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Source: Journal of Herpetology, 55(2) : 174-180

Published By: Society for the Study of Amphibians and Reptiles

URL: https://doi.org/10.1670/19-079

Journal of Herpetology, Vol. 55, No. 2, 174–180, 2021

The Use of Evoked Vocal Responses to Detect Cryptic, Low-Density Frogs in the Field

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ABSTRACT.—**The protection of rare amphibians depends upon accurate information about their distributions, yet cryptic, low-density populations are easily missed during field surveys. We used sites with known populations of the U.S. federally threatened species *Rana chiricahuensis* ($n = 34$) and its congener *Rana yavapaiensis* ($n = 11$) in Arizona, USA to test whether a conspecific call stimulus can improve detectability of species. We show that the use of the evoked vocal responses technique improves the detectability of initially silent anuran populations of *R. chiricahuensis* and *R. yavapaiensis* by 45% and 71%, respectively. Evoked vocal responses, however, were not strictly species specific: 19% of *R. chiricahuensis* and 45% of *R. yavapaiensis* populations also increased their vocal activity in response to heterospecific stimuli. The low costs of the material (<50 USD per set) and the short time (1 min) to play a stimulus suggest that the additional costs associated with this technique will be minor relative to existing survey protocols. This technique offers the potential to improve the detection of other frog species, particularly in sites that are difficult to search visually, provided it is carried out by surveyors who can identify species by their calls.**

Amphibians of the world have declined in large portions of their ranges (Stuart et al., 2004; Lannoo, 2005). The conservation and recovery of threatened species hinge upon accurate distribution maps, which not only help identify core populations, but also measure the effectiveness of conservation actions. Anuran species can be particularly difficult to monitor because of their patchy distributions, cryptic nature, and low detectabilities. In addition, morphological similarities between sympatric species can complicate species identification. The failure to detect small anuran populations could have negative consequences for the metapopulation dynamics (Hanski and Gilpin, 1991; Hanski and Ovaskainen, 2002) of a species. Thus, it is important for field surveys to maximize their detection-probability–to–effort ratio.

As its name implies, the evoked vocal responses (EVR) technique seeks to elicit a vocal response from individuals by playing a conspecific mating call. This approach has long been used by ornithologists (Ralph and Scott, 1981; Harris and Haskell, 2013) and in anuran behavioral research (Capranica, 1965; Sullivan, 1985; Ryan and Rand, 1998; Simmons, 2004). It has recently been integrated into amphibian survey protocols, although to date its efficacy has not been measured. Field tests need to be conducted in order to gauge the efficacy and reliability of the EVR technique. Can it provoke a silent frog into calling? If so, how often will such responses be observed? Do species also respond to heterospecific stimuli, and if so, how often? And how long must a human surveyor wait before detecting a response to a played stimulus?

Here, we use leopard frog species that co-occur in Arizona, USA as a case study to test the EVR technique. Southwestern leopard frogs, like amphibians world-wide, have declined in large portions of their range (Clarkson and Rorabaugh, 1989; Lannoo, 2005). In particular, the Chiricahua Leopard Frog (*Rana chiricahuensis*) has disappeared from 80–90% of historical localities in the United States and is currently listed under the Endangered Species Act as threatened (U.S. Fish and Wildlife Service, 2007). The Chiricahua Leopard Frog recovery plan includes several activities that require knowledge of existing populations: 1) reducing or eliminating threats to known populations and habitats, 2) maintaining existing and establishing new populations, 3) improving habitats for breeding and dispersal, and 4) supporting and integrating relevant research needed to provide effective conservation and recovery.

The Chiricahua Leopard Frog recovery plan outlines a protocol where observers detect frogs using standardized visual encounter surveys (U.S. Fish and Wildlife Service, 2007). Observers identify frogs to species using morphological characteristics. But this task can be vexing in the case of southwestern leopard frogs because multiple similar-looking species can co-occur (Platz and Mecham, 1979; Platz and Frost, 1984). In addition, remnant populations are frequently dispersed over large areas and in habitats with difficult access and thick vegetation (U.S. Fish and Wildlife Service, 2007) which makes capturing individuals by hand challenging. By contrast, calls of southwestern leopard frog species are relatively distinct (Hillis and Wilcox, 2005). Thus, they serve as useful cues in the identification process.

The question raised here is whether a safe and convenient technique exists to elicit calling behavior and thus increase the positive detection of a species. We specifically tested whether a standard conspecific call will increase vocal activity relative to a white noise control or modified amplitude call. We also tested the specificity of responses in a second test by measuring elicited calling behavior in response to conspecific and heterospecific stimuli.

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DOI: 10.1670/19-079

Materials and Methods

We used standard species breeding calls (single calls followed by small chorus) from a widely available CD (Elliott et al., 2009) as stimuli. Call files lasted for 30–31 sec and were in wav format, 44 KHz, mono. Locations of original recordings were as follows: *Rana yavapaiensis*: Muleshoe Ranch in the Galiuro Mountains, Cochise County, Arizona; *R. chiricahuensis*: Three Forks, Navajo County, Arizona; and *Rana catesbeiana*: various locations (Ithaca, New York, Felsenthal National Wildlife Refuge, Arkansas, Point Reyes National Seashore, Marin County, California; Elliott et al., 2009).

Number of Sites and Trials.—We initially visited 34 sites with known historical presence of *R. chiricahuensis* and 12 sites with known historical presence of *R. yavapaiensis*, all situated within the U.S. state of Arizona. Two *R. chiricahuensis* populations were captive (in outdoor enclosures). We attempted to run both EVR tests at each site. The number of sites and tests do not correspond because we sampled one *R. chiricahuensis* site four times, in three different months (the number of days between successive tests were 107, 16, and 44), and one *R. chiricahuensis* site was sampled in consecutive years. We assumed that each trial was sufficiently separated in time to be considered independent. Furthermore, a small number of sites were dropped from the analysis. In five cases (four *R. chiricahuensis* sites and one *R. yavapaiensis*) we were unable to confirm the presence of a target species during or after the test, which raised the question of whether data from these sites should be included in the analysis. Indeed, there is no reliable manner to distinguish true and false absences. In one of the five sites, we decided to retain the data even if we could not confirm the presence of individuals on the day of the test because numerous *R. chiricahuensis* adults had been seen at the site 2 wk earlier and because meteorological conditions were conducive to calling. In the remaining four sites, we felt it was preferable to exclude the information because we had no reliable indication that *R. chiricahuensis* adults were truly present or because temperatures (air: 5°C, water 10°C) probably precluded calling. Our choices to exclude trial information from four sites were done to balance the likelihood of Type I and Type II errors, and thus provide a reliable measure of the contribution of the EVR technique to improving detection probabilities. The final data set contained 31–34 trials using *R. chiricahuensis* (depending on the test being run; see below) and 10–11 *R. yavapaiensis* trials.

We ran all of the trials during daylight hours (from 0900 to 1800 h) to match the prevalent survey practices for these species, and during the months of March–November in 2011 and 2012 to match the breeding seasons of both species (Sredl, 2005; Sredl and Jennings, 2005; Goldberg, 2020). Egg masses of *R. chiricahuensis* or females in breeding condition have been reported in all months except January and December, and reports of oviposition in June are uncommon (Frost and Platz, 1983; U.S. Fish and Wildlife Service, 2007); however, in warm springs, the species may breed year-round (Sredl and Jennings, 2005). Egg masses in *R. yavapaiensis* have been observed in every month, but primarily from January through late April and to a lesser extent in the fall during the early monsoon (August–October; Sredl, 2005; Sredl unpubl. data). At each site we also recorded air temperature, water temperature, elevation (m), wind speed (Beaufort), and estimated number of adults of target species. We conducted our field work under Federal Fish and Wildlife Permit TE02368A-1 and Arizona Scientific Collecting permit SP 550490. Our animal-care protocol included the provision that we stop or alter our experiment if a clear negative impact on the focal animals was observed.

EVR Protocols and Hypothesis Testing.—At each site, we exposed the target population to two tests. Test 1 was designed to measure the probability of detecting a call in response to a conspecific stimulus. Test 1 consisted of three audio stimuli: two conspecific calls that differed in amplitude, and a white-noise control. The amplitude of the original call was halved to test whether amplitude influenced the response rate (for technical reasons, the amplitude could not be doubled). Hereafter, the original file is thus referred to as the "superstimulus" and the file with half the amplitude as simply the conspecific call. The control contains unstructured white noise from 0 to 5 kHz in the amplitude envelope of the modified conspecific call. We created all calls using the software Signal (Beeman, 2001).

Test 2 was designed to measure the probability of eliciting and hearing a call in response to conspecific versus heterospecific stimuli. Test 2 consisted of three audio stimuli: a conspecific call, heterospecific I mating call (*R. catesbeiana*), and heterospecific II mating call (*R. chiricahuensis* or *R. yavapaiensis*, depending on the target population).

Recording and Scoring of Vocal Responses to Audio Stimuli.—Each test was preceded by a 5-min quiet period. One or two observers then started recording all calling activity in 1-min segments for 5 min prior to a stimulus (called baseline calling activities) and 5 min following a stimulus. Stimuli were played using portable speakers and MP3 players and responses were audio-recorded. We randomized the order in which tests 1 and 2 were run, as well as the order of the three stimuli within each test. Thus, at a given site, a typical work sequence would consist of the following: install equipment and remain silent for 5 min; start trial with 5-min baseline recording of calling behavior; play first stimulus of first test; record frog calls for 5 min; play second stimulus of first test: record frog calls for 5 min; play third stimulus of first test; record frog calls for 5 min; play first stimulus of second test; record frog calls for 5 min; play second stimulus of second test; record frog calls for 5 min; play third stimulus of second test; record frog calls for 5 min. End of audio trial. If frogs were neither seen nor heard calling (either natural or elicited), then visually search site for presence of frogs.

Rana chiricahuensis and *R. yavapaiensis* mating calls are distinct but have a similar structure: a soft trill called a "snore" and "chuckle," respectively (Frost and Platz, 1983; Platz et al., 1990; Elliott et al., 2009), which may be followed by one or several shorter grunts, called "balloons" and "gulps," respectively. We defined a population as calling when at least one species-specific element was heard. The correct acoustic identification of a species in the field is a function of the number and strength of calls that can be heard. We therefore also defined a response variable *calling score* as the product of the number of calls per minute and the call detectability (defined below, a measure of the unambiguity of the species-specific signal) for each 1-min period. The *net calling score* is the difference between the calling score before and after the stimulus. We initially analyzed each test using two time frames (1 min before/after, and 5 min before/after) but we report only the 1-min time frame because there is an important practical advantage for a protocol that is quicker to execute in the field. Furthermore, as detailed below, our analyses show that the stimulus that elicited that the highest net calling score was identical in 93% of the trials when comparing the 1-min to the 5-min analyses.

We defined a measure of call detectability that reflects the probability of a correct species identification that is based on the types, the duration, and loudness (amplitude) of the calls. We scored the call detectability for each 1-min period on a 0–3 scale:

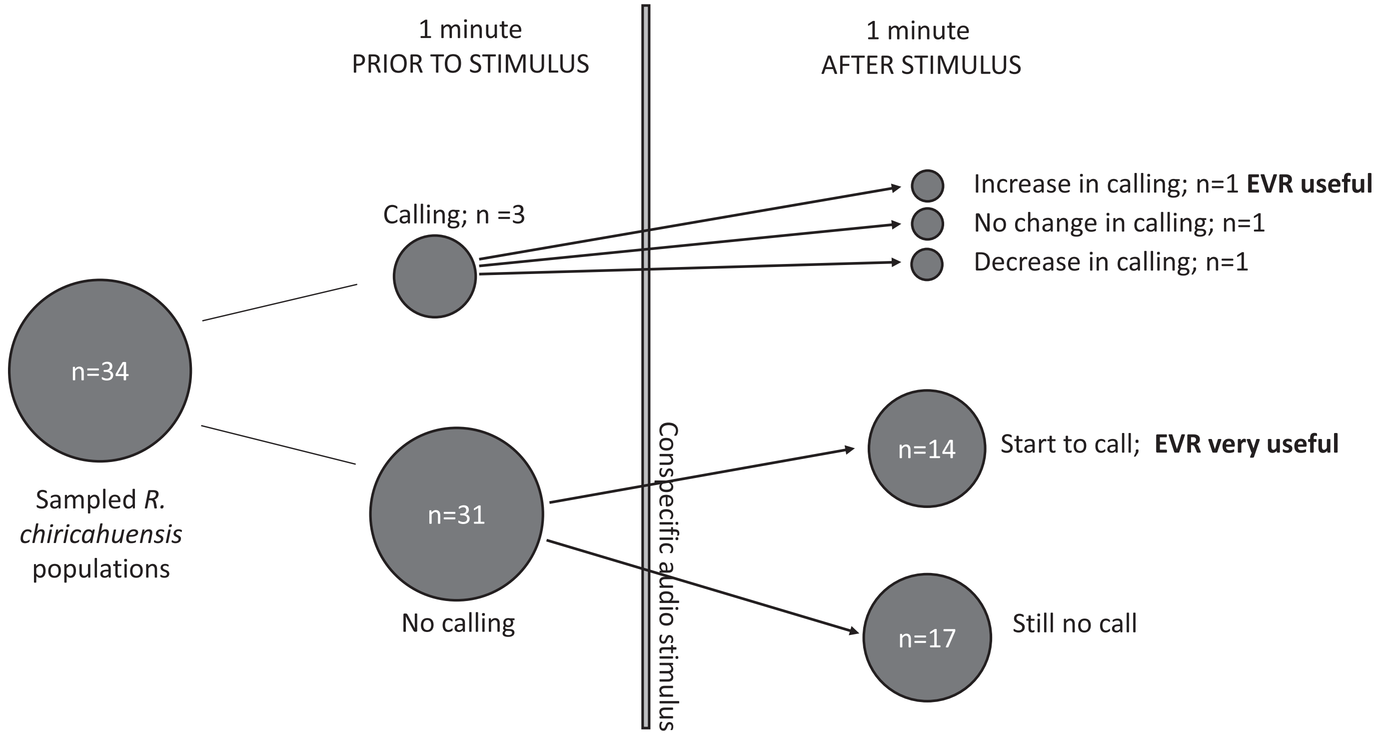

FIG. 1. Summary of calling responses of *R. chiricahuensis* focal populations to a conspecific stimulus. Surface area of circles are proportional to sample sizes.

0 = no calling; 1 = calls are infrequent (fewer than 1–2 calls per min per male) and subdued; 2 = high-intensity calls (full repertoire, including trills) but only 50% of time, or continuous low-intensity calls (only balloons or gulps); 3 = high-intensity calls (full repertoire, trills) by majority of calling individuals, at least 50% of time. Net calling scores in response to stimuli were compared using Friedman's test (nonparametric test for repeated measures, where target populations are blocks).

We defined the EVR technique as "helpful" in cases where the net calling increased as a result of conspecific stimulus, and as "very helpful" in situations where a population is initially silent and then begins to vocalize as a result of a conspecific stimulus. Raw data expunged of site-specific coordinates and a video illustrating the method being used in the field are stored in a long-term data repository (https://doi.org/10.26037/yareta:amxznnt6lbhvnnhle33uacttqm).

RESULTS

Response of Frog Populations to EVR Stimuli.—The vast majority of anuran populations were initially silent (*R. chiricahuensis*: 91%; *R. yavapaiensis*: 70%; Figs. 1, 2) when we approached and in the 5 min prior to testing. In *R. chiricahuensis*, 14 of 31 populations that were initially silent (45%) began to vocalize in response to a conspecific stimulus (Fig. 1). In *R. yavapaiensis*, five of seven populations that were initially silent (71%) began to vocalize in response to a conspecific stimulus (Fig. 2). Thus, the EVR technique was defined as "very helpful" in these situations as an unambiguous species identity was obtained with a 1-min effort. In addition, one out of three *R. chiricahuensis* and two out of three *R. yavapaiensis* populations that were initially vocalizing increased their net calling score in response to a conspecific stimulus (Figs. 1, 2). The EVR technique was defined as "helpful" in such situations as the conspecific stimulus would presumably increase the probability of making a correct species identification in the field.

Across species and experiments, the highest calling score occurred during the first minute following the end of a stimulus in 82% of trials (98 of 120), which is significantly greater than what one would expect by chance (20%; $\chi^2 = 316$, df = 1, $P < 0.001$). In 14 of the 22 cases where the highest calling score occurred after the first minute (i.e., during the second–fifth min), the stimulus with the highest calling score did not change. Thus, in 93% of trials (112 of 120) the result of the experiment after 1 min did not differ from the result after 5 min.

Homogeneity of Scores amongst Observers.—Eight observers participated in at least one of 27 trials with two simultaneous, independent observers. The stimulus with the highest net calling score was shared in 100% of the paired observations. Thus, there is no evidence of an observer effect on results.

Experiment (1): Can a Conspecific Stimulus Increase Calling Scores?—A conspecific stimulus increased the net calling scores in 44% of trials involving *R. chiricahuensis* and in 70% of trials with *R. yavapaiensis* (Table 1). A conspecific or superstimulus conspecific call would occasionally (3–10%) led to a decrease in calling score in *R. chiricahuensis*, but never in *R. yavapaiensis* (Table 1). For *R. chiricahuensis* the median call score in response to the conspecific stimulus was significantly greater than to the white noise control (Friedman $\chi^2 = 7.07$, df = 2 , $P = 0.029$). For *R. yavapaiensis* the median call score in response to the three stimuli (conspecific stimulus, superstimulus, white noise) did not differ significantly (Friedman $\chi^2 = 1.25$, df = 2, $P = 0.53$) but this test suffered from low power due to limited sample size.

Experiment (2): To What Extent Are Elicited Responses Species-Specific?—Each target species was generally more likely to increase their calling (mean score, number of calls that increased) in response to a conspecific stimulus than to a heterospecific stimulus (Table 2). The statistical difference in calling scores

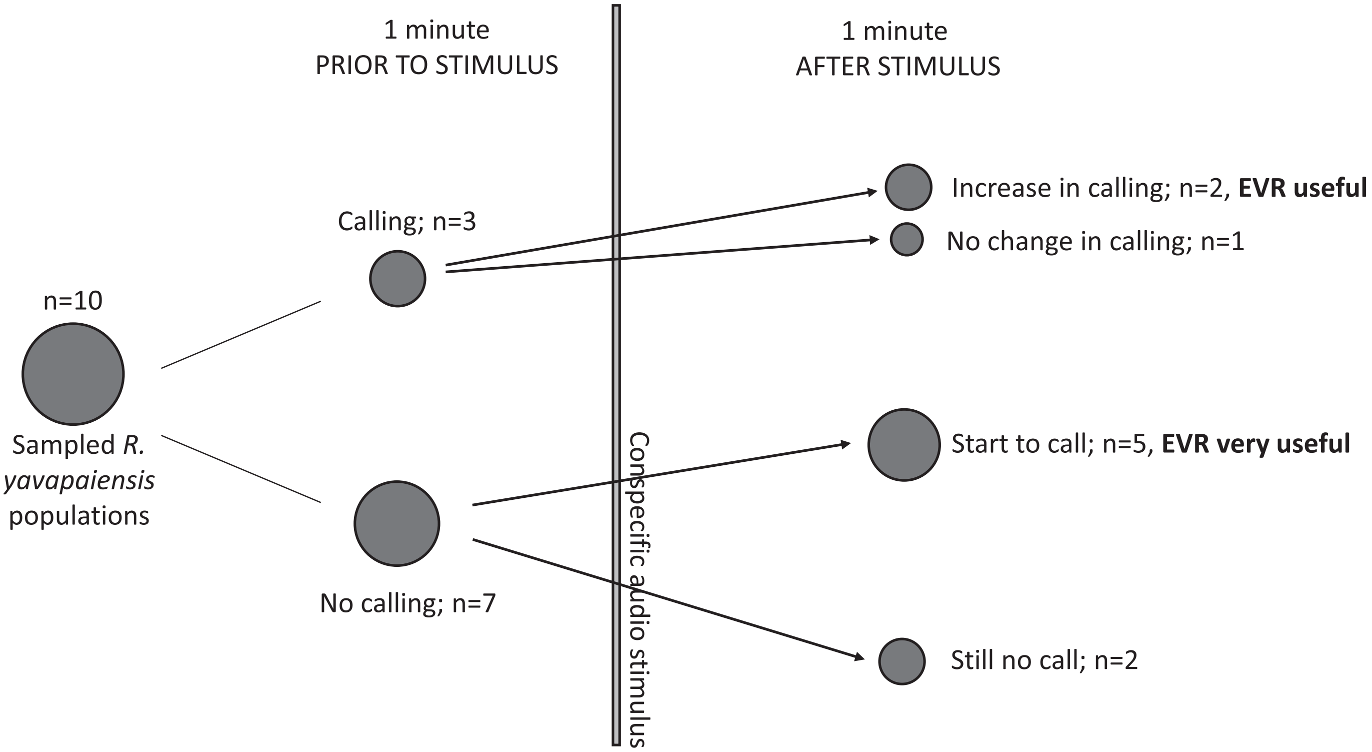

FIG. 2. Summary of calling responses of *R. yavapaiensis* focal populations to a conspecific stimulus. Surface area of circles are proportional to sample sizes.

between the three stimuli was significant in the case of *R. yavapaiensis* (Kruskal-Wallis H $= 8.1$, $P = 0.02$), but not in the case of *R. chiricahuensis* (Kruskal-Wallis H $= 2.1$, $P = 0.14$). Importantly, both target species (*R. chiricahuensis* and *R. yavapaiensis*) would occasionally increase their calling score in response to another species' call stimulus. In the case of *R. chiricahuensis*, the heterospecific *R. yavapaiensis* stimulus resulted in an increase in calling score in 5 of 31 (16%) trials (Table 1). In 3 of 31 trials (10%) the calling response of *R. chiricahuensis* target populations to the heterospecific *R. yavapaiensis* stimulus was even greater than to its own conspecific call (data not shown). For *R. yavapaiensis*, the heterospecific *R. chiricahuensis* stimulus also resulted in an increase in calling score in 4 of 11 trials (36%; Table 1) but never in a higher calling score than for the conspecific stimulus. The *R. catesbeiana* stimulus elicited lower calling scores in both *R. chiricahuensis* and *R. yavapaiensis* (Friedman $\chi^2 = 5.32$ and 9.13, respectively, df $= 2$, $P = 0.07$ and 0.01, respectively) and appeared to function essentially as a neutral sound, eliciting neither increase nor decrease in calling scores.

Eighty-eight percent of trials were conducted in the late spring (March–May), 23% during the summer (June–August), and 4% during the fall (September–November). We found no clear evidence that measured environmental covariables had a significant influence on the population's calling status and the vocal response to a conspecific stimulus in *R. chiricahuensis* after correcting for multiple comparisons (Fig. 3). There were hints (paired *t*-tests, $0.05 > P > 0.1$) that initially silent populations might be more likely to start calling in response to a conspecific stimulus at cooler air temperatures (20.9°C vs. 26.5°C), cooler water temperatures (17.3°C vs. 22.1°C), and earlier months of the year (3.9 vs. 5.9; Fig. 3). Collectively, abiotic conditions that correlate with populations that begin to vocalize in response to a conspecific stimulus correspond roughly to the conditions of the spring reproductive season for this species. Similar analyses were not conducted on *R. yavapaiensis* because of low sample sizes.

TABLE 1. Trial sample size, net calling scores, and number of trials that increased, did not change, or decreased relative to baseline conditions, for three variations of conspecific call stimuli.

Stimulus	*n*	Mean net calling score	Increase	No change	Decrease
Target species: *R. chiricahuensis*					
Conspecific	34	2.22	15	18	1
Superstimulus	34	1.53	13	18	3
White noise (control)	34	0.06	2	31	1
Target species: *R. yavapaiensis*					
Conspecific	10	3.95	7	3	0
Superstimulus	10	2.35	6	4	0
White noise (control)	10	1.35	4	6	0

TABLE 2. Trial sample size, net calling scores, and number of trials that increased, did not change, or decreased relative to baseline conditions, for conspecific and two heterospecific stimuli.

Stimulus	*n*	Mean net calling score	Increase	No change	Decrease
Target species: *R. chiricahuensis*					
R. chiricahuensis	31	1.30	12	17	2
R. yavapaiensis	31	1.25	5	22	4
R. catesbeiana	31	−0.13	1	26	2
Target species: *R. yavapaiensis*					
R. yavapaiensis	11	6.45	8	3	0
R. chiricahuensis	11	1.66	4	7	0
R. catesbeiana	11	0.09	1	10	0

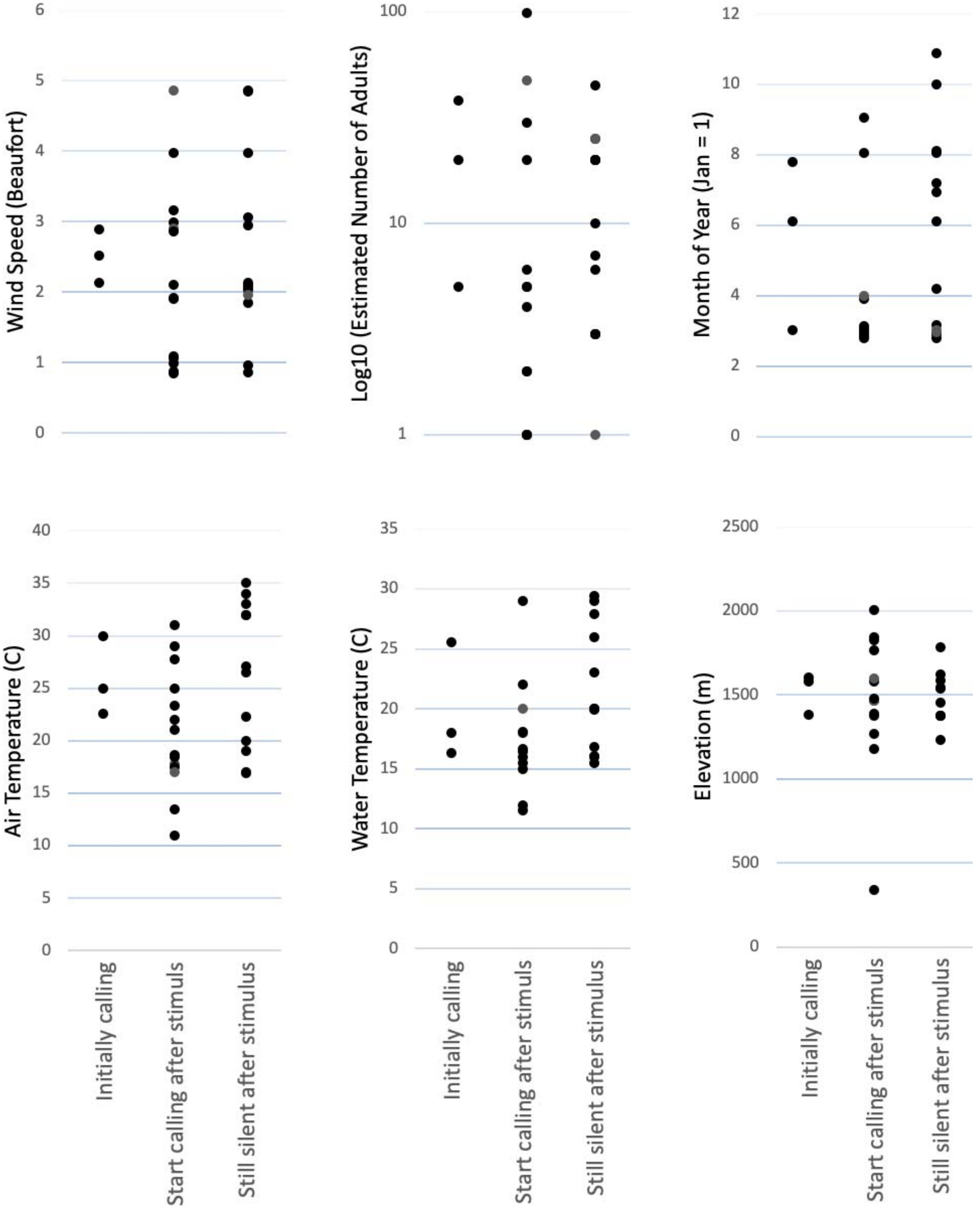

FIG. 3. Plots of population calling behavior and environmental covariates in *R. chiricahuensis*. Sampled populations ($n = 34$) from Figure 1 are assigned to one of three categories: initially calling before audio stimulus ($n = 3$), started calling in response to a conspecific audio stimulus ($n = 14$), and remained silent after conspecific stimulus ($n = 17$). A slight statistical jitter (±10%) is intentionally added to wind speed and months of year to avoid overlapping points.

Discussion

Overall, we found that a conspecific stimulus call will result in an increase in calling behavior in target populations of ranid species. There was an important qualitative gain in information regarding the identity of a species in cases when the target population began to vocalize as a result of the stimulus. Had we been conducting a survey using visual encounter surveys, a positive species identification would have required seeing an individual, and then capturing it or observing it well enough to distinguish key identifying characters. By contrast, the EVR technique using a conspecific stimulus call elicited calling activity in 14 of 31 (45%) of the initially silent *R. chiricahuensis* populations (Fig. 1) and in five of seven (71%) of the initially silent *R. yavapaiensis* populations (Fig. 2). Thus, the EVR technique likely improves and complements the detection and probability of a correct identification relative to a visual encounter survey. The EVR technique will be particularly useful in locations where the habitat (e.g., wetlands or rivers with dense vegetation) can make capturing or even observing an individual for a visual identification challenging. The technique is also relatively inexpensive and rapid to implement. Given the costs and time associated with traveling to remote sites where *R. chiricahuensis* populations are often found, any technique that helps reduce the probability of recording a false absence will be of great value.

A limitation to the EVR technique is that target frogs sometimes respond to the call stimulus of other species. *Rana chiricahuensis* and *R. yavapaiensis* are related species, and their call structures are superficially similar (Platz and Mecham, 1979; Platz and Frost, 1984). This may explain why individuals from both species frequently (19–45%) responded to heterospecific stimuli (Table 2). The important practical implication of this result is that trans-specific responses may occur and training of surveyors should include call recognition of all potential anuran species in the region that might respond when using this survey method.

Although recorded calls help increase the detectability of individuals, little is known about the broader fitness consequences of artificially generating a stimulus that normally plays an important role in social and reproductive settings. In the field, we noticed no obvious negative effects on focal individuals, as initially silent individuals exposed to the stimulus generally called for less than 2 min. No predation event nor intraspecific aggression was observed. We assume, based on our current observations, that the consequences of eliciting a vocal response are minor or insignificant for the calling individuals. It is conceivable, however, that a call stimulus could induce collateral effects such as a greater exposure to predators, unnecessary energetic expenditures, or maladaptive reproductive behaviors in the field (Schlaepfer et al., 2002). We report anecdotally that a captive population of *R. chiricahuensis* (Phoenix Zoo) produced a record number of egg clutches per female for that facility in 2012, a year during which the population was exposed to the recording of a conspecific call approximately 20 times over the course of 2 mo in the context of another experiment. Future research could explore the potential catalytic role of conspecific vocal stimuli in captive breeding, and the broader fitness consequences to individuals exposed to artificial call signals. Studies conducted with other frog species, for example, have demonstrated that social signaling influences levels of circulating sex steroids in receivers (Burmeister and Wilczynski, 2000).

Available evidence suggests that the EVR technique is not harmful for target populations and can be helpful for improving the detection of cryptic, low-density populations in the field. Future research should further explore the effects of seasonality, time of day, reproductive status, and temperature on the probability of response. Based on our empirical observations and behavioral ecology theory, we speculate that surveys that use the EVR technique will be most likely to elicit call responses if they are conducted during the reproductive season of each species and during the night when most activity occurs. We recommend that the EVR technique be included into formal *R. chiricahuensis* survey protocols and that this method be tested in surveys of other anuran species.

Acknowledgments.—The work was funded by the Arizona Heritage Grant Program to MAS, JR, and D. Turner (The Nature Conservancy). The work was conducted under Federal Fish and Wildlife Permit TE02368A-1 and Arizona Scientific Collecting permit SP 550490. We thank P. Rosen, C. Schwalbe, the Phoenix Zoo (T. Sprankle, S. Wells), the Phoenix Botanical Garden, B. Rogers, and B. Gebow for permission to record on their property or property that they manage. We also thank A. King, C. Akins, B. Burger, and K. Smith (all Arizona Game & Fish Department) for help collecting field data. We thank Anna Savage and an anonymous reviewer for their very useful comments on a previous version of this work.

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Accepted: 15 January 2021.