Limited Data Used to Make Valid Inference about Targeting Sites for Conservation: A Case Study in Urban Amphibian...

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ARTICLES

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Limited Data Used to Make Valid Inference about Targeting Sites for Conservation: A Case Study in Urban Amphibian Ecology

Field data collection is often hampered by budgetary constraints, extreme weather events, and other obstacles limiting the quality and quantity of gathered information. Faced with such challenges, researchers may feel compelled to avoid or terminate a study, leading to a limited understanding of some ecological processes and hindering management. Data gathered during droughts, which are increasing in frequency (IPCC 2014), can lead to insights on how organisms respond to water limitation and lead to understanding of how drought shapes species distributions (Matthews and Marsh-Matthers 2003; Engelbrecht et al. 2007). Sampling rare, hard-to-find taxa or periodic populations (e.g., our study area with fossorial amphibians that only emerge during monsoonal rainstorms in arid or semi-arid regions and may not emerge every year) is an especially thorny problem (Thompson 2004; Griffiths et al. 2015). As the extinction crisis deepens (Maclean et al. 2011; Urban 2015) and as anthropogenic climate change results in increasingly frequent severe climatic events (Seager and Vecchi 2010), "extreme" conditions are becoming more common. Traditional methods, which are more robust, such as occupancy analysis and estimating detection probabilities require more data for the computation of parameters (MacKenzie et al. 2006). Since we do not always have the luxury of adequate data, establishing efficient methods for extracting useful information from meager data collected under limiting conditions is growing in importance, but currently understudied. This approach can allow managers to identify sites that are most able to respond to management actions and consequently identify the locations where it is most efficient to apply resources for conservation.

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Our objective was to use data on amphibian occurrence collected during a record drought year of 2011, during which amphibian activity was severely curtailed (Ramesh et al. 2012), to predict likely occurrence of amphibians during more normal years like 2012. The study was conducted in the city of Lubbock, an urban area located in west Texas, USA. Most amphibians in this semi-arid region undergo explosive breeding cued by heavy rainfall and not all species breed every year (Sullivan 1989; Krupa 1994; Sullivan et al. 1996; Anderson et al. 1999). We collected initial data in 2011, during an unprecedented drought accompanied by record high temperature (NOAA 2011; 2012a; State Water Plan 2012). We combined this information with previously-identified landscape characteristics associated with amphibians in the area (Ramesh et al. 2012) to assess whether data collected during such abnormal circumstances could predict the likelihood of amphibian occurrence once drought conditions eased (NOAA 2012b). The ability to predict sites that would be most responsive to management actions to improve amphibian occupancy can help managers better allocate their limited resources. To accomplish this, we compared several modeling approaches (logit, Poisson, and zero-inflated Poisson) to determine the best method(s) for producing inferences based on such limited data.

METHODS

We assessed urban lakes located in the city of Lubbock, Lubbock County, Texas, USA. These are modified playa wetlands excavated to increase water storage capacity. Some are connected during extremely high rainfall events by a drainage system intended to reduce urban flooding (Lubbock City Storm Water Management https://www.ci.lubbock.tx.us/departmental-websites/departments/storm-water-management/maps). Connection of waters due to floods did not occur during the sampling period. Lakes averaged 6.3 ha (standard error [SE] = 1.0) and were located an average of 690 m apart (SE = 61) (Fig. 1).

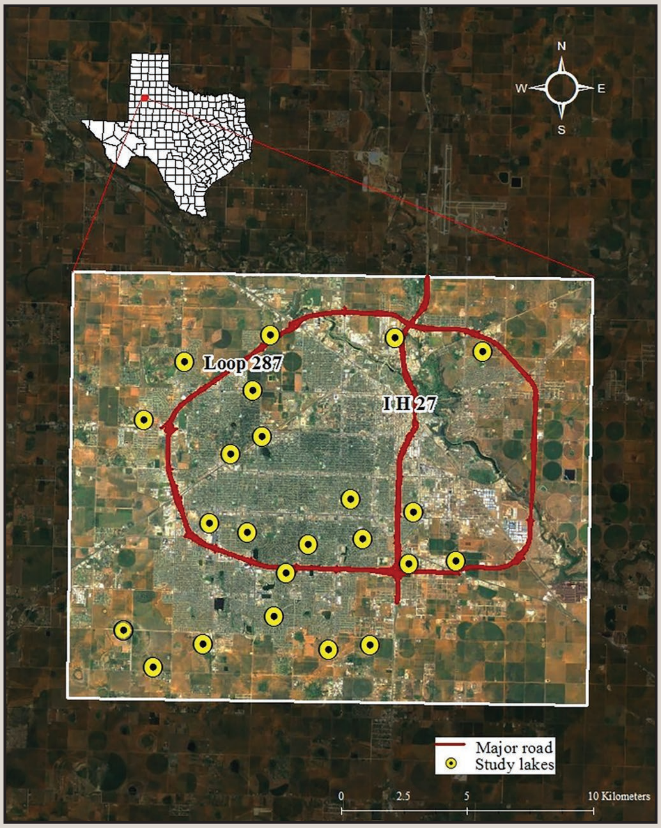

FIG. 1. Urban lakes sampled for amphibians in Lubbock, Texas during 2011 and 2012.

TABLE 1. Comparison of conditions and data totals between 2011 and 2012 for amphibian sampling in Lubbock, Texas.

	2011[1]	2012
Rain total (long term average 49 cm)	14.9 cm[2]	29.0 cm[3]
Number of lakes sampled	23	23
Number of lakes with water > 3 months	11	13
Number of lakes with amphibians	7	11
Number of amphibian species detected	5	9
Maximum species richness of amphibians at a site	3	5

[1] Ramesh et al. (2012)
[2] http://www.srh.noaa.gov/lub/?n=events-2011-20111231-summary
[3] http://www.srh.noaa.gov/lub/?n=events-2012-20121231-summary

Our 2011 drought presence/absence and species richness data and lake characteristics came from Ramesh et al. (2012) who surveyed 23 urban lakes located throughout the city from March to October, and only detected amphibians in seven of them. We then sampled the same lakes using the same methods in 2012 from March to June (difference in sampling period is related to differences in rainfall). We performed 5-min call surveys and 20-min visual encounter surveys starting half an hour after sunset on the nights following rain events generating over 2 cm of rain (2011: 11 August, 14 September, 8 October) (2012: 9, 18–21 March; 9, 11, 29 April). During both periods we sampled each lake for two consecutive weeks after these rain events using a pipe-sampler. The sampling locations were < 1 m deep and the number of samples was standardized based on lake area: eight samples for lake areas < 2 ha, 12 samples for lakes 2–4 ha, and 16 samples for lakes > 4 ha. Samples were at least 5 m apart to ensure independence (Korfel et al. 2009). At a sample site, the pipe sampler was thrown in the littoral zone of the lake, and pushed into the substrate to seal the sample space. A dipnet was then used to sweep tadpoles from the sample space. Sweeps were carried out until ten consecutive null sweeps were achieved (sweeps without catching any tadpoles) (Werner et al. 2007). We then identified (Altig 1970) and released all tadpoles caught. A combination of survey types was used to increase our ability to detect amphibian presence.

We sampled and evaluated lake characteristics including water quality measured with handheld probes (pH, conductivity: YSI 63 meter), the presence/absence of fish, ocular estimation of percent cover of emergent vegetation of the lake surface, hydroperiod class (1 – dried within two weeks; 2 – dried within three months; 3 – water present for > 3 months), and lake area (based on US Fish and Wildlife Service, Wetland Inventory data ground-truthed during surveys). Landscape characteristics were quantified from land-cover information provided by the Texas Natural Resources Information System (TNRIS) and the Lubbock City website within 500 m of the lake's maximum extent; buffer based on published literature of amphibian movements (Semlitsch and Bodie 2003; Gray et al. 2004). The landscape characteristics we quantified were land cover, road density, percent cover of impervious area, nearest wetland distance, and age of development of the urban area surrounding the lake using ERDAS IMAGINE (Intergraph Corporation Pert of Hexagon Group).

Our modeling was based on a year of sparse occurrences (2011) and we were testing whether these data could be helpful given inherent shortcomings related to a lack of detections. We made several assumptions/decisions in applying our techniques. First, we assumed that the variables we measured such as land cover are static. In a developed urban setting this is a relatively safe assumption depending on the time scale. Second, we lumped species together when we quantified amphibian presence, so if any species was present, that lake was recorded as having amphibians. We did this because amphibians can be difficult to observe during drought years, and all species use the same lakes for breeding in relatively the same way, at least in this system and at the scale of response we tested. In other words, individuals are similar in their response to rainfall (emergence and breeding migration). Third, we were relatively liberal regarding statistical criteria such as p-values to reduce the chance of classifying a lake as poor habitat when it could actually contain amphibians in a better year (Hosmer and Lemeshow 2000).

We performed exploratory univariate regressions using data from 2011 with lake-level amphibian presence/absence and species richness as response variables to identify predictors, from the field data discussed above, to include in model building. We used a significance level of $\alpha = 0.25$ as a threshold for including a variable since lower values have often failed to identify important variables when data are sparse (Hosmer and Lemeshow 2000).

Next, we formed biologically meaningful models for presence and species richness from variables identified in our exploratory analyses and avoided the inclusion of highly inter-correlated variables ($r_s \leq 0.7$) within the same model. We included a maximum of three variables in a model to minimize over-parameterization (Smallbone et al. 2011). The resultant *a priori* models which we assessed were: 1) Water quality model (pH + conductivity); 2) Hydroperiod model (hydroperiod); 3) Predator model (presence of fish); 4) Wetland isolation model (road density + nearest

Table 2. Models created from 2011 survey data, representing relationships between site-specific and landscape-scale variables with amphibian presence (logistic model) and species richness (Poisson model) ordered based on Δ_i.

Models	-Log likelihood	Δ_i	w_i
Amphibian presence			
pH + road density	10.8	0.00	0.23
road density + nearest wetland distance	10.8	0.08	0.22
neighborhood age	12.2	0.11	0.22
pH + conductivity + road density	9.8	0.97	0.14
pH + conductivity	11.7	1.93	0.09
hydroperiod	13.4	2.57	0.06
fish	13.8	3.30	0.04
Species richness			
pH + conductivity	17.4	0.00	0.38
pH + road density	17.8	0.74	0.26
pH + conductivity + road density	16.7	1.56	0.18
road density + nearest wetland distance	18.8	2.91	0.09
hydroperiod	21.2	4.91	0.03
neighborhood age	21.3	5.23	0.03
fish	21.4	5.36	0.03

wetland distance); 5) Development model (neighborhood age); 6) Combination model 1 (pH + road density); and 7) Combination model 2 (pH + conductivity + road density). To make predictions about the likelihood of amphibian occurrence in 2012, we used logistic regression to look at amphibian presence and Poisson models and zero-inflated Poisson models to examine species richness. Zero-inflated Poisson models were included since data during the drought year were sparse and included many zeroes (Lambert 1992; Welsh et al. 1996). We included the same seven models for each of the three modeling techniques and ranked these candidate models from 2011 data using Akaike's Information Criterion (AIC_c) corrected for small sample sizes. Modeling analyses were performed using SAS Ver. 9.3 (SAS Institute Inc., Cary, North Carolina, USA) and R version 3.1.3 (The R Foundation for Statistical Computing). We conducted model-averaging procedures for the logit, Poisson, and zero-inflated Poisson model sets among all the 2011 candidate models and used these predictions to rank lakes as to the likelihood of amphibian presence using the AICcmodavg package in R to calculate model averaged estimates of parameters using all models tested (Burnham and Anderson 2002; Anderson 2008; Mazerolle 2011). We compared the Poisson and zero-inflated Poisson approaches to determine which measure of species richness was most appropriate given our data using the Vuong closeness test for comparing relationships between models and the data based on likelihood ratios (Vuong 1989).

We then compared models between the techniques and evaluated our predictions against the data from 2012. We compared the model averaged expected values from 2011 for presence (logit model) and species richness (Poisson model) with the actual values from 2012 using a Spearman's rho (IBM SPSS Statistics version 23.0.0.0). One lake was excluded from the analysis because it never had water in 2012 and consequently could not have supported amphibians that year.

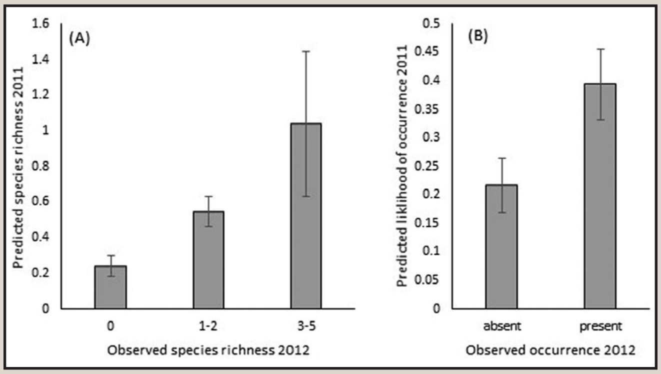

Fig. 2. Predicted species richness ± standard error (A) and occurrence (B) based on data from 2011 are able to identify lakes with a high probability of having amphibians use them for breeding in future years even when they are originally collected in a drought year in west Texas urban lakes. This method was able to predict amphibian occurrence in six lakes that did not have amphibians during 2011, but did have them in 2012. Data are binned as we are using data from limited years; this reduces the noise associated with the predictions and makes ranking conservation priorities easier.

Results

In 2012, a year with only slightly below-average rainfall (NOAA 2012b), more lakes filled, more lakes had amphibians, and we found more species of amphibians overall than in 2011 (Table 1).

We detected nine species of amphibians, only five of which were recorded by Ramesh et al. (2012) in 2011. Sightings included *Anaxyrus cognatus* (Great Plains Toad) in 2012, *Anaxyrus speciosus* (Texas Toad) in both years, *Gastrophryne olivacea* (Great Plains Narrow-mouthed Toad) in both years, *Lithobates blairi* (Plains Leopard Frog) in 2012, *Lithobates catesbeianus* (American Bullfrog) in both years, *Pseudacris clarki* (Spotted Chorus Frog) in both years, *Spea bombifrons* (Plains Spadefoot) in both years, *Spea multiplicata* (Mexican Spadefoot) in 2012, and *Ambystoma mavortium* (Barred Tiger Salamander) in 2012.

We ran the models (Table 2), and calculated the model averaged predicted values for species richness and amphibian presence for each lake (Table 3). The standard Poisson model better ranked the likelihood of 2012 species richness data than did the zero-inflated Poisson model (AIC corrected Vuong $z > 3.6$, $P < 0.001$ for models with $\Delta_i\text{AICc} < 2$) (Vuong 1989). Consequently, we did not include the zero inflated models in what we report.

In 2012, we detected amphibians at six lakes that did not have amphibians in 2011. These six lakes had relatively large predicted values (> $\bar{x}$ + standard error (SE) for those with no amphibians present) from the Poisson model, and three of the lakes had relatively large values as indicated by the logit models (> $\bar{x}$ + (SE) for those with no amphibians present) so were more likely to have amphibians in 2012 than in 2011 (Table 3). The logit model predicted three sites and the Poisson model predicted two sites without amphibians in 2011 to contain amphibians in the future, although none of those sites had amphibians either year (Table 3). We found a significant positive relationship between our 2011-ranked likelihoods and observed values from 2012 for both presence (Spearman's $\rho = 0.58$, $p = 0.005$) and species richness (Spearman's $\rho = 0.65$, $p = 0.001$) (Fig. 2). Only one lake with species present in 2011 did not have species in 2012, an unexpected result.

Table 3. Species richness and amphibian presence data from 2011 and 2012 along with predicted estimates from AICc. Model averaged predicted values based on 2011 data from Poisson regression and logistic regression for Lubbock, Texas. The value of the predictions (model-averaged estimates) is used to give the relative rank of how likely a lake is to contain amphibians rather than a true prediction of species richness or presence.

	Species Richness			Amphibian Presence		
Lake	2011	2012	2011 Poisson prediction	2011	2012	2011 logit prediction
20	0	0	0.09	0	0	0.08
22	0	0	0.11	0	0	0.1
44	0	0	0.13	0	0	0.08
17	0	0	0.15	0	0	0.12
16	0	0	0.18	0	0	0.24
24	0	0	0.2	0	0	0.11
89	0	0	0.21	0	0	0.14
31	0	0	0.23	0	0	0.29
27	0	2	0.26	0	1	0.2
29	0	0	0.27	0	0	0.17
94	1	5	0.3	1	1	0.42
42	0	1	0.32	0	1	0.19
51	0	0	0.32	0	0	0.36
93	1	5	0.37	1	1	0.46
48	0	2	0.45	0	1	0.3
21	2	2	0.55	1	1	0.22
84	0	2	0.65	0	1	0.58
105	0	1	0.71	0	1	0.37
85	2	0	0.77	1	0	0.56
56	0	1	0.9	0	1	0.26
132	1	5	1.66	1	1	0.76
13	3	3	1.83	1	1	0.6

Discussion

Effective sampling has long been a matter of concern in ecology and conservation (e.g., Oosting 1948; Balmford et al. 1996). Popular methods such as occupancy estimation (MacKenzie et al. 2006) are preferred by journal reviewers but can require more data than are able to be collected in bad years. Inferences are stronger when an assortment of diversity metrics are included in the modeling for conservation planning (Fleishman et al. 2006), which is excellent advice when there are time, resources, and conditions appropriate to gather those data. Studies that lack sufficient data for such analyses may be abandoned before completion or fail to find a suitable outlet. Scientists seeking to identify conservation priorities based on limited data have suggested various approaches, most including basing estimates of biodiversity and species richness on higher taxa richness (e.g., genera diversity or family diversity) (Williams and Gaston 1994; Balmford et al. 1996; Maes et al. 2005). Ours is the first we found that provides an evidence-based framework for identifying locations to prioritize for conservation even when using data from suboptimal years. Normally, a year such as the record drought that Lubbock experienced in 2011 would be considered inadequate for amphibian monitoring or conservation planning. Yet data collected during 2011 (Ramesh et al. 2012)—demonstrably a suboptimal year for sampling amphibians—allowed us to draw valid inferences about which sites were more likely to hold amphibians during better years as shown by 2012 data.

Species richness was a better measure for ranking the likelihood of a particular site to hold amphibian species during a normal year than was presence, although both were successful metrics. We were able to identify six lakes where no amphibians were found in 2011, that were likely to—and indeed did—contain species in 2012. These "new" detections are likely from species that did not get the necessary cues to initiate breeding in 2011 and are not likely colonizations. The rankings also identified lakes in which more rain was unlikely to—and, in fact, did not—lead to sightings (Fig. 2). However, the ability of this metric to accurately predict actual species richness is low and consistently under-predicts actual species richness. Consequently, this method should not be used as a predictor of species richness, instead it is an index of the likelihood of species being present in a future year. This is expected as we are using a drought year with few amphibians to rank the probability that those sites will in fact contain amphibians in future years. So, the fact that the predicted values are lower than values we find in future years is not a large issue given that the goal of this work is to identify conservation priorities rather than to precisely predict species richness at a given site (Balmford et al. 1996).

This study shows how even limited data collected during the worst of conditions can produce useful insights. However, this should not be taken as a recommendation of partial studies. Both the original study (Ramesh et al. 2012) and our current follow-up were carefully designed to systematically sample multiple locations using more than one method. The paucity of located animals was the result of few animals breeding, not of insufficient effort or partial sampling. Poorly conceived or performed studies will not produce valuable information. Nor do we claim ours to be the best approach for statistical analysis or strategizing.

Given a more extensive dataset, the computationally complex and data-demanding methods in current use would produce more nuanced predictions. Unfortunately, biologists are not always given these resources, and so must make do with limited information in some cases.

Working backwards from the problem and thinking about information needs can help identify data that can inform decisions. In this case, species richness and even presence can serve as an index of conservation priority (Grose 2014). We show that the relationship between appropriateness of the site and species richness, given the conditions within a year, can have enough of a consistent relationship to allow us to identify sites where our limited funding for conservation will be best used. The use of metrics of biodiversity as indices of conservation prioritization has a long history (Balmford et al. 1996; Sarkar et al. 2006); our work demonstrates we can still effectively use this approach based on data collection during years of environmental extremes and under suboptimal sampling conditions.

As weather conditions are becoming progressively more variable and increasing in extremes (IPCC 2014), we will have fewer and fewer years to collect "good" data. Our study shows that limited data—in this case, collected during an extreme drought—can provide useful information, allowing ranking of sites with high potential for amphibian occurrence in better years.

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