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USING CALLING ACTIVITY TO PREDICT CALLING ACTIVITY: A CASE STUDY WITH THE ENDANGERED HOUSTON TOAD (*BUFO* [*ANAXYRUS*] *HOUSTONENSIS*)

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ABSTRACT: Understanding anuran calling activity patterns is important for maximizing efficiency and value of call survey data collection and analyses. Previous studies have primarily focused on identifying and quantifying abiotic variables that influence anuran calling activity, and investigating relationships between calling activity and population estimates. In this study we investigated the use of a predictor pond approach to guide call survey effort. In this approach, calling activity at a subset of breeding sites (e.g., ponds) is used as a predictor of calling activity at additional breeding sites, with the goal being to minimize sampling effort while simultaneously maximizing sampling efficiency. We explored the efficiency of this approach using call survey data collected on the endangered Houston Toad (*Bufo* [*Anaxyrus*] *houstonensis*) at 15 known breeding ponds over 9 survey years. We found that if calling activity at 3 predictor ponds was used to decide if additional call surveys would occur at the remaining 12 ponds, we would have hypothetically correctly assumed calling activity was not occurring at non-predictor ponds on 92.1% of survey nights, and we would have hypothetically detected 93.9% of the total number of detected individuals over the 9 survey years. We found the predictor pond approach performed well in our case study, and believe it could be a valuable tool for many anuran monitoring programs.

INTRODUCTION

Amphibians are at the forefront of the current biodiversity crisis (Alford and Richards 1999, Beebee and Griffiths 2005, Becker et al. 2007). In response to this issue, many anuran call survey monitoring programs (e.g., the Amphibian Research and Monitoring Initiative and the North American Amphibian Monitoring Program) have been initiated to track long-term population trends. Research on anuran activity patterns is important for maximizing efficiency and value of call survey data collection and analyses (Nelson and Graves 2004, Steelman and Dorcas 2010). Previous studies have primarily focused on identifying and quantifying abiotic variables that influence anuran calling activity (Oseen and Wassersug 2002, Saenz et al. 2006, Steelman and Dorcas 2010, Cook et al. 2011, Pierce and Hall 2013), and investigating relationships between calling activity and population estimates (Nelson and Graves 2004, Grafe and Meuche 2006).

Annually, calling activity varies widely among anuran species, from highly explosive breeders that call only a few days a year to prolonged breeders that may call throughout most or all of the year (Wells 2007). Although predictive calling-activity models are valuable for prolonged breeders, they are most useful for explosive and erratic breeders due to inherently low baseline detection probabilities. For explosive and erratic breeders, when relationships between abiotic variables and calling activity are unknown, or perceived relationships are unreliable, extensive effort is required to ensure accurate calling-activity dynamics are captured through call survey sampling. Thus, sampling designs that seek to minimize sampling effort while simultaneously maximizing sampling efficiency are desirable.

In this study we explored the potential for using a predictor pond approach to guide call survey effort. In this approach, calling activity at a subset of breeding sites (e.g., ponds) is used as a predictor of calling activity at additional breeding sites. This approach could be useful in situations where sampling involves a large num-

Table 1. Year-specific results for this assessment of the value of a predictor pond approach to guide call-survey effort for the endangered Houston Toad (*Bufo* [*Anaxyrus*] *houstonensis*), a rare anuran endemic to east-central Texas. In this approach, calling activity at a subset of breeding sites (e.g., ponds) is used as a predictor of calling activity at additional breeding sites. The results in the table are based on a scenario where 3 predictor ponds were surveyed, and the remaining 12 ponds were surveyed only if at least 1 Houston Toad was detected during the predictor pond survey. The data are derived from 189 full call surveys on the Griffith League Ranch (GLR), Bastrop County, Texas, USA.

Year	Total survey nights	Positive detection nights[a]	Positive prediction error[b]	Individual (all ponds)[c]	Individual detections (non-predictor ponds)[d]
2001	20	2	0.00	1.00	1.00
2002	20	10	0.23	0.87	0.27
2003	20	7	0.19	0.85	0.17
2004	19	7	0.14	0.89	0.67
2005	19	8	0.08	0.97	0.88
2009	27	5	0.00	1.00	1.00
2010	27	15	0.29	0.93	0.81
2012	21	11	0.09	0.97	0.83
2013	16	2	0.00	1.00	N/A
$\bar{x}$(SD)	21 (3.6)	7.44 (4.22)	0.11 (0.11)	0.94 (0.06)	0.70 (0.32)

[a]Number of call-survey nights where at least 1 Houston Toad was detected.
[b]Proportion of nights where we detected at least 1 male Houston Toad at a non-predictor pond but no Houston Toads at predictor ponds.
[c]Proportion of total individual detections that would have been obtained using the predictor pond approach.
[d]Proportion of non-predictor pond individual detections that would have been obtained using the predictor pond approach.

ber of breeding sites, and thus extensive survey effort is expended, whether or not individuals are attempting to breed. We tested this concept using the federally endangered Houston Toad (*Bufo* [*Anaxyrus*] *houstonensis*), an anuran endemic to east-central Texas (U.S. Fish and Wildlife Service 1984). Breeding activity for this species occurs at irregular intervals, typically between January and May, with peak activity between February and April (Hillis et al. 1984, Brown et al. 2013). Given its endangered status and a focus on using monitoring data to aid in conservation-oriented research for this species (e.g., Swannack et al. 2009, Gaston et al. 2010, Vandewege et al. 2013), there is interest in optimizing both data quality and monitoring efficiency for the Houston Toad. To assist with maximizing detection, we recently developed predictive models for calling activity (Brown et al. 2013), and since 2009 we have supplemented complete call survey nights with additional survey nights using the predictor pond approach described in this paper. However, as far as we are aware this study represents the first statistically-based investigation of the efficiency of using predictor ponds to guide survey efforts.

METHODS

This study was conducted on the 1,948 ha Griffith League Ranch (GLR) in Bastrop County, Texas, USA. The GLR is located within designated Houston Toad critical habitat in the Lost Pines ecoregion, a 34,400 ha remnant patch of pine-dominated forest (Bryant 1977, Al-Rabah'ah and Williams 2004), and is considered an essential conservation tract for long-term persistence of the Houston Toad (Hatfield et al. 2004). The GLR contains three permanent ponds (i.e., ponds have not dried in at least 12 years), 10 semi-permanent ponds (i.e., ponds typically dry several times per decade), and 10 or more ephemeral ponds that hold water for days to months annually depending on rainfall. For this study we used 15 known Houston Toad breeding ponds that have been monitored since 2001.

We conducted manual call surveys on GLR between 2001 and 2013. On each survey night we surveyed for 5 minutes all ponds holding water and recorded the number of Houston Toads heard and seen. When Houston Toads were detected we captured them, recorded standard measurements, and individually marked them using either toe clips or Passive Integrated Transponder (PIT) tags (Camper and Dixon 1988, Donnelly et al. 1994). Previous research determined that handling and PIT-tagging Houston Toads during calling nights did not appear to have any negative impacts on behavior or subsequent returns to breeding sites (Dixon et al. 1990). Additional details on Houston Toad call surveys and monitoring on GLR are given in Jackson et al. (2006) and Brown et al. (2013).

We restricted our analyses to surveys conducted between February and April in the years 2001 to 2005 and 2009 to 2013 (excluding 2011 because no Houston Toads were detected on GLR during call surveys that year). The survey months correspond to the peak breeding months for the species, and the years correspond to those in which monitoring activity was most intense on GLR (Swannack 2007, Brown 2013). The data set used in this investigation included 189 call survey nights.

Breeding ponds naturally vary over time with respect to anuran occupancy and abundance (Petranka et al. 2004, Petranka and Holbrook 2006, Walls et al. 2011), but there are often breeding sites in a study area that are typically more productive than others (Skelly et al. 1999, Petranka et al. 2007, Hamer and Mahony 2010). After 12 years of monitoring GLR we have found that two ponds (ponds 2 and 12) typically have higher detection than the rest, with respect to total number of male detections over the course of the breeding season. In this study we also included the third most productive pond (Pond 9; based on total male detections over all years) as a potential predictor pond (Figure 1). For the 15 ponds included in this study, distance between ponds ranged from 155 m to 5,318 m (mean = 2,495 m). For Pond 12, distance to the other 14 ponds ranged from 1,322 to 3,423 (mean = 2,177 m), for Pond 2, 759 m to 5,318 m (mean = 2,548 m), and for Pond 9, 833 m to 3,500 m (mean = 2,148 m).

We analyzed the data using logistic regression, with predictor significance assessed against a null model using likelihood-ratio tests (Agresti 2007, Zuur 2009). We conducted three analyses, assessing the predictive performance when using detected calling activity at the most productive pond (Pond 12), the two most productive ponds (Pond 2 + Pond 12), and the three most productive ponds (Pond 2 + Pond 9 + Pond 12) as a predictor of calling activity at the remaining ponds. For each analysis, both our predictor and response data sets contained two levels (0 or 1; calling activity not detected or detected), with all 189 call survey nights included. Thus, we tested whether detected calling activity at any pond in our predictor data set was a significant predictor of detected calling activity at any of the remaining ponds on a given survey night. We also summarized results with respect to detection/non-detection, number of detected individuals, and annual variation, to gauge the efficiency of using predictor ponds to inform call survey effort.

RESULTS

We detected at least one male Houston Toad in 67 of 189 call survey nights. The logistic regressions including three ($D_{1,187}$ = 21.41, P < 0.0001), two ($D_{1,187}$ = 19.64, P < 0.0001), and one ($D_{1,187}$ = 15.97, P < 0.0001) predictor pond indicated detection/non-detection at the predictor pond(s) was significantly better than the null model at explaining detection/non-detection at the remaining ponds. The positive prediction error (i.e., nights where we detected at least one male Houston Toad at a non-predictor pond when we did not detect a Houston Toad at a predictor pond) was 23.3%, 11.6%, and 7.9% with one, two, and three predictor ponds, respectively. The annual variation in positive prediction error ranged from 0% to 29% when using 3 predictor ponds (Table 1). With respect to total detections, we would hypothetically have detected 48.4%, 81.8%, and 93.9% of the 444 detected male Houston Toads if we only surveyed the remaining ponds following detections at one, two, and three predictor ponds, respectively. The annual variation in total individuals detected using 3 predictor ponds ranged from 85% to 100% (Table 1). When just considering individuals detected at non-predictor ponds (i.e., removing all predictor pond detections), 27.8%, 51.2%, and 75.5% of the 110 male Houston toads would hypothetically have been detected with one, two, and three predictor ponds, respectively. The annual variation in non-predictor pond

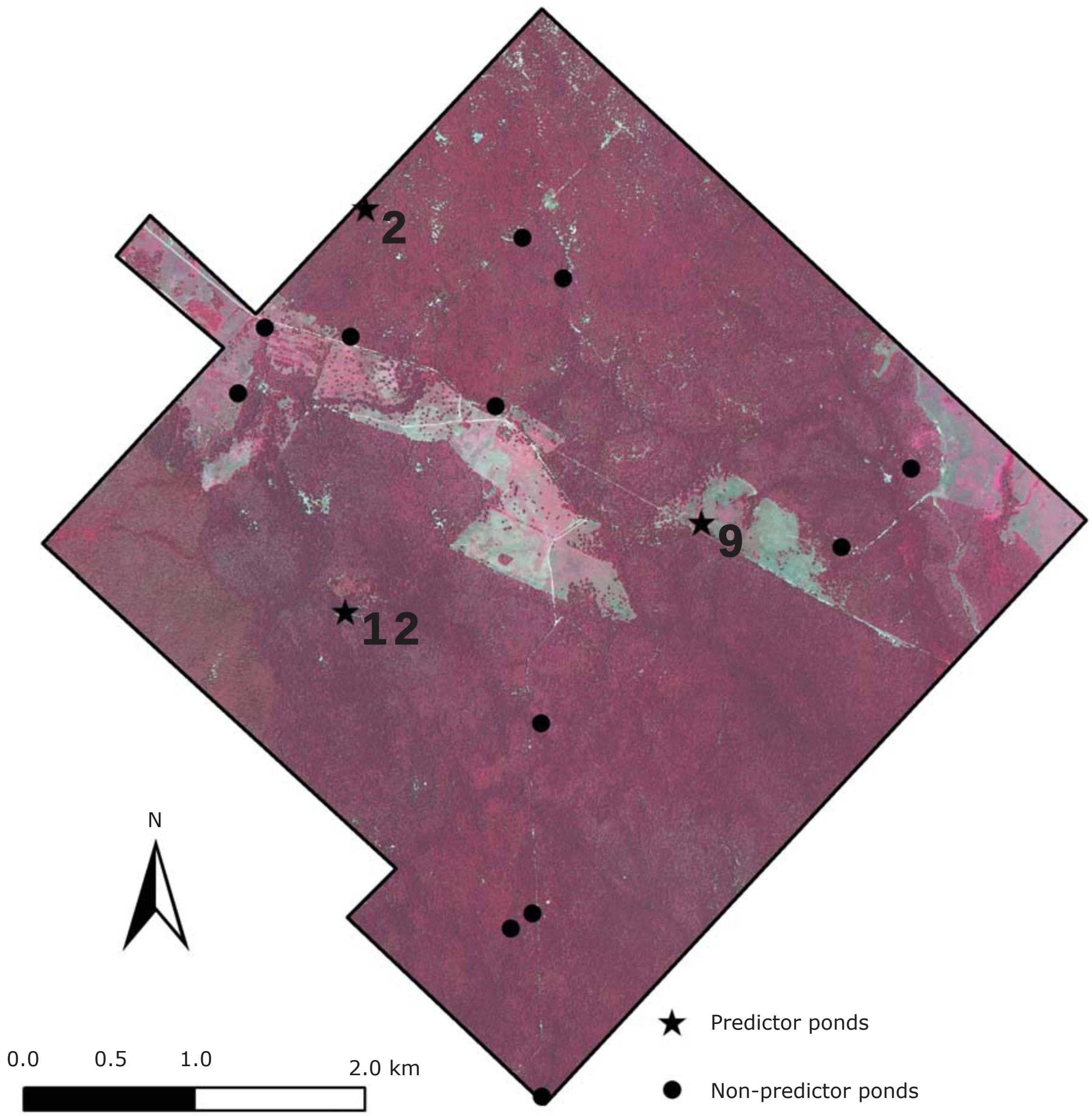

Figure 1. Ponds on the Griffith League Ranch (GLR), Bastrop County, Texas, USA used in this study to investigate the use of a predictor pond approach to guide call-survey effort. In this approach, calling activity at a subset of breeding sites (e.g., ponds) is used as a predictor of calling activity at additional breeding sites. The figure shows the spatial relationships among the 3 predictor ponds (including pond number) and 12 remaining ponds used in this study.

individuals detected using 3 predictor ponds ranged from 17% to 100% (Table 1).

DISCUSSION

We found the predictor pond approach to perform well for Houston Toad calling activity on GLR, even when only one predictor pond was used. As one would expect, increasing the number of predictor ponds increased the reliability of the predictor, with three ponds in our example being sufficient to account for most of the detection nights and number of detections at non-predictor ponds (see Table 1). Thus, in years when funding or personnel constraints limit the amount of time spent on call surveys, this approach appears to be useful for maximizing detection return on survey investment. For example, if a surveyor did not detect calling activity at GLR predictor ponds, it may be more efficient to move to another local property or another population fragment, rather than survey the remaining ponds on GLR. Moreover, the ability to reallocate personnel resources with confidence to additional surveys outside of the Bastrop County population fragment would enhance our understanding of calling activity correlations, or lack thereof, among the remaining population fragments.

The surveying concept described here would be most useful in situations where detection probabilities are inherently low, such as with explosive breeding anurans and in situations where the goal is to maximize both the number of sites surveyed and the number of individuals detected over the course of a sampling season. This protocol essentially increases the detection probability at non-predictor ponds. This could be useful for hierarchical modeling designs such as occupancy and *N*-mixture modeling, where estimators tend to perform poorly when baseline detection probabilities are very low (Bailey et al. 2004, MacKenzie et al. 2002).

The difficulty in using this approach is in choosing the best predictor pond(s), which requires prior knowledge of spatial and temporal pond-level dynamics in a study area. Although we chose to use the overall most productive ponds over the 13 year survey period as predictor ponds for our study area, there are other options that could perform better in some circumstances. For example, one could investigate correlations in calling activity among survey sites and choose those ponds with the historically highest correlation among all sites within subsets of survey sites. However, in study areas with high temporal variability in pond-level dynamics it may not be possible to delineate predictor ponds that perform well. In our case study the predictor ponds performed poorly in 2002 and 2003 with respect to number of individual detections at non-predictor ponds, but well in the remaining 7 survey years (see Table 1). Despite this issue we believe the predictor pond approach could be valuable for many anuran monitoring programs where the same sites are regularly surveyed.

The predictor pond approach described here has value beyond manual call surveys. The use of automated audio recorders for monitoring anuran calling activity is now common, and automated audio recorders that enable remote access to data are now available (e.g., Song Stream by Wildlife Acoustics). In this context, audio recorders set at predictor ponds would send data to a server, which could be downloaded remotely from a website by the call surveyor. This would allow the call surveyor to perform a predictor pond survey any night where the expectation of calling activity is not unreasonable, without leaving home or office. Thus, using the predictor pond approach in combination with remote calling activity monitoring has the potential to simultaneously minimize sampling effort and maximize sampling efficiency.

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