Assessment of detection methods for the endangered Amargosa vole

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FULL RESEARCH ARTICLE

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Abstract

Understanding which detection methods to use is important to endangered species research and management and often requires a balance between costs and benefits. We investigated the efficiency and costs of camera-trapping, live-trapping, and sign surveys (vole feces, clippings, runways) as methods for detection of the endangered Amargosa voles (*Microtus californicus scirpensis*). Although each method documented the presence of voles, baited camera-trapping was the most sensitive method for detecting voles and provided insights into vole activity and behavior. Although live-trapping had 100% specificity and provided data and access to biological samples that could not be collected through other methods, it had reduced sensitivity (85.2%) compared to camera-traps and incurred potential risk to individual voles. Sign surveys were the least sensitive method (78.9%) and suffered in that some types of sign could not accurately be attributed to species. Additionally, sign surveys could not inform about how recently vole activity had occurred because Amargosa vole feces can persist in the environment for long periods of

time and degrade 4.7 times faster in wetter marshes than dryer sites. Sign and fecal surveys are best suited for occupancy and distribution surveys at a coarse time scale (≥1-year intervals) but are likely to have low predictive values in years when vole abundance is low. Cost comparisons indicate the highest per session cost and moderate habitat impact for camera trapping, highest overall cost and highest impact to habitat for live-trapping, and lowest expense and habitat impact for sign surveys but relatively low yield in data quality.

Key words: camera-trap, *Microtus californicus scirpensis*, test concordance, fecal decay, live-trap, sign survey

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Introduction

Accurate monitoring is necessary in wildlife research and management (Pollock et al. 2002; Brubaker et al. 2014), but a core problem in the study of rare and geographically restricted species is the failure to detect organisms even when they are present (MacKenzie et al. 2002). However, optimal detection methods for a given species may not be apparent at the onset of a research project. Often there are multiple useful methods for detection of particular species (Schauster et al. 2002; Garden et al. 2007; Schmelzle and Kinziger 2016); while the use of multiple methods may increase data quality, it also impacts the cost of data collection (Schauster et al. 2002; Garden et al. 2007). Using differing detection methods at different times and places introduces bias and variable quality into the data, with implications for species conservation.

The Amargosa vole (*Microtus californicus scirpensis*, herein referred to as vole) is a federally and California state-listed endangered rodent that is endemic to eastern Inyo County, California (USFWS 2019; CNDDB 2024). This water-dependent species persists in a fragmented wetland ecosystem that has decreased in size and connectivity since the end of the Pleistocene (Neuwald 2010). Due to California's historic drought conditions and anthropogenic changes, habitat loss and extensive fragmentation has drastically altered the wetland community and constricted potential vole habitat to less than 20 km^2 (Foley 2017). While it is likely the species was never abundant across its range, it has high variability in

population size and detectability between seasons and years (Clifford et al. 2017). Data from a six-month trapping study on habitat selection by voles estimated occupancy at multiple scales in larger bulrush marshes but did not examine occupancy range-wide or in smaller marsh sites (Klinger et al. 2015). Accurate detection of this species across its range is needed to better understand the species ecology and aid in conservation efforts to move the species toward delisting (USFWS 1997).

While the need for monitoring is clear, there are considerable challenges to sampling rare and geographically restricted species. This necessitates the comparison of multiple monitoring techniques, to develop an optimal method to detect voles and determine occupancy. Various methods can be used to detect and study voles, each with benefits and limitations. Vole presence in the approximately 30 marshes within the species' range has been documented mainly through live-trapping and sign surveys (e.g., Klinger et al. 2015). However, live-trapping may provide false negative data in the event of low vole abundance or trap avoidance, if animals are "trap shy." Vole-sign surveys have also been used, but may yield variable results because the persistence of sign, especially feces, is influenced by climate, vegetation, microbial flora, and precipitation amongst other factors (Bider 1968; Wilson and Delahay 2001). Persistence of fecal sign across the vole's wetland habitat interspersed throughout an otherwise arid desert environment has not been characterized and may vary spatially (Neff 1968; Dzięciołowski 1976; Sanchez et al. 2004). False-positive sign surveys (e.g., feces or vegetation clippings from similarly sized animals) may incorrectly identify a marsh as occupied, even after local extirpation. Finally, remote cameras are widely used in detection and occupancy models for mammal species (Thorn et al. 2009; Sweitzer and Furnas 2016; Bowler et al. 2017), and have recently been employed to document vole presence as part of a range-wide survey of the species' habitat requirements (Foley et al. 2017) and behavior in a captive colony of voles (Clifford et al. 2017; Pesapane et al. 2018). Remotely triggered cameras may overcome problems of inaccuracy of sign surveys and low detection probabilities of live-trapping. Cameras may be set to collect data over longer periods of time (weeks or months) and detect animals that would otherwise be missed using methods that collect data over shorter time periods (Moreno and Halffter 2000). Additionally, assuming trained personnel can correctly identify species captured on cameras, they may have increased accuracy over surveys of sign such as runways or vegetative clippings. However, identification of rodents on cameras, particularly those that are closely related, may be difficult and may result in false positive or negative data.

Here, we compare three commonly used methods for detection of the Amargosa vole. We systematically evaluated live-trapping, camera-trapping, and sign surveys for their ability to detect the presence of voles. Specifically, we aimed to 1) evaluate the best methods (with respect to accuracy, sensitivity, and costs vs. benefits) for detecting vole presence and 2) determine the decay rate of vole feces and its accuracy as an indicator of vole presence. These data may help guide data collection for this and other rare and endangered small mammals.

Methods

Study Area

We conducted surveys and experiments within marsh habitats of the Amargosa vole (USFWS 1997), located in the Mojave Desert within the Amargosa River basin near Tecopa Hot Springs, Inyo County, California. The climate is extremely arid with an average annual rainfall of 12.3 cm, 70% of which falls between November and March (Klinger et al. 2015). Mean annual maximum and minimum temperatures

are 41.4°C and 3.2°C, respectively (NOAA 2024). This patchy wetland habitat, fed by natural and anthropogenic sources (Foley et al. 2017), is surrounded by alkaline playa and desert scrub. The dominant vegetation in these marshes is Olney's three-square bulrush (*Schoenoplectus americanus*) with peripheral zones of mixed rushes (*Juncus* spp.), yerba mansa (*Anemopsis californica*), salt grass (*Distichlis spicata*),boraxweed (*Nitrophila occidentalis*),and alkali sacaton (*Sporobolus airodes*). Study sites were typically associated with a trapping grid or discrete patches of bulrush or rushes (Foley et al. 2017). To the extent possible, sites were numbered consistently with a historical numbering system (McClenaghan and Montgomery 1998; Clifford et al. 2017).

Field Methods

We collected data from June 2014 through September 2016 in accordance with University of California, Davis (IACUC Protocol #18179), U.S. Fish and Wildlife Service (Recovery Permit TE54614A-1), and California Department of Fish and Wildlife (Scientific Collecting Permit #000854) permits and protocols.

Fecal decay.—We determined the rate of vole fecal decay from June 2014 through August 2016 using a litter bag technique (Singh and Gupta 1977; Bradford et al. 2002). We collected fresh fecal pellets from wild voles during trapping events or from cleaned cages in a captive colony of voles housed at UC Davis. After collection, we stored pellets at approximately 2°C for no more than three days. Fecal pellets were mixed well to evenly combine the pellet ages, then one-gram replicates were sewed into 6 cm x 12 cm nylon mesh bags. We placed the fecal pellet bags beneath bulrush litter (> 60 cm), typical of vole habitat (Foley et al. 2017), at 11 stations located within four sample sites (marshes). Six stations were located in dry areas (substrate completely dry or slightly moist) and five stations in wet areas (substrate saturated or standing water present). We selected stations where we expected site conditions (wet or dry) to remain constant between sampling periods. Each station received four time-replicates, consisting of four fecal pellet bags per time replicate (16 bags per station, 176 fecal pellet bags total). We collected one set of time-replicates (four bags) from each station at approximately two, six, 14, and 30 weeks after installation. After collection, we stored fecal pellet bags in double Ziplock© bags at approximately 2°C to minimize ongoing decomposition until processing (< three days). To process the bags, we carefully removed the fecal material from each bag and oven-dried it at 70°C for a minimum of two days until it reached a constant mass. We then used these data to calculate the decay rate (k) of feces based on a simple exponential model of decay:

$$X_t = Xe^{-kt}$$

X_t = fecal mass remaining at time t (days), X = initial fecal mass at time t, and k is expressed as day^{-1} and represents the instantaneous mass loss rate.

We collected a photo series of fecal pellet samples over the course of the decay study to document when fecal samples were no longer recognizable as distinctive vole sign. We used this in combination with k-values to estimate the time (in days) vole sign is no longer visibly detectable under field conditions (effective decay).

Sign surveys.—We conducted vole sign surveys in 2015 and 2016. We visited marshes containing vole habitat and searched for vole sign for thirty person-minutes and were limited to the perimeter of the site

to minimize damage to vole habitat. When we discovered vole sign (including vole feces, runways, burrows, and vegetative clippings; Jareño et al. 2014), we recorded a GPS location and the quality of sign was noted. We classified clippings as old if they were dry, brown or white, or decomposing, and defined fecal pellets as old if they were brittle, gray, white, or green, bloated, and/or overgrown with algae or mold. We considered runways and burrows active if cobwebs were absent and pathways were clear of debris and/or vegetation.

Live-trapping.—We conducted live-trapping for five consecutive days, approximately every six weeks, at 15 grids within randomly selected sites between November 2015 and September 2016 (**Fig. 1**). We trapped five sites during each sample period and trapped the remaining 10 sites (two groups of five sites) at alternate sampling periods, resulting in 10 sites being trapped every sample period (Foley et al. 2017). Trapping grid design followed established trapping protocols (Klinger et al. 2015). We baited 7.6 x 8.9 x 22.9 cm Sherman traps (H. B. Sherman Traps, Tallahassee, FL, USA) with a rolled oat, 4- way horse feed, alfalfa pellet, and peanut butter combination, and placed the traps underneath vegetation. We placed traps on substrate (when possible) so that they were stable and would intercept vole runways beneath overstory vegetation. When the predicted daily high temperature exceeded 27°C, we included a small piece of apple in each trap for animal hydration.

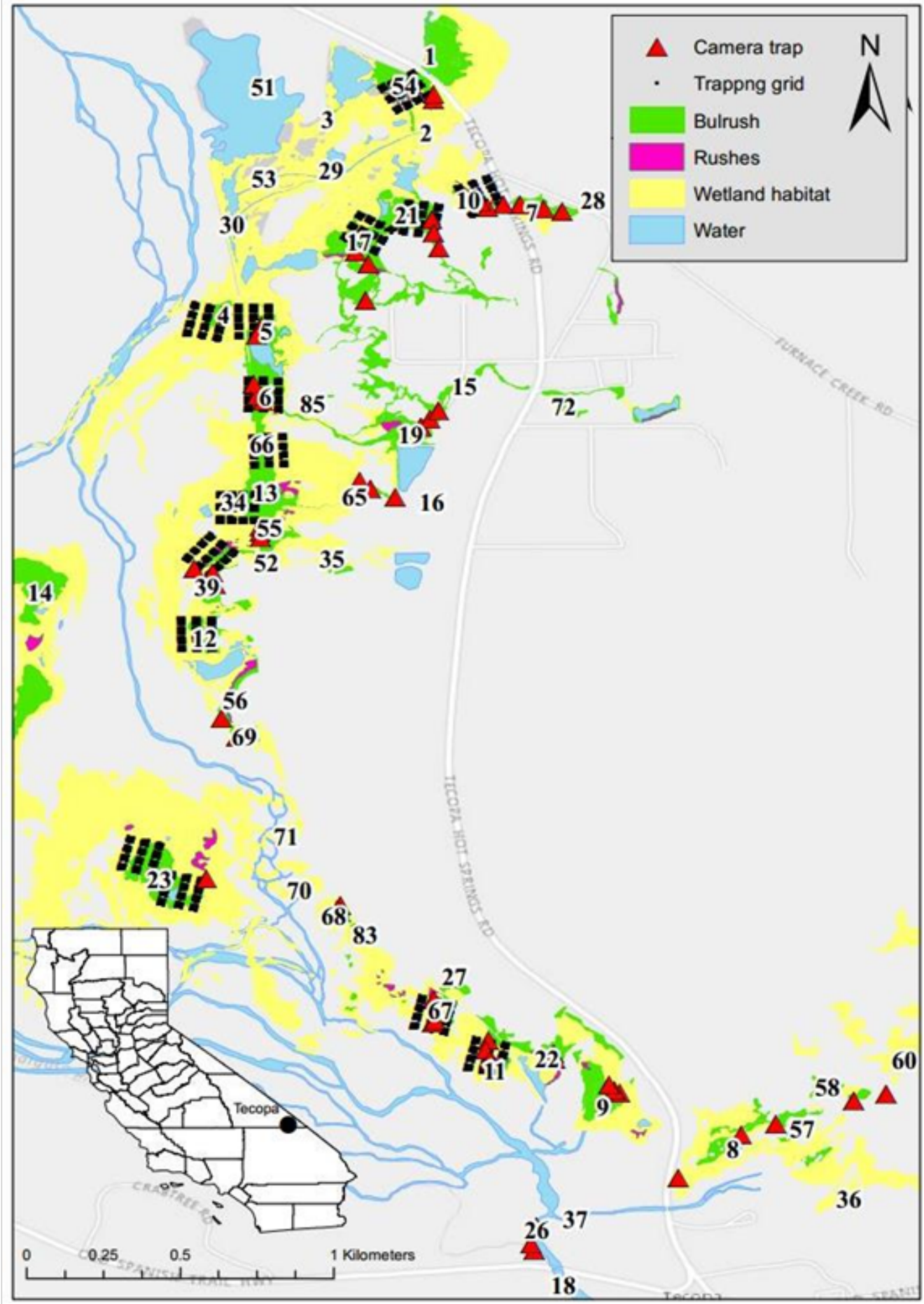
Camera trap
Trappng grid
Bulrush
Rushes
Wetland habitat
Water
N
TECOPA HOT SPRINGS RD
FURNACE CREEK RD
Tecopa
0
0.25
0.5
1 Kilometers

Figure 1. Locations of live-trapping grids and remote triggered cameras for assessing distribution of Amargosa voles in wetlands near Tecopa, Inyo County, CA, USA, November 2015 through October 2016.

Camera-trapping.—We placed cameras in 21 randomly selected sites (**Fig. 1**), all of which had bulrush as the dominant vegetation except Site 68, which was dominated by rushes. The camera in Site 23 was located in common reed (*Phragmites australis*) approximately 80 m from a bulrush patch. We deployed three NatureView CAMHD (Bushnell Overland Park, KS, USA) or Reconyx PC900 (Holmen, WI, USA) cameras per site (except in Site 23 which only had one camera), by fastening cameras to metal U-posts at a downward angle toward vole sign. We modified Bushnell cameras by placing black duct tape over half of the LED lights to minimize overexposure and attaching a 600mm lens for close-range photographs. We baited cameras with 200 g of oats, peanut butter, alfalfa, and 4-way horse feed in a pile in front of each camera on the day each camera was armed. We rotated cameras between half of the sites every six weeks. We programmed the cameras to take five photographs when triggered, with no delay between images, and remained active for approximately six weeks, although full memory cards at some sites resulted in fewer than six weeks of data being collected. This 4–6-week period was considered a "primary period." To minimize false triggers, we trimmed vegetation within the range of each camera lens.

Statistical Analysis

We maintained data in Excel (Microsoft, Redmond, WA, USA) and conducted analyses with the statistical program "R" (R-Development Core Team, **http://www.r-project.org**). Differences were considered significant at $P < 0.05$.

Fecal decay.— We determined differences in decay rates and time to effective decay between sites using an analysis of variance (ANOVA; Adair et al. 2010), and we determined differences in decay rates and time to effective decay between sites conditions (wet vs. dry) using Student's t-tests. All data met assumptions for normal distribution using a Shapiro-Wilk test and homogeneity of variances using Levene's test or were Log_{10}-transformed to meet assumptions of normalcy and homogeneity.

Concordance.—To assess concordance among survey methods, we used sampling periods consisting of any two consecutive months in which at least two of the following were conducted: five days of live-trapping, a sign survey, or at least four weeks of camera-trapping. To compare camera trapping to live-trapping and because at a few cameras, all bait was consumed within five days, we only used the first five days of camera data from each primary period. While voles were detected on cameras past the first five days of images, voles were not detected in new locations past the first five days. For sign data, we only used sign that were classified as fresh (feces, clippings) or active (runways, burrows). We summarized the percentages of times that each test detected at least one vole, and the percentages of times all three tests gave the same result or a 2 x 2 test comparison when only two tests were performed. We set camera-trapping to be the reference condition and used this to calculate sensitivity for the tests, i.e., the proportion of sites that were correctly identified as occupied as well as minimum precision or positive predictive value (Gordis 2009). Camera trapping was chosen as the reference condition because cameras may allow for higher detection rates when species can be accurately identified (whereas sign surveys may misassign detected to sign to the wrong species) and may detect "trap shy" individuals when they are present (unlike live-trapping). However, we could not calculate

specificity of camera-trapping as there are no known true negative camera events. We compared average trap success for each of the five trap nights with ANOVA. Data met assumptions for normal distribution using a Shapiro-Wilk test and homogeneity of variances using Levene's test or were Log_{10}-transformed to meet assumptions of normalcy and homogeneity

Cost analysis.—We determined the cost of each survey method on the basis of equipment costs, personnel costs (Garden et al. 2007), and amount of habitat damage incurred. We calculated equipment costs using the market price of equipment from the manufacturer in 2017 plus supplementary supplies for the equipment (e.g., rechargeable batteries). For simplicity, we did not include the cost of equipment if it was used in all three survey methods (e.g., GPS unit) or if it could not be specifically identified (e.g., cost of electricity for recharging batteries in an office setting). We calculated personnel costs as the amount of time it would take one individual to complete a task over the course of a year with the base hourly wage ($18.50 per hour) and benefits (40% of wages) of field staff on this project. We used the number of site incursions as our metric for habitat damage because repeated incursions into a site can destroy live plants and plant litter and create semi-permanent trails. Habitat damage was classified as low (1-5 incursions into a site per year), moderate (6-20 incursions per year), and high (>21 incursions per year). Housing and travel costs were not included in this analysis. Following the schedule used for this study (described above), we assumed that sign surveys would require one trip per year, live-trapping would require 10 trips (6 days per trip), and camera-trapping would require three trips per year (2 days per trip). This schedule allowed for one sign survey per year and for each live-trapped site to be sampled 3-8 times per year and each camera-trapped site to be sampled three times per year to assess both season detections and population status.

Results

Field Results

Fecal decay.—Fecal pellet replicates decayed under field conditions between 14-324 days. Overall, the mean rate of decay for fecal pellets was 0.009 g/day (SE = 0.003 g/day, **Table 1**, **Fig. 2A**), and there were no significant differences in rates of decay between individual sites. The series of photographs of fecal pellets indicated that pellets became unrecognizable when less than 22.9% of initial mass remained. Using this result in combination with *k*-values, mean time of effective decay of fecal pellets in the environment was 365 days (SE = 80.9, **Table 1**, **Fig. 2B**). The mean time to effective decay was 4.7 times faster in wet zones (k = 0.016, 105 days, SE = 42) than dry zones (k = 0.003, 582 days, SE = 56, t_6 = 8.1, $P < 0.001$, **Fig. 2B**).

Table 1. Fecal decay rates of Amargosa vole feces in wet and dry patches of bulrush vegetation near Tecopa, Inyo County, California, USA. Fecal samples were collected between June 2014 and August 2016.

Site	Condition	*k*-value (g/day)	Days until effective decay
7	Dry	0.00301	492
7	Wet	0.01907	78
9	Dry	0.00222	667

Site	Condition	*k*-value (g/day)	Days until effective decay
9	Wet	0.01334	111
10	Dry	0.00292	507
10	Wet	0.02697	55
1	Dry	0.00228	650
1	Wet	0.01282	116
9.1	Dry	0.00192	772
9.1	Wet	0.00894	166
9.1	Dry	0.00368	403
Mean	Wet	0.01622	105
Mean	Dry	0.00267	582

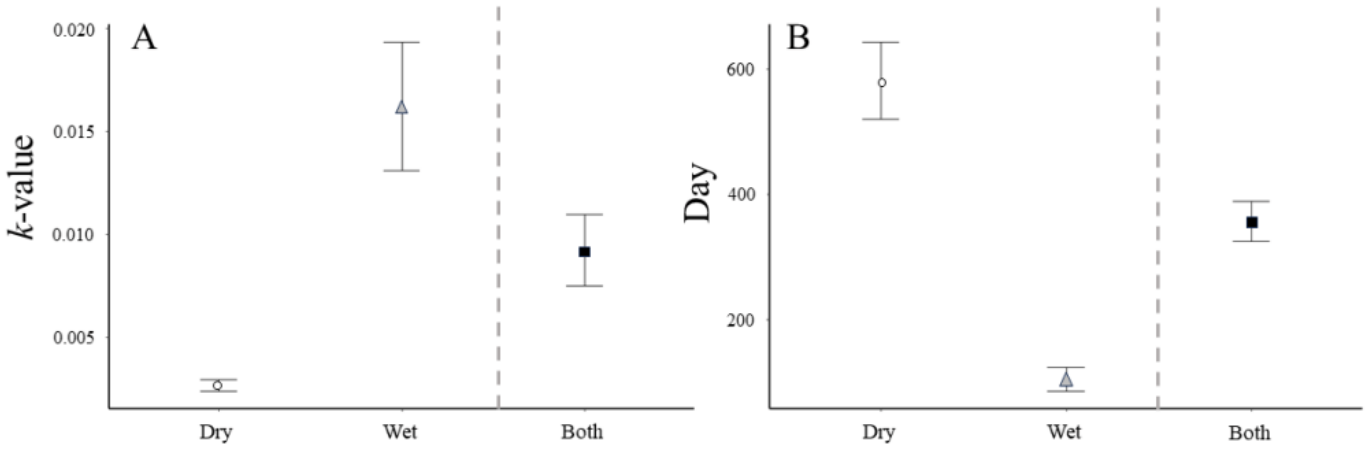

Figure 2. (A) Mean (± SE) decay rate (*k*, g/day) and (B) time (days) until effective decay of vole feces during the fecal decomposition experiment conducted near Tecopa, Inyo County, CA, USA, 2014–2016.

Sign surveys.— We detected vole sign in 34 of 51 sites surveyed (66.7%, CI = 52.0–78.9%, Fig. 3) between Tecopa Hot Springs Road (35.8843, –116.2345) and the confluence of the Amargosa River and Willow Creek (35.7838, –116.2021, Fig. 1). During the time periods when fresh sign was differentiated from old sign, we observed 84 individual indicators of vole presence, including 27 runways (32.1% of all sign), 18 old fecal piles (21.4%), 17 new fecal piles (20.2%), 12 fresh clippings (14.3%), 8 old clippings (9.5%), and 2 burrows (2.3%).

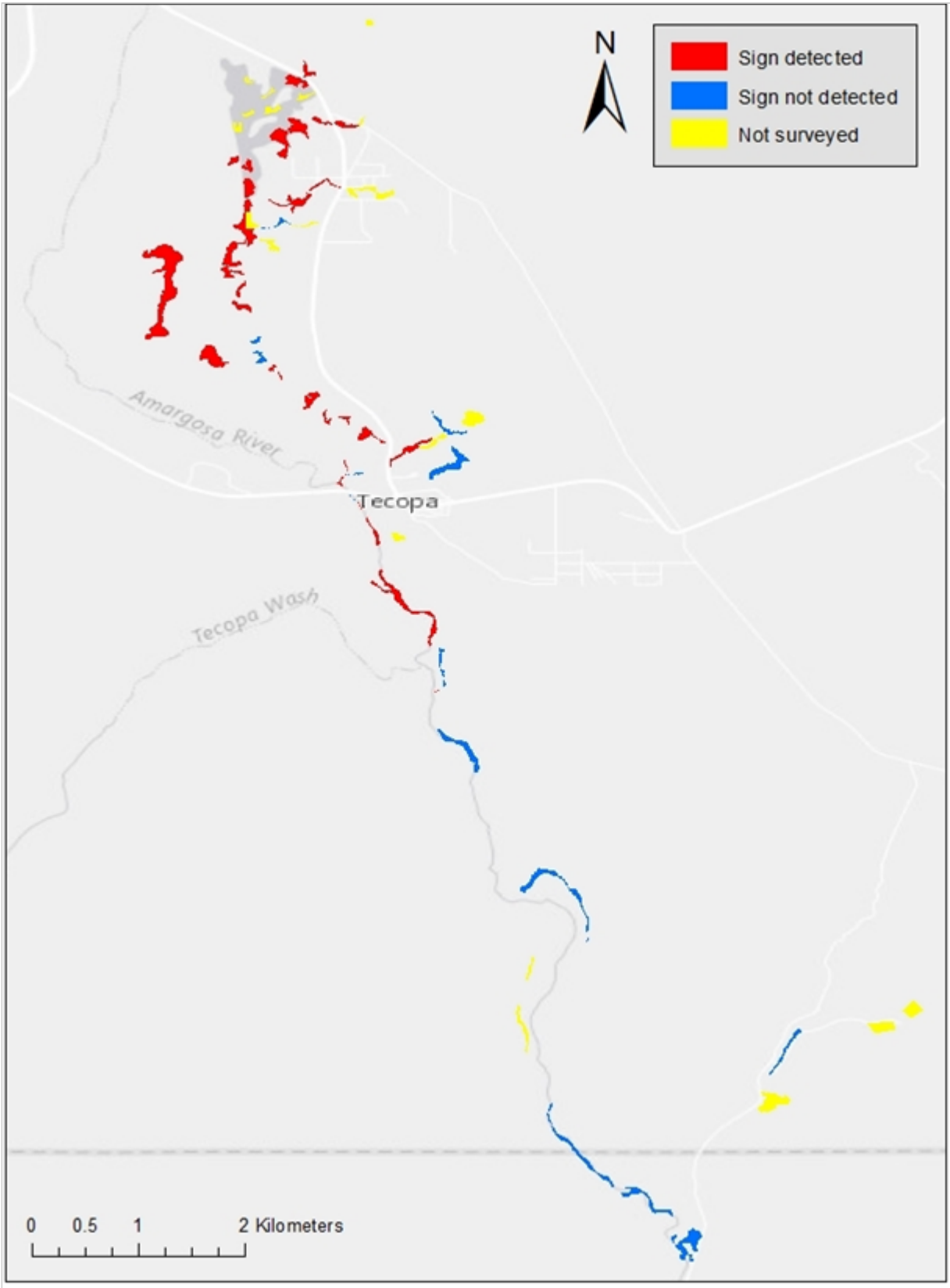

Figure 3. Wetland sites where Amargosa voles were detected during sign surveys from 2014 through 2016 near Tecopa, Inyo County, CA, USA.

Live-trapping.—Over the course of eight sample periods, there were approximately 37,640 trap occasions

yielding 689 individual voles (overall trap success was 4.1%). Except for Grid 4.2 (Site 4), voles were captured at least once in every grid. Voles were captured during each sample period in six of the grids sampled (Grid 2, 6, 10, 12, 39, 54), while voles were captured during one to seven sample periods in other grids. The capture of individual voles was lowest in January (n = 37) and highest in September (n = 215).

Camera-trapping.—A total of 1,220 camera-trap days were observed among all cameras and survey periods between November 2015 and August 2016. These camera-trap days captured 1,603 independent vole events. Voles were documented at least once at 20 of the 21 sites sampled, with 18 of those sites having voles present during each sample period. At Sites 26 and 70, voles were only observed during one sample period while no voles were seen at Site 58 despite cameras being deployed in this site for 11.6 weeks over two sample periods. During camera trapping, the bait as some camera locations was consumed within 5 days of deployment.

Concordance

Across the 15 sites where at least two detection methods were conducted in proximate time periods, 10 time periods distributed in nine sites were subject to all three tests, seven time periods in seven sites were assessed with live-trapping and sign surveys, 19 and 11 with live- and camera-trapping, and two and two with camera-trapping and sign surveys (**Table 2**). Live-trapping was successful in detecting voles in 29 of 36 (80.6%) total attempts, camera-trapping detected voles 29 out of 31 (93.5%) survey attempts, and sign indicated vole activity all 19 times attempted (100%). When all three tests were used together, they gave the same results seven times and discordant results three times, for a test agreement 70% of the time. Live-trapping and sign surveys were concordant four times and discordant three (57.1% concordant), live- and camera-trapping gave concordant results 17 times (80.9%) and discordant results only twice, while camera-trapping and sign surveys agreed once (50%) and disagreed once.

Table 2. Results of three methods of assessing Amargosa vole presence in wetlands near Tecopa, Inyo County, California from November 2015 through October 2016. Surveys were conducted within one month of each other at the same site. Survey methods included live-trapping (Trap), sign surveys (Sign), and remote camera-trapping (Camera), as described in text. Color- and letter-codes are provided below to highlight when two or three surveys were conducted in close temporal proximity. Positive indicates the test detected at least one vole and negative indicates no voles were detected. “N/A” indicates that no comparisons were made during the sampling period.

Data Key
Trap, sign, camera (TSC)
Trap and sign (TS)
Trap and camera (TC)
Camera and sign (CS)

Site	Method	Nov	Jan	March	May/June	Aug-Oct
5	Trap	- TSC	N/A	+ TC	+ TC	N/A
5	Sign	+ TSC	N/A	N/A	N/A	N/A
5	Camera	+ TSC	N/A	+ TC	+ TC	N/A
6	Trap	+ TS	+ TC	N/A	+ TC	+ TSC
6	Sign	+ TS	N/A	N/A	N/A	+ TSC
6	Camera	N/A	+ TC	N/A	+ TC	+ TSC
7	Trap	- TS	N/A	N/A	N/A	N/A
7	Sign	+ TS	N/A	N/A	N/A	N/A
7	Camera	N/A	N/A	N/A	N/A	N/A
8	Trap	N/A	N/A	N/A	N/A	N/A
8	Sign	+ CS	N/A	N/A	N/A	N/A
8	Camera	- CS	N/A	N/A	N/A	N/A
10	Trap	+ TS	N/A	+ TC	+ TC	N/A
10	Sign	+ TS	N/A	N/A	N/A	N/A
10	Camera	N/A	N/A	+ TC	+ TC	N/A
11	Trap	+ TSC	N/A	- TC	- TC	N/A
11	Sign	+ TSC	N/A	N/A	N/A	N/A
11	Camera	- TSC	N/A	+ TC	+ TC	N/A
17	Trap	+ TS	+ TC	N/A	+ TC	+ TSC
17	Sign	+ TS	N/A	N/A	N/A	+ TSC
17	Camera	N/A	+ TC	N/A	+ TC	+ TSC
19	Trap	N/A	TC	N/A	N/A	N/A
19	Sign	+ CS	N/A	N/A	N/A	N/A
19	Camera	+ CS	N/A	N/A	N/A	N/A
21	Trap	- TSC	N/A	N/A	+ TC	+ TSC
21	Sign	+ TSC	N/A	N/A	N/A	+ TSC
21	Camera	+ TSC	N/A	N/A	+ TC	+ TSC
22	Trap	- TS	N/A	N/A	N/A	N/A
22	Sign	+ TS	N/A	N/A	N/A	N/A

Site	Method	Nov	Jan	March	May/June	Aug–Oct
22	Camera	N/A	N/A	N/A	N/A	N/A
23.2	Trap	N/A	N/A	N/A	+ TSC	+ TC
23.2	Sign	N/A	N/A	N/A	+ TSC	TC
23.2	Camera	N/A	N/A	N/A	+ TSC	+ TC
34	Trap	+ TS	+ TC	N/A	+ TC	+ TSC
34	Sign	+ TS	N/A	N/A	N/A	+ TSC
34	Camera	N/A	+ TC	N/A	+ TC	+ TSC
39	Trap	+ TSC	N/A	N/A	+ TC	+ TC
39	Sign	+ TSC	N/A	N/A	N/A	N/A
39	Camera	+ TSC	N/A	N/A	+ TC	+ TC
54	Trap	+ TSC	N/A	N/A	+ TC	+ TC
54	Sign	+ TSC	N/A	N/A	N/A	N/A
54	Camera	+ TSC	N/A	N/A	+ TC	+ TC
67	Trap	- TS	N/A	N/A	+ TC	N/A
67	Sign	+ TS	N/A	N/A	N/A	N/A
67	Camera	N/A	N/A	N/A	+ TC	N/A

Camera trapping had the highest sensitivity (detection rate) at 93.5%, no false-positives, and only two occasions when live-trapping successfully captured voles and camera-traps were negative. However, we could not calculate the specificity of camera-trapping, as there were no known true-negative camera events during the time frame of this study. Compared to camera-trapping, live-trapping had a sensitivity of 85.2%, while sign surveys may have falsely identified a site as having voles as often as 21.1% of the time. This is equivalent to a minimum precision or positive predictive value for sign surveys of 78.9%.

For both camera- and live-trapping, only one or two days were required before a vole was detected if it was detected at all. For live-trapping, the number of first observations of individuals at a site was highest on Day 1 (n = 35) and lowest (n = 0) on Day 5. However, the total number of voles caught on a given trap night varied ($F_{4,37}$ = 3.3, P = 0.021) and generally increased with the number of trap nights, with the most individuals being captured during Night 4. Successful camera-trap events were highest on Day 1 (n = 29) and lowest on Day 4 (n = 0). During this study, when abundance and occupancy of voles appeared to be relatively high, neither baited camera- nor live-trapping would need to be conducted more than three consecutive days to capture virtually all needed data to confirm vole presence in a site.

Cost Analysis

Live-trapping was the most expensive detection method when compared with camera-trapping and sign surveys. We estimated staff hours as 2,390 hours per year to set, check, remove, and clean traps and process animals. The equipment cost of live-trapping was $12,821, and the total expense for live-trapping was $74,722 (or $7,472 per trip for 10 trips per year). The impact to habitat for live-trapping was high, with a minimum of 80 incursions per site per year. Camera-trapping was the next most expensive detection method. We estimated that it would take a single staff member approximately 450 hours a year to install, check, and review the data from cameras. The equipment cost for camera surveys was $18,250. In total the expense for camera trapping was estimated as $29,903 (or $9,967 per trip for 3 trips per year). The impact of this method on habitat was moderate, with 18 incursions per site over the course of the project. Sign surveys were the least expensive detection method and impact habitat the least. We estimated that a single field researcher could survey the entire known geographic range of the Amargosa vole in four days, or approximately 48 work hours, and field staff would only need to visit a site one time per year. Sign surveys did not require any additional equipment costs. The total expense of this method was $1,243 and the impact to habitat was low.

Discussion

We show that sign surveys, camera-trapping, and live-trapping each have utility for detecting Amargosa voles, but differ in accuracy, costs, and benefits. Camera-trapping maximized data quality, accuracy, detection, and cost, while reducing habitat impact and allowing for the collection of multiple data types (e.g., detections and behavior). While live-trapping provided essential data that other methods could not collect (e.g., demographic and health), it was relatively expensive and had high habitat impacts. Sign surveys were sensitive during this year of high site occupancy and had the lowest expense and habitat impact but lacked in specificity. While we identify camera-trapping as the best vole detection method in this study, appropriate detection method selection will depend on the goals and time and cost limitations of individual research efforts.

Baited camera-trapping is increasingly used for the detection of small mammals (De Bondi et al. 2010; Rendall et al. 2014; McDonald et al. 2015). Cameras allow for continuous observation without the disturbances associated with the presence of a human observer (Vine et al. 2009; McDonald et al. 2015) and cause minimal adverse outcomes to the target fauna. Camera-trapping has a moderate overall expense (depending on number of trips) and was the most expensive method per trip in our study. Some of these costs were derived from the person hours required to review camera images, and these costs may be decreased in the future with the development of better artificial intelligence camera programs. While camera-trapping had only moderate habitat impacts, fragile ecosystems such as Amargosa vole habitat may still be damaged by the installation of equipment and movement of personnel. Furthermore, individual voles cannot be identified with camera-trapping, making cameras less useful for population quantification or assessment of demographic, disease, or genetic characteristics of the population. However, new techniques are being developed to understand population characteristics from unmarked populations (Chandler et al. 2011; Zipkin et al. 2014) and may be useful in future efforts to research voles. It is also worth noting that while not necessary on this project, specialized training, and associated costs, to identify cryptic species on camera images may increase costs for using cameras on other projects. Additionally, the quality of cameras used on a project may be species dependent and the financial costs associated with camera purchases may increase or decrease depending on project

requirements.

Live-trapping provides unambiguous species identification and allows for additional sampling often crucial for health or genetics studies (Kelt 1996; De Bondi et al. 2010). These benefits are also paired with potential drawbacks, which include reduced detection, potential harm to individuals, increased predation risk, increased habitat impact, and increased project costs. Live-trapping may yield a longer time until initial detection or fewer detections than cameras, due in part to the phenomenon of small mammals initially avoiding new objects followed by cautious investigation (Tasker and Dickman 2001), resulting in the highest total capture rates not occurring until later in a trapping session (e.g., day 4 or day 5). Physical capture may potentially harm the individual (Fletcher and Boonstra 2006; De Bondi et al. 2010). For example, females exposed to heightened stress may exhibit diminished maternal care to offspring, affecting survival and reproductive success (Meaney 2001; Matthews 2002; Fletcher and Boonstra 2006). In addition, in the sites where we performed live-trapping, repeatedly walking along transect lines resulted in damage to vegetation and development of pathways that could be used by predators such as coyotes to access previously inaccessible portions of vole habitat. Due to the high number of trips in this study, live-trapping incurred the highest overall costs. However, if fewer trips are required, this method may be more comparable cost-wise to other methods. Furthermore, animal trapping and proper handling and restraint also require specialized training and associated costs. Given the potential costs associated with live-trapping, researchers and managers may consider camera-trapping as an alternative for routine monitoring of species occurrence in fragile habitats, interspersed with less frequent live-trapping periods to assess disease, genetics, and demography.

Sign surveys are useful in determining vole occurrence, especially due to their relatively low costs and low effort; we were able to survey the entire range of the Amargosa vole in four days. However, these surveys are dependent on staff skill and environmental conditions. False positive sign surveys may occur if sign from other species is misattributed to the target species and the predictive values of sign surveys are likely to decline in years when vole numbers are low. Molecular techniques using fecal DNA may improve the sensitivity of sign surveys (Galan et al. 2012), but these methods are likely too expensive to use in all surveys and should be reserved for confirmation where camera, live-trapping, or prior data suggest vole presence to be novel or unlikely. Even when fecal pellets are correctly identified as vole, false evidence of true occupancy can be inferred if a pellet is aged, and voles are truly no longer present. Our data show that feces can persist for almost two years depending on the condition of a site, although most fecal samples in the field are smaller than what we used in our study (<1 g) and would be expected to decay more quickly. We recommend that vole sign surveys using fecal presence be conducted at a course time scale (≥ 1 year) when being used to examine distribution and occupancy analyses.

Several untested factors may influence the detection of voles for each of the methods we examined. We did not account for the area or shape of a given site in our analysis and it is likely that larger sites would have a higher likelihood of having persistent and abundant vole populations compared to smaller sites or sites with less bulrush, which voles may use less commonly (López-Pérez et al. 2019). As such, voles in larger sites may be easier to detect than in smaller sites. For example, the spacing of traps used in this study may have allowed for traps to be placed outside of occupied microhabitats containing voles (e.g., placed in non-bulrush habitat when bulrush habitat was nearby). Opportunistic trapping (e.g., at areas of vole sign) or other sampling designs may yield higher detection rates for certain sites than established grids of evenly spaced stations (Parmenter et al. 2003; Rehnus and Bollmann 2016). Similarly, altering the camera sampling design or the duration of sign surveys at each site may also influence detection rates (Rovero et al. 2013). Some of these changes may ultimately have increased detection rates and

influenced our findings but would also have likely increased costs and habitat disturbance or altered the type of analyses that could be conducted with the data. Such factors should be considered prior to initiating surveys for similar species in sensitive habitats.

We recommend using camera traps if the research goal is solely to document species' presence or absence and we have found cameras to be the best method for doing so with Amargosa voles and other small mammals in sensitive habitats (e.g., salt marsh harvest mouse, *Reithrodonotmys raviventris*; Buena Vista Lake ornate shrew, *Sorex ornatus relictus*). Camera traps provide constant monitoring with relatively few impacts and while we did not use the data here, the data gained can be used to provide insights into behavior and activity patterns (Pesapane et al. 2018; Haswell et al. 2022; Roy et al. 2023), inter- and intra-specific interactions (Sutherland and Singleton 2003; Haswell et al. 2022), population estimates (Karanth 1995), and occupancy models (Rich et al. 2017). The use of cameras should be weighed alongside project costs and research objectives, as the initial costs for equipment may be high, but cameras can be used for multiple projects beyond this initial research or study species.

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