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Multiscale determinants of tree frog (*Hyla arborea* L.) calling ponds in western Switzerland

JÉRÔME PELLET*, SOPHIE HOEHN and NICOLAS PERRIN
*Laboratory for Conservation Biology, Institute of Ecology, Biology Building, University of Lausanne, CH-1015 Dorigny, Switzerland; *Author for correspondence (e-mail: jerome.pellet@ie-zea.unil.ch; fax: +41-21-692-4165)*

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Abstract. A tree frog (*Hyla arborea* L., 1758) metapopulation in western Switzerland was studied during spring 2001. All potential calling ponds in an area of 350 km^2 were searched for tree frog calling males. Twenty-nine out of 111 ponds sheltered between 1 and 250 callers. Most ponds were occupied by less than 12 males. Pond parameters were measured at three different levels using field analysis and a Geographical Information System (GIS). The first level was water chemistry and pond-associated measures. The second level was the surrounding land use in a 30 m buffer around the pond. The third level consisted of landscape indices on a broader scale (up to 2 km). Logistic regression was applied to identify parameters that can predict the presence of calling males in a pond. Response variable was the presence or absence of callers. Four significant parameters allowed us to explain about 40% of the total deviance of the observed occupational pattern. Urbanization around the pond had a highly negative impact on the probability of presence of calling males. Hours of direct sunlight on the pond was positively correlated with callers. Higher water conductivity was associated with a lesser probability of species presence. Finally, the further the closest two-lane road, the higher the probability of callers presence. Our results show that presence or absence of callers is influenced by factors acting at various geographical scales.

Introduction

Highly endangered in Switzerland (Duelli 1994), the European tree frog (*Hyla arborea*) has been disappearing from its distribution range over the last decades (Berthoud and Perret-Gentil 1976; Grossenbacher 1988). What once was a continuum from eastern to western Switzerland is now a series of more or less isolated metapopulations. The western-most of these metapopulations is now limited to a 350 km^2 area (Pellet and Neet 2001). Figure 1 shows the current distribution of tree frogs in Switzerland and the study area.

Tree frog population decline has been studied by many authors (reviewed by Borgula 1993) and has proved to be occurring at different geographic scales. Factors that influence tree frog populations at the pond level are, among others, predation (Tester 1990; Brönmark and Edenhamm 1994), competition (Fog 1988; Pavignano et al. 1990; Tester 1990), water pollution (Stumpel and Hanekamp 1986; Tester 1990), eutrophication (Fog 1988),

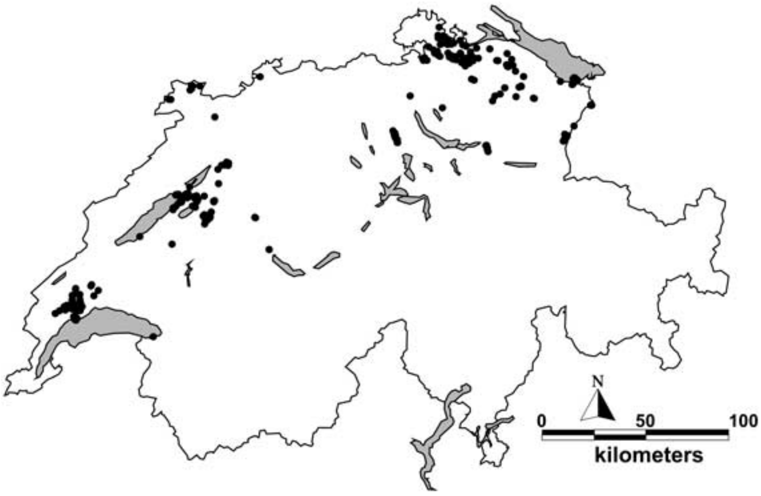

Figure 1. Black dots indicate tree frog observations in Switzerland from 1998 to 2002. The study area is the western-most metapopulation. Data source: Swiss Amphibian and Reptile Conservation Program.

natural succession (Tester 1990; Grosse 1994; Geiger 1995) or simply destruction. It has also been proposed that terrestrial determinants at a local scale around the pond affect tree frog populations. Food availability (Borgula 1990), traffic (Borgula 1993), disturbances and reduction of suitable terrestrial habitat are the most cited causes (Borgula 1990; Tester 1990; Stumpel 1993). At an even broader scale, factors such as pond isolation (Borgula 1990; Tester 1990; Edenhamm 1996; Vos 1999) proved to be of influence. The loss of landscape dynamics (Borgula 1990) and/or disappearance of particular structuring elements such as hedgerows or forest borders have been proposed as potentially influencing factors for many other amphibians (Knutson et al. 1999; Pope et al. 2000; Joly et al. 2001). Most probably a combination of all these factors, including some unknown, is leading populations toward extinction.

On the Swiss plateau, the intensification of agriculture has direct influence on most water bodies. Whether water quality or general landscape changes are responsible for the observed population decline is not clear. Exploring parameters at different scales should allow us to identify relevant features and the scale at which they are acting.

Here we investigate ponds and their immediate surroundings to establish a statistical model that can predict the presence or absence of tree frog calling males with a limited number of predictors readily available from field evaluation. The adequacy of the model to evaluate ponds is discussed.

Methods

Ponds identification and survey

Ponds were identified using various national and regional databases; national 1:25,000 maps, aerial photos, and field knowledge. All ponds were searched for calling males at least three times during the spring. Tape-recorded mating calls were used to stimulate isolated males (Tester 1990). All ponds where at least one calling male was heard were defined as occupied. Reproductive success or failure was not taken into account. All ponds were included in the analyses.

Ponds characterization

Three levels of pond characterization were used. The first level considers only the water itself and the pond vegetation. At this level, water conductivity and pH were measured using a HACH conductimeter (model 44600) and a METROHM pH-meter (model 691). For both, the final value is the mean of three measurements taken around the pond. Percentage of vegetation cover on the pond was estimated visually. Mean hours of direct sunlight on the pond was estimated with the help of a solar compass (calibrated for latitude 47° N) positioned at the southern-most end of the pond. This procedure allows to visually estimate for any given month the hours of the day when the sun is obscured by tree, building or hills. The shore development index was calculated as:

$$\mathrm{SHOREDEV} = \frac{\mathrm{PERIMETER}}{2 \cdot \sqrt{\mathrm{AREA} \cdot \pi}}$$

A shore development index equal to 1 indicates a circular pond. A higher development indicates that the pond shores are longer than expected for a circular pond with the same area as the one measured.

The second level describes the surroundings of the pond in a 30 m buffer, corresponding to the potential daytime refuge of individuals (Fog 1993) during the calling season. This set of parameters was computed via ground-proofed aerial photos interpretation. The third level is used to measure parameters on a broader scale of 2 km. This last set of measures describes the part of the landscape that is potentially reachable by migrating tree frogs (Fog 1993; Vos 1999). Geographical data originated from vector translation of national 1:25,000 maps (VECTOR25) for which precision is estimated to 4 m (Office Fédéral de la Topographie 2000). Levels of description and predictors are described in Table 1. In total, 35 predictors were measured on the field or using a GIS (Geographical Information System: MapInfo 6.0 and Idrisi32).

Table 1. Parameters measured and associated level of description.

Parameter	Description	Scale
AGRIC	Percent of agricultural landuse in a 30 m buffer	2
ALTITUDE	Altitude	1
BUSHES	Percent of bushes in 30 m buffer	2
BUSHVEG	Bushes overhanging the pond	1
CONDUCTIVITY	Mean water conductivity (μS/cm)	1
COUNTPOND	Number of ponds in 2 km buffer	3
COUNTSAT	Number of satellite ponds in 30 m buffer	2
DEPTH	Depth	1
DIST2FOREST	Distance from the nearest forest	3
DIST2POND	Distance from the nearest pond	3
DIST2RIVERS	Distance from the nearest river	3
DIST2ROAD	Distance from the nearest two-lane road	3
DISTURBAN	Distance from the nearest village	3
DISTURBEDLANDUSE	Percent of disturbed landuse in 30 m buffer	2
DIVSAT	Typological diversity of satellite ponds	2
ERECTEDVEG	Erected vegetation cover over the pond	1
FISH	Fish presence (yes/no)	1
FLOATINGVEG	Floating vegetation cover	1
FOREST	Percent of forest in 30 m buffer	2
GRAVELPITS	Percent of gravel pits landuse in 30 m buffer	2
HYDRIC	Water source (categorical)	1
LAKE	Percent of lake in 30 m buffer	2
LENGTHROAD	Total length of two-lane roads in 2 km buffer	3
MARSH	Percent marshes in 30 m buffer	2
MEADOWS	Percent of meadows in 30 m buffer	2
PERIMETER	Perimeter of the pond	1
PH	pH	1
QUANTRUBUS	Categorical quantity of *Rubus* sp.	2
SHOREDEV	Shore development index	1
SUN	Hours of sunlight during mating season	1
SURFACE	Surface	1
TREECOVER	Tree cover over the pond	1
TYPEPOND	Type of pond (categorical)	1
URBAN	Density of urban landuse in a buffer of 30 m around the pond	2
WINTERDRYING	Drying of the pond in winter 2000–2001 (yes/no)	1

Statistical analysis

The presence (1) or absence (0) of calling males in a pond was analyzed using stepwise logistic regression (Sokal and Rohlf 1995). We first tested all predictors individually in an univariate logistic regression and retained for further analysis only those whose *p*-value was lower than 0.25 (Hosmer and Lemeshow 1989). We entered all remaining predictors in the model (in a decreasing explained deviance order) and removed in a backwards stepwise fashion all those whose *p*-value was higher than 0.05. The significance of the explained

Table 2. Results of logistic regression for calling sites selection by males of *H. arborea* in western Switzerland.

Variable name	Regr. coef.	SE	Expl. dev. (%)	p(expl. dev.)	Wald χ^2	p(Wald)
URBAN	−0.229	±0.108	21	<0.001	4.483	0.037
SUN	0.382	±0.123	12	<0.001	9.666	0.002
CONDUCTIVITY	−5.201	±1.723	8	0.005	9.115	0.003
DIST2ROAD	0.012	±0.005	8	0.006	7.187	0.009

Null deviance = 127.51, residual deviance = 78.58, $D^2 = 0.38$.
Variables are density of urban landcover in a buffer of 30 m around the pond (URBAN), hours of direct sunlight during mating season (SUN), conductivity (mS/cm) of the water (CONDUCTIVITY) and distance (m) from the nearest two-lane road (DIST2ROAD). *p*(Wald) values test the linear component of the regression.

deviance of each of the predictors was tested in a 1000 permutations on the response variable (Guisan and Zimmermann 2000; Jaberg and Guisan 2001).

Evaluation of the model was made using a resubstitution of the dataset following methods described by Mondserund and Leemans (1992), Fielding and Bell (1997) and Pierce and Ferrier (2000). This method includes the computation of an occupational probability for each pond. This probability is converted to a presence/absence value using a threshold calculated via the kappa-statistic (Mondserund and Leemans 1992). It is then possible to compare predicted values versus observed ones in a confusion matrix. Misclassification indices can finally be calculated to evaluate the goodness-of-fit of the statistical model.

Correlation analysis was made using a Spearman rank correlation (Sokal and Rohlf 1995) at a 5% confidence level.

Results

A hundred and eleven ponds were identified in a 350 km^2 area. A little more than a quarter (28) of these sheltered at least one calling male during spring 2001. Most choruses were composed of less than 12 callers. One exceptional pond was used by more than 200 callers.

Logistic regression allowed us to identify four significant predictors (Table 2) for calling site selection. A fairly large proportion (38%) of the total deviance is explained by these parameters. The most important predictor is the density of urbanized surfaces in the immediate surroundings of the pond (URBAN). The exposure of the pond to sunlight (SUN) explains more than 10% of the deviance. Measured electrical conductivity (CONDUCTIVITY) seems to have a negative impact on caller presence. Finally, the probability of calling males being present increases with distance from roads (DIST2ROAD).

The kappa-statistic allowed us to compute a threshold value that optimizes the reclassification of the ponds in the right categories (presence or absence) based on the predicted occupation probabilities. With a 0.7 threshold (κ_{max} = 0.524), the false positive rate (unoccupied ponds with a predicted value higher than 0.7) is as low as 1.2% while the total misreclassification rate is 15.2%.

Discussion

The presence of urbanized (waterproofed) surfaces around the pond seems to have a negative impact on tree frog calling males. Although it seems trivial that artificialized areas are unsuitable for tree frog, there can be two reasons for this. First, callers face the absence of suitable terrestrial habitat (the quality of which is unknown here). Second, it could be possible that the human presence accompanying urbanized areas has a direct impact on populations in a way that is not yet known. Either way, creating private ponds in urban areas may not necessarily be an effective way of establishing new tree frog choruses.

The total hours of sunlight on the pond during the reproductive season positively influences the presence of callers. This feature has already been highlighted by many authors using different measurement techniques (Stumpel and Hanekamp 1986; Fog 1988; Tester 1990; Grosse and Nöllert 1993; Zysset 1995). It can be explained by the warming of the water and the potentially faster development of the tadpoles (Moravec 1993). Metamorphosing earlier, the larvae are less subjected to predation and reproductive success is higher.

A negative impact of conductivity in Zealand Flanders populations was also highlighted by Vos and Stumpel (1996). In their case, conductivity was highly correlated with chloride ions resulting from seawater flooding and seepage. In our study area, conductivity indirectly measures dissolved organic and mineral ions of another type. In gravel pits and quarries on limestone bedrocks, conductivity is mainly due to dissolved Ca^{++}, HCO_3^- and CO_3^{2-}. In agricultural landscapes, high conductivity usually indicates a high nitrates (NO_3^-) load resulting from agricultural runoffs (Tchobanoglous and Schroeder 1985). This hypothesis is supported by the observed correlation between agriculture intensity around the pond (AGRICULTURE) and measured conductivity (CONDUCTIVITY). A Spearman rank correlation between these two parameters showed significance with a correlation coefficient of $r_s = 0.303$ ($p < 0.05$). This tends to support the hypothesis that organic pollution via agricultural effluent can be high in such landscapes. The presence of effluents in water is potentially troublesome, as it indicates that pesticides and herbicides are probably being washed from fields in the same way. The lethal effects of some of these organic chemicals on tree frog larvae have been studied by Tester (1990) and could explain these results. Conductivity is also generally considered a measure for eutrophication. The proliferation of algae can cause acute anoxia in the morning due to oxygen consumption by algae and could be responsible for a lower larvae surviving rate.

The proximity to roads showed a negative impact on the caller probability of presence. Whether this is because of direct mortality due to traffic (Fahrig et al.

1995; Findlay and Bourdages 2000), although no casualties have been observed on potentially dangerous roads, or because of some unknown indirect effect is unclear. The creation of an index measuring traffic load around each pond would probably allow us to gain insights into the specific role played by vehicles.

The statistical model obtained is altogether satisfying, as it is able to correctly reclassify about 85% of the ponds with only four parameters that are pretty easily acquired in the field. One should also be aware that resubstitution methods tend to give relatively optimistic evaluation of models because of overfitting and loss of generality (Fielding and Bell 1997). However, this method permitted the identification of potentially suitable ponds for callers (not necessarily successful reproduction). This ability was validated by a colonization event in spring 2002 in a pond for which the model predicted a false presence in 2001. This clearly shows that such a model can be a tool for conservation in that it can help identify potentially suitable ponds for tree frogs. The best validation of the model would be to compute occupational probabilities for ponds situated in another metapopulation in Europe (included in a similar agricultural landscape). Comparing predicted and observed presence/absence patterns in another region would allow us to have an independent evaluation to validate the model. One should nevertheless be aware that such a model is developed at a regional scale (the Swiss plateau) and so cannot be simply applied to another type of landscape to calculate pond quality for tree frogs. It is more than likely that other limiting factors than those described here are affecting frog populations in other places.

This method and the obtained model show that determinants in calling sites selection can be found at various scales in the landscape. Here, parameters related to the water body (CONDUCTIVITY, SUN), its surroundings (URBAN) and adjacent landscape (DIST2ROAD) proved significant. It suggests that many mechanisms affect the calling sites selection by males of tree frogs.

Exploring landscape elements densities systematically at scales varying from pond to the potential dispersal distance of tree frog will certainly allow us to identify determinant structures and, even more important, the range at which they influence tree frog populations. Further analyses should also take into account the size of the choruses as well as (and even especially) the reproductive success, as the latter has the greatest importance in conservation policies.

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