United States Department of the Interior
U.S. GEOLOGICAL SURVEY
Western Ecological Research Center
San Diego Field Station
4165 Spruance Road, Suite 200
San Diego, California 92101

4/30/2020

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Dear Ms. Smith and Dr. Preston,

This letter transmits the U.S. Geological Survey (USGS) Western Ecological Research Center's Draft Final: American Badger Research in Western San Diego County; Results Synthesis, Literature Review and Pathway for Future Research and Monitoring. This work was completed under agreement number 5004597. We expect to publish these data in a paper in 2021 as part of a synthesis on badgers in San Diego County.

Please note that this information is preliminary or provisional and is subject to revision. It is being provided to meet the need for timely best science. The information has not received final approval by the USGS and is provided on the condition that neither the USGS nor the U.S. Government shall be held liable for any damages resulting from the unauthorized use of this draft data for interpretation or resource decision-making.

Please direct any questions to me at (619) 206-5686.

Sincerely,

Robert Fisher

Principal Investigator

American Badger Research in Western San Diego County; Results Synthesis, Literature Review and Pathway for Future Research and Monitoring, Draft Final

American Badger Research in Western San Diego County; Results Synthesis, Literature Review and Pathway for Future Research and Monitoring, Draft Final

By: Cheryl Brehme, Devin Adsit-Morris, and Robert N. Fisher

U.S. GEOLOGICAL SURVEY
WESTERN ECOLOGICAL RESEARCH CENTER

Data Summary

Prepared for:
San Diego Association of Governments

Research authorized by:
California Department of Fish and Wildlife
Scientific Collecting Permit (Entity) and MOU: SCP838

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USGS Western Ecological Research Center
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INTRODUCTION

Badgers (*Taxidea taxus*) are wide-ranging mid-sized predators that are known to inhabit San Diego County. Similar to the mountain lion, they are known to range over wide areas, often making movements of 10km or more per day (Messick and Hornocker 1981; Hoodicoff 2003; Minta 1993; Quinn 2008; Doyle et al. 2019). Therefore, they are a suitable focal species for monitoring regional-scale connectivity. Unlike mountain lions that prefer to move within riparian areas (Dickson et al. 2005), badgers prefer open or grassy areas and thus are likely better indicators for upland connectivity and represent a different suite of species (Quinn 2008). Badgers are a covered species under the San Diego Multiple Species Conservation Plan (MSCP) (SDMMP 2011, 2017) and have been identified by the San Diego Monitoring and Management Program (SDMMP) Connectivity Monitoring Strategic Plan (2011) as a target species for monitoring regional-scale functional connectivity of upland and grassland habitats as well as a species considered to be at risk of loss from the SDMMP Management Strategic Plan Area (MSPA; SDMMP and Nature Conservancy 2017). The U.S. Geological Survey has been studying badger distribution and activity in San Diego County since 2011 using a variety of methods to better understand their distribution and core use areas (Brehme et al. 2012, 2015, 2016). The purpose of this report is to synthesize the techniques used and findings from the Brehme et al. (2012, 2015, 2016) reports into one document as well as review the objectives and methods for potential future research on the status and trends of this highly sensitive and elusive species.

American Badger

The American badger (*Taxidea taxus*) is a nocturnal medium-sized fossorial carnivore of the Mustelid family that includes weasels and wolverines. Badgers are stocky with very powerful forearms and claws for digging. Their primary prey are small mammals such as ground squirrels, gophers, ground hogs, prairie dogs, voles, mice, woodrats, and kangaroo rats, but they also eat birds, herpetofauna, invertebrates, and plants (Errington 1937; Long 1972; Messick 1987; Quinn 2008). Their home ranges and densities have been associated with density of prey, particularly ground squirrels (i.e. Owings and Borchert 1975; Lay 2008; Prioulx 2016). Badger densities are typically low, ranging from 0.2 to 5 individuals per km^2, while their home ranges are large, ranging from 2 to 50 km^2 and sometimes up to 450 km^2 (Messick and Hornocker 1981; Hoodicoff 2003; Minta 1993; Quinn 2008; Doyle et al. 2019). Except for mothers with their young, adults are largely solitary, moving an average of 0.5km per night in search of prey (Lindzey 1978; Hoodicoff 2003). Badgers mate July through September, and with delayed implantation, females give birth the following spring to an average litter size of 2 to 3 young. Their lifespan is 9 to 10 years in the wild (Long 1972).

Badgers range across much of North America, from southern Mexico to central Canada and from the west coast of California to the Great Lakes region. Within the range of the species, they are known to prefer sandy loam soils and open grasslands, although they are found in open scrublands, open woodlands, and open chaparral (Grinnell et al. 1937; Long 1972; Messick and Hornocker 1981; Hoodicoff 2003; Quinn 2008). In Quinn's (2008) study of badger habitat and movement in Monterey County, California, she found they spent 91% of their time in grassland habitats.

Because of their large home ranges, habitat preferences, and low fecundity, badgers are especially vulnerable to the negative effects of habitat loss, habitat fragmentation, and road mortality (e.g. Crooks 2002; Lay 2008; Klafki 2014). Significant declines of badger populations and distribution have been documented in California and British Columbia (Williams 1986; Adams and Kinley 2004). In a habitat fragmentation study of southern California, badgers were only found in very large unfragmented sites (Crooks 2002). Even in less developed areas, badgers' large home ranges often require them to cross roads resulting in high rates of road mortality (e.g. Messick and Hornocker 1981; Klafki 2014). Finally, because rodents make up their primary prey base, rodenticide use is associated with lower badger densities (Proulx and MacKenzie 2012).

Badgers were extensively hunted for their pelts between the 1930s and 1970s, and are still reportedly being trapped in high numbers (Williams 1986; Quinn 2008). Currently, a California Department of Fish and Wildlife (CDFW) Trapping License is required for any for-profit trapping or hunting of badgers with no limits to the number of individuals. Depredation and predator control that is not for-profit does not require a permit or reporting. This species has long been considered a pest species for agriculture. It is hypothesized that there are many more badgers killed for depredation, and it is unknown how much this has contributed to their decline (Williams 1986; Quinn 2008). To date there is little known about the ecology of the badger in coastal southern California.

In 1986, the American badger was designated as a CDFW Species of Special Concern due to a substantial reduction of their distribution and abundance (CNDDB 2019). Primary stressors to the American badger in southern California include (Tremor 2017):

- Road mortality
- Habitat loss
- Habitat fragmentation: Lack of open habitat and/or corridors for movement and dispersal.
- Hunting and trapping: Predator control/sport shooting/fur trapping
- Reduced prey base from use of rodenticides.
- Consumption of rodenticides from small mammal prey

Summary of Badger Survey Efforts

In fiscal year 2011–2012, the Natural Community Conservation Plan (NCCP) Local Assistance Grant (LAG) program funded an initial study to determine if badgers persisted in the western portion of San Diego County (Brehme et al. 2012). Canine scent surveys were performed across the county in suitable grasslands within MSCP/Multiple Habitat Conservation Program (MHCP) boundaries and nearby areas. Badger sign (scat and/or burrows) was confirmed in Camp Pendleton, Fallbrook Naval Weapons Station, Daley Ranch (northern Escondido), Ramona Grasslands, Crestridge Ecological Reserve, Santa Ysabel Ecological Reserve, Hollenbeck Canyon Wildlife Area, and Marron Valley (Brehme et al. 2012). Because badgers do persist within the western portion of the county, it was determined that they may be a suitable species for assessing upland connectivity.

In 2013–2014, the NCCP LAG program and the San Diego Association of Governments SANDAG funded 2014 field studies to identify target areas with potentially higher densities of badgers and to better assess the level of connectivity between known occupied areas using canine scent detection and badger sign surveys. We found that many sites where badger activity was confirmed in 2011–12 had no recent sign of badger activity. In areas where we found fresh sign in the spring, activity quickly ceased, and no further activity was documented through the summer and fall (Brehme et al. 2015). Although stable populations with smaller home ranges have been documented in some parts of their range, badger home ranges of 35 to 300km^2 are common in other areas, with size largely determined by availability of dispersed prey, burrowing sites and mates (Goodrich and Buskirk 1998; Hoodicoff 2003). The 2014 results suggested that badgers in San Diego County also operate on a larger spatial scale. Thus, rather than stable population locations of badgers, areas may be used frequently or infrequently (Brehme et al. 2015). In 2014, we also established an outreach effort that included a poster and badger reporting hotline and email. This has been successful in identification of other badger use areas within the county. Finally, although we are presently able to genetically identify badgers at the species level from scat, there have been challenges to the identification of individuals except from hair or tissue samples (Wood et al. 2016).

In 2015, we focused on areas that were previously found to have high or repeated badger use. Our goal was to determine if American badgers use these areas annually and if so, to better document the duration and season(s) of activity. This would help us to better understand the spatial and temporal dynamics of badgers within core-use areas and inform locations and timing of any future trapping efforts for radio-telemetry. We focused our surveys in seven areas where we documented substantial badger use in previous years: Barnett Ranch, Ramona Grasslands, Santa Ysabel Ecological Reserve, Volcan Mountain, Marron Valley, Guejito Ranch, and Capitan Grande Reservation (upper San Diego River) (Brehme et al. 2012, 2015). Surveys included monthly on the ground searches for badger burrows and other sign as well as monitoring by use of infrared cameras. American badger activity was documented at two of the seven focal sites by the presence of fresh burrows and digs and with infrared camera photos and video; these sites were the upper San Diego River at El Capitan Grande Reservation and Rancho Guejito. Activity was detected in June, August and September at both sites as well as November in Rancho Guejito (Brehme et al. 2015, 2016). Our data indicated these sites are likely core-use areas for badgers in western San Diego County.

In 2016, there was a reduction in the program, and we focused on three locations (Volcan Mountain, Rancho Guejito, and Rancho Jamul) from March–December 2016 with other areas visited for discovery or in response to reported sightings from our badger hotline. Each site was surveyed 3–4 times during that time frame (more frequently if fresh badger sign was recently detected). Surveys included badger sign searches and infrared cameras set up in known use areas. We confirmed American badger activity at two previously occupied focal sites. Badger activity was documented in May, August, September, and November at Volcan Mountain and in September at Rancho Guejito. We used facial recognition to identify at least three individual badgers at Volcan Mountain (Brehme et al. 2016).

Since 2016, we have surveyed core sites for badger activity as our schedules allowed and have continued to distribute posters at open space kiosks, monitor the dedicated USGS badger hotline and email, and validate reports by interviews, photographs, and field surveys.

METHODS

We have used many methods to obtain information on badger distribution and activity including canine scent detection, badger sign surveys, infrared cameras, facial recognition, hair snags, genetic testing and development, outreach efforts, and recovery and processing of road mortalities. Each technique described below was used in one or more previous studies, which are reported in Brehme et al. (2012, 2015, 2016).

Canine Scent Surveys

We contracted Conservation Canines, Center for Conservation Biology (CCB, University of Washington), to conduct surveys for the American badger in San Diego County (Figure 1). Their detection dogs were initially trained using American badger scat from the Washington Zoo following the methods outlined in Wasser et al 2004. USGS biologists assisted as orienteers and for data collection. All routes and detection locations were recorded using a GPS unit attached to the dog. GPS coordinates were taken and pin flags were placed at locations where the dog indicated a scent detection (behavior change, "hit"). After a dog "hit," the handler would state the confidence level in the dog's response as well as the handler's confidence in the dog's response. All scat was collected with gloved hands, placed into a plastic bag, and stored frozen until DNA testing.

Figure 1. Photos showing canine scent survey and trained scent dog "Pips" from Conservation Canines, University of Washington.

Badger Sign Surveys

Badger sign surveys involved surveying the landscape for potential badger sign (burrows, digs, and tracks; Figure 2). The surveyor would walk around the site while scanning for mounds and burrows. Burrows were confirmed as badger if they were the correct size and shape (approximately 8–12 inches wide and 6–10 inches in height) and contained characteristic horizontal claw marks within the burrow (approximately one inch spacing between claws). Freshness was determined by evidence of loose soil at the entrance indicative of recent digging. Other evidence included body 'drags' and/or tracks observed at the burrow entrance (Figure 3). Older burrows were identified as such if they had new or substantial growth of grasses or forbs at the entrance, there was no evidence of recent digging, or they contained evidence of recent squirrel use.

We also recorded an index of prey density for squirrels and gophers at the survey sites. The index was based upon a visual estimate of squirrel and gopher burrow density with categorical estimates of 0, 1–5, 6–10, 11–20, 20–50, and >50 burrows/hectare.

Figure 2. Examples of American badger burrows in San Diego County with marks from body drags and prints.

A)

B)

C)

Figure 3. Examples of American badger A) claw marks in burrow and dig, B) scat, and C) tracks.

Infrared Cameras

Infrared cameras (Reconyx and Bushnell) were set facing landscapes with previous or recent badger activity, on nearby upland animal trails, facing suitable grassland habitat, and directly on any fresh and potentially occupied burrows using both motion detection and time-lapse settings (Figure 4). Reconyx PC800 HyperFire Professional Semi-Covert infrared cameras were set to medium sensitivity for motion detection and automatic time-lapse photo captures every 1 minute. Bushnell Trophy HD cameras were set with three different detection types, depending on the type of sign present: normal sensitivity motion detection (for burrows), low sensitivity motion detection with automatic 1-minute interval time-lapse capture (for landscapes and trails) and normal sensitivity motion detection with video (for high confidence burrows).

Figure 4. Examples of A) camera placement next to active burrow and in the landscape and B) infrared camera photos of badgers in San Diego County.

Facial Recognition

Individual American badgers have unique facial markings (Figure 5; Harrison 2016). When we were able to obtain badger photos that had a clear view of the side and top of the head, the photos were enhanced and added to an individual badger photo database. Photos were reviewed by multiple biologists for similarity in facial markings to identify individuals. Pattern recognition software is currently being evaluated to assist in identification of individuals.

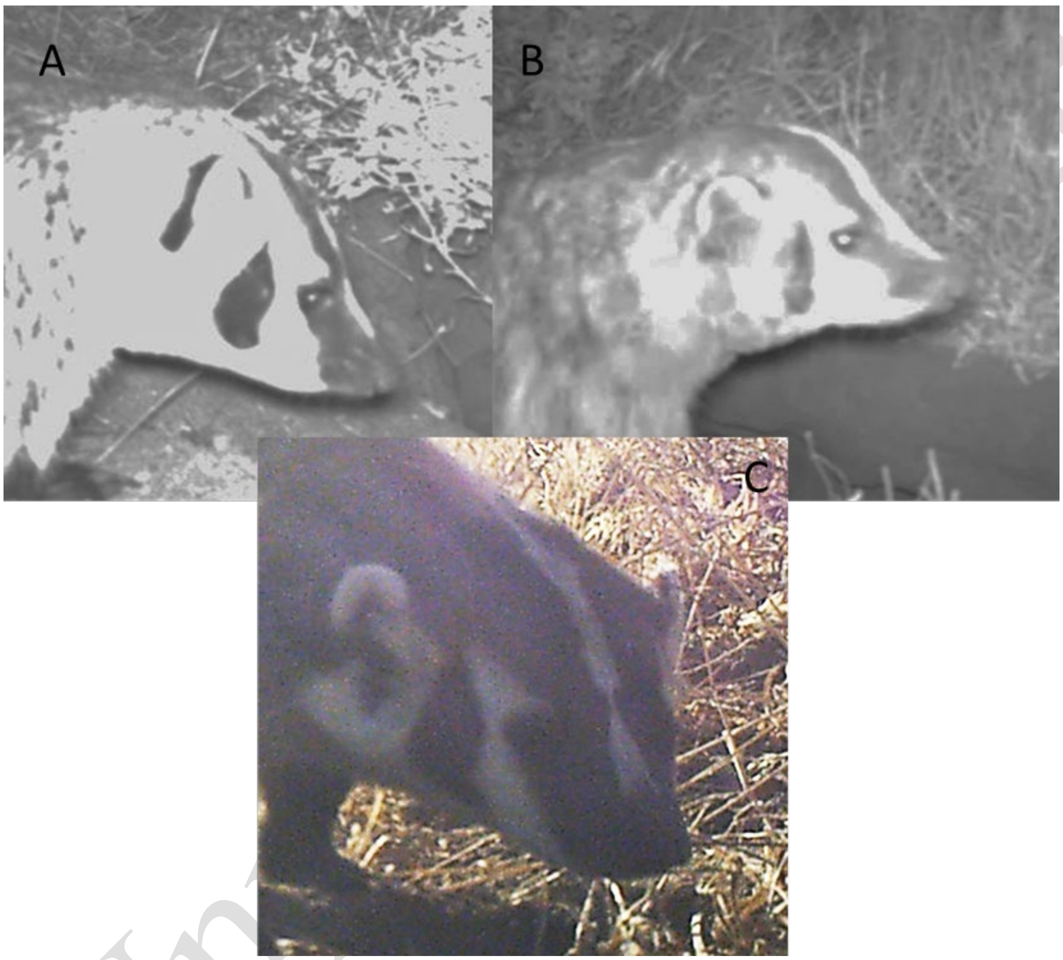

Figure 5. Examples of three different badgers detected on Volcan Mountain based on different facial markings, Longnose (A), Notch Face (B), and Side Burn (C).

Hair Snags

When fresh badger burrows were identified at sites where repeat visits were possible, hair snags were placed within the burrow entrances. Hair snags were constructed according to protocol provided by American badger researcher, Richard Klafki (British Columbia), who travelled to San Diego and shared his expertise and methods with the USGS from May 1 to May 6, 2014.

Snags were made from 30cm (12”) of 2-cm (3/4”) wide metal strapping formed into a ‘D’ (Figure 6). Two 3-inch nails were inserted through holes drilled at the base of the ‘D’ and were used to secure the snag inside the burrow. Three rivets were placed at each edge and in the middle to secure the strapping in its shape. Two squares (approximately 3–4cm by 2cm) of pinned-knaplock (used to anchor carpet in doorways) were riveted to the curved edge of the metal strapping. The teeth of the knaplock were slightly bent down to better force hair into the snag and prevent injury to an animal.

A) B)

Figure 6. (A) Hair snag in burrow and (B) snag with hair in San Diego County.

Genetic Testing

Mitochondrial DNA Testing

The goal of scat DNA testing was to identify if scat samples collected in the field were from the American badger. CCB developed a badger specific identification assay that amplifies two American badger specific DNA markers and tested all samples (Brehme et al. 2012, 2015).

The surfaces of all samples were swabbed in duplicate to remove mucosal cells for DNA extraction. DNA on the swabs was extracted using a modified version of Qiagen's DNeasy Tissue DNA extraction kit (Qiagen, Hilden, Germany). These DNA extracts were then PCR amplified three times on the duplicate extracts using two previously developed and validated badger-specific mitochondrial DNA markers, BGR1 and BGR3. Fragments were separated by size using capillary electrophoresis on an ABI 3730 (Applied Biosystems, Carlsbad, CA) and then visualized and scored using GeneMarker® software (SoftGenetics, State College, PA). Negative controls were used throughout each step of the process, and positive controls of known badger DNA and various non-target species were amplified along with experimental samples. Because of the specificity of the assay, all positive results were interpreted as DNA from the American badger. Negative results were interpreted as either being from another species or from the scat of an American badger where the DNA was too degraded to amplify in the PCR.

Microsatellite DNA Testing

Wood (2016) developed a badger specific microsatellite assay with nine loci to identify individual badgers from muscle, liver, and hair samples. These loci were originally developed in American badger (Tt-1, Tt-2, Tt-3, Tt-4; Davis and Strobeck 1998), American marten (Ma-1; Davis and Strobeck 1998), and European badger (Mel1, Mel14, Mel101, Mel111. This method has not been successful in identifying individual badgers from scat samples as the DNA is too degraded in these samples.

Outreach Efforts

Outreach efforts to the public and other wildlife professionals are commonly used to gain information on badger localities and their spatial and temporal use of habitat (Ministry of Environment Ecosystems 2007). We created and distributed a poster (modified from R. Klafki, Figure 7) and “San Diego Badger Hotline” dedicated phone and email to seek public and professional information in July 2014. Since that time, we have continued to distribute the outreach poster to wildlife professionals, land managers, and others. The poster was also posted to the Western Ecological Research Center and San Diego Monitoring and Management Program websites. *https://www.usgs.gov/centers/werc/science/american-badgers-san-diego-county?qt-science_center_objects=0#qt-science_center_objects*

Figure 7. Badger information outreach poster with hotline information (adapted from version provided by Richard Klafki). Example of poster in kiosk at Barnett Ranch Preserve.

Recovery and Processing of Badger Road Mortalities

When notified of a badger road mortality in the county, we arranged to collect the carcass and process it in our laboratory. We took a number of body, head, and tooth measurements, photos, as well as information on sexual condition. Tissue was also collected for future genetic analysis (Table 1). After processing, the carcass is given to the San Diego Natural History Museum for their collection and research.

Table 1. Badger carcass processing fields.

Animal Record ID	
Date of finding/ death	
Date of Carcass Processing	
Location of carcass (utm)	
Location Description	
Carcass processing start state	Frozen, Refrigerated
Cause of Death	
Body exterior notes:	
Sex	
Weight	
Sex Condition	
Head- body length (cm)	Distance between the tip of the nose to inflection point of tail.
Shoulder height	Distance between point of shoulder blade to tip of toe.
tail length	Distance between inflection point with body and tip of flesh.
neck circumference	Circumference of neck, measured midway between shoulders and head.
Axillary girth	Thorax circumference at the axilla.
Tooth (height to gums)- lower	Top of canine tooth to meeting with gums.
Tooth (height to gums)- upper	Top of canine tooth to meeting with gums.
Tooth (tooth to gum meets jaw	Top of canine tooth to meeting where gums meet jaw.
Nail (middle)	Tip of nail to end where nail hits skin.
Stomach contents	
Hair Sample collected	Yes, No
Liver Sample collected	Yes, No
Heart Sample collected	Yes, No
Lung sample collected	Yes, No
bacculum sample collected	Yes, No
Muscle sample collected	Yes, No
Photos	body and head (top, side views), teeth
Notes Other:	

RESULTS

The survey efforts have been variable according to the availability of funding. Since 2011, we have conducted 185 sign surveys for badgers across 38 sites in western San Diego County (not including outreach verification surveys). Of these, we confirmed badger activity at 19 sites and repeated activity at 13 sites (Table 2). In 2014, we conducted monthly surveys at six sites where activity was documented in 2011; we found that badgers visited two of the sites two to three times during the year, while other sites with previous activity in 2011 were not visited by badgers (Brehme et. al 2015). Further surveys at these and other sites have shown intermittent monthly or annual use.

Table 2. USGS survey effort and presence of badger activity in western San Diego County.

				Verified Sign Types						
	Years Surveyed	Years with Verified Sign (USGS Surveys)	Additional Years of Verified Sign (Outreach)	BUR	DIG	SCAT	TRK	CAM	Hair/ Tissue	Sighting
Barnett Ranch Preserve	2014,2015*,2018	2014		■						
Black Mountain Ranch	2011, 2014									
Boulder Oaks Preserve	2014									
Cañada de San Vicente	2014	2014			■					
Crestridge Ecological Reserve	2011, 2014				■	■				
Daley Ranch Open Space Preserve	2011				■	■				
Del Mar Mesa	2011									
Eagle Peak Preserve, SDRP	2017	2017	2014, 2017, 2019	■	■			■		
Fallbrook NWS- South	2011	2011			■	■				
Furby North Property	2011									
Hollenbeck Canyon Wildlife Area	2011,2014*,2016									■
Lake Morena	2011, 2019	2011, 2019	2017, 2019	■	■					
Los Penasquitos Canyon Preserve	2011									
Lower San Luis Rey River	2011									
Marron Valley Cornerstone Lands	2011,2014*,2015*,2017, 2019	2011,2014*,2017	2017	■	■	■	■	■		
MCB, Camp Pendleton	2011, [2012-2019]	2011, 2015, 2016, 2017, 2018, 2019		■	■	■			■	■
Mission Trails Regional Park	2011									
Otay Lakes Regional Park	2011									
Otay Valley / Otay Ranch Preserve	2011									
Otay Mountain Wilderness Area	2014									
Pauma Valley	2011									
Proctor Valley	2011									
Rancho Guejito	,2014*,2015*,2016*, 2017*, 2018, 2019	,2014*,2015*,2016* , 2017*		■	■			■		
Ramona Grasslands Open Space Preserve	2011,2014*,2015*,2018	2011,2014*			■	■				
Rancho Jamul Ecological Reserve	2011,2014*,2016*, 2017		2019							
Roberts Ranch	2011									
San Luis Rey River Park	2011									
Santa Margarita Ecological Reserve (Riverside County)	2011									
Santa Rosa Plateau	2011, 2014	2011			■	■				
Santa Ysabel Ecological Reserve- East	2011, 2014			■	■	■				
Santa Ysabel Ecological Reserve-West	2011, 2014*,2015*	2011, 2014*			■					
Sloan Canyon, Kumeyaay Diegueño Land Conservancy	2014									
Sweetwater Reservoir	2011									
Sycamore Canyon Open Space Preserve	2011									
Upper San Diego River: Capitan Grande Reservation/ El Capitan Reservoir	2014, 2015*			■	■	■	■	■	■	■
Volcan Mountain Ecological Reserve	2014*,2015*,2016*, 2017*, 2018*, 2019*	,2014*,2015*,2016* , 2018*		■	■	■	■	■		
Warner Springs Ranch	2011	2011, 2019		■	■	■				■
Whelan Lake/ Ranch	2011					■				

* Intensive/ repeated surveys throughout the year

Badger Sign Types: BUR= burrow(s), DIG= dig(s), SCAT= confirmed scat, TRK= tracks, Hair/Tissue= from snags or road mortality, Sighting= Direct observation

In addition to our own surveys, many badger locations have been documented through public outreach. Since distribution of the poster and establishment of the hotline in July 2014, we have received over 120 badger reports from biologists and citizens in San Diego and adjacent counties that we were able to verify with high confidence. These are American badger records across the region that may have otherwise gone undocumented. Several reports contained photographs, and all were followed up by phone or email interviews or onsite survey visits. All American badger documented localities within the county are shown in Figure 8, including USGS survey detections, sites documented through public outreach, iNaturalist expert verified badger reports, and historic records (e.g. museum specimens, historic reports, CNDDB)

We analyzed the frequency of outreach reports to get a better understanding of seasonal activity of badgers in the county (Figure 9). The greatest period of activity was documented in April through August. This is the time period of reproduction and weaning (March–May) and males looking for mates (June–August). Male badgers are known to increase the frequency and distance of travel during June and July to find breeding females (Minta 1993; Hoodicoff 2003; Weir et al. 2004; Quinn 2008). There was also higher activity in December and January when badgers in other parts of California, the country and Canada are less active (Goodrich and Buskirk 1998; Quinn 2008; Symes 2013). This may represent dispersal of young and indicate that badgers in San Diego County are actively foraging during this time. The frequency of road mortalities also closely followed this pattern (Figure 9).

There have been 32 reports of road mortalities. Of these, we processed and obtained tissue from 21 badgers. Almost all documented road mortalities were males. The remainder were historic detections or where the carcass was no longer present when we visited the site. A few processed carcasses were kept by the agencies or landowners (e.g. USGS, CDFW, MCBCP). The majority were transferred to the San Diego Natural History Museum. Locations of badger mortalities in the county are presented in Figure 10.

We have collected photographs of 22 badger occasions (unique times and locations) where at least some facial markings are visible. These are still being evaluated for matches; however, an individual that was documented at Capitan Grande Reservation at El Capitan Reservoir was later documented eight miles up the river at Eagle Peak (San Diego River Conservancy). We have also preliminarily documented repeat visits by the same badger at Volcan Mountain in successive years.

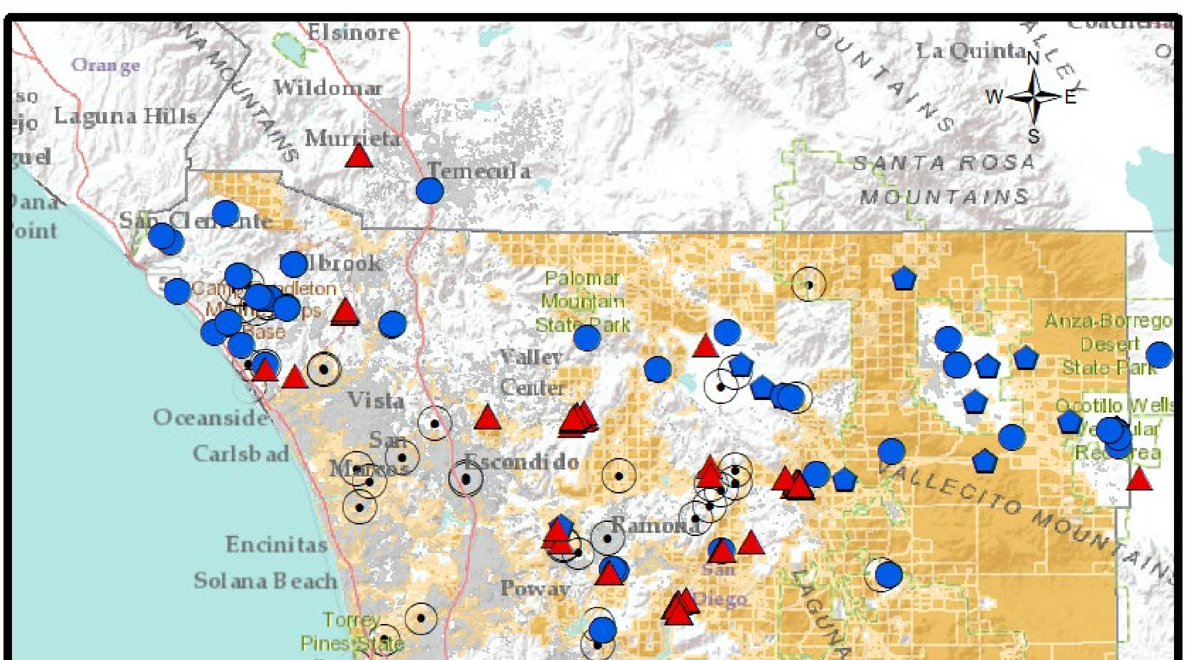

Figure 8. Historic and current badger detections across San Diego County.

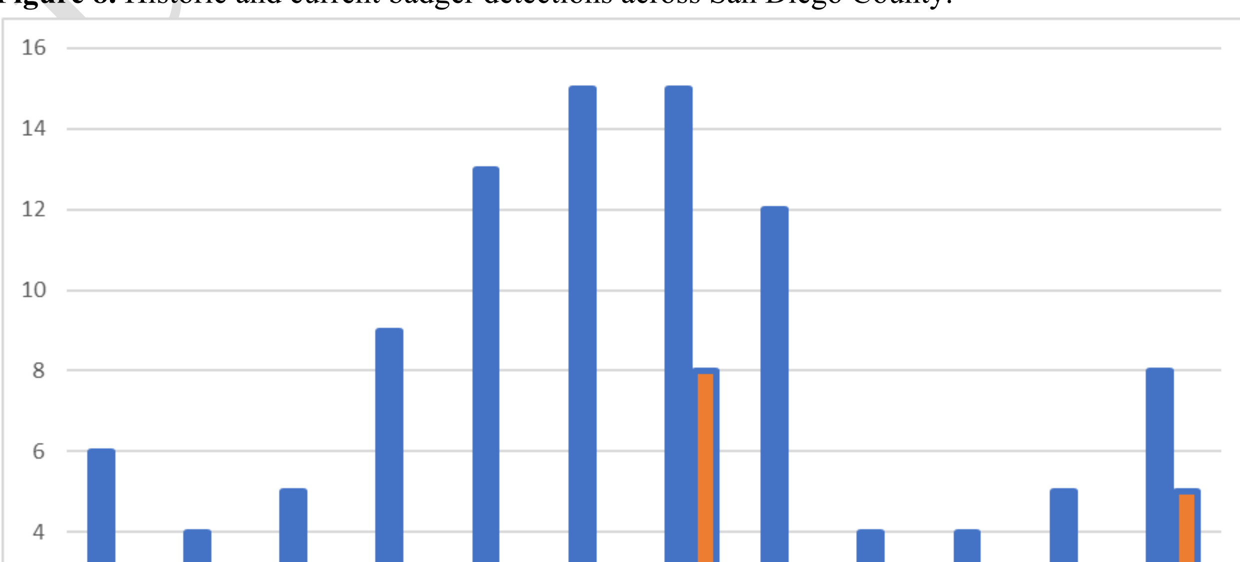

Figure 9. Frequency of verified badger sightings and mortalities in San Diego County by month 2014–2019.

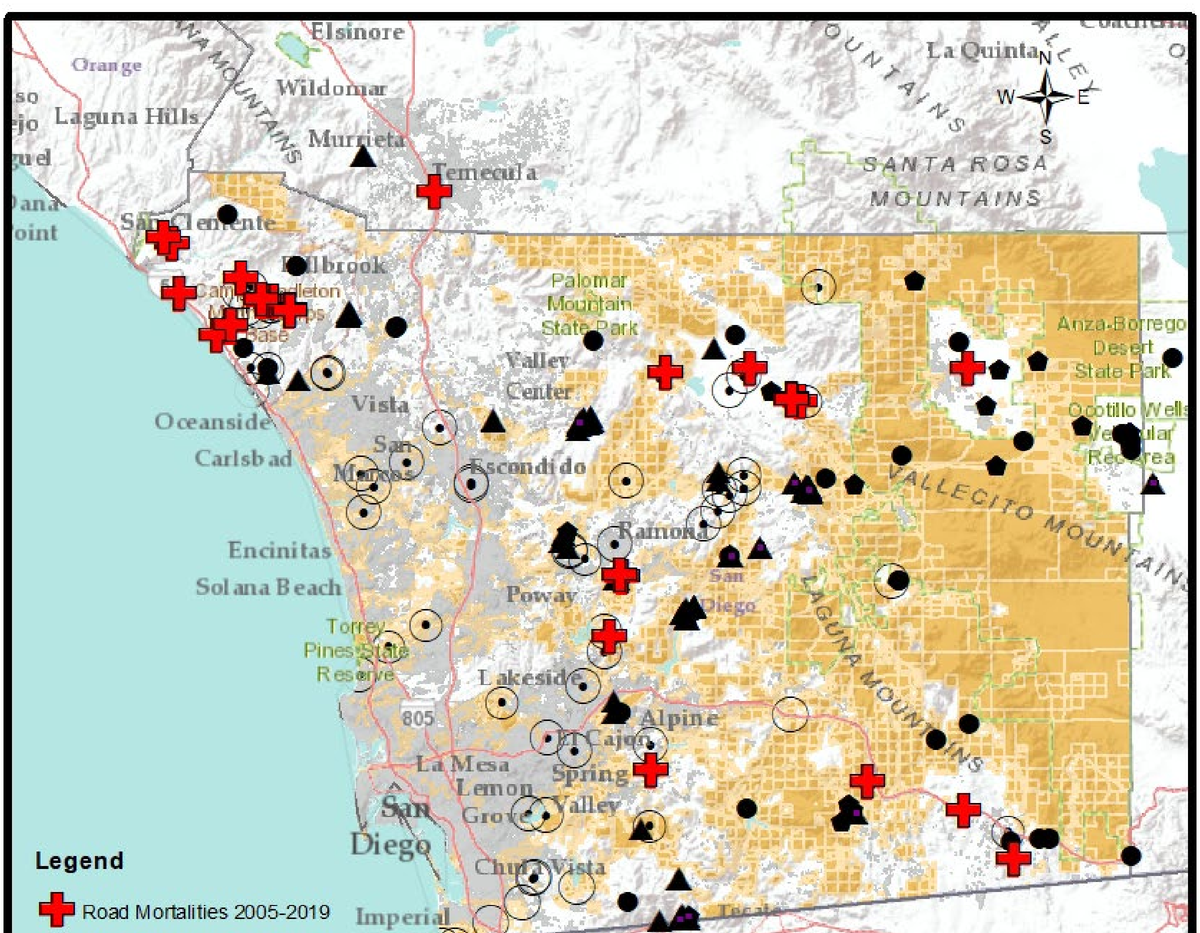

Figure 10. Badger road mortalities documented in San Diego County 2005–2019.

DISCUSSION OF FINDINGS

We have established that American badger are distributed throughout San Diego County in low densities and that they appear to absent from historically occupied lands in the urbanized western portion of the county. This is consistent with reported vulnerability of this species to habitat loss and fragmentation (e.g. Crooks 2002; Lay 2008; Klafki 2014). As in other regions of the country and Canada, badgers in San Diego County have primarily been detected in grasslands with sandy loam soils and desert habitats, with fewer detections (and surveys) in scrub, chaparral and oak woodland habitats (Grinnell 1937; Long 1972; Messick and Hornocker 1981; Hoodicoff 2003; Quinn 2008).

We have previously postulated that badgers in San Diego County are operating on a large spatial scale and do not appear to have stable populations occupying specific reserve areas (Brehme et al. 2012, 2015, 2016). Stable higher density populations containing individuals with smaller home ranges have been documented in other parts of their range, but larger badger home ranges of 35 to 300km^2 are common in many areas, with size largely determined by availability of dispersed prey, burrowing sites and mates (i.e. Lindzey 1978; Minta 1993; Hoodicoff 2003; Klafki 2014; Doyle et al. 2019). Although specific sites may not be occupied year around, some areas may be more frequently visited than others (i.e. core-use areas).

Data collected by USGS since 2011 indicate that Volcan Mountain Ecological Reserve, Marron Valley, Upper San Diego River, Rancho Guejito, Lake Morena, and Camp Pendleton are core-use areas for badgers in western San Diego County as badger activity has been documented in consecutive years and for multiple months throughout the year in these locations. There are likely other core areas yet to be surveyed or identified. Many areas may be important for badgers but used on an infrequent basis based upon such things as population densities and prey availability. Future systematic and repeated annual surveys over a large number of sites will be needed to determine whether this is the case. Because our focus has been in the western portion of the county (coast, inland, and foothills), badger distribution is likely underrepresented in mountain and desert regions.

Several studies of American badgers elsewhere have identified a strong correlation between badger occupancy and primary prey densities, particularly preferred squirrel species (Owings and Borchert 1975; Lay 2008; Prioux 2016). Studies have confirmed the dependence of badgers' home ranges upon spatially and temporally variable prey resources (e.g. Hoodicoff 2003). We have noted higher densities of ground squirrel activity concomitant with badger activity in previous years, but our data thus far are not conclusive (Brehme et al. 2015). Prolonged drought from 2011–2015 may have negatively impacted California ground squirrels, resulting in low prey densities for badgers and other species such as the burrowing owl (McCullough et al. 2016). During these periods, badgers may also move to alternate prey, such as gophers, a primary prey item in central California (J. Quinn, pers. comm). Studies are needed to better understand the natural fluctuations in ground squirrel and other prey densities in relation to badger activity in the county.

Badger activity is also likely underrepresented in chaparral and scrub habitats due to low probabilities of detection in these habitats. Visual surveys for badger sign are typically done at a landscape-level scale using a combination of moving across the landscape and scanning for soil mounds with binoculars in order to cover the area required to survey in a single day (Ministry of Environment Ecosystems 2007). This method is not feasible in shrub habitats where movement is impeded and the field of view for badger sign under the shrub canopy is of very short range. In 2015, we spent a large amount of time surveying scrublands adjacent to grasslands to find badger sign with very few detections. Thick shrublands also limited the movement of the scent dogs to detect badgers in these landscapes (Brehme et al. 2015). In central California, while badgers spent over 90% of their time in grasslands, they also used chaparral and shrub habitats for both foraging and denning (Quinn 2008; Quinn pers. comm). Thicker scrub may also be a safer choice for females to establish maternal den sites for their young. Due to their low densities and presumably large home ranges, radiotelemetry will likely be required to better understand the use and importance of habitat types other than grasslands.

Prior to our surveys and outreach effort, most badger records in this region were recorded from roadkill observations (i.e. Tremor 2017). Because of the wide-ranging nature of the species, road mortality is a primary concern for their continued persistence within the county. Road mortality has been identified as the largest cause of badger mortality in other parts of their range (i.e. Hoodicoff 2007; Klafki 2014). From road mortalities recorded in the past 15 years, primary roads of concern are Basilone and Las Pulgas Roads in MCB, Camp Pendleton, I-76 near Lake Hodges, S-22 in Anza Borrego, and Wildcat Canyon Road. Other roads of concern are San Vicente Road, I-8 at Peutz Valley Road, I-94 south of Jamul, Otay Lakes Road, Honey Springs Road, Buckman Springs Road in Campo, and I-78 and I-79 at Santa Ysabel. The regional management goals for the American badger include increasing connectivity (and reducing potential road mortality) between occupied and suitable habitat areas to allow expansion and movement and to ensure persistence of badgers in the MSPA over the long-term (SDMMP 2011). Badgers readily use culverts as safe crossing structures elsewhere (e.g. Grilo 2008, Kinley and Newhouse 2009). A combination of short barrier fencing and culverts could be installed in badger road mortality hotspots to help badgers get across safely.

FUTURE RESEARCH STATUS, TRENDS, AND CONSERVATION

We are beginning to get a clearer picture of distribution and status of the American badger within the western portion of the county. However, there is much to be learned about population trends, badger ecology and habitat selection in this region. This includes continued investigation into the spatial and temporal use of grasslands and other habitats for badgers, squirrel and prey density as a predictor of badger use patterns, effects of drought on badger and prey populations, if there are predictable areas used for reproductive denning, and if the denning areas in western San Diego County are more likely to be located in grasslands or thicker scrub and chaparral habitats.

To accomplish this, we suggest that a combination of spatial occupancy models, status and trends data, genetic, and radiotelemetry studies could be utilized to identify important upland habitats and movement corridors, describe conservation needs for the American badger in San Diego County, and inform management for upland connectivity of badgers and a wide range of upland species. Below we suggest components of a county-wide regional conservation strategy using a number of passive methods in accordance with our results and recommendations from other badger researchers (e.g. compiling trend and location data, analyzing genetic samples). We also present a literature review of methods to locate and capture live badgers as well as transmitter types and attachment methods for radiotelemetry.

Regional Status, Trends, and Genetics

Long-term research on status and trends for the American badger on San Diego County lands can be accomplished using a spatial occupancy framework and the use of multiple passive survey methods. This is currently being done at the Midpeninsula Open Space Lands in western central California (Dr. Jessie Quinn, pers. comm. *https://www.openspace.org/our-work/resource-management/badger-habitat-study*).

We now have sufficient data to attempt a finer scale habitat suitability analysis from badger detections over the past eight years. An updated habitat suitability model can be used to establish a sampling frame and to select a large enough number of sites to track the relative activity of badgers across the county. It will be important to include core sites already established to gain more information on seasonality and frequency of use. We recommend surveys be done on a seasonal basis to track trends in temporal/seasonal use of habitats and to estimate annual detection probabilities. Because passive infrared (PIR) cameras set in the landscape have low success in detecting badgers, active sign surveys should be the primary survey method with addition of specially placed cameras and hair snags where activity is documented.

The incorporation of habitat surveys with badger surveys is needed to model associations of badgers with habitat and prey resources. Habitat surveys would include covariates hypothesized to be predictive of badger use and activity such as soil texture, vegetation type, urbanization and disturbance measures, and squirrel and gopher burrow densities.

Determining badger abundance is another challenge as it is well established that the number and density of badger burrows in not correlated to the number of badgers, but more associated with prey availability, soil texture and length of time spent at a single location (Messick and Hornocker 1981; Messick 1987; Ministry of Environment Ecosystems 2007). American badgers are mostly solitary, so presence of sign would typically indicate a single badger, a mating pair, or potentially a mother and with young. Because density of burrows is not relatable to badger abundance, methods such as facial recognition (e.g. USGS present study; Harrison 2016) and genetic tools (Wood et al. 2016) can be used to identify and count minimum number of individuals. Although badgers can be identified genetically from hair samples (Kierepka and Latch 2015; Wood et al. 2016), these have been challenging to acquire in the county because finding a currently active badger den is rare. Individual identification of badgers from scat has not been successful (species only; Wood et al. 2016). Further development of a microsatellite library from southern California badger tissues has been suggested to increase the potential of identifying individuals from more easily acquired, but degraded, sources such as scat (Wood et al. 2016).

In addition to using genetic methods for badger identification, there is a need to better assess the range and status of subspecies. "Assessing the subspecies in the west remains a central question. Understanding the distributional limits of *jeffersonii* (which purportedly occupies the coast) and *berlandieri* (which purportedly occupies the foothills and desert regions) seems crucial to conservation within southern California. The fact that *berlandieri* also extends into the San Joaquin and (other locations within the) Great Central Valley is also of importance. Both those regions have distinct genetic and endemic taxa within them and the region has been more recently championed as a distinct desert biome, separate from Mojave Desert" (D. Wood, pers. comm.).

Components of Long-term Research Program: Status and Trends

- Creation of revised a habitat suitability model and creation of monitoring sample frame.
- Selection of survey sites for long-term occupancy monitoring (occupancy metric).
- Include large multi-scaled sample sites to enable both microhabitat selection and sitewide analyses (e.g. 1–25 ha).
    - Perhaps inclusion of an adaptive component to allow expansion of surveys in nearby areas when sign is found.
- Implement seasonal surveys of monitoring sites (at least 4 surveys/year).
    - Sign surveys (burrows, digs, tracks, scat).
    - Passive Infrared Cameras (1 per landscape, more if sign found).
    - Hair snags at burrows with genetic testing (microsatellite assay).
    - Include landscape, habitat and prey density surveys for space use models.
- Continued Outreach
    - Monitoring and verification of badger hotline notifications (Public/Agency Outreach).
- Discovery surveys
    - Field verification of hotline notifications.
    - A small percentage of survey effort (i.e. 10–20%) for surveying other potentially suitable lands.
    - Canine scent surveys appropriate for large scale discovery efforts or if assay is successfully developed for individual ID from scat.

Primary Research

- Conduct genetic evaluation of subspecies in the region to inform conservation.
- Develop species-specific microsatellite library for southern California badgers for potential to identify individual badgers from scat.
- Conduct radiotelemetry study to assess home range, space use and habitat selection in the county.

Literature Review: Location, Capture and Radiotelemetry of Badgers

The landscape in San Diego County where badgers occur contains patchy grasslands, riparian habitat, chaparral, and coastal sage scrub and ranges from inland, foothills, mountains, to desert. The terrain is highly variable, and a large proportion is private land. As previously discussed, radiotelemetry is currently the only viable method to obtain basic information on home ranges, habitat selection, use of conserved vs. non-conserved areas and habitat corridors, and to better document where and how often badgers are crossing roads. We have had few "recaptures" using facial patterns or hair snares to better understand home ranges. Even data from a small number of individuals would be helpful to inform resistance surfaces for a landscape level linkage analysis for the American badger in San Diego County.

We are currently in contact with a number of badger researchers across the country and Canada: Jessie Quinn (University of California, Davis), Gilbert Proulx (Alpha Wildlife, Canada), Richard Klafki and Stephen Symes (Environmental Science Program, Thompson Rivers University), Timothy Van Deelen and James Doyle (University of Wisconsin) as well as veterinarians who have performed intraperitoneal and subcutaneous transmitter implant procedures, including Dr Mike Murray (Monterey Bay Aquarium) and Lindsey Long (University of Wisconsin). We are also in contact with Joe Tomoleoni (USGS), who has multi-decade history of using intra-abdominal VHF implants in sea otters and is an expert in next generation transmitters. We are collaborating on a discussion of the safest and most effective methods for badger telemetry, including methods for capture, attachment and transmitter type, shape and weight. This discussion is ongoing. However, our current prospective procedure to ensure safety and efficacy is to locate active badgers in their burrows using scent hounds, to capture them using snare traps and handheld snares, and transport to an experienced veterinarian for surgical implantation of a GPS life history tag transmitter with a VHF component if badger shape and weight allow (however, see below for alternative transmitter attachment options). Below is an evaluation and discussion of methods being considered. Whatever methods are ultimately proposed for use will be assessed and approved through the USGS Animal Care and Use Committee (ACUC).

Location and Capture Methods

Locating live American badgers can be very difficult using traditional methods as they are far ranging, suspicious, and do not respond well to bait (e.g. Ministry of Environment Ecosystems 2007). The European badger is different from the American badger in that they have home setts where they generally congregate, live in higher densities and are easy to bait, which makes them easier to locate and trap. We have located live badgers on several occasions since 2011, but most often we find sign after the badgers have already left. By increasing the frequency of our search efforts at core sites, we will be more likely to locate an active badger. Alternatively, the use of scent hounds may be a more efficient way to locate an active badger den (rather than canine scent detection methods where the dogs are trained on scat). This method has been used to locate other elusive wildlife species (e.g. Dahlgren et al. 2012) and is considered a viable option in our conversation with other badger researchers in the United States and Canada.

There are many different capture methods used on badgers. The American badger is considered a species of special concern in San Diego County; therefore, trapping options must consider the health and well-being of the individual. Although leg hold traps are the most common capture method for badger research across the world, these are not legal for use in California. Cage traps and body snares are the other methods most commonly used and are approved by the state.

Box/cage Traps

Box or cage traps are a type of live trap that is placed outside a badger burrow, where they are foraging or where they might pass through. The trap is typically baited with freshly killed prey species. The badger enters the trap and the trap closes behind the individual.

Advantages of box traps include causing minimal discomfort to the captive animal. However, capture success is reported to be low because badgers are a wary species, are not reliably attracted to bait, and will not readily enter traps (Ministry of Environment Ecosystems 2007; R. Klafki pers. comm). Other disadvantages include a chance of minor injuries while in the trap, which can include dental injuries when the individual is trying to escape. Box traps are labor intensive because of their size and having to check them multiple times (every hour) during the trapping session. If badgers have multiple exit burrows, box traps must be placed at all entrances.

Body snares

Body snares can be used both at an active burrow or along a badger path. Since it is easier to locate badger burrows than paths, they are most often used at burrow entrances (Figure 11). “A loop of cable is set in an active burrow entrance and anchored in place by a coil of bailing wire wrapped around a thicker wire anchor that is driven into the side of the burrow. A piece of fishing line is tied from the one-way sliding lock to the opposite edge of the snare loop. The line catches on the badger’s shoulder as the badger walks through the snare loop, thus pulling the snare shut around the animal’s chest as the animal moves forward. The lock is stopped from closing the snare to a loop of a diameter less than 15cm by a piece of wire pinched on the snare side of the cable” (Quinn 2008, p. 93).

Advantages of body snare traps include their easy transport, quick setup process compared to other methods, and their design to avoid injury to the captured individual. Cheeseman and Mallinson (1980) used body snares to catch badgers for a radio-tracking study and stated that “Snares are more efficient and easier to handle then cage traps and in our opinion cause less stress to captive animals when used correctly” (p. 650; they had no injuries in more than 50 captures using body snares whereas badgers sometimes damaged their teeth and claws in cage traps. Potential disadvantages associated with body snares are that trapped animals might try to retreat down their burrows, the snares must be checked every hour in person, and the snares must be observed from a blind or from a distance in order to lessen the time the animal is trapped.

Snares at burrows and hand snares are the primary recommended method amongst the badger researchers we have consulted for this study. Once snared, the animal is transferred into a container for transport to a veterinarian (if internal implants are used-see below).

Figure 11. Body snare at burrow entrance (photo provided by Jessie Quinn).

Transmitter Attachment

Possibilities for transmitter attachment to badgers include collars, harnesses, and surgically implanted transmitters (intraperitoneal and subcutaneous).

Radio Collars and Harnesses

Radio collars and harnesses are less invasive, costly, and time intensive than surgical implants. However, because badgers are partly fossorial and have loose skin and a wide neck circumference compared to their head, high rates of collar loss have been reported for badgers (Messick and Hornaker 1981; Cheeseman, C.L. and P.J. Mallinson 2013; R. Klafki pers. comm; G. Proulx pers comm.). "I myself tried a regular collar on a captive and (relatively) tame badger, and was not at all comfortable with how tight I had to fasten it to make it stay put" (J. Quinn, pers comm.). Also impacting the use of collars on badgers is their use of burrows and tendency to go through dense brush which can cause badgers to be impeded or trapped.

Harnesses have been attempted in some studies, but most researchers have experienced similar issues as with collars in that badgers readily get out of or remove harnesses and harnesses catch on things in their environment. Chafing of the skin has also been reported and has required frequent welfare checks and recaptures of badgers that cause even greater stress to the animals (Figure 12: R. Klafki. pers. comm). Because of these issues, collars and harnesses are currently not the recommended method for tracking badgers (Begg et al. 2016).

Figure 12. Body harness on American badger (photo provided by Richard Klafki)

Surgically Implanted Transmitters

Internal transmitters may be used instead of radio collars as a best option for certain species. For this, a transmitter is surgically implanted in the intraperitoneal cavity with a coating to limit adherence to layers in the cavity. There are a wide variety of studies that have used internal transmitters with large numbers of American, European, Eurasian and Honey badgers and sciurids and other mustelids, such as marmots and otters, with little to no adverse effects reported in the duration of these studies (Messick & Hornocker 1981; Fowler and Racey 1988; Van Vuren 1989; Goodrich and Buskirk 1998; Hernandez-Divers et al. 2001; Newhouse and Kinley 2001; Hoodicoff 2003; Begg et al. 2005; Kinley and Newhouse 2008; Racheva et al. 2009; Kinley et al. 2014; Klafki 2014).

A primary disadvantage of internal transmitters is the need to perform an invasive surgical procedure that can stress, or even worse, risk the health of the individual. Mortality has been reported in some animals due to rupturing at the surgical site, internal adhesions, abscesses, and bleeding (Minta 1993; Ågren et al. 2000). Because of the potential health risks associated with surgeries, a trained veterinarian performs the procedure in a vet hospital, which limits the potential for infection. There have been cases where free floating transmitters become adhered to omentum which can create a high risk of infection and potentially death (Quinn et al. 2010: one in nine badgers; Arnemo et al. 2018: 59in 125 black bears). Arnemo et al. (2018) reported several bear deaths from a commercial Telonix VHF transmitter that short-circuited and corroded within the animal and an incidence where the VHF antenna punctured the stomach. Many internal transmitters are never recovered and the long term fate of animals after a multi-year study is often unknown.

There are various options for shape and size of implanted transmitters. Dr. Mike Murray (pers. comm), who has developed many of these surgical techniques and performs or supervises surgeries on sea otters as well as American badgers in California, stated that he would advocate a re-thinking of coating material and instrument size for the intraperitoneal implants used in Quinn

(2010). Joe Tomoleoni (USGS), who has multi-decade history of using intra-abdominal VHF implants in sea otters, noted that smaller cigar-shaped time depth recorders find their way into the omental bursa more easily than the larger, bulkier VHF. He also suggested that the size and shape of the transmitters used in badgers would need to be considered with respect to the internal anatomy of the badger, specifically the size of the opening of the omental bursa. "Small isn't always better with internal tags, because small objects can get stuck in places where they shouldn't be."

To address potential complications and poor VHF reception of intraperitoneal transmitters, Gilbert Prioux conducted a telemetry study on four American badgers in southwestern Saskatchewan using a method of dorsal implantation (Prioulx and MacKenzie 2013). Transmitters were subcutaneously implanted between the base of the neck and the shoulder blades and animals were monitored for 1–2 years with no apparent adverse effects, although abscesses and rejections of dorsal transmitters were documented in black bear cubs (Echols et al. 2004) and harbor seals (Blundell et al. 2014). Doyle (2015) and Doyle et al. (2019) modified this technique and dorsally implanted 16 badgers with VHF transmitters in Wisconsin and monitored them from 118–482 days with no apparent adverse effects over that time period. We are currently in contact with the veterinarian who performed these surgeries (Lindsey Long, University of Wisconsin) for further insight into their safety.

Transmitter Type

There are two main types of transmitters, traditional very high frequency (VHF) and Global Positioning System (GPS) technology. VHF telemetry requires biologists to be within a relatively short range of the animal with no obstructions; the biologists must either triangulate or singly move toward an audio signal to get a fix on an animal's location. This endeavor is easier for diurnal animals than nocturnal animals as tracking is challenging at night. However, VHF transmitters are less expensive and typically smaller in size. To date and due to the larger size of GPS/satellite transmitters, badger telemetry has almost wholly used VHF transmitters. The range of these transmitters is typically poor with intraperitoneal implants when badgers are above ground. Quinn reported that it was difficult to locate radio signals in hilly terrain across long distances. Badgers were below ground during the day, which obscured the signal until they were close to the burrow. When the badgers were above ground, they were navigating in the dark. According to Proulx and MacKenzie (2012), dorsal implants helped to extend the range up to 85m when badgers were 1m below the surface and up to 750m when badgers were above ground. At 2m below ground there was still no signal unless right at burrow. However, these are greatest distances with no obstructions. Due to the widely variable landscapes and patchwork of land ownership in San Diego County and because each location must be attained by triangulation at night for this wide-ranging mammal, it would likely be a difficult and costly endeavor to get each fix. However, it may still be a viable for desert regions.

GPS transmitters allow for the collection of finer scale movement data in remote locations, over large areas and long periods of time allowing for the construction of larger and more biologically accurate home ranges. GPS transmitters can also be programmed to take finer scale data near roads or less fine scale data when animals are sedentary. Practically, data is gathered in all weather conditions and without the need to maintain a costly team in the field. GPS transmitters are more expensive, but the use of GPS transmitters is more cost efficient for longer term projects (Recio et al. 2011).

Unfortunately, GPS transmitters are not effective unless they are outside of the body (external). To overcome these constraints for long-term monitoring of harbor seal pups, Horning et al. (2017) specifically developed the Life History Transmitter (LHX tag, 2nd generation) in collaboration with Wildlife Computers Inc. (Redmond, WA, USA). LHX tags are intraperitoneally implanted under general gas anesthesia using aseptic surgical procedures. LHX tags record data throughout the life of their host and have a projected life span of at least 10 years. Summary data are transmitted post-mortem via the Argos satellite data system after the tags are liberated from the decomposing, dismembered, or digested carcass.

Ideally, one would want to get real-time and life-long data for each badger using both GPS and VHF transmitters; however, due to size and weight limitations, it may be that only one can be chosen. If that is the case, we suggest using a GPS transmitter to get the finer scale and long-term information on home range and habitat use.

Conservation

The American badger is a unique and iconic mammal that may be an umbrella species for a large suite of animal species that occupy conserved upland habitats in western San Diego County. Their very large home ranges and sensitivity to habitat fragmentation make them particularly suitable for use in assessing connectivity of grasslands and uplands for conservation planning. This can be accomplished with a long-term research program and continued public outreach. This program could enable us to assess status and trends in American badger distribution, learn more about their basic ecology and genetics in the region, identify important lands and corridors for conservation and identify locations at which to consider installation of safe crossings that help ensure their long term persistence in San Diego County.

ACKNOWLEDGEMENTS

We are very grateful to the City of San Diego, the County of San Diego, the Rancho Guejito, Barona Band of Mission Indians, The Barona Tribal Council, Volcan Mountain Conservancy, Marine Corps Base Camp Pendleton, Bureau of Land Management, U.S. Forest Service, San Diego River Park Foundation and other generous landowners for access to the study sites on their lands. We also thank the many people who have contacted and contributed to the badger hotline since 2014. This project was funded by SANDAG Transnet Funding.

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