637	ENSTNIG00000016945	0.0441	0.5164
ENSDARG00000006983	ENSTRUG00000014225	NA	NA	NA
ENSDARG00000006990	ENSTRUG00000009959	ENSTNIG00000017928	0.0163	0.3683
ENSDARG00000007179	ENSTRUG00000018392	ENSTNIG00000012250	0.0571	0.3106
ENSDARG00000007195	ENSTRUG00000007956	ENSTNIG00000014741	0.0212	0.4584
ENSDARG00000007289	ENSTRUG00000005938	ENSTNIG00000014087	0.1667	0.9927
ENSDARG00000007356	ENSTRUG00000015359	ENSTNIG00000019361	0.017	0.2341
ENSDARG00000007412	ENSTRUG00000002051	ENSTNIG00000018304	0.0572	0.5536
ENSDARG00000007430	ENSTRUG00000018659	ENSTNIG00000009020	0.0155	0.5229
ENSDARG00000007654	ENSTRUG00000006590	ENSTNIG00000011158	0.0125	0.432
ENSDARG00000007678	ENSTRUG00000014928	ENSTNIG00000008257	0.0299	0.3874
ENSDARG00000007808	ENSTRUG00000011854	ENSTNIG00000016520	0.0392	0.377
ENSDARG00000007856	ENSTRUG00000000398	ENSTNIG00000016166	0.023	0.3169
ENSDARG00000007950	ENSTRUG00000014409	ENSTNIG00000002675	0.1482	0.7492
ENSDARG00000008100	ENSTRUG00000009024	ENSTNIG00000011893	0.0573	0.8371
ENSDARG00000008191	ENSTRUG00000002025	ENSTNIG00000019773	0.2412	1.284
ENSDARG00000008209	ENSTRUG00000015790	ENSTNIG00000010716	0.1039	0.9336
ENSDARG00000008767	ENSTRUG00000007051	ENSTNIG00000015458	0.0346	0.3277
ENSDARG00000008772	ENSTRUG00000000658	ENSTNIG00000019728	0.0186	0.6595
ENSDARG00000008912	ENSTRUG00000000015	ENSTNIG00000006069	0.2086	1.9787
ENSDARG00000008948	ENSTRUG00000018542	NA	NA	NA
ENSDARG00000009023	ENSTRUG00000015695	ENSTNIG00000018438	0.0117	0.2639
ENSDARG00000009351	ENSTRUG00000010251	ENSTNIG00000008811	0.0223	0.2939
ENSDARG00000009372	ENSTRUG00000016102	ENSTNIG00000017184	0.0019	0.2752
ENSDARG00000009524	ENSTRUG00000002641	ENSTNIG00000003327	0.0435	0.4237
ENSDARG00000009621	ENSTRUG00000000017	ENSTNIG00000018825	0.015	0.3185
ENSDARG00000009782	ENSTRUG00000010806	NA	NA	NA
ENSDARG00000009901	ENSTRUG00000015694	ENSTNIG00000003726	0.0558	0.3485
ENSDARG00000009903	ENSTRUG00000006650	ENSTNIG00000003408	0.0391	0.6179
ENSDARG00000010155	ENSTRUG00000010587	NA	NA	NA
ENSDARG00000010158	ENSTRUG00000006538	NA	NA	NA
ENSDARG00000010231	ENSTRUG00000011812	ENSTNIG00000007751	0.0272	0.5093
ENSDARG00000010255	ENSTRUG00000000397	ENSTNIG00000007370	0.1729	0.7144
ENSDARG00000010376	NA	ENSTNIG00000014513	NA	NA
ENSDARG00000010385	ENSTRUG00000010944	ENSTNIG00000003311	0.0997	0.4348
ENSDARG00000010655	ENSTRUG00000012257	ENSTNIG00000011047	0.0317	0.3517
ENSDARG00000010785	ENSTRUG00000018123	ENSTNIG00000012209	0.027	0.3448
ENSDARG00000010816	ENSTRUG00000011878	ENSTNIG00000006660	0.0108	0.3973
ENSDARG00000010958	ENSTRUG00000000383	ENSTNIG00000001477	0.1426	0.4029
ENSDARG00000010977	ENSTRUG00000014481	ENSTNIG00000016158	0.0551	0.4578
ENSDARG00000011029	ENSTRUG00000010253	ENSTNIG00000014208	0.074	0.5826
ENSDARG00000011188	ENSTRUG00000004589	ENSTNIG00000017166	0.0336	0.4996
ENSDARG00000011259	ENSTRUG00000007795	ENSTNIG00000010220	0.0421	0.5358
ENSDARG00000011571	ENSTRUG00000011835	ENSTNIG00000010610	0.0736	0.608
ENSDARG00000011683	ENSTRUG00000006993	ENSTNIG00000015232	0.0455	0.6374
ENSDARG00000011855	ENSTRUG00000002601	ENSTNIG00000004885	0.0733	0.3811
ENSDARG00000011932	ENSTRUG00000005834	ENSTNIG00000012603	0.0525	0.3238
ENSDARG00000012071	ENSTRUG00000018466	ENSTNIG00000010854	0.0189	0.4184
ENSDARG00000012125	ENSTRUG00000003216	ENSTNIG00000003112	0.0413	0.7439
ENSDARG00000012269	ENSTRUG00000001381	ENSTNIG00000008050	0.0725	0.4137
ENSDARG00000012482	ENSTRUG00000013782	ENSTNIG00000019198	0.3455	0.7717
ENSDARG00000012496	NA	NA	NA	NA
ENSDARG00000012586	ENSTRUG00000008302	ENSTNIG00000016480	0.0349	0.4776
ENSDARG00000012588	ENSTRUG00000014544	ENSTNIG00000018415	0.0463	0.3389
ENSDARG00000012823	ENSTRUG00000005583	ENSTNIG00000018712	0.0304	0.4001
ENSDARG00000013047	ENSTRUG00000007103	ENSTNIG00000017294	0.0096	0.375
ENSDARG00000013072	ENSTRUG00000001957	ENSTNIG00000010128	0.017	0.3745
ENSDARG00000013221	ENSTRUG00000011028	ENSTNIG00000011072	0.0209	0.3044
ENSDARG00000013222	ENSTRUG00000017803	ENSTNIG00000006641	0.0243	0.5438
ENSDARG00000013245	ENSTRUG00000001149	ENSTNIG00000005241	0.0668	0.3788
ENSDARG00000013360	NA	ENSTNIG00000003402	NA	NA
ENSDARG00000013460	ENSTRUG00000008658	ENSTNIG00000012635	0.0242	0.7238
ENSDARG00000013669	ENSTRUG00000007062	ENSTNIG00000001455	0.0046	0.3963
ENSDARG00000013685	NA	ENSTNIG00000011483	NA	NA
ENSDARG00000013690	ENSTRUG00000008061	ENSTNIG00000014154	0.0474	0.3644
ENSDARG00000013813	NA	ENSTNIG00000004677	NA	NA
ENSDARG00000013921	ENSTRUG00000005142	ENSTNIG00000016260	0.0335	0.274

ENSDARG00000014105	ENSTRUG00000012897	NA	NA	NA
ENSDARG00000014169	ENSTRUG00000000406	ENSTNIG00000006797	0.0188	0.4149
ENSDARG00000014320	ENSTRUG00000004638	ENSTNIG00000003180	0.0635	0.506
ENSDARG00000014439	ENSTRUG00000003102	ENSTNIG00000014470	0.1372	0.5256
ENSDARG00000014477	ENSTRUG00000007737	NA	NA	NA
ENSDARG00000014655	ENSTRUG00000009941	ENSTNIG00000014554	0.066	0.5036
ENSDARG00000014674	ENSTRUG00000013537	ENSTNIG00000015280	0.0246	0.4157
ENSDARG00000014675	ENSTRUG00000010789	ENSTNIG00000017559	0.0127	0.3797
ENSDARG00000014907	ENSTRUG00000007640	ENSTNIG00000011886	0.064	0.4461
ENSDARG00000014910	ENSTRUG00000010578	ENSTNIG00000006242	0.1894	0.4177
ENSDARG00000014973	ENSTRUG00000008038	ENSTNIG00000018965	0.0198	0.2847
ENSDARG00000014995	ENSTRUG00000012548	ENSTNIG00000010264	0.0253	0.8904
ENSDARG00000015184	ENSTRUG00000016624	ENSTNIG00000014945	0.018	0.48
ENSDARG00000015552	ENSTRUG00000010481	ENSTNIG00000014037	0.1503	0.8868
ENSDARG00000015566	ENSTRUG00000009738	ENSTNIG00000019290	0.0234	0.4172
ENSDARG00000015589	ENSTRUG00000005616	ENSTNIG00000002189	0.1115	0.9621
ENSDARG00000015731	ENSTRUG00000012377	ENSTNIG00000013682	0.0338	0.4406
ENSDARG00000015803	ENSTRUG00000013435	ENSTNIG00000008273	0.1961	1.1327
ENSDARG00000015854	ENSTRUG00000009820	ENSTNIG00000008650	0.0472	0.3756
ENSDARG00000015891	ENSTRUG00000005658	ENSTNIG00000010374	0.0232	0.361
ENSDARG00000016048	ENSTRUG00000018646	ENSTNIG00000005676	0.0502	0.4959
ENSDARG00000016348	ENSTRUG00000007662	ENSTNIG00000014569	0.0124	0.3201
ENSDARG00000016439	ENSTRUG00000001868	ENSTNIG00000009963	0.0348	0.5119
ENSDARG00000016470	ENSTRUG00000015464	ENSTNIG00000004295	0.0511	0.3223
ENSDARG00000016667	NA	NA	NA	NA
ENSDARG00000016718	ENSTRUG00000008280	ENSTNIG00000007106	0.1054	1.2519
ENSDARG00000016742	ENSTRUG00000013743	NA	NA	NA
ENSDARG00000016788	ENSTRUG00000001256	ENSTNIG00000007962	0.0553	0.586
ENSDARG00000016866	NA	NA	NA	NA
ENSDARG00000016963	NA	ENSTNIG00000018281	NA	NA
ENSDARG00000016999	ENSTRUG00000009454	ENSTNIG00000009802	0.1069	0.5561
ENSDARG00000017162	ENSTRUG00000001953	ENSTNIG00000019131	0.0347	1.4752
ENSDARG00000017211	ENSTRUG00000003774	ENSTNIG00000004937	0.0922	0.5215
ENSDARG00000017360	ENSTRUG00000005692	ENSTNIG00000018560	0.0844	0.2659
ENSDARG00000017649	ENSTRUG00000001931	NA	NA	NA
ENSDARG00000017880	ENSTRUG00000006718	ENSTNIG00000009102	0.0212	0.414
ENSDARG00000018047	ENSTRUG00000004343	ENSTNIG00000009707	0.0146	0.4824
ENSDARG00000018105	ENSTRUG00000005448	ENSTNIG00000007414	0.01	0.517
ENSDARG00000018130	ENSTRUG00000011952	ENSTNIG00000003293	0.0176	0.3555
ENSDARG00000018530	NA	NA	NA	NA
ENSDARG00000018566	ENSTRUG00000016964	ENSTNIG00000016020	0.0121	0.3312
ENSDARG00000018619	ENSTRUG00000000191	ENSTNIG00000011078	0.0741	0.3045
ENSDARG00000018750	ENSTRUG00000010360	ENSTNIG00000006188	0.1108	0.9706
ENSDARG00000018782	ENSTRUG00000008660	ENSTNIG00000004717	0.0741	0.5214
ENSDARG00000018935	ENSTRUG00000002628	NA	NA	NA
ENSDARG00000018997	ENSTRUG00000015618	ENSTNIG00000018067	0.0561	0.3771
ENSDARG00000019125	ENSTRUG00000017569	ENSTNIG00000012736	0.0412	0.5945
ENSDARG00000019335	ENSTRUG00000008624	ENSTNIG00000015237	0.22	0.8973
ENSDARG00000019405	ENSTRUG00000011158	ENSTNIG00000007347	0.123	0.4234
ENSDARG00000019541	ENSTRUG00000011343	ENSTNIG00000014844	0.025	0.4615
ENSDARG00000019601	ENSTRUG00000015310	ENSTNIG00000010706	0.08	0.4873
ENSDARG00000019622	ENSTRUG00000007697	ENSTNIG00000008214	0.06	0.3179
ENSDARG00000019658	ENSTRUG00000007484	ENSTNIG00000008004	0.0857	0.4591
ENSDARG00000019686	ENSTRUG00000011886	ENSTNIG00000012120	0.1918	0.7939
ENSDARG00000020000	ENSTRUG00000002780	ENSTNIG00000003427	0.0777	0.797
ENSDARG00000020176	ENSTRUG00000013323	ENSTNIG00000002630	0.3136	69.6845
ENSDARG00000020178	ENSTRUG00000016275	ENSTNIG00000018993	0.013	0.1982
ENSDARG00000020224	ENSTRUG00000015717	ENSTNIG00000011392	0.0586	0.5395
ENSDARG00000020228	ENSTRUG00000012954	ENSTNIG00000002633	0.0765	0.9346
ENSDARG00000020270	ENSTRUG00000012106	ENSTNIG00000014101	0.0314	0.5314
ENSDARG00000020395	ENSTRUG00000006568	ENSTNIG00000008859	0.1652	0.6544
ENSDARG00000020443	ENSTRUG00000012716	ENSTNIG00000014269	0.0128	0.4002
ENSDARG00000020493	ENSTRUG00000011322	ENSTNIG00000008655	0.0231	0.3502
ENSDARG00000020610	ENSTRUG00000011858	ENSTNIG00000015033	0.1124	0.8521
ENSDARG00000020845	ENSTRUG00000004813	ENSTNIG00000008863	0.0582	0.2953
ENSDARG00000020871	ENSTRUG00000012030	ENSTNIG00000006888	0.1019	0.7424
ENSDARG00000020872	ENSTRUG00000011018	ENSTNIG00000012108	0.0402	0.3809
ENSDARG00000020924	ENSTRUG00000014793	ENSTNIG00000011797	0.0309	0.3666
ENSDARG00000021389	ENSTRUG00000013426	ENSTNIG00000004242	0.0705	0.6341
ENSDARG00000021846	ENSTRUG00000011865	ENSTNIG00000009779	0.0296	0.4302
ENSDARG00000021882	ENSTRUG00000017201	ENSTNIG00000009457	0.0306	0.4383
ENSDARG00000022045	ENSTRUG00000015964	ENSTNIG00000010396	0.2464	1.3271
ENSDARG00000022309	ENSTRUG00000004758	ENSTNIG00000015195	0.0447	0.4111
ENSDARG00000022668	ENSTRUG00000010816	ENSTNIG00000004646	0.0228	0.2864
ENSDARG00000022772	ENSTRUG00000012868	ENSTNIG00000015850	0.0156	0.2662
ENSDARG00000022858	NA	ENSTNIG00000006787	NA	NA
ENSDARG00000022895	ENSTRUG00000007650	ENSTNIG00000016837	0.0345	0.3484
ENSDARG00000023210	ENSTRUG00000010235	ENSTNIG00000009808	0.0911	1.1394
ENSDARG00000023318	NA	ENSTNIG00000017025	NA	NA
ENSDARG00000023527	ENSTRUG00000011769	ENSTNIG00000003193	0.0189	0.6429
ENSDARG00000023624	ENSTRUG00000012517	NA	NA	NA
ENSDARG00000023683	ENSTRUG00000003920	ENSTNIG00000014174	0.1199	0.7343
ENSDARG00000023878	ENSTRUG00000008054	ENSTNIG00000013280	0.0058	0.6117
ENSDARG00000023886	ENSTRUG00000016579	ENSTNIG00000004494	0.1236	0.5739
ENSDARG00000024167	ENSTRUG00000001725	ENSTNIG00000007454	0.0128	0.4518
ENSDARG00000024189	ENSTRUG00000005668	NA	NA	NA
ENSDARG00000024365	ENSTRUG00000015730	ENSTNIG00000001783	0.0218	0.4011
ENSDARG00000024560	ENSTRUG00000002827	ENSTNIG00000018923	0.0216	0.4386
ENSDARG00000024847	ENSTRUG00000012263	ENSTNIG00000010611	0.1179	0.2866
ENSDARG00000024865	ENSTRUG00000001915	ENSTNIG00000006761	0.1821	0.9672

ENSDARG00000024966	ENSTRUG00000006414	ENSTNIG00000018983	0.0265	0.4074
ENSDARG00000025013	NA	ENSTNIG00000015809	NA	NA
ENSDARG00000025089	ENSTRUG00000006359	ENSTNIG00000008684	0.0244	0.39
ENSDARG00000025189	ENSTRUG00000010791	ENSTNIG00000013729	0.0284	0.4826
ENSDARG00000025299	ENSTRUG00000007049	ENSTNIG00000019258	0.0953	0.5423
ENSDARG00000025325	ENSTRUG00000005787	NA	NA	NA
ENSDARG00000025615	ENSTRUG00000001285	NA	NA	NA
ENSDARG00000025671	ENSTRUG00000013670	ENSTNIG00000007330	0.0099	0.5277
ENSDARG00000025974	ENSTRUG00000018140	ENSTNIG00000018298	0.1114	0.4844
ENSDARG00000026248	NA	NA	NA	NA
ENSDARG00000026333	ENSTRUG00000000692	ENSTNIG00000011339	0.08	0.454
ENSDARG00000026634	ENSTRUG00000009977	ENSTNIG00000005211	0.059	0.3648
ENSDARG00000026926	ENSTRUG00000014145	ENSTNIG00000016798	0.0223	0.28
ENSDARG00000027153	ENSTRUG00000016946	ENSTNIG00000010014	0.0179	0.3479
ENSDARG00000027345	ENSTRUG00000014632	ENSTNIG00000002462	0.0691	0.4198
ENSDARG00000027497	NA	ENSTNIG00000004534	NA	NA
ENSDARG00000027564	ENSTRUG00000012917	NA	NA	NA
ENSDARG00000027867	ENSTRUG00000002038	NA	NA	NA
ENSDARG00000027957	ENSTRUG00000008855	ENSTNIG00000015272	0	0.1555
ENSDARG00000027966	ENSTRUG00000013671	NA	NA	NA
ENSDARG00000028067	ENSTRUG00000007174	ENSTNIG00000005254	0.0215	0.3627
ENSDARG00000028071	ENSTRUG00000002403	ENSTNIG00000010819	0.0308	0.3954
ENSDARG00000028257	NA	NA	NA	NA
ENSDARG00000028348	ENSTRUG00000009198	ENSTNIG00000014313	0.0133	0.2925
ENSDARG00000028412	ENSTRUG00000012188	ENSTNIG00000016747	0.0404	0.3091
ENSDARG00000028521	ENSTRUG00000015091	ENSTNIG00000011696	0.0071	0.1488
ENSDARG00000028552	ENSTRUG00000008004	NA	NA	NA
ENSDARG00000028725	NA	NA	NA	NA
ENSDARG00000028776	ENSTRUG00000009023	ENSTNIG00000009949	0.0325	0.5056
ENSDARG00000028857	ENSTRUG00000014620	ENSTNIG00000015880	0.103	0.6271
ENSDARG00000028878	ENSTRUG00000008126	ENSTNIG00000007927	0.0731	0.5264
ENSDARG00000028896	ENSTRUG00000009052	ENSTNIG00000015456	0.0511	0.7166
ENSDARG00000029057	ENSTRUG00000018186	ENSTNIG00000013191	0.0598	0.3424
ENSDARG00000029457	ENSTRUG00000001782	ENSTNIG00000008294	0.0399	0.3887
ENSDARG00000029474	ENSTRUG00000004534	ENSTNIG00000007268	0.0617	0.4769
ENSDARG00000029493	ENSTRUG00000007324	ENSTNIG00000006321	0.1126	0.7719
ENSDARG00000029590	ENSTRUG00000006191	ENSTNIG00000001818	0.0338	0.5527
ENSDARG00000029881	ENSTRUG00000010880	NA	NA	NA
ENSDARG00000029994	ENSTRUG00000010086	ENSTNIG00000012130	0.0869	0.741
ENSDARG00000030012	ENSTRUG00000008570	ENSTNIG00000017845	0.1528	0.6745
ENSDARG00000030157	ENSTRUG00000004802	ENSTNIG00000003219	0.0349	0.6496
ENSDARG00000030292	ENSTRUG00000008973	ENSTNIG00000006208	0.0345	0.4803
ENSDARG00000030311	ENSTRUG00000001798	ENSTNIG00000014200	0.0657	0.4802
ENSDARG00000030411	ENSTRUG00000017468	ENSTNIG00000013544	0.0466	0.7737
ENSDARG00000030758	ENSTRUG00000013910	ENSTNIG00000003052	0.0142	0.4071
ENSDARG00000030782	NA	ENSTNIG00000000811	NA	NA
ENSDARG00000030832	ENSTRUG00000003831	ENSTNIG00000012284	0.0524	0.5403
ENSDARG00000030932	ENSTRUG00000007497	ENSTNIG00000009130	0.0218	0.7851
ENSDARG00000030933	ENSTRUG00000004793	ENSTNIG00000004984	0.1854	1.2164
ENSDARG00000031219	ENSTRUG00000013761	ENSTNIG00000009054	0.0283	0.3107
ENSDARG00000031383	NA	NA	NA	NA
ENSDARG00000031489	ENSTRUG00000011016	NA	NA	NA
ENSDARG00000031548	ENSTRUG00000007205	ENSTNIG00000007814	0.0313	0.7624
ENSDARG00000031651	ENSTRUG00000001311	ENSTNIG00000017001	0.0935	0.6913
ENSDARG00000031845	ENSTRUG00000014264	ENSTNIG00000017310	0.0382	0.3536
ENSDARG00000032083	ENSTRUG00000002983	ENSTNIG00000004206	0.0195	0.4057
ENSDARG00000032493	ENSTRUG00000017564	ENSTNIG00000016953	0.0204	0.3646
ENSDARG00000033251	ENSTRUG00000018171	ENSTNIG00000009202	0.0649	0.5307
ENSDARG00000033296	ENSTRUG00000016651	NA	NA	NA
ENSDARG00000033320	ENSTRUG00000007269	ENSTNIG00000008635	0.0121	0.3925
ENSDARG00000033446	ENSTRUG00000010603	ENSTNIG00000011842	0.1597	0.5937
ENSDARG00000033544	ENSTRUG00000011992	ENSTNIG00000014373	0.1054	1.6049
ENSDARG00000033635	ENSTRUG00000015587	ENSTNIG00000015347	0.0321	0.34
ENSDARG00000033804	ENSTRUG00000011162	ENSTNIG00000017554	0.0118	0.5173
ENSDARG00000034373	ENSTRUG00000018194	ENSTNIG00000018753	0.1332	0.304
ENSDARG00000034493	ENSTRUG00000011038	ENSTNIG00000011608	0.0658	0.4165
ENSDARG00000034555	ENSTRUG00000002389	ENSTNIG00000017054	0.1817	0.5355
ENSDARG00000034604	ENSTRUG00000012839	ENSTNIG00000015038	0.0487	0.3124
ENSDARG00000034714	ENSTRUG00000009603	NA	NA	NA
ENSDARG00000034808	ENSTRUG00000007648	ENSTNIG00000010772	0.0163	0.4285
ENSDARG00000034930	ENSTRUG00000005845	ENSTNIG00000003863	0.0437	0.5541
ENSDARG00000035273	ENSTRUG00000006515	ENSTNIG00000008786	0.0352	0.3865
ENSDARG00000035452	ENSTRUG00000002511	ENSTNIG00000008544	0.0336	0.4738
ENSDARG00000035533	ENSTRUG00000018617	ENSTNIG00000013587	0.0825	0.5203
ENSDARG00000035538	ENSTRUG00000005162	ENSTNIG00000009106	0.0246	0.4371
ENSDARG00000035895	ENSTRUG00000010948	ENSTNIG00000009270	0.0024	0.2258
ENSDARG00000035910	ENSTRUG00000008207	ENSTNIG00000018917	0.0209	0.3968
ENSDARG00000036017	NA	NA	NA	NA
ENSDARG00000036031	ENSTRUG00000018608	ENSTNIG00000013578	0.0226	0.3288
ENSDARG00000036065	NA	ENSTNIG00000000449	NA	NA
ENSDARG00000036139	ENSTRUG00000009494	ENSTNIG00000004762	0.0572	0.6905
ENSDARG00000036152	ENSTRUG00000017276	ENSTNIG00000009405	0.1219	0.439
ENSDARG00000036175	NA	ENSTNIG00000012969	NA	NA
ENSDARG00000036243	ENSTRUG00000018220	ENSTNIG00000009204	0	0.3447
ENSDARG00000036295	ENSTRUG00000006964	NA	NA	NA
ENSDARG00000036457	ENSTRUG00000006320	ENSTNIG00000018190	0.0669	0.5042
ENSDARG00000036463	ENSTRUG00000016459	ENSTNIG00000011761	0.0877	0.8116
ENSDARG00000036541	ENSTRUG00000011433	ENSTNIG00000018580	0.0111	0.2941
ENSDARG00000036815	ENSTRUG00000008243	ENSTNIG00000008007	0.0084	0.3896
ENSDARG00000036826	ENSTRUG00000015320	ENSTNIG00000012520	0.0134	0.2538

ENSDARG00000037337	ENSTRUG00000012558	NA	NA	NA
ENSDARG00000037357	ENSTRUG00000016671	ENSTNIG00000012863	0.0321	0.3095
ENSDARG00000037373	ENSTRUG00000005841	ENSTNIG00000006519	0.0315	0.7937
ENSDARG00000037415	ENSTRUG00000017849	ENSTNIG00000012774	0.0291	0.4195
ENSDARG00000037422	ENSTRUG00000016167	ENSTNIG00000012839	0.0663	0.4115
ENSDARG00000037495	ENSTRUG00000012555	ENSTNIG00000013124	0.0152	0.3658
ENSDARG00000037533	ENSTRUG00000016750	NA	NA	NA
ENSDARG00000037558	ENSTRUG00000006010	ENSTNIG00000000074	0.0627	0.4374
ENSDARG00000037587	ENSTRUG00000014148	ENSTNIG00000011109	0.0525	0.4571
ENSDARG00000037593	ENSTRUG00000008566	ENSTNIG00000011137	0.044	0.4333
ENSDARG00000037607	NA	ENSTNIG00000002298	NA	NA
ENSDARG00000037794	ENSTRUG00000009137	ENSTNIG00000011954	0.0345	0.3903
ENSDARG00000037859	ENSTRUG00000007510	ENSTNIG00000000618	0.0381	0.3048
ENSDARG00000037861	ENSTRUG00000007710	ENSTNIG00000013823	0.0525	0.3876
ENSDARG00000037904	ENSTRUG00000003936	ENSTNIG00000012020	0.0516	0.3646
ENSDARG00000038025	ENSTRUG00000006595	ENSTNIG00000006270	0.3236	1.8605
ENSDARG00000038119	ENSTRUG00000015854	ENSTNIG00000012001	0.1413	0.5982
ENSDARG00000038131	ENSTRUG00000017531	NA	NA	NA
ENSDARG00000038219	ENSTRUG00000018533	ENSTNIG00000013442	0.0373	0.2989
ENSDARG00000038239	ENSTRUG00000012698	ENSTNIG00000003295	0.0167	0.3399
ENSDARG00000038373	ENSTRUG00000012523	ENSTNIG00000009786	0.0578	0.5214
ENSDARG00000038574	NA	NA	NA	NA
ENSDARG00000038634	NA	ENSTNIG00000009248	NA	NA
ENSDARG00000038826	ENSTRUG00000011742	ENSTNIG00000003444	0.0594	0.8799
ENSDARG00000038918	ENSTRUG00000003589	ENSTNIG00000018218	0.0308	0.3949
ENSDARG00000038957	ENSTRUG00000018328	ENSTNIG00000017407	0.2981	1.1695
ENSDARG00000038968	NA	NA	NA	NA
ENSDARG00000039234	ENSTRUG00000005790	ENSTNIG00000018976	0.0693	2.2056
ENSDARG00000039238	ENSTRUG00000010409	ENSTNIG00000011944	0.016	0.345
ENSDARG00000039265	ENSTRUG00000015312	ENSTNIG00000015092	0.1296	0.4786
ENSDARG00000039453	NA	NA	NA	NA
ENSDARG00000039577	ENSTRUG00000008406	ENSTNIG00000016347	0.0451	0.4207
ENSDARG00000039901	ENSTRUG00000008117	ENSTNIG00000005460	0.0793	1.3514
ENSDARG00000039932	ENSTRUG00000012544	ENSTNIG00000018820	0.0503	0.6383
ENSDARG00000039943	ENSTRUG00000013574	ENSTNIG00000009661	0.0258	0.3763
ENSDARG00000039963	ENSTRUG00000006847	NA	NA	NA
ENSDARG00000039987	ENSTRUG00000015889	ENSTNIG00000010718	0.2585	1.0151
ENSDARG00000039999	ENSTRUG00000001862	ENSTNIG00000016202	0.0378	0.3768
ENSDARG00000040065	NA	ENSTNIG00000002166	NA	NA
ENSDARG00000040133	ENSTRUG00000017829	ENSTNIG00000000194	0.0714	0.4609
ENSDARG00000040137	ENSTRUG00000010344	ENSTNIG00000016355	0.1585	1.6336
ENSDARG00000040248	NA	ENSTNIG00000007207	NA	NA
ENSDARG00000040274	ENSTRUG00000010107	ENSTNIG00000018543	0.022	0.5824
ENSDARG00000040334	ENSTRUG00000003786	ENSTNIG00000009111	0.1072	0.7808
ENSDARG00000040430	ENSTRUG00000000762	ENSTNIG00000011501	0.0515	0.354
ENSDARG00000040474	ENSTRUG00000015244	ENSTNIG00000018426	0.0932	0.4842
ENSDARG00000040543	ENSTRUG00000017031	NA	NA	NA
ENSDARG00000040627	ENSTRUG00000014961	ENSTNIG00000019023	0.0058	0.3491
ENSDARG00000040684	NA	NA	NA	NA
ENSDARG00000040705	ENSTRUG00000012388	ENSTNIG00000015720	0.1595	0.6218
ENSDARG00000041115	ENSTRUG00000013896	NA	NA	NA
ENSDARG00000041162	ENSTRUG00000002341	ENSTNIG00000019307	0.0399	0.397
ENSDARG00000041173	ENSTRUG00000001030	ENSTNIG00000004653	0.0252	0.2635
ENSDARG00000041516	ENSTRUG00000004161	ENSTNIG00000014872	0.043	0.3841
ENSDARG00000041864	ENSTRUG00000006900	ENSTNIG00000010529	0.0116	0.4171
ENSDARG00000042021	ENSTRUG00000005120	NA	NA	NA
ENSDARG00000042055	ENSTRUG00000002101	ENSTNIG00000005535	0.2296	1.2843
ENSDARG00000042081	NA	NA	NA	NA
ENSDARG00000042114	ENSTRUG00000013580	ENSTNIG00000016448	0.1118	0.4483
ENSDARG00000042145	ENSTRUG00000017607	ENSTNIG00000010700	0.0134	0.428
ENSDARG00000042338	ENSTRUG00000014744	ENSTNIG00000004329	0.0747	0.5568
ENSDARG00000042350	NA	ENSTNIG00000019222	NA	NA
ENSDARG00000042379	ENSTRUG00000007407	ENSTNIG00000003853	0.1225	0.5805
ENSDARG00000042811	NA	ENSTNIG00000018207	NA	NA
ENSDARG00000042859	ENSTRUG00000007105	ENSTNIG00000002708	0.0576	0.6206
ENSDARG00000042947	ENSTRUG00000000132	ENSTNIG00000017160	0.0482	0.598
ENSDARG00000042954	ENSTRUG00000004565	ENSTNIG00000012489	0.0816	0.6427
ENSDARG00000042974	ENSTRUG00000004025	NA	NA	NA
ENSDARG00000042988	ENSTRUG00000015445	ENSTNIG00000019359	0.0467	0.3313
ENSDARG00000043037	ENSTRUG00000016154	ENSTNIG00000007801	0.2481	0.6934
ENSDARG00000043059	ENSTRUG00000011907	ENSTNIG00000005559	0.0349	0.3203
ENSDARG00000043220	ENSTRUG00000011415	ENSTNIG00000016364	0.0275	0.6062
ENSDARG00000043313	ENSTRUG00000008279	ENSTNIG00000005286	0.0679	1.1243
ENSDARG00000043396	ENSTRUG00000007116	ENSTNIG00000016337	0.0088	0.3033
ENSDARG00000043406	ENSTRUG00000013345	ENSTNIG00000009816	0.0531	0.5562
ENSDARG00000043661	ENSTRUG00000000340	ENSTNIG00000014254	0.0651	0.5672
ENSDARG00000043701	ENSTRUG00000001679	ENSTNIG00000012592	0.0194	0.6039
ENSDARG00000043746	ENSTRUG00000005194	ENSTNIG00000004158	0.0458	0.4427
ENSDARG00000043907	ENSTRUG00000007364	ENSTNIG00000010775	0.014	0.2368
ENSDARG00000044015	ENSTRUG00000018638	ENSTNIG00000013609	0.0468	0.5142
ENSDARG00000044161	ENSTRUG00000008397	ENSTNIG00000006105	0.0108	0.4835
ENSDARG00000044175	ENSTRUG00000007606	ENSTNIG00000014737	0.0598	0.4141
ENSDARG00000044179	ENSTRUG00000008492	ENSTNIG00000014563	0.0637	0.3977
ENSDARG00000044271	ENSTRUG00000009425	ENSTNIG00000008387	0.0114	0.2745
ENSDARG00000044441	ENSTRUG00000000755	ENSTNIG00000013767	0.0656	0.3971
ENSDARG00000044456	ENSTRUG00000016928	ENSTNIG00000010018	0.0139	0.4561
ENSDARG00000044632	ENSTRUG00000010038	ENSTNIG00000003713	0.0258	0.4232
ENSDARG00000044775	ENSTRUG00000010723	ENSTNIG00000013240	0.1997	1.9531
ENSDARG00000045006	ENSTRUG00000000403	NA	NA	NA
ENSDARG00000045023	ENSTRUG00000008118	ENSTNIG00000006794	0.0071	0.4949

ENSDARG00000045036	NA	ENSTNIG00000014450	NA	NA
ENSDARG00000045070	ENSTRUG00000013322	ENSTNIG00000011575	0.0324	0.4115
ENSDARG00000045087	ENSTRUG00000001984	ENSTNIG00000004135	0.0182	0.6103
ENSDARG00000045129	ENSTRUG00000010243	ENSTNIG00000006619	0.0489	0.4398
ENSDARG00000045200	ENSTRUG00000004875	ENSTNIG00000004370	0.0595	0.3227
ENSDARG00000045204	ENSTRUG00000008741	ENSTNIG00000015012	0.0267	0.3728
ENSDARG00000045316	NA	ENSTNIG00000005358	NA	NA
ENSDARG00000045415	ENSTRUG00000003658	ENSTNIG00000004383	0.0489	0.4932
ENSDARG00000045632	ENSTRUG00000014185	ENSTNIG00000009049	0.1196	0.394
ENSDARG00000045692	ENSTRUG00000016756	NA	NA	NA
ENSDARG00000045708	ENSTRUG00000014814	ENSTNIG00000000994	0.1516	0.4248
ENSDARG00000045758	ENSTRUG00000015180	ENSTNIG00000011027	0.0437	0.3417
ENSDARG00000045789	ENSTRUG00000006228	ENSTNIG00000018725	0.016	0.4129
ENSDARG00000045799	ENSTRUG00000015801	ENSTNIG00000010394	0.294	0.9187
ENSDARG00000045864	NA	ENSTNIG00000018485	NA	NA
ENSDARG00000045956	ENSTRUG00000013601	ENSTNIG00000017245	0.0265	0.307
ENSDARG00000051746	ENSTRUG00000001844	ENSTNIG00000008799	0.1067	0.7858
ENSDARG00000052045	ENSTRUG00000016330	NA	NA	NA
ENSDARG00000052142	ENSTRUG00000012480	ENSTNIG00000014589	0.0182	0.4841
ENSDARG00000052155	ENSTRUG00000016507	ENSTNIG00000015598	0.0075	0.3487
ENSDARG00000052386	ENSTRUG00000017545	NA	NA	NA
ENSDARG00000052631	ENSTRUG00000009669	NA	NA	NA
ENSDARG00000052642	ENSTRUG00000012054	ENSTNIG00000018587	0.112	0.5161
ENSDARG00000052658	ENSTRUG00000006527	ENSTNIG00000009103	0.0078	0.2975
ENSDARG00000052708	NA	NA	NA	NA
ENSDARG00000052734	ENSTRUG00000013186	ENSTNIG00000004289	0.025	0.3309
ENSDARG00000052748	NA	NA	NA	NA
ENSDARG00000052787	ENSTRUG00000013790	NA	NA	NA
ENSDARG00000052898	ENSTRUG00000008667	ENSTNIG00000010534	0.036	0.4752
ENSDARG00000052966	ENSTRUG00000016574	ENSTNIG00000014951	0.0122	0.2561
ENSDARG00000052982	ENSTRUG00000005681	NA	NA	NA
ENSDARG00000053179	ENSTRUG00000012608	ENSTNIG00000007036	0.0602	0.3862
ENSDARG00000053186	ENSTRUG00000017147	NA	NA	NA
ENSDARG00000053425	ENSTRUG00000014033	ENSTNIG00000009668	0.0769	0.4754
ENSDARG00000053449	ENSTRUG00000010705	ENSTNIG00000011155	0.0806	0.3173
ENSDARG00000053454	ENSTRUG00000009896	ENSTNIG00000007350	0.0617	0.3616
ENSDARG00000053559	ENSTRUG00000004757	ENSTNIG00000011359	0.0226	0.305
ENSDARG00000053586	ENSTRUG00000007984	NA	NA	NA
ENSDARG00000053724	ENSTRUG00000004289	ENSTNIG00000006236	0.0157	0.3781
ENSDARG00000053746	ENSTRUG00000002151	ENSTNIG00000015223	0.0817	0.3997
ENSDARG00000053859	ENSTRUG00000018042	ENSTNIG00000009697	0.0647	0.4055
ENSDARG00000054002	ENSTRUG00000012922	ENSTNIG00000003730	0	0.3155
ENSDARG00000054036	ENSTRUG00000010478	NA	NA	NA
ENSDARG00000054196	ENSTRUG00000018006	ENSTNIG00000009305	0.0688	0.5564
ENSDARG00000054641	ENSTRUG00000014751	ENSTNIG00000010935	0.0114	0.4122
ENSDARG00000054844	ENSTRUG00000015983	ENSTNIG00000016315	0.1061	0.5004
ENSDARG00000054894	ENSTRUG00000014337	ENSTNIG00000007157	0.0311	0.2299
ENSDARG00000055045	NA	NA	NA	NA
ENSDARG00000055120	ENSTRUG00000009391	ENSTNIG00000017695	0.0786	0.5959
ENSDARG00000055123	ENSTRUG00000008997	ENSTNIG00000017692	0.077	0.9046
ENSDARG00000055160	ENSTRUG00000007863	ENSTNIG00000005098	0.1038	0.3827
ENSDARG00000055317	ENSTRUG00000013483	ENSTNIG00000015080	0.0077	0.3139
ENSDARG00000055377	ENSTRUG00000007761	ENSTNIG00000010231	0.0302	0.4897
ENSDARG00000055412	ENSTRUG00000007027	ENSTNIG00000008226	0.0328	0.5299
ENSDARG00000055463	ENSTRUG00000015640	ENSTNIG00000000464	0.0551	0.4141
ENSDARG00000055502	ENSTRUG00000007193	ENSTNIG00000003521	0.2782	0.7327
ENSDARG00000055534	ENSTRUG00000006176	ENSTNIG00000019847	0.1472	0.6722
ENSDARG00000055855	ENSTRUG00000008518	ENSTNIG00000003610	0.1203	0.6088
ENSDARG00000056021	NA	NA	NA	NA
ENSDARG00000056125	ENSTRUG00000018174	NA	NA	NA
ENSDARG00000056156	NA	ENSTNIG00000019374	NA	NA
ENSDARG00000056206	ENSTRUG00000003332	ENSTNIG00000007458	0.0096	0.4074
ENSDARG00000056226	ENSTRUG00000017933	ENSTNIG00000010633	0.1069	0.4043
ENSDARG00000056228	ENSTRUG00000012776	ENSTNIG00000006664	0.0366	0.4778
ENSDARG00000056250	ENSTRUG00000006887	ENSTNIG00000013329	0.0413	0.3447
ENSDARG00000056347	ENSTRUG00000011189	ENSTNIG00000011073	0.0115	0.5473
ENSDARG00000056394	ENSTRUG00000007667	ENSTNIG00000018014	0.2488	0.8232
ENSDARG00000056619	ENSTRUG00000017091	ENSTNIG00000009985	0.0552	0.4866
ENSDARG00000056625	ENSTRUG00000017086	ENSTNIG00000009986	0.019	0.3548
ENSDARG00000056762	NA	NA	NA	NA
ENSDARG00000056910	ENSTRUG00000012848	ENSTNIG00000012554	0.0533	0.4243
ENSDARG00000056913	ENSTRUG00000006387	ENSTNIG00000010779	0.1312	0.3958
ENSDARG00000056934	ENSTRUG00000014792	ENSTNIG00000007783	0.0721	0.4326
ENSDARG00000057016	ENSTRUG00000008981	ENSTNIG00000004726	0.0867	0.5873
ENSDARG00000057025	ENSTRUG00000008002	ENSTNIG00000016346	0.0293	0.4148
ENSDARG00000057121	ENSTRUG00000013142	NA	NA	NA
ENSDARG00000057169	ENSTRUG00000001056	ENSTNIG00000008739	0.055	0.5041
ENSDARG00000057286	ENSTRUG00000009866	ENSTNIG00000013737	0.0629	0.802
ENSDARG00000057352	ENSTRUG00000012880	ENSTNIG00000010971	0.024	0.4311
ENSDARG00000057419	ENSTRUG00000017615	ENSTNIG00000010701	0.0444	0.3234
ENSDARG00000057433	ENSTRUG00000017634	ENSTNIG00000010702	0.1101	0.3752
ENSDARG00000057437	ENSTRUG00000008463	ENSTNIG00000013634	0.0965	0.6485
ENSDARG00000057527	NA	ENSTNIG00000011897	NA	NA
ENSDARG00000057568	NA	NA	NA	NA
ENSDARG00000057790	NA	NA	NA	NA
ENSDARG00000057940	ENSTRUG00000008781	ENSTNIG00000007301	0.1901	0.6363
ENSDARG00000058064	NA	NA	NA	NA
ENSDARG00000058103	ENSTRUG00000011755	ENSTNIG00000011832	0.0164	0.4671
ENSDARG00000058178	ENSTRUG00000008792	ENSTNIG00000008161	0.0684	0.5564
ENSDARG00000058230	ENSTRUG00000005648	ENSTNIG00000003337	0.02	0.8525

ENSDARG00000058243	ENSTRUG00000013667	ENSTNIG00000006539	0.0405	0.3481
ENSDARG00000058323	ENSTRUG00000010108	ENSTNIG00000007903	0.0332	0.4571
ENSDARG00000058392	ENSTRUG00000004979	ENSTNIG00000004420	0.1713	0.6311
ENSDARG00000058460	ENSTRUG00000009488	ENSTNIG00000005452	0.0481	0.3224
ENSDARG00000058646	ENSTRUG00000014006	ENSTNIG00000016445	0.1497	0.5427
ENSDARG00000058649	ENSTRUG00000010910	ENSTNIG00000017557	0.0283	0.493
ENSDARG00000058692	ENSTRUG00000004994	ENSTNIG00000017708	0.0483	0.4177
ENSDARG00000058736	ENSTRUG00000004791	ENSTNIG00000018194	0.0521	0.5896
ENSDARG00000058800	ENSTRUG00000014595	ENSTNIG00000005090	0.0465	0.652
ENSDARG00000058848	NA	NA	NA	NA
ENSDARG00000058960	ENSTRUG00000005786	ENSTNIG00000007715	0.079	0.4325
ENSDARG00000058987	ENSTRUG00000011006	ENSTNIG00000011938	0.1	0.4256
ENSDARG00000059054	ENSTRUG00000008711	NA	NA	NA
ENSDARG00000059081	ENSTRUG00000014762	ENSTNIG00000010934	0.1443	0.5222
ENSDARG00000059090	ENSTRUG00000017176	ENSTNIG00000007401	0.0139	0.4874
ENSDARG00000059123	ENSTRUG00000017499	ENSTNIG00000012741	0.0512	0.5219
ENSDARG00000059202	NA	ENSTNIG00000015021	NA	NA
ENSDARG00000059236	ENSTRUG00000015663	ENSTNIG00000016684	0.0234	0.3421
ENSDARG00000059308	ENSTRUG00000000487	ENSTNIG00000007241	0.0851	0.7177
ENSDARG00000059363	ENSTRUG00000007583	ENSTNIG00000013820	0.0667	0.4751
ENSDARG00000059484	ENSTRUG00000008752	ENSTNIG00000015828	0.0308	0.4686
ENSDARG00000059598	ENSTRUG00000012803	ENSTNIG00000010444	0.4675	0.9331
ENSDARG00000059677	ENSTRUG00000016613	ENSTNIG00000018855	0.1373	0.8071
ENSDARG00000059678	ENSTRUG00000014103	ENSTNIG00000015374	0.0333	0.4493
ENSDARG00000059680	ENSTRUG00000005218	NA	NA	NA
ENSDARG00000059685	ENSTRUG00000010485	ENSTNIG00000010079	0.051	0.6029
ENSDARG00000059773	ENSTRUG00000014357	ENSTNIG00000011686	0.0954	0.4584
ENSDARG00000059806	NA	NA	NA	NA
ENSDARG00000059818	ENSTRUG00000014533	ENSTNIG00000007062	0.04	0.3671
ENSDARG00000059822	ENSTRUG00000016379	ENSTNIG00000012845	0.0063	0.2846
ENSDARG00000059888	NA	ENSTNIG00000005822	NA	NA
ENSDARG00000059910	NA	NA	NA	NA
ENSDARG00000059960	NA	ENSTNIG00000003477	NA	NA
ENSDARG00000059965	ENSTRUG00000014682	ENSTNIG00000015295	0.1496	0.569
ENSDARG00000060016	ENSTRUG00000001818	NA	NA	NA
ENSDARG00000060025	ENSTRUG00000001451	ENSTNIG00000019819	0.2137	0.8454
ENSDARG00000060034	NA	ENSTNIG00000016393	NA	NA
ENSDARG00000060096	ENSTRUG00000006390	ENSTNIG00000009104	0.0546	0.4524
ENSDARG00000060236	ENSTRUG00000004434	ENSTNIG00000012048	0.1066	0.5996
ENSDARG00000060237	ENSTRUG00000014048	ENSTNIG00000013160	0.0136	0.2661
ENSDARG00000060248	ENSTRUG00000006575	ENSTNIG00000006918	0.0967	0.5044
ENSDARG00000060303	ENSTRUG00000004679	ENSTNIG00000016498	0.0283	0.3203
ENSDARG00000060452	ENSTRUG00000009922	ENSTNIG00000014451	0.0335	0.5695
ENSDARG00000060458	ENSTRUG00000015894	ENSTNIG00000017640	0.0261	0.463
ENSDARG00000060459	ENSTRUG00000009709	ENSTNIG00000008904	0.0218	0.3535
ENSDARG00000060520	ENSTRUG00000001021	ENSTNIG00000016713	0.1381	0.5575
ENSDARG00000060584	ENSTRUG00000018449	ENSTNIG00000007489	0.1977	0.4999
ENSDARG00000060675	NA	ENSTNIG00000004745	NA	NA
ENSDARG00000060723	ENSTRUG00000003281	ENSTNIG00000016252	0.0447	0.3507
ENSDARG00000060725	ENSTRUG00000009307	ENSTNIG00000006214	0.1886	0.5875
ENSDARG00000060756	ENSTRUG00000005869	ENSTNIG00000017494	0.0864	0.526
ENSDARG00000060805	ENSTRUG00000008258	ENSTNIG00000004722	0.257	1.0661
ENSDARG00000060860	ENSTRUG00000008138	ENSTNIG00000008380	0.0776	0.4131
ENSDARG00000060929	ENSTRUG00000000977	ENSTNIG00000007960	0.0375	0.2789
ENSDARG00000060933	ENSTRUG00000000798	ENSTNIG00000011500	1.0057	2.2505
ENSDARG00000060954	ENSTRUG00000012485	ENSTNIG00000014678	0.0226	0.342
ENSDARG00000061011	ENSTRUG00000003909	NA	NA	NA
ENSDARG00000061030	NA	NA	NA	NA
ENSDARG00000061047	ENSTRUG00000016628	ENSTNIG00000011744	0.0297	0.243
ENSDARG00000061082	ENSTRUG00000013681	ENSTNIG00000014691	0.0086	0.3738
ENSDARG00000061089	ENSTRUG00000006777	ENSTNIG00000010489	0.0634	0.4559
ENSDARG00000061093	ENSTRUG00000016591	ENSTNIG00000011750	0.1158	0.4411
ENSDARG00000061101	ENSTRUG00000016564	ENSTNIG00000011754	0.0721	0.3283
ENSDARG00000061143	ENSTRUG00000015598	ENSTNIG00000004298	0.0399	0.3529
ENSDARG00000061191	ENSTRUG00000004284	NA	NA	NA
ENSDARG00000061255	ENSTRUG00000005425	ENSTNIG00000014408	0.0286	0.5929
ENSDARG00000061282	ENSTRUG00000016546	NA	NA	NA
ENSDARG00000061342	ENSTRUG00000018390	ENSTNIG00000012251	0.0137	0.3345
ENSDARG00000061479	ENSTRUG00000001233	ENSTNIG00000006219	0.0457	0.4712
ENSDARG00000061641	NA	NA	NA	NA
ENSDARG00000061665	ENSTRUG00000018063	ENSTNIG00000010643	0.0137	0.4162
ENSDARG00000061688	ENSTRUG00000013715	ENSTNIG00000016764	0.0219	0.3875
ENSDARG00000061725	ENSTRUG00000010313	ENSTNIG00000011069	0.0199	0.397
ENSDARG00000061732	ENSTRUG00000008306	ENSTNIG00000014526	0.093	0.5503
ENSDARG00000061736	ENSTRUG00000009110	ENSTNIG00000017033	0.0225	0.4463
ENSDARG00000061757	ENSTRUG00000001690	NA	NA	NA
ENSDARG00000061758	ENSTRUG00000008431	ENSTNIG00000013324	0.0299	0.3652
ENSDARG00000061804	ENSTRUG00000014179	ENSTNIG00000009236	0.3142	0.6497
ENSDARG00000061835	NA	ENSTNIG00000008593	NA	NA
ENSDARG00000061852	ENSTRUG00000004228	ENSTNIG00000012410	0.1704	0.9668
ENSDARG00000061956	ENSTRUG00000001148	ENSTNIG00000008594	0.5211	1.4125
ENSDARG00000061970	ENSTRUG00000017851	ENSTNIG00000004974	0.0157	0.4668
ENSDARG00000061976	ENSTRUG00000004606	ENSTNIG00000010688	0.03	0.4501
ENSDARG00000061977	NA	ENSTNIG00000013816	NA	NA
ENSDARG00000062000	ENSTRUG00000010317	NA	NA	NA
ENSDARG00000062024	ENSTRUG00000005189	ENSTNIG00000015259	0.0376	0.3538
ENSDARG00000062030	ENSTRUG00000001244	ENSTNIG00000013768	0.0501	0.5098
ENSDARG00000062106	ENSTRUG00000011253	ENSTNIG00000014985	0.0868	0.4212
ENSDARG00000062113	ENSTRUG00000002650	ENSTNIG00000001498	0.0583	0.6748
ENSDARG00000062134	NA	ENSTNIG00000002486	NA	NA

ENSDARG00000062156	ENSTRUG00000015408	ENSTNIG00000002875	0.5795	0.8519
ENSDARG00000062199	ENSTRUG00000010747	ENSTNIG00000012112	0.1994	0.533
ENSDARG00000062220	ENSTRUG00000017298	ENSTNIG00000009385	0.0906	0.4397
ENSDARG00000062341	ENSTRUG00000007549	ENSTNIG00000017804	0.0939	0.4201
ENSDARG00000062372	ENSTRUG00000018056	ENSTNIG00000005530	0.2672	1.2979
ENSDARG00000062396	ENSTRUG00000010524	ENSTNIG00000012580	0.0421	0.399
ENSDARG00000062401	ENSTRUG00000007718	ENSTNIG00000003880	0.0484	2.3263
ENSDARG00000062445	ENSTRUG00000015008	ENSTNIG00000008434	0.0111	0.341
ENSDARG00000062449	ENSTRUG00000010426	NA	NA	NA
ENSDARG00000062462	NA	ENSTNIG00000008097	NA	NA
ENSDARG00000062552	ENSTRUG00000014206	ENSTNIG00000019036	0.0177	0.5192
ENSDARG00000062633	ENSTRUG00000014715	ENSTNIG00000019027	0.031	0.3641
ENSDARG00000062754	ENSTRUG00000009867	ENSTNIG00000006433	0.0127	0.3774
ENSDARG00000062799	ENSTRUG00000009172	ENSTNIG00000009792	0.0053	0.3345
ENSDARG00000062823	ENSTRUG00000012559	ENSTNIG00000015389	0.0167	0.3469
ENSDARG00000062900	ENSTRUG00000011671	ENSTNIG00000000111	0.1396	0.359
ENSDARG00000062942	ENSTRUG00000016864	ENSTNIG00000016001	0.008	0.383
ENSDARG00000062955	ENSTRUG00000005129	ENSTNIG00000006968	0.0583	0.6624
ENSDARG00000062967	ENSTRUG00000001506	ENSTNIG00000008803	0.0124	0.416
ENSDARG00000062976	NA	NA	NA	NA
ENSDARG00000062986	ENSTRUG00000000949	ENSTNIG00000002895	0.1235	0.6463
ENSDARG00000063006	ENSTRUG00000006755	ENSTNIG00000018192	0.0154	0.5118
ENSDARG00000063018	ENSTRUG00000002265	ENSTNIG00000007832	0.028	0.3773
ENSDARG00000063040	ENSTRUG00000003690	NA	NA	NA
ENSDARG00000063293	ENSTRUG00000012641	ENSTNIG00000017955	0.0634	0.4674
ENSDARG00000063313	ENSTRUG00000005509	ENSTNIG00000003179	0.0709	0.6189
ENSDARG00000063332	ENSTRUG00000012301	ENSTNIG00000017950	0.0712	0.2824
ENSDARG00000063361	ENSTRUG00000008238	ENSTNIG00000019255	0.0747	0.3893
ENSDARG00000063420	ENSTRUG00000002594	ENSTNIG00000003691	0.04	0.4114
ENSDARG00000063538	ENSTRUG00000008206	ENSTNIG00000006578	0.0341	0.5285
ENSDARG00000063544	ENSTRUG00000017352	ENSTNIG00000019618	0.2696	64.2405
ENSDARG00000063555	ENSTRUG00000008158	ENSTNIG00000001006	0.3165	66.9336
ENSDARG00000063568	ENSTRUG00000006379	ENSTNIG00000016076	0.0371	0.2716
ENSDARG00000063594	ENSTRUG00000004746	ENSTNIG00000012412	0.0474	0.8407
ENSDARG00000063682	ENSTRUG00000014678	ENSTNIG00000009233	0.0491	0.4695
ENSDARG00000067566	NA	ENSTNIG00000015843	NA	NA
ENSDARG00000067591	NA	ENSTNIG00000010005	NA	NA
ENSDARG00000067634	ENSTRUG00000011716	ENSTNIG00000010274	0.0602	0.4751
ENSDARG00000067683	ENSTRUG00000001830	ENSTNIG00000005281	0.1494	0.4648
ENSDARG00000067701	NA	NA	NA	NA
ENSDARG00000067720	ENSTRUG00000014235	ENSTNIG00000013161	0.0339	0.2239
ENSDARG00000067725	NA	ENSTNIG00000002518	NA	NA
ENSDARG00000067820	ENSTRUG00000010430	ENSTNIG00000015305	0.1495	0.3915
ENSDARG00000067908	ENSTRUG00000005453	ENSTNIG00000009710	0.1274	0.5668
ENSDARG00000067927	ENSTRUG00000017698	NA	NA	NA
ENSDARG00000067999	ENSTRUG00000014359	ENSTNIG00000017236	0	0.2831
ENSDARG00000068008	ENSTRUG00000011196	ENSTNIG00000010084	0.0611	0.5505
ENSDARG00000068232	NA	ENSTNIG00000000841	NA	NA
ENSDARG00000068242	NA	ENSTNIG00000004285	NA	NA
ENSDARG00000068296	ENSTRUG00000007682	NA	NA	NA
ENSDARG00000068397	ENSTRUG00000011718	ENSTNIG00000007191	0.074	0.3702
ENSDARG00000068483	ENSTRUG00000006700	ENSTNIG00000006336	0.267	1.4017
ENSDARG00000068705	ENSTRUG00000002346	ENSTNIG00000018521	0.0251	0.4991
ENSDARG00000068849	ENSTRUG00000017731	ENSTNIG00000013100	0.0306	0.3552
ENSDARG00000068890	NA	ENSTNIG00000006449	NA	NA
ENSDARG00000068918	NA	NA	NA	NA
ENSDARG00000069030	NA	ENSTNIG00000009548	NA	NA
ENSDARG00000069265	ENSTRUG00000006999	ENSTNIG00000018776	0.1956	1.006
ENSDARG00000069318	ENSTRUG00000014212	ENSTNIG00000016382	0.0259	0.3446
ENSDARG00000069388	ENSTRUG00000005134	ENSTNIG00000007019	0.2231	1.5284
ENSDARG00000069467	NA	NA	NA	NA
ENSDARG00000069589	ENSTRUG00000013224	ENSTNIG00000009652	0.0184	0.6295
ENSDARG00000069674	ENSTRUG00000001109	NA	NA	NA
ENSDARG00000069701	NA	NA	NA	NA
ENSDARG00000069742	NA	NA	NA	NA
ENSDARG00000069745	ENSTRUG00000011198	ENSTNIG00000003710	0.0887	0.4727
ENSDARG00000069748	ENSTRUG00000010580	ENSTNIG00000003712	0.0117	0.508
ENSDARG00000069765	ENSTRUG00000012329	ENSTNIG00000010304	0.0976	0.3857
ENSDARG00000069787	ENSTRUG00000010551	ENSTNIG00000009763	0.1978	0.4531
ENSDARG00000069829	ENSTRUG00000009237	ENSTNIG00000006131	0.0099	0.4584
ENSDARG00000069830	ENSTRUG00000009230	ENSTNIG00000006130	0.1554	0.5255
ENSDARG00000069994	ENSTRUG00000015650	NA	NA	NA
ENSDARG00000070056	ENSTRUG00000005994	ENSTNIG00000007262	0.0917	0.764
ENSDARG00000070100	ENSTRUG00000005096	ENSTNIG00000003658	0.1923	0.9957
ENSDARG00000070171	NA	NA	NA	NA
ENSDARG00000070314	ENSTRUG00000005432	ENSTNIG00000018525	0.5113	1.2996
ENSDARG00000070412	ENSTRUG00000009340	NA	NA	NA
ENSDARG00000070479	NA	NA	NA	NA
ENSDARG00000070507	ENSTRUG00000004394	ENSTNIG00000009931	0.0164	0.4653
ENSDARG00000070571	ENSTRUG00000013615	ENSTNIG00000007072	0.0832	0.3935
ENSDARG00000070575	NA	ENSTNIG00000008049	NA	NA
ENSDARG00000070590	ENSTRUG00000011497	ENSTNIG00000017477	0.0981	0.5062
ENSDARG00000070620	NA	ENSTNIG00000008101	NA	NA
ENSDARG00000070726	ENSTRUG00000006545	NA	NA	NA
ENSDARG00000070787	ENSTRUG00000000583	ENSTNIG00000004863	0.0346	0.7983
ENSDARG00000070919	ENSTRUG00000006293	ENSTNIG00000007260	0.03	0.3613
ENSDARG00000070941	NA	NA	NA	NA
ENSDARG00000070956	ENSTRUG00000012849	ENSTNIG00000010445	0.094	0.4717
ENSDARG00000070971	ENSTRUG00000000858	ENSTNIG00000012166	0.037	0.3045
ENSDARG00000070973	ENSTRUG00000012066	ENSTNIG00000010439	0.0701	0.4097

ENSDARG00000070995	ENSTRUG00000011479	ENSTNIG00000010620	0.0614	0.6613
ENSDARG00000071031	ENSTRUG00000015869	ENSTNIG00000008449	0.0301	0.4755
ENSDARG00000071091	ENSTRUG00000007974	ENSTNIG00000017024	0.0705	0.9104
ENSDARG00000071217	ENSTRUG00000011811	ENSTNIG00000013262	0.039	0.4804
ENSDARG00000071493	ENSTRUG00000008827	ENSTNIG00000018960	0.0146	0.5497
ENSDARG00000071637	ENSTRUG00000018424	ENSTNIG00000018261	0.0623	0.529
ENSDARG00000073699	ENSTRUG00000008551	ENSTNIG00000003267	0.0644	0.3538
ENSDARG00000073707	ENSTRUG00000016013	ENSTNIG00000011781	0.033	0.3655
ENSDARG00000073756	ENSTRUG00000004961	ENSTNIG00000006334	0.047	0.5523
ENSDARG00000073769	NA	ENSTNIG00000002062	NA	NA
ENSDARG00000073792	ENSTRUG00000001960	ENSTNIG00000005227	0.0583	0.5067
ENSDARG00000073822	ENSTRUG00000007493	ENSTNIG00000017938	0.0204	0.4018
ENSDARG00000073861	ENSTRUG00000006205	ENSTNIG00000009741	0.055	0.2726
ENSDARG00000073918	NA	ENSTNIG00000018369	NA	NA
ENSDARG00000073970	ENSTRUG00000008044	NA	NA	NA
ENSDARG00000074018	ENSTRUG00000018053	ENSTNIG00000011873	0.0363	0.7413
ENSDARG00000074073	ENSTRUG00000007180	ENSTNIG00000003291	0.0621	0.4183
ENSDARG00000074075	ENSTRUG00000007831	ENSTNIG00000009099	0.0544	0.5122
ENSDARG00000074153	NA	ENSTNIG00000013969	NA	NA
ENSDARG00000074173	NA	NA	NA	NA
ENSDARG00000074229	ENSTRUG00000012187	ENSTNIG00000015190	0.1568	0.679
ENSDARG00000074275	ENSTRUG00000015361	ENSTNIG00000018660	0.1364	0.511
ENSDARG00000074308	ENSTRUG00000016337	ENSTNIG00000011478	0.0316	0.6698
ENSDARG00000074321	ENSTRUG00000011546	ENSTNIG00000015031	0.0248	0.2909
ENSDARG00000074358	NA	ENSTNIG00000013079	NA	NA
ENSDARG00000074372	ENSTRUG00000015197	ENSTNIG00000008254	0.0277	0.463
ENSDARG00000074381	ENSTRUG00000012915	ENSTNIG00000008305	0.0583	0.4298
ENSDARG00000074396	ENSTRUG00000016738	ENSTNIG00000012869	0.0417	0.5833
ENSDARG00000074403	NA	NA	NA	NA
ENSDARG00000074419	ENSTRUG00000005413	ENSTNIG00000013712	0.0828	0.7466
ENSDARG00000074457	ENSTRUG00000011128	ENSTNIG00000006832	0.0282	0.5469
ENSDARG00000074526	ENSTRUG00000006950	ENSTNIG00000016189	0.0418	0.3996
ENSDARG00000074535	ENSTRUG00000015501	ENSTNIG00000005123	0.0263	0.2577
ENSDARG00000074599	ENSTRUG00000001241	ENSTNIG00000007361	0.0435	0.3075
ENSDARG00000074636	ENSTRUG00000013385	ENSTNIG00000017459	0.1362	0.3794
ENSDARG00000074638	ENSTRUG00000015693	ENSTNIG00000016685	0.0329	0.3461
ENSDARG00000074663	ENSTRUG00000014755	ENSTNIG00000016552	0.0508	0.3937
ENSDARG00000074681	ENSTRUG00000012302	ENSTNIG00000014297	0.022	0.3637
ENSDARG00000074777	ENSTRUG00000002322	ENSTNIG00000005321	0.0296	0.5899
ENSDARG00000074826	ENSTRUG00000006199	ENSTNIG00000009164	0.0482	0.5942
ENSDARG00000074843	ENSTRUG00000004827	ENSTNIG00000004469	0.1154	0.6371
ENSDARG00000074854	ENSTRUG00000007266	ENSTNIG00000015778	0.0338	0.2651
ENSDARG00000074897	NA	ENSTNIG00000011986	NA	NA
ENSDARG00000074905	ENSTRUG00000010641	ENSTNIG00000006896	0.0947	0.9663
ENSDARG00000074924	ENSTRUG00000012001	ENSTNIG00000016368	0.0783	0.4425
ENSDARG00000074976	ENSTRUG00000007595	ENSTNIG00000016267	0.0366	0.3536
ENSDARG00000074979	ENSTRUG00000007206	ENSTNIG00000014571	0.1007	0.3528
ENSDARG00000074984	ENSTRUG00000014536	ENSTNIG00000019030	0.0323	0.2118
ENSDARG00000075026	ENSTRUG00000004166	ENSTNIG00000007881	0.0873	0.4644
ENSDARG00000075054	ENSTRUG00000018567	ENSTNIG00000013535	0.0132	0.3848
ENSDARG00000075141	ENSTRUG00000007794	ENSTNIG00000014078	0.1313	0.5595
ENSDARG00000075147	ENSTRUG00000005811	ENSTNIG00000006518	0.0522	0.4413
ENSDARG00000075152	ENSTRUG00000007950	NA	NA	NA
ENSDARG00000075180	ENSTRUG00000005743	ENSTNIG00000005736	0.0757	0.5255
ENSDARG00000075192	ENSTRUG00000011211	ENSTNIG00000013648	0.0392	0.3249
ENSDARG00000075209	ENSTRUG00000014890	ENSTNIG00000014705	0.0539	0.3709
ENSDARG00000075227	ENSTRUG00000006938	NA	NA	NA
ENSDARG00000075265	ENSTRUG00000014454	ENSTNIG00000016543	0.1192	0.5117
ENSDARG00000075271	ENSTRUG00000008504	ENSTNIG00000002906	0.083	0.448
ENSDARG00000075328	ENSTRUG00000008576	ENSTNIG00000013635	0.0667	0.4608
ENSDARG00000075382	ENSTRUG00000010179	ENSTNIG00000018224	0.0248	0.7319
ENSDARG00000075394	ENSTRUG00000006008	ENSTNIG00000008683	0.0358	0.4089
ENSDARG00000075455	ENSTRUG00000014709	ENSTNIG00000010937	0.0193	0.4702
ENSDARG00000075519	ENSTRUG00000006067	ENSTNIG00000011858	0.1085	0.5258
ENSDARG00000075600	ENSTRUG00000006089	ENSTNIG00000013224	0.1538	0.4081
ENSDARG00000075648	NA	NA	NA	NA
ENSDARG00000075803	ENSTRUG00000001488	ENSTNIG00000008356	0.0695	0.3498
ENSDARG00000075831	ENSTRUG00000001705	ENSTNIG00000013847	0.035	0.5042
ENSDARG00000075846	NA	NA	NA	NA
ENSDARG00000075858	ENSTRUG00000010009	ENSTNIG00000010349	0.0228	0.2433
ENSDARG00000075865	ENSTRUG00000004155	ENSTNIG00000005214	0.0791	0.4714
ENSDARG00000075924	ENSTRUG00000002566	ENSTNIG00000011096	0.0246	0.3399
ENSDARG00000075930	ENSTRUG00000005652	NA	NA	NA
ENSDARG00000075942	ENSTRUG00000004866	ENSTNIG00000019247	0.151	0.72
ENSDARG00000075980	ENSTRUG00000013195	ENSTNIG00000006956	0.1138	0.6318
ENSDARG00000075986	NA	NA	NA	NA
ENSDARG00000076001	ENSTRUG00000018248	ENSTNIG00000013185	0.0211	0.4106
ENSDARG00000076076	ENSTRUG00000008049	ENSTNIG00000010060	0.2674	0.6762
ENSDARG00000076096	ENSTRUG00000015609	ENSTNIG00000016305	0.0553	0.3643
ENSDARG00000076111	ENSTRUG00000016769	ENSTNIG00000018506	0.0768	0.5355
ENSDARG00000076143	ENSTRUG00000013135	ENSTNIG00000003948	0.0106	0.3735
ENSDARG00000076174	ENSTRUG00000002750	NA	NA	NA
ENSDARG00000076220	ENSTRUG00000010496	ENSTNIG00000010762	0.1176	0.564
ENSDARG00000076265	ENSTRUG00000008355	ENSTNIG00000011053	0.0362	0.4452
ENSDARG00000076268	ENSTRUG00000001896	ENSTNIG00000003126	0.0372	0.5013
ENSDARG00000076281	ENSTRUG00000001086	ENSTNIG00000016501	0.0374	0.4372
ENSDARG00000076302	ENSTRUG00000009781	ENSTNIG00000006057	0.0128	0.3673
ENSDARG00000076309	ENSTRUG00000013330	ENSTNIG00000016452	0.1668	0.3513
ENSDARG00000076404	ENSTRUG00000002979	NA	NA	NA
ENSDARG00000076416	ENSTRUG00000012349	ENSTNIG00000006376	0.0937	0.6212

ENSDARG00000076431	ENSTRUG00000009156	ENSTNIG00000014442	0.0325	0.4787
ENSDARG00000076434	ENSTRUG00000017136	ENSTNIG00000004993	0.0455	0.498
ENSDARG00000076541	ENSTRUG00000012771	ENSTNIG00000009648	0.0972	0.5687
ENSDARG00000076546	ENSTRUG00000004532	ENSTNIG00000006885	0.0277	0.3157
ENSDARG00000076591	ENSTRUG00000000481	ENSTNIG00000006871	0.1337	0.4637
ENSDARG00000076595	ENSTRUG00000012429	ENSTNIG00000008660	0.0947	0.4288
ENSDARG00000076615	ENSTRUG00000015016	ENSTNIG00000008070	0.0888	0.766
ENSDARG00000076620	ENSTRUG00000003248	NA	NA	NA
ENSDARG00000076644	ENSTRUG00000016098	ENSTNIG00000001502	0.0093	0.5524
ENSDARG00000076712	ENSTRUG00000000351	ENSTNIG00000005353	0.0591	0.5732
ENSDARG00000076821	ENSTRUG00000005270	ENSTNIG00000017121	0.0349	0.4055
ENSDARG00000076826	ENSTRUG00000017923	ENSTNIG00000013620	0.0736	0.6365
ENSDARG00000076829	ENSTRUG00000008837	ENSTNIG00000019115	0.1278	0.4051
ENSDARG00000076854	ENSTRUG00000011224	ENSTNIG00000015025	0.117	0.6481
ENSDARG00000076861	ENSTRUG00000004032	ENSTNIG00000006092	0.2268	0.339
ENSDARG00000076868	ENSTRUG00000006298	ENSTNIG00000016263	0.0327	0.3426
ENSDARG00000076960	ENSTRUG00000007605	ENSTNIG00000014920	0.0062	0.5508
ENSDARG00000076962	NA	NA	NA	NA
ENSDARG00000076964	ENSTRUG00000006331	ENSTNIG00000012481	0.1695	0.7248
ENSDARG00000076970	ENSTRUG00000013684	NA	NA	NA
ENSDARG00000076996	ENSTRUG00000000791	ENSTNIG00000007857	0.0417	0.443
ENSDARG00000077038	ENSTRUG00000005335	ENSTNIG00000014731	0.0458	0.3989
ENSDARG00000077039	ENSTRUG00000004849	NA	NA	NA
ENSDARG00000077040	ENSTRUG00000008617	ENSTNIG00000014157	0.1854	0.573
ENSDARG00000077061	NA	NA	NA	NA
ENSDARG00000077083	ENSTRUG00000016314	ENSTNIG00000006727	0.0722	0.357
ENSDARG00000077103	NA	NA	NA	NA
ENSDARG00000077124	ENSTRUG00000012372	ENSTNIG00000015189	0.0289	0.3069
ENSDARG00000077134	ENSTRUG00000009386	ENSTNIG00000013641	0.0989	0.7798
ENSDARG00000077177	ENSTRUG00000003494	ENSTNIG00000011528	0.0214	0.4048
ENSDARG00000077187	NA	NA	NA	NA
ENSDARG00000077192	ENSTRUG00000017387	ENSTNIG00000013982	0.0724	0.312
ENSDARG00000077226	ENSTRUG00000004885	ENSTNIG00000004859	0.0393	0.3543
ENSDARG00000077228	NA	NA	NA	NA
ENSDARG00000077237	ENSTRUG00000017897	ENSTNIG00000009322	0.1578	0.6104
ENSDARG00000077244	ENSTRUG00000005579	NA	NA	NA
ENSDARG00000077275	ENSTRUG00000004446	ENSTNIG00000008176	0.0492	0.438
ENSDARG00000077313	ENSTRUG00000006786	NA	NA	NA
ENSDARG00000077326	NA	NA	NA	NA
ENSDARG00000077352	ENSTRUG00000012842	NA	NA	NA
ENSDARG00000077399	ENSTRUG00000004993	ENSTNIG00000014362	0.0783	0.8102
ENSDARG00000077531	NA	NA	NA	NA
ENSDARG00000077560	ENSTRUG00000017981	ENSTNIG00000014456	0.0219	0.4862
ENSDARG00000077606	ENSTRUG00000008055	ENSTNIG00000014223	0.0244	0.2831
ENSDARG00000077630	ENSTRUG00000017491	ENSTNIG00000009358	0.1142	0.3165
ENSDARG00000077645	ENSTRUG00000010986	ENSTNIG00000010147	0.0196	0.6801
ENSDARG00000077726	ENSTRUG00000004981	ENSTNIG00000014249	0.0723	0.4768
ENSDARG00000077740	ENSTRUG00000017320	ENSTNIG00000009912	0.1194	0.5349
ENSDARG00000077749	NA	ENSTNIG00000006395	NA	NA
ENSDARG00000077775	NA	ENSTNIG00000009171	NA	NA
ENSDARG00000077826	ENSTRUG00000018571	ENSTNIG00000007389	0.0918	0.6818
ENSDARG00000077844	ENSTRUG00000011960	ENSTNIG00000005392	0.0725	0.4902
ENSDARG00000077881	ENSTRUG00000012947	ENSTNIG00000015183	0.1198	0.3142
ENSDARG00000077888	NA	NA	NA	NA
ENSDARG00000077906	ENSTRUG00000018046	ENSTNIG00000006462	0.0256	0.2652
ENSDARG00000077996	ENSTRUG00000017632	ENSTNIG00000007950	0.0618	0.5221
ENSDARG00000078022	ENSTRUG00000016234	ENSTNIG00000018631	0.1559	0.6665
ENSDARG00000078052	ENSTRUG00000003490	ENSTNIG00000012493	0.1001	0.4525
ENSDARG00000078061	ENSTRUG00000017174	ENSTNIG00000009472	0.0559	0.2868
ENSDARG00000078142	ENSTRUG00000003579	ENSTNIG00000011509	0.0668	0.3943
ENSDARG00000078151	ENSTRUG00000003234	ENSTNIG00000005383	0.1105	0.7827
ENSDARG00000078187	ENSTRUG00000011523	ENSTNIG00000017905	0.0359	0.4245
ENSDARG00000078202	ENSTRUG00000009039	ENSTNIG00000001939	0.0498	0.4817
ENSDARG00000078222	ENSTRUG00000009081	ENSTNIG00000009791	0.0862	0.3988
ENSDARG00000078259	ENSTRUG00000010743	ENSTNIG00000017073	0.0402	0.5545
ENSDARG00000078272	ENSTRUG00000016477	ENSTNIG00000015602	0.004	0.39
ENSDARG00000078373	ENSTRUG00000001464	ENSTNIG00000008197	0.0685	0.5233
ENSDARG00000078378	ENSTRUG00000006395	ENSTNIG00000013466	0.0136	0.582
ENSDARG00000078430	ENSTRUG00000008344	ENSTNIG00000009947	0.0841	0.5155
ENSDARG00000078440	ENSTRUG00000014019	ENSTNIG00000012079	0.0727	0.5322
ENSDARG00000078485	ENSTRUG00000003126	NA	NA	NA
ENSDARG00000078486	ENSTRUG00000007019	ENSTNIG00000012978	0.1005	0.6447
ENSDARG00000078578	ENSTRUG00000005106	ENSTNIG00000006437	0.1138	0.6638
ENSDARG00000078599	ENSTRUG00000015336	ENSTNIG00000019362	0.0813	0.3802
ENSDARG00000078603	ENSTRUG00000011919	ENSTNIG00000009071	0.0297	0.3384
ENSDARG00000078615	ENSTRUG00000008779	ENSTNIG00000011320	0.021	0.387
ENSDARG00000078618	ENSTRUG00000001805	ENSTNIG00000009970	0.0416	0.3902
ENSDARG00000078640	ENSTRUG00000011482	ENSTNIG00000014940	0.1006	0.5166
ENSDARG00000078696	ENSTRUG00000009460	ENSTNIG00000006393	0.2682	0.8199
ENSDARG00000078722	ENSTRUG00000007660	ENSTNIG00000015823	0.2818	0.9258
ENSDARG00000078755	ENSTRUG00000002559	ENSTNIG00000005283	0.0668	0.6106
ENSDARG00000078797	ENSTRUG00000007196	ENSTNIG00000009165	0.0464	0.3836
ENSDARG00000078831	ENSTRUG00000013354	ENSTNIG00000009250	0.0652	0.4831
ENSDARG00000078878	NA	NA	NA	NA
ENSDARG00000078953	ENSTRUG00000011398	ENSTNIG00000010433	0.0681	0.2906
ENSDARG00000078981	ENSTRUG00000000256	ENSTNIG00000007011	0.0245	0.3615
ENSDARG00000079029	ENSTRUG00000002834	ENSTNIG00000013341	0.0632	0.3244
ENSDARG00000079167	ENSTRUG00000002437	ENSTNIG00000004127	0.0874	0.7994
ENSDARG00000079184	ENSTRUG00000008866	ENSTNIG00000017933	0.0208	0.4137
ENSDARG00000079235	ENSTRUG00000004684	ENSTNIG00000002623	0.0672	0.6127

ENSDARG00000079286	ENSTRUG00000002708	ENSTNIG00000005325	0.0795	1.2161
ENSDARG00000079324	ENSTRUG00000006745	ENSTNIG00000006400	0.1626	0.934
ENSDARG00000079348	ENSTRUG00000005518	ENSTNIG00000010847	0.0087	0.2877
ENSDARG00000079369	ENSTRUG00000011371	ENSTNIG00000016363	0.0958	0.6963
ENSDARG00000079374	ENSTRUG00000009304	ENSTNIG00000013698	0.037	0.4566
ENSDARG00000079443	ENSTRUG00000001139	ENSTNIG00000007449	0.1275	0.4864
ENSDARG00000079484	ENSTRUG00000018173	ENSTNIG00000018751	0.0127	0.343
ENSDARG00000079491	ENSTRUG00000018207	ENSTNIG00000018288	0.0126	0.4275
ENSDARG00000079496	ENSTRUG00000005933	ENSTNIG00000008789	0.0646	0.7136
ENSDARG00000079561	ENSTRUG00000011056	ENSTNIG00000012191	0.0269	0.394
ENSDARG00000079572	ENSTRUG00000003439	ENSTNIG00000010475	0.0606	0.9634
ENSDARG00000079613	ENSTRUG00000017423	ENSTNIG00000001257	0.0386	0.272
ENSDARG00000079716	ENSTRUG00000015995	ENSTNIG00000008454	0.0184	0.3211
ENSDARG00000079731	ENSTRUG00000005689	ENSTNIG00000011905	0.0559	1.0479
ENSDARG00000079790	ENSTRUG00000015764	ENSTNIG00000016688	0.1352	0.8629
ENSDARG00000079822	NA	ENSTNIG00000010929	NA	NA
ENSDARG00000079850	ENSTRUG00000006179	ENSTNIG00000009938	0.0544	0.4885
ENSDARG00000079858	ENSTRUG00000008099	NA	NA	NA
ENSDARG00000079876	NA	ENSTNIG00000015461	NA	NA
ENSDARG00000079879	ENSTRUG00000013351	ENSTNIG00000009659	0.0379	0.2763
ENSDARG00000079895	ENSTRUG00000008985	ENSTNIG00000018233	0.1893	1.1635
ENSDARG00000079898	ENSTRUG00000001248	ENSTNIG00000004072	0.1579	0.7936
ENSDARG00000079972	ENSTRUG00000018363	ENSTNIG00000018271	0.0479	0.4571
ENSDARG00000079977	ENSTRUG00000017046	ENSTNIG00000009504	0.0588	0.2934
ENSDARG00000080000	ENSTRUG00000012369	ENSTNIG00000015393	0.0565	0.4642
ENSDARG00000086013	ENSTRUG00000003962	ENSTNIG00000006557	0.0513	0.7687
ENSDARG00000086104	ENSTRUG00000002518	ENSTNIG00000007996	0.0386	0.8255
ENSDARG00000086109	ENSTRUG00000004833	ENSTNIG00000015804	0.0426	0.4589
ENSDARG00000086142	ENSTRUG00000005700	ENSTNIG00000014430	0.0703	0.3942
ENSDARG00000086158	ENSTRUG00000012531	ENSTNIG00000007527	0.1046	0.3192
ENSDARG00000086274	ENSTRUG00000005670	ENSTNIG00000002624	0.0635	0.4517
ENSDARG00000086411	ENSTRUG00000006317	NA	NA	NA
ENSDARG00000086450	ENSTRUG00000015289	ENSTNIG00000003097	0.1258	0.765
ENSDARG00000086499	ENSTRUG00000003431	ENSTNIG00000011665	1.058	0.851
ENSDARG00000086762	ENSTRUG00000014926	ENSTNIG00000002463	0.2275	0.4281
ENSDARG00000086775	ENSTRUG00000000575	ENSTNIG00000003868	0.0302	0.4532
ENSDARG00000086808	ENSTRUG00000014479	ENSTNIG00000017233	0.0367	0.3617
ENSDARG00000086965	ENSTRUG00000018362	ENSTNIG00000013485	0.0342	0.3361
ENSDARG00000087059	ENSTRUG00000004431	ENSTNIG00000014423	0.0901	0.3934
ENSDARG00000087086	ENSTRUG00000012297	ENSTNIG00000011598	0.0414	0.4973
ENSDARG00000087196	ENSTRUG00000016362	ENSTNIG00000009593	0.0204	0.3057
ENSDARG00000087260	NA	NA	NA	NA
ENSDARG00000087394	ENSTRUG00000006028	ENSTNIG00000008370	0.0322	0.2847
ENSDARG00000087446	ENSTRUG00000004208	ENSTNIG00000003992	0.205	1.2735
ENSDARG00000087517	ENSTRUG00000000170	ENSTNIG00000003173	0.009	0.3543
ENSDARG00000087599	ENSTRUG00000015740	ENSTNIG00000013031	0.0306	0.3342
ENSDARG00000087646	ENSTRUG00000012611	ENSTNIG00000018690	0.0186	0.3008
ENSDARG00000087687	NA	NA	NA	NA
ENSDARG00000087741	NA	ENSTNIG00000000041	NA	NA
ENSDARG00000087780	NA	ENSTNIG00000016884	NA	NA
ENSDARG00000087983	NA	ENSTNIG00000000980	NA	NA
ENSDARG00000088026	ENSTRUG00000004075	NA	NA	NA
ENSDARG00000088072	ENSTRUG00000008211	NA	NA	NA
ENSDARG00000088121	NA	NA	NA	NA
ENSDARG00000088124	ENSTRUG00000009069	ENSTNIG00000017062	0.0651	0.4799
ENSDARG00000088137	ENSTRUG00000002110	ENSTNIG00000013621	0.0726	0.5056
ENSDARG00000088437	ENSTRUG00000007274	NA	NA	NA
ENSDARG00000088466	ENSTRUG00000008670	ENSTNIG00000013665	0.0674	0.367
ENSDARG00000088521	ENSTRUG00000008954	NA	NA	NA
ENSDARG00000088630	ENSTRUG00000007101	ENSTNIG00000012205	0.1498	0.8753
ENSDARG00000088813	ENSTRUG00000016284	ENSTNIG00000008467	0.0842	0.4086
ENSDARG00000088842	ENSTRUG00000012508	ENSTNIG00000008186	0.0462	0.3541
ENSDARG00000088898	ENSTRUG00000016130	ENSTNIG00000018998	0.0022	0.3061
ENSDARG00000089134	ENSTRUG00000013474	ENSTNIG00000016142	0.0866	1.0394
ENSDARG00000089190	ENSTRUG00000006026	ENSTNIG00000016493	0.0378	0.2762
ENSDARG00000089233	ENSTRUG00000015789	ENSTNIG00000016689	0.1123	0.5823
ENSDARG00000089322	ENSTRUG00000014350	ENSTNIG00000002677	0.0444	0.4062
ENSDARG00000089334	ENSTRUG00000008869	ENSTNIG00000007897	0.0221	0.4644
ENSDARG00000089348	ENSTRUG00000010019	ENSTNIG00000015310	0.1972	1.134
ENSDARG00000089545	ENSTRUG00000009344	ENSTNIG00000017281	0.0588	0.374
ENSDARG00000089641	ENSTRUG00000006341	ENSTNIG00000007711	0.0329	0.3123
ENSDARG00000089647	ENSTRUG00000013687	ENSTNIG00000013163	0.0443	0.4383
ENSDARG00000089805	ENSTRUG00000013467	ENSTNIG00000012373	0.0247	0.3779
ENSDARG00000089817	ENSTRUG00000005487	ENSTNIG00000002413	0.0682	0.6419
ENSDARG00000089853	NA	ENSTNIG00000001053	NA	NA
ENSDARG00000089856	ENSTRUG00000015721	NA	NA	NA
ENSDARG00000089858	ENSTRUG00000010057	ENSTNIG00000013273	0.0575	0.4186
ENSDARG00000089871	ENSTRUG00000003292	NA	NA	NA
ENSDARG00000089887	NA	NA	NA	NA
ENSDARG00000089893	ENSTRUG00000004385	NA	NA	NA
ENSDARG00000089914	ENSTRUG00000013748	ENSTNIG00000016147	0.0564	0.3575
ENSDARG00000090106	ENSTRUG00000016136	ENSTNIG00000012838	0.0145	0.2974
ENSDARG00000090188	NA	NA	NA	NA
ENSDARG00000090292	ENSTRUG00000003829	ENSTNIG00000005594	0.0635	0.4012
ENSDARG00000090314	NA	ENSTNIG00000011503	NA	NA
ENSDARG00000090340	NA	ENSTNIG00000011604	NA	NA
ENSDARG00000090375	NA	ENSTNIG00000011361	NA	NA
ENSDARG00000090402	ENSTRUG00000005437	ENSTNIG00000001404	0.2043	0.4634
ENSDARG00000090514	NA	ENSTNIG00000013800	NA	NA
ENSDARG00000090524	ENSTRUG00000006610	NA	NA	NA

ENSDARG00000090585	ENSTRUG00000012906	ENSTNIG00000015275		0.0984		0.4911
ENSDARG00000090631	NA	ENSTNIG00000014424		NA		NA
ENSDARG00000090669	NA	ENSTNIG00000011106		NA		NA
ENSDARG00000090760	ENSTRUG00000017457	ENSTNIG00000011247		0.1788		0.5837
ENSDARG00000090933	ENSTRUG00000008695	ENSTNIG00000011848		0.0649		0.5722
ENSDARG00000090937	NA	NA		NA		NA
ENSDARG00000091027	ENSTRUG00000013577	ENSTNIG00000000241		0.1432		0.5036
ENSDARG00000091053	ENSTRUG00000005738	ENSTNIG00000019800		0.1973		0.716
ENSDARG00000091059	ENSTRUG00000008911	ENSTNIG00000015320		0.0509		0.4491
ENSDARG00000091163	ENSTRUG00000003485	NA		NA		NA
ENSDARG00000091173	NA	ENSTNIG00000012303		NA		NA
ENSDARG00000091238	ENSTRUG00000002885	ENSTNIG00000008720		0.1118		0.4832
ENSDARG00000091359	NA	ENSTNIG00000003513		NA		NA
ENSDARG00000091406	ENSTRUG00000016751	ENSTNIG00000012871		0.1963		0.7701
ENSDARG00000091509	NA	ENSTNIG00000017498		NA		NA
ENSDARG00000091540	ENSTRUG00000012438	ENSTNIG00000014050		0.1393		0.4116
ENSDARG00000091550	ENSTRUG00000003983	ENSTNIG00000017119		0.1391		0.5166
ENSDARG00000091623	ENSTRUG00000004659	ENSTNIG00000006886		0.0531		0.3737
ENSDARG00000091637	ENSTRUG00000018528	ENSTNIG00000018238		0.0591		0.4121
ENSDARG00000091902	NA	ENSTNIG00000009843		NA		NA
ENSDARG00000092081	ENSTRUG00000007848	ENSTNIG00000010770		0.0045		0.2773
ENSDARG00000092154	ENSTRUG00000003737	ENSTNIG00000014619		0.036		0.3802
ENSDARG00000092158	ENSTRUG00000015222	ENSTNIG00000018425		0.0958		0.6942
ENSDARG00000092553	ENSTRUG00000016841	ENSTNIG00000010037		0.0085		0.3705
ENSDARG00000092610	ENSTRUG00000012964	NA		NA		NA
ENSDARG00000093021	ENSTRUG00000015772	NA		NA		NA
ENSDARG00000093091	ENSTRUG00000015173	ENSTNIG00000019218		0.0245		0.2562
ENSDARG00000093357	ENSTRUG00000012837	ENSTNIG00000015273		0.1412		0.4872
ENSDARG00000093359	NA	ENSTNIG00000015839		NA		NA
ENSDARG00000093401	NA	NA		NA		NA
ENSDARG00000093411	ENSTRUG00000017805	ENSTNIG00000016929		0.0327		0.4285
ENSDARG00000093515	NA	ENSTNIG00000010549		NA		NA
ENSDARG00000094052	ENSTRUG00000012398	ENSTNIG00000009069		0.0053		0.3712
ENSDARG00000094243	ENSTRUG00000016015	ENSTNIG00000017190		0.0415		0.3314
ENSDARG00000094255	ENSTRUG00000000725	ENSTNIG00000007859		0.0198		0.34
ENSDARG00000094377	ENSTRUG00000004052	NA		NA		NA
ENSDARG00000094510	ENSTRUG00000017608	ENSTNIG00000010548		0.1078		0.6005
ENSDARG00000094665	NA	ENSTNIG00000016548		NA		NA
ENSDARG00000094908	NA	ENSTNIG00000009159		NA		NA
ENSDARG00000095378	ENSTRUG00000012585	ENSTNIG00000016525		0.0671		0.4175
ENSDARG00000095603	ENSTRUG00000016907	ENSTNIG00000012909		0.0634		0.5452
ENSDARG00000095614	ENSTRUG00000008613	ENSTNIG00000008511		0.0985		0.5764
ENSDARG00000078973	ENSTRUG00000004158	ENSTNIG00000017876		0.0067		0.3954
ENSDARG00000011408	ENSTRUG00000015798	NA	NA		NA	
ENSDARG00000001549	ENSTRUG00000017623	ENSTNIG00000016947		0.0353		0.3995
ENSDARG00000013979	ENSTRUG00000007238	ENSTNIG00000008944		0.1148		0.664
ENSDARG00000030053	ENSTRUG00000005970	ENSTNIG00000008232		0.1048		0.6106
ENSDARG00000006125	ENSTRUG00000011074	NA	NA		NA	
ENSDARG00000036628	ENSTRUG00000005735	ENSTNIG00000014229		0.3123		0.2731
ENSDARG00000086881	NA	ENSTNIG00000012623	NA		NA	
ENSDARG00000030583	ENSTRUG00000002114	ENSTNIG00000011273		0.0857		0.8095
ENSDARG00000087346	ENSTRUG00000012733	ENSTNIG00000007040		0.0049		0.1028
ENSDARG00000035054	NA	NA	NA		NA	
ENSDARG00000013582	ENSTRUG00000007789	ENSTNIG00000003879		0.0045		0.6611
ENSDARG00000071691	ENSTRUG00000016755	ENSTNIG00000012872		0.0294		0.4323
ENSDARG00000055433	ENSTRUG00000006004	ENSTNIG00000011629		0.0887		0.3875
ENSDARG00000007323	ENSTRUG00000002361	ENSTNIG00000006573		0.0623		0.5395
ENSDARG00000010279	ENSTRUG00000016067	NA	NA		NA	
ENSDARG00000007257	ENSTRUG00000009771	ENSTNIG00000011661		0.0101		0.4577
ENSDARG00000002271	ENSTRUG00000011466	ENSTNIG00000005232		0.0593		0.2491
ENSDARG00000071076	ENSTRUG00000016868	ENSTNIG00000016004		0.0355		0.6259
ENSDARG00000075954	NA	NA	NA		NA	
ENSDARG00000010745	ENSTRUG00000014675	ENSTNIG00000019210		0.0044		0.3869
ENSDARG00000043555	NA	NA	NA		NA	
ENSDARG00000034201	ENSTRUG00000012820	ENSTNIG00000005579		0.0763		0.5719
ENSDARG00000019362	ENSTRUG00000011360	ENSTNIG00000002060		0.0297		0.2837
ENSDARG00000039880	NA	NA	NA		NA	
ENSDARG00000038780	ENSTRUG00000009527	ENSTNIG00000003066		0.0518		0.8207
ENSDARG00000007959	ENSTRUG00000015370	ENSTNIG00000018428		0.0352		0.278
ENSDARG00000023279	ENSTRUG00000002109	ENSTNIG00000018343		0.0418		0.3904
ENSDARG00000045230	ENSTRUG00000016356	NA	NA		NA	
ENSDARG00000035715	NA	NA	NA		NA	
ENSDARG00000043448	ENSTRUG00000006075	ENSTNIG00000014326		0.0439		0.6013
ENSDARG00000015790	ENSTRUG00000000740	ENSTNIG00000007841		0.0625		0.5017
ENSDARG00000035869	NA	ENSTNIG00000009173	NA		NA	
ENSDARG00000007409	ENSTRUG00000005996	ENSTNIG00000008632		0.0514		0.3726
ENSDARG00000071018	ENSTRUG00000009851	ENSTNIG00000013318		0.0021		0.1177
ENSDARG00000029663	ENSTRUG00000000409	NA	NA		NA	
ENSDARG00000005134	ENSTRUG00000002031	NA	NA		NA	
ENSDARG00000044092	ENSTRUG00000008454	NA	NA		NA	
ENSDARG00000068940	NA	ENSTNIG00000018873	NA		NA	
ENSDARG00000077329	ENSTRUG00000002211	ENSTNIG00000004188		0.0085		0.4993
ENSDARG00000089610	ENSTRUG00000007203	NA	NA		NA	
ENSDARG00000002549	NA	ENSTNIG00000004238	NA		NA	
ENSDARG00000007682	ENSTRUG00000005040	ENSTNIG00000002328		0.0565		0.8625
ENSDARG00000091756	ENSTRUG00000015478	ENSTNIG00000001062		0.0766		0.6946
ENSDARG00000028664	NA	NA	NA		NA	
ENSDARG00000022509	NA	NA	NA		NA	
ENSDARG00000059311	ENSTRUG00000004660	ENSTNIG00000019135		0.0215		0.3677
ENSDARG00000061120	ENSTRUG00000003499	ENSTNIG00000006856		0.061		0.4747

ENSDARG00000005254	ENSTRUG00000016003	ENSTNIG00000017976		0.0408		0.4079
ENSDARG00000073734	NA	NA	NA		NA	
ENSDARG00000002994	ENSTRUG00000014239	ENSTNIG00000011809		0.0475		0.3008
ENSDARG00000025428	ENSTRUG00000011640	ENSTNIG00000000237		0.051		0.3628
ENSDARG00000015831	ENSTRUG00000012934	ENSTNIG00000010446		0.0491		0.7594
ENSDARG00000036496	NA	NA	NA		NA	
ENSDARG00000076836	ENSTRUG00000009426	ENSTNIG00000015343		0.0571		0.3012
ENSDARG00000091481	ENSTRUG00000011513	ENSTNIG00000008526		0.039		0.4413
ENSDARG00000054771	ENSTRUG00000015040	ENSTNIG00000001788		0.0893		0.307
ENSDARG00000007369	ENSTRUG00000001134	ENSTNIG00000006080		0.1184		0.5726
ENSDARG00000029764	ENSTRUG00000018605	ENSTNIG00000013575		0.031		0.3116
ENSDARG00000076440	ENSTRUG00000016244	ENSTNIG00000004804		0.0237		0.4561
ENSDARG00000045971	ENSTRUG00000008580	ENSTNIG00000006398		0.1509		0.4894
ENSDARG00000013704	ENSTRUG00000012292	ENSTNIG00000017545		0.0569		0.5491
ENSDARG00000077044	ENSTRUG00000001162	ENSTNIG00000007362		0.0609		0.3191
ENSDARG00000003098	ENSTRUG00000006793	NA	NA		NA	
ENSDARG00000006275	ENSTRUG00000011333	NA	NA		NA	
ENSDARG00000005122	NA	NA	NA		NA	
ENSDARG00000011934	ENSTRUG00000014211	ENSTNIG00000019431		0.0494		0.3132
ENSDARG00000007818	ENSTRUG00000011574	NA	NA		NA	
ENSDARG00000011929	ENSTRUG00000015475	ENSTNIG00000011791		0.0234		0.207
ENSDARG00000036073	ENSTRUG00000006448	ENSTNIG00000001629		0.0539		0.7084
ENSDARG00000009594	ENSTRUG00000008460	ENSTNIG00000009796		0.0936		0.6775
ENSDARG00000023443	ENSTRUG00000012991	ENSTNIG00000004291		0.0283		0.5158
ENSDARG00000017294	ENSTRUG00000009040	NA	NA		NA	
ENSDARG00000035809	ENSTRUG00000007520	ENSTNIG00000014440		0.0774		0.1474
ENSDARG00000015559	ENSTRUG00000006066	ENSTNIG00000009856		0.1364		0.3153
ENSDARG00000071015	ENSTRUG00000010742	NA	NA		NA	
ENSDARG00000031075	ENSTRUG00000012483	NA	NA		NA	
ENSDARG00000052330	ENSTRUG00000010602	ENSTNIG00000017145		0.0324		0.4019
ENSDARG00000027600	ENSTRUG00000013562	ENSTNIG00000009055		0.1077		0.5787
ENSDARG00000016016	ENSTRUG00000002172	ENSTNIG00000006277		0.0584		0.3691
ENSDARG00000069054	ENSTRUG00000001238	ENSTNIG00000015234		0.0126		0.7529
ENSDARG00000035949	ENSTRUG00000001495	ENSTNIG00000005001		0.059		0.5059
ENSDARG00000034956	ENSTRUG00000013977	ENSTNIG00000009239		0.0578		0.5494
ENSDARG00000005481	ENSTRUG00000004942	ENSTNIG00000009708		0.0584		0.5803
ENSDARG00000005739	ENSTRUG00000013892	ENSTNIG00000008313		0.0513		0.4756
ENSDARG00000044526	ENSTRUG00000000296	ENSTNIG00000005892		0.1023		0.5354
ENSDARG00000032849	ENSTRUG00000010413	ENSTNIG00000006430		0.0467		0.5247
ENSDARG00000061774	ENSTRUG00000008081	ENSTNIG00000015324		0.0278		0.4418
ENSDARG00000056483	ENSTRUG00000017822	ENSTNIG00000004007		0.0127		0.2547
ENSDARG00000052856	ENSTRUG00000012039	ENSTNIG00000017471		0.0161		0.5008
ENSDARG00000036121	ENSTRUG00000000287	ENSTNIG00000007013		0.014		0.3606
ENSDARG00000014947	ENSTRUG00000002524	ENSTNIG00000000228		0.1877		1.5592
ENSDARG00000045808	ENSTRUG00000015662	ENSTNIG00000010390		0.0108		1.045
ENSDARG00000037783	ENSTRUG00000015935	NA	NA		NA	
ENSDARG00000069440	ENSTRUG00000009836	ENSTNIG00000017035		0.1647		0.6405
ENSDARG00000002632	ENSTRUG00000013880	NA	NA		NA	
ENSDARG00000009311	NA	ENSTNIG00000011499	NA		NA	
ENSDARG00000036344	ENSTRUG00000018012	ENSTNIG00000009303		0.0249		0.5551
ENSDARG00000036577	ENSTRUG00000005326	ENSTNIG00000011581		0		0.5083
ENSDARG00000031086	ENSTRUG00000010357	ENSTNIG00000010737		0.0315		0.2297
ENSDARG00000010953	ENSTRUG00000011075	ENSTNIG00000011838		0.0371		0.609
ENSDARG00000058538	ENSTRUG00000006355	ENSTNIG00000016172		0.111		0.374
ENSDARG00000069752	NA	ENSTNIG00000012392	NA		NA	
ENSDARG00000009738	ENSTRUG00000014531	ENSTNIG00000015695		0.0197		0.3857
ENSDARG00000070173	NA	NA	NA		NA	
ENSDARG00000035327	ENSTRUG00000001749	ENSTNIG00000006759		0.0113		1.036
ENSDARG00000055455	ENSTRUG00000015645	ENSTNIG00000013027		0.0066		0.2198
ENSDARG00000008310	ENSTRUG00000010054	ENSTNIG00000007100		0.0576		0.4519
ENSDARG00000026165	ENSTRUG00000001411	ENSTNIG00000018961		0.0358		0.2254
ENSDARG00000069991	NA	NA	NA		NA	
ENSDARG00000043235	NA	ENSTNIG00000009619	NA		NA	
ENSDARG00000060457	ENSTRUG00000009718	ENSTNIG00000014448		0.061		0.2516
ENSDARG00000055100	ENSTRUG00000006259	ENSTNIG00000016533		0.2298		0.8203
ENSDARG00000076833	ENSTRUG00000005896	ENSTNIG00000014477		0.0588		0.4428
ENSDARG00000006526	ENSTRUG00000017137	ENSTNIG00000009479		0.1054		0.4292
ENSDARG00000013730	ENSTRUG00000015446	ENSTNIG00000015348		0.0149		0.3195
ENSDARG00000017710	NA	ENSTNIG00000011189	NA		NA	
ENSDARG00000021366	ENSTRUG00000015762	ENSTNIG00000015637		0.0269		0.2987
ENSDARG00000013168	NA	ENSTNIG00000016644	NA		NA	
ENSDARG00000070404	ENSTRUG00000009452	ENSTNIG00000014744		0.0515		0.4842
ENSDARG00000034424	ENSTRUG00000016164	ENSTNIG00000011776		0.035		0.4189
ENSDARG00000036080	ENSTRUG00000001429	ENSTNIG00000004998		0.1585		0.5085
ENSDARG00000035734	ENSTRUG00000001692	NA	NA		NA	
ENSDARG00000032175	ENSTRUG00000008843	ENSTNIG00000003069		0.0271		0.6633
ENSDARG00000018989	ENSTRUG00000006546	ENSTNIG00000008942		0.0214		0.4021
ENSDARG00000026482	NA	ENSTNIG00000008769	NA		NA	
ENSDARG00000053668	ENSTRUG00000004601	ENSTNIG00000015785		0.0238		0.2617
ENSDARG00000043973	ENSTRUG00000004819	ENSTNIG00000019194		0.2652		0.5946
ENSDARG00000007915	ENSTRUG00000004107	ENSTNIG00000004943		0.0767		0.8262
ENSDARG00000028336	ENSTRUG00000013036	NA	NA		NA	
ENSDARG00000006624	ENSTRUG00000006787	ENSTNIG00000005253		0.0037		0.4292
ENSDARG00000063535	ENSTRUG00000000137	ENSTNIG00000004095		0.1466		0.6489
ENSDARG00000034434	ENSTRUG00000015459	ENSTNIG00000011921		0.0545		1.0008
ENSDARG00000003213	ENSTRUG00000003946	NA	NA		NA	
ENSDARG00000017338	ENSTRUG00000005483	ENSTNIG00000002502		0.0871		1.0143
ENSDARG00000044251	ENSTRUG00000005484	ENSTNIG00000013225		0.0375		0.7449
ENSDARG00000016481	ENSTRUG00000012316	ENSTNIG00000013312		0.0439		0.2504
ENSDARG00000036510	ENSTRUG00000012138	ENSTNIG00000010364		0.0692		0.3559

ENSDARG00000039784	ENSTRUG00000010414	ENSTNIG00000004372		0.1066		1.1232
ENSDARG00000074248	ENSTRUG00000009812	NA	NA		NA	
ENSDARG00000020964	ENSTRUG00000007070	ENSTNIG00000003292		0.0578		0.7167
ENSDARG00000013830	ENSTRUG00000011220	ENSTNIG00000010928		0.0357		0.4292
ENSDARG00000024598	NA	ENSTNIG00000000498	NA		NA	
ENSDARG00000004189	NA	ENSTNIG00000003151	NA		NA	
ENSDARG00000034062	ENSTRUG00000018222	ENSTNIG00000009205		0.0991		0.5018
ENSDARG00000062954	ENSTRUG00000009138	ENSTNIG00000017573		0.0367		0.6168
ENSDARG00000016773	ENSTRUG00000012004	ENSTNIG00000014673		0.1801		0.5652
ENSDARG00000061587	ENSTRUG00000017282	ENSTNIG00000009399		0.0358		0.4483
ENSDARG00000062082	ENSTRUG00000004241	ENSTNIG00000013812		0.16		0.5403
ENSDARG00000071658	NA	NA	NA		NA	
ENSDARG00000006299	ENSTRUG00000014456	ENSTNIG00000013868		0.029		0.3076
ENSDARG00000018976	ENSTRUG00000003776	NA	NA		NA	
ENSDARG00000021488	ENSTRUG00000018136	ENSTNIG00000004818		0.0375		1.1768
ENSDARG00000088440	NA	NA	NA		NA	
ENSDARG00000040039	ENSTRUG00000008959	ENSTNIG00000016478		0.0788		0.5973
ENSDARG00000022213	ENSTRUG00000012683	ENSTNIG00000006951		0.0135		0.1915
ENSDARG00000034933	ENSTRUG00000016881	NA	NA		NA	
ENSDARG00000028099	ENSTRUG00000008304	NA	NA		NA	
ENSDARG00000025012	NA	NA	NA		NA	
ENSDARG00000013087	ENSTRUG00000010616	NA	NA		NA	
ENSDARG00000062581	ENSTRUG00000008583	ENSTNIG00000008977		0.0244		0.2734
ENSDARG00000037498	ENSTRUG00000007674	ENSTNIG00000008978		0.0065		0.1888
ENSDARG00000058424	ENSTRUG00000002684	ENSTNIG00000017971		0.1378		0.3868
ENSDARG00000030106	ENSTRUG00000001455	ENSTNIG00000019174		0.0086		0.3539
ENSDARG00000009142	ENSTRUG00000011779	ENSTNIG00000016366		0.0305		0.3869
ENSDARG00000003854	NA	NA	NA		NA	
ENSDARG00000070651	ENSTRUG00000005119	ENSTNIG00000011122		0.0716		0.4144
ENSDARG00000041051	NA	NA	NA		NA	
ENSDARG00000022531	ENSTRUG00000008060	ENSTNIG00000010205		0.1922		1.0512
ENSDARG00000010511	ENSTRUG00000011711	ENSTNIG00000013688		0.1019		0.75
ENSDARG00000003933	ENSTRUG00000012678	ENSTNIG00000006352		0.0173		0.7471
ENSDARG00000005776	ENSTRUG00000014041	ENSTNIG00000015532		0.0334		0.4057
ENSDARG00000057456	ENSTRUG00000018642	ENSTNIG00000005671		0.0257		0.3432
ENSDARG00000056664	ENSTRUG00000006003	ENSTNIG00000009937		0.0284		0.7723
ENSDARG00000038288	ENSTRUG00000004585	ENSTNIG00000016071		0.0455		0.361
ENSDARG00000056892	ENSTRUG00000014887	ENSTNIG00000018422		0.027		0.3764
ENSDARG00000040649	ENSTRUG00000016783	ENSTNIG00000015985		0.034		0.3951
ENSDARG00000038363	ENSTRUG00000015396	NA	NA		NA	
ENSDARG00000058356	ENSTRUG00000017643	ENSTNIG00000006624		0.0433		0.334
ENSDARG00000008388	ENSTRUG00000005793	ENSTNIG00000007935		0.0508		0.4661
ENSDARG00000019235	ENSTRUG00000014935	ENSTNIG00000011024		0.0198		0.4178
ENSDARG00000032606	ENSTRUG00000007476	ENSTNIG00000018198		0.0743		0.9003
ENSDARG00000075597	ENSTRUG00000013952	ENSTNIG00000001417		0.0212		0.3073
ENSDARG00000033234	ENSTRUG00000013626	ENSTNIG00000018402		0.0235		0.2401
ENSDARG00000056084	NA	NA	NA		NA	
ENSDARG00000042904	ENSTRUG00000001458	ENSTNIG00000006390		0.077		0.4265
ENSDARG00000059368	ENSTRUG00000011517	ENSTNIG00000002369		0.0069		0.5294
ENSDARG00000003399	ENSTRUG00000000925	ENSTNIG00000006362		0.0171		0.3219
ENSDARG00000011862	ENSTRUG00000006071	ENSTNIG00000009882		0.0482		0.5337
ENSDARG00000074030	ENSTRUG00000007068	ENSTNIG00000004354		0.0752		0.7771
ENSDARG00000038569	ENSTRUG00000016955	ENSTNIG00000007978		0.0529		0.3618
ENSDARG00000035899	ENSTRUG00000016358	ENSTNIG00000009594		0.0271		0.344
ENSDARG00000056783	ENSTRUG00000016415	ENSTNIG00000012850		0.0029		0.3149
ENSDARG00000045524	ENSTRUG00000015177	NA	NA		NA	
ENSDARG00000023362	NA	NA	NA		NA	
ENSDARG00000003091	ENSTRUG00000005624	ENSTNIG00000004547		0.1842		1.0037
ENSDARG00000043716	ENSTRUG00000016497	ENSTNIG00000001355		0.022		0.4432
ENSDARG00000078416	ENSTRUG00000005095	ENSTNIG00000017169		0.0286		0.4788
ENSDARG00000001127	ENSTRUG00000012164	ENSTNIG00000001186		0.0122		0.4607
ENSDARG00000061848	ENSTRUG00000003337	ENSTNIG00000017607		0.2545		0.5391
ENSDARG00000010791	ENSTRUG00000010455	ENSTNIG00000003274		0.071		1.4571
ENSDARG00000004232	ENSTRUG00000006928	ENSTNIG00000014241		0.0176		1.0034
ENSDARG00000053884	ENSTRUG00000008851	NA	NA		NA	
ENSDARG00000011515	ENSTRUG00000005503	NA	NA		NA	
ENSDARG00000037100	ENSTRUG00000002767	ENSTNIG00000014473		0.2395		0.4343
ENSDARG00000020114	ENSTRUG00000007953	ENSTNIG00000003931		0.0835		0.3326
ENSDARG00000069093	ENSTRUG00000003937	ENSTNIG00000012588		0.0381		0.2381
ENSDARG00000045768	NA	ENSTNIG00000012660	NA		NA	
ENSDARG00000055383	ENSTRUG00000009623	NA	NA		NA	
ENSDARG00000077012	ENSTRUG00000015502	ENSTNIG00000013021		0.0514		0.4676
ENSDARG00000056656	NA	ENSTNIG00000003437	NA		NA	
ENSDARG00000025718	ENSTRUG00000013293	ENSTNIG00000007325		0.0263		0.5405
ENSDARG00000087417	ENSTRUG00000012652	ENSTNIG00000013126		0.022		0.309
ENSDARG00000007135	ENSTRUG00000015732	ENSTNIG00000008082		0.0704		0.4615
ENSDARG00000032426	ENSTRUG00000006469	ENSTNIG00000019321		0.0385		0.4593
ENSDARG00000035598	ENSTRUG00000014266	ENSTNIG00000015870		0.0287		0.3805
ENSDARG00000009273	ENSTRUG00000009943	ENSTNIG00000010766		0.1323		0.6339
ENSDARG00000037589	ENSTRUG00000004712	ENSTNIG00000012488		0.0019		0.3519
ENSDARG00000035596	ENSTRUG00000014258	ENSTNIG00000015868		0.0442		0.4297
ENSDARG00000071583	ENSTRUG00000005241	ENSTNIG00000012711		0.0873		0.5346
ENSDARG00000073997	ENSTRUG00000016288	ENSTNIG00000015119		0.048		0.3496
ENSDARG00000070371	ENSTRUG00000014388	ENSTNIG00000011146		0.0746		0.4938
ENSDARG00000027500	NA	ENSTNIG00000012747	NA		NA	
ENSDARG00000020574	ENSTRUG00000006271	ENSTNIG00000011586		0.0117		0.3174
ENSDARG00000045814	ENSTRUG00000015298	ENSTNIG00000003096		0.0412		0.5211
ENSDARG00000026723	ENSTRUG00000005365	ENSTNIG00000017299		0.0008		0.1973
ENSDARG00000056059	ENSTRUG00000017035	ENSTNIG00000002397		0.1135		0.5796
ENSDARG00000005870	ENSTRUG00000015013	ENSTNIG00000006707		0.1526		0.4306

ENSDARG00000035905	ENSTRUG00000016638	NA	NA		NA	
ENSDARG00000018478	ENSTRUG00000007149	ENSTNIG00000015260		0.0577		0.3557
ENSDARG00000070076	ENSTRUG00000011717	ENSTNIG00000009830		0.0054		0.3021
ENSDARG00000044225	ENSTRUG00000001254	ENSTNIG00000007550		0.0134		0.362
ENSDARG00000010002	ENSTRUG00000006509	ENSTNIG00000015459		0.0526		0.4274
ENSDARG00000042827	ENSTRUG00000000675	ENSTNIG00000004833		0.087		0.3977
ENSDARG00000009346	ENSTRUG00000017296	ENSTNIG00000009387		0.1165		0.4807
ENSDARG00000029075	ENSTRUG00000009609	ENSTNIG00000014606		0.018		0.3604
ENSDARG00000029402	ENSTRUG00000001762	ENSTNIG00000007276		0.0492		0.396
ENSDARG00000078133	ENSTRUG00000013920	ENSTNIG00000013139		0.0707		0.4791
ENSDARG00000088318	ENSTRUG00000015263	NA	NA		NA	
ENSDARG00000062577	ENSTRUG00000012205	ENSTNIG00000007755		0.0318		0.3768
ENSDARG00000020405	ENSTRUG00000009864	ENSTNIG00000016282		0.0351		0.3718
ENSDARG00000003169	ENSTRUG00000007355	ENSTNIG00000011135		0.0464		0.3385
ENSDARG00000076009	NA	NA	NA		NA	
ENSDARG00000005754	ENSTRUG00000011594	ENSTNIG00000014887		0.0082		0.2883
ENSDARG00000055350	ENSTRUG00000015866	ENSTNIG00000017972		0.0886		0.3488
ENSDARG00000077297	ENSTRUG00000005561	ENSTNIG00000014410		0.1933		0.7544
ENSDARG00000036721	ENSTRUG00000012339	ENSTNIG00000003559		0.0597		0.563
ENSDARG00000042128	ENSTRUG00000001255	ENSTNIG00000018310		0.0658		0.5997
ENSDARG00000042018	ENSTRUG00000013559	ENSTNIG00000000462		0.0113		0.6227
ENSDARG00000017312	NA	ENSTNIG00000018749	NA		NA	
ENSDARG00000059466	ENSTRUG00000004356	ENSTNIG00000012715		0.0189		0.4607
ENSDARG00000038446	ENSTRUG00000003723	ENSTNIG00000007570		0.091		0.5254
ENSDARG00000039266	ENSTRUG00000003076	ENSTNIG00000004673		0.0698		0.5198
ENSDARG00000042308	ENSTRUG00000012535	ENSTNIG00000015519		0.1079		0.7714
ENSDARG00000070000	NA	NA	NA		NA	
ENSDARG00000057671	ENSTRUG00000005627	ENSTNIG00000009866		0.1821		0.5312
ENSDARG00000061226	ENSTRUG00000018130	ENSTNIG00000002318		0.0487		0.7163
ENSDARG00000011506	ENSTRUG00000007993	ENSTNIG00000007219		0.086		0.458
ENSDARG00000014196	ENSTRUG00000006953	ENSTNIG00000000127		0.0438		0.5288
ENSDARG00000036058	ENSTRUG00000017975	ENSTNIG00000009309		0		0.3188
ENSDARG00000069006	ENSTRUG00000016796	ENSTNIG00000009554		0.0378		0.7808
ENSDARG00000024537	ENSTRUG00000001240	ENSTNIG00000019175		0.0944		0.4632
ENSDARG00000056133	NA	ENSTNIG00000004103	NA		NA	
ENSDARG00000056697	ENSTRUG00000010928	ENSTNIG00000018219		0.0867		0.6461
ENSDARG00000006112	NA	ENSTNIG00000012860	NA		NA	
ENSDARG00000038401	ENSTRUG00000003565	NA	NA		NA	
ENSDARG00000011065	ENSTRUG00000016081	ENSTNIG00000015627		0.0099		0.2216
ENSDARG00000091726	ENSTRUG00000018622	ENSTNIG00000013592		0.0367		0.3383
ENSDARG00000026070	ENSTRUG00000011027	NA	NA		NA	
ENSDARG00000057661	ENSTRUG00000002712	ENSTNIG00000001827		0.0246		0.3941
ENSDARG00000029432	ENSTRUG00000013147	ENSTNIG00000004167		0.0162		0.3281
ENSDARG00000021352	ENSTRUG00000005608	ENSTNIG00000017056		0.0515		0.4498
ENSDARG00000056819	NA	ENSTNIG00000001769	NA		NA	
ENSDARG00000054973	ENSTRUG00000009768	ENSTNIG00000017697		0.1432		0.6149
ENSDARG00000006060	ENSTRUG00000018250	ENSTNIG00000012305		0.1041		0.5079
ENSDARG00000059158	ENSTRUG00000010010	ENSTNIG00000004585		0.1212		1.1837
ENSDARG00000086370	NA	NA	NA		NA	
ENSDARG00000061173	ENSTRUG00000010614	ENSTNIG00000016289		0.1421		0.5713
ENSDARG00000071673	ENSTRUG00000017548	ENSTNIG00000012739		0.0708		0.4698
ENSDARG00000013976	ENSTRUG00000009482	NA	NA		NA	
ENSDARG00000079906	ENSTRUG00000007932	ENSTNIG00000017111		0.0864		0.3583
ENSDARG00000077523	ENSTRUG00000005266	NA	NA		NA	
ENSDARG00000067958	ENSTRUG00000006047	ENSTNIG00000015336		0.1191		0.4789
ENSDARG00000069654	ENSTRUG00000014722	NA	NA		NA	
ENSDARG00000004930	ENSTRUG00000010628	NA	NA		NA	
ENSDARG00000056181	ENSTRUG00000002966	ENSTNIG00000003848		0.115		0.7569
ENSDARG00000009852	ENSTRUG00000011307	ENSTNIG00000013690		0.0699		0.4438
ENSDARG00000011696	ENSTRUG00000015470	ENSTNIG00000017713		0.0331		0.6363
ENSDARG00000035056	ENSTRUG00000006744	ENSTNIG00000016839		0		0.1564
ENSDARG00000011163	ENSTRUG00000011002	ENSTNIG00000014748		0.0046		0.3106
ENSDARG00000053499	ENSTRUG00000005679	ENSTNIG00000011357		0.0202		0.3045
ENSDARG00000055291	ENSTRUG00000004984	ENSTNIG00000008717		0.0155		0.3477
ENSDARG00000039256	NA	ENSTNIG00000008346	NA		NA	
ENSDARG00000017748	ENSTRUG00000002577	ENSTNIG00000014873		0.0783		0.397
ENSDARG00000012609	ENSTRUG00000014903	ENSTNIG00000006703		0.0841		0.6986
ENSDARG00000056744	ENSTRUG00000014615	ENSTNIG00000011974		0.0514		0.4295
ENSDARG00000060106	NA	NA	NA		NA	
ENSDARG00000026907	ENSTRUG00000014423	NA	NA		NA	
ENSDARG00000020252	ENSTRUG00000017470	ENSTNIG00000009361		0.0119		0.4762
ENSDARG00000074332	ENSTRUG00000011123	ENSTNIG00000014666		0.0819		0.5297
ENSDARG00000002589	ENSTRUG00000004965	ENSTNIG00000000835		0.0656		0.4017
ENSDARG00000042948	ENSTRUG00000004830	ENSTNIG00000012487		0.0022		0.5697
ENSDARG00000000189	ENSTRUG00000001211	ENSTNIG00000006164		0.0923		0.847
ENSDARG00000043281	ENSTRUG00000018287	ENSTNIG00000013181		0.1301		0.8764
ENSDARG00000001881	ENSTRUG00000000500	NA	NA		NA	
ENSDARG00000056995	ENSTRUG00000012293	ENSTNIG00000007311		0.0323		0.4146
ENSDARG00000094792	NA	NA	NA		NA	
ENSDARG00000069415	ENSTRUG00000009182	ENSTNIG00000014160		0.6424		2.5621
ENSDARG00000076262	ENSTRUG00000000239	NA	NA		NA	
ENSDARG00000070626	ENSTRUG00000004912	ENSTNIG00000008104		0.0025		0.3462
ENSDARG00000071230	ENSTRUG00000003566	ENSTNIG00000006985		0.2307		1.1783
ENSDARG00000003974	ENSTRUG00000008272	ENSTNIG00000010986		0.0138		0.2853
ENSDARG00000016454	ENSTRUG00000013709	ENSTNIG00000003064		0.0857		0.7115
ENSDARG00000078690	ENSTRUG00000012455	ENSTNIG00000006688		0.0259		0.3222
ENSDARG00000037833	ENSTRUG00000012080	ENSTNIG00000012564		0.0555		0.4414
ENSDARG00000022254	ENSTRUG00000010099	ENSTNIG00000011612		0.1358		0.6881
ENSDARG00000005139	ENSTRUG00000017565	ENSTNIG00000012737		0.0476		0.3911
ENSDARG00000089790	ENSTRUG00000012828	ENSTNIG00000003814		0.0315		0.5114

ENSDARG00000012987	NA	ENSTNIG00000019788	NA		NA	
ENSDARG00000012627	ENSTRUG00000006796	ENSTNIG00000015463		0.0168		0.4168
ENSDARG00000071498	ENSTRUG00000003991	ENSTNIG00000016850		0.0338		0.504
ENSDARG00000053542	ENSTRUG00000017237	ENSTNIG00000009432		0.0402		0.3928
ENSDARG00000040280	ENSTRUG00000005723	ENSTNIG00000001207		0.023		0.4977
ENSDARG00000031343	ENSTRUG00000004881	ENSTNIG00000015257		0.0022		0.3094
ENSDARG00000029036	ENSTRUG00000018379	ENSTNIG00000012254		0.0336		0.4837
ENSDARG00000006508	ENSTRUG00000007907	ENSTNIG00000015419		0.0257		0.5008
ENSDARG00000068920	ENSTRUG00000002936	ENSTNIG00000006961		0.0643		0.451
ENSDARG00000053625	ENSTRUG00000002332	ENSTNIG00000004286		0.0705		0.7116
ENSDARG00000025027	ENSTRUG00000018432	ENSTNIG00000018080		0.0872		0.4246
ENSDARG00000088663	ENSTRUG00000016637	ENSTNIG00000018857		0.0568		0.5816
ENSDARG00000045801	ENSTRUG00000016520	NA	NA		NA	
ENSDARG00000068477	ENSTRUG00000004175	ENSTNIG00000004955		0.1874		0.8785
ENSDARG00000060797	ENSTRUG00000005234	ENSTNIG00000014574		0.033		0.325
ENSDARG00000029501	ENSTRUG00000004889	ENSTNIG00000006988		0.0317		0.2769
ENSDARG00000010957	NA	NA	NA		NA	
ENSDARG00000039203	NA	ENSTNIG00000007847	NA		NA	
ENSDARG00000028740	ENSTRUG00000005544	ENSTNIG00000015782		0.0137		0.3153
ENSDARG00000055101	NA	NA	NA		NA	
ENSDARG00000057060	ENSTRUG00000004279	ENSTNIG00000011870		0.0881		0.4857
ENSDARG00000007149	ENSTRUG00000014373	ENSTNIG00000015084		0.1014		0.3551
ENSDARG00000044954	ENSTRUG00000008791	ENSTNIG00000005554		0.0198		0.3186
ENSDARG00000004358	ENSTRUG00000010132	ENSTNIG00000008026		0.0122		0.4717
ENSDARG00000015230	NA	ENSTNIG00000018950	NA		NA	
ENSDARG00000001634	ENSTRUG00000011778	ENSTNIG00000003847		0.0307		0.435
ENSDARG00000055075	ENSTRUG00000017408	ENSTNIG00000008766		0.2426		0.8366
ENSDARG00000079009	NA	ENSTNIG00000006354	NA		NA	
ENSDARG00000028148	ENSTRUG00000008891	ENSTNIG00000008644		0.0355		0.1669
ENSDARG00000037159	ENSTRUG00000013741	ENSTNIG00000009663		0.0571		0.5405
ENSDARG00000036386	ENSTRUG00000013334	ENSTNIG00000004821		0.0471		0.3146
ENSDARG00000004015	ENSTRUG00000003782	ENSTNIG00000017117		0.0875		0.2455
ENSDARG00000031422	ENSTRUG00000003825	ENSTNIG00000008865		0.3076		0.486
ENSDARG00000055518	ENSTRUG00000017024	ENSTNIG00000010002		0.0169		0.3914
ENSDARG00000010727	ENSTRUG00000009676	ENSTNIG00000009794		0.0419		0.2954
ENSDARG00000011298	ENSTRUG00000015923	ENSTNIG00000015107		0.0211		0.2585
ENSDARG00000036254	ENSTRUG00000015364	ENSTNIG00000001781		0.1222		0.386
ENSDARG00000007009	ENSTRUG00000015327	ENSTNIG00000000494		0.0466		0.3791
ENSDARG00000005775	ENSTRUG00000015715	ENSTNIG00000015105		0.0106		0.3174
ENSDARG00000020708	ENSTRUG00000013268	ENSTNIG00000013753		0.1812		1.0589
ENSDARG00000005221	ENSTRUG00000000247	ENSTNIG00000017154		0.0112		0.4466
ENSDARG00000038508	ENSTRUG00000001764	NA	NA		NA	
ENSDARG00000037998	ENSTRUG00000011892	ENSTNIG00000008015		0.0207		0.4769
ENSDARG00000013990	ENSTRUG00000005684	ENSTNIG00000013711		0.0723		0.4599
ENSDARG00000055999	NA	NA	NA		NA	
ENSDARG00000059360	NA	ENSTNIG00000001003	NA		NA	
ENSDARG00000014329	ENSTRUG00000007621	ENSTNIG00000010773		0.0826		0.6245
ENSDARG00000058158	ENSTRUG00000008556	ENSTNIG00000004027		0.0472		0.6475
ENSDARG00000003544	ENSTRUG00000006823	ENSTNIG00000008894		0.0149		0.2868
ENSDARG00000018787	ENSTRUG00000007035	ENSTNIG00000018328		0.0613		0.2343
ENSDARG00000004218	ENSTRUG00000015649	ENSTNIG00000015099		0.0329		0.3801
ENSDARG00000035909	ENSTRUG00000014004	ENSTNIG00000009238		0.083		0.4832
ENSDARG00000000151	ENSTRUG00000005981	ENSTNIG00000011162		0.0752		0.545
ENSDARG00000061862	ENSTRUG00000002509	ENSTNIG00000004982		0.0492		0.8583
ENSDARG00000061383	ENSTRUG00000003241	NA	NA		NA	
ENSDARG00000024894	ENSTRUG00000015054	ENSTNIG00000009036		0.0114		0.3024
ENSDARG00000023840	ENSTRUG00000009968	ENSTNIG00000012583		0.0353		0.3341
ENSDARG00000014113	ENSTRUG00000016308	ENSTNIG00000010409		0.1871		1.0263
ENSDARG00000052129	ENSTRUG00000011955	ENSTNIG00000003258		0.0461		0.562
ENSDARG00000054858	ENSTRUG00000010361	NA	NA		NA	
ENSDARG00000036251	ENSTRUG00000009434	ENSTNIG00000002540		0.0672		0.3706
ENSDARG00000027828	ENSTRUG00000004131	ENSTNIG00000004002		0.0829		0.3272
ENSDARG00000019208	ENSTRUG00000018134	ENSTNIG00000018750		0.086		0.4234
ENSDARG00000068992	ENSTRUG00000005265	ENSTNIG00000008602		0.0078		0.4353
ENSDARG00000061915	ENSTRUG00000014889	ENSTNIG00000015883		0.0241		0.3647
ENSDARG00000060149	ENSTRUG00000017554	ENSTNIG00000013418		0.0227		0.2316
ENSDARG00000069981	ENSTRUG00000002121	NA	NA		NA	
ENSDARG00000076215	NA	NA	NA		NA	
ENSDARG00000042826	ENSTRUG00000000657	ENSTNIG00000004834		0.0803		0.687
ENSDARG00000079122	ENSTRUG00000012763	ENSTNIG00000013127		0.0346		0.4189
ENSDARG00000017634	ENSTRUG00000004109	ENSTNIG00000018123		0.0629		0.436
ENSDARG00000031420	ENSTRUG00000003418	ENSTNIG00000007794		0.1254		0.7895
ENSDARG00000023768	ENSTRUG00000000083	ENSTNIG00000007380		0.1116		0.482
ENSDARG00000037059	ENSTRUG00000008525	ENSTNIG00000012063		0.0208		0.4223
ENSDARG00000076856	ENSTRUG00000005292	ENSTNIG00000009933		0.068		0.4943
ENSDARG00000002006	ENSTRUG00000015903	ENSTNIG00000018446		0.0056		0.2946
ENSDARG00000062222	ENSTRUG00000002364	ENSTNIG00000007274		0.1541		0.6134
ENSDARG00000011876	ENSTRUG00000014468	ENSTNIG00000017728		0.1128		0.4124
ENSDARG00000071601	NA	ENSTNIG00000000256	NA		NA	
ENSDARG00000040503	ENSTRUG00000003178	ENSTNIG00000019802		0.1651		1.9287
ENSDARG00000010294	ENSTRUG00000012573	ENSTNIG00000017907		0.0834		0.4184
ENSDARG00000033706	ENSTRUG00000015395	ENSTNIG00000011442		0.0943		0.84
ENSDARG00000057074	ENSTRUG00000012085	ENSTNIG00000010259		0.2002		1.3377
ENSDARG00000029239	ENSTRUG00000005464	ENSTNIG00000007797		0.1192		0.4931
ENSDARG00000039497	ENSTRUG00000002280	NA	NA		NA	
ENSDARG00000015174	ENSTRUG00000005146	NA	NA		NA	
ENSDARG00000038981	ENSTRUG00000004412	ENSTNIG00000015243		0.0255		0.4354
ENSDARG00000046010	ENSTRUG00000010230	NA	NA		NA	
ENSDARG00000037393	ENSTRUG00000012955	ENSTNIG00000013130		0.0603		0.5147
ENSDARG00000041900	ENSTRUG00000006914	ENSTNIG00000017124		0.0833		0.4298

ENSDARG00000034685	ENSTRUG00000000232	ENSTNIG00000017155		0.027		0.8815
ENSDARG00000052769	ENSTRUG00000015901	ENSTNIG00000013035		0.3052		0.8059
ENSDARG00000074222	ENSTRUG00000002741	ENSTNIG00000004777		0.0737		0.3647
ENSDARG00000024139	NA	NA	NA		NA	
ENSDARG00000077818	ENSTRUG00000017016	ENSTNIG00000010004		0.0419		0.2518
ENSDARG00000077188	ENSTRUG00000003406	ENSTNIG00000009868		0.0657		0.4097
ENSDARG00000003631	ENSTRUG00000001837	ENSTNIG00000004102		0.0929		0.5215
ENSDARG00000071524	ENSTRUG00000012281	ENSTNIG00000015518		0.0443		0.4581
ENSDARG00000063230	ENSTRUG00000003888	ENSTNIG00000012614		0.0153		0.2798
ENSDARG00000011370	ENSTRUG00000014739	NA	NA		NA	
ENSDARG00000042141	ENSTRUG00000003728	ENSTNIG00000017302		0.0627		0.4663
ENSDARG00000036894	ENSTRUG00000001709	ENSTNIG00000002124		0.2585		1.1917
ENSDARG00000060319	ENSTRUG00000014639	NA	NA		NA	
ENSDARG00000034105	ENSTRUG00000009212	NA	NA		NA	
ENSDARG00000074597	ENSTRUG00000012594	ENSTNIG00000008661		0.083		0.4142
ENSDARG00000019457	ENSTRUG00000013198	ENSTNIG00000007324		0.0565		0.4752
ENSDARG00000069402	ENSTRUG00000014390	ENSTNIG00000011018		0.011		0.2914
ENSDARG00000005510	ENSTRUG00000000004	NA	NA		NA	
ENSDARG00000020746	NA	NA	NA		NA	
ENSDARG00000012311	ENSTRUG00000008669	ENSTNIG00000011321		0.1755		0.5152
ENSDARG00000028048	ENSTRUG00000005536	ENSTNIG00000001228		0.0167		0.3454
ENSDARG00000017703	ENSTRUG00000001442	NA	NA		NA	
ENSDARG00000075904	ENSTRUG00000010058	ENSTNIG00000014069		0.0701		0.5919
ENSDARG00000038352	NA	NA	NA		NA	
ENSDARG00000014134	ENSTRUG00000012732	ENSTNIG00000010443		0.0303		0.3626
ENSDARG00000019001	ENSTRUG00000017984	ENSTNIG00000012220		0.1655		0.3985
ENSDARG00000025091	ENSTRUG00000017761	ENSTNIG00000016405		0.1209		0.5886
ENSDARG00000012824	ENSTRUG00000016519	ENSTNIG00000012855		0.1336		0.4249
ENSDARG00000010047	ENSTRUG00000016814	ENSTNIG00000010043		0.0561		0.3707
ENSDARG00000074533	ENSTRUG00000007084	ENSTNIG00000017523		0.0794		0.6767
ENSDARG00000025076	ENSTRUG00000018563	ENSTNIG00000013532		0.0504		0.609
ENSDARG00000053855	ENSTRUG00000010508	ENSTNIG00000013988		0.1023		0.9177
ENSDARG00000017773	ENSTRUG00000000965	ENSTNIG00000007447		0.1013		0.4766
ENSDARG00000008797	ENSTRUG00000002374	ENSTNIG00000014422		0.0537		0.4245
ENSDARG00000056151	NA	NA	NA		NA	
ENSDARG00000012684	ENSTRUG00000015646	ENSTNIG00000006716		0.0169		0.2798
ENSDARG00000044254	ENSTRUG00000007232	ENSTNIG00000013216		0.0478		0.3778
ENSDARG00000042902	ENSTRUG00000001505	ENSTNIG00000012280		0.1015		0.3891
ENSDARG00000061525	ENSTRUG00000008662	ENSTNIG00000013323		0.1093		0.5064
ENSDARG00000012866	ENSTRUG00000000796	NA	NA		NA	
ENSDARG00000038018	ENSTRUG00000018038	ENSTNIG00000014460		0.0237		0.6083
ENSDARG00000015374	NA	NA	NA		NA	
ENSDARG00000014430	ENSTRUG00000008465	ENSTNIG00000008826		0.0705		0.6669
ENSDARG00000052896	ENSTRUG00000011838	ENSTNIG00000019402		0.0298		0.3396
ENSDARG00000012671	ENSTRUG00000017466	ENSTNIG00000013546		0.1326		0.7942
ENSDARG00000019990	ENSTRUG00000016318	ENSTNIG00000002350		0.0513		0.7992
ENSDARG00000087443	ENSTRUG00000012418	ENSTNIG00000008926		0.0058		0.388
ENSDARG00000013963	ENSTRUG00000004134	ENSTNIG00000012599		0.0076		0.5504
ENSDARG00000015445	ENSTRUG00000014474	ENSTNIG00000005092		0.0563		0.3587
ENSDARG00000034453	ENSTRUG00000016070	ENSTNIG00000019705		0.0439		0.5693
ENSDARG00000032380	NA	NA	NA		NA	
ENSDARG00000037925	ENSTRUG00000011662	ENSTNIG00000005809		0.1553		0.557
ENSDARG00000015349	ENSTRUG00000016888	ENSTNIG00000009541		0.0533		0.5365
ENSDARG00000070408	ENSTRUG00000010895	ENSTNIG00000011409		0.0122		0.18
ENSDARG00000013596	ENSTRUG00000001000	ENSTNIG00000006776		0.0663		0.6433
ENSDARG00000038281	ENSTRUG00000008485	NA	NA		NA	
ENSDARG00000055043	ENSTRUG00000005631	ENSTNIG00000013810		0.088		0.3792
ENSDARG00000041141	ENSTRUG00000016104	NA	NA		NA	
ENSDARG00000038658	ENSTRUG00000001994	ENSTNIG00000000801		0.0353		0.8333
ENSDARG00000062962	ENSTRUG00000013996	ENSTNIG00000017525		0.0911		0.5451
ENSDARG00000001014	ENSTRUG00000001884	ENSTNIG00000003735		0.0451		0.4255
ENSDARG00000068013	NA	ENSTNIG00000015630	NA		NA	
ENSDARG00000006816	ENSTRUG00000018005	ENSTNIG00000004440		0.0711		0.4451
ENSDARG00000095002	ENSTRUG00000004094	ENSTNIG00000019679		0.0533		1.124
ENSDARG00000070746	NA	ENSTNIG00000007215	NA		NA	
ENSDARG00000052910	NA	NA	NA		NA	
ENSDARG00000058231	ENSTRUG00000014556	ENSTNIG00000012088		0.0115		0.4785
ENSDARG00000071011	NA	NA	NA		NA	
ENSDARG00000033184	ENSTRUG00000009384	ENSTNIG00000012025		0.0166		0.2026
ENSDARG00000056267	ENSTRUG00000017048	ENSTNIG00000009998		0.2035		0.5846
ENSDARG00000018345	ENSTRUG00000012994	ENSTNIG00000008407		0.1826		0.9468
ENSDARG00000059950	ENSTRUG00000008838	ENSTNIG00000005847		0.0288		0.3376
ENSDARG00000017537	ENSTRUG00000008850	ENSTNIG00000014529		0.0924		0.4686
ENSDARG00000019426	ENSTRUG00000012584	NA	NA		NA	
ENSDARG00000057644	ENSTRUG00000009792	ENSTNIG00000011846		0.123		0.5702
ENSDARG00000006568	ENSTRUG00000006378	ENSTNIG00000007818		0.077		0.7906
ENSDARG00000010296	ENSTRUG00000004122	ENSTNIG00000018931		0.0784		0.4515
ENSDARG00000051981	ENSTRUG00000005789	ENSTNIG00000004243		0.1052		0.8633
ENSDARG00000012625	ENSTRUG00000017483	ENSTNIG00000013541		0.1585		0.9657
ENSDARG00000035308	ENSTRUG00000009828	ENSTNIG00000019120		0.0333		0.3157
ENSDARG00000044827	NA	NA	NA		NA	
ENSDARG00000007245	ENSTRUG00000011302	ENSTNIG00000014939		0.0217		0.5133
ENSDARG00000028485	ENSTRUG00000003005	ENSTNIG00000002418		0.062		0.5284
ENSDARG00000024642	ENSTRUG00000003020	ENSTNIG00000018345		0.0365		0.3782
ENSDARG00000014081	ENSTRUG00000007214	ENSTNIG00000019144		0.1491		1.0901
ENSDARG00000029234	ENSTRUG00000003152	ENSTNIG00000019309		0.0406		0.3765
ENSDARG00000019525	ENSTRUG00000012392	ENSTNIG00000003224		0.1105		0.7751
ENSDARG00000005966	ENSTRUG00000018616	ENSTNIG00000013586		0.086		0.5436
ENSDARG00000060626	ENSTRUG00000015424	ENSTNIG00000012518		0.0207		0.3511
ENSDARG00000069095	ENSTRUG00000002880	ENSTNIG00000012589		0.0306		0.4793

ENSDARG00000063651	ENSTRUG00000015653	NA	NA		NA	
ENSDARG00000058476	ENSTRUG00000018626	ENSTNIG00000013596		0.04		0.4351
ENSDARG00000039240	ENSTRUG00000016225	NA	NA		NA	
ENSDARG00000077403	ENSTRUG00000015374	NA	NA		NA	
ENSDARG00000062415	ENSTRUG00000002126	ENSTNIG00000006368		0.0535		0.4037
ENSDARG00000078744	NA	NA	NA		NA	
ENSDARG00000029039	ENSTRUG00000016906	ENSTNIG00000010026		0.1008		0.4658
ENSDARG00000069598	ENSTRUG00000018108	ENSTNIG00000012213		0.0988		0.4416
ENSDARG00000076079	ENSTRUG00000004939	ENSTNIG00000011867		0.0364		0.4915
ENSDARG00000045383	ENSTRUG00000016992	ENSTNIG00000016028		0.0518		0.5102
ENSDARG00000014792	NA	ENSTNIG00000012789	NA		NA	
ENSDARG00000068217	NA	ENSTNIG00000004001	NA		NA	
ENSDARG00000044447	ENSTRUG00000011689	NA	NA		NA	
ENSDARG00000020102	ENSTRUG00000006217	ENSTNIG00000018211		0.0311		0.4473
ENSDARG00000069774	ENSTRUG00000005208	ENSTNIG00000006436		0.0317		0.4723
ENSDARG00000017835	ENSTRUG00000008740	NA	NA		NA	
ENSDARG00000027963	ENSTRUG00000010503	ENSTNIG00000000530		0.0294		0.355
ENSDARG00000016062	ENSTRUG00000010565	ENSTNIG00000001274		0.2116		1.12
ENSDARG00000074647	NA	NA	NA		NA	
ENSDARG00000058937	ENSTRUG00000007790	NA	NA		NA	
ENSDARG00000063711	ENSTRUG00000008860	ENSTNIG00000016272		0.0061		0.3557
ENSDARG00000027799	ENSTRUG00000010125	NA	NA		NA	
ENSDARG00000014680	ENSTRUG00000006452	NA	NA		NA	
ENSDARG00000008200	ENSTRUG00000011364	NA	NA		NA	
ENSDARG00000012741	ENSTRUG00000002945	ENSTNIG00000016916		0.0242		0.3454
ENSDARG00000019709	ENSTRUG00000006909	ENSTNIG00000017679		0.09		0.7269
ENSDARG00000043026	ENSTRUG00000018097	ENSTNIG00000003667		0.0787		0.3694
ENSDARG00000021013	NA	NA	NA		NA	
ENSDARG00000077953	ENSTRUG00000013881	ENSTNIG00000008264		0.0891		0.5078
ENSDARG00000021480	NA	NA	NA		NA	
ENSDARG00000056774	ENSTRUG00000013954	NA	NA		NA	
ENSDARG00000036993	ENSTRUG00000010319	ENSTNIG00000015062		0.0631		0.3738
ENSDARG00000004721	ENSTRUG00000017940	ENSTNIG00000012225		0.0501		0.4409
ENSDARG00000090189	ENSTRUG00000011581	ENSTNIG00000019406		0.0263		0.539
ENSDARG00000075870	ENSTRUG00000000044	ENSTNIG00000004530		0.0663		0.2162
ENSDARG00000091662	ENSTRUG00000016812	ENSTNIG00000015992		0.0595		0.4065
ENSDARG00000055374	ENSTRUG00000002946	ENSTNIG00000008222		0.057		0.3611
ENSDARG00000019428	ENSTRUG00000008966	ENSTNIG00000019116		0.0386		0.5006
ENSDARG00000068888	NA	ENSTNIG00000016921	NA		NA	
ENSDARG00000008639	NA	NA	NA		NA	
ENSDARG00000029511	NA	ENSTNIG00000003665	NA		NA	
ENSDARG00000037905	ENSTRUG00000002449	ENSTNIG00000012624		0.0354		0.3148
ENSDARG00000044615	ENSTRUG00000004366	ENSTNIG00000011097		0.0403		0.43
ENSDARG00000034668	ENSTRUG00000012064	ENSTNIG00000017546		0.0226		0.3319
ENSDARG00000074886	NA	NA	NA		NA	
ENSDARG00000058853	ENSTRUG00000004578	ENSTNIG00000019311		0.045		0.448
ENSDARG00000004150	ENSTRUG00000003231	ENSTNIG00000014620		0.01		0.5069
ENSDARG00000052555	ENSTRUG00000010943	ENSTNIG00000010429		0.0411		0.3939
ENSDARG00000086070	ENSTRUG00000003722	ENSTNIG00000003619		0.0283		0.3371
ENSDARG00000001437	NA	ENSTNIG00000003275	NA		NA	
ENSDARG00000088563	ENSTRUG00000013239	ENSTNIG00000005859		0.0451		0.8059
ENSDARG00000038991	ENSTRUG00000002989	ENSTNIG00000006062		0.0362		0.375
ENSDARG00000034473	ENSTRUG00000013933	ENSTNIG00000005558		0.0587		0.4305
ENSDARG00000015989	ENSTRUG00000017097	ENSTNIG00000004699		0.1237		0.6927
ENSDARG00000055578	ENSTRUG00000004030	ENSTNIG00000016198		0.0274		0.3965
ENSDARG00000036086	ENSTRUG00000016742	ENSTNIG00000009560		0.1921		0.668
ENSDARG00000051730	NA	ENSTNIG00000004495	NA		NA	
ENSDARG00000056740	ENSTRUG00000017441	ENSTNIG00000006521		0.084		0.6907
ENSDARG00000006212	ENSTRUG00000003414	ENSTNIG00000008296		0.1516		0.5006
ENSDARG00000042484	ENSTRUG00000007715	ENSTNIG00000015457		0.0115		0.3154
ENSDARG00000052360	ENSTRUG00000010480	ENSTNIG00000011943		0.0105		0.3301
ENSDARG00000040625	ENSTRUG00000010175	ENSTNIG00000014278		0.034		0.5048
ENSDARG00000078718	NA	NA	NA		NA	
ENSDARG00000086326	ENSTRUG00000014907	ENSTNIG00000017774		0.0455		0.4796
ENSDARG00000045856	ENSTRUG00000011078	ENSTNIG00000011411		0.0628		0.2976
ENSDARG00000028066	NA	NA	NA		NA	
ENSDARG00000024827	ENSTRUG00000013568	ENSTNIG00000006840		0.0485		0.4074
ENSDARG00000032565	ENSTRUG00000000134	NA	NA		NA	
ENSDARG00000006281	ENSTRUG00000000581	ENSTNIG00000011287		0.0299		0.4656
ENSDARG00000014587	ENSTRUG00000001541	ENSTNIG00000003277		0.0449		0.431
ENSDARG00000087722	NA	NA	NA		NA	
ENSDARG00000062991	ENSTRUG00000005181	ENSTNIG00000007886		0.0208		0.3344
ENSDARG00000070080	ENSTRUG00000004232	ENSTNIG00000009920		0.0158		0.3878
ENSDARG00000057032	ENSTRUG00000014288	ENSTNIG00000011808		0.0448		0.5013
ENSDARG00000003219	ENSTRUG00000015052	ENSTNIG00000012526		0.0637		0.3412
ENSDARG00000077812	ENSTRUG00000011373	ENSTNIG00000013943		0.0468		0.4318
ENSDARG00000035683	ENSTRUG00000015731	ENSTNIG00000005815		0.008		0.7768
ENSDARG00000076011	NA	NA	NA		NA	
ENSDARG00000063430	ENSTRUG00000014573	ENSTNIG00000017441		0.0301		0.3327
ENSDARG00000079231	ENSTRUG00000002825	ENSTNIG00000004125		0.0774		0.7179
ENSDARG00000058267	ENSTRUG00000003973	ENSTNIG00000006964		0.1044		0.4804
ENSDARG00000045628	NA	ENSTNIG00000016231	NA		NA	
ENSDARG00000054680	ENSTRUG00000013071	ENSTNIG00000005176		0.0576		0.4687
ENSDARG00000079944	NA	NA	NA		NA	
ENSDARG00000061399	ENSTRUG00000011806	ENSTNIG00000008398		0.007		0.3452
ENSDARG00000011473	ENSTRUG00000006816	ENSTNIG00000008869		0.0242		0.3484
ENSDARG00000074528	ENSTRUG00000009046	ENSTNIG00000013636		0.0585		0.5174
ENSDARG00000077686	ENSTRUG00000008307	NA	NA		NA	
ENSDARG00000007601	ENSTRUG00000009049	ENSTNIG00000007302		0.0473		0.3036
ENSDARG00000003025	ENSTRUG00000009057	ENSTNIG00000007861		0.0236		0.3873

ENSDARG00000029898	ENSTRUG00000010274	ENSTNIG00000010564		0.0305		0.4924
ENSDARG00000062084	NA	NA	NA		NA	
ENSDARG00000063299	ENSTRUG00000014864	ENSTNIG00000011023		0.115		0.4528
ENSDARG00000003900	ENSTRUG00000002554	NA	NA		NA	
ENSDARG00000075041	ENSTRUG00000010475	ENSTNIG00000010608		0.1125		0.668
ENSDARG00000036114	ENSTRUG00000010448	ENSTNIG00000009183		0.0449		0.2836
ENSDARG00000060849	ENSTRUG00000009651	ENSTNIG00000012584		0.0552		0.2884
ENSDARG00000043902	NA	NA	NA		NA	
ENSDARG00000051962	ENSTRUG00000009190	ENSTNIG00000008819		0.0867		0.8223
ENSDARG00000002411	ENSTRUG00000006287	ENSTNIG00000010195		0.0275		0.3611
ENSDARG00000020981	ENSTRUG00000002416	ENSTNIG00000007831		0.07		0.2744
ENSDARG00000029751	ENSTRUG00000014761	ENSTNIG00000012090		0.0633		0.4145
ENSDARG00000007302	ENSTRUG00000014107	ENSTNIG00000002681		0.1384		0.5896
ENSDARG00000059139	ENSTRUG00000003421	ENSTNIG00000004170		0.077		0.6028
ENSDARG00000069101	NA	ENSTNIG00000010723	NA		NA	
ENSDARG00000054050	ENSTRUG00000005094	NA	NA		NA	
ENSDARG00000074680	ENSTRUG00000004020	ENSTNIG00000009888		0.0601		0.2853
ENSDARG00000016396	ENSTRUG00000015586	ENSTNIG00000010681		0.0048		0.3867
ENSDARG00000056001	NA	ENSTNIG00000009914	NA		NA	
ENSDARG00000074328	ENSTRUG00000012403	ENSTNIG00000005600		0.125		0.8293
ENSDARG00000025206	ENSTRUG00000011452	ENSTNIG00000012569		0.0111		0.26
ENSDARG00000056045	ENSTRUG00000017007	ENSTNIG00000012936		0.0971		0.8274
ENSDARG00000076025	ENSTRUG00000013299	ENSTNIG00000013754		0.0433		0.3552
ENSDARG00000074958	ENSTRUG00000000013	ENSTNIG00000018823		0.0468		0.5285
ENSDARG00000074149	ENSTRUG00000014551	ENSTNIG00000007339		0.015		0.3621
ENSDARG00000032079	ENSTRUG00000009826	ENSTNIG00000014309		0.0562		0.4337
ENSDARG00000032485	ENSTRUG00000006985	ENSTNIG00000018329		0.0106		0.3929
ENSDARG00000032831	ENSTRUG00000006226	ENSTNIG00000017012		0.0452		0.6669
ENSDARG00000025285	ENSTRUG00000006765	NA	NA		NA	
ENSDARG00000073713	ENSTRUG00000012524	ENSTNIG00000014878		0.1238		0.6529
ENSDARG00000041071	ENSTRUG00000015380	ENSTNIG00000002877		0.0637		0.3266
ENSDARG00000062667	ENSTRUG00000005965	ENSTNIG00000018919		0.0539		0.4599
ENSDARG00000032221	ENSTRUG00000013938	ENSTNIG00000009665		0.1178		0.4506
ENSDARG00000005394	ENSTRUG00000003838	ENSTNIG00000019134		0.0086		0.4831
ENSDARG00000058357	ENSTRUG00000001992	NA	NA		NA	
ENSDARG00000036147	ENSTRUG00000017278	NA	NA		NA	
ENSDARG00000052818	ENSTRUG00000006263	ENSTNIG00000006268		0.0856		0.4653
ENSDARG00000089929	ENSTRUG00000011392	ENSTNIG00000019407		0.0649		0.3482
ENSDARG00000021151	ENSTRUG00000004436	ENSTNIG00000013338		0.0176		0.197
ENSDARG00000006491	ENSTRUG00000016556	ENSTNIG00000015934		0.0306		0.3608
ENSDARG00000005350	ENSTRUG00000015870	ENSTNIG00000015106		0.0133		0.248
ENSDARG00000041874	ENSTRUG00000014559	ENSTNIG00000019029		0.0759		0.5152
ENSDARG00000026406	ENSTRUG00000006853	ENSTNIG00000013047		0.0377		0.3601
ENSDARG00000018967	ENSTRUG00000005601	ENSTNIG00000011647		0.0025		0.4879
ENSDARG00000026325	ENSTRUG00000009346	ENSTNIG00000016733		0.0481		0.4661
ENSDARG00000060601	ENSTRUG00000014809	ENSTNIG00000005136		0.0425		0.2813
ENSDARG00000013207	ENSTRUG00000001422	ENSTNIG00000008768		0.078		0.8911
ENSDARG00000025846	ENSTRUG00000004766	ENSTNIG00000016719		0.036		0.4032
ENSDARG00000068572	NA	ENSTNIG00000002301	NA		NA	
ENSDARG00000004328	ENSTRUG00000006069	NA	NA		NA	
ENSDARG00000079500	NA	ENSTNIG00000019287	NA		NA	
ENSDARG00000075821	ENSTRUG00000014605	NA	NA		NA	
ENSDARG00000028524	ENSTRUG00000014058	ENSTNIG00000008262		0.0662		0.3041
ENSDARG00000023542	ENSTRUG00000009801	ENSTNIG00000013662		0.0328		0.548
ENSDARG00000076181	ENSTRUG00000016652	ENSTNIG00000016708		0.1058		0.8914
ENSDARG00000006235	ENSTRUG00000006288	ENSTNIG00000016873		0.0248		0.5147
ENSDARG00000038716	ENSTRUG00000007394	ENSTNIG00000007930		0.0342		0.4367
ENSDARG00000070316	ENSTRUG00000012264	ENSTNIG00000003231		0.0378		0.5
ENSDARG00000002552	ENSTRUG00000003687	ENSTNIG00000007288		0.0428		0.5137
ENSDARG00000018820	ENSTRUG00000002003	ENSTNIG00000006148		0.0455		0.387
ENSDARG00000031387	ENSTRUG00000012847	NA	NA		NA	
ENSDARG00000031751	ENSTRUG00000000936	ENSTNIG00000004620		0.075		1.0069
ENSDARG00000019103	ENSTRUG00000008046	ENSTNIG00000011051		0.2304		0.7736
ENSDARG00000079586	ENSTRUG00000005507	ENSTNIG00000008935		0.0035		0.275
ENSDARG00000077736	ENSTRUG00000004906	ENSTNIG00000013077		0.0289		0.5015
ENSDARG00000039052	ENSTRUG00000008522	ENSTNIG00000007926		0.0499		0.6446
ENSDARG00000007097	ENSTRUG00000006688	ENSTNIG00000014324		0.0667		0.6061
ENSDARG00000062880	ENSTRUG00000013213	ENSTNIG00000015184		0.0429		0.3684
ENSDARG00000055642	ENSTRUG00000006150	ENSTNIG00000008146		0.1044		0.5932
ENSDARG00000078322	ENSTRUG00000010103	ENSTNIG00000016879		0.0424		0.3329
ENSDARG00000035994	ENSTRUG00000000346	ENSTNIG00000004626		0.2654		1.1553
ENSDARG00000036816	ENSTRUG00000003777	ENSTNIG00000006986		0.0946		0.3729
ENSDARG00000019861	ENSTRUG00000016721	ENSTNIG00000018496		0.0503		0.7703
ENSDARG00000030104	ENSTRUG00000000489	ENSTNIG00000011555		0.06		0.4808
ENSDARG00000003251	ENSTRUG00000003954	ENSTNIG00000000019		0.1532		1.3051
ENSDARG00000017673	ENSTRUG00000006617	ENSTNIG00000011634		0.0052		0.196
ENSDARG00000051936	ENSTRUG00000010974	ENSTNIG00000012127		0.0362		0.3295
ENSDARG00000087519	ENSTRUG00000005182	NA	NA		NA	
ENSDARG00000069937	ENSTRUG00000013442	ENSTNIG00000010452		0.0639		0.4041
ENSDARG00000075608	ENSTRUG00000017484	ENSTNIG00000009359		0.048		0.3453
ENSDARG00000043410	ENSTRUG00000005489	ENSTNIG00000016331		0.012		0.1292
ENSDARG00000058421	ENSTRUG00000009657	ENSTNIG00000018909		0.018		0.2982
ENSDARG00000031920	NA	NA	NA		NA	
ENSDARG00000078842	ENSTRUG00000013916	ENSTNIG00000008342		0.1324		0.718
ENSDARG00000051814	ENSTRUG00000016441	ENSTNIG00000010416		0.3491		1.696
ENSDARG00000014022	ENSTRUG00000017537	ENSTNIG00000009352		0.0314		0.2874
ENSDARG00000061579	ENSTRUG00000011349	NA	NA		NA	
ENSDARG00000014246	ENSTRUG00000000042	ENSTNIG00000012383		0.0836		0.6994
ENSDARG00000015091	ENSTRUG00000005259	ENSTNIG00000011865		0.0571		0.4299
ENSDARG00000078003	ENSTRUG00000010459	NA	NA		NA	

ENSDARG00000059601	ENSTRUG00000013325	ENSTNIG00000003949		0.1434		0.6239
ENSDARG00000076673	ENSTRUG00000004870	ENSTNIG00000012317		0.112		0.4706
ENSDARG00000005414	ENSTRUG00000011846	ENSTNIG00000011605		0.0474		0.575
ENSDARG00000053487	ENSTRUG00000004558	ENSTNIG00000009107		0.0352		0.5487
ENSDARG00000071107	ENSTRUG00000016453	ENSTNIG00000019059		0.0028		0.291
ENSDARG00000056603	ENSTRUG00000006824	ENSTNIG00000006322		0.0653		0.7088
ENSDARG00000094201	ENSTRUG00000013521	ENSTNIG00000000731		0.0579		0.4105
ENSDARG00000061778	ENSTRUG00000008993	ENSTNIG00000010247		0.0435		0.3147
ENSDARG00000012649	ENSTRUG00000014045	ENSTNIG00000009050		0.0272		0.5533
ENSDARG00000038012	ENSTRUG00000007358	ENSTNIG00000011260		0.0506		0.4862
ENSDARG00000010933	ENSTRUG00000000739	ENSTNIG00000012499		0.0457		0.6101
ENSDARG00000031413	ENSTRUG00000017397	ENSTNIG00000013983		0.0316		0.4609
ENSDARG00000026855	ENSTRUG00000016420	ENSTNIG00000007578		0.0416		0.4343
ENSDARG00000023236	NA	ENSTNIG00000005069	NA		NA	
ENSDARG00000025024	NA	NA	NA		NA	
ENSDARG00000006368	ENSTRUG00000017809	ENSTNIG00000019587		0.0934		0.5943
ENSDARG00000012881	ENSTRUG00000016704	NA	NA		NA	
ENSDARG00000031678	ENSTRUG00000002092	ENSTNIG00000008867		0.0548		0.2378
ENSDARG00000028118	NA	ENSTNIG00000004972	NA		NA	
ENSDARG00000023914	NA	NA	NA		NA	
ENSDARG00000035178	NA	ENSTNIG00000007555	NA		NA	
ENSDARG00000075310	ENSTRUG00000006290	ENSTNIG00000014084		0.0579		0.5696
ENSDARG00000037926	ENSTRUG00000007481	ENSTNIG00000010488		0.0702		0.4828
ENSDARG00000045706	ENSTRUG00000014879	ENSTNIG00000012670		0.0269		0.5783
ENSDARG00000040085	ENSTRUG00000007921	ENSTNIG00000017686		0.2533		0.9457
ENSDARG00000029308	ENSTRUG00000012473	NA	NA		NA	
ENSDARG00000017742	ENSTRUG00000009004	ENSTNIG00000002806		0.128		1.2627
ENSDARG00000076916	ENSTRUG00000003426	NA	NA		NA	
ENSDARG00000034940	ENSTRUG00000013031	ENSTNIG00000006954		0.0083		0.4348
ENSDARG00000036952	ENSTRUG00000006478	ENSTNIG00000012480		0.0404		0.6806
ENSDARG00000068157	NA	NA	NA		NA	
ENSDARG00000019752	ENSTRUG00000000890	NA	NA		NA	
ENSDARG00000030750	ENSTRUG00000017676	ENSTNIG00000008706		0.0206		0.3789
ENSDARG00000088742	ENSTRUG00000003471	ENSTNIG00000001427		0.1303		0.785
ENSDARG00000088789	NA	NA	NA		NA	
ENSDARG00000052405	ENSTRUG00000004444	NA	NA		NA	
ENSDARG00000042186	NA	NA	NA		NA	
ENSDARG00000062542	NA	ENSTNIG00000011226	NA		NA	
ENSDARG00000076073	ENSTRUG00000010174	ENSTNIG00000014306		0.0913		0.5149
ENSDARG00000025468	ENSTRUG00000000602	NA	NA		NA	
ENSDARG00000028053	ENSTRUG00000007352	ENSTNIG00000009100		0.0388		0.5907
ENSDARG00000056281	ENSTRUG00000004442	NA	NA		NA	
ENSDARG00000010192	ENSTRUG00000013444	ENSTNIG00000015279		0.0203		0.2811
ENSDARG00000003259	NA	ENSTNIG00000009114	NA		NA	
ENSDARG00000031013	ENSTRUG00000013104	NA	NA		NA	
ENSDARG00000010144	ENSTRUG00000011591	NA	NA		NA	
ENSDARG00000027638	ENSTRUG00000004310	ENSTNIG00000017820		0.0308		0.3655
ENSDARG00000069159	ENSTRUG00000006585	NA	NA		NA	
ENSDARG00000075376	ENSTRUG00000012834	ENSTNIG00000009063		0.065		0.4975
ENSDARG00000059058	ENSTRUG00000017596	ENSTNIG00000012733		0.0274		0.3816
ENSDARG00000002231	ENSTRUG00000015990	ENSTNIG00000017191		0.082		0.8732
ENSDARG00000029982	ENSTRUG00000010612	ENSTNIG00000015304		0.0615		0.3399
ENSDARG00000042552	ENSTRUG00000013571	ENSTNIG00000015082		0.013		0.3139
ENSDARG00000060116	ENSTRUG00000005116	ENSTNIG00000014730		0.0106		0.3846
ENSDARG00000010097	ENSTRUG00000007026	ENSTNIG00000016838		0.1152		0.4323
ENSDARG00000059534	ENSTRUG00000012196	ENSTNIG00000005022		0.0849		0.5834
ENSDARG00000060053	ENSTRUG00000002206	ENSTNIG00000008782		0.2371		1.099
ENSDARG00000055577	ENSTRUG00000015946	ENSTNIG00000011397		0.0737		2.6841
ENSDARG00000095170	NA	NA	NA		NA	
ENSDARG00000021265	ENSTRUG00000013734	ENSTNIG00000012787		0.0745		0.3884
ENSDARG00000059438	ENSTRUG00000017462	ENSTNIG00000009362		0.0248		0.311
ENSDARG00000033104	ENSTRUG00000011665	ENSTNIG00000005233		0.0594		0.4782
ENSDARG00000087437	ENSTRUG00000004691	ENSTNIG00000000542		0.0117		0.2806
ENSDARG00000044629	ENSTRUG00000005393	ENSTNIG00000006328		0.0304		0.7349
ENSDARG00000008414	ENSTRUG00000007139	NA	NA		NA	
ENSDARG00000020581	ENSTRUG00000008649	ENSTNIG00000019293		0.0286		0.3982
ENSDARG00000067548	ENSTRUG00000016593	ENSTNIG00000015936		0.0238		0.2203
ENSDARG00000068714	ENSTRUG00000011530	ENSTNIG00000011835		0.051		0.3706
ENSDARG00000005600	ENSTRUG00000005555	ENSTNIG00000015803		0.0366		0.4356
ENSDARG00000040278	ENSTRUG00000005434	ENSTNIG00000019106		0.0545		0.5134
ENSDARG00000044132	ENSTRUG00000009433	ENSTNIG00000002672		0.0618		0.683
ENSDARG00000033589	ENSTRUG00000007094	NA	NA		NA	
ENSDARG00000054447	ENSTRUG00000014077	ENSTNIG00000005073		0.2101		0.5907
ENSDARG00000042551	NA	NA	NA		NA	
ENSDARG00000038974	ENSTRUG00000000663	NA	NA		NA	
ENSDARG00000087701	ENSTRUG00000012830	ENSTNIG00000008303		0.022		0.3885
ENSDARG00000040482	ENSTRUG00000014932	ENSTNIG00000018423		0.1399		0.4859
ENSDARG00000074563	ENSTRUG00000016271	ENSTNIG00000010407		0.1164		1.4488
ENSDARG00000042794	NA	NA	NA		NA	
ENSDARG00000036787	ENSTRUG00000003771	ENSTNIG00000018180		0.1396		0.7619
ENSDARG00000029124	ENSTRUG00000016569	ENSTNIG00000011753		0.0474		0.2826
ENSDARG00000060702	ENSTRUG00000018455	ENSTNIG00000007487		0.0584		0.5713
ENSDARG00000016977	ENSTRUG00000007624	ENSTNIG00000018322		0.0175		0.3162
ENSDARG00000028236	ENSTRUG00000016525	ENSTNIG00000015595		0.1171		0.2626
ENSDARG00000070543	ENSTRUG00000012978	ENSTNIG00000008277		0.0261		0.507
ENSDARG00000067785	ENSTRUG00000009883	ENSTNIG00000014532		0.1655		0.7045
ENSDARG00000018881	ENSTRUG00000009123	NA	NA		NA	
ENSDARG00000014239	ENSTRUG00000009321	ENSTNIG00000014559		0.0991		0.4863
ENSDARG00000022109	ENSTRUG00000010568	ENSTNIG00000013112		0.0321		0.3936
ENSDARG00000057792	ENSTRUG00000001958	NA	NA		NA	

ENSDARG00000045753	ENSTRUG00000015242	ENSTNIG00000011030		0.0591		0.4582
ENSDARG00000015134	ENSTRUG00000006711	ENSTNIG00000016238		0.0506		0.347
ENSDARG00000016025	ENSTRUG00000009160	ENSTNIG00000018870		0.0261		0.4824
ENSDARG00000035565	ENSTRUG00000013490	ENSTNIG00000015858		0.0293		0.3576
ENSDARG00000069739	ENSTRUG00000012090	ENSTNIG00000008921		0.0118		0.7064
ENSDARG00000000567	ENSTRUG00000016619	NA	NA		NA	
ENSDARG00000034907	ENSTRUG00000014214	ENSTNIG00000009670		0.009		0.4803
ENSDARG00000013843	ENSTRUG00000016478	ENSTNIG00000015926		0.1295		0.7035
ENSDARG00000012407	ENSTRUG00000005316	ENSTNIG00000011643		0.0634		0.9525
ENSDARG00000016337	ENSTRUG00000014732	ENSTNIG00000008430		0.0285		0.4558
ENSDARG00000001259	ENSTRUG00000012108	ENSTNIG00000013683		0.0408		0.4626
ENSDARG00000062720	ENSTRUG00000008240	ENSTNIG00000010769		0.0223		0.3361
ENSDARG00000056793	ENSTRUG00000015434	ENSTNIG00000018430		0.0153		0.4396
ENSDARG00000031461	ENSTRUG00000005925	ENSTNIG00000008682		0.1492		0.8119
ENSDARG00000046079	ENSTRUG00000005385	ENSTNIG00000008105		0.1033		0.5751
ENSDARG00000067678	ENSTRUG00000015308	ENSTNIG00000013001		0.1638		0.8437
ENSDARG00000017367	ENSTRUG00000016931	ENSTNIG00000012915		0.1669		0.5103
ENSDARG00000018259	ENSTRUG00000002904	NA	NA		NA	
ENSDARG00000063576	ENSTRUG00000013030	ENSTNIG00000007078		0.0929		0.3105
ENSDARG00000091683	ENSTRUG00000000938	NA	NA		NA	
ENSDARG00000040657	ENSTRUG00000011117	ENSTNIG00000005980		0.1448		0.4545
ENSDARG00000021539	ENSTRUG00000005498	ENSTNIG00000012202		0.1042		0.9172
ENSDARG00000014280	ENSTRUG00000007747	ENSTNIG00000006036		0.0664		0.3623
ENSDARG00000007129	ENSTRUG00000005532	ENSTNIG00000018946		0.0298		0.3125
ENSDARG00000052012	ENSTRUG00000014703	ENSTNIG00000012351		0.0171		0.4695
ENSDARG00000040683	ENSTRUG00000011996	ENSTNIG00000003958		0.0805		0.4678
ENSDARG00000017086	ENSTRUG00000017179	ENSTNIG00000004458		0.0824		0.4709
ENSDARG00000044278	ENSTRUG00000003258	ENSTNIG00000014727		0.0367		0.2501
ENSDARG00000020982	ENSTRUG00000004254	ENSTNIG00000017910		0.0074		0.2484
ENSDARG00000074902	ENSTRUG00000005056	ENSTNIG00000012485		0.0599		0.5188
ENSDARG00000045164	ENSTRUG00000016838	NA	NA		NA	
ENSDARG00000058557	ENSTRUG00000007988	ENSTNIG00000001814		0.268		0.8507
ENSDARG00000013295	ENSTRUG00000005156	ENSTNIG00000018188		0.0256		0.5286
ENSDARG00000024004	ENSTRUG00000012870	ENSTNIG00000014681		0.0122		0.3556
ENSDARG00000087181	ENSTRUG00000017065	NA	NA		NA	
ENSDARG00000073684	ENSTRUG00000013233	ENSTNIG00000018710		0.0696		0.3737
ENSDARG00000053918	ENSTRUG00000011448	ENSTNIG00000002923		0.0916		0.498
ENSDARG00000036156	ENSTRUG00000018230	ENSTNIG00000002885		0.0656		0.3891
ENSDARG00000042887	ENSTRUG00000009453	ENSTNIG00000014071		0.0062		0.4335
ENSDARG00000019418	ENSTRUG00000003000	NA	NA		NA	
ENSDARG00000017470	NA	NA	NA		NA	
ENSDARG00000070810	NA	ENSTNIG00000019093	NA		NA	
ENSDARG00000058603	ENSTRUG00000003443	ENSTNIG00000008179		0.0372		0.3481
ENSDARG00000071640	ENSTRUG00000011080	NA	NA		NA	
ENSDARG00000031506	ENSTRUG00000009429	ENSTNIG00000016350		0.051		0.5421
ENSDARG00000087474	ENSTRUG00000005295	ENSTNIG00000004790		0.121		3.533
ENSDARG00000045957	NA	NA	NA		NA	
ENSDARG00000074669	ENSTRUG00000000689	NA	NA		NA	
ENSDARG00000015003	ENSTRUG00000006232	ENSTNIG00000005011		0.0494		0.9732
ENSDARG00000071877	ENSTRUG00000017206	ENSTNIG00000006858		0.0701		0.3444
ENSDARG00000022841	ENSTRUG00000017337	ENSTNIG00000014508		0.0913		0.4738
ENSDARG00000023600	ENSTRUG00000010559	ENSTNIG00000011037		0.0248		0.4565
ENSDARG00000038011	ENSTRUG00000007372	ENSTNIG00000011261		0.0463		0.5888
ENSDARG00000011797	ENSTRUG00000010330	ENSTNIG00000014035		0.0433		0.6949
ENSDARG00000091660	ENSTRUG00000015541	NA	NA		NA	
ENSDARG00000018773	ENSTRUG00000007039	ENSTNIG00000019322		0.0576		0.4052
ENSDARG00000077691	ENSTRUG00000004641	ENSTNIG00000007677		0.1092		0.4559
ENSDARG00000069450	ENSTRUG00000005827	ENSTNIG00000009857		0.0641		0.431
ENSDARG00000078729	ENSTRUG00000008480	ENSTNIG00000002194		0.1143		0.5099
ENSDARG00000020133	ENSTRUG00000018323	ENSTNIG00000017406		0.0273		0.4103
ENSDARG00000016545	ENSTRUG00000009841	ENSTNIG00000013410		0.0306		0.4114
ENSDARG00000018743	ENSTRUG00000005905	ENSTNIG00000013710		0.0266		0.4787
ENSDARG00000037121	ENSTRUG00000011059	ENSTNIG00000015840		0.0508		0.6044
ENSDARG00000053375	ENSTRUG00000003680	ENSTNIG00000018841		0.0664		0.6328
ENSDARG00000004405	ENSTRUG00000015910	ENSTNIG00000009208		0.114		0.5318
ENSDARG00000040898	ENSTRUG00000012762	ENSTNIG00000013894		0.1347		0.5068
ENSDARG00000069139	ENSTRUG00000008769	ENSTNIG00000009948		0.0354		0.5024
ENSDARG00000057975	ENSTRUG00000006810	ENSTNIG00000014500		0.043		0.3709
ENSDARG00000062812	ENSTRUG00000000086	ENSTNIG00000017162		0.0064		0.3258
ENSDARG00000088589	NA	NA	NA		NA	
ENSDARG00000026796	ENSTRUG00000018354	ENSTNIG00000012255		0.0608		0.4923
ENSDARG00000011317	ENSTRUG00000008130	ENSTNIG00000007601		0.0316		0.4701
ENSDARG00000044422	NA	NA	NA		NA	
ENSDARG00000043035	ENSTRUG00000018064	ENSTNIG00000003670		0.0466		0.3674
ENSDARG00000006409	ENSTRUG00000008589	ENSTNIG00000006907		0.0867		0.7975
ENSDARG00000023053	NA	NA	NA		NA	
ENSDARG00000088096	ENSTRUG00000007938	ENSTNIG00000014076		0.0444		0.5756
ENSDARG00000058820	ENSTRUG00000012332	NA	NA		NA	
ENSDARG00000002330	ENSTRUG00000007669	ENSTNIG00000005708		0.0677		0.3761
ENSDARG00000042561	ENSTRUG00000015976	ENSTNIG00000003514		0.0509		0.848
ENSDARG00000030614	ENSTRUG00000013727	ENSTNIG00000012655		0.0205		0.3559
ENSDARG00000030914	ENSTRUG00000012088	ENSTNIG00000010276		0.0513		0.5697
ENSDARG00000017542	ENSTRUG00000007357	ENSTNIG00000008945		0.075		0.6878
ENSDARG00000014599	ENSTRUG00000005333	ENSTNIG00000019318		0.0883		0.3238
ENSDARG00000069133	ENSTRUG00000012935	ENSTNIG00000015714		0.0436		0.6822
ENSDARG00000011049	ENSTRUG00000005255	ENSTNIG00000017880		0.0268		0.3434
ENSDARG00000002230	ENSTRUG00000001866	ENSTNIG00000012498		0.0185		0.5664
ENSDARG00000063158	ENSTRUG00000006161	NA	NA		NA	
ENSDARG00000016818	ENSTRUG00000011817	ENSTNIG00000011046		0.0403		0.4474
ENSDARG00000070721	ENSTRUG00000011576	ENSTNIG00000007031		0.0072		0.343

ENSDARG00000069117	ENSTRUG00000004743	ENSTNIG00000012379		0.0304		0.5564
ENSDARG00000009026	ENSTRUG00000008093	ENSTNIG00000017807		0.0331		0.3802
ENSDARG00000009949	NA	ENSTNIG00000010616	NA		NA	
ENSDARG00000013422	ENSTRUG00000013535	ENSTNIG00000005062		0.1423		0.8904
ENSDARG00000070567	NA	ENSTNIG00000014728	NA		NA	
ENSDARG00000043180	ENSTRUG00000018403	ENSTNIG00000018264		0.0483		0.5404
ENSDARG00000062693	ENSTRUG00000017991	ENSTNIG00000009700		0.1238		0.5978
ENSDARG00000069662	ENSTRUG00000003682	ENSTNIG00000005897		0.0286		0.3252
ENSDARG00000042723	ENSTRUG00000000629	ENSTNIG00000003988		0.3803		1.6317
ENSDARG00000074583	ENSTRUG00000001747	ENSTNIG00000017014		0.0168		0.4515
ENSDARG00000033956	ENSTRUG00000003223	ENSTNIG00000014624		0.035		0.4356
ENSDARG00000056150	ENSTRUG00000006839	ENSTNIG00000015056		0.0244		0.3337
ENSDARG00000017901	ENSTRUG00000006371	ENSTNIG00000011353		0.0116		0.4803
ENSDARG00000077201	ENSTRUG00000006629	ENSTNIG00000007892		0.1309		0.4975
ENSDARG00000058162	ENSTRUG00000008380	ENSTNIG00000008159		0.0823		0.8012
ENSDARG00000061937	ENSTRUG00000002538	ENSTNIG00000004772		0.0177		0.4166
ENSDARG00000069408	ENSTRUG00000002532	ENSTNIG00000019375		0.1798		1.4486
ENSDARG00000060123	ENSTRUG00000004636	ENSTNIG00000014729		0.0675		0.3671
ENSDARG00000056458	ENSTRUG00000016319	ENSTNIG00000015120		0.0266		0.3175
ENSDARG00000039704	NA	NA	NA		NA	
ENSDARG00000056767	ENSTRUG00000016290	ENSTNIG00000011722		0.0881		0.4868
ENSDARG00000037916	ENSTRUG00000007028	ENSTNIG00000011161		0.012		0.355
ENSDARG00000062796	ENSTRUG00000015994	ENSTNIG00000002614		0.0803		0.5617
ENSDARG00000040490	ENSTRUG00000014275	ENSTNIG00000011565		0.0259		0.3203
ENSDARG00000078760	ENSTRUG00000012572	ENSTNIG00000014679		0.0311		0.4517
ENSDARG00000068480	NA	ENSTNIG00000010021	NA		NA	
ENSDARG00000075850	ENSTRUG00000010005	ENSTNIG00000014854		0.0205		0.2018
ENSDARG00000061769	ENSTRUG00000015051	ENSTNIG00000011429		0.0653		0.557
ENSDARG00000088062	ENSTRUG00000016785	ENSTNIG00000015986		0.0689		0.3344
ENSDARG00000078875	ENSTRUG00000007873	NA	NA		NA	
ENSDARG00000068231	ENSTRUG00000006673	ENSTNIG00000008785		0.0845		0.8388
ENSDARG00000007461	ENSTRUG00000006667	ENSTNIG00000008375		0.0104		0.3376
ENSDARG00000035891	ENSTRUG00000012986	ENSTNIG00000003947		0.2163		0.6234
ENSDARG00000045634	ENSTRUG00000016324	NA	NA		NA	
ENSDARG00000062849	NA	NA	NA		NA	
ENSDARG00000015623	ENSTRUG00000011247	ENSTNIG00000011412		0.0773		0.6586
ENSDARG00000078258	ENSTRUG00000010990	ENSTNIG00000009081		0.1224		0.4529
ENSDARG00000018968	ENSTRUG00000012489	NA	NA		NA	
ENSDARG00000032188	ENSTRUG00000018330	ENSTNIG00000018759		0.0115		0.4168
ENSDARG00000046085	ENSTRUG00000008926	NA	NA		NA	
ENSDARG00000020072	ENSTRUG00000017990	ENSTNIG00000014272		0.0291		0.5037
ENSDARG00000045145	ENSTRUG00000016966	ENSTNIG00000012922		0.0467		0.2736
ENSDARG00000011122	ENSTRUG00000015796	ENSTNIG00000011450		0.0089		0.3097
ENSDARG00000000474	ENSTRUG00000012124	ENSTNIG00000015035		0.0046		0.4181
ENSDARG00000059301	ENSTRUG00000018375	NA	NA		NA	
ENSDARG00000052702	ENSTRUG00000008487	ENSTNIG00000016627		0.026		0.4858
ENSDARG00000076632	ENSTRUG00000005570	ENSTNIG00000016721		0.0701		0.6218
ENSDARG00000043466	ENSTRUG00000017711	ENSTNIG00000016402		0.0984		0.5853
ENSDARG00000057206	ENSTRUG00000008585	ENSTNIG00000018914		0.0978		0.3493
ENSDARG00000014057	NA	NA	NA		NA	
ENSDARG00000056091	ENSTRUG00000007389	ENSTNIG00000004012		0.0205		0.1835
ENSDARG00000010154	ENSTRUG00000013424	ENSTNIG00000000558		0.1104		0.525
ENSDARG00000056532	ENSTRUG00000010900	NA	NA		NA	
ENSDARG00000035832	ENSTRUG00000016462	ENSTNIG00000001330		0.1024		0.3042
ENSDARG00000013647	ENSTRUG00000012648	ENSTNIG00000015182		0.0313		0.3069
ENSDARG00000034753	ENSTRUG00000008013	ENSTNIG00000008379		0.0207		0.2659
ENSDARG00000093420	ENSTRUG00000014697	NA	NA		NA	
ENSDARG00000029989	ENSTRUG00000012410	ENSTNIG00000018630		0.0627		0.568
ENSDARG00000011281	ENSTRUG00000015809	ENSTNIG00000017642		0.0515		0.3639
ENSDARG00000089691	NA	NA	NA		NA	
ENSDARG00000029419	ENSTRUG00000011545	ENSTNIG00000011935		0.0274		0.3107
ENSDARG00000038300	NA	ENSTNIG00000014690	NA		NA	
ENSDARG00000009482	ENSTRUG00000004695	NA	NA		NA	
ENSDARG00000037183	ENSTRUG00000002143	ENSTNIG00000006875		0.0161		0.4393
ENSDARG00000078241	ENSTRUG00000008554	ENSTNIG00000019294		0.3081		0.6667
ENSDARG00000036428	ENSTRUG00000014642	ENSTNIG00000014785		0.058		0.4786
ENSDARG00000017905	ENSTRUG00000015915	ENSTNIG00000007133		0.0822		0.5448
ENSDARG00000067570	ENSTRUG00000012315	NA	NA		NA	
ENSDARG00000007151	ENSTRUG00000013276	ENSTNIG00000016373		0.0121		0.3465
ENSDARG00000075903	ENSTRUG00000017043	ENSTNIG00000012942		0.0598		0.6097
ENSDARG00000011549	ENSTRUG00000005065	ENSTNIG00000014575		0.0385		0.3077
ENSDARG00000092921	ENSTRUG00000011047	NA	NA		NA	
ENSDARG00000091260	ENSTRUG00000011481	ENSTNIG00000008525		0.044		0.5063
ENSDARG00000057054	ENSTRUG00000005427	ENSTNIG00000008289		0.0582		0.3724
ENSDARG00000071150	NA	NA	NA		NA	
ENSDARG00000020602	ENSTRUG00000000698	ENSTNIG00000007842		0.0285		0.3333
ENSDARG00000037933	ENSTRUG00000013244	NA	NA		NA	
ENSDARG00000068892	NA	NA	NA		NA	
ENSDARG00000088546	ENSTRUG00000007975	ENSTNIG00000019298		0.0717		0.327
ENSDARG00000074697	NA	NA	NA		NA	
ENSDARG00000071395	ENSTRUG00000013465	NA	NA		NA	
ENSDARG00000090903	ENSTRUG00000007468	ENSTNIG00000015328		0.1312		0.3792
ENSDARG00000057125	ENSTRUG00000005513	NA	NA		NA	
ENSDARG00000040874	ENSTRUG00000006499	NA	NA		NA	
ENSDARG00000043835	ENSTRUG00000006009	ENSTNIG00000010193		0.0004		0.4492
ENSDARG00000009217	ENSTRUG00000016860	ENSTNIG00000012898		0.1141		0.3624
ENSDARG00000010654	ENSTRUG00000012664	ENSTNIG00000019046		0.1308		0.463
ENSDARG00000067730	ENSTRUG00000013189	ENSTNIG00000019044		0.0979		0.4251
ENSDARG00000057706	ENSTRUG00000016425	ENSTNIG00000011765		0.1906		0.5252
ENSDARG00000061099	ENSTRUG00000000328	ENSTNIG00000006125		0.094		0.5118

ENSDARG00000052057	ENSTRUG00000014354	NA	NA		NA	
ENSDARG00000077945	ENSTRUG00000000452	ENSTNIG00000007621		0.067		0.648
ENSDARG00000013858	NA	NA	NA		NA	
ENSDARG00000006602	NA	NA	NA		NA	
ENSDARG00000042172	ENSTRUG00000014834	ENSTNIG00000005137		0.1113		0.4912
ENSDARG00000062661	ENSTRUG00000000686	ENSTNIG00000014874		0.0506		0.4268
ENSDARG00000051819	ENSTRUG00000017420	ENSTNIG00000009368		0.087		0.5591
ENSDARG00000059052	ENSTRUG00000009698	ENSTNIG00000017278		0.0275		0.366
ENSDARG00000017398	ENSTRUG00000010504	ENSTNIG00000018140		0.1664		0.5689
ENSDARG00000039220	NA	NA	NA		NA	
ENSDARG00000060345	ENSTRUG00000004136	NA	NA		NA	
ENSDARG00000031756	ENSTRUG00000007090	ENSTNIG00000019231		0.0797		0.2369
ENSDARG00000012426	ENSTRUG00000016436	ENSTNIG00000011485		0.076		0.5751
ENSDARG00000029370	ENSTRUG00000002266	ENSTNIG00000007252		0.4362		1.635
ENSDARG00000057907	ENSTRUG00000006582	ENSTNIG00000000421		0.2391		0.5427
ENSDARG00000035553	ENSTRUG00000012976	ENSTNIG00000011825		0.0087		0.3474
ENSDARG00000006865	ENSTRUG00000011746	ENSTNIG00000015753		0.0385		0.4765
ENSDARG00000055066	ENSTRUG00000016932	ENSTNIG00000010017		0.0618		0.4342
ENSDARG00000018399	ENSTRUG00000008385	ENSTNIG00000011636		0.0404		0.4655
ENSDARG00000019304	ENSTRUG00000000766	ENSTNIG00000007366		0.0216		0.3074
ENSDARG00000090534	ENSTRUG00000009154	ENSTNIG00000010991		0.0178		0.3444
ENSDARG00000014588	ENSTRUG00000012172	ENSTNIG00000009256		0.0232		0.3697
ENSDARG00000076401	ENSTRUG00000010025	ENSTNIG00000011613		0.0083		0.2857
ENSDARG00000077047	ENSTRUG00000000335	ENSTNIG00000017152		0.0363		0.7771
ENSDARG00000012367	ENSTRUG00000007247	ENSTNIG00000018326		0.0292		0.4484
ENSDARG00000021664	ENSTRUG00000007145	NA	NA		NA	
ENSDARG00000075058	ENSTRUG00000005703	ENSTNIG00000008936		0.0401		0.4423
ENSDARG00000052954	ENSTRUG00000007504	ENSTNIG00000004004		0.0651		0.3564
ENSDARG00000002285	ENSTRUG00000002835	ENSTNIG00000014120		0.0863		0.7074
ENSDARG00000001771	ENSTRUG00000008134	ENSTNIG00000015267		0.0888		0.2769
ENSDARG00000013479	ENSTRUG00000012928	ENSTNIG00000003731		0.32		0.6579
ENSDARG00000020876	ENSTRUG00000013086	ENSTNIG00000016966		0.0348		0.6371
ENSDARG00000017213	NA	ENSTNIG00000001140	NA		NA	
ENSDARG00000069806	ENSTRUG00000009727	ENSTNIG00000000288		0.0469		0.3854
ENSDARG00000034080	ENSTRUG00000009158	ENSTNIG00000007923		0.0665		0.6343
ENSDARG00000003754	ENSTRUG00000018212	ENSTNIG00000018286		0.1165		0.4575
ENSDARG00000035415	ENSTRUG00000018438	ENSTNIG00000007493		0.0728		0.5376
ENSDARG00000022795	ENSTRUG00000016875	NA	NA		NA	
ENSDARG00000034541	ENSTRUG00000013188	ENSTNIG00000006473		0.0514		0.5598
ENSDARG00000060627	ENSTRUG00000018502	ENSTNIG00000013509		0.0525		0.4518
ENSDARG00000079062	NA	NA	NA		NA	
ENSDARG00000073695	ENSTRUG00000012326	ENSTNIG00000018658		0.1057		0.4243
ENSDARG00000074894	ENSTRUG00000015521	ENSTNIG00000010680		0.0106		0.2797
ENSDARG00000037747	ENSTRUG00000014882	ENSTNIG00000008259		0.0239		0.4545
ENSDARG00000078136	ENSTRUG00000014812	ENSTNIG00000015296		0.0222		0.2816
ENSDARG00000057448	ENSTRUG00000006934	ENSTNIG00000011857		0.0402		0.4418
ENSDARG00000015290	ENSTRUG00000003634	NA	NA		NA	
ENSDARG00000005470	ENSTRUG00000015920	ENSTNIG00000012002		0.0177		0.4738
ENSDARG00000062618	ENSTRUG00000008462	ENSTNIG00000011622		0.0173		0.5042
ENSDARG00000063079	ENSTRUG00000012737	NA	NA		NA	
ENSDARG00000090897	ENSTRUG00000010647	ENSTNIG00000017081		0.3038		0.8908
ENSDARG00000056805	ENSTRUG00000014166	ENSTNIG00000014775		0.0363		0.3857
ENSDARG00000062173	ENSTRUG00000010238	ENSTNIG00000010080		0.0504		0.4562
ENSDARG00000060705	ENSTRUG00000005108	ENSTNIG00000007635		0.0061		0.5164
ENSDARG00000061506	NA	NA	NA		NA	
ENSDARG00000079878	ENSTRUG00000011127	ENSTNIG00000008916		0.0372		1.3465
ENSDARG00000077871	ENSTRUG00000005864	ENSTNIG00000003085		0.0218		0.51
ENSDARG00000088164	NA	ENSTNIG00000006060	NA		NA	
ENSDARG00000079840	ENSTRUG00000003720	ENSTNIG00000008628		0.012		0.2014
ENSDARG00000011830	ENSTRUG00000005594	ENSTNIG00000008790		0.0267		0.5976
ENSDARG00000063133	ENSTRUG00000008287	ENSTNIG00000013279		0.0094		0.3124
ENSDARG00000078116	ENSTRUG00000009921	ENSTNIG00000010422		0.0208		0.3718
ENSDARG00000045137	ENSTRUG00000001856	ENSTNIG00000015222		0.0448		0.4289
ENSDARG00000077489	ENSTRUG00000006117	ENSTNIG00000004891		0.0272		0.4267
ENSDARG00000063011	ENSTRUG00000004794	ENSTNIG00000013226		0.0886		0.4645
ENSDARG00000060102	ENSTRUG00000015725	ENSTNIG00000015638		0.0787		0.3857
ENSDARG00000068710	ENSTRUG00000013221	ENSTNIG00000016660		0.0778		0.7925
ENSDARG00000061560	ENSTRUG00000005578	NA	NA		NA	
ENSDARG00000059699	ENSTRUG00000017717	ENSTNIG00000010926		0.0613		0.4898
ENSDARG00000070894	ENSTRUG00000010887	ENSTNIG00000017899		0.0329		0.4552
ENSDARG00000060326	ENSTRUG00000016047	ENSTNIG00000017188		0.0838		0.456
ENSDARG00000053568	ENSTRUG00000005179	ENSTNIG00000011358		0.248		0.6332
ENSDARG00000075183	ENSTRUG00000013999	NA	NA		NA	
ENSDARG00000016483	NA	ENSTNIG00000018838	NA		NA	
ENSDARG00000076747	ENSTRUG00000011412	ENSTNIG00000017923		0.0083		0.5855
ENSDARG00000074752	ENSTRUG00000003731	NA	NA		NA	
ENSDARG00000008247	ENSTRUG00000011480	ENSTNIG00000011836		0.0326		0.3277
ENSDARG00000078068	NA	ENSTNIG00000014379	NA		NA	
ENSDARG00000090308	ENSTRUG00000008196	ENSTNIG00000015009		0.1283		0.643
ENSDARG00000061131	ENSTRUG00000011492	ENSTNIG00000013728		0.0595		0.6147
ENSDARG00000079378	ENSTRUG00000010591	NA	NA		NA	
ENSDARG00000079931	ENSTRUG00000012133	ENSTNIG00000014374		0.1639		0.9105
ENSDARG00000073999	ENSTRUG00000006181	ENSTNIG00000013045		0.0612		0.3814
ENSDARG00000077499	ENSTRUG00000008144	ENSTNIG00000002943		0.2061		0.8932
ENSDARG00000060130	ENSTRUG00000005865	NA	NA		NA	
ENSDARG00000013780	ENSTRUG00000015083	ENSTNIG00000018797		0.0212		0.7305
ENSDARG00000079342	ENSTRUG00000004508	ENSTNIG00000019310		0.105		0.5951
ENSDARG00000090496	ENSTRUG00000008080	ENSTNIG00000011651		0.0799		0.4152
ENSDARG00000077086	ENSTRUG00000018566	ENSTNIG00000013534		0.0953		0.8806
ENSDARG00000090115	ENSTRUG00000009472	ENSTNIG00000015314		0.0067		0.3056

ENSDARG00000074329	ENSTRUG00000014229	ENSTNIG00000009048		0.0489		0.4891
ENSDARG00000086505	ENSTRUG00000008430	ENSTNIG00000010062		0.0355		0.3696
ENSDARG00000006301	ENSTRUG00000015785	ENSTNIG00000011537		0.0731		0.5898
ENSDARG00000077582	ENSTRUG00000007033	ENSTNIG00000014414		0.0397		0.6382
ENSDARG00000060315	ENSTRUG00000015759	ENSTNIG00000017199		0.0735		0.6155
ENSDARG00000060148	ENSTRUG00000009926	ENSTNIG00000014163		0.0522		0.479
ENSDARG00000060340	ENSTRUG00000011747	ENSTNIG00000017474		0.255		0.6862
ENSDARG00000063372	ENSTRUG00000006175	ENSTNIG00000016173		0.0483		0.4567
ENSDARG00000062171	ENSTRUG00000018469	ENSTNIG00000018251		0.0469		0.573
ENSDARG00000075436	ENSTRUG00000005192	ENSTNIG00000016175		0.2852		0.8532
ENSDARG00000067815	ENSTRUG00000008968	ENSTNIG00000015319		0.015		0.3195
ENSDARG00000036626	ENSTRUG00000005145	ENSTNIG00000015338		0.0354		0.3423
ENSDARG00000029168	ENSTRUG00000007868	ENSTNIG00000006343		0.1105		0.5473
ENSDARG00000059751	NA	NA	NA		NA	
ENSDARG00000061817	ENSTRUG00000016686	ENSTNIG00000007146		0.3172		1.1769
ENSDARG00000045427	ENSTRUG00000017838	ENSTNIG00000012770		0.1095		0.3439
ENSDARG00000015506	ENSTRUG00000010429	ENSTNIG00000017039		0.2134		2.3493
ENSDARG00000044146	ENSTRUG00000012824	ENSTNIG00000013758		0.0119		0.4422
ENSDARG00000087247	ENSTRUG00000015274	ENSTNIG00000014799		0.1211		0.3721
ENSDARG00000071095	ENSTRUG00000000774	ENSTNIG00000006602		0.397		2.0553
ENSDARG00000062020	ENSTRUG00000018255	ENSTNIG00000009279		0.0829		0.4583
ENSDARG00000060813	ENSTRUG00000014805	ENSTNIG00000004905		0.2439		1.0591
ENSDARG00000074617	ENSTRUG00000010741	NA	NA		NA	
ENSDARG00000019596	ENSTRUG00000015775	ENSTNIG00000017198		0.0298		0.3508
ENSDARG00000078901	ENSTRUG00000003639	ENSTNIG00000018306		0.0454		0.4362
ENSDARG00000073856	ENSTRUG00000012157	NA	NA		NA	
ENSDARG00000036094	ENSTRUG00000016843	NA	NA		NA	
ENSDARG00000029671	ENSTRUG00000006747	ENSTNIG00000007175		0.0174		0.4297
ENSDARG00000063144	ENSTRUG00000007219	ENSTNIG00000005662		0.1665		0.7999
ENSDARG00000069441	ENSTRUG00000015898	ENSTNIG00000011785		0.0941		0.3604
ENSDARG00000009930	ENSTRUG00000005651	ENSTNIG00000009965		0.0302		0.2549
ENSDARG00000040069	ENSTRUG00000016243	ENSTNIG00000005794		0.0592		0.4507
ENSDARG00000060587	ENSTRUG00000005780	ENSTNIG00000011882		0.0187		0.4793
ENSDARG00000076724	ENSTRUG00000018559	ENSTNIG00000013531		0.0105		0.3819
ENSDARG00000062450	ENSTRUG00000010873	ENSTNIG00000019502		0.1065		0.383
ENSDARG00000017108	ENSTRUG00000001616	ENSTNIG00000002493		0.0291		1.9965
ENSDARG00000061362	ENSTRUG00000000590	ENSTNIG00000013765		0.0659		0.7115
ENSDARG00000051892	ENSTRUG00000011767	ENSTNIG00000003443		0.026		0.5413
ENSDARG00000062108	ENSTRUG00000004325	ENSTNIG00000008041		0.0887		0.8021
ENSDARG00000040002	NA	NA	NA		NA	
ENSDARG00000070624	ENSTRUG00000004672	ENSTNIG00000008103		0.0223		0.553
ENSDARG00000062889	ENSTRUG00000017806	ENSTNIG00000006642		0.0199		0.5138
ENSDARG00000063255	NA	NA	NA		NA	
ENSDARG00000062343	ENSTRUG00000009667	ENSTNIG00000011891		0.0209		0.5881
ENSDARG00000076015	NA	NA	NA		NA	
ENSDARG00000063054	ENSTRUG00000004729	ENSTNIG00000002866		0.0751		1.0975
ENSDARG00000063008	ENSTRUG00000011408	ENSTNIG00000003456		0.1036		1.0608
ENSDARG00000002031	ENSTRUG00000006959	ENSTNIG00000007931		0.0901		0.3935
ENSDARG00000078117	ENSTRUG00000008097	ENSTNIG00000015650		0.0391		0.4561
ENSDARG00000003776	ENSTRUG00000002428	ENSTNIG00000008139		0.0018		0.3663
ENSDARG00000087330	NA	NA	NA		NA	
ENSDARG00000078060	ENSTRUG00000017289	ENSTNIG00000009392		0.0281		0.2974
ENSDARG00000077095	ENSTRUG00000010772	ENSTNIG00000002579		0.0552		0.3518
ENSDARG00000061904	ENSTRUG00000015843	ENSTNIG00000018445		0.0535		0.4179
ENSDARG00000094708	NA	ENSTNIG00000009112	NA		NA	
ENSDARG00000024890	ENSTRUG00000006789	ENSTNIG00000004639		0.0065		0.1868
ENSDARG00000030532	ENSTRUG00000014895	NA	NA		NA	
ENSDARG00000012490	ENSTRUG00000012166	ENSTNIG00000018635		0.0129		0.3585
ENSDARG00000093552	ENSTRUG00000004548	NA	NA		NA	
ENSDARG00000018492	ENSTRUG00000003530	ENSTNIG00000008627		0.0179		0.2608
ENSDARG00000077430	ENSTRUG00000009887	ENSTNIG00000016883		0.0229		0.4371
ENSDARG00000005783	ENSTRUG00000018168	ENSTNIG00000013192		0.1962		0.7254
ENSDARG00000079636	NA	ENSTNIG00000003924	NA		NA	
ENSDARG00000061405	ENSTRUG00000005246	ENSTNIG00000012296		0.0468		0.4434
ENSDARG00000070781	NA	NA	NA		NA	
ENSDARG00000010433	ENSTRUG00000010412	ENSTNIG00000010426		0.0288		0.2963
ENSDARG00000063376	ENSTRUG00000006947	ENSTNIG00000003684		0.0722		1.036
ENSDARG00000042107	ENSTRUG00000009490	ENSTNIG00000008817		0.0196		0.7051
ENSDARG00000018726	ENSTRUG00000008048	ENSTNIG00000012694		0.0989		0.582
ENSDARG00000076292	NA	NA	NA		NA	
ENSDARG00000071596	ENSTRUG00000010454	ENSTNIG00000008169		0.0262		0.4452
ENSDARG00000062168	ENSTRUG00000016264	ENSTNIG00000008465		0.0671		0.4728
ENSDARG00000060830	ENSTRUG00000009193	ENSTNIG00000009177		0.0702		0.436
ENSDARG00000088634	ENSTRUG00000012530	ENSTNIG00000003212		0.0311		0.2767
ENSDARG00000006609	ENSTRUG00000017876	ENSTNIG00000003242		0.0112		0.2952
ENSDARG00000062448	ENSTRUG00000014982	ENSTNIG00000001504		0.2208		0.7914
ENSDARG00000069245	ENSTRUG00000018152	ENSTNIG00000003118		0.1343		0.8015
ENSDARG00000033516	ENSTRUG00000009327	ENSTNIG00000002247		0.0721		0.4283
ENSDARG00000056920	ENSTRUG00000006872	NA	NA		NA	
ENSDARG00000033845	ENSTRUG00000007727	ENSTNIG00000016185		0.0029		0.2159
ENSDARG00000074503	NA	ENSTNIG00000009809	NA		NA	
ENSDARG00000027687	ENSTRUG00000004462	ENSTNIG00000000205		0.0495		0.4449
ENSDARG00000089957	ENSTRUG00000006766	ENSTNIG00000019753		0.8677		3.2826
ENSDARG00000004260	ENSTRUG00000010860	ENSTNIG00000003711		0.0016		0.397
ENSDARG00000090686	ENSTRUG00000005526	ENSTNIG00000002451		0.0489		0.4939
ENSDARG00000069717	ENSTRUG00000005683	ENSTNIG00000006028		0.0352		0.6358
ENSDARG00000063713	ENSTRUG00000005680	ENSTNIG00000009162		0.0698		0.4405
ENSDARG00000004875	ENSTRUG00000012500	ENSTNIG00000014049		0.1379		0.6228
ENSDARG00000059154	ENSTRUG00000009884	ENSTNIG00000004586		0.0514		1.3471
ENSDARG00000086453	ENSTRUG00000006302	ENSTNIG00000005726		0.0403		0.8977

ENSDARG00000091783	NA	NA	NA	NA	
ENSDARG00000075694	ENSTRUG00000016343	ENSTNIG00000015123	0.0396		0.4078
ENSDARG00000079095	NA	ENSTNIG00000018230	NA	NA	
ENSDARG00000086098	ENSTRUG00000015391	ENSTNIG00000011993	0.1605		0.6348
ENSDARG00000086391	ENSTRUG00000016845	ENSTNIG00000015996	0.4883		1.3451
ENSDARG00000037101	ENSTRUG00000008364	ENSTNIG00000004216	0.0843		0.4751
ENSDARG00000068883	ENSTRUG00000006323	ENSTNIG00000002353	0.0714		0.814
ENSDARG00000062183	ENSTRUG00000008483	ENSTNIG00000016270	0.0474		0.3652
ENSDARG00000078155	ENSTRUG00000016183	ENSTNIG00000015114	0.0909		0.4002
ENSDARG00000070952	NA	NA	NA	NA	
ENSDARG00000035883	ENSTRUG00000012786	ENSTNIG00000014033	0.0293		0.4794
ENSDARG00000086207	ENSTRUG00000006912	ENSTNIG00000018193	0.0386		0.5719
ENSDARG00000012297	ENSTRUG00000006140	ENSTNIG00000014476	0.0442		0.4865
ENSDARG00000059067	ENSTRUG00000013363	ENSTNIG00000010216	0.0453		0.3891
ENSDARG00000061466	ENSTRUG00000016323	ENSTNIG00000015121	0.0307		0.3401
ENSDARG00000090833	ENSTRUG00000000803	ENSTNIG00000002914	0.1005		0.4021
ENSDARG00000025904	ENSTRUG00000004571	ENSTNIG00000014091	0.0318		0.5668
ENSDARG00000062909	ENSTRUG00000018061	ENSTNIG00000009297	0.064		0.402
ENSDARG00000036272	ENSTRUG00000014346	ENSTNIG00000012358	0.0765		0.4978
ENSDARG00000063352	ENSTRUG00000013844	ENSTNIG00000013875	0.0292		0.3897
ENSDARG00000079116	ENSTRUG00000016594	NA	NA	NA	
ENSDARG00000071298	ENSTRUG00000008654	NA	NA	NA	
ENSDARG00000069500	ENSTRUG00000002194	ENSTNIG00000013976	0.0085		0.3958
ENSDARG00000039174	ENSTRUG00000000624	ENSTNIG00000014875	0.0123		0.2834
ENSDARG00000008329	ENSTRUG00000001950	ENSTNIG00000012591	0.1213		0.6838
ENSDARG00000031483	ENSTRUG00000016172	ENSTNIG00000016583	0.0552		0.3202
ENSDARG00000074480	ENSTRUG00000005486	ENSTNIG00000013626	0.0402		0.3472
ENSDARG00000062058	ENSTRUG00000001624	ENSTNIG00000008778	0.0136		0.6632
ENSDARG00000021590	NA	NA	NA	NA	
ENSDARG00000076592	NA	ENSTNIG00000003306	NA	NA	
ENSDARG00000016551	ENSTRUG00000002405	ENSTNIG00000007391	0.0321		0.5375
ENSDARG00000078388	ENSTRUG00000016060	ENSTNIG00000003516	0.109		0.5085
ENSDARG00000075046	ENSTRUG00000006988	ENSTNIG00000018010	0.0164		0.3702
ENSDARG00000001414	ENSTRUG00000007374	ENSTNIG00000019232	0.0898		0.4117
ENSDARG00000077868	ENSTRUG00000018019	ENSTNIG00000009788	0.0238		0.302
ENSDARG00000074521	ENSTRUG00000017372	ENSTNIG00000008576	0.0761		0.6001
ENSDARG00000025672	NA	ENSTNIG00000002996	NA	NA	
ENSDARG00000076987	ENSTRUG00000014112	NA	NA	NA	
ENSDARG00000060181	ENSTRUG00000004258	ENSTNIG00000002743	0.0821		0.4598
ENSDARG00000075849	NA	NA	NA	NA	
ENSDARG00000079060	ENSTRUG00000007537	ENSTNIG00000013052	0.2249		0.4862
ENSDARG00000091128	ENSTRUG00000010607	ENSTNIG00000009083	0.0957		0.6111
ENSDARG00000063649	ENSTRUG00000018177	ENSTNIG00000018296	0.0102		0.1819
ENSDARG00000073716	ENSTRUG00000008974	ENSTNIG00000010537	0.0461		0.5299
ENSDARG00000078141	ENSTRUG00000013856	ENSTNIG00000007006	0.0128		0.2687
ENSDARG00000063695	ENSTRUG00000017356	NA	NA	NA	
ENSDARG00000059574	ENSTRUG00000011674	ENSTNIG00000009778	0.0207		0.4899
ENSDARG00000022518	ENSTRUG00000017628	ENSTNIG00000015542	0.0517		0.3491
ENSDARG00000061685	ENSTRUG00000013040	ENSTNIG00000011958	0.0382		0.3047
ENSDARG00000037140	ENSTRUG00000009725	ENSTNIG00000012443	0.033		0.4813
ENSDARG00000007184	NA	ENSTNIG00000005798	NA	NA	
ENSDARG00000069970	NA	ENSTNIG00000005643	NA	NA	
ENSDARG00000076496	ENSTRUG00000012132	ENSTNIG00000012563	0.0403		0.39
ENSDARG00000078327	ENSTRUG00000002785	ENSTNIG00000004797	0.2109		0.945
ENSDARG00000094738	ENSTRUG00000018049	ENSTNIG00000006461	0.0258		0.5068
ENSDARG00000076184	ENSTRUG00000013638	ENSTNIG00000013164	0.0093		0.4494
ENSDARG00000062427	ENSTRUG00000006310	ENSTNIG00000004780	0.0679		0.5946
ENSDARG00000059093	ENSTRUG00000011938	ENSTNIG00000015846	0.0176		0.3052
ENSDARG00000077427	ENSTRUG00000011849	ENSTNIG00000018386	0.0298		0.3781
ENSDARG00000079889	ENSTRUG00000016936	ENSTNIG00000010015	0.1583		0.6897
ENSDARG00000095348	NA	NA	NA	NA	
ENSDARG00000068168	ENSTRUG00000015204	ENSTNIG00000011985	0.0482		0.4036
ENSDARG00000017446	ENSTRUG00000016926	ENSTNIG00000016011	0.0189		0.6776
ENSDARG00000077559	ENSTRUG00000004209	ENSTNIG00000019096	0.0437		0.3436
ENSDARG00000018856	ENSTRUG00000003577	ENSTNIG00000009924	0.0254		0.5886
ENSDARG00000078401	ENSTRUG00000015939	ENSTNIG00000015109	0.075		0.5526
ENSDARG00000062347	ENSTRUG00000011512	ENSTNIG00000009962	0.0343		0.431
ENSDARG00000075450	ENSTRUG00000004560	ENSTNIG00000008716	0.0517		0.4445
ENSDARG00000002816	ENSTRUG00000013821	NA	NA	NA	
ENSDARG00000077080	ENSTRUG00000015922	ENSTNIG00000017973	0.0654		0.376
ENSDARG00000087745	ENSTRUG00000006571	ENSTNIG00000012203	0.0102		0.3147
ENSDARG00000040027	NA	NA	NA	NA	
ENSDARG00000079272	NA	ENSTNIG00000014853	NA	NA	
ENSDARG00000087253	ENSTRUG00000004667	ENSTNIG00000007884	0.0609		0.3194
ENSDARG00000071233	NA	ENSTNIG00000006143	NA	NA	
ENSDARG00000004445	ENSTRUG00000009134	ENSTNIG00000009950	0.0705		0.5506
ENSDARG00000039145	ENSTRUG00000005457	ENSTNIG00000011864	0.1185		0.6175
ENSDARG00000074307	ENSTRUG00000015817	ENSTNIG00000018443	0.0498		0.3141
ENSDARG00000075673	ENSTRUG00000006402	ENSTNIG00000015231	0.0739		0.4488
ENSDARG00000009209	ENSTRUG00000003407	ENSTNIG00000016851	0.0251		0.4461
ENSDARG00000059826	ENSTRUG00000006661	ENSTNIG00000014083	0.0623		0.432
ENSDARG00000063311	ENSTRUG00000004481	ENSTNIG00000019103	0.0365		0.4405
ENSDARG00000055713	ENSTRUG00000014461	ENSTNIG00000011687	0.0646		0.3703
ENSDARG00000076735	ENSTRUG00000016672	ENSTNIG00000015943	0.0802		0.5348
ENSDARG00000061471	ENSTRUG00000014169	ENSTNIG00000015700	0.0812		0.7978
ENSDARG00000073881	ENSTRUG00000008029	ENSTNIG00000002694	0.0224		0.5337
ENSDARG00000054343	ENSTRUG00000003224	ENSTNIG00000007947	0.0832		0.4456
ENSDARG00000043993	NA	ENSTNIG00000016515	NA	NA	
ENSDARG00000086224	ENSTRUG00000005600	ENSTNIG00000013928	0.237		0.4509
ENSDARG00000077349	ENSTRUG00000007771	ENSTNIG00000013326	0.037		0.3381

ENSDARG00000079872	ENSTRUG00000017642	ENSTNIG00000016944		0.0384		0.4394
ENSDARG00000091328	ENSTRUG00000000197	ENSTNIG00000004746		0.0641		0.4598
ENSDARG00000079622	ENSTRUG00000003355	ENSTNIG00000011362		0.0613		0.4326
ENSDARG00000073768	ENSTRUG00000018482	ENSTNIG00000018091		0.0356		0.3017
ENSDARG00000077459	ENSTRUG00000009056	ENSTNIG00000000372		0.1481		0.7425
ENSDARG00000009442	ENSTRUG00000009216	ENSTNIG00000015344		0.0387		0.5198
ENSDARG00000076068	ENSTRUG00000010109	ENSTNIG00000011067		0.0854		0.2837
ENSDARG00000020239	ENSTRUG00000000190	ENSTNIG00000004655		0.073		0.3916
ENSDARG00000022550	ENSTRUG00000016788	ENSTNIG00000015989		0.1531		0.5673
ENSDARG00000073909	ENSTRUG00000015871	ENSTNIG00000010395		0.0367		0.6807
ENSDARG00000031817	ENSTRUG00000007701	ENSTNIG00000007110		0.0221		0.4445
ENSDARG00000079414	ENSTRUG00000000207	ENSTNIG00000003508		0.1287		0.8119
ENSDARG00000077229	ENSTRUG00000003456	ENSTNIG00000003633		0.0355		0.3841
ENSDARG00000076873	ENSTRUG00000007763	ENSTNIG00000004916		0.0469		0.4727
ENSDARG00000062687	ENSTRUG00000009685	ENSTNIG00000013275		0.0462		0.5001
ENSDARG00000078016	NA	NA	NA		NA	
ENSDARG00000074815	ENSTRUG00000004815	ENSTNIG00000014492		0.1474		0.4019
ENSDARG00000060871	ENSTRUG00000018607	ENSTNIG00000013577		0.0451		0.3764
ENSDARG00000076371	ENSTRUG00000000157	NA	NA		NA	
ENSDARG00000079366	ENSTRUG00000013089	ENSTNIG00000014013		0.0814		0.7073
ENSDARG00000021255	ENSTRUG00000013138	ENSTNIG00000016528		0.0795		0.3404
ENSDARG00000074394	ENSTRUG00000008479	NA	NA		NA	
ENSDARG00000036159	ENSTRUG00000003549	ENSTNIG00000004683		0.07		0.792
ENSDARG00000015931	ENSTRUG00000014784	ENSTNIG00000010933		0.0562		0.3753
ENSDARG00000088143	ENSTRUG00000004957	ENSTNIG00000014428		0.0367		0.5157
ENSDARG00000027192	NA	ENSTNIG00000006067	NA		NA	
ENSDARG00000079719	ENSTRUG00000008288	ENSTNIG00000006610		0.0402		0.445
ENSDARG00000062906	ENSTRUG00000004595	ENSTNIG00000010324		0.0807		0.528
ENSDARG00000063436	ENSTRUG00000018535	NA	NA		NA	
ENSDARG00000061249	ENSTRUG00000010610	ENSTNIG00000018646		0.0484		0.448
ENSDARG00000024744	NA	ENSTNIG00000015230	NA		NA	
ENSDARG00000060768	ENSTRUG00000009032	ENSTNIG00000009176		0.039		0.54
ENSDARG00000059935	ENSTRUG00000018203	ENSTNIG00000018291		0.0303		0.4225
ENSDARG00000071250	ENSTRUG00000003803	NA	NA		NA	
ENSDARG00000079542	ENSTRUG00000001125	ENSTNIG00000009919		0.0562		0.3978
ENSDARG00000074160	ENSTRUG00000005707	ENSTNIG00000000846		0.0244		0.342
ENSDARG00000077284	ENSTRUG00000003607	NA	NA		NA	
ENSDARG00000017154	ENSTRUG00000000646	ENSTNIG00000004886		0.0751		0.4977
ENSDARG00000010764	ENSTRUG00000010229	ENSTNIG00000014305		0.0172		0.4312
ENSDARG00000060618	ENSTRUG00000018436	ENSTNIG00000010861		0.0213		0.255
ENSDARG00000003877	ENSTRUG00000006061	ENSTNIG00000014632		0.0379		0.4776
ENSDARG00000076639	ENSTRUG00000004469	ENSTNIG00000016180		0.053		0.4157
ENSDARG00000074589	ENSTRUG00000001462	ENSTNIG00000013401		0.087		0.7624
ENSDARG00000078605	ENSTRUG00000007446	ENSTNIG00000012058		0.215		0.6166
ENSDARG00000045788	ENSTRUG00000006025	ENSTNIG00000018724		0.0679		0.4717
ENSDARG00000062352	NA	NA	NA		NA	
ENSDARG00000077545	ENSTRUG00000013664	ENSTNIG00000004874		0.0783		0.4828
ENSDARG00000079665	ENSTRUG00000006165	ENSTNIG00000007890		0.0381		0.4577
ENSDARG00000063583	ENSTRUG00000004901	NA	NA		NA	
ENSDARG00000074839	NA	NA	NA		NA	
ENSDARG00000044528	ENSTRUG00000007507	ENSTNIG00000013281		0.1465		0.6863
ENSDARG00000008350	ENSTRUG00000001378	ENSTNIG00000004536		0.0229		0.4055
ENSDARG00000063035	ENSTRUG00000002667	ENSTNIG00000011911		0.0036		0.289
ENSDARG00000074522	ENSTRUG00000008008	ENSTNIG00000013706		0.0392		0.5021
ENSDARG00000060847	ENSTRUG00000009533	ENSTNIG00000009090		0.042		0.4044
ENSDARG00000013293	ENSTRUG00000006427	ENSTNIG00000006335		0.1269		0.6974
ENSDARG00000079933	NA	ENSTNIG00000009939	NA		NA	
ENSDARG00000021820	NA	NA	NA		NA	
ENSDARG00000061520	ENSTRUG00000013087	ENSTNIG00000015076		0.1047		0.4175
ENSDARG00000061243	ENSTRUG00000016536	ENSTNIG00000011756		0.0692		0.4007
ENSDARG00000075892	ENSTRUG00000006054	NA	NA		NA	
ENSDARG00000078149	ENSTRUG00000004640	ENSTNIG00000011279		0.0115		0.4268
ENSDARG00000063359	ENSTRUG00000005894	ENSTNIG00000007971		0.0687		0.9324
ENSDARG00000070683	ENSTRUG00000007047	ENSTNIG00000004487		0.0555		0.5629
ENSDARG00000074600	ENSTRUG00000008133	ENSTNIG00000012042		0.0487		0.7883
ENSDARG00000078525	ENSTRUG00000014977	ENSTNIG00000012346		0.0902		0.8946
ENSDARG00000073917	ENSTRUG00000005003	ENSTNIG00000016259		0.0105		0.3039
ENSDARG00000077948	ENSTRUG00000011462	ENSTNIG00000000895		0.1094		0.7451
ENSDARG00000089549	ENSTRUG00000007980	ENSTNIG00000016345		0.2787		1.3753
ENSDARG00000079765	ENSTRUG00000000145	ENSTNIG00000007376		0.1544		0.5088
ENSDARG00000061070	ENSTRUG00000009339	ENSTNIG00000008645		0.0421		0.408
ENSDARG00000076233	ENSTRUG00000010466	ENSTNIG00000007349		0.0878		0.3916
ENSDARG00000019185	NA	ENSTNIG00000014998	NA		NA	
ENSDARG00000078817	ENSTRUG00000015714	ENSTNIG00000016686		0.0299		0.2912
ENSDARG00000075960	ENSTRUG00000013111	ENSTNIG00000006994		0.0417		0.2273
ENSDARG00000056689	NA	ENSTNIG00000006634	NA		NA	
ENSDARG00000076299	ENSTRUG00000002445	ENSTNIG00000017871		0.0366		0.3263
ENSDARG00000082979	NA	NA	NA		NA	
ENSDARG00000074531	ENSTRUG00000008729	ENSTNIG00000012637		0.0835		0.4946
ENSDARG00000075764	ENSTRUG00000005275	ENSTNIG00000005311		0.0086		0.3123
ENSDARG00000075815	ENSTRUG00000018315	ENSTNIG00000018274		0.0111		0.4139
ENSDARG00000060018	ENSTRUG00000002056	NA	NA		NA	
ENSDARG00000077477	ENSTRUG00000005565	ENSTNIG00000011881		0.0849		0.4622
ENSDARG00000078063	ENSTRUG00000013480	ENSTNIG00000016143		0.0601		0.42
ENSDARG00000060846	ENSTRUG00000012475	ENSTNIG00000009067		0.008		0.2968
ENSDARG00000063037	ENSTRUG00000012533	ENSTNIG00000003561		0.1578		1.1177
ENSDARG00000030173	ENSTRUG00000004769	ENSTNIG00000010596		0.0343		0.5966
ENSDARG00000025920	ENSTRUG00000015042	ENSTNIG00000019018		0.0317		0.3562
ENSDARG00000063681	ENSTRUG00000004190	ENSTNIG00000007459		0.0496		0.4457
ENSDARG00000075539	ENSTRUG00000007513	NA	NA		NA	

ENSDARG00000077855	ENSTRUG00000013841	ENSTNIG00000009243		0.0334		0.2793
ENSDARG00000059886	ENSTRUG00000000704	ENSTNIG00000008532		0.0838		0.4792
ENSDARG00000074255	NA	NA	NA		NA	
ENSDARG00000061968	ENSTRUG00000015306	ENSTNIG00000015893		0.0385		0.3982
ENSDARG00000076499	ENSTRUG00000014217	ENSTNIG00000012361		0.0469		0.5225
ENSDARG00000076338	ENSTRUG00000012655	ENSTNIG00000014293		0.1045		0.4492
ENSDARG00000079252	NA	ENSTNIG00000018927	NA		NA	
ENSDARG00000077293	ENSTRUG00000003079	ENSTNIG00000007457		0.1446		0.4406
ENSDARG00000079483	ENSTRUG00000018514	ENSTNIG00000013512		0.1908		0.6786
ENSDARG00000079671	ENSTRUG00000004648	ENSTNIG00000003369		0.0658		1.091
ENSDARG00000013153	ENSTRUG00000012181	ENSTNIG00000018388		0.113		0.4331
ENSDARG00000076874	ENSTRUG00000013439	ENSTNIG00000006468		0.0872		0.4882
ENSDARG00000055437	ENSTRUG00000013260	ENSTNIG00000013887		0.0735		0.4482
ENSDARG00000004633	ENSTRUG00000005396	ENSTNIG00000014089		0.1789		0.8574
ENSDARG00000075956	ENSTRUG00000015053	ENSTNIG00000016299		0.0383		0.4059
ENSDARG00000077461	ENSTRUG00000008780	ENSTNIG00000010368		0.0761		0.3429
ENSDARG00000074604	ENSTRUG00000006246	ENSTNIG00000014910		0.4699		0.6663
ENSDARG00000075571	NA	ENSTNIG00000014684	NA		NA	
ENSDARG00000062040	ENSTRUG00000015919	ENSTNIG00000015633		0.0528		0.5449
ENSDARG00000042329	ENSTRUG00000015467	ENSTNIG00000011444		0.0492		0.5711
ENSDARG00000076320	ENSTRUG00000012789	ENSTNIG00000013681		0.0356		0.5084
ENSDARG00000030376	ENSTRUG00000000055	NA	NA		NA	
ENSDARG00000060534	ENSTRUG00000002803	ENSTNIG00000012374		0.1241		0.6503
ENSDARG00000077506	ENSTRUG00000017285	ENSTNIG00000009396		0.0401		0.3672
ENSDARG00000078247	NA	NA	NA		NA	
ENSDARG00000079098	ENSTRUG00000016571	ENSTNIG00000015594		0.0162		0.309
ENSDARG00000063282	ENSTRUG00000011200	ENSTNIG00000015023		0.0044		0.3951
ENSDARG00000074357	ENSTRUG00000011186	ENSTNIG00000007235		0.1039		0.5793
ENSDARG00000074655	ENSTRUG00000010537	ENSTNIG00000019817		0.389		1.9557
ENSDARG00000052957	ENSTRUG00000016563	ENSTNIG00000014952		0.0355		0.4804
ENSDARG00000057586	ENSTRUG00000003369	NA	NA		NA	
ENSDARG00000059812	ENSTRUG00000016648	ENSTNIG00000009568		0.0405		0.3114
ENSDARG00000073859	ENSTRUG00000003931	ENSTNIG00000019168		0.0629		0.5836
ENSDARG00000053381	ENSTRUG00000014543	ENSTNIG00000007546		0.0558		0.496
ENSDARG00000079161	ENSTRUG00000013807	ENSTNIG00000014692		0.094		0.4001
ENSDARG00000070025	ENSTRUG00000009226	ENSTNIG00000016276		0.0449		0.3115
ENSDARG00000088227	ENSTRUG00000012240	ENSTNIG00000010365		0.062		0.5005
ENSDARG00000079556	ENSTRUG00000009442	ENSTNIG00000015342		0.0332		0.2852
ENSDARG00000060073	ENSTRUG00000012325	ENSTNIG00000004670		0.0501		0.4738
ENSDARG00000057353	ENSTRUG00000005012	NA	NA		NA	
ENSDARG00000077938	ENSTRUG00000009214	ENSTNIG00000018232		0.0774		0.4848
ENSDARG00000076640	ENSTRUG00000006498	NA	NA		NA	
ENSDARG00000070227	ENSTRUG00000012853	ENSTNIG00000006370		0.115		0.4492
ENSDARG00000076381	ENSTRUG00000018555	ENSTNIG00000013530		0.025		0.4469
ENSDARG00000019301	ENSTRUG00000012507	ENSTNIG00000011597		0.031		0.3459
ENSDARG00000071685	ENSTRUG00000011533	ENSTNIG00000004255		0.0103		0.4042
ENSDARG00000087341	NA	ENSTNIG00000009053	NA		NA	
ENSDARG00000061798	NA	ENSTNIG00000006506	NA		NA	
ENSDARG00000060022	NA	ENSTNIG00000011933	NA		NA	
ENSDARG00000017391	ENSTRUG00000014700	NA	NA		NA	
ENSDARG00000022415	NA	NA	NA		NA	
ENSDARG00000013004	ENSTRUG00000015232	NA	NA		NA	
ENSDARG00000070831	ENSTRUG00000015756	ENSTNIG00000009213		0.19		0.5748
ENSDARG00000040485	ENSTRUG00000018162	ENSTNIG00000000830		0.2427		0.5751
ENSDARG00000070545	ENSTRUG00000012346	ENSTNIG00000007313		0.0261		0.6557
ENSDARG00000037042	NA	NA	NA		NA	
ENSDARG00000059997	ENSTRUG00000006668	ENSTNIG00000015424		0.016		0.3715
ENSDARG00000057378	NA	NA	NA		NA	
ENSDARG00000079722	ENSTRUG00000002350	ENSTNIG00000019529		0.5757		1.6867
ENSDARG00000039949	ENSTRUG00000011882	NA	NA		NA	
ENSDARG00000028943	ENSTRUG00000005593	ENSTNIG00000008368		0.0513		0.3295
ENSDARG00000015959	ENSTRUG00000005330	ENSTNIG00000004737		0.099		0.5025
ENSDARG00000089090	NA	NA	NA		NA	
ENSDARG00000005544	ENSTRUG00000009813	ENSTNIG00000004738		0.0541		1.2703
ENSDARG00000005479	ENSTRUG00000011052	ENSTNIG00000005377		0.0301		0.5651
ENSDARG00000025921	ENSTRUG00000001483	NA	NA		NA	
ENSDARG00000090990	NA	ENSTNIG00000000687	NA		NA	
ENSDARG00000008473	ENSTRUG00000004831	ENSTNIG00000017499		0.0994		0.6533
ENSDARG00000040719	NA	ENSTNIG00000002519	NA		NA	
ENSDARG00000090953	ENSTRUG00000002338	ENSTNIG00000004971		0.6889		4.8252
ENSDARG00000091140	NA	NA	NA		NA	
ENSDARG00000060632	ENSTRUG00000013149	ENSTNIG00000005481		0.0911		0.4578
ENSDARG00000086702	ENSTRUG00000005586	ENSTNIG00000000844		0.2175		0.5403
ENSDARG00000054510	ENSTRUG00000014131	ENSTNIG00000016152		0.0302		0.5068
ENSDARG00000088937	NA	ENSTNIG00000010013	NA		NA	
ENSDARG00000075715	ENSTRUG00000009142	ENSTNIG00000018654		0.1498		0.6542
ENSDARG00000038894	ENSTRUG00000004925	ENSTNIG00000003075		0.1978		0.9753
ENSDARG00000001767	ENSTRUG00000007976	ENSTNIG00000002730		0.1261		0.8306
ENSDARG00000074244	ENSTRUG00000001371	ENSTNIG00000003281		0.1075		0.4882
ENSDARG00000090468	NA	ENSTNIG00000001426	NA		NA	
ENSDARG00000038862	ENSTRUG00000009302	ENSTNIG00000018131		0.0311		0.6334
ENSDARG00000069766	ENSTRUG00000014343	ENSTNIG00000016156		0		0.1968
ENSDARG00000056680	ENSTRUG00000010867	ENSTNIG00000017076		0.0655		0.3557
ENSDARG00000077073	ENSTRUG00000017182	ENSTNIG00000009470		0.0258		0.2079
ENSDARG00000040535	ENSTRUG00000014511	ENSTNIG00000007545		0.0399		0.4383
ENSDARG00000051827	ENSTRUG00000016496	ENSTNIG00000009580		0.1957		0.9052
ENSDARG00000053498	ENSTRUG00000007046	ENSTNIG00000013965		0.0416		0.2565
ENSDARG00000071325	ENSTRUG00000018088	ENSTNIG00000010647		0.089		0.4361
ENSDARG00000043673	ENSTRUG00000004803	ENSTNIG00000012233		0.0403		0.5729
ENSDARG00000063218	ENSTRUG00000008078	ENSTNIG00000015266		0.011		0.3874

ENSDARG00000013623	ENSTRUG00000003173	NA	NA		NA	
ENSDARG00000052494	ENSTRUG00000005635	ENSTNIG00000007176		0.0632		0.4693
ENSDARG00000043864	ENSTRUG00000010655	ENSTNIG00000011959		0.0587		0.4422
ENSDARG00000014313	ENSTRUG00000010445	ENSTNIG00000014536		0.0813		0.8253
ENSDARG00000088825	ENSTRUG00000015991	ENSTNIG00000011455		0.0174		0.5672
ENSDARG00000088979	ENSTRUG00000000854	ENSTNIG00000016505		0.1273		0.2892
ENSDARG00000088405	ENSTRUG00000002682	NA	NA		NA	
ENSDARG00000055479	NA	NA	NA		NA	
ENSDARG00000013346	ENSTRUG00000006258	ENSTNIG00000017883		0.1591		0.6454
ENSDARG00000025535	ENSTRUG00000009500	ENSTNIG00000017065		0.1422		0.5562
ENSDARG00000016480	ENSTRUG00000006463	ENSTNIG00000018945		0.0415		0.3682
ENSDARG00000074270	ENSTRUG00000009065	NA	NA		NA	
ENSDARG00000089193	ENSTRUG00000013303	ENSTNIG00000013653		0.1282		0.8223
ENSDARG00000088204	NA	ENSTNIG00000001284	NA		NA	
ENSDARG00000062929	ENSTRUG00000010810	ENSTNIG00000004645		0.0299		0.4107
ENSDARG00000078989	ENSTRUG00000004542	ENSTNIG00000019249		0.047		0.2845
ENSDARG00000067723	NA	NA	NA		NA	
ENSDARG00000075433	ENSTRUG00000008910	ENSTNIG00000003271		0.0524		0.5827
ENSDARG00000079472	ENSTRUG00000018360	ENSTNIG00000013484		0.0919		0.43
ENSDARG00000019341	ENSTRUG00000018408	ENSTNIG00000018077		0.0353		0.3083
ENSDARG00000076974	ENSTRUG00000012702	ENSTNIG00000008662		0.1028		0.4763
ENSDARG00000037576	ENSTRUG00000013175	ENSTNIG00000005178		0.072		0.452
ENSDARG00000061021	ENSTRUG00000015188	ENSTNIG00000003377		0.1641		0.8932
ENSDARG00000078102	ENSTRUG00000005491	ENSTNIG00000013360		0.1225		0.862
ENSDARG00000077964	ENSTRUG00000012503	ENSTNIG00000009646		0.0629		0.4892
ENSDARG00000023713	ENSTRUG00000013591	ENSTNIG00000008474		0.0232		0.2578
ENSDARG00000069419	ENSTRUG00000013013	ENSTNIG00000014097		0.1483		0.7412
ENSDARG00000056395	NA	ENSTNIG00000004331	NA		NA	
ENSDARG00000087907	ENSTRUG00000014749	ENSTNIG00000007053		0.0958		0.2807
ENSDARG00000074515	ENSTRUG00000009259	ENSTNIG00000004953		0.0182		0.767
ENSDARG00000010583	ENSTRUG00000001921	ENSTNIG00000007975		0.0847		0.8166
ENSDARG00000059475	ENSTRUG00000003622	ENSTNIG00000018556		0.0962		0.3998
ENSDARG00000089276	ENSTRUG00000011660	ENSTNIG00000009777		0.0696		0.3396
ENSDARG00000090963	NA	ENSTNIG00000015013	NA		NA	
ENSDARG00000031126	ENSTRUG00000010595	ENSTNIG00000009765		0.0076		0.4134
ENSDARG00000061196	ENSTRUG00000010123	ENSTNIG00000018648		0.1054		0.524
ENSDARG00000086535	ENSTRUG00000004121	ENSTNIG00000004239		0.0839		0.4723
ENSDARG00000031020	ENSTRUG00000000666	NA	NA		NA	
ENSDARG00000052376	ENSTRUG00000001047	ENSTNIG00000004506		0.2782		1.4864
ENSDARG00000058875	NA	ENSTNIG00000002645	NA		NA	
ENSDARG00000087939	NA	NA	NA		NA	
ENSDARG00000003860	ENSTRUG00000015895	ENSTNIG00000001200		0.0209		0.681
ENSDARG00000042521	ENSTRUG00000011723	NA	NA		NA	
ENSDARG00000077944	ENSTRUG00000017211	ENSTNIG00000009454		0.0985		0.4407
ENSDARG00000077470	ENSTRUG00000001677	ENSTNIG00000010171		0.1163		0.4755
ENSDARG00000075792	ENSTRUG00000015542	ENSTNIG00000011033		0.0629		0.4277
ENSDARG00000079581	NA	ENSTNIG00000011187	NA		NA	
ENSDARG00000078542	NA	ENSTNIG00000009110	NA		NA	
ENSDARG00000027657	ENSTRUG00000008766	ENSTNIG00000000114		0.0363		0.1238
ENSDARG00000027419	ENSTRUG00000008178	ENSTNIG00000007895		0.0094		0.4435
ENSDARG00000026137	ENSTRUG00000013695	ENSTNIG00000015740		0.0309		0.376
ENSDARG00000060751	ENSTRUG00000016256	ENSTNIG00000015617		0.0965		0.5846
ENSDARG00000062109	ENSTRUG00000009238	ENSTNIG00000015453		0.0525		0.4604
ENSDARG00000090698	ENSTRUG00000018444	ENSTNIG00000010859		0.0591		0.4774
ENSDARG00000079978	NA	ENSTNIG00000012492	NA		NA	
ENSDARG00000088248	ENSTRUG00000013772	ENSTNIG00000015739		0.3733		0.8528
ENSDARG00000061498	ENSTRUG00000014736	ENSTNIG00000016549		0.068		0.3991
ENSDARG00000078527	NA	ENSTNIG00000006176	NA		NA	
ENSDARG00000073891	ENSTRUG00000017119	ENSTNIG00000004705		0.0829		0.6044
ENSDARG00000076103	ENSTRUG00000004886	ENSTNIG00000018000		0.0477		0.3661
ENSDARG00000062346	ENSTRUG00000009289	ENSTNIG00000015498		0.0451		0.3773

3.4 Supplementary table of human duplicates with mouse singletons, with results of comparisons of expression patterns and dN/dS information

A : dN between duplicate 1 and mouse singleton

B : dS between duplicate 1 and mouse singleton

C : dN between duplicate 2 and mouse singleton

D : dS between duplicate 2 and mouse singleton

Human duplicate 1 Ensembl ID	A	B	Human duplicate 2 Ensembl ID	C	D	Mouse singleton Ensembl ID	Mouse singleton Ensembl name	Spatio-temporal analysis	Spatial-only analysis	Expression vs. No Expression	High quality data
ENSG00000112378	0.049	0.8421	ENSG00000228998	0.202	1.507	ENSMUSG00000019851	Perp	Overlap	Overlap	Overlap	Overlap
ENSG00000173262	0.1212	0.7693	ENSG00000059804	0.1052	0.7384	ENSMUSG00000003153	Slc2a3	Overlap	Overlap	Overlap	Overlap
ENSG00000173272	0.1962	1.3313	ENSG00000152082	0.1794	1.2261	ENSMUSG00000022671	Mzt2	Overlap	Overlap	Overlap	Overlap
ENSG00000188428	0.0625	0.6096	ENSG00000239264	0.0849	0.5374	ENSMUSG00000038991	Txndc5	Overlap	Overlap	Overlap	Overlap
ENSG00000228716	0.0494	0.4173	ENSG00000178700	0.0716	0.3886	ENSMUSG00000021707	Dhfr	Overlap	Overlap	Overlap	Overlap
ENSG00000116580	0.1504	0.5209	ENSG00000163374	0.2102	0.52	ENSMUSG00000054199	Gon4l	Overlap	Overlap	Overlap	Neofunct
ENSG00000169664	0.3853	0.6453	ENSG00000172116	0.3931	0.6403	ENSMUSG00000053044	Cd8b1	Overlap	Both	Both	Neofunct
ENSG00000169474	0.1663	0.6788	ENSG00000169469	0.1544	0.8777	ENSMUSG00000050359	Sprr1a	Neofunct	Neofunct	Neofunct	Overlap
ENSG00000100068	0.1361	1.8662	ENSG00000162337	0.0278	1.2138	ENSMUSG00000024913	Lrp5	Neofunct	Neofunct	Neofunct	Neofunct
ENSG00000196954	0.3011	0.9746	ENSG00000137757	0.3577	0.8579	ENSMUSG00000033538	Casp4	Neofunct	Neofunct	Neofunct	Neofunct
ENSG00000135702	0.1531	1.2902	ENSG00000183196	0.0979	1.075	ENSMUSG00000031952	Chst5	Neofunct	Both	Both	Neofunct
ENSG00000249471	0.2266	1.111	ENSG00000083812	0.2139	1.0355	ENSMUSG00000004500	Zfp324	Both	Overlap	Overlap	Overlap
ENSG00000105889	0.4863	1.1262	ENSG00000164647	0.1066	0.5343	ENSMUSG00000015652	Steap1	Both	Neofunct	Neofunct	Neofunct
ENSG00000187758	0.1016	0.7319	ENSG00000196616	0.1015	0.6744	ENSMUSG00000074207	Adh1	Both	Both	Both	Both
ENSG00000022556	0.4961	1.1687	ENSG00000167634	0.5276	1.9406	ENSMUSG00000035177	Nlrp2	Overlap	Overlap	Overlap	NA
ENSG00000051825	0.1443	0.67	ENSG00000257076	0.3307	0.7191	ENSMUSG00000038126	Mphosph	Overlap	Overlap	Overlap	NA
ENSG00000054219	0.1414	0.5832	ENSG00000248672	0.1499	0.6072	ENSMUSG00000026980	Ly75	Overlap	Overlap	Overlap	NA
ENSG00000090857	0.0404	0.435	ENSG00000214331	0.1646	0.4872	ENSMUSG00000033624	Pdpr	Overlap	Overlap	Overlap	NA
ENSG00000106086	0.049	0.5522	ENSG00000134297	0.0621	0.5033	ENSMUSG00000005225	Plekha8	Overlap	Overlap	Overlap	NA
ENSG00000115042	0.0761	0.5339	ENSG00000144199	0.0796	0.5368	ENSMUSG00000027371	Fahd2a	Overlap	Overlap	Overlap	NA
ENSG00000116685	0.0386	0.849	ENSG00000255862	0.0482	0.8391	ENSMUSG00000044496	2510039	Overlap	Overlap	Overlap	NA
ENSG00000120586	0.1028	0.6965	ENSG00000183748	0.1025	0.6901	ENSMUSG00000026712	Mrc1	Overlap	Overlap	Overlap	NA
ENSG00000124508	0.1909	0.7399	ENSG00000112763	0.234	0.7456	ENSMUSG00000053216	Btn2a2	Overlap	Overlap	Overlap	NA
ENSG00000144134	0.1001	0.4185	ENSG00000079974	0.0995	0.4223	ENSMUSG00000022621	Rabl2	Overlap	Overlap	Overlap	NA
ENSG00000152076	0.1914	0.9122	ENSG00000163040	0.1857	0.8535	ENSMUSG00000041617	Ccdc74a	Overlap	Overlap	Overlap	NA
ENSG00000162747	0.2555	0.7426	ENSG00000203747	0.261	0.7852	ENSMUSG00000059089	Fcgr4	Overlap	Overlap	Overlap	NA
ENSG00000165055	0.1156	0.4948	ENSG00000087995	0.1193	0.5014	ENSMUSG00000020691	Mettl2	Overlap	Overlap	Overlap	NA
ENSG00000166664	0.076	0.9021	ENSG00000175344	0.0334	0.6436	ENSMUSG00000030525	Chrna7	Overlap	Overlap	Overlap	NA
ENSG00000173531	0.1099	0.7332	ENSG00000186715	0.1811	0.8994	ENSMUSG00000032591	Mst1	Overlap	Overlap	Overlap	NA
ENSG00000174428	0.1082	1.2513	ENSG00000196275	0.1101	1.2621	ENSMUSG00000015942	Gtf2ird2	Overlap	Overlap	Overlap	NA
ENSG00000175029	0.0602	0.6429	ENSG00000212884	0.1338	0.9948	ENSMUSG00000030970	Ctbp2	Overlap	Overlap	Overlap	NA
ENSG00000180574	0.0437	0.5747	ENSG00000130741	0.0019	0.4743	ENSMUSG00000035150	Eif2s3x	Overlap	Overlap	Overlap	NA
ENSG00000182481	0.0293	0.5569	ENSG00000215769	0.1242	0.8644	ENSMUSG00000018362	Kpna2	Overlap	Overlap	Overlap	NA
ENSG00000183434	0.156	0.8818	ENSG00000198176	0.0234	0.759	ENSMUSG00000038482	Tfdp1	Overlap	Overlap	Overlap	NA
ENSG00000184110	0.0161	0.6566	ENSG00000205609	0.0161	0.6566	ENSMUSG00000030738	Eif3c	Overlap	Overlap	Overlap	NA
ENSG00000189152	0.0873	1.678	ENSG00000154016	0.0356	1.0484	ENSMUSG00000004837	Grap	Overlap	Overlap	Overlap	NA
ENSG00000189266	0.089	0.3992	ENSG00000215700	0.089	0.3992	ENSMUSG00000028675	Pnrc2	Overlap	Overlap	Overlap	NA
ENSG00000197620	0.1411	0.526	ENSG00000197021	0.1522	0.5613	ENSMUSG00000045237	1110012	Overlap	Overlap	Overlap	NA
ENSG00000198019	0.286	0.6749	ENSG00000150337	0.2503	0.6141	ENSMUSG00000015947	Fcgr1	Overlap	Overlap	Overlap	NA
ENSG00000243207	0.1699	1.3815	ENSG00000130810	0.1699	1.3815	ENSMUSG00000004100	Ppan	Overlap	Overlap	Overlap	NA
ENSG00000244414	0.3046	1.2711	ENSG00000080910	0.2565	0.7574	ENSMUSG00000057037	Cfhr1	Overlap	Overlap	Overlap	NA
ENSG00000255398	0.1254	0.9543	ENSG00000182782	0.1092	0.9472	ENSMUSG00000045502	Niacr1	Overlap	Overlap	Overlap	NA
ENSG00000185303	0.1955	0.596	ENSG00000122852	0.1937	0.5972	ENSMUSG00000021789	Sftpa1	Overlap	Neofunct	Neofunct	NA
ENSG00000243335	0.019	0.656	ENSG00000154710	0.019	0.656	ENSMUSG00000025340	Rabgef1	Overlap	Neofunct	Neofunct	NA
ENSG00000175548	0.0889	0.6405	ENSG00000139133	0.0822	0.6381	ENSMUSG00000075470	Alg10b	Subfuncti	Overlap	Overlap	NA
ENSG00000198455	0.0985	0.8566	ENSG00000198205	0.1077	0.8472	ENSMUSG00000073062	Zxdb	Subfuncti	Overlap	Overlap	NA
ENSG00000175105	0.0736	0.4561	ENSG00000229729	NA	NA	ENSMUSG00000047141	Zfp654	Subfuncti	Subfuncti	Subfuncti	NA
ENSG00000197721	0.3257	0.6144	ENSG00000203710	0.2926	0.5434	ENSMUSG00000016481	Cr1l	Neofunct	Overlap	Overlap	NA
ENSG00000065371	0.0886	0.4324	ENSG00000114547	0.0815	0.425	ENSMUSG00000022832	Ropn1	Neofunct	Neofunct	Neofunct	NA

ENSG00000203795	0.3871	0.7379	ENSG00000213185	0.4989	0.5486	ENSMUSG00000030859	Fam24a	Neofunct	Neofunct	Neofunct	NA
ENSG00000107014	0.4064	0.8884	ENSG00000107018	0.3907	1.0069	ENSMUSG00000039097	Rln1	Neofunct	Both	Both	NA
ENSG00000163735	0.4159	0.7015	ENSG00000124875	0.3838	0.9014	ENSMUSG00000029371	Cxcl5	Neofunct	Both	Both	NA
ENSG00000167618	0.6364	1.1243	ENSG00000167613	0.5071	0.83	ENSMUSG00000055541	Lair1	Both	Both	Both	NA
ENSG00000187010	0.3471	0.6898	ENSG00000188672	0.3314	0.6837	ENSMUSG00000028825	Rhd	Both	Both	Both	NA
ENSG00000142615	0.1805	0.9497	ENSG00000215704	0.2121	0.9671	ENSMUSG00000058579	Cela2a	NA	Overlap	Overlap	NA
ENSG00000181315	0.0819	0.5554	ENSG00000188801	0.0859	0.5455	ENSMUSG00000046351	Zfp322a	NA	Overlap	Overlap	NA
ENSG00000130943	0.2624	0.9442	ENSG00000188599	12.56	14.123	ENSMUSG00000052496	Pkdrej	NA	Neofunct	Neofunct	NA
ENSG00000183747	0.1457	0.5157	ENSG00000066813	0.1496	0.5357	ENSMUSG00000030945	Acsm2	Overlap	NA	NA	NA
ENSG00000033327	0.0345	0.4743	ENSG00000215568	0.2609	0.5999	ENSMUSG00000004508	Gab2	NA	NA	NA	NA
ENSG00000051596	0.0052	0.6528	ENSG00000253323	0.0039	0.6634	ENSMUSG00000025872	Thoc3	NA	NA	NA	NA
ENSG00000065923	0.0239	0.407	ENSG00000227825	0.074	0.5537	ENSMUSG00000037341	Slc9a7	NA	NA	NA	NA
ENSG00000068781	0.158	0.6152	ENSG00000243244	0.138	0.5784	ENSMUSG00000033855	Ston1	NA	NA	NA	NA
ENSG00000089505	2.1022	1.6928	ENSG00000254788	2.0138	0.4809	ENSMUSG00000031876	Cmtm1	NA	NA	NA	NA
ENSG00000099715	0.0983	0.459	ENSG00000102290	0.1068	0.472	ENSMUSG00000034755	Pcdh11x	NA	NA	NA	NA
ENSG00000099822	0.0276	1.3785	ENSG00000256952	0.0238	2.4115	ENSMUSG00000020331	Hcn2	NA	NA	NA	NA
ENSG00000099992	0.0404	0.6477	ENSG00000248751	0.1338	1.5591	ENSMUSG00000034412	Tbc1d10	NA	NA	NA	NA
ENSG00000100342	0.9994	0.7457	ENSG00000128335	0.4966	0.7002	ENSMUSG00000090792	AL59218	NA	NA	NA	NA
ENSG00000105835	0.0198	0.3621	ENSG00000229644	0.0225	0.3606	ENSMUSG00000020572	Nampt	NA	NA	NA	NA
ENSG00000107262	0.1588	0.3569	ENSG00000254882	0.1732	0.3924	ENSMUSG00000028416	Bag1	NA	NA	NA	NA
ENSG00000108448	0.0838	0.5862	ENSG00000221926	0.119	0.633	ENSMUSG00000047821	Trim16	NA	NA	NA	NA
ENSG00000108786	0.1926	1.3601	ENSG00000108785	0.1739	1.1091	ENSMUSG00000019301	Hsd17b1	NA	NA	NA	NA
ENSG00000110057	0.0447	1.0908	ENSG00000233094	0.0908	1.0853	ENSMUSG00000036908	Unc93b1	NA	NA	NA	NA
ENSG00000110801	0.0782	0.8189	ENSG00000256950	0.0867	0.7873	ENSMUSG00000029440	Psmd9	NA	NA	NA	NA
ENSG00000111704	0.3075	0.6877	ENSG00000176654	0.2698	0.7895	ENSMUSG00000012396	Nanog	NA	NA	NA	NA
ENSG00000117984	0.1134	1.239	ENSG00000250644	0.2085	1.4862	ENSMUSG00000007891	Ctsd	NA	NA	NA	NA
ENSG00000122674	0.0222	0.5922	ENSG00000146574	0.0221	0.5816	ENSMUSG00000029617	Ccz1	NA	NA	NA	NA
ENSG00000122696	0.0725	1.0203	ENSG00000141437	0.0799	1.0452	ENSMUSG00000045973	Mcart1	NA	NA	NA	NA
ENSG00000122728	0.0453	0.43	ENSG00000147133	0.0224	0.3935	ENSMUSG00000031314	Taf1	NA	NA	NA	NA
ENSG00000123569	0.5274	10.231	ENSG00000101812	0.5636	52.398	ENSMUSG00000048155	1700014	NA	NA	NA	NA
ENSG00000124103	0.2896	0.5535	ENSG00000213714	0.3009	0.5689	ENSMUSG00000027505	1700029	NA	NA	NA	NA
ENSG00000124172	0.0265	0.5064	ENSG00000180389	0.0461	0.6148	ENSMUSG00000016252	Atp5e	NA	NA	NA	NA
ENSG00000125363	0.086	0.1648	ENSG00000099721	0.1226	0.1734	ENSMUSG00000031354	Amelx	NA	NA	NA	NA
ENSG00000126522	0.0303	0.8265	ENSG00000249319	0.1636	1.0436	ENSMUSG00000025533	Asl	NA	NA	NA	NA
ENSG00000127529	0.1664	0.5844	ENSG00000127530	0.182	0.7756	ENSMUSG00000051190	Olfr1356	NA	NA	NA	NA
ENSG00000128185	0.0551	1.2449	ENSG00000183628	0.0492	1.4449	ENSMUSG00000003531	Dgcr6	NA	NA	NA	NA
ENSG00000128524	0.0072	0.5789	ENSG00000226138	0.0579	0.6348	ENSMUSG00000004285	Atp6v1f	NA	NA	NA	NA
ENSG00000131471	0.0956	0.5644	ENSG00000256493	0.13	2.645	ENSMUSG00000019326	Aoc3	NA	NA	NA	NA
ENSG00000133433	0.1518	0.8261	ENSG00000099984	0.1521	0.7774	ENSMUSG00000033318	Gstt2	NA	NA	NA	NA
ENSG00000135175	0.0466	0.6601	ENSG00000122543	0.0561	0.6057	ENSMUSG00000029618	Ocm	NA	NA	NA	NA
ENSG00000136698	0.3748	1.565	ENSG00000152093	0.3778	1.5476	ENSMUSG00000026124	Cfc1	NA	NA	NA	NA
ENSG00000137259	0.0031	3.0941	ENSG00000168274	0.0032	3.1833	ENSMUSG00000069304	Hist1h2a	NA	NA	NA	NA
ENSG00000138297	0.014	0.3946	ENSG00000204152	0.0141	0.4084	ENSMUSG00000013701	Timm23	NA	NA	NA	NA
ENSG00000139675	0.0144	0.3699	ENSG00000135486	0.0013	0.2756	ENSMUSG00000046434	Hnrnpa1	NA	NA	NA	NA
ENSG00000139719	0.0102	0.7471	ENSG00000256861	0.0194	0.8134	ENSMUSG00000029434	Vps33a	NA	NA	NA	NA
ENSG00000143185	0.2886	0.5651	ENSG00000143184	0.2754	0.5931	ENSMUSG00000026573	Xcl1	NA	NA	NA	NA
ENSG00000144589	0.1613	0.5796	ENSG00000254493	0.1613	0.5796	ENSMUSG00000026213	Stk11ip	NA	NA	NA	NA
ENSG00000146066	0.0882	0.8867	ENSG00000175202	0.1512	1.1141	ENSMUSG00000025868	Higd2a	NA	NA	NA	NA
ENSG00000148110	0.0548	0.3931	ENSG00000196312	0.1011	0.3564	ENSMUSG00000038212	Hiatl1	NA	NA	NA	NA
ENSG00000148187	0.0887	0.3449	ENSG00000224236	0.1264	0.3537	ENSMUSG00000026887	Mrrf	NA	NA	NA	NA
ENSG00000148483	0.1611	0.6778	ENSG00000184040	0.1611	0.6778	ENSMUSG00000061531	Fam23a	NA	NA	NA	NA
ENSG00000148824	0.1203	0.9471	ENSG00000254536	0.1831	1.059	ENSMUSG00000039018	Mtg1	NA	NA	NA	NA
ENSG00000149397	0.0463	0.4623	ENSG00000256269	0.0512	0.461	ENSMUSG00000032126	Hmbs	NA	NA	NA	NA
ENSG00000149507	0.3763	0.5534	ENSG00000214788	4.6778	0	ENSMUSG00000055895	Plac1l	NA	NA	NA	NA
ENSG00000151033	0.1529	0.6842	ENSG00000120563	0.1446	0.599	ENSMUSG00000024233	Lyzl1	NA	NA	NA	NA
ENSG00000151967	0.0339	0.4202	ENSG00000250588	0.0339	0.4202	ENSMUSG00000027777	Schip1	NA	NA	NA	NA
ENSG00000155026	0.1749	1.0741	ENSG00000169402	0.1756	1.0806	ENSMUSG00000075569	Rsph10b	NA	NA	NA	NA
ENSG00000155252	0.021	0.3318	ENSG00000249967	0.169	0.587	ENSMUSG00000025178	Pi4k2a	NA	NA	NA	NA
ENSG00000155957	0.089	0.6507	ENSG00000228144	0.1225	0.7746	ENSMUSG00000020225	Tmbim4	NA	NA	NA	NA
ENSG00000160221	0.0636	0.8787	ENSG00000248354	0.193	1.2676	ENSMUSG00000053329	D10Jhu8	NA	NA	NA	NA
ENSG00000162654	0.1916	0.5983	ENSG00000213512	0.211	0.6775	ENSMUSG00000028268	Gbp3	NA	NA	NA	NA
ENSG00000163093	0.0162	0.6174	ENSG00000251569	0.0581	0.7939	ENSMUSG00000063145	Bbs5	NA	NA	NA	NA
ENSG00000163737	0.1952	0.8385	ENSG00000109272	0.2408	0.8454	ENSMUSG00000029373	Pf4	NA	NA	NA	NA
ENSG00000164037	0.2721	0.6854	ENSG00000183704	0.2358	0.5228	ENSMUSG00000050150	Nhedc1	NA	NA	NA	NA
ENSG00000164556	0.1484	0.7589	ENSG00000186973	0.1404	0.5959	ENSMUSG00000049154	Fam183	NA	NA	NA	NA
ENSG00000165874	0.1987	0.4559	ENSG00000122376	0.2372	0.4954	ENSMUSG00000041471	Fam35a	NA	NA	NA	NA
ENSG00000166157	0.3348	0.7113	ENSG00000132958	0.2676	0.774	ENSMUSG00000031481	Tpte	NA	NA	NA	NA
ENSG00000168255	0.4159	1.4844	ENSG00000205236	0.3014	0.9195	ENSMUSG00000006143	2310043	NA	NA	NA	NA
ENSG00000168522	0.0419	0.4926	ENSG00000254673	0.0995	0.6651	ENSMUSG00000015994	Fnta	NA	NA	NA	NA
ENSG00000169249	0.1726	0.9269	ENSG00000212643	0.1829	0.8991	ENSMUSG00000044068	Zrsr1	NA	NA	NA	NA
ENSG00000169953	0.4354	0.9082	ENSG00000172468	0.4354	0.9082	ENSMUSG00000045336	Hsfy2	NA	NA	NA	NA
ENSG00000169991	0.0102	0.469	ENSG00000255275	0.0102	0.469	ENSMUSG00000041025	Iffo2	NA	NA	NA	NA
ENSG00000170276	0.0184	0.3574	ENSG00000254445	0.0184	0.3574	ENSMUSG00000038086	Hspb2	NA	NA	NA	NA
ENSG00000170379	0.1641	0.6271	ENSG00000233768	0.1632	0.631	ENSMUSG00000029851	Fam115c	NA	NA	NA	NA
ENSG00000170667	0.0735	0.9848	ENSG00000105808	0.0722	0.9799	ENSMUSG00000004952	Rasa4	NA	NA	NA	NA
ENSG00000170748	0.0927	1.1689	ENSG00000175718	0.251	1.7192	ENSMUSG00000073894	Rbmxl2	NA	NA	NA	NA
ENSG00000171847	1.1876	1.796	ENSG00000229924	1.0748	1.7047	ENSMUSG00000079112	C86695	NA	NA	NA	NA
ENSG00000171865	0.1396	0.8047	ENSG00000255767	0.0961	2.2551	ENSMUSG00000020630	Rnaseh1	NA	NA	NA	NA
ENSG00000172487	0.1033	0.6926	ENSG00000167822	0.1011	0.6266	ENSMUSG00000075198	Olfr1045	NA	NA	NA	NA
ENSG00000172774	0.1262	0.563	ENSG00000197887	0.1268	0.6096	ENSMUSG00000048356	Olfr1496	NA	NA	NA	NA
ENSG00000173366	0.1671	1.1178	ENSG00000239732	0.1665	1.1142	ENSMUSG00000045322	Tlr9	NA	NA	NA	NA
ENSG00000173546	0.0926	0.6829	ENSG00000235370	0.1431	0.7375	ENSMUSG00000032911	Cspg4	NA	NA	NA	NA
ENSG00000174100	0.1175	0.5337	ENSG00000228782	0.1749	0.5679	ENSMUSG00000018882	Mrpl45	NA	NA	NA	NA
ENSG00000174483	0.0411	0.5821	ENSG00000256349	0.0544	0.6145	ENSMUSG00000006464	Bbs1	NA	NA	NA	NA
ENSG00000175768	0.2478	1.5625	ENSG00000256966	0.5645	1.0444	ENSMUSG00000078713	Tomm5	NA	NA	NA	NA
ENSG00000176055	0.0152	0.361	ENSG00000254059	0.0152	0.361	ENSMUSG00000051098	Mblac2	NA	NA	NA	NA
ENSG00000176231	0.1397	0.7908	ENSG00000171936	0.1373	0.8207	ENSMUSG00000054666	Olfr63	NA	NA	NA	NA
ENSG00000176797	0.1963	1.034	ENSG00000177243	0.1963	1.034	ENSMUSG00000046354	Defb14	NA	NA	NA	NA
ENSG00000177021	0.0997	1.335	ENSG00000254402	0.0997	1.335	ENSMUSG00000033707	Lrrc24	NA	NA	NA	NA
ENSG00000177151	0.0876	0.886	ENSG00000196240	0.0915	0.8948	ENSMUSG00000091809	CT02568	NA	NA	NA	NA

ENSG00000178397	0.5067	0.6388	ENSG00000176007	0.469	0.5716	ENSMUSG00000048910	2810453I	NA	NA	NA	NA
ENSG00000178934	0.1243	1.2791	ENSG00000205076	0.1241	1.3561	ENSMUSG00000053522	Lgals7	NA	NA	NA	NA
ENSG00000179899	0.0403	0.3618	ENSG00000111752	0.0393	0.3661	ENSMUSG00000040669	Phc1	NA	NA	NA	NA
ENSG00000181433	0.8335	1.748	ENSG00000239430	0.5394	1.3378	ENSMUSG00000064016	Gm648	NA	NA	NA	NA
ENSG00000181552	0.338	0.9587	ENSG00000181562	0.4116	0.997	ENSMUSG00000072575	Eddm3b	NA	NA	NA	NA
ENSG00000181625	0.1433	1.0648	ENSG00000132207	0.1433	1.0648	ENSMUSG00000059772	Slx1b	NA	NA	NA	NA
ENSG00000181698	0.1564	0.672	ENSG00000172489	0.1296	0.6439	ENSMUSG00000047969	Olfr1093	NA	NA	NA	NA
ENSG00000182117	0	0.4107	ENSG00000198923	0.0981	0.3591	ENSMUSG00000027133	Nop10	NA	NA	NA	NA
ENSG00000182450	0.0979	0.7344	ENSG00000257069	0.0979	0.7344	ENSMUSG00000024957	Kcnk4	NA	NA	NA	NA
ENSG00000182518	0.9001	88.865	ENSG00000133193	15.273	2.0645	ENSMUSG00000090483	AL80814	NA	NA	NA	NA
ENSG00000182646	0.3411	0.9876	ENSG00000179304	0.3411	0.9876	ENSMUSG00000041353	Tmem29	NA	NA	NA	NA
ENSG00000182774	0.0775	0.7299	ENSG00000184779	0.0775	0.7299	ENSMUSG00000050978	Gm5215	NA	NA	NA	NA
ENSG00000182974	0.0615	0.6637	ENSG00000176299	0.0446	0.6267	ENSMUSG00000045306	Olfr734	NA	NA	NA	NA
ENSG00000183336	0.064	0.5127	ENSG00000169627	0.064	0.5127	ENSMUSG00000047721	Bola2	NA	NA	NA	NA
ENSG00000183558	0	1.1531	ENSG00000203812	0	1.1531	ENSMUSG00000064220	Hist2h2a	NA	NA	NA	NA
ENSG00000183598	0.0034	3.3979	ENSG00000203852	0.0013	1.3199	ENSMUSG00000062808	Hist1h3d	NA	NA	NA	NA
ENSG00000184937	0.0304	0.4853	ENSG00000254922	0.0304	0.5215	ENSMUSG00000016458	Wt1	NA	NA	NA	NA
ENSG00000184945	0.1626	1.1801	ENSG00000185176	0.1585	1.1668	ENSMUSG00000045091	Aqp12	NA	NA	NA	NA
ENSG00000184979	0.1828	0.8055	ENSG00000161133	0.2614	1.2179	ENSMUSG00000030107	Usp18	NA	NA	NA	NA
ENSG00000187372	0.1527	0.6711	ENSG00000120322	0.1484	0.6222	ENSMUSG00000047910	Pcdhb16	NA	NA	NA	NA
ENSG00000187607	0.0967	0.6095	ENSG00000255104	0.0967	0.6095	ENSMUSG00000047342	Zfp286	NA	NA	NA	NA
ENSG00000187721	0.2906	1.0431	ENSG00000077809	0.0136	0.6498	ENSMUSG00000060261	Gtf2i	NA	NA	NA	NA
ENSG00000187951	0.148	0.7682	ENSG00000198826	0.1802	0.603	ENSMUSG00000041219	Arhgap1	NA	NA	NA	NA
ENSG00000188092	0.0153	0.5931	ENSG00000117262	0.0152	0.6031	ENSMUSG00000028096	Gpr89	NA	NA	NA	NA
ENSG00000188529	0	0.2781	ENSG00000215699	0	0.2781	ENSMUSG00000028676	Srsf10	NA	NA	NA	NA
ENSG00000188686	0.0209	0.9015	ENSG00000187786	0.0209	0.9015	ENSMUSG00000034161	Scx	NA	NA	NA	NA
ENSG00000188818	0.3907	1.4664	ENSG00000206077	0.4093	1.4756	ENSMUSG00000069189	Zdhhc11	NA	NA	NA	NA
ENSG00000188831	0.6606	2.0971	ENSG00000187569	0.6607	2.0446	ENSMUSG00000046323	Dppa3	NA	NA	NA	NA
ENSG00000189366	0.2089	0.683	ENSG00000033011	0.1274	0.6055	ENSMUSG00000039427	Alg1	NA	NA	NA	NA
ENSG00000196381	2.4891	1.3754	ENSG00000253375	0.3503	0	ENSMUSG00000074732	Zfp950	NA	NA	NA	NA
ENSG00000196565	0.1401	0.7354	ENSG00000213934	0.1482	0.7347	ENSMUSG00000052217	Hbb-bh1	NA	NA	NA	NA
ENSG00000196826	0.2563	1.0216	ENSG00000242852	0.2563	1.0216	ENSMUSG00000054519	Zfp867	NA	NA	NA	NA
ENSG00000196990	0.0454	1.0865	ENSG00000215611	0.0508	1.0949	ENSMUSG00000009216	Fam163	NA	NA	NA	NA
ENSG00000197479	0.1522	0.6819	ENSG00000120328	0.1557	0.6096	ENSMUSG00000043313	Pcdhb19	NA	NA	NA	NA
ENSG00000198129	0.3821	1.222	ENSG00000186572	0.3821	1.222	ENSMUSG00000044222	Defb13	NA	NA	NA	NA
ENSG00000198225	0.0358	0.2679	ENSG00000088832	0.0131	0.2675	ENSMUSG00000032966	Fkbp1a	NA	NA	NA	NA
ENSG00000199631	NA	NA	ENSG00000252022	NA	NA	ENSMUSG00000084445	SNORD3	NA	NA	NA	NA
ENSG00000199652	NA	NA	ENSG00000251916	NA	NA	ENSMUSG00000064769	U1.32	NA	NA	NA	NA
ENSG00000200418	NA	NA	ENSG00000201229	NA	NA	ENSMUSG00000064880	SNORA6	NA	NA	NA	NA
ENSG00000200536	NA	NA	ENSG00000252665	NA	NA	ENSMUSG00000088335	SNORA2	NA	NA	NA	NA
ENSG00000200972	NA	NA	ENSG00000251984	NA	NA	ENSMUSG00000075930	U5.10	NA	NA	NA	NA
ENSG00000202160	NA	NA	ENSG00000251750	NA	NA	ENSMUSG00000065042	U5.4	NA	NA	NA	NA
ENSG00000202343	NA	NA	ENSG00000199959	NA	NA	ENSMUSG00000088677	SNORA2	NA	NA	NA	NA
ENSG00000203546	0.1331	0.8704	ENSG00000129480	0.0834	1.0615	ENSMUSG00000020956	6530401	NA	NA	NA	NA
ENSG00000204267	0.1442	0.704	ENSG00000250264	0.1949	0.7955	ENSMUSG00000024339	Tap2	NA	NA	NA	NA
ENSG00000204370	0.1011	0.5007	ENSG00000255292	0.247	0.9267	ENSMUSG00000000171	Sdhd	NA	NA	NA	NA
ENSG00000204775	0.0583	0.9853	ENSG00000170727	0.1007	0.9611	ENSMUSG00000022557	Bop1	NA	NA	NA	NA
ENSG00000204933	0.6042	1.3495	ENSG00000204936	0.4067	51.256	ENSMUSG00000052212	Cd177	NA	NA	NA	NA
ENSG00000205030	0.1357	0.7529	ENSG00000186117	0.1209	0.7259	ENSMUSG00000075143	Olfr1157	NA	NA	NA	NA
ENSG00000205571	0.0792	0.5682	ENSG00000172062	0.0792	0.557	ENSMUSG00000021645	Smn1	NA	NA	NA	NA
ENSG00000205595	0.1732	0.7682	ENSG00000109321	0.1732	0.7676	ENSMUSG00000029378	Areg	NA	NA	NA	NA
ENSG00000205863	0.1011	0.6655	ENSG00000240654	0.0909	0.7166	ENSMUSG00000071347	C1qtnf9	NA	NA	NA	NA
ENSG00000207171	NA	NA	ENSG00000201516	NA	NA	ENSMUSG00000065028	SNORA5	NA	NA	NA	NA
ENSG00000211637	0.2643	1.1381	ENSG00000211639	0.2901	1.1617	ENSMUSG00000076939	Iglv3	NA	NA	NA	NA
ENSG00000212608	NA	NA	ENSG00000212624	NA	NA	ENSMUSG00000077497	SNORA2	NA	NA	NA	NA
ENSG00000212993	0.0913	0.7035	ENSG00000204531	0.0731	0.67	ENSMUSG00000024406	Pou5f1	NA	NA	NA	NA
ENSG00000213760	0.0228	0.8032	ENSG00000254870	0.3693	59.482	ENSMUSG00000024403	Atp6v1g	NA	NA	NA	NA
ENSG00000213920	0.092	0.4791	ENSG00000255526	0.2421	0.6176	ENSMUSG00000002329	Mdp1	NA	NA	NA	NA
ENSG00000214338	0.0454	0.4644	ENSG00000255330	0.0454	0.4644	ENSMUSG00000038916	6330407	NA	NA	NA	NA
ENSG00000214753	0.0271	0.3163	ENSG00000234857	0.0406	0.3614	ENSMUSG00000071659	Hnrnpul2	NA	NA	NA	NA
ENSG00000215029	0.2063	0.7382	ENSG00000215046	0.2063	0.7382	ENSMUSG00000058252	1700008I	NA	NA	NA	NA
ENSG00000215616	0.0099	1.1688	ENSG00000197859	0.0553	1.0386	ENSMUSG00000036040	Adamtsl2	NA	NA	NA	NA
ENSG00000215897	0.0894	0.8813	ENSG00000254553	0.1208	0.9625	ENSMUSG00000048485	Zbtb8b	NA	NA	NA	NA
ENSG00000220023	0.1478	1.2345	ENSG00000109536	0.012	0.5737	ENSMUSG00000031590	Frg1	NA	NA	NA	NA
ENSG00000221803	NA	NA	ENSG00000221139	NA	NA	ENSMUSG00000080607	SNORD2	NA	NA	NA	NA
ENSG00000222301	NA	NA	ENSG00000202129	NA	NA	ENSMUSG00000087897	Y_RNA.1	NA	NA	NA	NA
ENSG00000222345	NA	NA	ENSG00000212493	NA	NA	ENSMUSG00000088866	SNORD1	NA	NA	NA	NA
ENSG00000222765	NA	NA	ENSG00000222536	NA	NA	ENSMUSG00000064398	U2.1	NA	NA	NA	NA
ENSG00000224389	0.1449	0.75	ENSG00000244731	0.1444	0.754	ENSMUSG00000073418	C4b	NA	NA	NA	NA
ENSG00000226650	0.0943	0.4081	ENSG00000090889	0.0761	0.4071	ENSMUSG00000034311	Kif4	NA	NA	NA	NA
ENSG00000229631	0.2359	0.6142	ENSG00000196458	0.2204	0.6107	ENSMUSG00000023284	Zfp605	NA	NA	NA	NA
ENSG00000230218	1.4587	6.3578	ENSG00000213793	1.4498	11.321	ENSMUSG00000071284	Zfp738	NA	NA	NA	NA
ENSG00000230425	0.053	0.5262	ENSG00000148484	0.0128	0.703	ENSMUSG00000026727	Rsu1	NA	NA	NA	NA
ENSG00000230567	0.1387	0.8963	ENSG00000235173	0.1373	0.8955	ENSMUSG00000022554	Brp16	NA	NA	NA	NA
ENSG00000230997	0.1111	0.6959	ENSG00000188060	0.1257	0.7462	ENSMUSG00000089687	Rab42-	NA	NA	NA	NA
ENSG00000232268	0.1264	0.566	ENSG00000226288	0.1202	0.5763	ENSMUSG00000073969	Olfr556	NA	NA	NA	NA
ENSG00000232329	0.0888	0.6047	ENSG00000166473	0.2091	0.6251	ENSMUSG00000034416	Pkd1l2	NA	NA	NA	NA
ENSG00000232387	0.1391	0.3309	ENSG00000182628	0.1139	0.3189	ENSMUSG00000020492	Fam33a	NA	NA	NA	NA
ENSG00000232457	0.0846	0.8776	ENSG00000108932	0.091	0.6936	ENSMUSG00000041920	Slc16a6	NA	NA	NA	NA
ENSG00000232629	0.1873	0.6333	ENSG00000179344	0.1566	0.7606	ENSMUSG00000073421	H2-Ab1	NA	NA	NA	NA
ENSG00000232948	0.2538	0.771	ENSG00000233050	0.2538	0.771	ENSMUSG00000075573	Defb47	NA	NA	NA	NA
ENSG00000237102	0.2604	1.1254	ENSG00000125122	0.143	0.6206	ENSMUSG00000041679	Lrrc29	NA	NA	NA	NA
ENSG00000237240	0.3131	0.5449	ENSG00000111665	0.1708	0.3549	ENSMUSG00000023505	Cdca3	NA	NA	NA	NA
ENSG00000238421	NA	NA	ENSG00000201699	NA	NA	ENSMUSG00000065050	U1.57	NA	NA	NA	NA
ENSG00000239789	0.0931	0.7074	ENSG00000249773	0.0931	0.7074	ENSMUSG00000034211	Mrps17	NA	NA	NA	NA
ENSG00000241484	0.1068	1.0702	ENSG00000248405	0.1128	0.9961	ENSMUSG00000078954	Arhgap8	NA	NA	NA	NA
ENSG00000241697	0.0229	0.5435	ENSG00000251349	0.0662	0.7245	ENSMUSG00000028347	Tmeff1	NA	NA	NA	NA
ENSG00000241852	0.2322	0.7072	ENSG00000248235	0.2674	1.0959	ENSMUSG00000044551	9930012	NA	NA	NA	NA
ENSG00000241962	0.0922	0.5994	ENSG00000185414	0.0922	0.5994	ENSMUSG00000026087	Mrpl30	NA	NA	NA	NA
ENSG00000241978	0.1013	0.6212	ENSG00000157654	0.1013	0.6212	ENSMUSG00000089945	AF06478	NA	NA	NA	NA

ENSG00000242616	0.0215	0.4722	ENSG00000182625	0.0518	0.4873	ENSMUSG00000038607	Gng10	NA	NA	NA	NA
ENSG00000243646	0.2133	0.6486	ENSG00000249624	0.2306	0.7616	ENSMUSG00000022969	Il10rb	NA	NA	NA	NA
ENSG00000243708	0.0998	0.6874	ENSG00000168970	0.1027	0.6962	ENSMUSG00000033852	Pla2g4b	NA	NA	NA	NA
ENSG00000243989	0.0796	0.4688	ENSG00000114786	0.0796	0.4688	ENSMUSG00000023262	Acy1	NA	NA	NA	NA
ENSG00000244255	0.1008	0.5857	ENSG00000243649	0.095	0.5693	ENSMUSG00000090231	Cfb	NA	NA	NA	NA
ENSG00000248098	0.0335	0.9146	ENSG00000255730	0.0695	1.1534	ENSMUSG00000060376	Bckdha	NA	NA	NA	NA
ENSG00000248592	0.0142	0.4438	ENSG00000213533	0.0126	0.4299	ENSMUSG00000006526	Tmem11	NA	NA	NA	NA
ENSG00000248919	0.1489	0.8055	ENSG00000106246	0.1489	0.8055	ENSMUSG00000029624	Ptcd1	NA	NA	NA	NA
ENSG00000249139	0.2694	0.7711	ENSG00000101448	0.2496	0.6893	ENSMUSG00000017733	Spinlw1	NA	NA	NA	NA
ENSG00000249398	0.0131	0.3761	ENSG00000145050	0.0131	0.3761	ENSMUSG00000032575	Manf	NA	NA	NA	NA
ENSG00000250021	0.0665	0.8942	ENSG00000242498	0.06	0.8731	ENSMUSG00000039043	2610034	NA	NA	NA	NA
ENSG00000250151	0.2473	1.1512	ENSG00000214021	0.1469	0.584	ENSMUSG00000030276	Ttll3	NA	NA	NA	NA
ENSG00000250254	0.2516	0.5237	ENSG00000164611	0.1782	0.4893	ENSMUSG00000020415	Pttg1	NA	NA	NA	NA
ENSG00000250423	0.5165	0.6115	ENSG00000248857	0.5535	0.4877	ENSMUSG00000091556	RP23-	NA	NA	NA	NA
ENSG00000250424	0.0857	0.7272	ENSG00000240583	0.0347	0.7241	ENSMUSG00000004655	Aqp1	NA	NA	NA	NA
ENSG00000250709	0.4101	0.6787	ENSG00000120669	0.3775	0.6689	ENSMUSG00000027794	Sohlh2	NA	NA	NA	NA
ENSG00000251201	0.1658	0.8058	ENSG00000243414	0.1658	0.8058	ENSMUSG00000056130	Ticam2	NA	NA	NA	NA
ENSG00000251715	NA	NA	ENSG00000201388	NA	NA	ENSMUSG00000089007	SNORA6	NA	NA	NA	NA
ENSG00000252067	NA	NA	ENSG00000223175	NA	NA	ENSMUSG00000084675	U4.32	NA	NA	NA	NA
ENSG00000252237	NA	NA	ENSG00000252501	NA	NA	ENSMUSG00000084581	U4.25	NA	NA	NA	NA
ENSG00000252635	NA	NA	ENSG00000223247	NA	NA	ENSMUSG00000084484	U2.30	NA	NA	NA	NA
ENSG00000252992	NA	NA	ENSG00000252727	NA	NA	ENSMUSG00000088208	SCARNA	NA	NA	NA	NA
ENSG00000253000	NA	NA	ENSG00000253089	NA	NA	ENSMUSG00000088278	U1.164	NA	NA	NA	NA
ENSG00000253047	NA	NA	ENSG00000251704	NA	NA	ENSMUSG00000089052	SNORA4	NA	NA	NA	NA
ENSG00000253085	NA	NA	ENSG00000251898	NA	NA	ENSMUSG00000088151	SCARNA	NA	NA	NA	NA
ENSG00000253094	NA	NA	ENSG00000251846	NA	NA	ENSMUSG00000065295	SNORD3	NA	NA	NA	NA
ENSG00000254085	0.0975	0.6377	ENSG00000176018	0.0975	0.6377	ENSMUSG00000035840	Lysmd3	NA	NA	NA	NA
ENSG00000254413	0.071	0.7044	ENSG00000100288	0.071	0.5978	ENSMUSG00000022617	Chkb	NA	NA	NA	NA
ENSG00000254692	0.0118	0.2804	ENSG00000100926	0.0118	0.2804	ENSMUSG00000002320	Tm9sf1	NA	NA	NA	NA
ENSG00000254709	0.9768	3.6996	ENSG00000211679	0.9378	2.6279	ENSMUSG00000076498	Trbc2	NA	NA	NA	NA
ENSG00000254908	0.0336	0.7917	ENSG00000223953	0.0336	0.7917	ENSMUSG00000079592	C1qtnf5	NA	NA	NA	NA
ENSG00000254979	0.4878	0.7268	ENSG00000186652	0.3235	0.6517	ENSMUSG00000027073	Prg2	NA	NA	NA	NA
ENSG00000254996	0.036	0.3505	ENSG00000131503	0.036	0.3505	ENSMUSG00000024483	Ankhd1	NA	NA	NA	NA
ENSG00000255073	0.0486	0.2779	ENSG00000186660	0.0363	0.2536	ENSMUSG00000024695	Zfp91	NA	NA	NA	NA
ENSG00000255152	0.071	0.4856	ENSG00000204410	0.0617	0.4548	ENSMUSG00000007035	Msh5	NA	NA	NA	NA
ENSG00000255508	0.1068	0.51	ENSG00000149016	0.1351	0.4521	ENSMUSG00000071645	Tut1	NA	NA	NA	NA
ENSG00000255552	0.2287	1.0092	ENSG00000204422	0.1802	0.8107	ENSMUSG00000013766	Ly6g6e	NA	NA	NA	NA
ENSG00000255639	0.2092	1.2606	ENSG00000139180	0.1431	0.6714	ENSMUSG00000000399	Ndufa9	NA	NA	NA	NA
ENSG00000255792	0.2161	0.8179	ENSG00000164919	0.1536	0.572	ENSMUSG00000014313	Cox6c	NA	NA	NA	NA
ENSG00000255835	0.1846	0.7539	ENSG00000143811	0.0377	0.6544	ENSMUSG00000026520	Pycr2	NA	NA	NA	NA
ENSG00000255872	0.0724	0.8662	ENSG00000107338	0.0274	0.8225	ENSMUSG00000044813	Shb	NA	NA	NA	NA
ENSG00000255898	0.0605	0.4251	ENSG00000011009	0.0061	0.2899	ENSMUSG00000028670	Lypla2	NA	NA	NA	NA
ENSG00000256051	0.0872	0.5578	ENSG00000149262	0.0153	0.3892	ENSMUSG00000025133	Ints4	NA	NA	NA	NA
ENSG00000256078	0.2586	0.4261	ENSG00000164808	0.2449	0.5265	ENSMUSG00000041974	2310008	NA	NA	NA	NA
ENSG00000256340	0.168	0.9018	ENSG00000091262	0.1205	0.7748	ENSMUSG00000030834	Abcc6	NA	NA	NA	NA
ENSG00000256409	0.0372	1.029	ENSG00000185324	0.0147	1.0194	ENSMUSG00000033862	Cdk10	NA	NA	NA	NA
ENSG00000256519	0.0671	0.7519	ENSG00000256453	0.0671	0.7519	ENSMUSG00000044595	Dnd1	NA	NA	NA	NA

3.5 Supplementary table of mouse duplicates with human singletons, with results of comparisons of expression patterns and dN/dS information.

A : dN between duplicate 1 and human singleton

B : dS between duplicate 1 and human singleton

C : dN between duplicate 2 and human singleton

D : dS between duplicate 2 and human singleton

Mouse duplicate 1 Ensembl ID	A	B	Mouse duplicate 2 Ensembl ID	C	D	Human singleton Ensembl ID	Human singleton Ensembl name	Spatio-temporal analysis	Spatial-only analysis	Expression vs. No Expression	High quality data
ENSMUSG00000015247	0.094	0.524	ENSMUSG00000015242	0.1668	0.5177	ENSG00000136783	NIPSNAP3	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000021514	0.307	0.5918	ENSMUSG00000058638	0.2846	0.5846	ENSG00000171606	ZNF274	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000023832	0.0683	0.4686	ENSMUSG00000062480	0.0792	0.4796	ENSG00000120437	ACAT2	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000029430	6e-04	0.5846	ENSMUSG00000083649	0.0294	0.563	ENSG00000132341	RAN	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000029472	0.0272	0.3874	ENSMUSG00000073226	0.1707	0.9495	ENSG00000089053	ANAPC5	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000036167	0.1408	0.498	ENSMUSG00000079737	0.4087	0.7412	ENSG00000134283	PPHLN1	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000038633	0.0855	0.702	ENSMUSG00000038768	0.1747	0.6203	ENSG00000143753	DEGS1	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000039224	0.0221	0.5631	ENSMUSG00000000787	0.0069	0.3605	ENSG00000215301	DDX3X	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000046667	0.1354	0.4445	ENSMUSG00000052137	0.1341	0.4478	ENSG00000183808	RBM12B	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000046934	0.0526	0.3928	ENSMUSG00000005683	0.0316	0.4544	ENSG00000062485	CS	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000048164	0.0478	0.3585	ENSMUSG00000028691	0.0285	0.3669	ENSG00000117450	PRDX1	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000048188	0.006	0.4307	ENSMUSG00000006423	0.002	0.434	ENSG00000018610	CXorf56	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000050855	0.4016	1.1449	ENSMUSG00000011427	0.3699	1.4298	ENSG00000197863	ZNF790	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000061633	0.2271	0.4749	ENSMUSG00000031059	0.1345	0.4682	ENSG00000147123	NDUFB11	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000068303	0.2335	1.005	ENSMUSG00000033735	0.1683	0.75	ENSG00000116096	SPR	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000068479	0.002	0.5615	ENSMUSG00000048222	0.002	0.5615	ENSG00000140259	MFAP1	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000068877	0.069	0.5544	ENSMUSG00000068874	0.067	0.5426	ENSG00000143416	SELENBP1	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000079076	0.0633	0.8153	ENSMUSG00000030079	0.001	0.6682	ENSG00000175792	RUVBL1	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000091898	0.0026	0.8398	ENSMUSG00000021909	0.0026	0.8398	ENSG00000114854	TNNC1	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000091964	0.0178	0.405	ENSMUSG00000036948	0.0178	0.405	ENSG00000146826	C7orf43	Overlap	Overlap	Overlap	Overlap
ENSMUSG00000029402	0.0472	1.0884	ENSMUSG00000031998	0.4938	51.591	ENSG00000184209	SNRNP35	Overlap	Overlap	Overlap	Neofunc
ENSMUSG00000052763	0.1127	0.69	ENSMUSG00000045466	1.0231	55.983	ENSG00000170260	ZNF212	Overlap	Subfunct	Subfunct	Overlap
ENSMUSG00000020364	0.0698	0.6024	ENSMUSG00000020335	0.1192	0.7514	ENSG00000169131	ZNF354A	Overlap	Subfunct	Subfunct	Neofunc
ENSMUSG00000063652	0.126	0.577	ENSMUSG00000018900	0.082	0.4159	ENSG00000197375	SLC22A5	Overlap	Subfunct	Subfunct	Both
ENSMUSG00000026401	0.505	0.9201	ENSMUSG00000026399	0.513	0.8915	ENSG00000196352	CD55	Overlap	Neofunc	Neofunc	Neofunc
ENSMUSG00000041828	0.2216	0.6693	ENSMUSG00000020620	0.156	0.6037	ENSG00000141338	ABCA8	Overlap	Neofunc	Neofunc	Neofunc
ENSMUSG00000056978	0.4086	1.2419	ENSMUSG00000050440	0.3358	1.2908	ENSG00000105697	HAMP	Subfunct	Subfunct	Subfunct	Overlap
ENSMUSG00000075269	0.5095	0.1046	ENSMUSG00000047844	0.4911	0.3064	ENSG00000102409	BEX4	Subfunct	Subfunct	Subfunct	Subfunct
ENSMUSG00000020072	0.0967	0.8281	ENSMUSG00000020068	0.125	0.7413	ENSG00000108187	PBLD	Subfunct	Subfunct	Subfunct	Neofunc
ENSMUSG00000028270	0.1929	0.7255	ENSMUSG00000028269	0.2044	0.6253	ENSG00000162645	GBP2	Neofunc	Overlap	Overlap	Neofunc
ENSMUSG00000038112	0.2284	0.7017	ENSMUSG00000023186	0.2296	0.6665	ENSG00000110002	VWA5A	Neofunc	Overlap	Overlap	Neofunc
ENSMUSG00000024174	0.1762	0.6641	ENSMUSG00000029676	0.1519	0.6757	ENSG00000128513	POT1	Neofunc	Neofunc	Neofunc	Overlap
ENSMUSG00000000290	0.1016	1.1666	ENSMUSG00000000157	0.3197	1.2522	ENSG00000160255	ITGB2	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000005078	0.0093	0.5933	ENSMUSG00000056197	0.193	0.7069	ENSG00000050130	JKAMP	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000021327	0.1846	0.4827	ENSMUSG00000054931	0.152	0.5446	ENSG00000187626	ZKSCAN4	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000021417	0.1493	0.6274	ENSMUSG00000021416	0.2112	0.6961	ENSG00000198721	PECI	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000025808	0.4428	0.9418	ENSMUSG00000056018	0.5023	0.8066	ENSG00000216937	CCDC7	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000030048	0.7612	48.971	ENSMUSG00000030050	0.2435	0.7953	ENSG00000169605	GKN1	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000031400	0.0296	0.864	ENSMUSG00000089992	0.0638	0.9123	ENSG00000160211	G6PD	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000035804	0.1163	0.9531	ENSMUSG00000000215	0.1025	0.8414	ENSG00000254647	INS	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000036138	0.0832	0.5145	ENSMUSG00000010651	0.0789	0.5	ENSG00000060971	ACAA1	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000039337	0.2975	1.2261	ENSMUSG00000039329	0.4691	0.9849	ENSG00000182459	TEX19	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000041718	0.0706	0.5135	ENSMUSG00000031286	0.0583	0.5779	ENSG00000101901	ALG13	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000041750	0.2645	0.6448	ENSMUSG00000028076	0.2578	0.6345	ENSG00000158473	CD1D	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000046805	0.1498	0.6461	ENSMUSG00000040065	0.2685	0.7781	ENSG00000197629	MPEG1	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000048398	0.0877	0.5713	ENSMUSG00000042363	0.0028	0.3629	ENSG00000119862	AC008074.	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000051242	0.1292	0.6414	ENSMUSG00000045062	0.1268	0.6189	ENSG00000081818	PCDHB4	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000054988	0.0397	0.6855	ENSMUSG00000049115	0.0293	0.6039	ENSG00000144891	AGTR1	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000066639	0.0997	0.5142	ENSMUSG00000022280	0.0316	0.5036	ENSG00000034677	RNF19A	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000071713	0.3067	0.8166	ENSMUSG00000071714	0.3104	0.8529	ENSG00000100368	CSF2RB	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000072878	0.2729	0.9101	ENSMUSG00000016619	0.1221	0.5667	ENSG00000093000	NUP50	Neofunc	Neofunc	Neofunc	Neofunc
ENSMUSG00000040950	0.3679	0.9188	ENSMUSG00000000318	0.397	0.8705	ENSG00000132514	CLEC10A	Neofunc	Neofunc	Neofunc	Both
ENSMUSG00000025804	0.1246	1.1303	ENSMUSG00000064039	0.289	1.0696	ENSG00000163823	CCR1	Neofunc	Both	Both	Neofunc
ENSMUSG00000036814	0.0385	0.7132	ENSMUSG00000025243	0.0702	0.7274	ENSG00000163817	SLC6A20	Neofunc	Both	Both	Neofunc

ENSMUSG00000040749	0.0118	0.3519	ENSMUSG00000036840	0.0017	0.3295	ENSG00000196470	SIAH1	Neofunc	Both	Both	Neofunc
ENSMUSG00000042157	0.0958	0.7141	ENSMUSG00000042212	0.1512	0.5951	ENSG00000159516	SPRR2G	Neofunc	Both	Both	Neofunc
ENSMUSG00000029359	0.0134	0.8091	ENSMUSG00000055826	0.2589	3.8079	ENSG00000088992	TESC	Neofunc	Both	Both	Both
ENSMUSG00000040584	0.0742	0.461	ENSMUSG00000028970	0.1185	0.5183	ENSG00000085563	ABCB1	Neofunc	Both	Both	Both
ENSMUSG00000023341	0.1679	0.9178	ENSMUSG00000000386	0.2127	1.0657	ENSG00000157601	MX1	Both	Subfunct	Subfunct	Both
ENSMUSG00000029802	0.1147	0.5497	ENSMUSG00000029299	0.3363	0.6195	ENSG00000118777	ABCG2	Both	Neofunc	Neofunc	Neofunc
ENSMUSG00000046157	0.0198	0.9522	ENSMUSG00000056219	0.025	0.9525	ENSG00000198133	TMEM229B	Both	Neofunc	Neofunc	Neofunc
ENSMUSG00000042854	0.074	0.7401	ENSMUSG00000039725	0.078	0.7318	ENSG00000172315	TP53RK	Both	Both	Both	Overlap
ENSMUSG00000022754	0.2506	0.7249	ENSMUSG00000046748	0.4381	0.6373	ENSG00000181458	TMEM45A	Both	Both	Both	Neofunc
ENSMUSG00000027484	0.3379	0.5012	ENSMUSG00000027483	0.2038	0.438	ENSG00000198183	PLUNC	Both	Both	Both	Neofunc
ENSMUSG00000036136	0.9511	42.335	ENSMUSG00000050105	0.1228	0.6784	ENSG00000197245	GRRP1	Both	Both	Both	Neofunc
ENSMUSG00000039264	0.3183	0.9022	ENSMUSG00000043505	0.3484	0.868	ENSG00000196329	GIMAP5	Both	Both	Both	Neofunc
ENSMUSG00000040364	0.183	2.0466	ENSMUSG00000055978	0.1231	1.2381	ENSG00000176920	FUT2	Both	Both	Both	Neofunc
ENSMUSG00000060459	0.3021	0.6163	ENSMUSG00000022875	0.2982	0.5968	ENSG00000113889	KNG1	Both	Both	Both	Neofunc
ENSMUSG00000039364	1.5135	1.2517	ENSMUSG00000025165	0.5878	1.3018	ENSG00000141574	SECTM1	Both	Both	Both	Both
ENSMUSG00000042508	0.0236	0.3258	ENSMUSG00000058670	0.2362	0.4938	ENSG00000135164	DMTF1	NA	Overlap	Overlap	Overlap
ENSMUSG00000023806	0.2629	0.644	ENSMUSG00000073471	0.2645	0.6157	ENSG00000130363	RSPH3	Overlap	Overlap	Overlap	NA
ENSMUSG00000025287	0.1002	0.4321	ENSMUSG00000047565	0.112	0.4417	ENSG00000123130	ACOT9	Overlap	Overlap	Overlap	NA
ENSMUSG00000025762	0.1383	0.4914	ENSMUSG00000037814	0.0687	0.5126	ENSG00000138709	LARP1B	Overlap	Overlap	Overlap	NA
ENSMUSG00000026492	0.3554	0.6448	ENSMUSG00000091277	0.3543	0.6433	ENSG00000162851	TFB2M	Overlap	Overlap	Overlap	NA
ENSMUSG00000027708	0.0035	0.2105	ENSMUSG00000074910	0.0069	0.2203	ENSG00000043093	DCUN1D1	Overlap	Overlap	Overlap	NA
ENSMUSG00000027882	0.0413	0.5461	ENSMUSG00000071640	0.0789	0.649	ENSG00000116266	STXBP3	Overlap	Overlap	Overlap	NA
ENSMUSG00000030735	0.0361	0.5802	ENSMUSG00000073838	0.0349	0.5743	ENSG00000178952	TUFM	Overlap	Overlap	Overlap	NA
ENSMUSG00000032375	0.09	0.3488	ENSMUSG00000053040	0.1133	0.355	ENSG00000138613	APH1B	Overlap	Overlap	Overlap	NA
ENSMUSG00000032566	0.24	1.3393	ENSMUSG00000032565	0.1245	0.5937	ENSG00000198585	NUDT16	Overlap	Overlap	Overlap	NA
ENSMUSG00000035337	0.0207	0.4924	ENSMUSG00000022111	0.0081	0.4903	ENSG00000118939	UCHL3	Overlap	Overlap	Overlap	NA
ENSMUSG00000041852	0.0375	0.3626	ENSMUSG00000071262	0.1439	0.4276	ENSG00000100207	TCF20	Overlap	Overlap	Overlap	NA
ENSMUSG00000050122	0.2184	0.5339	ENSMUSG00000026115	0.245	0.7085	ENSG00000168658	VWA3B	Overlap	Overlap	Overlap	NA
ENSMUSG00000053007	0.0121	0.4342	ENSMUSG00000090982	0.0305	0.3606	ENSG00000146592	CREB5	Overlap	Overlap	Overlap	NA
ENSMUSG00000063888	0.0911	0.484	ENSMUSG00000058101	0.1335	0.4328	ENSG00000146223	RPL7L1	Overlap	Overlap	Overlap	NA
ENSMUSG00000064065	2.643	7.0095	ENSMUSG00000015202	0.0402	0.649	ENSG00000153721	CNKSR3	Overlap	Overlap	Overlap	NA
ENSMUSG00000068262	0.0129	0.7661	ENSMUSG00000060036	0.0075	0.7726	ENSG00000100316	RPL3	Overlap	Overlap	Overlap	NA
ENSMUSG00000068417	0.1061	0.4683	ENSMUSG00000021871	0.0926	0.4991	ENSG00000198805	PNP	Overlap	Overlap	Overlap	NA
ENSMUSG00000078157	0.0611	1.6548	ENSMUSG00000043683	0.0468	1.648	ENSG00000141965	FEM1A	Overlap	Overlap	Overlap	NA
ENSMUSG00000078776	0.212	0.8699	ENSMUSG00000047730	0.1201	0.7447	ENSG00000090920	FCGBP	Overlap	Overlap	Overlap	NA
ENSMUSG00000086784	0.0955	0.7899	ENSMUSG00000052605	0.1401	1.2487	ENSG00000063241	ISOC2	Overlap	Overlap	Overlap	NA
ENSMUSG00000090115	0.05	0.4256	ENSMUSG00000023984	0.05	0.4256	ENSG00000164663	USP49	Overlap	Overlap	Overlap	NA
ENSMUSG00000092005	0.141	0.6555	ENSMUSG00000055172	0.1324	0.6544	ENSG00000159403	C1R	Overlap	Overlap	Overlap	NA
ENSMUSG00000029682	0.321	0.7116	ENSMUSG00000029678	0.309	0.9439	ENSG00000106304	SPAM1	Overlap	Neofunc	Neofunc	NA
ENSMUSG00000060204	0.05	0.6221	ENSMUSG00000029219	0.0757	0.7506	ENSG00000145248	SLC10A4	Overlap	Neofunc	Neofunc	NA
ENSMUSG00000069922	0.2303	0.6799	ENSMUSG00000062181	0.2304	0.6866	ENSG00000172828	CES3	Overlap	Neofunc	Neofunc	NA
ENSMUSG00000042647	0.1569	0.6456	ENSMUSG00000029456	0.1201	0.6668	ENSG00000111271	ACAD10	Subfunct	Subfunct	Subfunct	NA
ENSMUSG00000024571	0.0703	1.0444	ENSMUSG00000046000	0.0644	1.1144	ENSG00000156269	NAA11	Neofunc	Neofunc	Neofunc	NA
ENSMUSG00000026937	18.798	1.9581	ENSMUSG00000036449	0.1977	0.7903	ENSG00000204001	LCN8	Neofunc	Neofunc	Neofunc	NA
ENSMUSG00000037169	0.0766	0.9617	ENSMUSG00000044597	0.2425	1.2428	ENSG00000134323	MYCN	Neofunc	Neofunc	Neofunc	NA
ENSMUSG00000041754	1.3132	0.5284	ENSMUSG00000042265	0.5242	0.6309	ENSG00000124731	TREM1	Neofunc	Neofunc	Neofunc	NA
ENSMUSG00000048602	0.1719	0.5684	ENSMUSG00000034543	0.0511	0.5054	ENSG00000133422	MORC2	Neofunc	Neofunc	Neofunc	NA
ENSMUSG00000049103	0.2011	0.6479	ENSMUSG00000079227	0.2108	0.6451	ENSG00000121807	CCR2	Neofunc	Neofunc	Neofunc	NA
ENSMUSG00000049676	0.33	1.2529	ENSMUSG00000049123	0.3287	1.2672	ENSG00000099338	CATSPER	Neofunc	Neofunc	Neofunc	NA
ENSMUSG00000054672	0.3586	2.2237	ENSMUSG00000025461	0.2377	1.1204	ENSG00000214279	RP11-	Neofunc	Neofunc	Neofunc	NA
ENSMUSG00000068349	0.509	1.2388	ENSMUSG00000068600	0.5099	1.3128	ENSG00000104499	GML	Neofunc	Neofunc	Neofunc	NA
ENSMUSG00000074127	0.466	1.1993	ENSMUSG00000035785	0.5365	1.4982	ENSG00000140932	CMTM2	Neofunc	Neofunc	Neofunc	NA
ENSMUSG00000074734	0.2801	0.7268	ENSMUSG00000009596	0.4661	0.7452	ENSG00000102387	TAF7L	Both	Both	Both	NA
ENSMUSG00000032554	0.1778	0.6444	ENSMUSG00000090639	0.1859	0.6969	ENSG00000091513	TF	NA	Overlap	Overlap	NA
ENSMUSG00000062488	0.2974	0.8087	ENSMUSG00000074896	0.2997	0.8299	ENSG00000119917	IFIT3	NA	Overlap	Overlap	NA
ENSMUSG00000091002	0.1315	0.5817	ENSMUSG00000091965	0.1315	0.5817	ENSG00000176769	TCERG1L	NA	Overlap	Overlap	NA
ENSMUSG00000029917	0.1237	0.4693	ENSMUSG00000058400	0.0893	0.5227	ENSG00000186867	QRFPR	NA	Neofunc	Neofunc	NA
ENSMUSG00000049230	0.0598	0.4044	ENSMUSG00000027201	0.0422	0.3802	ENSG00000104177	MYEF2	Overlap	NA	NA	NA
ENSMUSG00000008690	0.1133	0.7921	ENSMUSG00000090957	0.1051	0.8007	ENSG00000025770	NCAPH2	NA	NA	NA	NA
ENSMUSG00000009588	0.2283	0.7683	ENSMUSG00000078586	0.302	0.7724	ENSG00000070526	ST6GALNA	NA	NA	NA	NA
ENSMUSG00000012422	0.0127	0.29	ENSMUSG00000073376	0.0423	0.2576	ENSG00000174695	TMEM167A	NA	NA	NA	NA
ENSMUSG00000015217	0.011	0.4757	ENSMUSG00000062588	0.0133	0.4665	ENSG00000029993	HMGB3	NA	NA	NA	NA
ENSMUSG00000015672	0.1591	0.5563	ENSMUSG00000057223	0.2609	0.6947	ENSG00000106591	MRPL32	NA	NA	NA	NA
ENSMUSG00000020027	0.0286	0.3213	ENSMUSG00000050974	0.0312	0.3355	ENSG00000120833	SOCS2	NA	NA	NA	NA
ENSMUSG00000020295	0.2735	2.6122	ENSMUSG00000073063	0.1464	1.7951	ENSG00000086506	HBQ1	NA	NA	NA	NA
ENSMUSG00000021243	0.0089	0.6202	ENSMUSG00000070308	0.0757	0.4757	ENSG00000119616	FCF1	NA	NA	NA	NA
ENSMUSG00000022674	0.0059	0.254	ENSMUSG00000060811	0.0652	0.2353	ENSG00000169139	UBE2V2	NA	NA	NA	NA
ENSMUSG00000022863	0.0292	0.3323	ENSMUSG00000044645	0.0292	0.3323	ENSG00000154640	BTG3	NA	NA	NA	NA
ENSMUSG00000023210	0.4635	3.8326	ENSMUSG00000069080	16.355	0	ENSG00000148386	LCN9	NA	NA	NA	NA
ENSMUSG00000026063	0.2629	0.8787	ENSMUSG00000042433	0.2596	0.6712	ENSG00000080572	CXorf41	NA	NA	NA	NA
ENSMUSG00000026673	0.2204	0.2971	ENSMUSG00000073494	0.232	0.3396	ENSG00000198574	SH2D1B	NA	NA	NA	NA
ENSMUSG00000027968	0.1035	0.9216	ENSMUSG00000066107	0.1424	1.3406	ENSG00000174720	LARP7	NA	NA	NA	NA
ENSMUSG00000028333	0.0725	0.3689	ENSMUSG00000090323	0.149	0.3279	ENSG00000136938	ANP32B	NA	NA	NA	NA
ENSMUSG00000029319	0.1382	0.6737	ENSMUSG00000091408	0.1464	0.6405	ENSG00000173085	COQ2	NA	NA	NA	NA
ENSMUSG00000029394	0.008	0.8123	ENSMUSG00000078154	0.008	0.8123	ENSG00000111328	CDK2AP1	NA	NA	NA	NA
ENSMUSG00000031181	2.4725	5.9767	ENSMUSG00000079536	2.0392	5.881	ENSG00000184033	CTAG1B	NA	NA	NA	NA
ENSMUSG00000032595	0.1817	0.6826	ENSMUSG00000079323	0.3552	0.7102	ENSG00000187492	CDHR4	NA	NA	NA	NA
ENSMUSG00000032889	0.0941	0.6914	ENSMUSG00000044795	0.0916	0.6934	ENSG00000182224	CYB5D1	NA	NA	NA	NA
ENSMUSG00000033405	0.0676	0.7196	ENSMUSG00000037603	0.0782	0.7933	ENSG00000136159	NUDT15	NA	NA	NA	NA
ENSMUSG00000033450	0.1962	0.713	ENSMUSG00000079571	0.1962	0.713	ENSG00000164691	TAGAP	NA	NA	NA	NA
ENSMUSG00000034674	0.0665	0.8138	ENSMUSG00000047347	0.0852	0.9465	ENSG00000139372	TDG	NA	NA	NA	NA
ENSMUSG00000034953	0.0867	0.821	ENSMUSG00000073083	0.0867	0.821	ENSG00000151327	FAM177A1	NA	NA	NA	NA
ENSMUSG00000035367	0.1676	0.5763	ENSMUSG00000075359	0.1683	0.5689	ENSG00000178966	RMI1	NA	NA	NA	NA
ENSMUSG00000036427	0.0596	0.7309	ENSMUSG00000043192	0.0765	0.8172	ENSG00000105220	GPI	NA	NA	NA	NA
ENSMUSG00000036850	0.1405	2.4291	ENSMUSG00000091233	0.1733	2.6175	ENSG00000182154	MRPL41	NA	NA	NA	NA
ENSMUSG00000037772	0.1036	1.1504	ENSMUSG00000075279	0.1036	1.1504	ENSG00000214026	MRPL23	NA	NA	NA	NA
ENSMUSG00000038064	0.1606	0.6618	ENSMUSG00000061974	0.1813	0.6611	ENSG00000177300	CLDN22	NA	NA	NA	NA
ENSMUSG00000038218	0.1163	0.791	ENSMUSG00000038209	0.12	0.5635	ENSG00000179914	ITLN1	NA	NA	NA	NA
ENSMUSG00000038646	0.0667	0.6924	ENSMUSG00000048648	0.0667	0.6924	ENSG00000169612	FAM103A1	NA	NA	NA	NA
ENSMUSG00000039159	0	0.2988	ENSMUSG00000074903	0.005	0.302	ENSG00000186591	UBE2H	NA	NA	NA	NA

ENSMUSG00000040824	0	1.2663	ENSMUSG00000062678	0.0106	1.2077	ENSG00000125743	SNRPD2	NA	NA	NA	NA
ENSMUSG00000041620	0.3313	0.6028	ENSMUSG00000043089	0.3128	0.6269	ENSG00000196611	MMP1	NA	NA	NA	NA
ENSMUSG00000042165	0.0659	0.8952	ENSMUSG00000039041	0.0159	0.7488	ENSG00000130706	ADRM1	NA	NA	NA	NA
ENSMUSG00000042796	0.0422	0.781	ENSMUSG00000045392	0.0596	0.7294	ENSG00000174937	OR5M3	NA	NA	NA	NA
ENSMUSG00000042870	0.0561	0.6503	ENSMUSG00000037827	0.0561	0.6503	ENSG00000100284	TOM1	NA	NA	NA	NA
ENSMUSG00000043051	0.3439	0.8145	ENSMUSG00000079751	0.4246	0.7408	ENSG00000162946	DISC1	NA	NA	NA	NA
ENSMUSG00000043424	0.0174	0.2695	ENSMUSG00000027236	0.0174	0.2695	ENSG00000104131	EIF3J	NA	NA	NA	NA
ENSMUSG00000045126	0.12	0.6887	ENSMUSG00000048456	0.1129	0.7745	ENSG00000172362	OR5B12	NA	NA	NA	NA
ENSMUSG00000045609	0.2078	0.6382	ENSMUSG00000040621	0.2118	0.6609	ENSG00000046647	GEMIN8	NA	NA	NA	NA
ENSMUSG00000046643	0.1482	0.7119	ENSMUSG00000049456	0.1794	0.6986	ENSG00000196266	OR10J3	NA	NA	NA	NA
ENSMUSG00000047053	0.2172	0.3961	ENSMUSG00000043282	0.1961	0.4063	ENSG00000203730	TEDDM1	NA	NA	NA	NA
ENSMUSG00000047323	0.0463	0.6701	ENSMUSG00000056820	0.0463	0.6701	ENSG00000116918	TSNAX	NA	NA	NA	NA
ENSMUSG00000049233	0.1011	0.3127	ENSMUSG00000079508	0.1011	0.3127	ENSG00000184831	APOO	NA	NA	NA	NA
ENSMUSG00000049249	0.1431	1.006	ENSMUSG00000054312	0.0459	0.9408	ENSG00000187145	MRPS21	NA	NA	NA	NA
ENSMUSG00000050251	0.0841	0.6055	ENSMUSG00000052818	0.0785	0.6061	ENSG00000185821	OR6C76	NA	NA	NA	NA
ENSMUSG00000050539	0.0813	0.71	ENSMUSG00000058075	0.086	0.744	ENSG00000255713	OR4D2	NA	NA	NA	NA
ENSMUSG00000050628	0.0409	0.5317	ENSMUSG00000047370	0.0437	0.5364	ENSG00000185262	FAM100B	NA	NA	NA	NA
ENSMUSG00000050884	0.1523	0.9319	ENSMUSG00000066910	0.139	0.9371	ENSG00000170920	OR7G3	NA	NA	NA	NA
ENSMUSG00000051133	0.1281	1.0013	ENSMUSG00000059534	0.0842	0.9744	ENSG00000184076	UQCR10	NA	NA	NA	NA
ENSMUSG00000053178	0.1541	0.4569	ENSMUSG00000040429	0.1582	0.4445	ENSG00000127989	MTERF	NA	NA	NA	NA
ENSMUSG00000053338	0.3738	0.8986	ENSMUSG00000078814	0.4423	1.3265	ENSG00000248385	TARM1	NA	NA	NA	NA
ENSMUSG00000055124	0.0992	0.6688	ENSMUSG00000047163	0.0801	0.5383	ENSG00000176239	OR51B6	NA	NA	NA	NA
ENSMUSG00000055452	0.1811	0.6992	ENSMUSG00000075600	0.1799	0.7047	ENSG00000014164	ZC3H3	NA	NA	NA	NA
ENSMUSG00000056782	0.1109	0.5324	ENSMUSG00000063582	0.0543	0.5675	ENSG00000180988	OR52N2	NA	NA	NA	NA
ENSMUSG00000056822	0.096	1.1071	ENSMUSG00000061361	0.0937	1.0506	ENSG00000196071	OR2L13	NA	NA	NA	NA
ENSMUSG00000056853	0.073	0.5229	ENSMUSG00000059762	0.0569	0.5303	ENSG00000179615	OR2AP1	NA	NA	NA	NA
ENSMUSG00000057403	0.0874	0.446	ENSMUSG00000057151	0.0748	0.4951	ENSG00000188324	OR6C6	NA	NA	NA	NA
ENSMUSG00000057657	0.0062	0.4237	ENSMUSG00000069117	0.0499	0.4311	ENSG00000231500	RPS18	NA	NA	NA	NA
ENSMUSG00000057762	0.1313	0.4068	ENSMUSG00000031146	0.1308	0.3826	ENSG00000102007	PLP2	NA	NA	NA	NA
ENSMUSG00000058084	0.0668	0.6383	ENSMUSG00000059862	0.0641	0.6015	ENSG00000170605	OR9K2	NA	NA	NA	NA
ENSMUSG00000058443	0	0.5791	ENSMUSG00000008682	0	0.5791	ENSG00000147403	RPL10	NA	NA	NA	NA
ENSMUSG00000058662	0.1228	0.7506	ENSMUSG00000061626	0.1168	0.6785	ENSG00000171944	OR52A5	NA	NA	NA	NA
ENSMUSG00000059069	0.0668	0.463	ENSMUSG00000057179	0.0768	0.4819	ENSG00000176198	OR11H4	NA	NA	NA	NA
ENSMUSG00000059280	0.1695	0.5266	ENSMUSG00000059305	0.1745	0.4888	ENSG00000169575	VPREB1	NA	NA	NA	NA
ENSMUSG00000059301	0.0574	0.3763	ENSMUSG00000034343	0.0152	0.3045	ENSG00000184182	UBE2F	NA	NA	NA	NA
ENSMUSG00000059503	0.1233	0.5311	ENSMUSG00000066672	0.097	0.5049	ENSG00000186400	OR10X1	NA	NA	NA	NA
ENSMUSG00000059873	0.0783	0.5579	ENSMUSG00000057207	0.0762	0.5636	ENSG00000255223	OR5M11	NA	NA	NA	NA
ENSMUSG00000060105	0.1265	0.5509	ENSMUSG00000073923	0.1015	0.5917	ENSG00000181023	OR56B1	NA	NA	NA	NA
ENSMUSG00000060422	0.062	0.8764	ENSMUSG00000061704	0.0708	0.8749	ENSG00000150269	OR5M9	NA	NA	NA	NA
ENSMUSG00000060503	0.0847	0.6598	ENSMUSG00000062987	0.0879	0.6761	ENSG00000166368	OR2D2	NA	NA	NA	NA
ENSMUSG00000060640	0.0747	0.744	ENSMUSG00000068385	0.0911	0.7248	ENSG00000169208	OR10G3	NA	NA	NA	NA
ENSMUSG00000060680	0.0203	0.2612	ENSMUSG00000090841	0	0.2779	ENSG00000092841	MYL6	NA	NA	NA	NA
ENSMUSG00000061474	0.0748	0.5302	ENSMUSG00000021631	0.0744	0.5296	ENSG00000134056	MRPS36	NA	NA	NA	NA
ENSMUSG00000061479	0.0154	0.8185	ENSMUSG00000071273	0.0364	0.8205	ENSG00000077312	SNRPA	NA	NA	NA	NA
ENSMUSG00000061619	0.0371	0.6881	ENSMUSG00000073131	0.0184	0.7479	ENSG00000160131	VMA21	NA	NA	NA	NA
ENSMUSG00000061961	0.1255	0.6007	ENSMUSG00000059134	0.1163	0.6107	ENSG00000184954	OR6C70	NA	NA	NA	NA
ENSMUSG00000062093	0.0139	0.4737	ENSMUSG00000011257	0.0109	0.4273	ENSG00000090621	PABPC4	NA	NA	NA	NA
ENSMUSG00000062103	0.0799	0.616	ENSMUSG00000064333	0.0999	0.6333	ENSG00000197263	OR8D2	NA	NA	NA	NA
ENSMUSG00000062582	0	0.3258	ENSMUSG00000058600	0	0.2707	ENSG00000156482	RPL30	NA	NA	NA	NA
ENSMUSG00000063120	0.1558	0.6134	ENSMUSG00000063764	0.1437	0.5974	ENSG00000182334	OR5P3	NA	NA	NA	NA
ENSMUSG00000063549	0.0897	1.1521	ENSMUSG00000060030	0.0991	1.3341	ENSG00000238243	OR2W3	NA	NA	NA	NA
ENSMUSG00000063867	0.0663	0.4281	ENSMUSG00000063106	0.0552	0.4472	ENSG00000255582	OR10G2	NA	NA	NA	NA
ENSMUSG00000064129	0.5523	0.8836	ENSMUSG00000061392	0.5456	0.888	ENSG00000188408	MAGEB5	NA	NA	NA	NA
ENSMUSG00000064245	0.0889	0.5927	ENSMUSG00000059414	0.0848	0.5982	ENSG00000205330	OR6C1	NA	NA	NA	NA
ENSMUSG00000064317	0.0118	2.1374	ENSMUSG00000035215	0.0118	2.1374	ENSG00000130332	LSM7	NA	NA	NA	NA
ENSMUSG00000064326	0.2006	1.2837	ENSMUSG00000059830	0.2402	1.4364	ENSG00000184990	SIVA1	NA	NA	NA	NA
ENSMUSG00000064500	NA	NA	ENSMUSG00000077755	NA	NA	ENSG00000200969	SNORD95.	NA	NA	NA	NA
ENSMUSG00000064665	NA	NA	ENSMUSG00000089072	NA	NA	ENSG00000201133	SNORA4.1	NA	NA	NA	NA
ENSMUSG00000064738	NA	NA	ENSMUSG00000088702	NA	NA	ENSG00000194297	U1.1	NA	NA	NA	NA
ENSMUSG00000064871	NA	NA	ENSMUSG00000065853	NA	NA	ENSG00000212615	SNORD58.	NA	NA	NA	NA
ENSMUSG00000065151	NA	NA	ENSMUSG00000065088	NA	NA	ENSG00000207419	SNORA67.	NA	NA	NA	NA
ENSMUSG00000065200	NA	NA	ENSMUSG00000064671	NA	NA	ENSG00000201302	SNORA65	NA	NA	NA	NA
ENSMUSG00000065232	NA	NA	ENSMUSG00000084606	NA	NA	ENSG00000222238	U2.5	NA	NA	NA	NA
ENSMUSG00000065258	NA	NA	ENSMUSG00000064816	NA	NA	ENSG00000206611	SNORD24	NA	NA	NA	NA
ENSMUSG00000065283	NA	NA	ENSMUSG00000065651	NA	NA	ENSG00000206898	SNORA51.	NA	NA	NA	NA
ENSMUSG00000065392	NA	NA	ENSMUSG00000088306	NA	NA	ENSG00000206874	SNORD26	NA	NA	NA	NA
ENSMUSG00000065629	NA	NA	ENSMUSG00000080664	NA	NA	ENSG00000252981	U3.78	NA	NA	NA	NA
ENSMUSG00000065634	NA	NA	ENSMUSG00000077337	NA	NA	ENSG00000207130	SNORA24.	NA	NA	NA	NA
ENSMUSG00000065794	NA	NA	ENSMUSG00000064613	NA	NA	ENSG00000201493	U1.46	NA	NA	NA	NA
ENSMUSG00000065947	0.2005	18.596	ENSMUSG00000067736	0.2005	18.584	ENSG00000212907	MT-ND4L	NA	NA	NA	NA
ENSMUSG00000066252	0.0332	0.5417	ENSMUSG00000074768	0.0296	0.5249	ENSG00000145692	BHMT	NA	NA	NA	NA
ENSMUSG00000066442	0.0822	0.5168	ENSMUSG00000079427	0.082	0.5089	ENSG00000136371	MTHFS	NA	NA	NA	NA
ENSMUSG00000067038	0	0.4521	ENSMUSG00000078087	0	0.4521	ENSG00000112306	RPS12	NA	NA	NA	NA
ENSMUSG00000067063	0.1404	1.4241	ENSMUSG00000033307	0.0487	1.239	ENSG00000240972	MIF	NA	NA	NA	NA
ENSMUSG00000067156	0.2945	1.1289	ENSMUSG00000042156	0.2103	0.8269	ENSG00000134874	DZIP1	NA	NA	NA	NA
ENSMUSG00000068537	0.1855	0.4771	ENSMUSG00000024248	0.0849	0.368	ENSG00000115944	COX7A2L	NA	NA	NA	NA
ENSMUSG00000068749	0	0.2505	ENSMUSG00000050490	0.0081	0.2681	ENSG00000143106	PSMA5	NA	NA	NA	NA
ENSMUSG00000068806	0.0985	0.3972	ENSMUSG00000045148	0.1039	0.3885	ENSG00000221954	OR4C12	NA	NA	NA	NA
ENSMUSG00000069671	0.0067	0.224	ENSMUSG00000075259	0.2094	0.4917	ENSG00000188580	NKAIN2	NA	NA	NA	NA
ENSMUSG00000070035	0.0256	0.4556	ENSMUSG00000022992	0.0229	0.4179	ENSG00000139620	C12orf41	NA	NA	NA	NA
ENSMUSG00000070263	NA	NA	ENSMUSG00000065658	NA	NA	ENSG00000206863	U5.12	NA	NA	NA	NA
ENSMUSG00000070390	0.3807	0.6726	ENSMUSG00000069830	0.3572	0.6956	ENSG00000091592	NLRP1	NA	NA	NA	NA
ENSMUSG00000070421	0.0676	0.616	ENSMUSG00000060759	0.0925	0.6335	ENSG00000181074	OR52N4	NA	NA	NA	NA
ENSMUSG00000070522	0.2005	0.4978	ENSMUSG00000075054	0.2007	0.5085	ENSG00000241127	C7orf36	NA	NA	NA	NA
ENSMUSG00000070531	0.4064	0.9339	ENSMUSG00000074595	0.3201	0.8889	ENSG00000243543	WFDC6	NA	NA	NA	NA
ENSMUSG00000071151	0.0507	0.4414	ENSMUSG00000043866	0.0406	0.32	ENSG00000166337	TAF10	NA	NA	NA	NA
ENSMUSG00000071172	0	0.3963	ENSMUSG00000078134	0.017	0.3981	ENSG00000112081	SRSF3	NA	NA	NA	NA
ENSMUSG00000071522	0.0758	0.4997	ENSMUSG00000060404	0.0828	0.4854	ENSG00000204704	OR2W1	NA	NA	NA	NA
ENSMUSG00000071748	0.018	0.4234	ENSMUSG00000053205	0.018	0.4234	ENSG00000198252	STYX	NA	NA	NA	NA
ENSMUSG00000073018	NA	NA	ENSMUSG00000053012	0.1414	0.3192	ENSG00000172086	KRCC1	NA	NA	NA	NA

ENSMUSG00000073111	0.0783	1.0201	ENSMUSG00000091386	0.0545	1.4687	ENSG00000221858	OR2A12	NA	NA	NA	NA
ENSMUSG00000073468	0.0518	0.5408	ENSMUSG00000069899	0.0518	0.5392	ENSG00000198818	SFT2D1	NA	NA	NA	NA
ENSMUSG00000073609	0.1164	1.2128	ENSMUSG00000091067	0.0812	1.6232	ENSG00000180902	D2HGDH	NA	NA	NA	NA
ENSMUSG00000073909	0.1681	0.5167	ENSMUSG00000073907	0.2021	0.5538	ENSG00000180913	AC111177.	NA	NA	NA	NA
ENSMUSG00000073912	0.0852	0.6974	ENSMUSG00000073911	0.0834	0.7082	ENSG00000184478	OR56A3	NA	NA	NA	NA
ENSMUSG00000073934	0.0938	0.6857	ENSMUSG00000073933	0.1008	0.6487	ENSG00000167360	OR51Q1	NA	NA	NA	NA
ENSMUSG00000073970	0.0951	0.4792	ENSMUSG00000052785	0.144	0.594	ENSG00000176904	OR51H1P	NA	NA	NA	NA
ENSMUSG00000073997	0.1092	0.8579	ENSMUSG00000073998	0.0757	0.7681	ENSG00000171561	OR2AT4	NA	NA	NA	NA
ENSMUSG00000074154	0.0096	0.2239	ENSMUSG00000024480	200E-	0.2275	ENSG00000177879	AP3S1	NA	NA	NA	NA
ENSMUSG00000074608	0.3941	1.0323	ENSMUSG00000070708	0.2251	0.7156	ENSG00000124196	GTSF1L	NA	NA	NA	NA
ENSMUSG00000074684	0.0177	0.5847	ENSMUSG00000023932	0.0091	0.5647	ENSG00000096401	CDC5L	NA	NA	NA	NA
ENSMUSG00000074846	0.0063	1.3779	ENSMUSG00000038489	0	1.2509	ENSG00000177700	POLR2L	NA	NA	NA	NA
ENSMUSG00000075137	0.141	0.9599	ENSMUSG00000075139	0.1203	0.9792	ENSG00000186113	OR5D14	NA	NA	NA	NA
ENSMUSG00000075211	0.0694	0.5453	ENSMUSG00000033850	0.0982	0.7871	ENSG00000172457	OR9G4	NA	NA	NA	NA
ENSMUSG00000075382	0.1277	0.6984	ENSMUSG00000075383	0.0909	0.8213	ENSG00000171505	OR1N1	NA	NA	NA	NA
ENSMUSG00000075837	NA	NA	ENSMUSG00000084435	NA	NA	ENSG00000222821	U4.70	NA	NA	NA	NA
ENSMUSG00000076438	0.15	1.4101	ENSMUSG00000076436	0.1487	1.4191	ENSG00000198754	OXCT2	NA	NA	NA	NA
ENSMUSG00000076514	0.2847	0.6195	ENSMUSG00000076508	0.2682	0.6435	ENSG00000211599	IGKV5-2	NA	NA	NA	NA
ENSMUSG00000077713	NA	NA	ENSMUSG00000065155	NA	NA	ENSG00000200340	U1.26	NA	NA	NA	NA
ENSMUSG00000078139	0.018	0.7388	ENSMUSG00000044792	0.0143	0.7129	ENSG00000135070	ISCA1	NA	NA	NA	NA
ENSMUSG00000078305	0.1054	0.9233	ENSMUSG00000018040	0.0879	0.8949	ENSG00000189306	RRP7A	NA	NA	NA	NA
ENSMUSG00000078632	0.6122	1.5919	ENSMUSG00000034239	0.6328	1.3165	ENSG00000204173	C9orf29	NA	NA	NA	NA
ENSMUSG00000079071	0.1528	0.4432	ENSMUSG00000027219	0.1237	0.4533	ENSG00000137860	SLC28A2	NA	NA	NA	NA
ENSMUSG00000079129	0.2325	1.3908	ENSMUSG00000024032	0.2325	1.3908	ENSG00000160182	TFF1	NA	NA	NA	NA
ENSMUSG00000079197	0.0293	0.3656	ENSMUSG00000078153	0.0293	0.3654	ENSG00000100911	PSME2	NA	NA	NA	NA
ENSMUSG00000079228	0.0769	1.0537	ENSMUSG00000066860	0.0736	1.0365	ENSG00000129355	CDKN2D	NA	NA	NA	NA
ENSMUSG00000079301	0.0287	0.4321	ENSMUSG00000079828	0.0287	0.4321	ENSG00000112972	HMGCS1	NA	NA	NA	NA
ENSMUSG00000079302	0.04	0.5697	ENSMUSG00000079833	0.04	0.5697	ENSG00000177453	AC114947.	NA	NA	NA	NA
ENSMUSG00000079343	0.1579	0.5587	ENSMUSG00000038521	0.1604	0.5579	ENSG00000182326	C1S	NA	NA	NA	NA
ENSMUSG00000079374	1.1301	3.0643	ENSMUSG00000073294	1.0651	3.2973	ENSG00000187690	CXorf67	NA	NA	NA	NA
ENSMUSG00000079553	0.1151	0.6157	ENSMUSG00000024301	0.1344	0.6042	ENSG00000237649	KIFC1	NA	NA	NA	NA
ENSMUSG00000079570	0.8951	2.314	ENSMUSG00000071984	0.1936	0.7611	ENSG00000164694	FNDC1	NA	NA	NA	NA
ENSMUSG00000079575	0.0126	0.4545	ENSMUSG00000039191	0.0103	0.4263	ENSG00000168214	RBPJ	NA	NA	NA	NA
ENSMUSG00000079840	0.0278	0.3769	ENSMUSG00000079303	0.0278	0.3769	ENSG00000172262	ZNF131	NA	NA	NA	NA
ENSMUSG00000079941	0.0998	0.3363	ENSMUSG00000061518	0.0994	0.3084	ENSG00000135940	COX5B	NA	NA	NA	NA
ENSMUSG00000084425	NA	NA	ENSMUSG00000084703	NA	NA	ENSG00000222177	U4.55	NA	NA	NA	NA
ENSMUSG00000084745	NA	NA	ENSMUSG00000065100	NA	NA	ENSG00000206597	SNORA57	NA	NA	NA	NA
ENSMUSG00000087642	0.5094	1.7616	ENSMUSG00000076611	0.5244	1.8686	ENSG00000211891	IGHE	NA	NA	NA	NA
ENSMUSG00000087760	NA	NA	ENSMUSG00000087786	NA	NA	ENSG00000207501	U1.93	NA	NA	NA	NA
ENSMUSG00000087831	NA	NA	ENSMUSG00000065899	NA	NA	ENSG00000207067	SNORA72	NA	NA	NA	NA
ENSMUSG00000087901	NA	NA	ENSMUSG00000064776	NA	NA	ENSG00000221345	U3.47	NA	NA	NA	NA
ENSMUSG00000088081	NA	NA	ENSMUSG00000089566	NA	NA	ENSG00000221044	U3.43	NA	NA	NA	NA
ENSMUSG00000088228	NA	NA	ENSMUSG00000087816	NA	NA	ENSG00000252657	SNORA70.	NA	NA	NA	NA
ENSMUSG00000088243	NA	NA	ENSMUSG00000089516	NA	NA	ENSG00000200338	U1.25	NA	NA	NA	NA
ENSMUSG00000088772	NA	NA	ENSMUSG00000088135	NA	NA	ENSG00000238390	SNORA81.	NA	NA	NA	NA
ENSMUSG00000088825	NA	NA	ENSMUSG00000065293	NA	NA	ENSG00000206959	Y_RNA.524	NA	NA	NA	NA
ENSMUSG00000088843	NA	NA	ENSMUSG00000080425	NA	NA	ENSG00000252620	U6atac.37	NA	NA	NA	NA
ENSMUSG00000089111	NA	NA	ENSMUSG00000088059	NA	NA	ENSG00000252213	SNORA74.	NA	NA	NA	NA
ENSMUSG00000089225	NA	NA	ENSMUSG00000065160	NA	NA	ENSG00000200729	SNORD79	NA	NA	NA	NA
ENSMUSG00000089390	NA	NA	ENSMUSG00000088231	NA	NA	ENSG00000200975	U1.35	NA	NA	NA	NA
ENSMUSG00000089752	0.0867	0.6569	ENSMUSG00000074579	0.1636	0.6407	ENSG00000178110	LEKR1	NA	NA	NA	NA
ENSMUSG00000090343	0.1314	0.5081	ENSMUSG00000091220	0.1427	0.5373	ENSG00000176246	OR4L1	NA	NA	NA	NA
ENSMUSG00000090429	0.2564	0.5371	ENSMUSG00000062683	0.046	0.3636	ENSG00000135390	ATP5G2	NA	NA	NA	NA
ENSMUSG00000090461	0.1404	0.7525	ENSMUSG00000074695	0.137	0.7386	ENSG00000127318	IL22	NA	NA	NA	NA
ENSMUSG00000090538	0.0664	3.4555	ENSMUSG00000063457	0.0028	2.8141	ENSG00000115268	RPS15	NA	NA	NA	NA
ENSMUSG00000090637	0.1398	0.5908	ENSMUSG00000019715	0.0938	0.553	ENSG00000119392	GLE1	NA	NA	NA	NA
ENSMUSG00000090665	0.0245	0.3926	ENSMUSG00000070880	0.0126	0.3894	ENSG00000128683	GAD1	NA	NA	NA	NA
ENSMUSG00000090850	0.0182	1.0516	ENSMUSG00000039747	0.0164	1.0688	ENSG00000160991	ORAI2	NA	NA	NA	NA
ENSMUSG00000090894	0.1065	0.7072	ENSMUSG00000090675	0.1094	0.6948	ENSG00000243729	OR5V1	NA	NA	NA	NA
ENSMUSG00000091018	0.0088	0.5233	ENSMUSG00000025508	0.0044	0.5649	ENSG00000177600	RPLP2	NA	NA	NA	NA
ENSMUSG00000091230	0.1728	7.0301	ENSMUSG00000058773	0.0421	6.1729	ENSG00000184357	HIST1H1B	NA	NA	NA	NA
ENSMUSG00000091240	0.1707	0.5475	ENSMUSG00000024273	0.1608	0.5743	ENSG00000141428	C18orf21	NA	NA	NA	NA
ENSMUSG00000091476	1.2743	48.414	ENSMUSG00000066667	0.4276	0.8009	ENSG00000179397	C1orf101	NA	NA	NA	NA
ENSMUSG00000091512	0.0118	0.4556	ENSMUSG00000059039	0.0117	0.4252	ENSG00000109270	LAMTOR3	NA	NA	NA	NA
ENSMUSG00000091515	0.081	1.1787	ENSMUSG00000059878	0.0844	0.9506	ENSG00000165512	ZNF22	NA	NA	NA	NA
ENSMUSG00000091743	0.173	0.9875	ENSMUSG00000074895	0.2157	1.2084	ENSG00000175766	EIF4E1B	NA	NA	NA	NA
ENSMUSG00000091873	0.0805	0.8089	ENSMUSG00000090874	0.1025	0.7537	ENSG00000183706	OR4N4	NA	NA	NA	NA
ENSMUSG00000091896	0	0.1056	ENSMUSG00000037096	0	0.1056	ENSG00000131508	UBE2D2	NA	NA	NA	NA
ENSMUSG00000091900	0.0336	0.5613	ENSMUSG00000026999	0.0336	0.554	ENSG00000163002	NUP35	NA	NA	NA	NA