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Assessment of the status of the Townsend's big-eared bat in California

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The California Department of Fish and Wildlife lists the Townsend's big-eared bat (*Corynorhinus townsendii*, COTO) as a Species of Special Concern and a Species of Greatest Conservation Need. The only California statewide field assessment of the species' status, however, was conducted in the 1980s and 1990s. Our goal was to quantify the current distribution of COTO in California by conducting a comprehensive roost assessment at sites visited during the previous statewide survey and a geographic expansion of that effort. We sampled during two complete winters (2014–15 and 2015–16) and three spring/summer/fall periods (2015 through 2017). We searched published and unpublished records and databases for records of COTO and communicated with biologists and other individuals to gather previously unreported and new records of occurrence and potential locations. We used the basic sampling units (sampling frame consisting of 10 x 10 km [100 km^2] grid cells) of the North American Bat Monitoring Program (NABat) as the foundation of our survey and drew potential sampling cells by first dividing the state into Level III Ecoregions, and then randomly listing all cells in the state. Historical locations not known to be closed or otherwise uninhabitable were re-visited in the appropriate season. We surveyed 304 grid cells during this study, with 206 in summer and 98 in winter, and within those cells surveyed approximately 620 potential roost sites. Statewide, we located the species in 209 active season roost sites without evidence of a maternity colony, 84 maternity sites, and 80 hibernacula. About one-half of the maternity colonies were in abandoned mines, 29% in natural caves, and the remaining colonies in various structures (e.g., buildings, bridges, culverts). For all sites visited, 58% had signs of human disturbance. We confirmed the species at 53 of 80 (66%) historical sites in summer and 37 of 63 (58%) historical sites in winter. We were able to determine the status of about two-thirds of the sites surveyed by Pierson and Rainey (1998) during the 1980-1990s period. Of those sites, we determined that about one-half remained active while the other half were inactive for a variety of reasons. Pierson and Rainey (1998) reported a total of 39-43 maternity colonies, while we documented at least 84 maternity colonies. Although our surveys identified substantially more maternity colonies than were known to Pierson and Rainey, we cannot conclude this indicates a substantial increase in site use because Pierson and Rainey were not able to cover the state in as intensive a manner as we could. Historical data for the "new" sites is not available and as such, we cannot state whether these colonies represent restriction or expansion of past occupancy. Additionally, our study did not focus on numbers of bats at a given site. As bats are long lived, the persistence of a maternity colony or bat presence at a site cannot be equated with viability of that particular population. Our surveys, along with other data known to exist on the species, indicated Townsend's big-eared bat remains distributed across much of California, in part because of their use of anthropogenic sites. Unless actively managed, however, available abandoned mines, and to a similar degree, buildings, will continue to decrease in number because of collapse or repurposing. Adequate foraging locations must also be available. We recommend allocating resources to implement long-term monitoring of the species, and so that individual owners-managers can be contacted and encouraged to work with agency personnel in protecting the bat resource through cooperative approaches.

Key words: California, *Corynorhinus townsendii,* distribution, impacts, status, trend, Townsend's big-eared bat

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The Townsend's big-eared bat (*Corynorhinus townsendii*, COTO) is generally regarded as a bat species at high risk of endangerment throughout its range in western North America. The California Department of Fish and Wildlife (CDFW) has designated it as a Species of Special Concern (SSC) and also a Species of Greatest Conservation Need (SGCN) and it was recently (2012–16) the subject of a petition for listing as threatened or endangered under the California Endangered Species Act (CESA). The only statewide field assessment of the species' status was conducted in the 1980s and 1990s. Based on their statewide survey effort, which ended in 1991, Pierson and Rainey (1998) concluded that COTO had undergone a substantial population decline over the previous 40 years (i.e., since about 1950), with a 55% decline in maternity colonies, a 44% decline in the number of roosts, a 55% decline in total abundance, and a 32% decline in average maternity colony size. As summarized by Pierson and Rainey (1998), the species is highly sensitive to human disturbance, particularly of maternity colonies. In addition to disturbance, the number of alternate roosts has been declining due to mine closures, renewed mining, timber harvest, cave commercialization, and general recreational exploration (Pierson and Rainey 1998, CDFW 2016).

Although the California Fish and Game Commission determined that COTO did not warrant a CESA listing in 2016, effective conservation and management of this species would benefit from a comprehensive management plan based upon a thorough survey of the current distribution and abundance of the species. A multi-state assessment and conservation strategy developed for COTO in the late 1990s (Pierson et al. 1999) recommended annual or biannual monitoring of selected sites across the species' range and monitoring of COTO numbers and roost conditions at all sites at 10-year intervals. Although some COTO roosts in California have been monitored at a variety of intervals in the past two decades, a comprehensive and extensive monitoring initiative at all known COTO sites in California has never been conducted.

This project aimed to quantify the current distribution of COTO in California by conducting a comprehensive roost assessment through revisiting the previous statewide survey sites and geographically expanding that effort. This project constituted a comprehensive assessment of this species using similar methods as used for the first statewide survey project more than two decades earlier and thus generated a comparable data set, save for colony count data, which were not collected. The project also expanded coverage to newly documented and potential habitat locations. This assessment provided information to CDFW's CESA Status Review (CDFW 2016) and will provide baseline data and recommendations to support CDFW to implement effective management actions that lead to conservation of the species.

Herein we provide a summary on the distribution, abundance, condition of historical and currently occupied sites, recommendations for maintaining or enhancing existing populations, and a discussion of likely future threats. Ancillary benefits of this study included increased jurisdictional interest in bats and associated habitat surveys, and additional public education on the status and value of bats through our contacts during surveys. Our specific objectives were: (1) assess the occupancy, activity, and condition of all known (historical and current) COTO roost locations; (2) design and conduct a stratified random sampling plan to determine occupancy of potential roosts based on known habitat features; (3) determine the current status and trend of the species relative to historical assessments; and (4) develop recommendations for research and management designed to enhance persistence of the species.

Methods

The sampling scheme consisted of two primary components. First, to the degree feasible, all historical and roost sites not known to be destroyed (e.g., mine closure) were surveyed for current activity and condition. Second, we used a modification of a national bat survey protocol to generate a stratified random scheme for sampling to determine bat occupancy and abundance across its range in California. We initiated preliminary sampling in fall 2014 and field work continued through summer 2017, thus encompassing two complete winters (2014–15 and 2015–16) and three spring/summer/fall periods (2015 through 2017).

Historical data.—We searched the published and unpublished records and databases summarized below for records of COTO, and communicated with biologists (private, government agency), cavers, and other individuals to gather previously unreported records of occurrence and potential locations. We gathered all existing site locations for COTO from the California Natural Diversity Database (CNDDB) and cross-checked those with the literature to ensure no known records were missed. Pierson and Rainey (1998) summarized existing records through about 1998; here again we cross-checked their records with other known records (e.g., CNDDB, literature prior to 1998. We attempted to gather all known literature records for COTO, which we then reviewed and cross-checked with existing data (e.g., CNDDB, Pierson and Rainey 1998). We contacted State (e.g., CDFW, California Department of Parks and Recreation [CDPR]) and Federal (e.g., Bureau of Land Management [BLM], United States Forest Service [USFS], United States Fish and Wildlife Service [USFWS]) agency personnel to gather unpublished location records of COTO observations and locations of potential roosts known to them. Additionally, we used existing bat information networks (e.g., Western Bat Working Group) to request location data. Lastly, we have been conducting intensive winter and summer surveys throughout the Inyo and White mountain ranges (Inyo and Mono counties) and the adjacent eastern slopes of the Sierra Nevada Mountains since 2010, as a follow-up to surveys initiated in the 1990s; this work is ongoing and is continuing as of summer 2019. These data were incorporated into the overall analyses for this study (described below).

All location records (COTO observations) were entered into a FileMaker (FileMaker, Inc.) database and coded such that records can be summarized and also displayed (GIS mapping) by various characteristics including: record type (maternity, hibernacula, unknown), protected (e.g., gated or administrative protection) or unprotected, and timeframes (i.e., categorize data by 5-year blocks). As noted below, all new locations (not known to be previously visited) were entered into the database.

Selection of study cells for current occupancy.—We used the basic sampling units developed first by the Pacific Northwest Bat Grid (PNWBG) (Ormsbee et al. 2006) and subsequently incorporated into the North American Bat Monitoring Program (NABat) (Loeb et al. 2015) as the foundation of our survey. We focused on COTO hibernacula and maternity colonies; we did not attempt to sample general multi-species bat occurrence as is a goal of NABat. We used the NABat sampling frame that consists of 10 x 10 km (100 km^2) grid cells that are the focal analytical unit for regional and range-wide assessments. Although we did not implement the specific NABat field survey protocol, our use of the same geographic grid boundaries will allow geographic or sampling comparisons between our data set and other studies using the NABat grid system.

We drew potential sampling cells (from 4,365 total in California) by first dividing the state into Level III Ecoregions, and then randomly listing all cells in the state, prioritizing visits to the lower numbered grid cells within each region where suitable habitat could be identified. Because little is known regarding COTO use of different areas for inactive and active periods throughout much of California, we did not make separate draws for each period.

After selecting the initial set of potential sampling cells, we screened each cell for the presence of potential roosts using GIS, visual examination of topographic maps, and Google Earth. Mine structures, including adits, shafts, and buildings, and other features such as publicly advertised caves are usually included on topographic maps. In our experience, these maps do not reveal about 5% of all mine structures. It is unlikely, however, if multiple mine structures occur in a concentrated location mapmakers would have completely missed them. Tools such as Google Earth were useful in some areas where lack of vegetation cover allowed locating abandoned buildings and determining potential extent of a mine working (e.g., size of waste piles), although it was seldom possible to determine if the structure was open (i.e., portal not collapsed or otherwise accessible for occupancy by bats). As part of this desktop review process, where possible, we contacted jurisdictional biologists, land managers, recreational groups, and private landowners for additional information about the presence of bats and habitat.

Each cell was characterized as: (1) not environmentally suitable (i.e., too warm in winter [>5 °C] or too cold in summer [<20 °C], which was usually based on elevation or region), (2) environmentally suitable but no suitable roost sites, or (3) environmentally suitable with potential roost sites; these latter cells were included in the sampling schedule. Because of logistics, we usually could not visit each cell in the order it was selected. Accessibility issues, study timeframe and logistical constraints combined with the unexpected number of "new historical" sites (potential Townsend's occurrence records known to various jurisdictions, land managers and the caving community but not included in the CNDDB database of original historical records) that emerged through our data compilation and records requests, meant that not all sites or target cells were visited. Few jurisdictions refused access outright, with Joshua Tree National Park the only jurisdiction to refuse a submitted research use request. We did not target cells or historical sites that fell within jurisdictions where monitoring for bats is formalized and ongoing, as is the case with several National and State Park jurisdictions, because we wanted to focus our field efforts where surveying was not being conducted. Thus, our results may represent a conservative estimate of the distribution and status of COTO.

To the extent possible we used the presence of COTO as the basis for implementation of an adaptive surveying strategy. We implemented this additional surveying strategy because we were focusing on a single bat species, and to mimic to some degree the search within 15 km conducted by Pierson and Rainey around maternity roost sites. In such an adaptive strategy, all cells that meet basic selection criteria (i.e., habitat) adjacent to the occupied cell (see occupancy definition, below) would be surveyed; any additional occupied cells would then serve as the focal point for surveying the adjacent cells; and so forth until no occupied cells are located.

Indications of occupancy (e.g., guano; see below), acoustic identification, and visual identification can all indicate recent bat activity at a site. However, only certain methods provide reliable estimates of site bat abundance (e.g., internal counts of individuals; night emergence counts). For our sampling and implementation of the adaptive sampling scheme, we used the presence of even one bat to indicate occupancy of a sampling cell. Calculation of occupancy of sampling cells can later be determined using several different criteria for "presence" (see below under "Analyses"). Because we gathered at least two, and sometimes three, measures of presence (i.e., visual, guano, and rarely, acoustic) at each site, and never based occupancy assessment on acoustics alone, we minimized the probability of making false-positive acoustic detections in our occupancy estimation (Clement et al. 2014).

Selection of historical sites.—We re-visited historical locations not known to be closed in the appropriate season, where access and feasibility allowed; we included all historical sites in our analyses. Pierson and Rainey (1998) surveyed a 15-km radius around the original site if it was unoccupied; they deemed this an appropriate area because of the high site fidelity of colonies. Rather than a priori set a sampling limit, we applied our adaptive survey system (described above) to a former roost site. Variables used as the primary sampling strata to exclude potential sampling areas included lakes, urban areas (the outskirts of cities were retained), and regions where COTO have not been shown to occur because of extreme seasonal conditions (e.g., high elevations in the Sierra Nevada).

We broke the initial broad-scale filter by "active" (spring/summer/fall) and "inactive" (winter/hibernating) periods. Elevation was the primary factor separating potentially suitable priority locations between summer and winter; elevation is, of course, correlated with seasonal changes in temperature in many regions. There were locations where potential winter and summer locations overlapped.

Field surveys.—Surveys were conducted from fall 2014 through summer 2017, thus encompassing three active (2015 through 2017) and three inactive (2014–15, 2015-16, and 2016–17) periods; most work occurred from fall 2014 through winter 2016–17. As logistically feasible, we attempted to sample an equal representation of geographic locations across the state each year (i.e., not concentrate in one geographic location each year).

Selected roost locations within a cell were visited in the active or inactive season, but in most cases not both, unless the roost had characteristics that might serve for both seasons. A cell with substantial elevation gain, or potential roosts with favorable characteristics (e.g., cold air flow for winter), could be visited in both seasons. This is because, while male COTO will often spend the inactive season at lower elevations, the ones that do so comprise a very small proportion of individuals and we could not expend the time and logistical effort to revisit locations that would potentially harbor only a few individuals (personal observation). This factor mostly came into play in areas with colder winter temperatures where we would expect overwintering bats to employ hibernation. For example, in the Inyo-White mountains and adjacent Sierra Nevada (Inyo Co.), most (>95%) individuals hibernate >2500 m, whereas maternity roosts are <2000 m elevation. Here again, our focused efforts on a broad spatial extent while recognizing we were missing some more local occupancy patterns. Because cells are only used for our general randomization as a basis for locating potential roosts, this strategy did not bias our survey in a substantial manner.

The Level III Ecoregions of California along with their USGS numerical designation (parentheses) and number of potential sampling cells were: Coast Range (1)—172; Cascades (4)—139; Sierra Nevada (5)—529 ; Southern/Central California Chaparral/Oak Woodlands (6)—805; Central California Valley (7)—467; Southern California Mountains (8)—158; Eastern Cascade Slopes and Foothills (9)—192; Central Basin and Range (13)—147; Mojave Basin and Range (14)—777; Klamath Mountains (78)—332; Northern Basin and Range (80)—50; Sonoran Basin and Range (81)—310; Southern California/Northern Baja Coast (85)—275.

Sampling occurred primarily throughout daylight hours by conducting internal surveys for the presence of bats or their sign. In few cases, we also conducted nighttime acoustic or visual exit surveys when safe entry of a site was not possible (see below). In addition to making an internal inspection for COTO, we recorded the occurrence of guano pellets or piles consistent with COTO sign. When a cluster of bats was encountered, we immediately exited the roost to minimize disturbance. During winter we attempted to count bats we could safely observe; our data thus represent a minimum estimate. We considered guano recognizable as COTO if it had unambiguous characteristic light golden patina and twisted shape, and more confidently when also occurring as a Gaussian-patterned pile below a domed section of a passage or other typical roost location. Such sign was considered indicative of maternity colony presence and was included in our final count of maternity sites.

In few situations, when entry could not be safely made and the field schedule allowed remaining in the area for evening emergence work, we used Pettersson Elektronik ultrasonic detectors (various models) to determine if COTO were present during spring/summer/fall. We based the specific placement and number of detectors on site characteristics, such as number of portal or cave openings, or exits from a building. Although such recordings are not appropriate for determining absolute abundance or absence, they can be used to establish presence. For example, a large number (e.g., >20) of separate recorded files at a portal near sunset during the appropriate time of year could suggest a maternity colony. Likewise, acoustic analysis during the late fall could indicate the potential location of large hibernacula; follow up internal surveys during winter could be conducted. COTO do not always echolocate, and when they do, their calls can be such low amplitude as to be nearly undetectable. Thus, a lack of acoustic detection, without corresponding visual confirmation of absence, was not used as confirmation of absence, nor were passively collected calls alone used to confirm the presence of a maternity colony, as acoustic data cannot confirm number of bats present.

We analyzed acoustic recordings using SonoBat software to recognize bat call sequences and identify them to species using a hierarchical decision engine trained on multiple time-frequency and time-amplitude parameters extracted from a library of >10,000 species-known recordings (Szewczak 2010). We used automated identifications with manual confirmation of species identifications using known call characteristics (Szewczak et al. 2011). Manual vetting is of particular importance for COTO because it vocalizes with lower amplitude compared to other bats, imparting lower automated acoustic detectability (Parsons and Szewczak 2009).

We gathered data on the estimated level of human disturbance at each roost. Because we were not monitoring human visitation at roosts, we made a visual estimate of disturbance based on proximity to easily travelled roads, footprints inside and outside roosts, trash, graffiti, and other signs. We then categorized our observations into none, slight (little or no fresh footprints or trash), frequent (numerous footprints, substantial trash), and continual (roosts readily accessible by road and open to visitation).

Other ongoing studies.—We gathered reports of the status of COTO surveys that were being conducted on a regular basis by resource agencies. In some cases, we did not need to conduct our own surveys because that work was being accomplished. We did not include those data directly in our databases because the data were not obtained within our sampling strategy. We do, however, report those data separately herein.

Analyses.—Pierson and Rainey (1998) focused their survey on what they termed "significant maternity colonies," which they defined as >30 individuals. No definition was provided by them for hibernacula; rather, they sampled "a selection of known hibernating sites." Thus, we could not know how many smaller (i.e., ≤30 individuals) maternity colonies they did not survey. Based on our results that found few maternity colonies of <30 bats, we doubt they excluded many sites. However, because they did not systematically look for previously unknown roost sites, but rather focused on known sites, our comparison with their findings cannot be taken as an overall assessment of the status (i.e., declining, stable, increasing) of COTO in California. Rather, our comparison with Pierson and Rainey is an assessment of change in status of the specific locations they surveyed and potential relocations of roost sites.

Basic occupancy was defined as the presence of ≥1 individual bat (visual detection, COTO guano, or acoustic identification) at a site within a cell. We present results on occupancy by several spatial extents (scales), including statewide (overall) and Level III Ecoregion. We also divided most data by season (active versus inactive). We summarized these data on the scale of the Ecoregion (i.e., ≥1 cell met the above criteria), and on the proportion of occupied versus unoccupied cells for each category for an Ecoregion.

We did not attempt to count (e.g., exit or emergence surveys) maternity colony size because our goal was to survey for presence; counting would have focused our attention in fewer survey cells. Although we were able to more thoroughly survey roosts in the winter, time, safety, and general logistical constraints often prevented us from conducting a complete internal survey. As such we chose to categorize hibernacula into several classifications of bat abundance (i.e., solitary, >1 to 5, and >5 bats). Pierson and Rainey conducted counts (emergence or internal) of number of individuals present at most of the maternity colonies they surveyed. Their counts were estimates, however, because they applied a correction factor rather than standardizing when the counts occurred; that is, some colonies were counted prior to young emerging, whereas others were counted after young started emerging. In addition to the logistical limitations that attempting to count individuals' places on a study (see above), because of the number of locations we wanted to visit, we decided to forego counts at maternity roosts. Thus, our presence-absence data provides location data on which future, more intensive studies of changes in abundance can be based.

Results

Survey effort.—Although it varied by Ecoregion, our initial screening of the potential suitability of grid cells for survey indicated that usually 50% to 70% of the cells were within adequate environmental parameters for the species to occur during summer or winter. In the Sierra Nevada Ecoregion, for example, we deemed ~70% of the cells to be within acceptable environmental parameters for summer occupancy, but upon detailed examination (e.g., using Google Earth, topographic maps), concluded that only ~25% contained potential roost sites that were identifiable through desktop review and outreach means. Similarly, for winter, only about 50% were acceptable environmentally, with about 15% containing identifiable potential hibernacula.

Based on our initial screening of cells, we surveyed 304 grid cells during this study, with 206 in summer and 98 in winter (Table 1). The geographically small Ecoregion in the northeast, Northern Basin and Range, received no direct survey effort because we determined the sites of the few historical records were no longer viable (e.g., hotel torn down), and lack of readily identifiable potential roost sites. Similarly, the Central California Valley region received little effort because of the lack of potential roost sites (i.e., region primarily commercial-residential-urban and agriculture) and the extent of private land representing identification and accessibility obstacles to such habitat as might exist, given the scope of the study. Across all Ecoregions this study visited and surveyed approximately 620 potential roost sites (Figure 1).

Occupancy.—We located Townsend's big-eared bats in all Ecoregions of California; recent anecdotal sightings indicate their presence in the Northern Basin and Range. Statewide (all Ecoregions combined), we located the species in 209 active season roost sites without evidence of a maternity colony, 84 maternity sites, and 80 hibernacula (Figure 1).

Table 1.—Number of grid cells sampled during Townsend's big-eared bat survey by Level III Ecoregion and season (different portions of cells with substantial elevation gain or other characteristics [see text] could be visited in both winter and summer).

Ecoregion (USGS no.)	No. cells in summer	No. cells in winter	No. cells total
Statewide	206	98	304
Coast Range (1)	11	5	16
Cascades (4)	9	5	14
Sierra Nevada (5)	36	20	56
Southern/Central California Chaparral/Oak Woodlands (6)	32	6	38
Central California Valley (7)	2	0	2
Southern California Mountains (8)	17	10	27
Eastern Cascade Slopes and Foothills (9)	10	1	11
Central Basin and Range (13)	8	27	35
Mojave Basin and Range (14)	42	12	54
Klamath Mountains (78)	28	7	35
Northern Basin and Range (80)	-[a]	-	-
Sonoran Basin and Range (81)	5	1	6
Southern California/Northern Baja Coast (85)	6	4	10

[a]Potential cells were excluded from survey based on pre-screening.

The Mojave Basin and Range contained the most roost sites and maternity colonies, while the Central Basin and Range contained the most hibernacula. These data do not include the roost sites (of all purposes) known for some federal properties, including especially National Parks and Monuments in the northern portion of the state (see below).

Maternity structures.—About one-half of the maternity colonies were in abandoned mines (Table 2). The bulk of the remaining colonies were in natural caves (29%), which included limestone and other rock caves and lava tubes. Buildings, bridges, culverts, water flumes, tree basal hollows, and other structures accounted for the remaining locations. Types of roost structures were not surveyed in equal proportion, thus the proportion of colonies in each type of feature are not necessarily indicative of habitat preference.

Site condition and disturbance.—About 10% of all sites we visited had no potential roost habitat because of site removal (e.g., mine reclamation), portal collapse, structure removal or modification, regular human disturbance (e.g., recreational site), or other causes.

For all sites visited (with or without COTO or other bat species), few (2%) had continual human disturbance, but 22% had what we considered identifiable signs of frequent disturbance (Table 3). The remainder had signs of no (42%) or slight (34%) disturbance. Excluding the Central California Valley and Northern Basin and Range ecoregions because of small sample size due to few visited COTO cells, sites with frequent disturbance ranged from between ~10% and 38% (Table 3). For active maternity sites, overall 24% showed evidence of frequent disturbance while 41% showed only slight disturbance; the remaining 35% showed no evidence of disturbance.

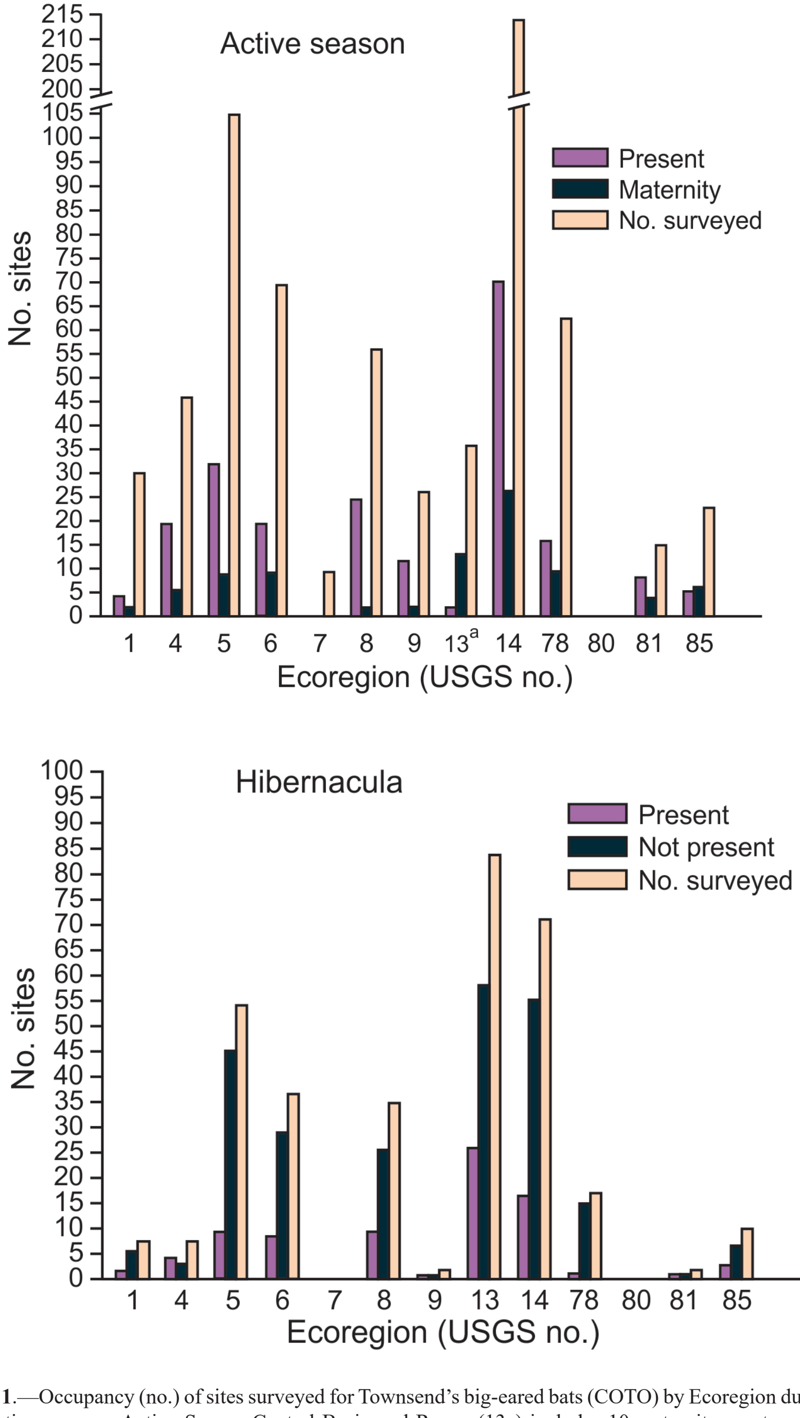

FIGURE 1.—Occupancy (no.) of sites surveyed for Townsend's big-eared bats (COTO) by Ecoregion during active and inactive seasons. Active Season Central Basin and Range (13a) includes 10 maternity roosts not obtained through random cell selection.

Table 2.—Type of structure used by Townsend's big-eared bats for maternity roosts by Ecoregions.

Ecoregion (USGS no.)	Mine	Cave	Building	Other[a]
Statewide	44	25	10	7
Coast Range (1)		1	1	
Cascades (4)		6		
Sierra Nevada (5)	2	4	3	
Southern/Central California Chaparral/Oak Woodlands (6)	3	3	3	
Central California Valley (7)				
Southern California Mountains (8)	2			
Eastern Cascade Slopes and Foothills (9)		3		
Central Basin and Range (13)	11[b]	2[c]		
Mojave Basin and Range (14)	21	2	1	
Klamath Mountains (78)	2	4	2	
Northern Basin and Range (80)				
Sonoran Basin and Range (81)	3			1
Southern California/Northern Baja Coast (85)				6

[a]Bridges, culverts, water flumes, and other structures.
[b]Includes 8 maternity roosts not obtained through random cell selection.
[c]Not obtained through random cell selection.

Overall historical.—Based on all data sources available to us (e.g., CNDDB, unpublished reports, literature), we located the species at 53 of 80 (66%) historical sites in summer and 37 of 63 (58%) historical sites in winter (Figure 2); our totals include sites known to be closed or otherwise uninhabitable (i.e., unoccupied). Note these records include all roost purposes, including maternity, day and night roosts, and hibernacula. Ecoregions with the most historical occurrences indicated that about one-half to three-quarters of all historical roosts were still active, although the use of the roost could have changed; e.g., no longer maternity but some bats present. These data can best be viewed as a crude indication of continued availability of the roost site (e.g., mine still open).

Pierson and Rainey (1998).—We were able to determine the status of about two-thirds of the sites surveyed by Pierson and Rainey (1998) during the 1980-1990s period. Of those sites, we determined that about one-half remained active maternities while the other half were inactive for a variety of reasons, including portal collapse or exclusion (i.e., permanently collapsed by management activity), commercialization of the site, or high human visitation. We were not able to determine the status of the remaining one-third of the sites for various reasons (e.g., insufficient resources, could not obtain access permission, could not locate site).

Abundance in hibernacula.—Most (94%) hibernacula contained >1 individual, with the majority (63%) containing 1-5 bats (Table 4). Most relatively large (>5 bats) hibernacula were located in the Central Basin and Range (35%) and the Mojave Basin and Range (23%).

Table 3.—Level of disturbance at sites visited by Ecoregion for Townsend's big-eared bat, winter and summer combined. Approximate sample sizes are provided in Table 2.

	Disturbance level (% of Sites)			
Ecoregion (USGS no.)	None	Slight	Frequent	Continual
Statewide	42	34	22	2
Coast Range (1)	26	33	38	3
Cascades (4)	53	29	16	2
Sierra Nevada (5)	47	30	21	2
Southern/Central California Chaparral/Oak Woodlands (6)	46	32	22	0
Central California Valley (7)	22	0	56	22
Southern California Mountains (8)		49	30	20
Eastern Cascade Slopes and Foothills (9)	46	15	35	4
Central Basin and Range (13)	38	32	29	1
Mojave Basin and Range (14)	38	38	20	
Klamath Mountains (78)	46	38	16	0
Northern Basin and Range (80)	-	-	-	-
Sonoran Basin and Range (81)	25	50	25	0
Southern California/ Northern Baja Coast (85)	33	53	10	3

Discussion

Pierson and Rainey (1998) summarized the known records of the species and reported that 46 maternity colonies were known prior to 1980, with most of the records made from the late 1940s to the 1960s. They could not locate 24 of the known colonies either at the original previous roost site or within the 15 km radius they searched. They also identified an additional 18–21 colonies during their surveys and through other means, bringing the total colonies known to them to 39-43. We documented at least 84 maternity colonies and determined that another 8 colonies occurred across multiple government land holdings.

Of the Pierson and Rainey maternity colonies that we could survey or otherwise determine status, about one-half were active, while the other one-half were inactive because the known colony roost site was no longer suitable (i.e., collapsed, destroyed, high human use). Overall, we did not determine the status of about one-third of their sites. Although our surveys identified substantially more maternity colonies than were known to Pierson and Rainey, we cannot conclude this indicates a substantial increase in site use because Pierson and Rainey were not able to cover the state in as intensive a manner as we could. As we did not count the number of bats in each of the extant colonies, we also cannot state whether the maternity colonies still present in historical locations have experienced any change in size. Given that Pierson and Rainey found COTO in only about half of historically occupied roosts, and our survey found about half of those still occupied, the data suggest a net decline of roost occupancy of about 75% since the 1950s. However, the fact there are twice or more colonies now known to exist establishes a new baseline for understanding and monitoring the species through time and provides a broad distribution of sites available as candidates

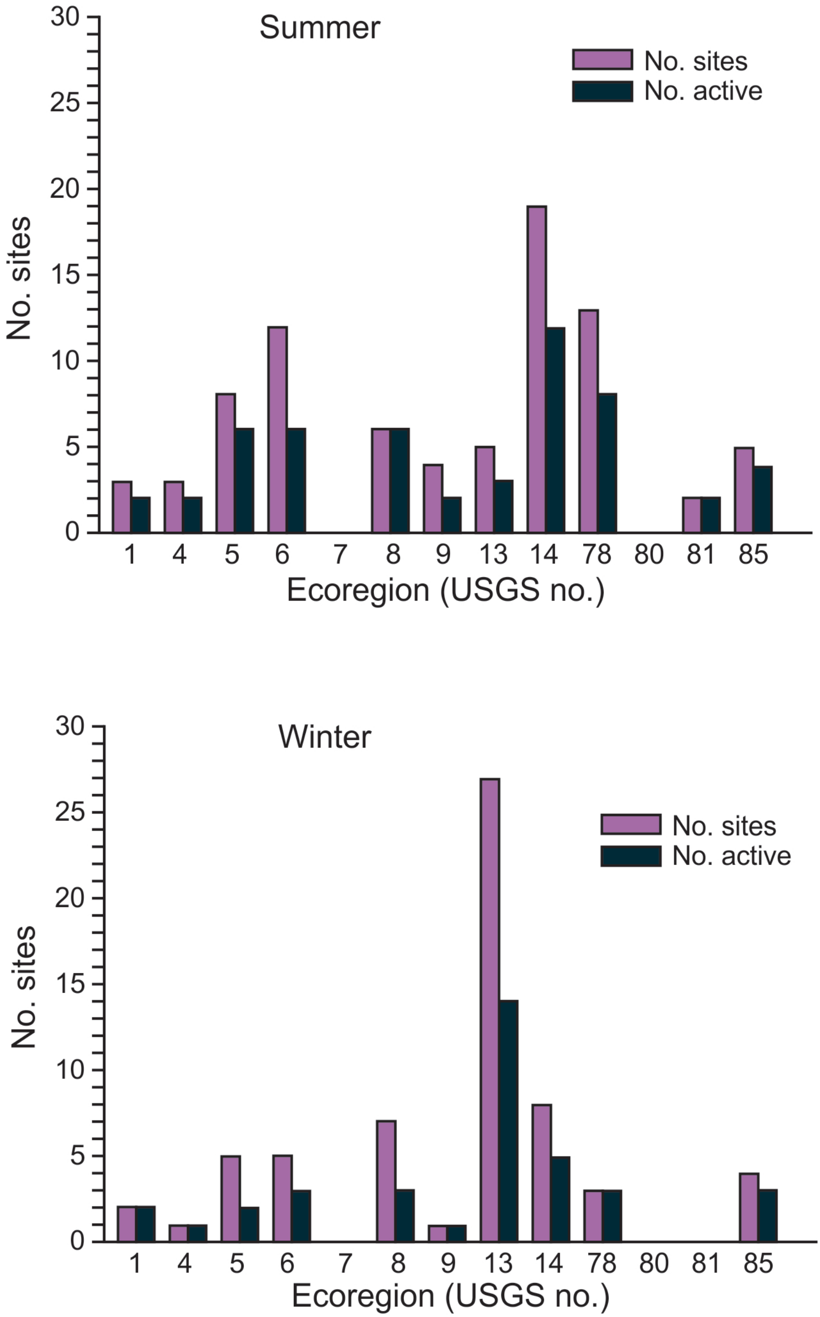

FIGURE 2.—Number of historic sites visited and determined to be active for summer and winter roosting Townsend’s big-eared bats.

Table 4.—Summary of hibernacula surveyed by minimum roost size category (1, 1-5, >5 bats) by Ecoregions for Townsend's big-eared bat.

	Number of sites		
Ecoregion (USGS no.)	1	1-5	>5
Statewide	5	52	26
Coast Range (1)			1
Cascades (4)		2	4
Sierra Nevada (5)		9	
Southern/Central California Chaparral/Oak Woodlands (6)	2	3	3
Central California Valley (7)			
Southern California Mountains (8)		9	1
Eastern Cascade Slopes and Foothills (9)			1
Central Basin and Range (13)		18	9
Mojave Basin and Range (14)	3	6	6
Klamath Mountains (78)			2
Northern Basin and Range (80)			
Sonoran Basin and Range (81)		1	

for long-term monitoring efforts. We also speculate that colony relocation is occurring. The possibility of extirpation of a colony followed by recolonization requires research.

Based on the focus of Pierson and Rainey on known historical colonies, and lack of any randomization across potential roost locations, they could not draw a valid inference regarding the status of the species statewide. Thus, the Pierson and Rainey study is best viewed as an analysis of the status of previously known roosts, rather than a statewide assessment of status. Extension of their results statewide would require assuming that their sample represented conditions across a very broad spatial scale. Additionally, historical locations for most species are largely based on convenience sampling; that is, locations that are easy to access logistically. A sampling design based on an appropriate randomization method forces observers to traverse rugged terrain and often visit remote locations. Because prior to our work no broad-scale survey that incorporated randomization had been conducted, the Pierson and Rainey survey is by design biased towards readily accessible locations. As such, their design could also be biased towards human disturbance (selecting sites known to humans) as a cause for roost abandonment. Logistical and access issues may have inevitably introduced some level of the same bias to our efforts, though to a lesser degree given survey design.

Determining the overall trend of hibernacula or overwintering sites is problematic because Pierson and Rainey (1998) did not focus on the winter period. Additionally, although large hibernacula (i.e., >30 individuals in a single site) are known, most sites harbor far fewer individuals. Ongoing long-term research in the Inyo-White mountains is showing, for example, that individuals from a single maternity colony scatter across the landscape and occupy multiple hibernacula in numbers ranging from solitary individuals to several groups of up to 35 (M. Morrison, Texas A&M, unpublished data). Likewise, at Lava Beds National

Monument, there were 91 known hibernacula in 2017 with only nine sites having a mean abundance of >30 bats (K. Smith, pers. comm.; see also Weller et al. 2014). Especially on the west side of the Sierra Nevada, the species is known to frequently emerge from hibernation for short periods during winter when weather conditions permit (i.e., warm temperature periods). The use of a large number of sites, as well as potential movements between sites, makes it difficult to make conclusions on the status of wintering sites.

Pierson and Rainey did not use Ecoregions but rather divided the state into what they designated as nine study areas known to harbor populations of the species. They found the majority of bat colonies occurred in what they termed the lava flow area of the northeast (their Area 3, which roughly corresponds to Ecoregions 4, 9, and 80); the limestone caves and old mines of the Mother Lode and western Sierra (Area 4; Ecoregion 5); the abandoned mine workings in the eastern Sierra and western White Mountain foothills (Area 5; Ecoregion 13); and at various sites in the northern coastal areas and inner coast range (Area 1; Ecoregion 1 and 78). We also found a substantial number of maternity colonies in the region corresponding to their Area 5, and to a lesser extent, Areas 4 and 1. We did find substantially more colonies in their Area 6, which corresponded in part to our Ecoregion 14, the Mojave Basin and Range, likely because they did not emphasize the deserts for survey effort. We found relatively fewer colonies in the regions corresponding to their Area 3, which is likely because we did not include colonies known to exist on public lands (especially National Parks and Monuments) that are under regular monitoring by agency personnel (and would have biased our sampling strategy and comparison with Pierson and Rainey).

The type of structure used for maternity colonies that we found was somewhat different than that reported by Pierson and Rainey (1998:Fig. 2). Whereas we found about half of our colonies in abandoned mines and ~29% in natural caves, they found ~39% in mines and 43% in caves. We think this difference was due primarily to the lesser survey effort they expended in the Central Basin and Range and especially the Mojave Basin and Range Ecosystems relative to our efforts, rather than any shift in structure use by the species. Additionally, we are including maternity colonies from the Central Basin and Range that are part of an ongoing research effort by Morrison. Although we did not include known maternity colonies under study by others in north-central portions of the State, we learned that another 8 maternity colonies were active (Szewczak et al. 2018:Appendix C). Thus, although we cannot quantitatively assess, there does not appear to have been any shift in overall structure use. Moreover, we did not survey all structures in equal proportions; mine features dominated the survey effort. These percentage detections by structure type are not adjusted for distribution of effort.

Overall for all sites surveyed including maternities, ~70% showed no or slight disturbance due to human activities. Thus, ~30% of sites experience what we considered frequent disturbance. It is commonly assumed that timing of the disturbance is the primary factor determining the influence of human activities on bat occupancy. Because we conducted a one-time survey, it is not possible for us to evaluate the impact disturbance is having on the species, although almost three-fourths of the sites—including maternities—receive little disturbance. Because COTO occupy a large number of abandoned mines, survey access is becoming increasingly difficult and time consuming because mining roads and trails are seldom maintained. For example, there were many historical sites that could be accessed by vehicle during the Pierson and Rainey survey that now require long (>10 km one-way hikes); many locations cannot even be accessed by modern off-road vehicles (e.g., ATVs).

Conclusions and management implications.—CDFW (2016) published a status review of COTO, which included a comprehensive list of recommendations for research and management of the species. They summarized recommendations into seven broad categories: Research and monitoring needs, administrative actions, management of known roosts, landscape management actions, regulatory review of proposed development projects, public education and outreach, and health and disease issues.

Although we do not provide data on bat abundance, our surveys, along with other data known to exist on the species, indicated Townsend's big-eared bat remains distributed across much of California. Where naturally occurring structures are destroyed or highly disturbed, the species can exist in suitable anthropogenic sites. Suitable anthropogenic habitat, therefore, whether mines, buildings, or even bridges in some cases where the superstructure forms an appropriate cavern analog, appear to provide important refuge resources for the species. Numerous other variables play a role in the viability of a roost site, particularly for maternity roosts, such as distance to foraging habitat, or factors affecting vulnerability of a given colony to disturbance. Such evaluations reach beyond the scope of this study but must be considered in management approaches and warrant additional research.

Unless actively managed, abandoned mines, and to a similar degree, buildings, and other suitable roost structures, will continue to decline from deterioration and human use. Of greatest concern regarding the use of mines are Ecoregions 13 (Central Basin and Range) and 14 (Mojave Basin and Range), where most maternity sites occur in abandoned mines. Based on the variety of structures used by the species, including buildings and bridges, we anticipate that some colonies will be able to relocate locally when a mine becomes unusable. For natural roost structures, emphasis should be placed on managing and protecting natural roost structures. However, we also recommend that management entities consider use of artificial roost structures to replace or augment the availability of artificial roosts. Purpose-built artificial roosts should be designed for the particular climate and habitat onsite and proven to be suitable alternative structures for COTO or species with closely related roost requirements, such as vertical concrete towers (e.g., Mering and Chambers 2014) or wooden buildings with long-term maintenance plans. For artificial roost habitat to succeed as a replacement, long-term maintenance, and monitoring programs (including adequate funding) and adaptive management options are needed to ensure the artificial roost provides appropriate microclimates and volume and fulfils the same life history functions as the original roost. Alternative structures also provide an opportunity for efficient monitoring and colony study. In the Mojave Desert and Central Basin and Range, areas exist where natural caves are available but are frequently visited by humans for recreational use. Such natural roost sites should be closed from human visitation during either maternity season or winter season depending on use, while remaining available for human exploration during the inactive season.

Land management agencies, particularly the BLM, NPS, and USFS, have active programs for identifying, stabilizing, and protecting bat roost sites with an emphasis on the Townsend's big-eared bat. As emphasized by CDFW (2016), continuation and expansion of these programs provides a practical method of ensuring access to suitable roost sites by the species. Sites that are initially protected are, however, frequently vandalized by humans seeking entry into caves, mines, and abandoned buildings for recreational purposes, and thus require regular inspection and repair. During our statewide survey we frequently encountered vandalized sites that had been "protected" by gates or locks, but likely had been open to the public for multiple years because agencies often lacked sufficient personnel and funding to conduct regular inspections. In addition to increasing the potential for bats to abandon such sites, many of the sites posed substantial risk of bodily harm to the public (e.g., falling into internal shafts). Thus, increased attention to previously protected sites would enhance conservation of COTO as well as other animals using the protected sites.

We were able to work with various private recreation groups, especially the caving community, in locating and accessing potential bat roosts. Because some individuals fear a loss of access to caving opportunities because of potential government actions, we encourage the relevant government agencies to work with these recreational groups to determine ways to allow continued site access while also protecting the bat resource (e.g., seasonal rather than permanent closures). Additionally, many roost sites exist on private lands, where identification of and communication with property owners-managers can require extensive time or prove futile. CDFW (2016) provided recommendations for enhanced public outreach and education, which we echo here. We recommend allocating resources so that individual owners-managers can be contacted and encouraged to work with agency personnel in protecting the bat resource in ways that are cooperative and do not create perceptions of infringing on personal property uses.

Disease is another area of research and monitoring that should be emphasized in the future (CDFW 2016). Although we did not identify any apparent disease issues (e.g., abandoned colonies were usually due to human disturbance), and COTO is not known to develop white-nose syndrome, the causative fungus, *Pseudogymnoascus destructans,* has been detected on the species in other states, and we found potentially susceptible *Myotis* species sharing hibernacula with COTO. Several locations we visited in the state in the course of this study had a high level of visitation yet no interpretive or cautionary signs to raise awareness and help protect the sites from human-caused pathogen spread. Land managers also showed varying degrees of knowledge regarding the white-nose syndrome threat, with some locations indicating the lack of interpretive signs was due to white-nose syndrome not yet occurring in California, and thus not needing to inform visitors. Like CDFW (2016), we recommend a systematic educational outreach effort to land managers and support for interpretive signs, decontamination stations, and gear loan options for visitors with gear from contaminated states. Various entities have conducted research showing the effectiveness of properly designed interpretive signs in altering visitor behavior (e.g., Duncan and Martin 2002).

We (see also CDFW 2016) encourage additional efforts to more fully understand the current and likely future status of the Townsend's big-eared bat in California including: (1) continued efforts to survey additional locations to identify roost sites, including other known historical sites; (2) periodic monitoring (including roost counts) of all maternity and selected hibernacula located during our survey (e.g., all sites could be visited over a moving 5-year period); (3) expanded coordination by CDFW with all land management agencies to promote protection and subsequent monitoring of the status of roost sites; (4) expanded communication with recreational groups that regularly access known or potential roost sites; (5) expanded communication and outreach to private land owners and managers who have roost sites on their properties; (6) development of a centralized, regularly updated database to track all of the monitoring efforts and roost locations from the groups above (i.e., we found in many cases, these data were not shared with CDFW); and (7) continued support for basic research on conservation-relevant aspects of the species' life history, such as disturbance vulnerability/resilience, seasonal movements, and foraging and roost ecology.

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