Amphibian observation and pond data (Aargau, Switzerland)

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This dataset consists of monitoring data for all 12 pond-breeding amphibian species in the canton of Aargau from **1999 to 2019** in 856 ponds, and environmental variables that describe the ponds and the landscape surrounding the ponds. The 12 species include eight anurans (toads and frogs) : *Alytes obstetricans* (Red-List status in Switzerland: EN; Schmidt & Zumbach 2019), *Bombina variegata* (EN), *Bufo bufo* (VU), *Epidalea calamita* (EN), *Hyla arborea* (EN), *Pelophylax ridibundus* (an invasive species, NE), *Pelophylax* sp. (aggregate of *P. lessonae* and *P. esculentus*, which form a hybrid species complex and are difficult to distinguish; both LC), and *Rana temporaria* (LC); and four newts: *Ichthyosaura alpestris* (LC), *Lissotriton helveticus* (VU), *L. vulgaris* (EN), and *Triturus cristatus* (EN).

The canton of Aargau is the owner of the monitoring data; the original datafile is only disclosed upon request and in consultation with the canton of Aargau.

The edited dataset contains cleaned, compiled and edited observation data for the 12 amphibian species and covariate data required to fit dynamic occupancy models for all species.

Species observation and pond data

Species observation data consists of detection/non-detection data from the amphibian monitoring of the canton of Aargau from 1999 to 2019. The monitoring is focused on 10 core areas (within five regions) that are surveyed comprehensively and regularly in a rotating panel design. All potentially suitable sites within an area were surveyed. Between 1999 and 2019, each core area was surveyed on average 5.5 times with a mean (±SD) period of 3.8 (± 1.38) years between surveys. For the analysis, the 10 core areas were aggregated to five regions that follow major river valleys: the Rheintal (combined from the core areas upper and lower Rheintal), the Aaretal (from core areas upper and lower Aaretal), the Reusstal (from core areas southern and northern Reuss plain and the lower Reusstal), and the Suhretal and Wiggertal (identical to the original core areas). An overview of the number of sites with at least one detection between 1999 and 2019 is given for all species and regions in **Table 1**.

Of particular interest in this dataset is the ongoing landscape-scale construction of new ponds, which began in the canton of Aargau in the 1990s (Kantonales Amphibienschutzkonzept KASK, Meier & Schelbert 1999). Pond construction was focused on the regions that were monitored in parallel. Within these regions, the total number of sites increased from 469 in 1999 to 780 in 2019 through the construction of new ponds. 422 new ponds were added, while 76 ponds got destroyed (e.g., through drainage or infill). Ponds constructed since 1991 are considered new ponds, ponds existing in 1990 already are considered old ponds.

For 362 of the new ponds, the exact year of construction could be determined (from information from the agencies that built the sites (canton of Aargau, Agrofutura) or from aerial photographs, https://www.ag.ch/app/agisviewer4/v1/agisviewer.html); of these, 35 were constructed during the 1990s, the rest after 1999. For 60 new sites, the exact year of construction was unknown. Where there was uncertainty in the year of construction or destruction, we conservatively assumed the minimum duration of existence, i.e. sites were assumed to exist from the first or until the last year, respectively, in which there was survey data for them, and assumed to be nonexistent before or after these years. Information on whether a pond exists in a particular year or not is stored in variable **Extant**.

Within a survey year, each site of a surveyed area was visited three times (Cruickshank et al. 2019). The first two visits occurred at night, between April 20 and May 15 (first visit) and between May 16 and June 6 (second visit). The third visit occurred during the day, between June 15 and July 31, mainly to survey the presence of diurnal species and tadpoles. In total 260 trained volunteers conducted the fieldwork, organized by a professional coordination office. Surveyors used a standardized field protocol determining survey dates, suitable weather conditions, time of day, and duration of a visit; durations ranged from 20 to 90 minutes per site and were a priori defined, depending on the total size of water surface areas of all water bodies at a site (Bühler 2020). During each visit, the presence of species was recorded based on detection of any life-stage or the detection of calls. To ensure population closure we filtered each species-specific dataset prior to analysis (MacKenzie et al. 2002): For each species, we identified the first and last date that it was reported and considered these dates the start and end of the breeding season for that species.

Species observation data hence consists of detection/non-detection data during 3 visits to all sites in a core area during core area survey years, within the breeding season of that species.

Table 1. Species list, with red-list status in Switzerland in brackets (Schmidt & Zumbach 2019). N sites gives the total number of old (existing before the 1990s) and new (newly constructed since 1991) sites in the five regions modelled. The number of sites with at least one detection between 1999 and 2019 per species and region, split into old and new sites, is given below. Regions with ≤10 sites with detections were excluded from analysis for that species (italicized). Three species (*H. arborea, L. vulgaris, T. cristatus*) had sufficient data for analysis in a single region only (Reusstal). LC: least concern; VU: vulnerable; EN: endangered; NE: not evaluated.

	Rheintal (215 km^2)		**Aaretal (132 km^2)**		**Reusstal (146 km^2)**		**Suhretal (84km^2)**		**Wiggertal (82 km^2)**	
	Old	New	Old	New	Old	New	Old	New	Old	New
N sites	131	198	72	98	149	79	49	36	33	11
Species (Redlist status)										
Alytes obstetricans (EN)	47	33	30	9	*9*	*1*	20	3	*4*	*0*
Bombina variegata (EN)	62	93	41	55	49	28	15	7	*5*	*0*
Bufo bufo (VU)	98	117	61	43	93	26	41	17	28	9
Epidalea calamita (EN)	14	14	19	9	33	15	18	11	11	0
Hyla arborea (EN)	*7*	*2*	*6*	*0*	58	24	*0*	*0*	*0*	*0*
Pelophylax sp. (LC)	68	92	37	29	130	61	26	8	18	7
Pelophylax ridibundus (NE)	22	24	9	6	24	8	*5*	*2*	*0*	*0*
Rana temporaria (LC)	95	146	60	74	116	47	44	28	29	10
Ichthyosaura alpestris (LC)	106	156	60	68	102	54	45	26	29	10
Lissotriton helveticus (VU)	63	54	36	23	82	29	19	7	23	4
Lissotriton vulgaris (EN)	*5*	*4*	*7*	*1*	33	12	*5*	*0*	*0*	*0*
Triturus cristatus (EN)	*4*	*3*	*1*	*1*	48	19	*1*	*0*	*0*	*0*

Covariate data

Pond characteristics were **elevation** (m.a.s.l), the surface area of all water bodies at a site (**water surface**, m^2, log-transformed), and **fluctuations** of the water table (0/1), all recorded in the monitoring scheme. The age (years since construction) of newly constructed ponds was calculated for new ponds from the first known year of existence onwards (**pond age**).
The surroundings of each pond were characterized by the percent area of forest within a circular buffer of radius 100m (**forest cover**), and the area of large (width ≥6m) roads within a circular buffer of radius 1km (**area roads**). Both of these variables were extracted from the swissTLM3D vector data (swissTLM3D © 2021 Bundesamt für Landestopografie swisstopo (5704000000)) in QGIS v.3.16 (QGIS.org, 2021).
Structural **connectivity** (Connectivity.a1000 in CovData2.csv) was calculated for each pond *i* in each year *t* as $C_{it} = \sum_{j \neq i} \exp(-d_{ij})$, where d_{ij} is the pairwise Euclidean distance (km) between the focal pond *i* and all other ponds *j* existing in year *t*. This metric assumes a negative exponential dispersal kernel with mean dispersal distance of 1km.
Old and new ponds were distinguished by means of a factor with levels "old" and "new".

Additional covariate data: connectivity quantified by different metrics

Additional covariate data quantifies connectivity of two different types, with five metrics each. The two types were **structural connectivity**, which is based on the spatial distribution of all habitat patches in the landscape, irrespective of their occupancy status, and **potential population connectivity**, which quantifies connectivity only to those patches that were observed to be occupied in the last survey before the year in question. Structural connectivity changes only because ponds get created or destroyed; potential population connectivity changes with changes in the spatial distribution of each individual species. For both of these connectivity types, we calculated three metrics: two simple metrics, i.e., the Euclidean ***distance*** (m) to the nearest (occupied) neighbour and the ***density*** of (occupied) ponds within a circular area of $1km^2$ around the focal pond, and three values of the theory-derived ***kernel connectivity*** metric used previously. Structural kernel connectivity was calculated as $Conn_{str,\alpha,i,t} = \sum_{j \neq i} exp(-d_{ij}/\alpha)$, where d_{ij} is the pairwise Euclidean distance (m) between the focal pond *i* and all other ponds *j* existing in year *t*, and $\alpha = \{200, 500, 1000m\}$ is a scaling parameter that corresponds to typical dispersal distance. Potential population kernel connectivity was calculated as $Conn_{pop,\alpha,i,t} = \sum_{j \neq i} exp(-d_{ij}/\alpha)y_j$, where $y_j = \{1, 0\}$ indicates whether site *j* was observed to be occupied or not by the focal species in the last available survey prior to year *t*, using the same values for $\alpha = \{200, 500, 1000m\}$.

Dataset

The openly accessible dataset consists of 1) **ObsData.csv**: a file containing edited and anonymized observation data for all species as well as an identifier for the observer (**ObserverID**, largest value corresponds to NA), where variable **Detectable** indicates whether visit *j* to site *i* in year *t* occurred or not, stored in long format; 2) **CovData1.csv**: a file containing covariate data that does not change through time; and 3) **CovData2.csv**: a file containing covariate data that changes through time, stored in long format.

The R markdown script **RunModels1.Rmd** contains the model descriptions and all code necessary to standardize covariates and run models for all species, as reported on in Moor et al. (2022).

Additional data are 4) **CovData_StructConn.csv**, which contains the additionally calculated structural connectivity metrics, and 5) **CovData_PopConn.csv**, which contains the additionally calculated potential population connectivity metrics for all species. Both files store covariate values in long format.

The R markdown script **RunModels2.Rmd** contains the model descriptions and all code necessary to standardize and format the covariate data, including the structural and potential population connectivity metrics, and run models for all species. This script fits 10 models per species, with one connectivity metric included in each.

References

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