Ecography

E6150
Indermaur, L., Schaub, M., Jokela, J., Tockner, K. and Schmidt, B. R. 2010. Differential response to abiotic conditions and predation risk rather than competition avoidance determine breeding site selection by anurans. – Ecography 33: 887-895.

Supplementary material

Appendix 1

Correlation matrix of factors used in candidate models for predicting the probability of occurrence.

Code	Factor	Ar	De	St	Hp	Sh	T	Al	Ox	Ph	Cy	Pr	Ebb	Ebv	Ete	Ela
Ar	Pond surface area	1.000	0.290	–0.140	0.160	–0.180	–0.060	0.360	0.070	0.070	0.090	0.020	–0.110	–0.040	–0.070	–0.070
De	Water depth		1.000	0.310	0.400	0.120	–0.140	0.350	–0.060	–0.080	–0.040	0.010	–0.100	–0.120	–0.060	0.040
St	Structural elements for egg attachment			1.000	0.270	0.480	–0.190	0.150	–0.100	–0.170	–0.120	0.040	0.140	–0.190	0.010	0.110
Hp	Hydroperiod length				1.000	0.210	–0.180	0.310	0.020	–0.050	–0.080	0.050	–0.090	–0.130	0.060	0.100
Sh	Shading					1.000	–0.270	–0.090	–0.180	–0.170	–0.360	0.090	0.160	–0.180	0.060	0.140
T	Temperature						1.000	–0.040	0.160	0.340	–0.010	0.040	0.130	0.250	–0.040	–0.130
Al	Algae cover							1.000	0.320	0.270	0.050	–0.020	–0.050	–0.010	–0.090	–0.060
Ox	Oxygen concentration								1.000	0.630	0.150	0.060	–0.100	0.090	–0.130	–0.080
Ph	Ph									1.000	–0.060	0.090	0.040	0.150	–0.050	–0.090
Cy	Specific conductance										1.000	–0.120	–0.090	0.000	–0.130	–0.080
Pr	Predation risk											1.000	–0.010	–0.020	<0.001	–0.010
Ebb	Egg density *B. b. spinosus*												1.000	0.010	0.030	<0.001
Ebv	Egg density *B.viridis*													1.000	–0.050	–0.050
Ete	Egg density *Rana temporaria*														1.000	0.130
Ela	Egg density *R. latastei*															1.000

See Table 1 and Appendix 2 for description of factors. All factors were standardized prior to calculating Pearson coefficients.

Appendix 2

Factors used for predicting the probability of occurrence and detection.

Process	Factor	Explanation	Sampling interval	Measuring detail	Reference
Probability of occurrence					
	YY	Year (2005,2006)			
Abiotic conditions (Factors reflecting landscape context)					
	Ht	Habitat type/spatial location (4 levels: riparian forest, edge of riparian forest, exposed gravel, island edge)			Guerry and Hunter 2002
	(Sh)	Shading [%]	Monthly (4 times)	Visually	Wellborn et al. 1996
Abiotic conditions (Factors reflecting hydrogeomorphology)					
	Ar[*]	Pond surface area [m^2]	Monthly (4 times)	dGPS (Trimble GeoXT, Zurich)	Pearman 1993
	De[*]	Water depth [m]	Weekly	Maximum water depth	Pearman 1993
	St	Availability of structural elements for egg attachment: percental cover by twigs, branches and aquatic vegetation [%]	Monthly (4 times)	Visually	Mazerolle et al. 2005
	(Hp)	Hydroperiod length [d], i.e. # days ponds contained water	Weekly		Wellborn et al. 1996
Abiotic condition (Factors reflecting water quality)					
	pH[*]	pH [H$^+$]	Monthly (4 times)	WTW pH 340[†]	Cummins 1986
	T[*]	Mean maximum temperature °C	Hourly	Thermochron ibutton loggers DS1921G	Herreid and Kinney 1967
	(Al)	Algae cover [%]	Monthly (4 times)	Visually quantification of algae cover	Mallory and Richardson 2005
	(Cy)	Specific conductance [µS cm^{-1}]	Monthly (4 times)	WTW LF 340[†]	Knutson et al. 2004
	(Ox)	Oxygen concentration [mg l^{-1}]	Monthly (4 times)	WTW Oxi 340[†]	Wassersug and Seibert 1975
Biotic condition					
	Fi	Fishes ≥ 10 cm (present/absent)	Monthly (4 times)	Visually	Knapp et al. 2003
	Pr[§]	Predation risk (index: 0–1)	Once	Sweep netting and funnel traps proportional to pond surface area	Skelly and Werner 1990, Knutson et al. 2004
	Pbb	Presence of *Bufo b. spinosus* (0,1)	Weekly	Visually	
	Pbv	Presence of *B. viridis* (0,1)	Weekly	Visually	
	Pte	Presence of *Rana temporaria* (0,1)	Weekly	Visually	
	Pla	Presence of *R. latastei* (0,1)	Weekly	Visually	
	(Ebb)	Egg density *Bufo b. spinosus* (n clutches m^{-2})	Weekly	Visually	

(Ebv)	Egg density *B. viridis* (n clutches m^{-2})	Weekly	Visually
(Ete)	Egg density *Rana temporaria* (n clutches m^{-2})	Weekly	Visually
(Ela)	Egg density *R. latastei* (n clutches m^{-2})	Weekly	Visually
Probability of detection			
YY	Year (2005,2006)		
Day[*]	Day in the season		
Ar[*]	Pond surface area [m^2]	s. above	
De[*]	Water depth [m]	s. above	
Si	Site (two levels: riparian forest, active tract)		

Factors in brackets were not used for modelling as they were highly correlated with other factors (Appendix 1).

[*] Factor that were also modelled as quadratic terms to reflect non-linear responses of species to environmental factors.

[†] Wissenschaftlich-Technische Werkstätten, Weilheim, Germany.

[§] Sum of individuals of newts (*Triturus carnifex, T. vulgaris*), snakes (*Natrix natrix*), insects (larvae and adults of *Dytiscus marginalis, Aeshna* sp.), normalized between 0 and 1.

Appendix 3

Formulation of candidate models for modelling p and Ψ.

p-models. The factors used to estimate probabilities of detection (p) included seasonal (year, day in the season), and spatial components (pond surface area, habitat type) (Table 1, Appendix 4). Factors day and pond surface area were also included as quadratic effects.

Ψ-models. The analysis of pond occupancy (ψ) was done in three steps. First, we assigned explanatory variables to four groups: habitat type, abiotic conditions reflecting hydrogeomorphology, abiotic conditions reflecting water quality, and biotic conditions (Table 1). We first formulated models per factor group. Models included both linear and quadratic effects. In the second step, we formulated models that combined linear factors of multiple factors groups. In the third step, we formulated models that combined linear and quadratic factors of multiple factor groups. These models hypothesized that ψ changes nonlinearly. Factor year was used in every model to correct for its potential effects.

Appendix 4

Model selection results for predicting the probability of detection (p), sorted after differences between Akaike's small sample information criterion (ΔQAICc), corrected for overdispersion with the variance inflation factor ($\hat{c}$). Only models with an Akaike weight > 0.05 are shown.

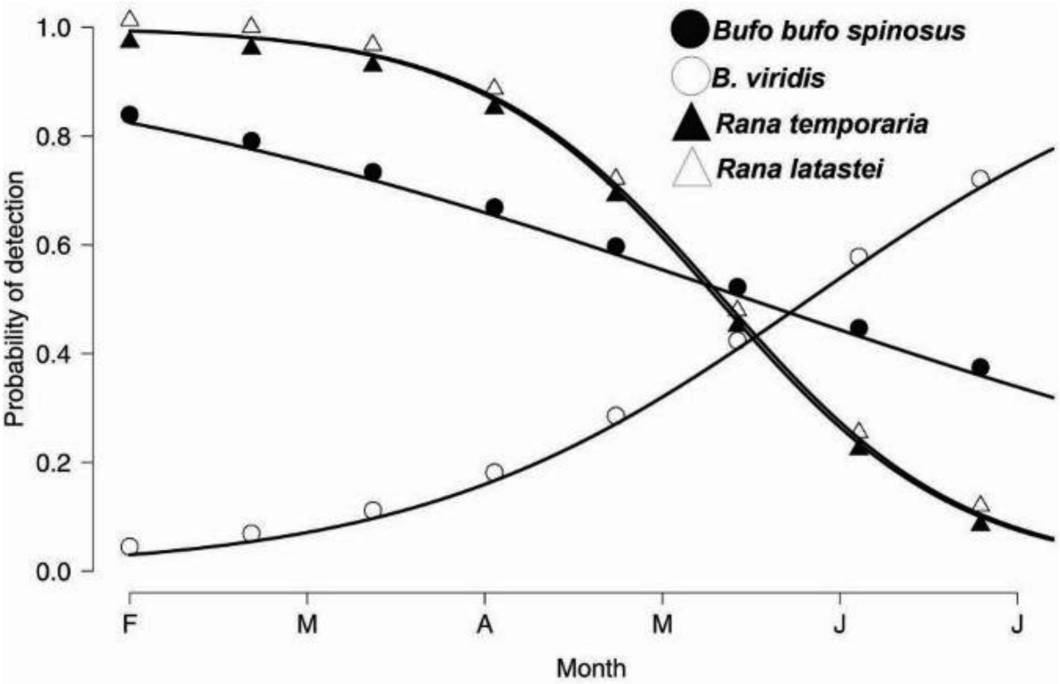
Model no.	Factors						K	ΔQAICc	Qweight	Qdeviance
Bufo b. spinosus: $\psi = (.)$, $\hat{c} = 4.75$										
10	YY	Day	Day^2				5	0.00	0.431	653.19
11	YY	Day	Day^2			Si	6	1.92	0.165	653.04
12	YY	Day	Day^2	Ar			6	2.05	0.155	653.17
5		Day	Day^2				4	2.74	0.110	657.99
14	YY	Day	Day^2	Ar	Ar^2		7	3.98	0.059	653.02
13	YY	Day	Day^2	Ar		Si	7	3.99	0.059	653.03
Rana temporaria: $\psi = (.)$, $\hat{c} = 1.79$										
13	YY	Day	Day^2	Ar		Si	7	0.00	0.489	1146.40
15	YY	Day	Day^2	Ar	Ar^2	Si	8	1.11	0.280	1145.41
12	YY	Day	Day^2	Ar			6	2.75	0.124	1151.23
14	YY	Day	Day^2	Ar	Ar^2		7	4.57	0.050	1150.97
B. viridis: $\psi = (.)$, $\hat{c} = 3.84$										
5		Day	Day^2				4	0.00	0.452	235.16
10	YY	Day	Day^2				5	1.66	0.197	234.76
11	YY	Day	Day^2			Si	6	2.97	0.102	234.00
14	YY	Day	Day^2	Ar	Ar^2		7	3.14	0.094	232.10
12	YY	Day	Day^2	Ar			6	3.71	0.071	234.75
R. latastei: $\psi = (.)$, $\hat{c} = 9.24$										
10	YY	Day	Day^2				5	0.00	0.394	353.56
12	YY	Day	Day^2	Ar			6	1.25	0.211	352.74
11	YY	Day	Day^2			Si	6	1.60	0.177	353.09
13	YY	Day	Day^2	Ar		Si	7	2.66	0.104	352.07
14	YY	Day	Day^2	Ar	Ar^2		7	3.29	0.076	352.69

See Table 1 for description of factors. (.) = constant probability of occurrence (ψ). The top ranked model with ΔQAICc = 0 best approximates the data and models with ΔQAICc ≤ 2 are considered to receive substantial support from the data. Number of factors (K) and Akaike weights are given. When one model receives weights ≥ 0.9 there is no model selection uncertainty apparent. Factor year was included in every model to correct for its potential impact. All factors were modelled as additive effects.

Models including seasonal effects (Year+Day+Day^2) explained the detectability of *B. b. spinsous* and *R. latastei* best (Akaike weights: 0.43 and 0.39, respectively). Similarly, for *B. viridis* seasonal effects explained detection best (Day+Day^2) (Akaike weight: 0.45). The detection of *R. temporaria* depended on both spatial (pond surface area, site), and temporal components (Year+Day+Day^2) (Akaike weight: 0.48).

Appendix 5

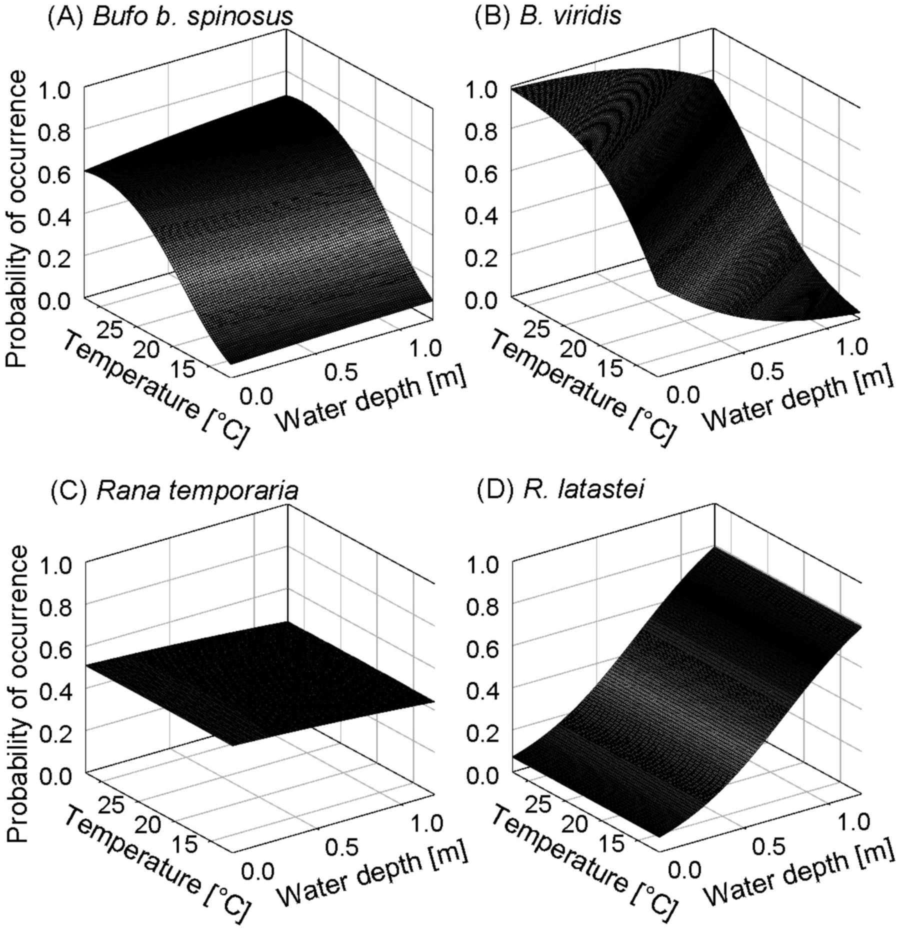
Predicted probability of detection (*p*) over the season, separated for the four species. All lines are thick, thereby denoting significant relationships (i.e. regression slopes did not include zero in confidence intervals).



Per-visit probabilities of detection (*p*) of frogs (*R. temporaria, R. latastei*) were highest (~99–90%) from February until the end of March when frogs aggregated at breeding sites. Similarly, *B. b. spinosus* was detected best from February until the end of March (82–67%). In early July, the detection probability was low as 7% for frogs and 40.4% for *B. b. spinosus*. The detection probability of *B. viridis*, a typical late breeder, increased from April to early July from 17 to 79%.

Appendix 6

Predicted probabilities of occurrence (ψ) in relation to the additive effects of temperature (T), water depth (De), and the quadratic effects of these factors, separately for (A) *Bufo b. spinosus*, (B) *B. viridis*, (C) *Rana temporaria*, and (D) *R. latastei*. We used 200 values of each factor within the range of observed factor values for the predictions. Factor values were z-standardized (mean = 0). The following model was used to predict probabilities of occurrence: $\mathrm{logit}(\psi)=\exp(\mathrm{Intercept}+\alpha T_i+\beta T_i^2+\gamma{*}De_i+\delta De_i^2)/\ (\exp(\mathrm{Intercept}+1+\alpha Ti_i+\beta Ti_i^2+\gamma De_i+\delta De_i^2))$, where *i* are the different factor values and *α, β, γ* ,and *δ* are the regression slopes out of Table 4. The intercept was the regression slope of the habitat type "forest edge", which was similarly used by all species.



The factors that separated *B. b. spinosus* (A) and *R. latastei* (D) in breeding site selection were temperature and water depth. Occurrence of *B. b. spinosus* (A) was highest in warm ponds independent of pond size (Fig. 1B). Occurrence of *R. latastei* (D) was highest in cool and deep ponds. *Bufo viridis* (B) preferred warm and shallow ponds.

Appendix 7

Factors used to predict the number of species in ponds (n = 353). Effect sizes (Beta), standard errors (SE), lower (LCI) and upper (UCI) 95% confidence intervals are given.

Code	Factors	Beta	SE	LCI	UCI
	Intercept	0.504	0.069	0.368	0.640
Ar	Area	0.364	0.100	0.168	0.561
Ar^2	$Area^2$	–0.052	0.018	–0.087	–0.016
De	Depth	0.384	0.081	0.225	0.544
De^2	$Depth^2$	–0.141	0.034	–0.208	–0.073
St	Structure for egg attachment	0.261	0.058	0.148	0.374
T	Temperature	0.332	0.056	0.222	0.442
T^2	$Temperature^2$	–0.170	0.049	–0.265	–0.075

We used a general linear model (link function=”Poisson”) to predict species diversity (number of species) at the pond-level in relation to the additive and quadratic effects of abiotic factors ($Ar+Ar^2+De+De^2+St+T+T^2$). Factor values were z-standardized (mean = 0) prior to analysis. None of the factors included zero in confidence intervals. See Table 1 for description of factors. Habitat type was excluded as an explaining factor because species largely used habitat types similarly. The factors predation risk and the presence of fish were excluded as well. These factors covaried with the occurrence of anurans (Fig. 1). Predation risk and the presence of fish do not increase the attractiveness of ponds for anurans, rather predators and fish prefer the same habitat characteristics as anuran species.