Social media data are reliable for monitoring the emerging global pet trade in ants

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Running head. Social media to track global pet trades

Impact statement. Social media data can be used to monitor the emerging global pet trade in ants and accurately detect invasive species in trade

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Abstract

The global pet trade is a major risk to biodiversity and humans. Over the recent decades, the pet trade has become increasingly globalized, diversified, digitalized and extremely difficult to control. With billions of Internet users posting online daily, social media could serve as a powerful surveillance tool. But it is still unknown how reliable social media are to track the global pet trade. Here, focusing on the emerging pet trade in ants (Hymenoptera, Formicidae), we show that social media data (~38,000 posts from Instagram) identify the countries involved in the pet trade and reflect the taxonomic composition and commercial success of traded ant species. Moreover, Instagram data accurately estimated the overrepresentation of invasive species among traded species. Overall, our findings show that social media provide affordable and reliable data for monitoring emerging pet trades and advocate for an easier access to these data in the future.

Introduction

Each year, millions of animals are traded as pets in legal and illegal markets for billions of dollars (Scheffers et al. 2019; Andersson et al. 2021; Liew et al. 2021). This global trade in non-traditional (or 'exotic') pets is a major risk to global biodiversity and human societies. First, it directly causes species extinctions through the overexploitation of natural populations (Mandimbihasina et al. 2020; Marshall et al. 2020). According to the IUCN red list (www.iucnredlist.org; November 2021), 18% of the 10,416 animal species that are, or have been, traded as pets are classified as vulnerable (8.6%), endangered (6.2%), critically endangered (3%), or already extinct (0.3%). Second, traded pets themselves can represent a risk for biodiversity if they are released by their owners or escape captivity outside of their natural range (Lockwood *et al.* 2019; Gippet and Bertelsmeier 2021; Stringham and Lockwood 2018). Finally, the pet trade can also contribute to the spread of zoonotic diseases affecting native wildlife, livestock and humans (Weldon et al. 2004; Chomel et al. 2007; Karesh et al. 2007). As a result, the global pet trade has become one of the main targets of international biodiversity conservation efforts and public health policies (Hughes 2021).

Yet, over the last twenty years, the global pet trade became increasingly difficult to control because wildlife markets shifted online, following the rise of Internet (Haysom 2018). Online pet stores have partially replaced physical pet stores and traditional surveillance methods, such as visits to pet stores, became insufficient to properly assess the taxonomic composition of global pet markets (Siriwat & Nijman 2018; Marshall et al. 2020). Moreover, surveys of sellers and consumers are costly and thus, often limited geographically and temporally (Su et al. 2016; Pinnegar & Murray 2019; Shukhova & MacMillan 2020). Moreover, existing global pet trade

databases rely on official import/export declarations (e.g., CITES; Scheffers *et al.* 2019) that are mostly limited to the legal trade in vertebrate species (Andersson et al. 2021).

Therefore, we lack data for the vast majority of legally and illegally traded non-traditional pets, especially for emerging pet taxa such as invertebrates (Kumschick et al. 2016; Andersson et al. 2021; Gippet & Bertelsmeier 2021). To overcome this data limitation, we could exploit the massive, yet mostly unexplored, amount of information published daily on social media, including date, location, user information, pictures or videos, comments and hashtags of posts (Toivonen et al. 2019; Jarić et al. 2020; Li & Hu 2021). Social media platforms have been developed in the mid 2000's, soon after the rise of the Internet, and are now used by half of the human population (Perrin 2015). In the last 15 years, hundreds of billions of text messages, photos and videos have been posted on social media platforms, including numerous posts about pets. This information could provide a cheap and timely solution to monitor the global pet trade and quantify associated threats to biodiversity. A rapidly increasing number of studies are using social media platforms such as Facebook, YouTube or Instagram and other Internet sources such as Google Trends to document the pet trade (Martin et al. 2018; Morgan & Chng 2018; Siriwat & Nijman 2018; Jensen et al. 2019; Spee et al. 2019; Nijman et al. 2021; Sung et al. 2021; Valdez 2021; Davies et al. 2022a). But it is still unknown whether information sourced from social media reflects accurately the geography of pet markets, the taxonomic composition and commercial success of pet species, and the environmental threats posed by the pet trade.

To test that, we analyzed the textual content (i.e., the comments) of ~38,000 Instagram posts referencing ants (Formicidae) as non-traditional pets. We focused on the pet trade in ants as pets because it is an emerging and rapidly growing global pet trade (>500 species traded worldwide), which disperses many invasive species (Gippet & Bertelsmeier 2021). In addition, the

global pet trade in ants is still mostly unregulated (i.e., in most countries, it is legal to sell and own any ant species) which simplifies the study system because it limits biases due to protection status or illegal ownership. The pet trade in ants occurs mostly online and ant colonies are delivered by standard mail (Buschinger 2004; Gippet & Bertelsmeier 2021). This pet trade is particularly concerning because ants can profoundly impact ecosystems and easily become problematic household and agricultural pests in both their native and introduced ranges (Holway et al. 2002; Swanson et al. 2019). To date, 256 ant species have established populations outside of their native range and these species were found to be overrepresented in the pet trade, probably because the ecological characteristics associated with a greater invasiveness are also linked to a greater commercial success (Gippet & Bertelsmeier 2021).

In this study, we tested i) whether the country of origin of Instagram users posting about pet ants predicted the location of ant sellers, ii) whether the ants referenced as pets on Instagram matched those offered in pet shops and iii) whether ant species' popularity on Instagram (i.e., number of posts, users, likes) predicted their commercial success on the pet market (i.e., number of sellers). Finally, to evaluate if Instagram data could inform conservation efforts regarding this emerging pet trade, we tested how accurately Instagram data detected invasive species in the pet trade. This is a particular concern given that invasive species have previously been shown to be overrepresented in the global pet trade (Gippet & Bertelsmeier 2021).

To assess the benefits of using social media rather than direct surveys to pet stores for monitoring global wildlife trades, we also compared both methods in terms of costs and time needed to acquire the data.

Methods

Data collection

Online stores survey. Between May and October 2020, we did a systematic search of websites specialized in selling ant colonies (e.g., Figure 1) following the general working framework described by Stringham and colleagues (2020). To find online stores offering ant colonies as pets on the Internet, we used the following keywords: “Buy living ants”, “Buy queen ant”, “Buy ant colony”, “Living ants for sale”, “Queen ant for sale” and “Ant colony for sale” in 20 languages (Arabic, simplified Chinese, Dutch, English, Finnish, French, German, Hindi, Italian, Japanese, Korean, Malay, Persian, Polish, Portuguese, Russian, Spanish, Swedish, Turkish and Vietnamese; Appendix S1). We performed the search using Google Search (with the Incognito feature to avoid search biases linked to user data; www.google.com) and DuckDuckGo (https://duckduckgo.com). For each query (6 keywords translated in 20 languages and searched with 2 search engines = 240 queries), we identified candidate websites among the 50 first search results. Non-specialized websites (e.g., Amazon, Ebay) and websites selling only ant workers (without queen) were ignored. We found 138 websites specialized in selling ants as pets (Appendix S2). Among them, one was an international platform regrouping 61 sellers from all over the world. We thus considered 198 sellers selling living ants on the Internet. We searched each of the 138 websites and recorded all sold species. Species identified only to the genera were not recorded. Using the AntWeb database (www.antweb.org), species names were checked for synonyms and misspellings. Records with invalid or inexistent species names were removed from the dataset.

Social media data. In March 2020, we collected posts referencing ants as pets on the social media Instagram (www.instagram.com; Figure 1) using a scraping algorithm coded in Python (code available; Van Rossum & Drake 2009). We chose to use Instagram because it is one of the largest

social media platforms (>1.4 billion users in 2021) and it allows to filter posts on precise topics as Instagram users tend to reference their posts with hashtags (i.e., referencing keywords) to increase posts' visibility (Figure 1). In addition, exotic pets are a popular topic on Instagram (~1.7 million posts containing "#exoticpets" as of September 2021). We collected all Instagram posts containing at least one of the following 14 hashtags: #antkeeping, #formicarium, #antlove, #antloveforever, #queenant, #antkeeper, #antstore, #antfarms, #queenants, #antkeepinghobby, #antkeepers, #antformicarium, #antsforsale and #antfarming. These hashtags were selected because they are highly specific to the ant keeping hobby (contrarily to more general hashtags such as #ants or #pets). This data mining campaign was carefully designed to not overload Instagram servers (i.e., several seconds separated each request; code available in Supporting Information). Only public data were retrieved and all collected posts were anonymized (Di Minin et al. 2021; Sandbrook et al. 2021). Then, we removed duplicates (i.e., posts found by two or more of the 14 hashtags) and obtained a dataset containing 38,552 unique Instagram posts from a total of 6,288 unique users. These posts were published between 2012 and March 2020 (Instagram launched in 2010) but 95% were published from 2017 on (Figure 2). We then cross-referenced the text (i.e., comment and hashtags) of each post with an exhaustive list of ant species scientific names (e.g., "*Lasius niger*"; antmaps.org) to find if and which species was referenced in each post. To detect a species name in a string even if it contained small orthographic errors (e.g., "Mirmica rubra" rather than "Myrmica rubra"), we used a Levenshtein distance ratio threshold of 0.9. The Levenshtein distance is a string metric commonly used to measure the difference between two short sequences (Levenshtein 1966). Sequences that have a Levenshtein distance ratio greater than 0.9 are thus more than 90% similar. Our final dataset consisted of a list of all ant species referenced as pets on Instagram and we computed, for each species, three indices of social media popularity: the total number of users

160 referencing the species, the average number of posts referencing the species (i.e., total number of
161 posts/total number of users) and the median number of likes by posts referencing the species.
162
163 **Do Instagram data reflect the global pet trade in ants?**
164 **Geographical patterns.** Country location was available for 1,846 Instagram users (out of 6,288).
165 We tested if the number of Instagram users per country was linked to the number of ant sellers per
166 country using a negative binomial GLM (R packages *MASS*; Venables & Ripley 2002). We also
167 tested if the global distribution of Instagram users (i.e., the overall number of Instagram users per
168 country; Source: statista.com) could predict the distribution of ant sellers across the globe using a
169 negative binomial GLM. Model performance was compared using their coefficient of
170 determination (pseudo-R^2).
171 **Taxonomic composition.** To test if Instagram data reflected the taxonomic composition of traded
172 ant species, we compared species listed as pets on Instagram to species traded in online stores.
173 First, at the subfamily level, we compared the proportions of species in each ants' subfamilies
174 among traded (N = 631) and Instagram (N = 714) species to their proportion in the global species
175 pool (N = 15,377) using Chi-squared tests for given probabilities with Bonferroni correction for
176 multiple comparisons. Second, at the genus level, we used a Generalized Linear Model (GLM)
177 with a binomial link function to test if the probability of being traded is correlated to the proportion
178 of species referenced as pets on Instagram (N = 207 genera). Third, at the species level, we tested
179 the overlap between species referenced as pets on Instagram and species traded in online stores
180 using a Pearson's Chi-squared test with Yates' continuity correction. Among species traded in
181 online stores (N = 631), we used a Wilcoxon rank sum test to compare the number of sellers among
182 species referenced as pets on Instagram and species not referenced as pets on Instagram. Among

183 species refenced as pets on Instagram (N = 714), we used a Wilcoxon rank sum test to compare
184 the number of Instagram users refencing the species among traded and non-traded species.
185 **Commercial success.** To test the link between species' popularity on social media and commercial
186 success on the pet market, we tested if the number of users referencing a species, the number of
187 posts per species and the number of likes per post were correlated to the number of online sellers
188 offering the species. For this analysis, we considered only species referenced as pets on Instagram
189 (N = 714). Species' number of sellers was modelled using a zero-inflated negative binomial GLM
190 (to account for the excess in zero values, i.e., no sellers, and overdispersion; R packages *MASS*
191 and *glmmTMB*; Venables and Ripley 2002; Brooks et al. 2017) with sub-family as random factor
192 (to control for potential phylogenetic effect).
193 **Invasive species among pets.** Based on the Antmaps database (Janicki et al. 2016), ant species
194 were classified as invasive if they have established populations outside of their native range (at
195 outdoor locations) and as noninvasive otherwise. We tested if Instagram data allow to accurately
196 identify which invasive ant species were traded as pets using a Pearson's Chi-squared test with
197 Yates' continuity correction. To test if the number of sellers was higher for invasive than
198 noninvasive ant species traded in online pet stores (N = 631), we used a zero-truncated negative
199 binomial GLM (with ants' sub-family as a random factor; R package *glmmTMB*). To test if the
200 number of Instagram users referencing invasive ant species was higher than the number of users
201 referencing noninvasive ant species, we used a gaussian GLM (with ants' sub-family as a random
202 factor; R package *glmmTMB*). For this last model, we considered only species referenced by more
203 than one user (N = 421) and log-transformed the response variable (i.e., the number of social media
204 users per species) to model it using a gaussian error distribution because we could not obtain a
205 valid model with the entire dataset (N = 714) and with a count error distribution.

The statistical validity of all GLMs performed in this study was assess using diagnostic tools from the R package *DHARMa* (Hartig 2018), their goodness of fit was measured using pseudo-R^2 from the R package *performance* (Ludecke et al. 2019) and their effects (i.e., estimates and 95% CIs) were computed using the R package *ggeffects* (Lüdecke 2018).

Results

Data collection.

Social media data. The collection of social media data took approximately 10 hours of work for one person (i.e., preparing scraping campaign, running and supervising algorithms, handling outputs, anonymizing data) and additional 50h for one computer to scrape the data from Instagram (Figure 1). We collected a total of 38,552 unique posts, from 6,288 unique Instagram users. Comments analysis detected a total of 714 ant species referenced as pets on Instagram (Figure 1, 2; data available in Supporting Information).

Pet stores. The search of online sellers and the inventory of their stores took approximately 220 hours for one person (Figure 1). We found 198 sellers offering living ant colonies in specialized online pet stores (Appendix S2). A total of 631 ant species could be bought from these sellers. Among these species, 154 were offered by only one seller, 57 by two sellers, and 420 by three or more sellers (up to 90 sellers; data available in Supporting Information).

Do Instagram data reflect the global pet trade in ants?

Geographical patterns. The number of Instagram users referencing pet ants per country was a better predictor of the number of online ant sellers per country (Estimate ± s.e. = 1.35 ± 0.12; z =

11.5, $P < 0.0001$; pseudo-$R^2 = 0.87$) than the total number of Instagram users per country (Estimate ± s.e. = 1.04 ± 0.14; $z = 7.6$, $P < 0.0001$; pseudo-$R^2 = 0.77$) (Figure 3).

Taxonomic composition. We found 631 species of ants traded in online pet stores and 714 species referenced as pets on Instagram. At the sub-family level, Instagram data and online stores survey were consistent as they both indicate an over-representation of Formicinae (e.g. red wood ants; $\chi^2_{traded} = 13.9$, $P = 0.004$, $\chi^2_{Instagram} = 11.3$, $P = 0.016$) and Myrmeciinae (e.g. bulldog ants; $\chi^2_{traded} = 57.8$, $P < 0.0001$, $\chi^2_{Instagram} = 54.8$, $P < 0.0001$) and an underrepresentation of Myrmicinae (e.g. leaf-cutter ants, fire ants; $\chi^2_{traded} = 177.3$, $P < 0.0001$, $\chi^2_{Instagram} = 197.8$, $P < 0.0001$) and Dorylinae (e.g. army ants; $\chi^2_{traded} = 33.2$, $P < 0.0001$, $\chi^2_{Instagram} = 23.5$, $P < 0.0001$) (Figure 4a,b). At the genus level, the proportion of species referenced as pets on Instagram was a good predictor of the probability of being traded at online stores (Estimate ± s.e. = 0.69 ± 0.04, $z = 15.9$, $P < 0.0001$; $R^2_{marginal} = 0.56$; Figure 4c,d). Among 631 ant species offered in online stores, 439 (70%) were also referenced as pets on Instagram ($\chi^2 = 6{,}249.8$, $P < 0.0001$; Figure 5a). Using the entire Instagram dataset (2010-2020) maximized the proportion of traded species detected (70%), although almost the same percentage of traded ant species were detected using only recent Instagram posts over the last year (64%) or the last two years (68%) (see Appendix S3 for details). In addition, among traded species ($N = 631$), species referenced as pets on Instagram were offered by three times more sellers than non-referenced species ($W = 20{,}534$, $P < 0.0001$; Figure 5b) and, among species referenced as pets on Instagram ($N = 714$), traded species were referenced by eight times more Instagram users than non-traded species ($W = 21{,}288$, $P < 0.0001$; Figure 5c). Thus, when species are weighted by the number of sellers offering them, the proportion of traded species detected by Instagram was of 87% (compared to 70% if all species are considered equally traded).

Commercial success. The number of sellers offering a species was strongly correlated to the number of Instagram users referencing the species as pet (conditional sub-model: Estimate ± s.e. = 0.66 ± 0.03; z = 23.2, P < 0.0001 and zero-inflated sub-model: Estimate ± s.e. = -2.43 ± 0.32; z = -7.7, P < 0.0001) and by the average number of posts referencing the species (zero-inflated sub-model only: Estimate ± s.d. = -0.53 ± 0.23; z = -2.29, P = 0.02) (*pseudo-*R^2 = 0.77; Appendix S4, Figure 5d).

Invasive species among pets. Among the 631 species of ant species traded in online pet stores, 68 (10.8%) were invasive species, and, among 714 ant species referenced as pets on Instagram, 84 (11.8%) were invasive species (Figure 6a). Furthermore, 87% (59 of 68) of traded invasive ant species were referenced as pets on Instagram, which is significantly higher than for all traded species (i.e., 70%; Proportion test: $\chi 2$ = 8.04, P = 0.005). Finally, invasive species were offered by 1.73 times more sellers (Zero-truncated negative binomial model: Estimate ± s.d. = 0.74 ± 0.19; z = 3.9, P < 0.0001; Figure 6b) and referenced as pets on Instagram by 2.65 times more users (Gaussian model: Estimate ± s.d. = 0.53 ± 0.11; z = 4.7, P < 0.0001; Figure 6c) than noninvasive species.

Discussion

We found that social media offer an affordable and reliable source of information to identify the countries involved in the ant-keeping business, to know which species are traded as pets, to quantify species' commercial success and to detect the trade in already invasive ant species. Instagram data are thus representative of the global pet trade in ants, probably because social media users referencing ants as pets are a combination of owners posting about their pets and of sellers using social media for advertisement (Jensen et al. 2019; Siriwat et al. 2019; Spee et al. 2019;

Norconk et al. 2020; Davies et al. 2022b). The amount of time (and money) necessary to monitor the global pet trade in ants was 22 times lower when collecting social media data than with conventional inventories of online pet stores (Figure 1). In addition, Instagram data allowed to assess ant species inclusion in trade and their popularity over time (e.g., number of new species per year; Figure 2), while stores' inventories only gave a snapshot of the current state of the pet market.

Interestingly, the location of Instagram users referencing ant-keeping precisely reflected the geographical distribution of ant sellers across the globe, except for India where no ant sellers were present despite many ant-keepers from that country posting on Instagram (Figure 3). There are at least two possible explanations for this. First, there may be ant sellers in India, but we did not detect them because they do not use specialized websites, but rather generalist marketplaces such as e-commerce companies (e.g., eBay, Etsy, Amazon) or social media (e.g., Facebook marketplace). Second, perhaps there are no or few ant sellers in India and Indian ant-keepers either collect their pet ants directly from the wild (e.g., newly mated queens after their mating flight) or buy them in online stores from other countries. A more detailed analysis of Instagram posts from Indian users might allow to identify which ant species they keep as pets in order to know if these species are sourced in India or imported from other parts of the world (Davies et al. 2022b).

The global pet trade is one of the main cause of animals invasions worldwide (Lockwood et al. 2019; Gippet & Bertelsmeier 2021). Thus, being able to estimate species' commercial success is important because the most traded species are more likely to be released outside of their native range (Stringham & Lockwood 2018). Moreover, Instagram data accurately detected the trade in invasive ant species (87% of traded invasive species were referenced on Instagram; Figure 6a) and allowed to assess their overrepresentation on the pet market as they were traded by twice as many

297 sellers and referenced as pets by three times more social media users than noninvasive species
298 (Figure 6b,c). Social media data could therefore be highly valuable to detect early problematic
299 species on pet markets.

300 Traded ant species that were not detected using Instagram data were species offered by a
301 small number of sellers (less than 5% of all sellers; Fig. 5b). Thus, from a conservation perspective,
302 Instagram data captured the most important fraction of the pet market, as the most problematic
303 species are those that are heavily traded. This is because they are at higher risk of extinction
304 through over-exploitation or because they are more likely to become established outside their
305 native range owing to the effects of propagule pressure on establishment probability (García-Díaz
306 et al. 2015). Yet, if comprehensiveness is needed, future studies should use more detailed analyses
307 of social media data to improve the detection of traded species on the pet market. Additional
308 analyses could also allow to determine the importance of species referenced as pets on social media
309 but not found in online pet stores (Fig. 5a,c). These records might represent species that are desired
310 but not (yet) traded, or traded species that were missed during the survey of online stores. This can
311 happen if 1) some pet species are traded by other means than specialized sellers (generalist
312 platforms, Whatsapp groups), 2) these species are traded by specialized sellers, but not at the time
313 of our pet market survey, or 3) these species are harvested in the wild by their owners but did not
314 enter the global pet market. Additional data (*e.g.*, time series of online stores inventories, survey
315 of pet owners) and more detailed analyses of the content of social media posts (*e.g.*, image
316 classification using computer vision; Di Minin et al. 2018) will be needed to further evaluate and
317 exploit social media data for monitoring the global pet trade.

318 Additional research is also needed to assess the reliability of social media data for
319 monitoring other exotic pet trades, especially in highly regulated taxa such as birds and mammals

(Jensen et al. 2019; Harrington et al. 2021; Sung et al. 2021; Davies et al. 2022a). Social media may be particularly suitable for monitoring emerging wildlife trades such as the pet trade in insects, arachnids and mollusks because they are mostly unregulated (Nelufule et al. 2020; Shivambu et al. 2020; Marshall et al. 2022). However, highly regulated wildlife trades such as vertebrate pets and products from endangered animal species might be less visible on social media given that public advertisement of illegal pets constitutes a risk for both sellers and consumers (Andersson et al. 2021). Yet, in many countries, regulations are insufficient or not enforced and illegal wildlife trade is thus not hidden (Siriwat & Nijman 2018; Marshall et al. 2020; Borges et al. 2021; Sung et al. 2021). In addition, as people can easily remain anonymous online, social media users might be able to disclose the illegal ownership, or sale, of rare and endangered species without risking legal consequences (Haysom 2018). Despite that, it has been shown that the number of posts on Facebook pages dedicated to the trade in African parrots decreased sharply (by ~95%) one year after the species was added to CITES Appendix I (in 2017), suggesting that social media data reflect the impact of trade regulation on the pet market (Davies et al. 2022a). Finally, although ants are less popular pets than birds or mammals, and the pet trade in ants is younger and smaller than most other exotic pet trades, ants have already proven useful to understand the link between invasiveness and commercial success (Gippet & Bertelsmeier 2021). Moreover, the pet trade in ants shares similarities with other pet trades. For example, ant species with wide spatial distribution are more traded (Gippet & Bertelsmeier 2021), a pattern that was also found in birds and amphibians (Tingley et al. 2010; Su et al. 2014). Interestingly, large-bodied species are favored in the pet trades in ants and amphibians (Tingley et al. 2010; Gippet & Bertelsmeier 2021), while smaller species are preferred in traded birds (Su et al. 2014).

Overall, our findings support the idea that social media are powerful and affordable tools to track emerging pet trades at global scale and in real time. But, because social media data are difficult to access, they are still largely underutilized in global wildlife trade studies (Di Minin et al. 2018; Toivonen et al. 2019) and existing studies are often limited taxonomically, temporally and geographically as they mostly rely on small, manually acquired, datasets (Martin et al. 2018; Morgan & Chng 2018; Siriwat & Nijman 2018; Spee et al. 2019; Nijman et al. 2021; Davies et al. 2022a). This data limitation is the primary obstacle to the routine utilization of social media data for monitoring the global wildlife trade so far (Di Minin et al. 2018).

Opening the access to social media data for conservation purposes would allow the early detection of potential threats for biodiversity and human societies and thus their prevention by informing national and international policy responses in time. However, the routine utilization of social media will first depend on further assessments of their reliability across traded taxa and on the development of tools to process and analyze the massive and ever-growing volume of information produced daily by social media users.

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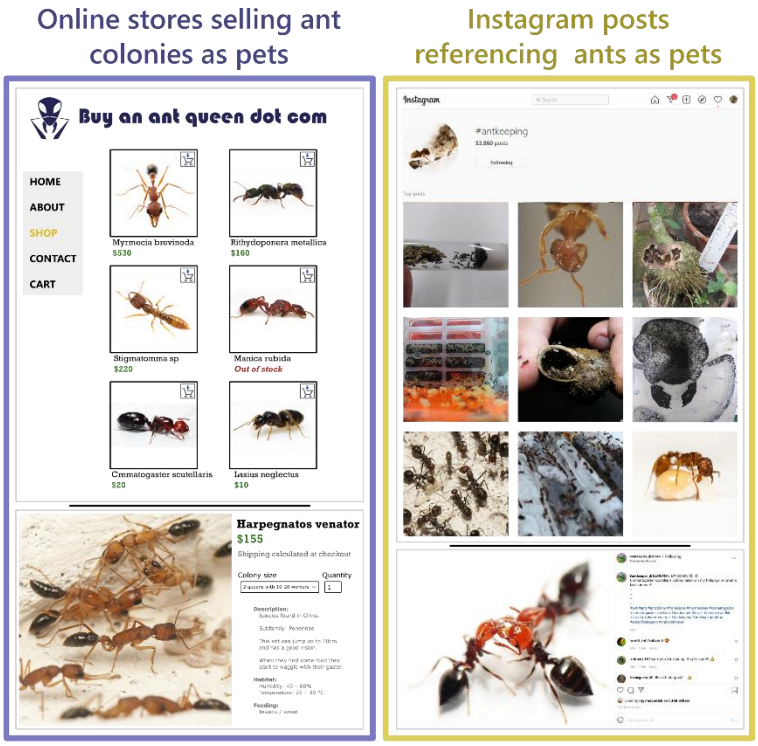


DATA ACQUISITION	**Time**	Website search: on av. 1h per language Website inventory: on av. 1h per seller **Total:** 220h (for one person)	Preparation, run algorithms, handle outputs: 10h Scrapping process: 50h **Total:** 60h (10h for one person + 50h for one computer)
	Cost	Salary: 5,720[1] - 8,800[2] CHF	Salary: 260[1] - 400[2] CHF
	Type of data	Inventories of 139 online pet stores	Public information of 38,552 posts from 6,288 unique users
RETRIEVED INFORMATION	**Spatial**	Country of sellers (~90% of sellers)	Country of Instagram users (30% of users)
	Temporal	One snapshot in 2020	Continuous from 2010 to 2020
	Taxonomic	631 species traded as pets	714 species referenced as pets
	Commercial stat. **Popularity metrics**	Number of sellers per species Mean price per species	Number of users referencing each species Number of posts per species Number of likes and comments per post

[1]Minimum wage in Switzerland
[2]Median wage in Switzerland

Figure 1. The global trade in ants as non-traditional pets. On the upper left box (blue frame), a website selling ants as pets. The lower part shows a detailed sheet for a commonly traded species, *Harpegnathos venator*. On the upper right box (yellow frame), Instagram posts containing the hashtag "*#antkeeping*", with a highlight on one post (lower part) were a picture and its associated comments and information (location, date, usernames) are displayed. For copyright reasons and to protect the anonymity of users, these screenshots are simulacra inspired from existing examples. Credits: T. Colin (ORCID: 0000-0003-0223-4479) for all images except four (marked with a black dot in the bottom-right corner) that are from the authors; for the right box, the background elements are screenshots of two Instagram pages (but comments, location, date and usernames were

replaced). The bottom table is a comparison of the two methods in terms of costs of data acquisition as well as quality and quantity of retrieved information.

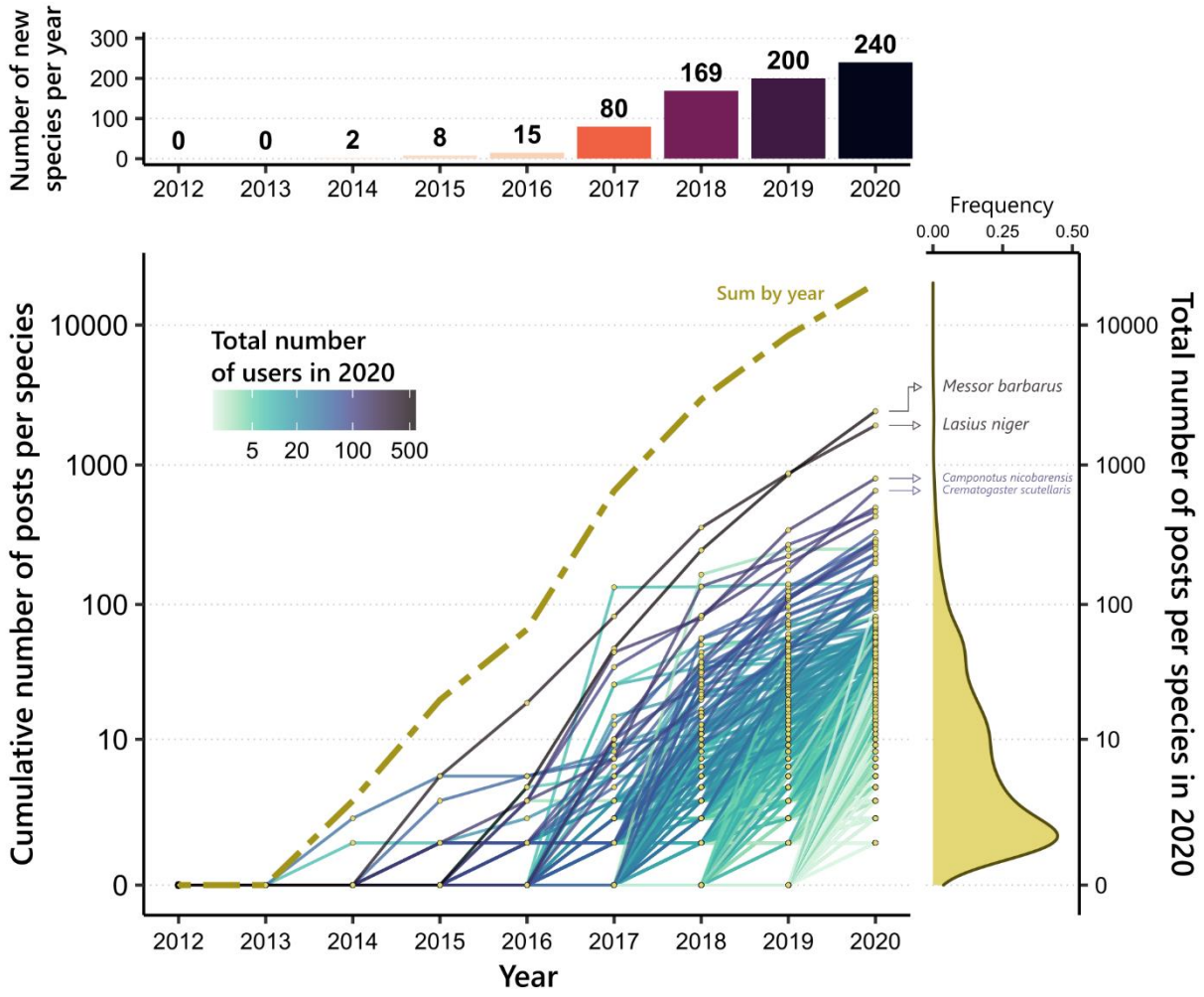


Figure 2. Using social media to monitor the emerging global pet trade in ants. Among 38,552 posts referencing ants as pets on Instagram, we found ~20,000 references to a total of 714 species of ants. The earliest Instagram posts about ant-keeping were in 2012 (Instagram was created in 2010), although, no ant species was specifically referenced until 2014. Approximately 85% of Instagram posts were published in 2019 and 2020 (57% in 2020 alone).

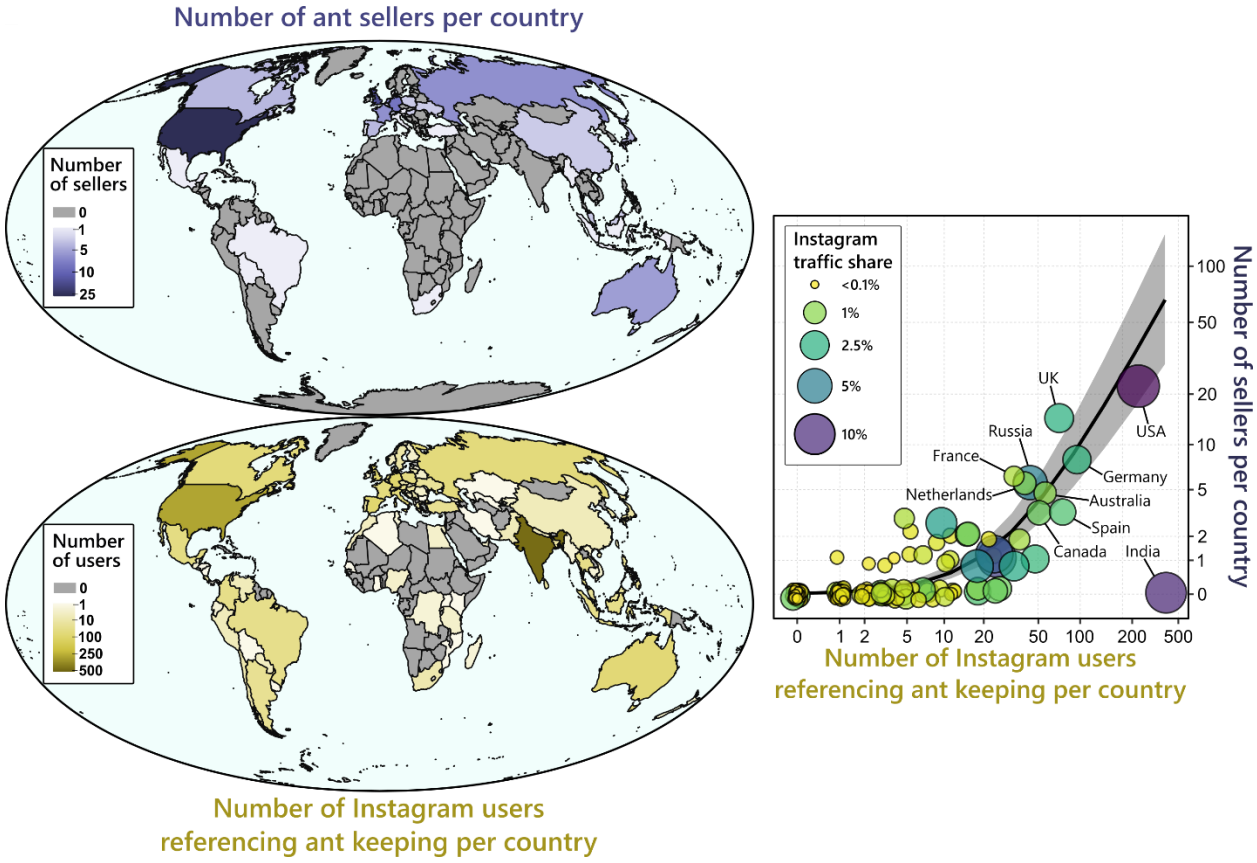


Figure 3. The location of Instagram users (posting about ant keeping) matches the location of ant sellers across the globe (R^2 = 0.87). On the right, the correlation between the number of social media users referencing ants as pets and the number of ant sellers per country. The black line and the grey shade represent the mean ± 95% CI link estimated with a negative binomial model. Both axes are log-transformed. The position of points was slightly jittered for visualization purposes. The size and color of the points correspond to the proportion of Instagram users per country (e.g., 12.3% of Instagram users are in the USA). The total number of Instagram users per country was also correlated to the number of ant sellers per country, but to a lower extent (R^2 = 0.77).

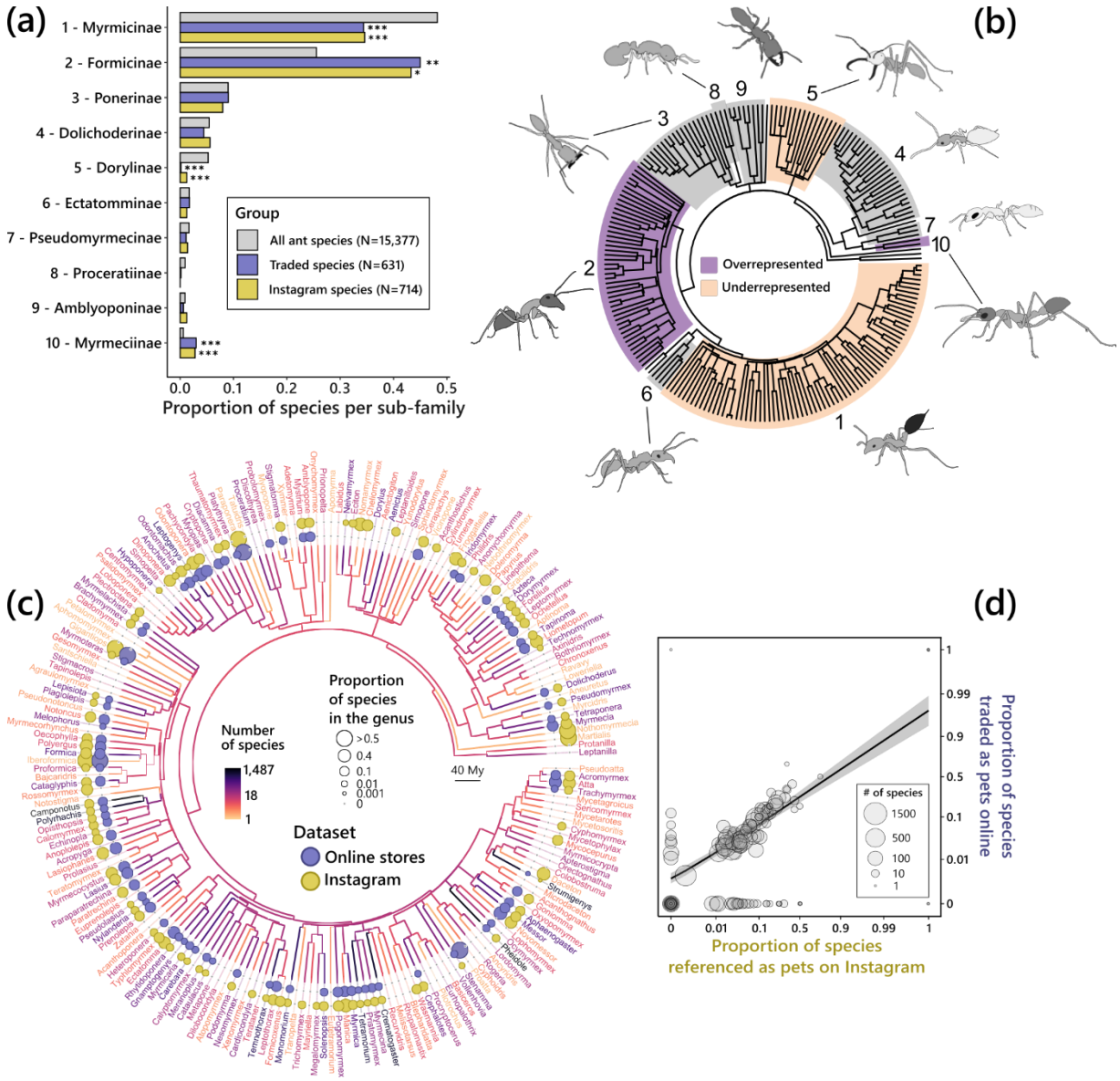


Figure 4. Instagram data reflect the taxonomic composition in ant subfamilies (a-b) and genera (c-d) in the online pet trade. (a) Proportion of species in each ant subfamilies (only the 10 largest) for all ant species (grey), traded species (blue) and species referenced as pets on Instagram (yellow). **(b)** Phylogenetic tree representing the 10 main subfamilies (branches are ants' genera) and indicating which subfamilies are overrepresented (purple) or underrepresented (orange) in the pet trade. Ants' silhouettes highlight the morphological diversity of ants' subfamilies (drawn from images by A. Wild; www.alexanderwild.com)**. (c)** Phylogenetic tree of ant genera (207 genera) with terminal branches' color indicating the number of species per genus. Bubbles represent the proportion of species referenced as pets on Instagram (yellow) and the proportion of species traded at online stores (blue), per ant genus. **(d)** Correlation between these two proportions. The black line and the grey shade represent the mean ± 95% CI link estimated with a binomial model. Both axes are log-transformed.

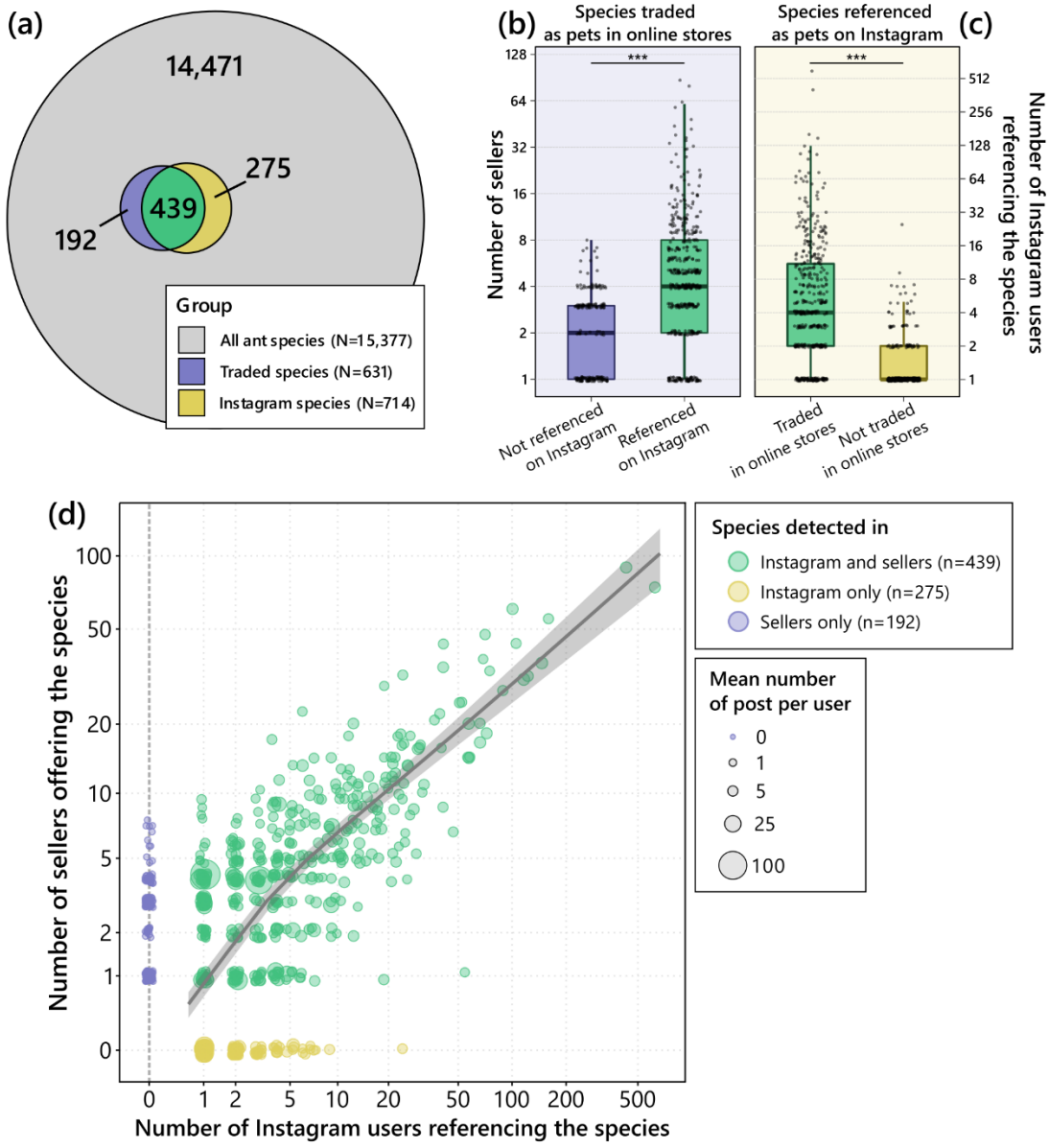


Figure 5. Instagram data predicts which ant species are traded as pets and their commercial success. (a) Seventy percent of species traded in online stores (blue) are referenced as pets on Instagram (yellow). **(b)** Traded species that are not referenced as pets on Instagram (blue) are proposed by fewer sellers compared to traded species referenced on Instagram (green). **(c)** Species that are referenced as pets on Instagram but not traded in online stores (yellow) are referenced by fewer Instagram users compared to traded species (green). **(d)** The number of users referencing a species as a pet on Instagram is a predictor of the number of sellers offering the species (R^2 = 0.77). The black line and the grey shade represent the mean ± 95% CI effect estimated with a negative binomial zero-inflated model (N = 714). Circles' size is proportional to the mean number of posts per user. Circles are slightly jittered horizontally and vertically to improve readability.

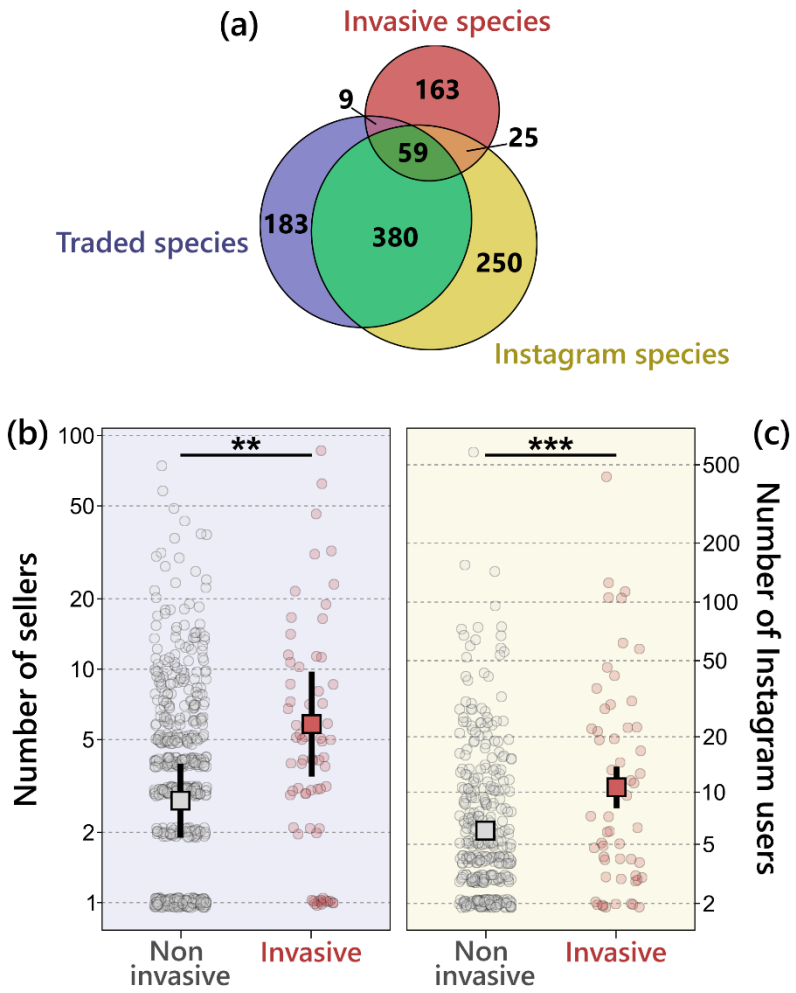


Figure 6. Invasive ant species are overrepresented in the pet trade and on Instagram. (a) Among 256 invasive ant species (i.e., species that established at least one population outside of their native range), 93 (36%) were either offered in online pet stores or referenced as pets on Instagram. In addition, 87% (59 out of 68) of traded invasive ant species were detected on Instagram (compared to 70% for all ants; Figure 5). Finally, invasive species are, in average, offered by 1.7 times more sellers **(b)** and referenced on Instagram by 2.3 times more users **(c)** than noninvasive species.

Appendix S1. Internet search for websites selling ants. Search expression used to detect websites on Google search.

Language	Search expressions					
English	**buy living ants**	**buy queen ant**	**buy ant colony**	**living ants for sale**	**queen ant for sale**	**ant colony for sale**
Arabic	شراء النمل المعيشة	شراء ملكة النمل	شراء مستعمرة النمل	النمل المعيشة للبيع	ملكة النمل للبيع	مستعمرة النمل للبيع
Chinese (simplified)	买活蚂蚁	购买蚁后	购买蚁群	出售活蚂蚁	蚁后出售	蚂蚁殖民地出售
Dutch	koop levende mieren	koop koningin mier	koop mierenkolonie	levende mieren te koop	koningin mier te koop	mierenkolonie te koop
Finnish	ostaa eläviä muurahaisia	osta kuningatar muurahainen	osta muurahaiskolonia	eläviä muurahaisia myytävänä	kuningatar muurahainen myytävänä	ant kolonia myytävänä
French	acheter fourmis vivantes	acheter reine de fourmi	acheter colonie de fourmis	fourmis vivantes à vendre	reine de fourmi à vendre	colonie de fourmis à vendre
German	kaufen Sie lebende Ameisen	kaufen Sie Königin Ameise	ameisenkolonie kaufen	lebende Ameisen zu verkaufen	königin Ameise zu verkaufen	ameisenkolonie zu verkaufen
Hindi	जीवित चींटियों को खरीदें	रानी चींटी खरीदें	चींटी कॉलोनी खरीदें	बिक्री के लिए जीवित चींटियों	बिक्री के लिए रानी चींटी	बिक्री के लिए चींटी कॉलोनी
Italian	Compra le formiche viventi	acquista formica regina	acquista una colonia di formiche	formiche vive in vendita	Formica regina in vendita	colonia di formiche in vendita
Japanese	生きているアリを買う	女王アリを買う	アリのコロニーを購入する	生きているアリ	女王アリ	アリのコロニー販売
Korean	살아있는 개미를 사다	여왕 개미를 사다	개미 식민지 구매	살아있는 개미 판매	여왕 개미 판매	개미 식민지 판매
Malay	membeli semut hidup	beli semut ratu	beli koloni semut	semut hidup untuk dijual	semut ratu untuk dijual	koloni semut untuk dijual
Persian	مورچه های زنده بخرید	مورچه ملکه را بخرید	کلونی مورچه را بخرید	مورچه های زندگی برای فروش	مورچه ملکه برای فروش	مستعمره مورچه برای فروش
Polish	kup żywe mrówki	kup królową mrówkę	kup kolonię mrówek	żywe mrówki na sprzedaż	królowa mrówek na sprzedaż	kolonia mrówek na sprzedaż
Portuguese	comprar formigas vivas	comprar formiga rainha	comprar colônia de formigas	formigas vivas à venda	formiga rainha para venda	colônia de formigas à venda
Russian	купить живых муравьев	купить королеву муравьев	купить муравьиную колонию	живые муравьи на продажу	королева муравьев для продажи	колония муравьев для продажи
Spanish	comprar hormigas vivas	comprar reina de hormiga	comprar colonia de hormigas	hormigas vivas en venta	reina de hormigas en venta	colonia de hormigas en venta
Swedish	köpa levande myror	köp drottning myr	köp myrkoloni	levande myror till salu	drottningsmyr till salu	myrkoloni till salu
Turkish	canlı karıncalar satın al	kraliçe karınca satın al	karınca kolonisi satın Alın	satılık yaşayan karıncalar	satılık kraliçe karınca	satılık karınca kolonisi
Vietnamese	mua kiến sống	mua kiến chúa	mua đàn kiến	kiến sống để bán	kiến chúa để bán	bán kiến

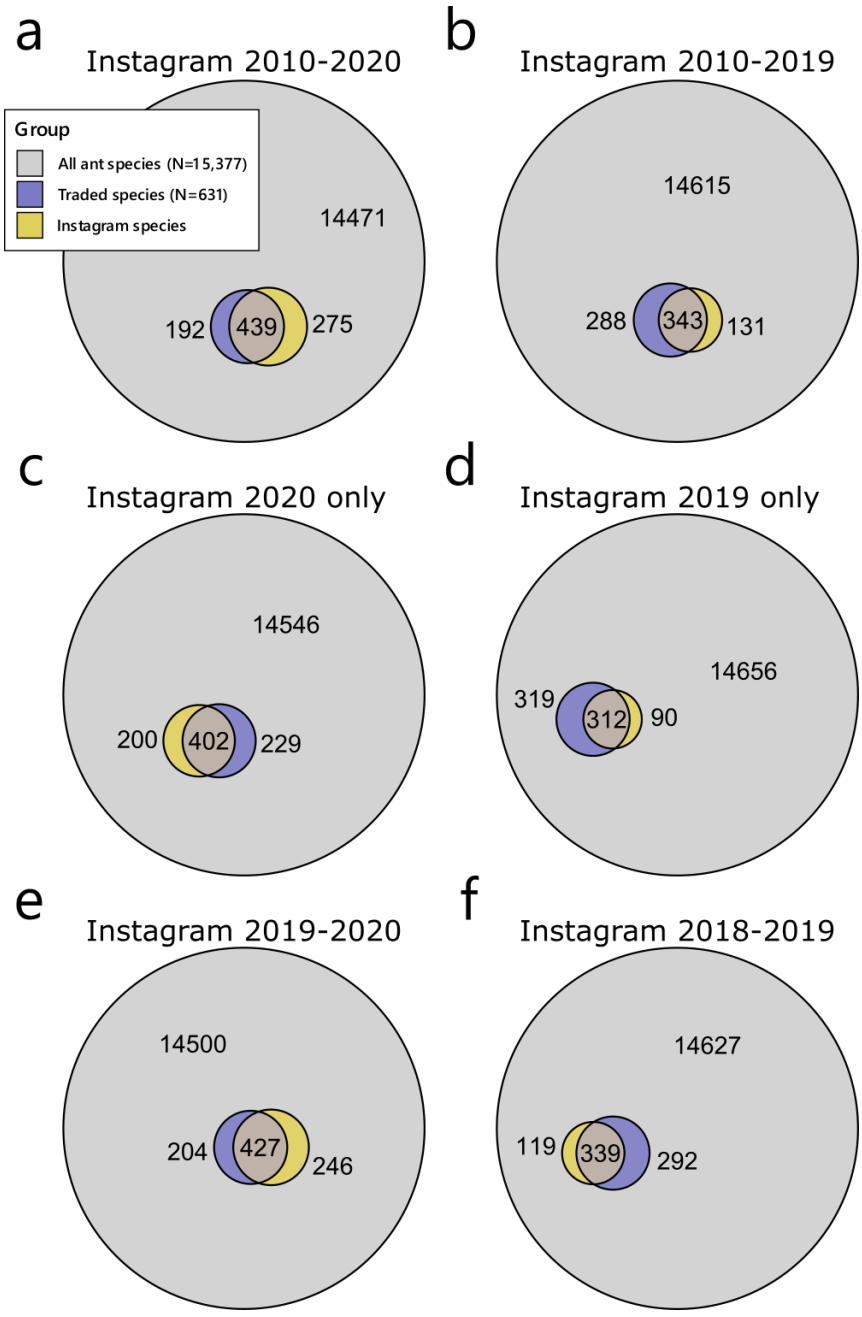
Appendix S2. List of the 138 websites selling ant colonies in 2020. Each website corresponds to one seller, except for one (www.antcanada.com) which is a platform were ant sellers can register and propose ants for sale. This website corresponded, at the time of the survey, to 61 sellers (we considered one seller by country or states for North America).

URL	Country	Oldest Activity
https://www.antscanada.com/queen-ants-for-sale/	Global	2010
https://www.antsrus.com/european-ants.html	UK	2017
https://www.ants-kalytta.com/Ants.html	Germany	2008
https://tarheelants.com/	USA	2012
https://www.antskingdom.com/	Netherlands	2016
https://antsuk.com/	UK	2011
https://www.antkeepingdepot.com/collections/ants	Australia	2019
https://canada-ant-colony.com/collections/all-ants	Canada	2020
https://www.antsylvania.com/	USA	2018
https://antssingapore.wixsite.com/ants/queen-ants-for-sale	Singapore	NA
https://www.antsonline.com.au/	Australia	2019
https://www.wakooshi.com/collections/queen-ants	UK	2020
https://www.antseverything.com.au/store/antsforsale	Australia	2018
https://antkit.uk/	UK	2014
https://hailesaquariums.com/collections/ants-and-queens-for-sale	Australia	2019
https://www.britishants.com/	UK	2015
http://www.antsfromasia.com/shop/4589082101	Thailand	2015
https://anthouse.es/	Spain	2008
https://antmalaysia.wixsite.com/mysite/ant-queen-for-sale	Malaysia	2016
https://www.antstore.net/	Germany	2003
https://www.antcenter.com.pl/	Poland	2016
https://www.antworldafrica.com/	South Africa	2018
http://www.leafcuttingants.com/coloniesforsale.html	UK	2016
https://fourmiculture.com/en/	France	2020
https://theantcollective.ca/	Canada	2020
http://www.washingtonants.com/shop.html	USA	2019
https://www.bestantsuk.com/	UK	2019
https://www.antzforall.co.uk/shop	UK	2018
https://www.antkeeping.co.uk/product-category/ants-for-sale/	UK	2017
https://www.fourmis.fr/fr/	France	2014
https://www.fourmis-city.com/	France	2012
https://linsecterie.com/collections/acheter-votre-colonie-de-fourmis	France	2015
https://www.fourmishome.fr/	France	2010
https://www.lemanreptiles.ch/boutique-geschaft-negozio/fourmis/	Switzerland	2016
https://www.fourmis.bio/	France	2016
https://www.detritus-ant.com/	France	2018
https://www.fourmisquebec.com/boutique/	Canada	2020
https://www.francefourmis.fr/	France	2020
https://fourmicurieuse.fr/9-fourmis	France	2020
https://grainesdegaia.fr/	France	2018
http://olivier-et-ses-fourmis.over-blog.com/2020/07/vente-de-colonies-fondations-ou-gynes.juillet-2020.html	France	2018
https://www.theantwarehouse.com/	UK	2019
https://www.hightechants.co.uk/queen-ants-for-sale-uk	UK	2020

http://www.ant-home.idv.tw/888/shopping/shopping-Product/shopping-p-ant/shopping-p-a16.htm	China	2003
https://www.mierenboerderij.nl/	Netherlands	2010
https://www.mierenspecialist.nl/	Netherlands	2016
https://mierenhuis.nl/	Netherlands	2020
https://beants.be/mieren-koopgids/	Belgium	NA
https://www.mierwinkel.nl/	Netherlands	2019
https://www.ongewoonongewerveld.nl/webshop.html	Netherlands	NA
http://mieren.eu/winkel/mieren/	Netherlands	NA
http://antsflanders.be/exotische-mieren.html	Belgium	2019
https://www.perrysantsstore.nl/mieren	Netherlands	NA
https://mierenkopen.jouwweb.nl/mieren-kopen	Netherlands	NA
https://www.mondoformiche.it/	Italy	2017
https://www.antsradica-italia.com/it/ilmondo-delleformiche	Italy	NA
https://kraina-mrowek.pl/sklep/	Poland	2020
https://vantisterra.pl/sklep/3-zwierzeta	Poland	2020
https://www.antkeeper.pl/	Poland	2019
https://www.mrowkoyad.pl/Mrowki-Europy-srodkowej-c15	Poland	2012
https://www.cheap-queens.pl/	Poland	2020
https://ant3d.pl/kategoria-produktu/mrowki/	Poland	2020
https://4ants.ru/collection/muravi-dlya-fermy	Russia	2016
https://antplanet.ru/catalog/list/5	Russia	2013
https://blackant.ru/muravi-dlya-fermy/	Russia	2020
https://planetexotic.ru/zhivotnye/muravi/	Russia	2016
https://ant-house.by/g5545599-muravi?sort=position	Belarus	2019
http://www.bugdesign.com.ua/ant-colonies/	Ukraine	2016
https://antcity.in.ua/collection/muravi	Ukraine	2016
https://antkingdom.reshop.com.ua/catalog/muravi	Ukraine	2016
https://7ants.ru/	Russia	2018
https://www.zoonemo.ru/shop/products/9319/99565	Russia	2019
https://antgear.ru/collection/muravi	Russia	2020
https://tribalants.com.ua/katalog/muravi	Ukraine	2018
https://pro-ant.ru/	Russia	2018
https://muravdom.ru/formikarii-fermy/fermy/muravinaya-ferma-jungle/	Russia	2020
https://d.ant-temple.com.ua/ants	Ukraine	NA
https://www.figlik.ru/catalog/	Russia	2020
https://myants.pro/muravey	Russia	2020
https://www.zoo-ekzo.ru/taxonomy/term/166	Russia	2016
http://antscountry.ru/catalog/Otechestvennye	Russia	2018
https://antlife.ru/product-category/muravyi/	Russia	2018
https://mr-ant.ru/muravi/	Russia	2020
http://antmama.by/muravi	Belarus	2019
https://zoogoods.ru/muravi.html	Russia	NA
https://samizoo.ru/brendy/Ant-prima/	Russia	NA
https://antqueens.ru/index.php/muravi	Russia	NA
https://muraveydom.ru/collection/muravi	Russia	NA
http://www.antsfromua.com/moorahi/	Ukraine	NA
https://www.zodibox.ru/	Russia	2013
https://antsworld.ru/	Russia	2017
https://vinniants.com/product-category/ants/?v=1ee0bf89c5d1	Ukraine	NA
https://ant-island.ru/	Russia	2019
https://www.antfarmdv.com/muravi	Russia	NA
https://ant5.ru/catalog/muravi/	Russia	NA

https://xn----7sbabhus3agg3ah4av9i3b.xn--p1acf/%D0%BA%D1%83%D0%BF%D0%B8%D1%82%D1%8C-%D0%BC%D1%83%D1%80%D0%B0%D0%B2%D1%8C%D0%B5%D0%B2	Russia	NA
https://antfarms.ru/	Russia	2013
https://antground.ru/	Russia	2018
https://topant.ru/catalog/ants/	Russia	2020
https://www.karincahobisi.com/kraliceler	Turkey	NA
http://www.surungenpazari.com/AltKategoriler.aspx?id=152	Turkey	2015
https://www.hayvanalsat.com/messor-structor-hasatci-karinca-2-422	Turkey	2011
https://kralicekarinca.com/messorstructorkoloni/	Turkey	NA
https://anadolukarincalari.blogspot.com/2020/08/guncel-satlk-kralice-ve-koloniler.html	Turkey	NA
http://evcilciftlik.blogspot.com/2018/06/satlk-camponotus-sanctus.html	Turkey	NA
https://tienda.lombricesdecalifornia.com/22-hormigueros-y-hormigas	Spain	2016
https://hormigueando.com/22-hormigas	Spain	2020
https://quillants.co/	Colombia	2019
https://anthillshop.es/	Spain	2020
https://www.linsecterie-es.com/collections/comprar-hormigas	Spain	2020
https://mihormiguero.es/	Spain	2017
https://hormigashormigueros.mercadoshops.cl/	Chile	NA
https://hormigasmx.mercadoshops.com.mx/MLM-632710449-hormiga-reina-solenopsis-invicta-con-obreras-_JM	Mexico	NA
https://labellaant.com/	Spain	2018
https://www.ecosferas.com/view_ecosferas/	Spain	2008
https://casadassauvas.blogspot.com/p/vendas.html	Brazil	2014
https://arinko-spot.com/	Japan	2010
http://antroom.cart.fc2.com/	Japan	2011
https://xn-----0b4ab9wcd81a4dxeoe2e6ep326dy8sbrg3fplua9vzw35c.com/html/ANT00_ari_queen_itiran.html	Japan	2019
https://aliceinunder.theshop.jp/	Japan	2019
http://antmuseum114.cart.fc2.com/	Japan	NA
https://www.s-tillandsia.com/	Japan	2018
http://www.kajitsuken.net/%E6%96%B0%E5%A5%B3%E7%8E%8B%E3%82%A2%E3%83%AA.html	Japan	2015
https://ahiruants.thebase.in/	Japan	NA
https://shop.ant-street.net/	Japan	2020
https://www.antdealer.com/Ameisenkolonien/	Germany	2012
https://www.antshop.ch/shop/	Switzerland	2009
https://www.ameisenshop.swiss/de/	Switzerland	2018
https://antshome.shop/	Austria	2020
https://myants.de/	Germany	2014
https://www.bestants.de/	Germany	2019
https://shop.crazyants.de/	Germany	2020
https://swiss-ants.ch/	Switzerland	2020
https://www.antshop.at/shop/de/	Austria	2020
https://www.exotic-ants.de/	Germany	2015
https://magicants.de/	Germany	2019
https://www.simants.de/de/Ameisen/	Germany	2015
https://ameisen-boutique.de/	Germany	2017

Appendix S3. Comparison of the proportion of traded species detected by Instagram data with a) Instagram posts until 2020 (*i.e.*, the entire dataset), b) Instagram posts until 2019 (without the last year), c) Instagram posts of 2020 only, d) Instagram posts of 2019 only, e) Instagram posts of years 2019 and 2020, and f) Instagram posts of 2018 and 2019. The results were very similar to what we found with the entire Instagram dataset and show that using the entire dataset maximizes the proportion of traded species detected with Instagram data.



Appendix S4. Fixed effects of the zero-inflated negative binomial mixed model used to predict the number of sellers offering a species based on three Instagram popularity metrics.

	Estimate	s.e.	*z*	*P*	
Conditional model (count values)					
(Intercept)	0.723	0.287	2.52	0.0118	*
Number of users	0.662	0.029	23.19	< 0.0001	***
Number of posts per user	-0.014	0.067	- 0.21	0.8313	
Number of likes per post	-0.082	0.063	- 1.29	0.1960	
Zero-inflation model (probability of zero value)					
(Intercept)	2.193	0.785	2.79	0.0052	**
Number of users	-2.432	0.318	- 7.66	< 0.0001	***
Number of posts per user	-0.532	0.232	- 2.29	0.0221	*
Number of likes per post	0.148	0.155	0.96	0.3388	