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NOTE

Diurnal versus nocturnal surveys for foothill yellow-legged frogs

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Abstract

Foothill yellow-legged frogs (*Rana boylii*) are a declining species, and methodologies for assessing population occupancy have been associated with only diurnal work on the species. Diurnal visual encounter surveys are typically used to determine presence within suitable habitat; however, studies of ecologically similar species indicate a potential advantage of nocturnal surveys. At 5 sites in 4 counties in California, USA, we compared diurnal and nocturnal surveys ($n = 53$ paired surveys) for foothill yellow-legged frogs, conducted 2016-2023, to determine the value of each survey period. Generally, occupancy probabilities increased 1–22 times, detection probabilities 1–69 times, and estimated abundances 3–12 times during nocturnal versus diurnal surveys. Associated standard errors were also lower in nocturnal versus diurnal surveys. However, we noted 2 locations where diurnal surveys yielded higher detection probability or higher estimates densities compared to nocturnal surveys. We suggest that both diurnal and nocturnal surveys be required when assessing occupancy of foothill yellow-legged frogs.

KEYWORDS

anuran, California red-legged frog, endangered species, nocturnal surveys, *Rana boylii*, survey technique

The foothill yellow-legged frog (*Rana boylii*), which has been declining in range (primarily in California, USA) and number of individuals since the 1990s (Jennings and Hayes 1994, Thomson et al. 2016), was recently proposed for listing at the state (Title 14, Section 670.1; 2020) and federal level (86-FR-73914, 2023). The listing justification stated that a variety of human activities, including urban encroachment, construction of reservoirs and water diversions, introduction of exotic predators and competitors, and habitat fragmentation, had contributed greatly to local and regional extirpation of foothill yellow-legged frogs, and that these issues continue to be a threat to the

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species (Jennings and Hayes 1994, Thomson et al. 2016). The California Endangered Species Act currently protects the frog while the listing process continues (State of California 2020). Additionally, the United States Fish and Wildlife Service (USFWS) recently listed the foothill yellow-legged frog as threatened in 2 distinct population segments and endangered in 2 additional population segments (USFWS 2023). These new protections will likely entail increased regulatory oversight, which will include standardized surveys for the foothill yellow-legged frog as a part of environmental compliance guidelines for activities that may affect the species. The USFWS is currently preparing a survey methodology that will include visual encounter surveys for this species. While no standardized methodology exists for surveys for this species, biologists have primarily employed diurnal surveys to determine the presence or lack of presence of the species in presumed or potentially occupied habitat. These diurnal surveys followed recommendations from unpublished efforts in 2002 (C. Seltenrich and A. Pool, Pacific Gas and Electric Company, unpublished report).

Useful survey guidelines exist for the occasionally sympatric threatened California red-legged frog (*R. draytonii*) in the form of USFWS-approved survey guidelines, which include conducting both diurnal and nocturnal visual encounter surveys to determine presence or the lack of presence (USFWS 1996, 1997). In 2005, the USFWS updated these guidelines with detailed techniques for carrying out field surveys, including the addition of nocturnal surveys, and qualifications for biologists that are conducting surveys (USFWS 2005). These guidelines included use of binoculars, a specific light for night surveys, and defined conditions and timing for surveys. Subsequently, Fellers and Kleeman (2006) tested the use of diurnal versus nocturnal surveys for detecting California red-legged frogs, concluding that nocturnal surveys were far more efficacious at detecting presence, and showed significantly higher numbers of frogs observed. Further, they reported that it was important for protocol surveys to have a high likelihood of detecting presence when the species was extant because these data were to be used to determine future site management activities. Our goal was to determine if, like the California red-legged frog, detection probability for foothill yellow-legged frog would increase with nocturnal surveys conducted in conjunction with diurnal surveys, at the same location.

We compared diurnal and nocturnal surveys for foothill yellow-legged frogs in a manner similar to that by Fellers and Kleeman (2006), which was developed for California red-legged frogs. Our hypothesis was premised on 1) foothill yellow-legged frogs and California red-legged frogs being native congeners and occasionally sympatric (J. A. Alvarez, The Wildlife Project, and J. T. Wilcox, Sonoma Mountain Ranch Preservation Foundation, unpublished data), and 2) they overlap in microhabitat requirements that meet the mutual ecological demands of both species (Erway 2022) such as temperature (Olalla-Tarraga et al. 2009), water balance (Mokhatla et al. 2019, Lemenager et al. 2022), predator avoidance, and foraging requirements. Thus, if nocturnal surveys reveal higher numbers of California red-legged frogs (Fellers and Kleeman 2006) than diurnal surveys, then it is reasonable to assume that foothill yellow-legged frogs would also be present in surveys in higher numbers at night. The goal of our investigation was to determine if there was a difference in diurnal versus nocturnal detections of our target species in a 24-hour survey period. We conducted paired (diel) diurnal and nocturnal surveys for adult and subadult foothill yellow-legged frogs at sites in the Sierra Nevada foothills and the Northern and Southern Coast Ranges to compare the efficacy of the timing of surveys for this species.

STUDY AREA

We surveyed 5 sites in 4 counties in California (Figure 1). The sites were located in Sonoma County (North Coast Range), Santa Clara County (South Coast Range), and Mariposa County (Sierra Nevada), and comprised a range of land cover types, including 1 large impoundment, 1 small stock pond, 3 ephemeral creeks, and 1 perennial creek (Table 1). Stewart Pond, a 0.8-ha freshwater impoundment in eastern Sonoma County lay at the western slope of Mount St. Helena (529550.1 m E, 4277540.0 m N; Zone 10S). This pond is approximately 8 m in maximum depth with a silt and gravel bottom and is filled with water from 3 small intermittent streams. Additional detail for this site

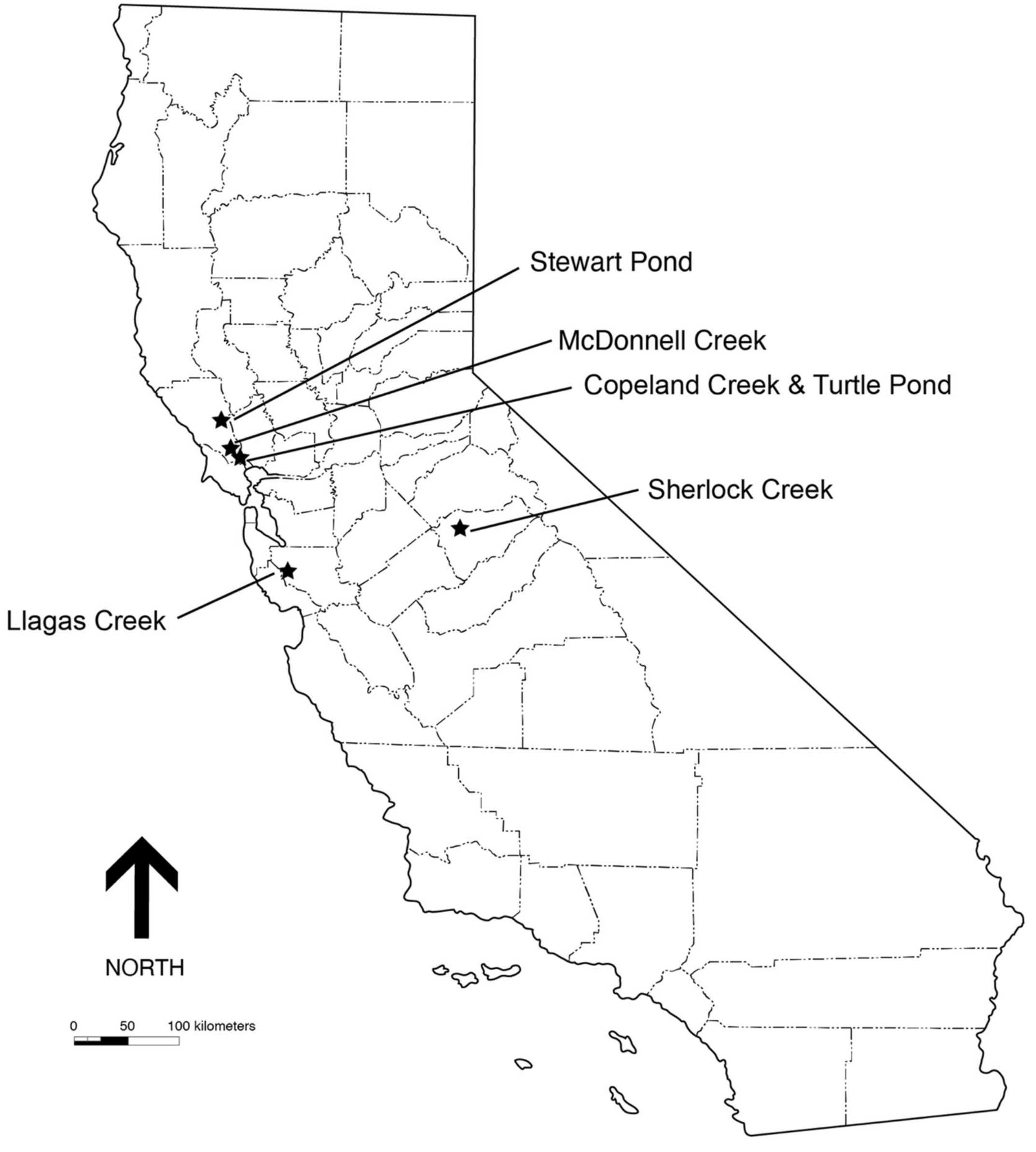

FIGURE 1 Distribution of foothill yellow-legged frog sites in northern California, USA, where we conducted diurnal and nocturnal surveys from Sep 2016–June 2023. Four sites were located in Sonoma County, where we conducted the majority of the surveys.

is described elsewhere (Wilcox and Alvarez 2019, Alvarez and Wilcox 2021). Similarly, Turtle Pond on the Mitsui Ranch, a cattle ranch at the top of Sonoma Mountain, approximately 8 km west of the city of Petaluma (536661.9 m E, 4242809.5 m N, Zone 10S) is a small (0.004 ha), deep (2 m), mud-bottomed freshwater stock pond that is heavily shaded and covered in duckweed (*Lemna* spp.) most of the year. Copeland Creek, our third site, also on the Mitsui Ranch in Sonoma County (536711.9 m E, 4243194.6 m N, Zone 10S), is a low-gradient stream associated with a series of isolated springs. This intermittent creek flows through open grasslands and a dense canopy of valley oak (*Quercus lobata*), coast live oak (*Quercus agrifolia*), California bay laurel (*Umbellularia californica*), and willow (*Salix* spp.), just prior

TABLE 1 Site characteristics for foothill yellow-legged frog (*Rana boylii*) diurnal and nocturnal surveys conducted in northern California, USA, from September 2016–June 2023. Dimensions are described as linear meters of creek or approximate hectares of surface area.

Site	County	Land cover	Dimensions
Sherlock Creek	Mariposa	Ephemeral stream	1,000 m
Llagas Creek	Santa Clara	Ephemeral stream	400 m
Stewart Pond	Sonoma	Perennial pond	0.8 ha
McDonnell Creek	Sonoma	Perennial stream	400 m
Copeland Creek	Sonoma	Ephemeral stream	400 m
Turtle Pond	Sonoma	Perennial pond	0.004 ha

to intersecting Rose Creek and becoming a second-order stream (Vannote et al. 1980). This reach of Copeland Creek descends through a riparian forest but flows through a long, low meadow shortly after the Rose Creek confluence. The channel width through this meadow is never >1.5 m. Shallow runs through this site are typically dominated by Himalayan blackberry (*Rubus armeniacus*). More detailed habitat conditions are described in Alvarez and Wilcox (2021) and Alvarez et al. (2022). Also in Sonoma County, we surveyed McDonnell Creek on the Modini-Mayacamas Preserve, a third-order perennial tributary of the Russian River (via Maacama Creek) that drains the western slope of the southern North Coast Range above the Alexander Valley. McDonnell Creek was bordered by red alder (*Alnus rhombifolia*), Oregon ash (*Fraxinus latifolia*), poison oak (*Toxicodendron diversilobum*), and Himalayan blackberry, with mixed oak (*Quercus* spp.) and Douglas fir (*Pseudosuga douglasii*) woodlands in the surrounding upland areas. The creek substrate included cobble and boulder intermixed with gravel and bedrock, and was characterized by short runs, riffles, pools, and glides that vary in length and speed depending upon year, season, and proximity to rain events. Llagas Creek, in Santa Clara County, was a tributary of the Pajaro River system. At our survey site in the Rancho Cañada del Oro Open Space, Llagas Creek is a third-order stream that drains the precipitous eastern slope of the South Coast Range above the Coyote Valley through annual grasslands and oak savanna. Llagas Creek was perennial in normal rainfall years and had a substrate similar to that described for McDonnell Creek. Lastly, we surveyed a reach of Sherlock Creek just above its confluence with the Merced River. The riparian forest community composition was similar for McDonnell, Llagas, and Sherlock creeks. These 5 locations lay within central and coastal-central portion of California, and following the Köppen-Geiger climate classification, experience a temperate climate—typified by cool wet winters and warm-hot dry summers (Peel et al. 2007). Annual rainfall can reach as high as 76 cm but varies greatly year to year. Our northern sites (Sonoma County) can range from an average low of 7°C to an average high of 23°C, while our southern-most site can range from an average low of 0°C to and average high of 34°C. These 5 locations were visited between 2 and 37 times with diurnal and nocturnal visits within the same 24-hour period.

Syntopic with foothill yellow-legged frogs at all sites were Pacific treefrogs (*Pseudacris regilla*) and western toads (*Anaxyrus boreas*). Other amphibians were present at these sites, such as bullfrogs (*Lithobates catesbeianus*; 4 sites), Coast Range newt (*Taricha torosa*; 4 sites), rough-skinned newt (*Tarchia granulosa*; 3 sites), Sierra newt (*Taricha sierrae*; 1 site), California giant salamander (*Dicamptodon ensatus*; 3 sites), and California red-legged frog (2 sites).

METHODS

We conducted 53 paired diurnal and nocturnal surveys (following Fellers and Kleeman 2006) from September 2016 through June 2023. Number of visits to each site ranged from 2–37 (Table 2). Surveys were typically conducted from February through November. We avoided surveys following large rain events that made survey conditions

TABLE 2 Foothill yellow-legged frog (*Rana boylii*) counts during diurnal and nocturnal surveys conducted September 2016–June 2023 in northern California, USA. Timing and number of site visits varied by site and year, ranging from 2–8/year.

Site	County	Land cover	Number of visits	Diurnal detections	Nocturnal detections
Stewart Pond	Sonoma	Perennial pond	37	2	482
Sherlock Creek	Mariposa	Ephemeral creek	2	1	5
McDonnell Creek	Sonoma	Perennial creek	2	14	22
Copeland Creek	Sonoma	Ephemeral creek	8	9	31
Llagas Creek	Santa Clara	Ephemeral creek	2	6	105
Turtle Pond	Sonoma	Perennial pond	2	0	2
		Total	53	32	647
				4.5%	95.5%

difficult or unsafe for surveyors. Many of the surveys were completed as part of additional or unrelated projects but included one or both authors for each survey. For example, we conducted surveys as part of bullfrog control projects, graduate research projects, or as part of California red-legged frog and foothill yellow-legged frog workshops. Surveys that did not include both authors simultaneously included ≥1 trained volunteers that worked with one of the authors and the focal species for months or years. We felt strongly that the variation in sampling seasons and times (i.e., operationally realistic) was unlikely to affect the diurnal and nocturnal comparisons that we report here. This study was not developed specifically to conduct an analysis of diurnal versus nocturnal detectability of foothill yellow-legged frogs. Rather, we mined the data from other studies or surveys that used a similar survey methodology and were conducted in occupied habitat. We then used those mined data to assess whether there was a higher frequency of nocturnal versus diurnal detections.

At each location we conducted both diurnal and nocturnal surveys within a 24-hour period using the same observers (at least one of the authors, typically both). Each author has >30 years of experience surveying for foothill yellow-legged frogs and syntopic species. To maximize detections, we conducted surveys within the following parameters: air temperature exceeded 12°C during the day and did not fall below 5°C at night; wind speed was ≤20 km/hour; and fog, when present, did not reduce visibility below 200 m. These surveys were tested *post hoc*, following the Fellers and Kleeman (2006) method for assessing differences between diurnal and nocturnal detections in California red-legged frogs. Similar to Fellers and Kleeman (2006), we did distinguish between adults and subadult life stages in the field but totaled both for statistical testing. We did not include larval counts.

Two or more skilled and experienced biologists conducted diurnal surveys by slowly walking the perimeter of each site (pond or creek) while searching the bank, exposed rocks, creek bottom, root tangles, and other suitable areas for frogs with 8x or 10x binoculars (Fellers and Freel 1995). We used a similar methodology to conduct nocturnal surveys except that we used binoculars, along with hand-held flashlights or headlamps (400–500 lumens) to look for frog eye-shine (Corben and Fellers 2001). Typically, we placed the light below and against the binoculars, between the 2 barrels, which allowed the light and binoculars to move in unison to scan the habitat within 10 m of the observer. When in creeks, we typically began at the downstream portion of the reach and moved upstream. All nocturnal surveys began at least 1 hour after sunset and were completed before 0100 hours. Although other researchers have avoided conducting surveys in association with a full moon (Fellers and Kleeman 2006), we noted that canopy cover over most stretches of surveyed habitat provided filtered light not likely to reduce observability or increase detection of surveyors to frogs (Table 1).

We reported a foothill yellow-legged frog (positive observation) when the specimen detected had features known for the species, which included ≥1 of the following: a light triangle between the eyes and tip of nose, a partial dorsal lateral line, tubercles on the lower side above the lower legs, and yellow legs (Storer 1925, Stebbins 2003). We counted frogs only when we were able to approach sufficiently close to allow detection of the diagnostic features of each. When the specimen sought cover before we could identify it, we considered the species unknown. We omitted all unknowns from our analysis.

We performed all calculations using R 4.3.2 software (R Core Team 2024) using the unmarked package (Fiske and Chandler 2011). We used Royle-Nichols (RN) occupancy models to compare diurnal and nocturnal surveys because these models are useful for estimating occupancy and detection probabilities of cryptic species, where accounting for abundance is often essential (Royle and Nichols 2003, Morán-López et al. 2022). To assess differences between survey methods, we created 2 RN occupancy models: one based on data from diurnal surveys and another from nocturnal surveys. In both models, we included land cover type (i.e., perennial pond, perennial creek, and ephemeral creek) as a site covariate, as these variables may influence occupancy and detection across sites.

RESULTS

We often detected a > 10-fold increase in numbers of known foothill yellow-legged frogs during nocturnal surveys over diurnal surveys; 95.5% of the foothill yellow-legged frogs were observed during nocturnal surveys (Table 2). Half of our project sites included ≤2 frogs observed during diurnal surveys, and 17 of the 53 diurnal visits (mostly at Copeland Creek and Stewart Pond) produced no detections at all. Conversely, nocturnal surveys always included detections of foothill yellow-legged frogs. The higher proportion of diurnal sightings at McDonnell Creek can be attributed to the presence of newly transitioned froglets (metamorphs), a life-history stage that is more active during daylight (Pizzato et al. 2008, Székely et al. 2020). We recorded unidentified frogs, or frogs referred to as *Rana* sp., at all sites, during both diurnal and nocturnal surveys. We did, however, detect foothill yellow-legged frogs during nocturnal surveys 100% of the time when we recorded unknowns at the same site. Unknowns typically represented a minority of observations during any survey (0–5 max.). Only diurnal surveys were composed of unknowns only, whereas nocturnal surveys included positive identifications of foothill yellow-legged frogs along 0–4 unknowns.

Our models indicated that, with the exception of Turtle Pond (where the standard error was notably high), occupancy and detection probabilities of foothill yellow-legged frogs were 1–22 and 1–69 times higher, respectively, and estimated abundances were 3–12 times higher during nocturnal versus diurnal surveys (Table 3). Additionally, the standard errors for occupancy and detection probabilities were lower, resulting in more precise estimates for nocturnal surveys compared to diurnal surveys (Table 3). However, in one location (Sherlock Creek) detection probability was higher in diurnal versus nocturnal surveys, and in another site (Turtle Pond) estimated abundance was higher when derived from diurnal surveys.

DISCUSSION

In this study we compared surveys for foothill yellow-legged frogs during diurnal and nocturnal surveys conducted on the same date at the same locations. Within a range of land cover types that included ponds and ephemeral and perennial creeks (Wilcox and Alvarez 2019, Alvarez and Wilcox 2021, Alvarez et al. 2022), our results indicated that nocturnal surveys are typically more efficient at detecting foothill yellow-legged frogs. Additionally, with better detection of foothill yellow-legged frogs, the estimated abundance of frogs at sites was generally higher when considering nocturnal data. These results indicate that restricting surveys to daylight hours may grossly underestimate the number of foothill yellow-legged frogs at a site. The proportion (95.5%) of frogs we found during

TABLE 3 Diurnal and nocturnal data Royle-Nichols occupancy model results showing the occupancy probability, detection probability, and estimated abundance of foothill yellow-legged frogs (*Rana boylii*) across 2 pond sites and 3 creek sites, from September 2016–June 2023, in California, USA.

	Occupancy probability estimate (SE)		Detection probability estimate (SE)		Abundance estimate	
Site	**Diurnal**	**Nocturnal**	**Diurnal**	**Nocturnal**	**Diurnal**	**Nocturnal**
Stewart Pond	0.04 (0.02)	0.87 (0.10)	0.55 (0.48)	0.68 (0.02)	9 (0.74)	31 (0.09)
Turtle Pond	0.69 (0.29)	0.78 (0.14)	0.42 (0.74)	0.49 (0.34)	18 (0.23)	9 (0.11)
Copeland Creek	0.09 (0.04)	0.37 (0.17)	0.89 (0.60)	0.91 (0.75)	13 (0.21)	36 (0.50)
Llagas Creek	0.69 (0.29)	0.82 (0.01)	0.01 (0.48)	0.69 (0.07)	24 (0.46)	70 (0.15)
McDonnell Creek	0.68 (0.35)	0.73 (0.28)	0.95 (0.60)	0.97 (0.18)	7 (0.30)	87 (0.16)
Sherlock Creek	0.03 (0.70)	0.66 (0.44)	0.24 (0.86)	0.12 (0.45)	1 (0.71)	6 (0.42)

nocturnal surveys was slightly higher than those of Fellers and Kleeman (2006), who reported 89.4% of their detections of California red-legged frogs during nocturnal surveys. Our findings indicate that any survey guidelines for foothill yellow-legged frogs should include nocturnal surveys within all appropriate landscapes, and that if only a single period can be surveyed that priority be given to nocturnal surveys. Similar to Fellers and Kleeman (2006), we found that the numbers of unidentified frogs observed during the diurnal versus nocturnal were far greater, and we concur that it was often easier to closely observe and identify frogs during nocturnal surveys. Similarly, we found that frogs of any species are more likely to flush without being detected, seeking refuge in water during diurnal surveys, and thus become recorded as unknown. Further, frog coloration, markings, and their level of wariness may make them difficult to detect diurnally, whereas nocturnal surveys allow the observer to approach more closely and have more favorable conditions for identification. However, higher relative humidity and absence of sunlight allows foothill yellow-legged frogs to linger out of water longer nocturnally (Erway 2022), and a reflective tapetum lucidum (i.e., eye-shine) makes them relatively easy to detect at night with the aid of a flashlight (Corben and Fellers 2001).

We strongly suggest nocturnal surveys be incorporated into any survey guidelines for foothill yellow-legged frogs, but we also found that including diurnal surveys plays an important role in conducting safe and efficient anuran surveys in a single visit. Alvarez and Wilcox (2024) recommended conducting diurnal and nocturnal surveys during the same visit to familiarize surveyors with the landscape, its obstacles, appropriate microhabitat, and other conditions in daylight such that the following nocturnal surveys include a comprehensive understanding of the habitat conditions for efficient surveys and for surveyor safety. Diurnal visits may also allow surveyors to detect egg masses and larvae most effectively. This is particularly true when identifying larvae, which may often require observations of tooth rows and an identification key.

Although we have found all life stages (egg mass, larvae, adult form) present and identifiable in a single creek reach on a single date, special care should be taken to focus on specific life stages over a season. Surveys should include multiple dates to determine if breeding is successful, or to identify 1 of the 3 life stages in case the others are no longer detectable (i.e., the site dries out completely). Dukas and Kamil (2001), and Clark and Dukas (2003) reported a decrease in surveyor effectiveness when the surveyor attempted to detect all life stages during a single visit. Our survey experience suggests that egg masses, larvae, and adults may use different microhabitat during different seasons. Thus, focusing on a single life stage may increase efficiency and probability of positive detections. This makes local knowledge indispensable. Different populations of foothill yellow-legged frogs may breed during different times of the year depending on the year, location, elevation, climate, water flows, and other factors. Seeking out local, knowledgeable individuals can make positive detections more likely.

MANAGEMENT IMPLICATIONS

This study suggests that, like California red-legged frog, nocturnal surveys are the most efficacious method to detect the presence of foothill yellow-legged frogs. Biologists doing surveys for foothill yellow-legged frogs should be knowledgeable about all sympatric species, both special-status and common, that are found within the range of foothill yellow-legged frogs. This is particularly critical when identifying larvae of any species—this may be the only life stage observed at some sites. Surveys are the main method used to determine potential presence of a declining species. Therefore, it is critical to use methods that increase the probability for positive detection. We recommend that surveys for this species include several site visits, which should include a diurnal and nocturnal survey conducted on the same day.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

We conducted fieldwork under United States Fish and Wildlife permits TE-27427 and TE-068745, and California Department of Fish and Game permits SCP-00040 and SCP-005654. No animals were collected or harmed during any portion of this study.

DATA AVAILABILITY STATEMENT

No data, other than those provided in the Tables, are currently available.

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