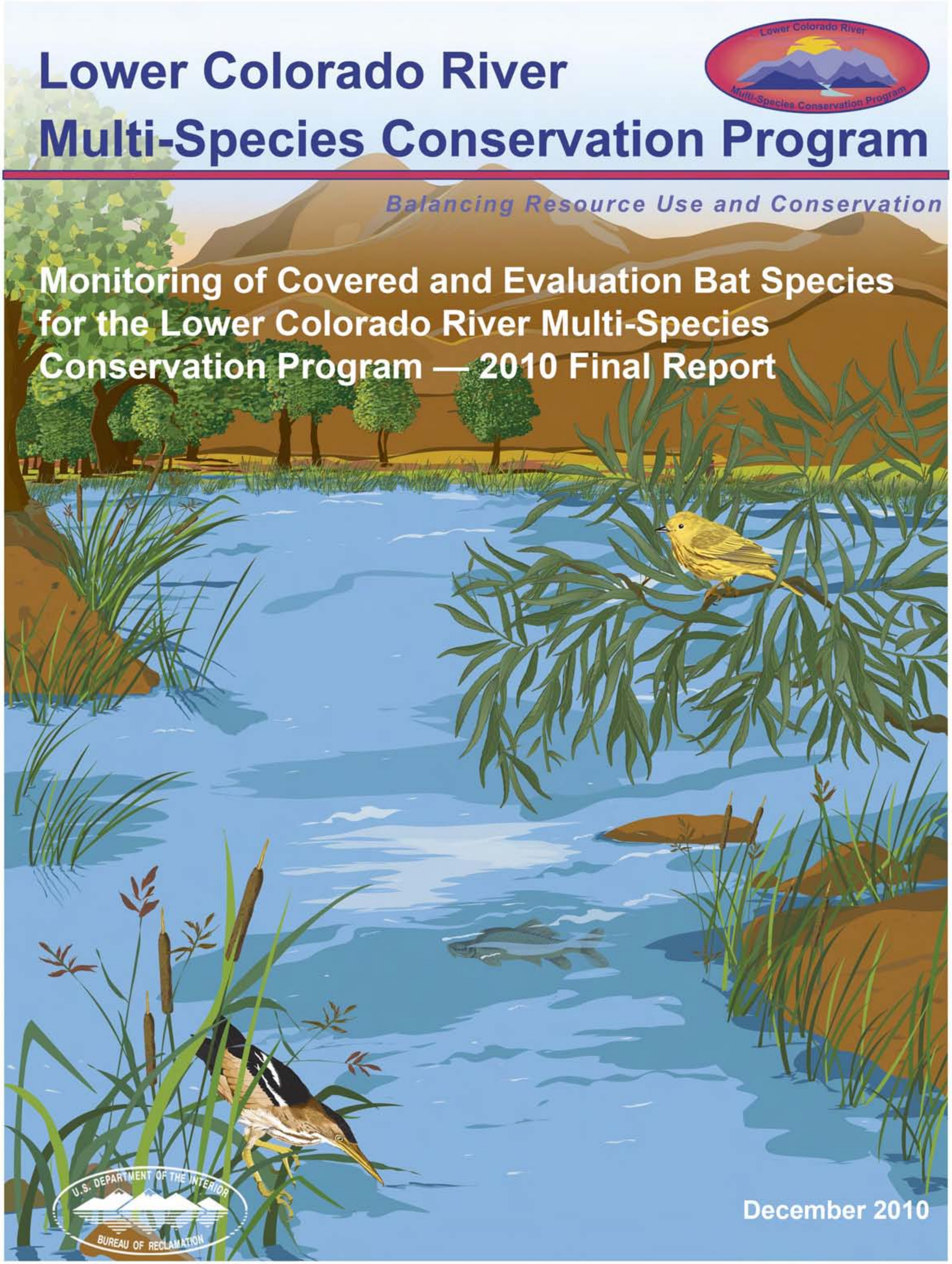
Lower Colorado River
Multi-Species Conservation Program

Balancing Resource Use and Conservation



Monitoring of Covered and Evaluation Bat Species for the Lower Colorado River Multi-Species Conservation Program — 2010 Final Report

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

December 2010

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Lower Colorado River
Multi-Species Conservation Program

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Lower Colorado River
Multi-Species Conservation Program
Bureau of Reclamation
Lower Colorado Region
Boulder City, Nevada
http://www.lcrmscp.gov

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ABSTRACT

This project was initiated to satisfy conservation measures within the Lower Colorado River (LCR) Multi-Species Conservation Program relating to bat species conservation. These measures specify surveys for 4 bat covered species to better determine their seasonal distributions and habitat use along the LCR. These species are the western red bat (*Lasiurus blossevillii*), western yellow bat (*Lasiurus xanthinus*), pale Townsend's big-eared bat (*Corynorhinus townsendii pallescens*), and California leaf-nosed bat (*Macrotus californicus*). The study area included riparian areas from Davis Dam to Laguna Dam in southwestern Arizona and southeastern California. During March 2008 to May 2010, we deployed acoustical bat detectors at 144 sampling points throughout the study area. Locations of the points were stratified in 3 reaches of the LCR and across 4 vegetation types likely to be affected by restoration activities. Each point was sampled for a 2-night period during each of 4 seasons. We used occupancy modeling to evaluate various factors affecting detection and occupancy of these 4 focal species. We found that for western red bats, occupancy was positively correlated with area of cottonwood/willow and proximity to river. For western yellow bats, cottonwood/willow and total native riparian (primarily mesquite) were positive correlates. For both of these species, models predicted that occupancy probability is high even for small proportions of cottonwood/willow within other vegetation types. For Townsend's big-eared bats, occupancy was positively correlated with area of mature saltcedar and proximity to mines. Occupancy of California leaf-nosed bats was positively correlated with proximity to roosts and negatively to proximity to river. We established 4 permanent acoustic detector stations along the river to analyze seasonal activity and migration movements along the river as well as correlate bat activity with environmental variables. At the permanent stations, bat activity was generally positively correlated with temperature and moonlight and negatively with humidity and wind. Activity was highest in the summer and lowest in the winter for the 4 focal species. We recorded extreme nightly variation in activity and were unable to discern obvious migration movements by western red bats or western yellow bats. We offer recommendations for management of the 4 focal bat species, including continued restoration of cottonwood/willow for western red bats and western yellow bats, creation of smaller but more numerous cottonwood/willow restorations, expanded surveys for Townsend's big-eared bats roosts, continued roost monitoring for California leaf-nosed bats, and continued roost protection measures for Townsend's big-eared bats and California leaf-nosed bats. We also offer recommendations for continued bat monitoring along the LCR.

INTRODUCTION

The Bureau of Reclamation (Reclamation) is the lead implementing agency for the Lower Colorado River (LCR) Multi-Species Conservation Plan (MSCP). The LCR MSCP is a 50-year cooperative Federal-State-Tribal-County-Private endeavor that will manage the natural resources of the lower Colorado River watershed, provide regulatory relief for the use of water resources of the river, and create native habitat types along the LCR. Implementation of the LCR MSCP began in October 2005. The western red bat (*Lasiurus blossevillii*) and western yellow bat (*Lasiurus xanthinus*) are covered species under the program. The California leaf-nosed bat (*Macrotus californicus*) and pale Townsend's big-eared bat (*Corynorhinus townsendii pallescens*) are evaluation species under the program. In this report, we use "focal" in refer to these 4 covered and evaluation species.

The LCR MSCP (2004) proposed conservation measures to avoid, minimize, and mitigate impacts to the covered and evaluation species that may result from the implementation of covered activities. These measures were to create 765 acres of western red bat roosting habitat, to create 765 acres of western yellow bat roosting habitat, to create covered species habitat near California leaf-nosed bat roost sites, and to create covered species habitat near Townsend's big-eared bat roost sites. Associated with these restoration activities were measures to determine the use of these created habitats by the 4 bat species as well as the distribution and habitat use of the 2 covered species within the LCR MSCP area. The purpose of this study was to implement those measures. Specifically, they were:

- Conduct surveys and research to better identify covered and evaluation species habitat requirements.
- Monitor and adaptively manage created covered and evaluation species habitats.
- Conduct surveys to determine species distribution of western red bats in Reaches 3-5.
- Conduct surveys to determine species distribution of western yellow bats in Reaches 3-5.

Brown and Berry (2003) conducted wide-scale distributional surveys of bats along the LCR. Other bat surveys in the area provided only specific locality records (Arizona Game and Fish Department, unpublished data). Reclamation (2007) reviewed previous distribution information for the 4 focal species along the LCR. Based on this review and more recent data (Arizona Game and Fish Department, unpublished data; Calvert 2010; A. Calvert, Reclamation, unpublished data), all 4 species appear to be distributed along at least most of the length of the LCR and occur throughout the year.

Brown (1996) used radio-telemetry to investigate roosting habitat preferences by western yellow bats along the Bill Williams River and the LCR. This was the only previous evaluation of bat habitat use along the LCR. Elsewhere in the southwest, there have been several recent investigations of bat use of riparian and marsh habitats. Along Colorado River tributaries in southern Nevada, O'Farrell (2006a, b) and Williams et al. (2006) evaluated bat use in riparian woodland, shrubland, and marsh. Buecher and Sidner (2007) compared bat activity in cottonwood and saltcedar habitats along the San Pedro River in southeast Arizona. Koprowski and Buecher (2008) and Buccia et al. (2010) compared use of riparian habitats and adjacent desert in southeastern and central Arizona, respectively. All of these studies used bat acoustic detectors to quantify bat activity. Many studies elsewhere have investigated use of riparian habitats by bats (e.g., Grindal et al. 1999, Seidman and Zabel 2001, Ford et al. 2005, Menzel et al. 2005, Rogers et al. 2006).

Vegetation type is just one among the suite of factors that likely affects bat use of an area. Others that have been documented or suspected include proximity to roosts (Dalton et al. 2000), vegetation structure (Sherwin et al. 2000, Swystun et al. 2007), proximity to water (Duff and Morrell 2007), presence of travel corridors (Swystun et al. 2007), and proximity to development (Kurta and Teramino 1992). A primary objective of this study was to evaluate the influence of these and other potential factors on bat occupancy along the LCR. We include a more detailed discussion of previous distributional and habitat use information of the 4 focal bat species in the Discussion section of this report.

STUDY AREA

Our study area encompassed Reaches 3-5 of the LCR, as defined by the LCR MSCP, which extend from Davis Dam to Imperial Dam (Figure 1). In addition to this stretch of river, we included the Laguna Division of Reach 6 (Mittry Lake area) because of the documented occurrence of western yellow bats and California leaf-nosed bats and the presence of a diversity of habitats that may be attractive to bats. With the exception of the ‘Ahakhav Preserve, we did not include the Colorado River Indian Tribe (CRIT) Reservation (river miles 154-176 on both sides of river, miles 133-154 on Arizona side). We also did not sample within the Chemehuevi Reservation on the west side of Lake Havasu or the Fort Mohave Indian Reservation north of Needles.

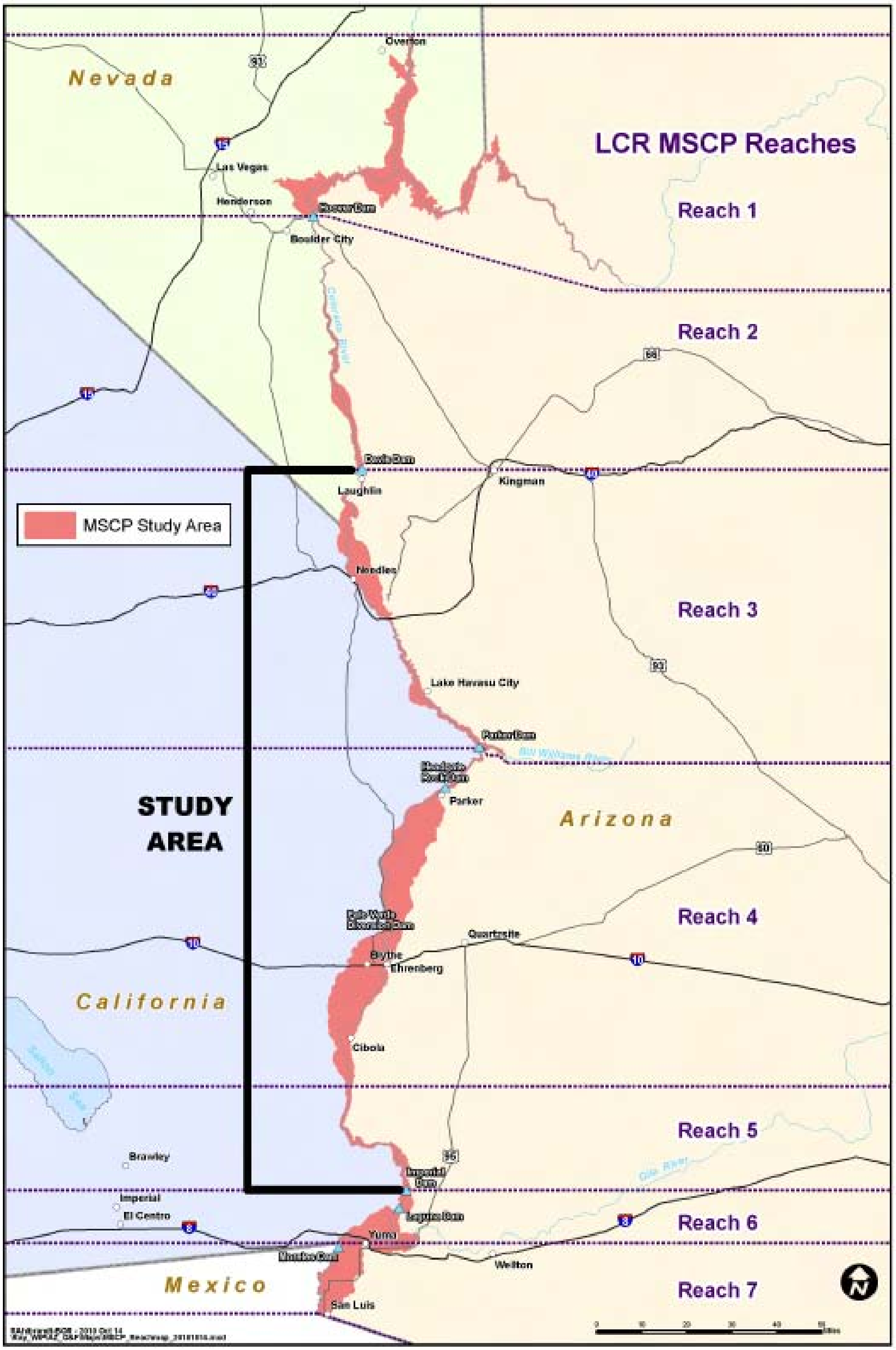


Figure 1. Location of study area.

METHODS

Temporary stations

To determine the occurrence of the 4 focal bat species, we conducted acoustic surveys using Anabat SD1 detectors (Titley Scientific, Ballina, Australia) that record the ultrasonic calls of bats as they pass by the detector. This indirect and unattended sampling technique provides an efficient means to sample a large portion of a bat community over a short period of time (Miller 2001, O'Farrell and Gannon 1999). We used an ultrasonic transmitter to calibrate each of the Anabat units to ensure that results from different detectors were comparable. We used a hi-mic microphone connected to each Anabat by a 3-m cable and PVC housing and reflector plates to protect detectors and elevate them about 1.5 m off the ground (Messina 2004).

We used occupancy models (MacKenzie et al. 2002) to estimate the probability of each species' occurrence throughout the study area and correlate their presence with habitat variables under an information-theoretic framework (Burnham and Anderson 2002). This method is uniquely suited to bat detector data since detectors can only gather presence or absence information, which is all that is required for occupancy models. It has been used in previous studies to evaluate bat habitat use by Duff and Morrell (2007) and Goressen et al. (2008). Minimum, or naïve, estimates of site occupancy can be calculated by dividing the total number of detections by the number of survey occasions. However, this method does not account for false absences or situations where a species is detected imperfectly. A variety of environmental factors such as season (Kuenzi and Morrison 2003, O'Farrell et al. 2004, O'Farrell 2006a, Mering and Chambers 2010), temperature (Hayes 1997, Milne et al. 2005, Mering and Chambers 2010), wind (Fischer et al. 2009), rain (Fischer et al. 2009, Mering and Chambers 2010), and moonlight (Brown and Berry 2004, Milne et al. 2005, Lang et al. 2006, Mering and Chambers 2010) may cause temporal variation in bat activity, thus influencing an observer's ability to detect a target species when present on a study area. Further, some species, such as Townsend's big-eared bats and California leaf-nosed bats, emit calls of such low intensity that they can easily be missed by a detector if they don't pass close to the microphone. Detection can also be affected by characteristics of the surrounding vegetation (Patriquin et al. 2003). The statistical approach used in occupancy modeling incorporates missed detections such as these into estimates of occupancy rates for a survey area.

We divided the study area into 3 study reaches that comprised LCR MSCP Reaches 3, 4, and 5/6. Within each reach, we identified sampling segments that included each of 4 target vegetation types. We selected these vegetation types because of their suspected importance to bats and because they are the most likely to be created or manipulated under the LCR MSCP. These are Fremont cottonwood (*Populus fremontii*) and Goodding's willow (*Salix gooddingii*), honey mesquite (*Prosopis glandulosa*) and screwbean mesquite (*P. pubescens*), saltcedar (*Tamarix* spp.), and marsh (primarily southern cattail, *Typha domingensis*, and California bulrush, *Schoenoplectus californicus*). Following Anderson and Ohmart (1976), these types are classified as cottonwood/willow (CW), mesquite (HM [honey mesquite], SH [saltcedar/honey mesquite], and SM [saltcedar/screwbean mesquite]), saltcedar (SC), and marsh (MA). For each vegetation type, we considered only the more mature classes, designated as I-III for CW, HM, SH, and SM, and I-IV for SC. We considered all classes (I-VI) of MA. Marsh classes were based on species composition, irrespective of maturity. We attempted to delineate 6 sampling segments within each reach using vegetation maps developed from aerial photographs taken in 2004 (Bio-West, Inc. and GEO/Graphics, Inc. 2006). However, because Reach 4 included limited cottonwood/willow and marsh habitat (Table 1), and much of it is included within CRIT, we identified only 5 segments within that reach. We identified 7 segments within Reach 5/6, however, and therefore included the upper of the 7 segments (Upper Imperial) with Reach 4 so that each reach had 6 segments. See Appendix A for a description of the 18 resulting sampling segments.

Table 1. Acres of target vegetation types in each Lower Colorado River Multispecies Conservation Program (LCR MSCP) Reach (LCR MSCP 2004).

Reach	Cottonwood/willow	Mesquite	Saltcedar	Marsh	Total
3	1,412	671	8,517	4,358	14,958
4	486	1,113	15,233	2,091	18,923
5-6	1,329	137	10,348	5,176	16,990
Total	3,227	1,921	34,098	11,625	50,871

Within each of the 18 segments we sampled each of the 4 vegetation types, for a total of 72 sampling points each year (144 points in 2 years) within the entire study area. We selected the sampling points using the following procedure: within each of the 18 sampling segments, we overlaid a 1-km^2 grid (following UTM 1,000-m interval lines) on the 2004 vegetation map. The 1-km^2 blocks that we delineated were then sorted randomly to determine which would be considered for sampling. We discarded blocks if we determined that they were inaccessible based on review of maps and discussion with local biologists, or were outside the defined LCR MSCP boundary. Within each block chosen for sampling, we overlaid a grid comprising 100 possible sampling points spaced at 100-m intervals and randomly chose a single point for placement of the acoustic station. We discarded points upon inspection of maps, or in the field, if we determined they required more than 20 minutes to access. We replaced discarded points with other randomly-chosen points. We repeated the process as necessary until a point was selected that met the accessibility conditions. More specific procedures for choosing sampling points are detailed in Appendix B. The location of the 18 segments and the 144 sampling points are shown in Figure 2.

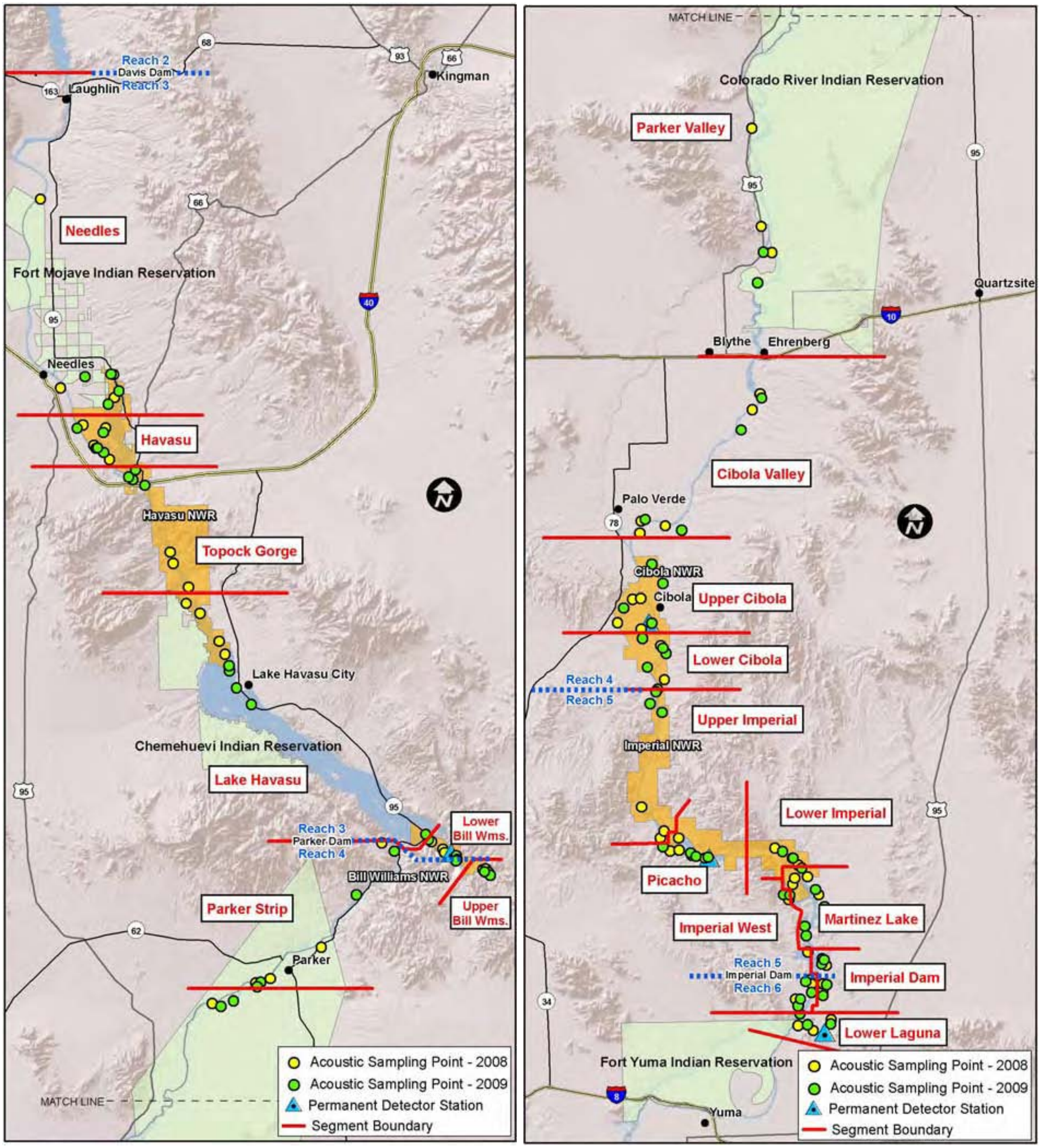


Figure 2. Sampling segments and sampling point locations, Lower Colorado River, 2008-2010.

Our field classification of the habitat types at the 144 temporary detector points are listed in Table 2. As mentioned previously, we considered only areas that were mapped as HM, SH, and SM classes I-III for our mesquite samples. However, in the field we classified most of our mesquite points as class IV. This disagreement is likely due to misinterpretation of the aerial photographs during the 2004 mapping effort or our different interpretation of classification guidelines. Regardless, since very little mesquite vegetation was mapped as class I or II (the most mature classes), these points represented the most mature mesquite communities available in the study area.

Table 2. Field classification of vegetation at the 144 acoustic sampling points along the Lower Colorado River, 2008-2010.

	Cottonwood/willow		**Mesquite**		**Saltcedar**		**Marsh**	
Reach 3	**2008/09**	**2009/10**	**2008/09**	**2009/10**	**2008/09**	**2009/10**	**2008/09**	**2009/10**
Needles	CW I	CW II	SM IV	HM IV	SC IV	SC IV	MA V	MA V
Havasu	CW I	CW III	SM IV	SM IV	SC IV	SC IV	MA V	MA V
Topock Gorge	CW III	CW II	SM IV	HM IV	SC IV	SC IV	MA I	MA V
Lake Havasu	CW III	CW III	SM IV	SH IV	SC IV	SC IV	MA I	MA V
Lower Bill Wms.	CW I	CW I	HM IV	HM IV	SC III	SC IV	MA II	MA V
Upper Bill Wms.	CW III	CW I	SH IV	HM IV	SC IV	SC IV	MA IV	MA V
Reach 4	**2008/09**	**2009/10**	**2008/09**	**2009/10**	**2008/09**	**2009/10**	**2008/09**	**2009/10**
Parker Strip	CW III	CW I	SH IV	HM IV	SC IV	SC IV	MA III	MA V
Parker Valley	CW III	CW II	SH IV	SH IV	SC IV	SC IV	MA III	MA IV
Cibola Valley	CW II	CW I	SH IV	SH IV	SC IV	SC IV	MA V	MA V
Upper Cibola	CW III	CW II	SM IV	HM IV	SC IV	SC IV	MA V	MA V
Lower Cibola	CW III	CW I	SH IV	SM IV	SC IV	SC IV	MA II	MA V
Upper Imperial	CW II	CW I	SM III	HM IV	SC III	SC IV	MA I	MA V
Reach 5/6	**2008/09**	**2009/10**	**2008/09**	**2009/10**	**2008/09**	**2009/10**	**2008/09**	**2009/10**
Picacho	CW II	CW I	SH III	HM IV	SC III	SC IV	MA VI	MA III
Lower Imperial	CW I	CW I	SH IV	HM IV	SC IV	SC IV	MA III	MA V
Martinez Lake	CW II	CW I	SH III	HM IV	SC IV	SC IV	MA I	MA IV
Imperial West	CW III	CW I	SH III	HM IV	SC III	SC IV	MA I	MA V
Imperial Dam	CW II	CW I	HM IV	HM IV	SC IV	SC IV	MA II	MA I
Lower Laguna	CW I	CW I	SH III	SH IV	SC IV	SC IV	MA I	MA V

We placed 4 bat detectors simultaneously (Sherwin et al. 2000) in each segment (1 in each vegetation type) for a period of 2 nights and then moved to another segment the next day. We deployed 8 detectors in a leapfrog manner during a 10-day sampling effort that covered all 6 segments within an entire reach. We sampled each reach once during each of the 4 seasons, delineated as March-May, June-August, September-November, and December-February. We considered spring and fall to comprise migration and mixed roost use, summer to comprise activity by breeding adults and newly-volant juveniles and use of warm-season roosts, and winter to comprise hibernation and use of cold-season roosts (Patricia E. Brown, Brown-Berry Biological Consulting, personal communication; Koprowski and Buecher 2008). These were the primary factors that we expected to influence seasonal bat occupancy and habitat use. We sampled the same points during each season from spring 2008 through winter 2008/2009. We then selected a new sample of 72 points, which we sampled from spring 2009 through winter 2009/2010.

We separated call files into individual nights, and visually analyzed the frequency-time signature of all files. We then compared files categorized as focal species to a reference library collected by Chris Corben (private consultant, personal communication) for verification. We also coordinated analysis techniques directly with Susan Broderick (Reclamation). Her techniques are documented in Broderick (2008). We developed encounter histories for each of the 4 focal species for each season based on presence or absence of verified calls during either night of the 2-night sampling period. Encounter histories are the basic data structure for occupancy analysis.

To gather information to construct occupancy models, we first selected a panel of experts (S. Amellon, A. Calvert, P. Brown, B. Burger, C. Chambers, J. Corbett, L. Piest, T. Snow) with considerable knowledge of the ecology of the focal species along the LCR or bats in general. These experts were asked to complete a questionnaire (Appendix C) regarding the factors affecting detectability and occupancy of the focal species in our study area. Responses were used to guide *a priori* development of a candidate model set for each species that were assessed using a structured 2-step process. All occupancy analyses were performed in program PRESENCE (v3.0; Hines 2010).

In order to appropriately account for imperfect detection in our occupancy models, we first assembled models that allowed detection probability to vary with survey-specific covariates while keeping occupancy constant. Covariates we determined could influence detection probability included moon phase, daily precipitation, average wind speed, maximum wind speed, average temperature, minimum daily temperature, maximum daily temperature, 2-seasons (this model assumed that spring and summer combined detection probabilities differed from fall and winter combined probabilities), 4 seasons (assumed that detection probabilities differed between each of the 4 seasons), year (assumed that detection probabilities differed between the 2 years of sampling), individual survey event (assumed a different detection probability for each survey event/ 2 sequential nights). For Townsend's big-eared bats, we included an additional time covariate, 2 seasons-a, (this model assumed equal detection probabilities for the months of March to November, and a different detection probability for the months of December to February) to account for hibernation patterns. We modeled hibernation patterns based on O'Farrell (2006b) for Townsend's big-eared bats in southern Nevada. All weather data were obtained from the National Climate Data Center of the National Oceanic and Atmospheric Administration (http://www.ncdc.noaa.gov/oa/ncdc.html).

All candidate models were compared to a null model that assumed constant detection probability and occupancy according to support given our data using Akaike's Information Criterion (AIC; Akaike 1973) corrected for small sample size (AICc; Burnham and Anderson 2002). We considered the model with the lowest AICc value to be our best model. We used the best detection model for each species in the subsequent modeling of occupancy.

The second step in our modeling process was to assess habitat variables that our expert panel suggested could affect site occupancy (Appendix D). All habitat variables were measured for our study area using a Geographic Information System (GIS; ArcGIS 9.3, Environmental Systems Research Institute, Redlands, California, USA). In order to avoid multicollinearity between variables, we performed a Spearman's correlation analyses of all variables prior to conducting occupancy analyses by using SPSS (SPSS 14.0, Chicago, Illinois, USA). We did not include more than one correlated variable (p>0.05). We assembled a candidate suite of models for each species that included various combinations of habitat covariates that represented expert hypotheses of focal species habitat use along the LCR. We ranked all candidate models according to AICc values, and regarded the model with the lowest AICc value as our best model. We considered models that were ranked within 4 AICc values of the best model to be competing, and averaged parameter estimates from all competing models (Burnham and Anderson 2002). Averaged parameter estimates were used to predict the distribution of each focal species within our study area. These predictions reflected year-round distribution of each species, and likely encompassed periods during which occupancy status of our study area changed. As such, our final estimates of probability of occupancy should more appropriately be interpreted as probability of use (MacKenzie et al. 2004). For each variable, we summed the AIC weights across all possible models in which a given variable (*j*) occurred and considered a cumulative AIC weight ($w_+(j)$) ≥ 0.50 to be strong evidence for a response (Barbieri and Berger 2004, Dickson et al. 2009). AIC weights were interpreted as either negative (-) or positive (+) based on the direction of resulting parameter estimates. All detection and occupancy covariates that we considered are listed and defined in Appendix D.

Permanent stations

To better assess seasonal activity of bat species on the LCR and their relationship to environmental variables, we placed 4 permanent detector stations along the river. These stations were constructed by EME Systems, Inc., Berkeley, California. Three were equipped with an Anabat II detector with ZCAIM, and 1 used an Anabat SD1 detector. They all included internal and external temperature and humidity sensors, anemometer, and an OWL data logger and controller. Locations were chosen to provide good coverage of the river when combined with those placed by Reclamation at Beal Lake on Havasu National Wildlife Refuge (NWR), ‘Ahakhav Preserve on CRIT, Palo Verde Ecological Reserve, and probably eventually at Cibola Valley Conservation Area and Imperial NWR (Susan Broderick, Reclamation, personal communication). Other factors we considered when choosing locations for the permanent stations included the presence of some attractant for bats or other characteristics that might tend to concentrate them. These included areas near water or native riparian trees, which are preferred by bats (Brown and Berry 2003, O’Farrell 2006a, Buecher and Sidner 2007). Migrating bats may tend to linger in these habitats rather than passing through quickly and possibly not being detected. We also considered areas where the river corridor narrows and migrating bats may be more confined (e.g., Picacho), or in other potential travel corridors (Bill Williams River). We used temporary Anabat detectors at potential sites to aid in our selection. Our site selection also considered the need for equipment security.

The first permanent station was placed at the nursery stand at Imperial NWR on 17 December 2007. We later relocated this station to a site at Mittry Lake, however, because of our concern that the Imperial site will be affected by planned native riparian restorations and because Reclamation will likely place a station at that location in the future. We established the 3 remaining stations in June, 2008 (Table 3). We normally visited each of these stations every 1-2 months to ensure they were operating correctly and to download Anabat call files. Every 3-6 months, we downloaded OWL (weather) data and reset the OWL and ZCAIM times.

Table 3. Locations of permanent detector stations placed along the Lower Colorado River**.**

Geographic area	Location	Date deployed
Bill Williams River NWR	Mosquito Flats	6/9/08
Cibola NWR	Island Unit	6/9/08
Picacho State Rec. Area	Near housing area	6/6/08
Imperial NWR	Nursery stand	12/17/07
Mittry Lake	Southeast side	7/9/08

We installed the station at Bill William River NWR on 9 June 2008 on a ridge overlooking Mosquito Flats along the south side of the Bill Williams River (Figure 3). Mosquito Flats is a large area of mature cottonwoods and willows with saltcedar and mesquite in the understory and margins. The 2004 vegetation classification of the site was CW IV, although there was a diverse mixture of mature cottonwoods, willows, saltcedar, and mesquite and would probably be more accurately considered class II or III. The station and the microphone were positioned to detect bats that are flying over the canopy of the dense riparian forest.

The station at Cibola NWR was placed on the Island Unit on 9 June 2008 in a wet, grassy meadow with scattered mature Goodding's willows. Marsh, agricultural fields, and dense stands of mesquite and saltcedar were also nearby. The 2004 vegetation classification was SC IV, but there was a diversity of habitat at and adjacent to the site. The area was flooded during the winter to provide waterfowl habitat and duck hunting opportunities.

We placed the station at Picacho State Recreation Area on 6 June 2008 just west of the parking area of the lower boat launch, near the housing area. It was on a dirt ridge in a stand comprised of mesquite, saltcedar, and arrowweed (*Pluchea sericea*). The microphone was aimed toward a cottonwood/willow revegetation site that could be classified as CW II. The 2004 classification apparently did not identify the restoration areas at Picacho, as the entire area was classified as SC IV.

The station at Imperial NWR was installed at the southwest corner of the Nursery Stand, classified as CW I. It operated continually until we relocated it on 9 July 2008 to Mittry Lake. We relocated it in anticipation of Reclamation eventually establishing a station at the Nursery Stand and a desire to sample a more natural and stable habitat. The microphone was aimed away from the stand toward the adjacent native fish pond to reduce noise interference from leaves and insects.

We relocated the unit from Imperial NWR to Mittry Lake Wildlife Area on 9 July 2008. The station was along the southeast shoreline of Mittry Lake, within an area of arrowweed, saltcedar, and mesquite. The microphone was aimed toward a patch of mesquite and cottonwoods, with marsh vegetation just beyond. The 2004 vegetation classification was SC IV.

Bill Williams River National Wildlife Refuge

Cibola National Wildlife Refuge

Picacho State Recreation Area

Imperial National Wildlife Refuge

Mittry Lake Wildlife Area.

Figure 3. Photographs of permanent bat detector locations placed along the Lower Colorado River, 2007-2008.

Because of occasional interference from insects, vegetation, and electronic noise, some files collected were largely noise with little or no bat call information. These files were larger in size than normal bat call files. The "All bats" filter was designed by Chris Corben to identify such files, but we found it to be ineffective. However, after inspecting a sample of these files for the 2009 annual report, we determined that files larger than 17 kb were generally not usable and so we removed those files from our samples for that report. Further inspection for the current report revealed that smaller files were also often problematic. Even if the file contained a good call, it was often misidentified by our filters because of the large amount of static. We therefore removed files larger than 8 kb.

We analyzed call files from the permanent stations using multiple filters (Table 4). We used filters to analyze 14 bat species: Townsend's big-eared bat, California leaf-nosed bat, western red bat, western yellow bat, big brown bat (*Eptesicus fuscus*), pallid bat (*Antrozous pallidus*), big free-tailed bat (*Nyctinomops macrotis*), greater western mastiff bat (*Eumops perotis*), hoary bat (*Lasiurus cinereus*), Mexican free-tailed bat (*Tadarida brasiliensis*), pocketed free-tailed bat (*Nyctinomops femorosaccus*), California myotis (*Myotis californicus*), Yuma myotis (*Myotis yumanensis*), and canyon bat (*Parastrellus hesperus*). Due to overlap and similarities in calls among species, we created frequency bandwidth guilds for most. We placed big free-tailed bats and greater western mastiff bats into a 7-15 kHz guild, hoary bats, Mexican free-tailed bats, and pocketed free-tailed bats into a 15-24 kHz guild, big brown bats and pallid bats into a 24-30 kHz guild, and Yuma myotis and California myotis into a 50 kHz Myotis guild. Cave myotis (*Myotis velifer*) and Arizona myotis (*Myotis occultus*) were not analyzed separately but most would have been picked up by the Myotis filter.

The main features used to build filters were characteristic frequency and slope. Corben (2006) determined that these 2 parameters are important indicators for identifying species. Slope variation dictates the shape of the call, and characteristic frequency limits the range of probabilities to species bandwidths (Corben 2006). Because of their high priority in this study, we identified calls of the 4 focal species down to individual species. However, unlike our analysis of files from the temporary stations, we did not examine each file individually but instead used methods and filters developed by Broderick (2008) to analyze calls of focal species. Due to the similarities between calls of canyon bats and western red bats, we were able to work out canyon bats in the process of sorting out western red bats. Next, to identify canyon bat files, we first separated them from western red bat files by examining each call file that passed the western red bat filter. We then used a canyon bat filter to ensure we captured the majority of canyon bat call files missed by the western red bat filter. A visual scan of these calls was necessary to sort out Myotis species. A second procedure was used to analyze Myotis species. In the process of identifying California leaf-nosed bat call files, we sorted out and labeled Myotis files.

We analyzed bandwidth categories using the following sequence of filters, which we tested on Chris Corben's U.S. bats call library. All files were labeled each time they were selected by a filter. First, we used high- and low-slope filters for the 7-15 kHz bandwidth (big brown bats and big free-tailed bats). The high-slope filter for this frequency band correctly identified 54% of big brown bat files and 85% of big free-tailed bat files (Table 4). The low-slope filter for the 7-15 kHz bandwidth correctly identified 88% of greater western mastiff bats and 35% of pocketed free-tailed bat call files. We then used a low-slope 15-19 kHz filter for the 15-24 bandwidth (hoary bats, pocketed free-tailed bats, and Mexican free-tailed bats), which identified 86% of hoary bat call files, 24% of pocketed free-tailed bat files, and 6% of Mexican free-tailed bat files. Next, we used mid- and low-slope 19-24 kHz filters to complete the 15-24 kHz bandwidth. The mid-slope filter identified 77% of hoary bat calls, 88% of pocketed free-tailed bat calls, and 58% of Mexican free-tailed bat calls. The low-slope filter identified 87% of hoary bat calls, 30% of pocketed free-tailed bat calls, and 85% of Mexican free-tailed bat calls. Last, we used mid- and high-slope filters for the 24-30 kHz bandwidth (pallid bats and big brown bats). The mid-slope filter identified 75% of pallid bat calls and 100% of big brown bat calls. The high-slope filter identified 19% of pallid bat calls and 81% of big brown bat calls.

Overall, these filters overlapped and did select files of incorrect species. Yet, because most call files were previously identified and labeled by preceding sets of filters, we were able to easily sort them out and disregard the files belonging to a different species group. Thus the sequence in which we used the bandwidth filters was key for accuracy. Nonetheless, a small amount of error prevailed. It is important to acknowledge the uncertainty in quantifying error rates for these filters. For instance, we can't quantify the error produced by those calls that were not selected by the proper filter but later were selected by an erroneous one. However, we can reduce this error by running multiple filters. For example, the mid-slope filter for 7-15 kHz could miss some calls that would be picked up by the low-slope filter.

Table 4. Number of files selected in bandwidth filters tests on a reference collection of call files; bold numbers indicate correct filter selection[1].

Species	No. of call files	HS 7-15k	LS 7-15k	LS 15-19k	MS 19-24k	LS 19-24k	MS 24-30k	HS 24-30k	PAHE
MACA[1]	46					1			1
EUPE	24	**13**	**21**	1	1	1		1	
NYMA	20	**17**	**7**	3	1	1	1	1	
NYFE	33		1	**8**	**29**	**10**			
TABR	136	1		**8**	**79**	**116**	107	94	
LACI	74			**64**	**57**	**64**	38	18	
ANPA	16			1		4	**12**	**3**	
EPFU	42				2	6	**42**	**34**	
COTO	26								
LABL	20								20
LAXA	21								
PAHE	58				1	3		1	**57**
MYCA	74			1					2
MYVE	12			1		1			
MYYU	197	1						1	6

[1]LS=low slope, MS=medium slope, HS=high slope

[2]MACA=California leaf-nosed bat, EUPE=greater western mastiff bat, NYMA=big free-tailed bat, NYFE=pocketed free-tailed bat, TABR=Mexican free-tailed bat, LACI=hoary bat, ANPA=pallid bat, EPFU=big brown bat, COTO=Townsend's big-eared bat, LABL=western red bat, LAXA=western yellow bat, PAHE=canyon bat, MYCA=California myotis, MYVE=cave myotis, MYYU=Yuma myotis.

We used bat minutes as a relative measure of bat activity from data collected at the permanent stations. A bat minute is a 1-minute interval in which a particular species was recorded (Miller 2001). This index reduces the bias associated with the tendency for individual bats to be detected multiple times or for multiple bats to be detected within an individual file. While inappropriate for estimating abundance, Miller (2001) demonstrated that this method provides reliable estimates of activity. It has been used to evaluate bat activity along the LCR region by Brown and Berry (2003), O'Farrell (2006a, b), and Williams et al. (2006), as well as elsewhere in Arizona by Koprowski and Buecher (2008).

We summarized weather variables collected at the permanent stations for the period from sunset to sunrise. We also summarized the same data from sunset to midnight to test whether there was a stronger correlation during this time period since most bat activity occurs before midnight (54% of bat minutes in our study). We calculated an index of moonlight, varying from 0 to 1, for each hour-interval of each night, with the first interval beginning at sunset. Intervals occurring predominantly before moonrise or after moonset were coded as zero. Hour-intervals between moonrise and moonset were calculated as the absolute value of the number of days before or after the new moon, divided by 14, which is the approximate moon phase mid-point (full moon). A value of 1.0, therefore, would be coded for an hour-interval that was between moonrise and moonset during a full moon. We combined these data to derive a nightly mean and a pre-midnight mean. Sun and moon data were obtained from the U.S. Naval Observatory (2010). We used multiple linear regression to analyze correlations between bat call minutes and environmental variables, sites, and seasons.

Mist-net surveys

We conducted mist-net surveys at some sites to verify species occurrence, attempt to document reproductive status of focal species, and to evaluate sites for future studies that would require capture. These data were not used in our occupancy analysis. We chose locations and times so as to not affect bat activity at the detector sites.

RESULTS

Temporary stations

Due to logistical issues that occurred the first sampling year, efforts varied somewhat among years. We sampled 72 sites for 2 consecutive nights in 2008-09 each of the 4 seasons, with the exception of spring, when we sampled 60 sites. In 2009-10, we sampled 72 sites each of the 4 seasons for 2 consecutive nights. The total number of sample nights for 2008-10 was 1,128. Maps that depict detection locations for the 4 focal species are in Appendix E.

Detection probability

Covariates used to model detection probability in western red bat occupancy models included minimum temperature, wind speed, precipitation, 4-seasons (assumed that detection probabilities differed between each of the 4 seasons), 2-seasons (assumed that spring and summer combined detection probabilities differed from fall and winter combined probabilities), and year (assumed that detection probabilities differed between the 2 years of sampling; Appendix F). Our best model included survey-specific minimum temperatures and modeled detection probability separately for each of 4 seasons (Table 5).

Table 5. Competing models (delta Akaike Information Criteria adjusted for small sample size [ΔAIC_c] ≤4) of detection probability (p) for each focal species of bats along the Lower Colorado River, 2008-2010. Occupancy was kept constant [$\psi(.)$] in all models.

Model[1]	**AIC_C**	**ΔAIC_C**	**Model Weight**	**No. Of Parameters**
Western red bat				
$\psi(.),p$(4Seasons+MinTemp)	362.71	0.00	0.69	4
$\psi(.),p$(4Seasons+MaxTemp)	364.29	1.58	0.31	4
Western yellow bat				
$\psi(.),p$(2Seasons+MinTemp)	509.19	0.00	0.66	4
$\psi(.),p$(2Seasons+MinTemp+WindSpeed)	510.56	1.37	0.33	5
Townsend's big-eared bat				
$\psi(.),p$(2Seasons-a+MinTemp)	311.08	0.00	0.98	4
California leaf-nosed bat				
$\psi(.),p$(4Seasons+AvgTemp)	387.12	0.00	0.27	4
$\psi(.),p$(4Seasons+MaxTemp)	387.43	0.31	0.23	4
$\psi(.),p$(4Seasons+WindSpeed+AvgTemp)	388.07	0.95	0.17	5
$\psi(.),p$(4Seasons+WindSpeed+MaxTemp)	388.33	1.21	0.15	5
$\psi(.),p$(4Seasons+MinTemp)	388.59	1.47	0.13	4
$\psi(.),p$(2Seasons+WindSpeed+AvgTemp)	390.16	3.04	0.06	5

[1] Abbreviations for covariates are defined in Appendix D.

Covariates considered in *a priori* models of detection probability for western yellow bats included minimum temperature, average temperature, maximum temperature, precipitation, wind speed, 4-seasons, 2-seasons, and year (Appendix F). Our best model allowed detection probability to vary with survey-specific minimum temperature and modeled detection probability separately for each of 2-seasons (Table 5).

Covariates we considered in *a priori* models of detection probability for Townsend's big-eared bats included minimum temperature, wind speed, moon phase, 2-seasons, 2-seasons-a (assumed equal detection probabilities for March to November and a different detection probability for December to February), 4-seasons, and year (Appendix F). Our best model allowed detection probability to vary with minimum temperature and modeled detection probability separately for each of 2 seasons (Table 5).

Covariates we considered in *a priori* models of detection probability for California leaf-nosed bats included maximum temperature, average temperature, minimum temperature, wind speed, moon phase, precipitation, 4-seasons, 2-seasons, and year (Appendix F). Our best model allowed detection probability to vary with minimum temperature and modeled detection probability separately for each of 4 seasons (Table 5).

Occupancy probability

Naive occupancy probability for western red bats throughout our study area was 0.20. We assembled an *a priori* set of 15 candidate models for western red bats (Appendix G). All *a priori* models performed much better than the null model. The best model allowed occupancy to vary with site-specific values of CW300m, which was found to be a strong positive predictor of western red bats occupancy (Table 6; Figure 4). Competing models included CW300m, and also DistRiv, which showed a weak negative relationship with western red bats occupancy (Table 7). Detection probability in competing models ranged from 0.03 to 0.54. Spatial application of competing models indicated that the highest probability of western red bat use of our study area is localized to extant stands of cottonwood-willow, particularly in areas near Laguna Dam and the Bill Williams River (Figure 5).

Table 6. Competing models (delta Akaike Information Criteria adjusted for small sample size [ΔAIC_c] ≤4) of occupancy (ψ) for each focal bat species of bats along the Lower Colorado River, 2008-2010. For each species, the most parsimonious model of detection probability was used.

Model[1]	**AIC_C**	**ΔAIC_C**	**Model Weight**	**No. Of Parameters**
Western red bat				
ψ(CW300m^2),p(MinTemp+4Seasons)	323.25	0.00	0.70	5
ψ(CW300m+DistRiv),p(MinTemp+4Seasons)	324.91	1.66	0.30	6
Western yellow bat				
ψ(CW100m+NAT100m),p(MinTemp+Seasons)	467.68	0.00	0.67	6
ψ(CW100m+SC100m),p(MinTemp+Seasons)	469.56	1.88	0.26	6
Townsend’s big-eared bat				
ψ(mSC100m+DistMine),p(MinTemp+2Seasons-a)	303.38	0.00	0.57	6
ψ(Pop1000m+mSC100m),p(MinTemp+2Seasons-a)	305.74	2.36	0.17	6
California leaf-nosed bat				
ψ(DistRiv+DistMACARoost),p(MinTemp+4Seasons)	355.68	0.00	0.88	6

[1] Abbreviations for covariates are defined in Appendix D.

Table 7. AIC weights (*w+(j)*) and correlation of habitat variables included in *a priori* models of occupancy by focal bat species along the Lower Colorado River, 2008-2010. Definitions of variables are in Appendix D.

	Western red bat	Western yellow bat	Townsend's big-eared bat	California leaf-nosed bat
CW				0.00 (+)
CW100m		0.79 (+)	0.02 (+)	
mCW		0.00 (+)		
mCW100m			0.05 (-)	
CW300m	1.00 (+)			
MA		0.00 (+)		
MA100m			0.05 (-)	0.04 (-)
MA300m	0.00 (.)			
Native		0.54 (+)	0.05 (-)	
Nat300m	0.00 (.)			
mNative		0.00 (+)		0.00 (+)
mNat300m	0.00 (.)			
SC		0.21 (-)		
SC100m			0.07 (+)	0.08 (+)
mSC100m			0.74 (+)	
SC300m	0.00 (.)			
AAC		0.00 (+)	0.02 (-)	0.00 (-)
AAC300m	0.00 (.)			
AG		0.00 (+)	0.01 (-)	0.00 (-)
DistRiv	0.30 (-)	0.05 (-)		0.88 (+)
Water		0.00 (+)	0.01 (+)	
Water100m				0.00 (+)
Water300m	0.00 (.)			
BW			0.00 (+)	
DistMine			0.65 (-)	
DistCOTORst			0.04 (-)	
DistMACARst				1.00 (-)
DistDam	0.00 (.)			0.05 (-)
DistBridge			0.00 (-)	
Pop1000m	0.00 (.)	0.05 (-)	0.20 (-)	0.00 (-)

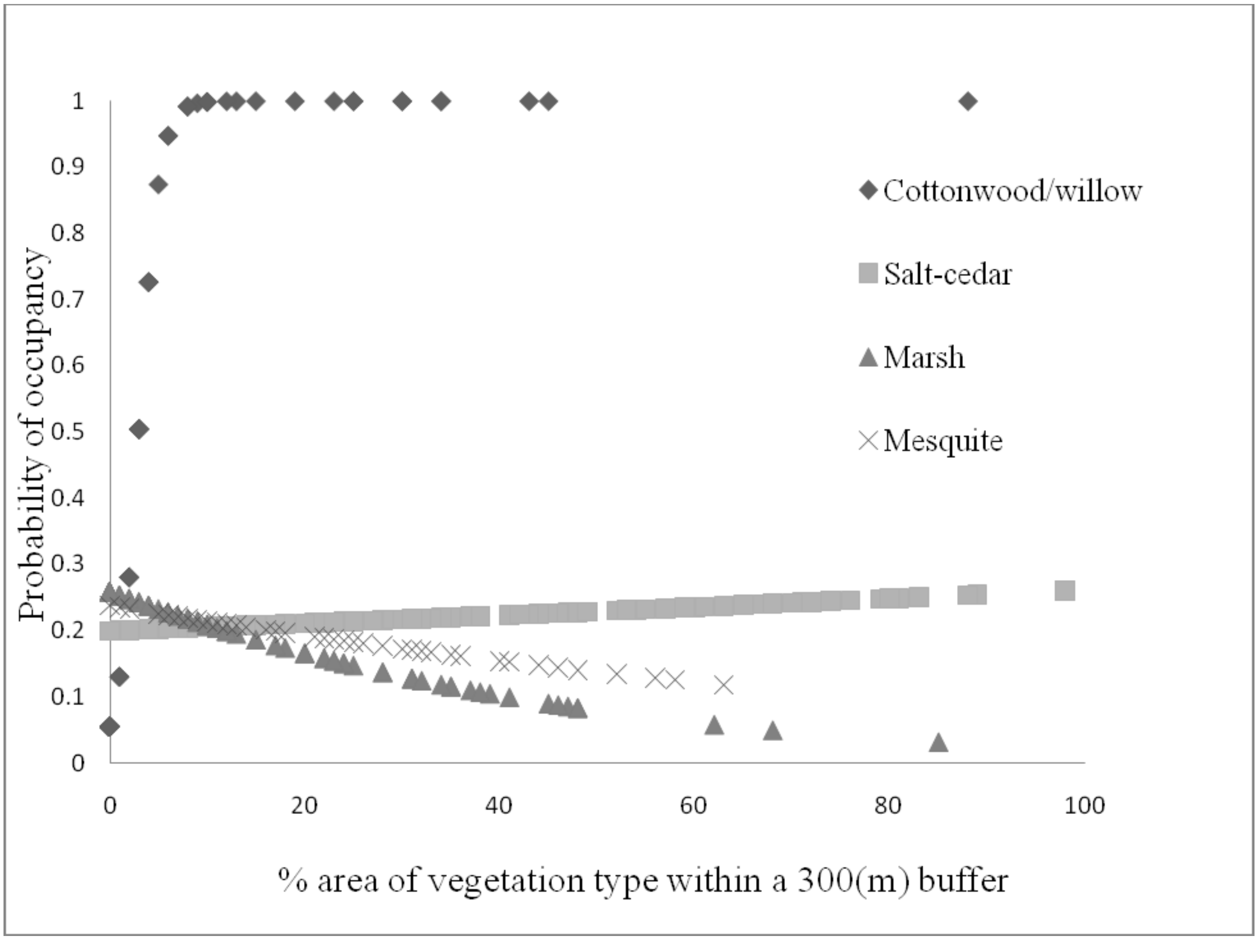


Figure 4. Probability of occupancy of western red bats in response to vegetation type within 300 m of a sampling location, Lower Colorado River, 2008-2010. Relationships were calculated using model-averaged estimates of occupancy according to Akaike's Information Criterion.

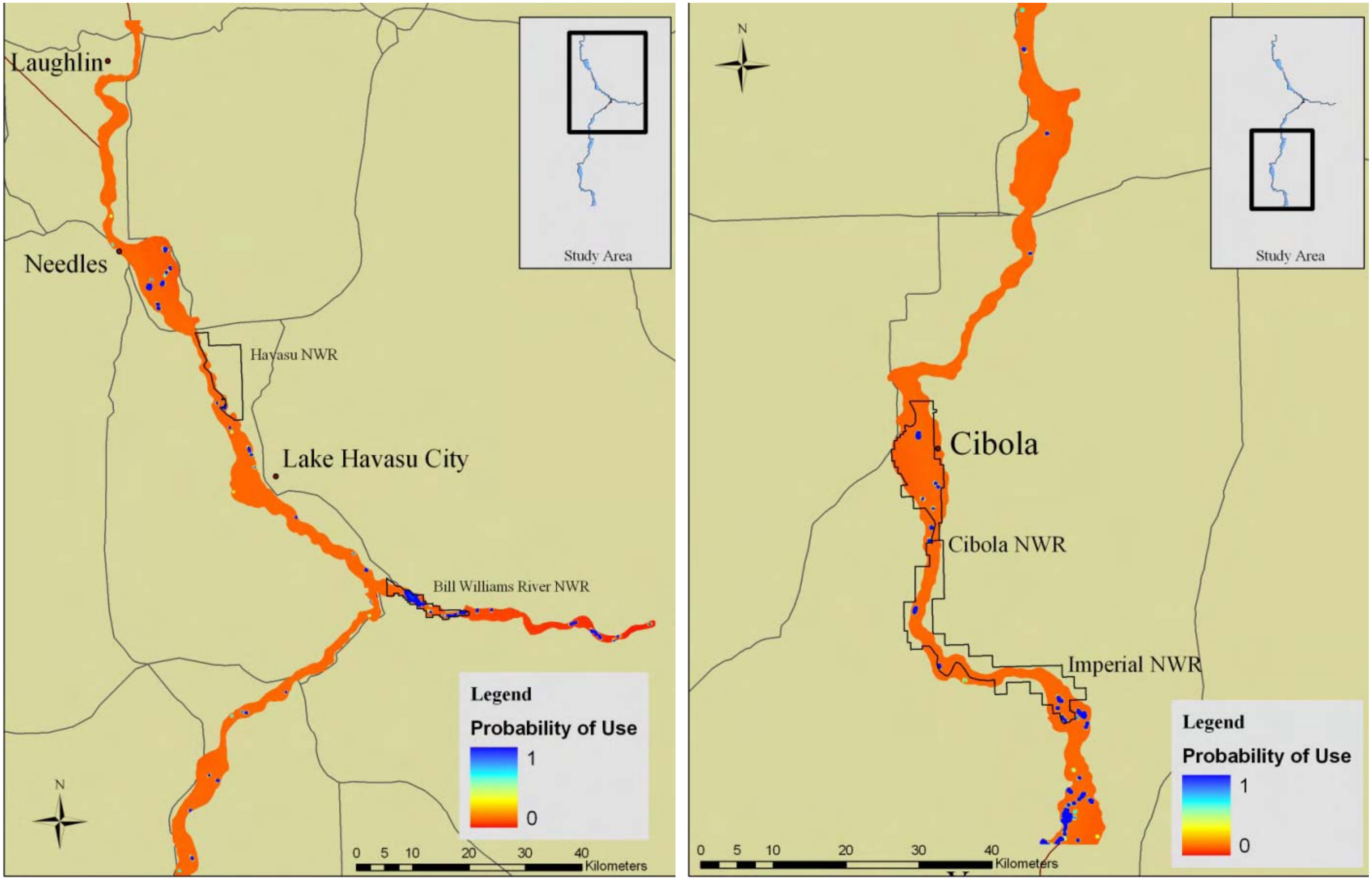


Figure 5. Estimated distribution of western red bats along the Lower Colorado River using averaged estimates from all competing occupancy models, 2008-2010.

The naïve occupancy probability of western yellow bats throughout our study area was 0.31. We assembled a suite of 16 *a priori* models for western yellow bats, all of which performed much better than the null model (Appendix G). The best model included CW100m and NAT100m (Table 6), which were a strong positive predictor and a moderately strong positive predictor, respectively (Table 7; Figure 6). A competing model indicated a strong positive relationship with CW100M, as well as a weak negative relationship with SC100M. Detection probability in the 2 competing models ranged from 0.04 to 0.57. Spatial application of competing models indicated that although more widely distributed than western red bats, western yellow bat use of our study area was closely associated with limited extant stands of native vegetation (Figure 7).

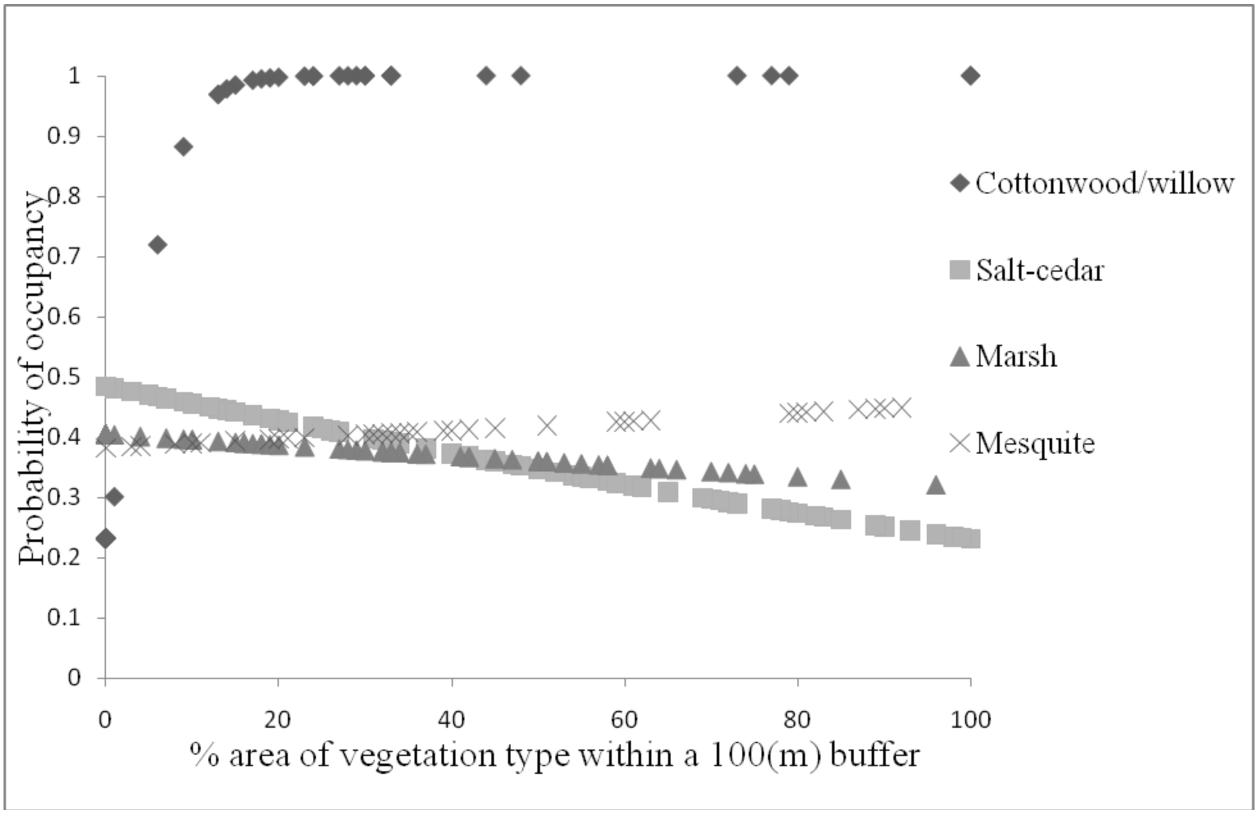


Figure 6. Probability of occupancy of western yellow bats in response to vegetation type within 100 m of a sampling location, Lower Colorado River, 2008-2010. Relationships were calculated using model-averaged estimates of occupancy according to Akaike's Information Criterion.

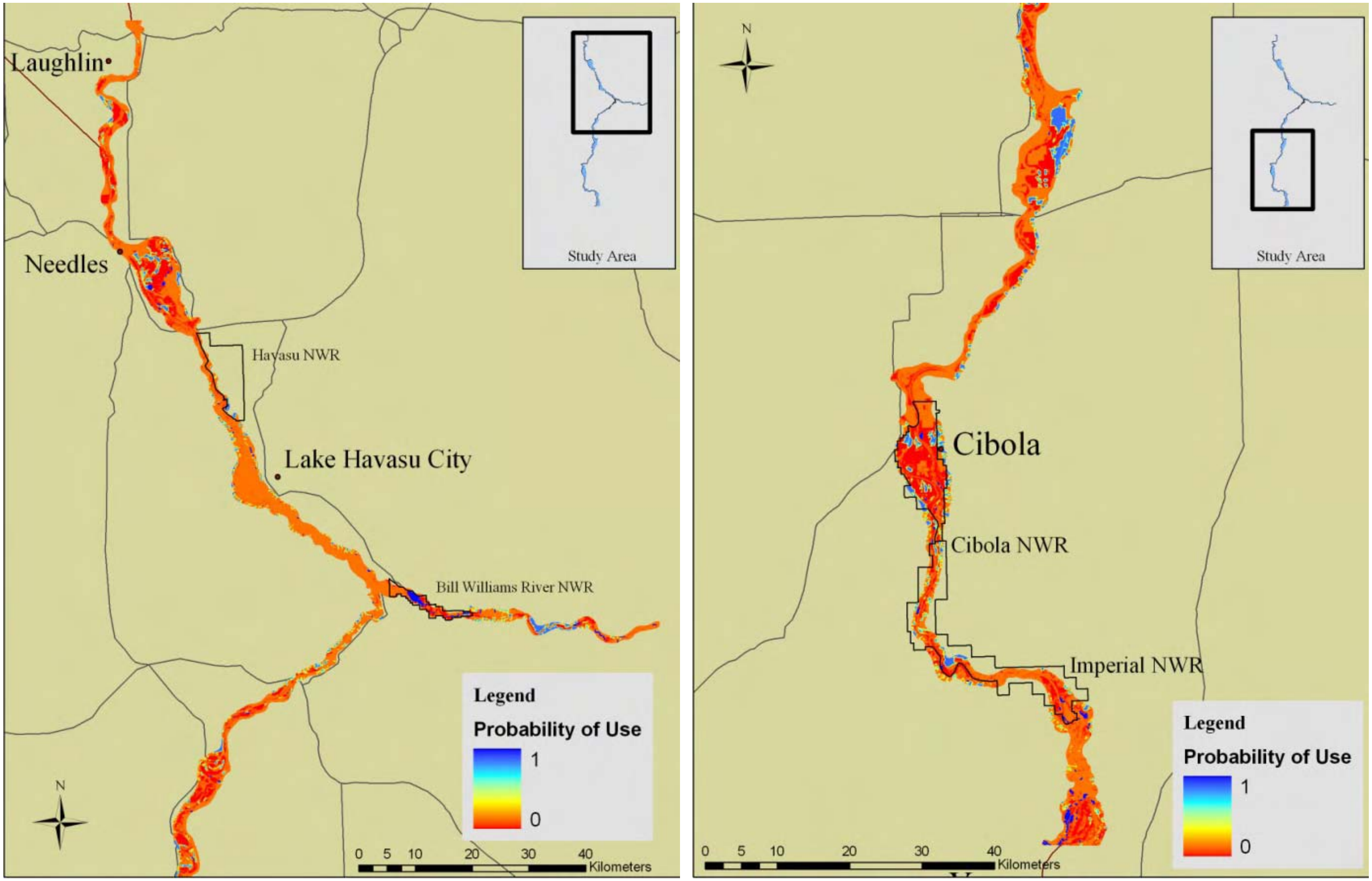


Figure 7. Estimated distribution of western yellow bats along the Lower Colorado River using averaged estimates from all competing occupancy models, 2008-2010.

The naïve occupancy probability of Townsend's big-eared bats throughout our study area was 0.19. We assembled a suite of 16 *a priori* models for Townsend's big-eared bats, all of which performed better than the null model (Appendix G). The best model included mSC100m and DistMine (Table 6), which were positive and negative predictors, respectively (Table 7; Figure 8). A competing model indicated a positive relationship with mSC100m, as well as a weak negative relationship with Pop1000m. Detection probability in the top models ranged from 0.01 to 0.34. Spatial application of competing models indicated the occurrence of Townsend's big-eared bats was strongly correlated with the prevalence of mature saltcedar and mines (Table 7), which occur widely throughout the LCR (Figure 9).

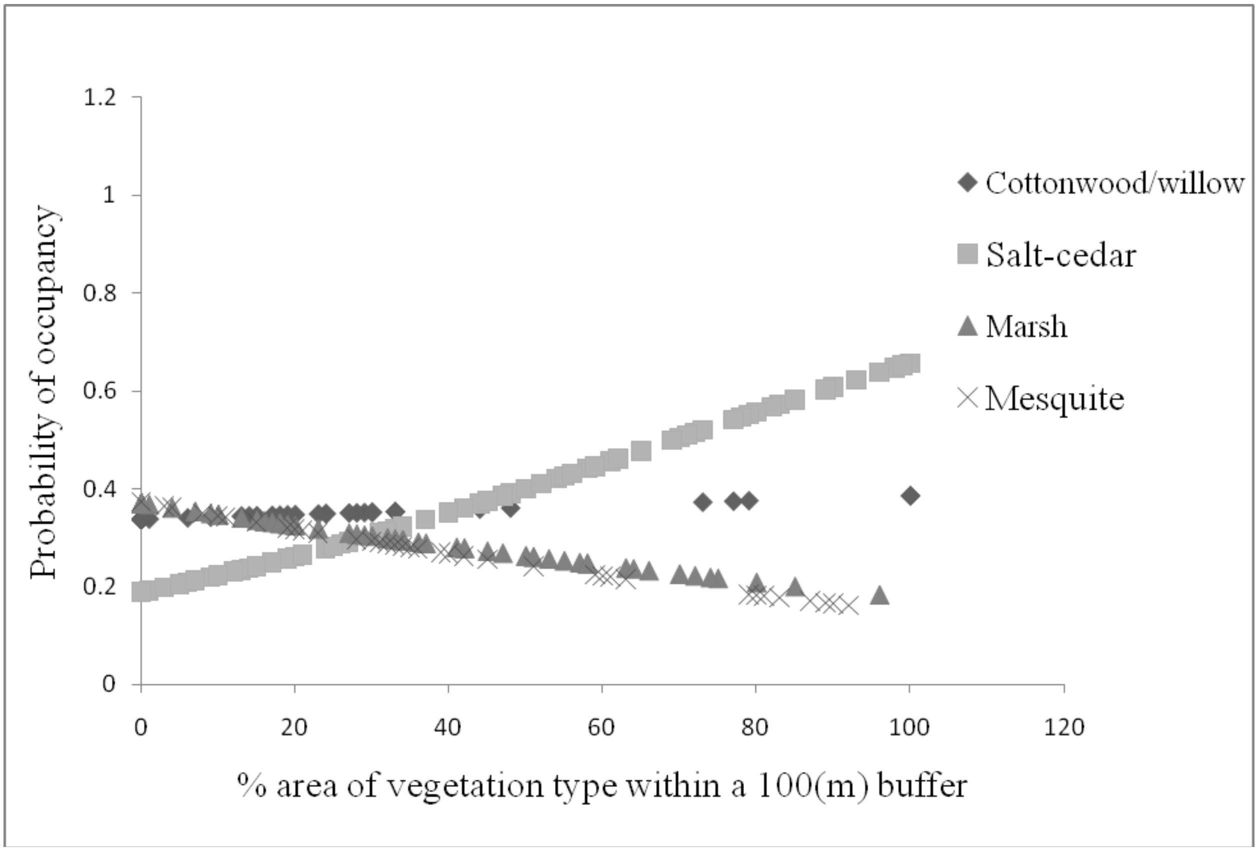


Figure 8. Probability of occupancy of Townsend's big-eared bats in response to vegetation type within 100 m of a sampling location, Lower Colorado River, 2008-2010. Relationships were calculated using model-averaged estimates of occupancy according to Akaike's Information Criterion.

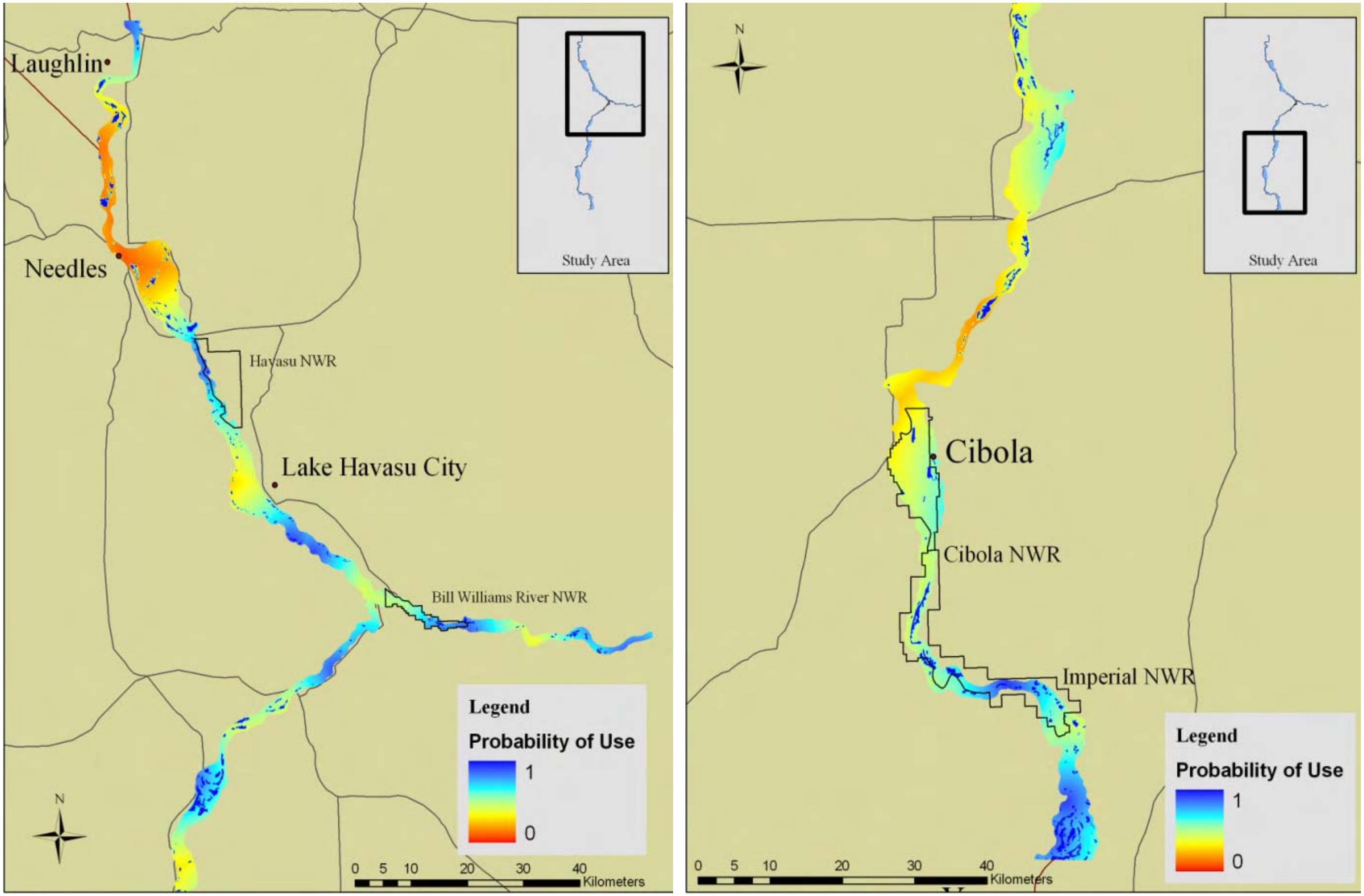


Figure 9. Estimated distribution of Townsend's big-eared bats along the Lower Colorado River using averaged estimates from all competing occupancy models, 2008-2010.

The naïve occupancy probability of California leaf-nosed bats throughout our study area was 0.22. We assembled a suite of 15 *a priori* models for California leaf-nosed bats, all of which performed better than the null model (Appendix G). The best model (Table 6) indicated a strong negative relationship with DistMACArst, and a strong positive relationship with DistRiv (Table 7; Figure 10). Detection probability for the best model ranged from 0.10 to 0.39. Spatial application based on the best model indicated the occurrence of California leaf-nosed bats to be highly correlated with proximity to known roosts of the species, particularly along the Bill Williams River (Figure 11).

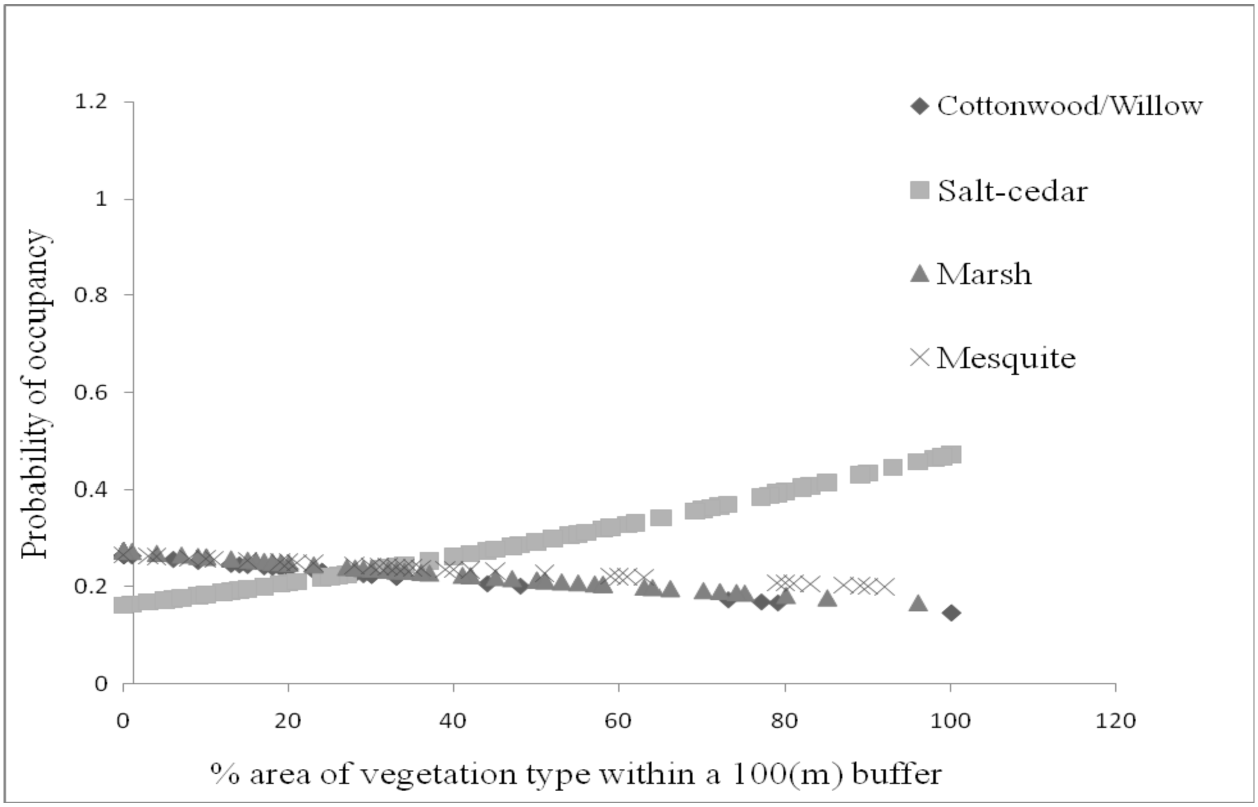


Figure 10. Probability of occupancy of California leaf-nosed bats in response to vegetation type within 100 m of a sampling location, Lower Colorado River, 2008-2010. Relationships were calculated using model-averaged estimates of occupancy according to Akaike's Information Criterion.

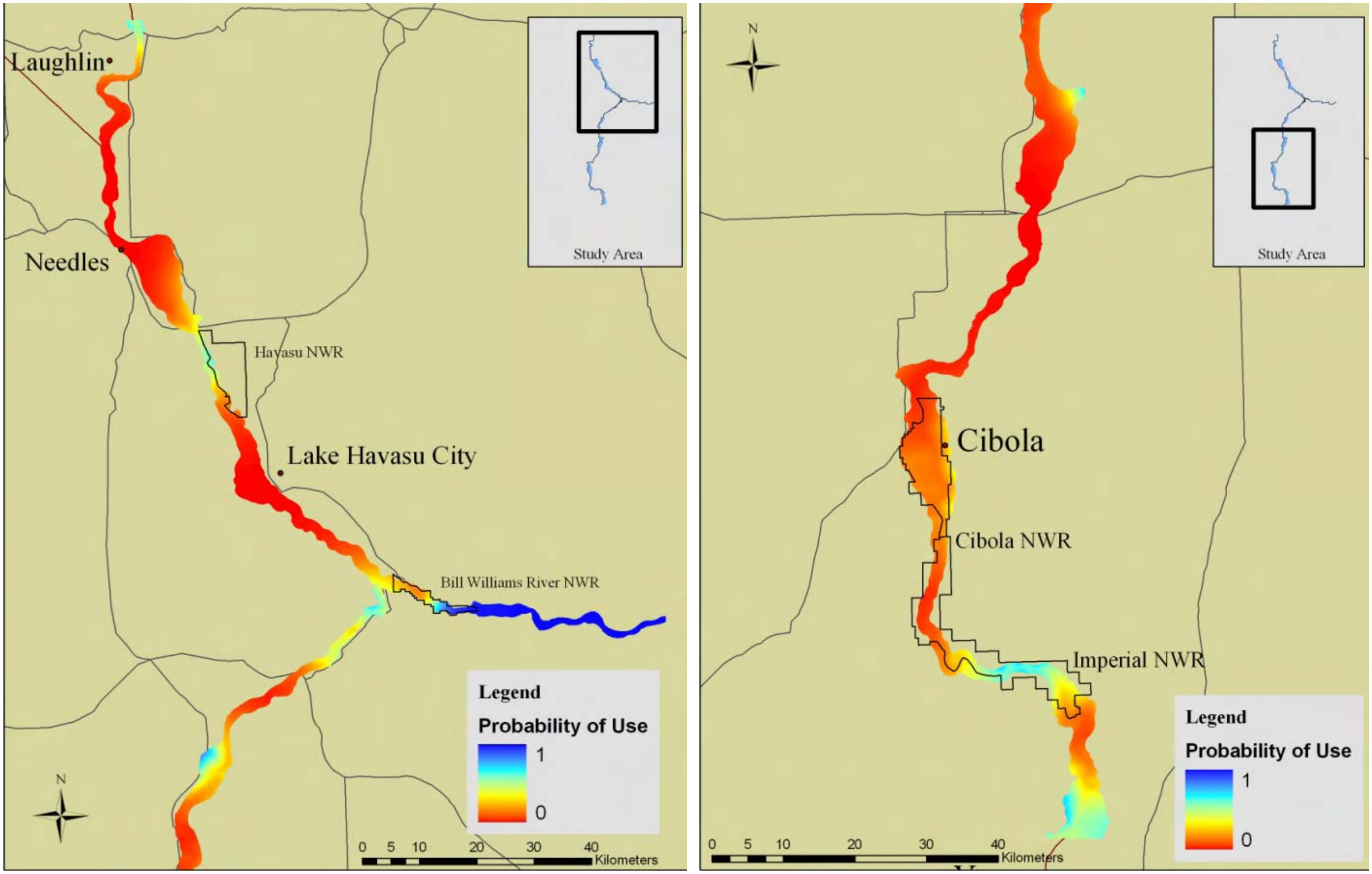


Figure 11. Estimated distribution of California leaf-nosed bats along the Lower Colorado River using averaged estimates from all competing occupancy models, 2008-2010.

Permanent stations

We encountered several problems with the permanent stations, particularly during 2008. The unit that uses a SD1 detector experienced an apparent heat-related malfunction in summer 2008. We solved this problem by wrapping the electronics box with several layers of window insulation; we did this at the other 3 stations as well. During both summers, our detectors experienced varying levels of interference from insect noise. In late 2008, the microphone and cables at the Bill Williams and Cibola stations both malfunctioned, perhaps as a result of a heavy rain, and had to be replaced. Problems with the microphone at Bill Williams continued in 2009. Unfortunately, several weeks of data were lost while diagnosing and addressing these problems. During the year ending June 2010, however, all stations appeared to operate normally. We recorded 148,968 usable bat call files at the Bill Williams station, 85,459 at Cibola, 118,202 at Picacho, 144,382 at Imperial, and 105,365 at Mittry, for a total of 602,376 usable call files. These figures do not include files that were rejected based on file size, as discussed above, which were 225,451 at Bill Williams (60.2% of total), 33,938 at Cibola (28.4%), 4,640 at Picacho (3.8%), 16,240 at Imperial (10.1%), and 32,511 at Mittry (23.5%), for a total of 312,780 (34.2%).

We analyzed our data to look for differences in activity among sites and seasons. The multiple regression procedure compensated for sample sizes (number of nights), and differences reported below were significant at $P<0.05$. Activity by western red bats was higher at Bill Williams, Imperial, and Mittry than at Picacho and Cibola (Table 8). Western red bat activity was higher in the summer and fall than in the winter (Figure 12). Spikes in activity in the spring at the Mittry and Picacho stations and during late summer and fall at Bill Williams and Cibola could have resulted from migration movements.

Bill Williams and Cibola received more western yellow bat activity than Picacho and Imperial. Activity of this species was significantly highest in the summer and lowest in the fall (Figure 13). Extreme peaks of activity in early spring at the Mittry and Imperial stations and later at Bill Williams and Cibola may have been migratory pulses.

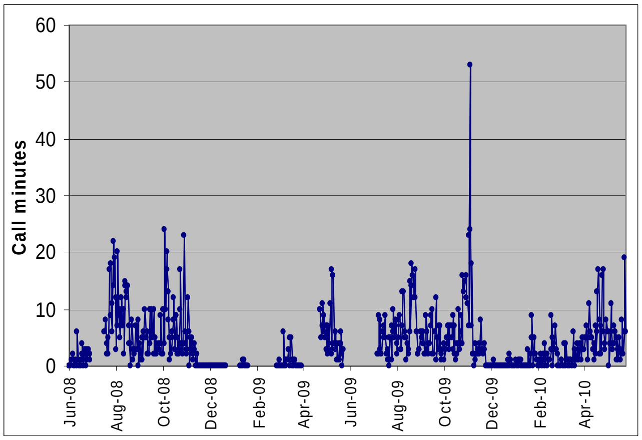
Bill Williams and Imperial received more activity by Townsend’s big-eared bats than Cibola and Picacho. Townsend’s big-eared bat activity was higher in the spring and summer than in the fall and winter (Figure 14). April and August accounted for 31 of the 40 (78%) highest nightly totals, primarily at Bill Williams.

Bill Williams, Imperial, and Mittry received more activity by California leaf-nosed bats than Cibola and Picacho. California leaf-nosed bat activity was significantly higher in spring and summer than in fall and winter, though there was high activity during the fall at Mittry (Figure 15).

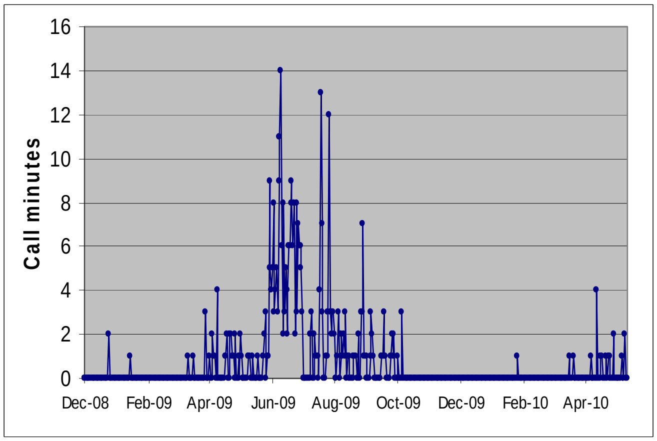
Graphs for the remaining species and bandwidths are in Appendix H. For all species combined, activity was significantly higher at the Imperial and Bill Williams stations than at the Cibola, Picacho, and Mittry stations. Activity was significantly higher during the summer, followed by spring, fall, and winter. Variances of mean call minutes for the focal species and total species were generally lowest in the summer and highest in fall and winter.

Table 8. Numbers of bat call minutes at permanent stations along the Lower Colorado River, 2007-2010.

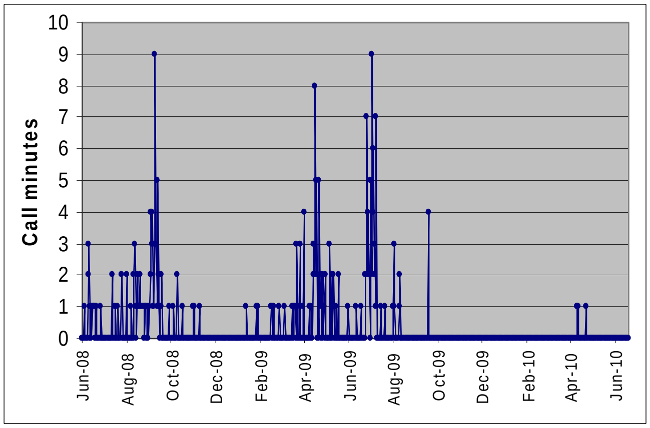
	Bill Wms.	**Cibola**	**Picacho**	**Imperial**	**Mittry**	**Total**
Western red bat	2,426	385	254	576	219	3,860
Western yellow bat	1,063	900	12	99	1,262	3,336
Townsend's big-eared bat	3,104	293	12	504	78	3,991
California leaf-nosed bat	4,050	505	45	1,137	3,657	9,394
Bandwidth 7-15 kHz	1,011	138	1,267	290	408	3,114
Bandwidth 15-24 kHz	20,083	1,049	13,554	4,177	5,403	44,266
Bandwidth 24-30 kHz	13,635	1,305	1,308	6,397	3,662	26,307
Myotis	60,807	36,307	36,596	39,002	22,314	195,026
Canyon bat	15,995	2,900	22,588	22,574	37,246	101,303
Unclassified	361	20,559	12,719	9,571	3,291	46,501
Total call minutes	122,534	64,341	88,355	84,327	77,540	437,097
Number of nights	585	528	749	193	666	2,721
Call minutes per night	209	122	118	437	116	161



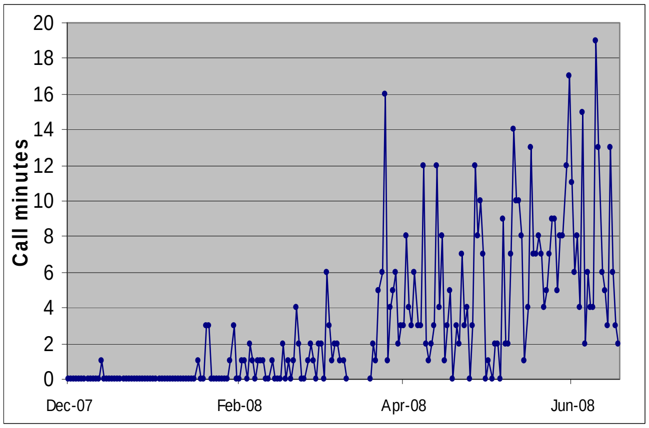
Bill Williams River NWR



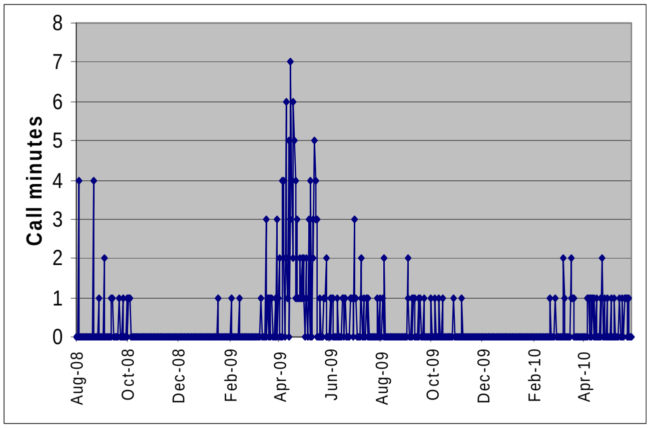
Cibola NWR



Picacho State Recreation Area

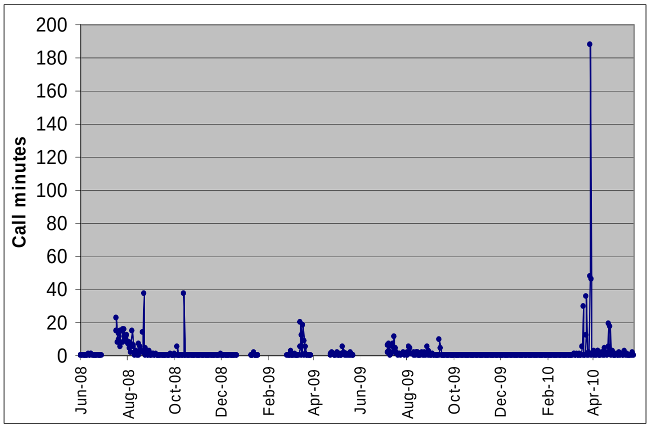


Imperial NWR

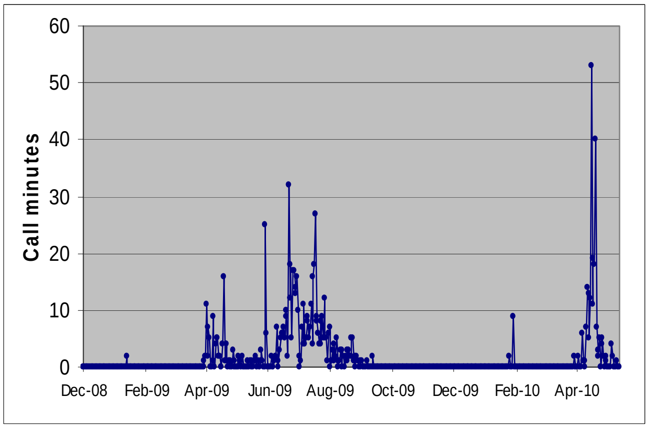


Mittry Lake Wildlife Area

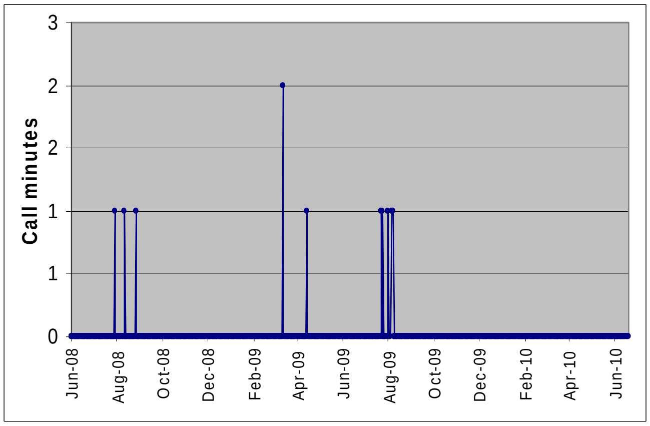
Figure 12. Numbers of call minutes recorded for western red bats at permanent stations along the Lower Colorado River, 2007-2010.



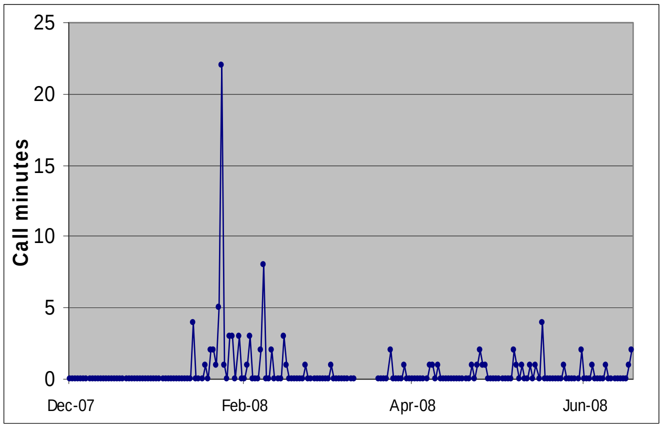
Bill Williams River NWR



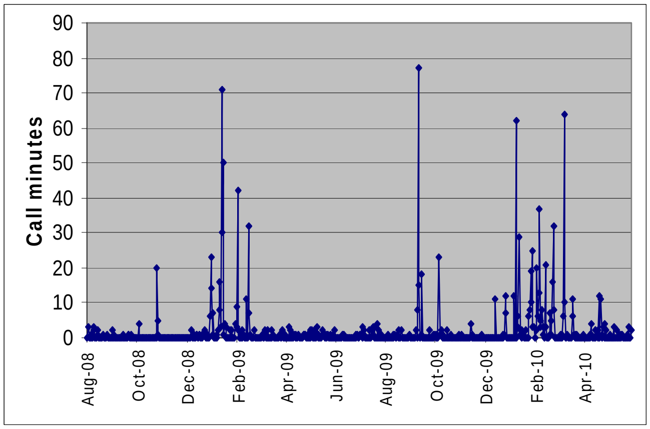
Cibola NWR



Picacho State Recreation Area

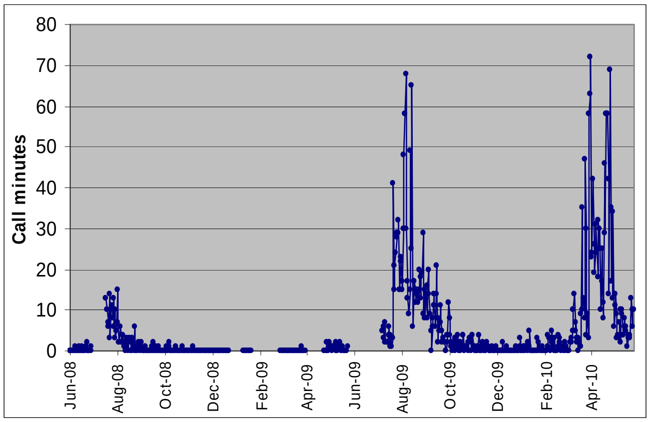


Imperial NWR

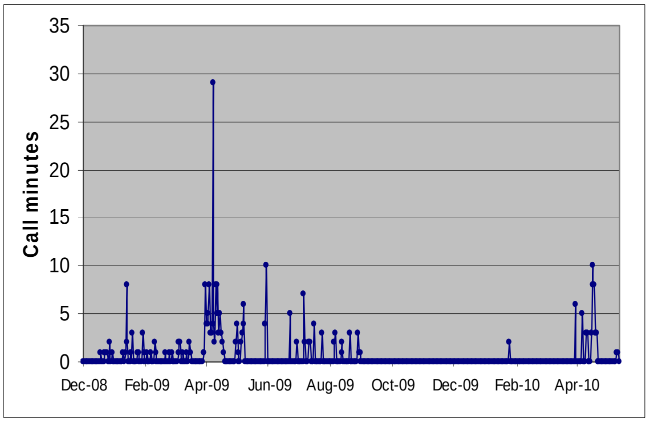


Mittry Lake Wildlife Area

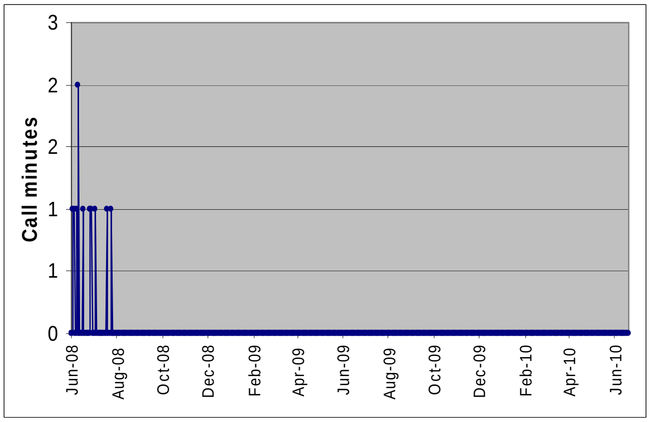
Figure 13. Numbers of call minutes recorded for western yellow bats at permanent stations along the Lower Colorado River, 2007-2010.



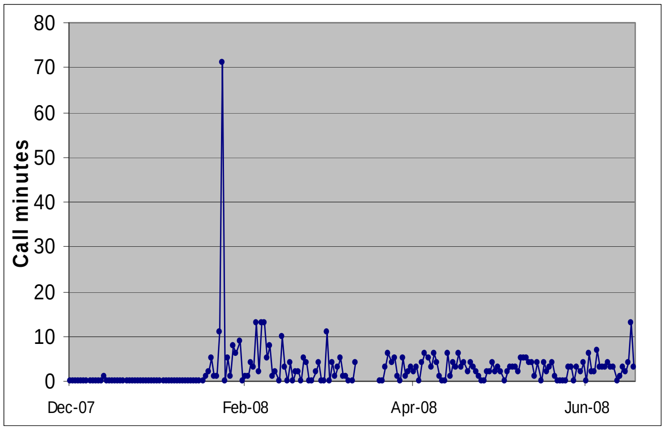
Bill Williams River NWR



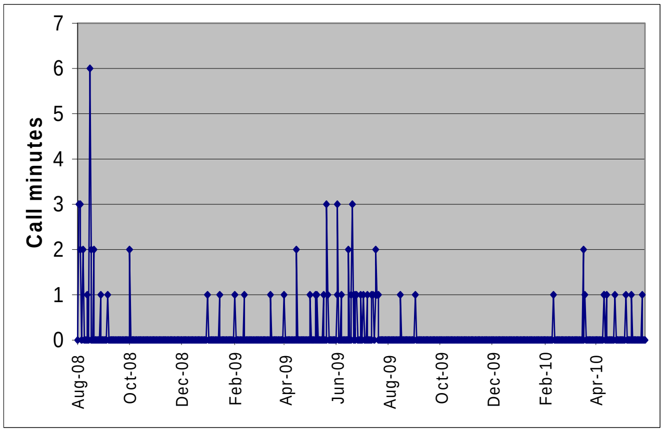
Cibola NWR



Picacho State Recreation Area

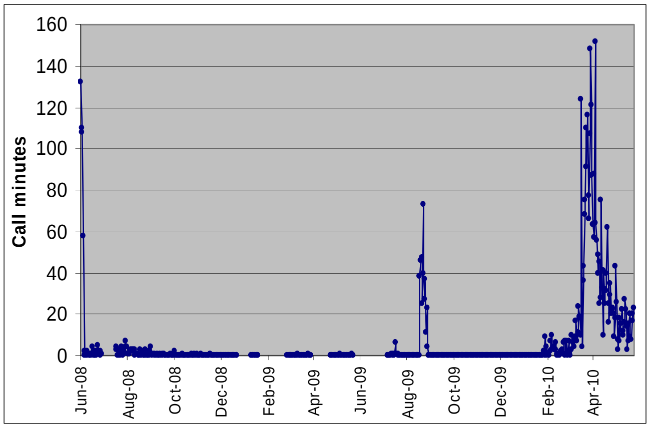


Imperial NWR

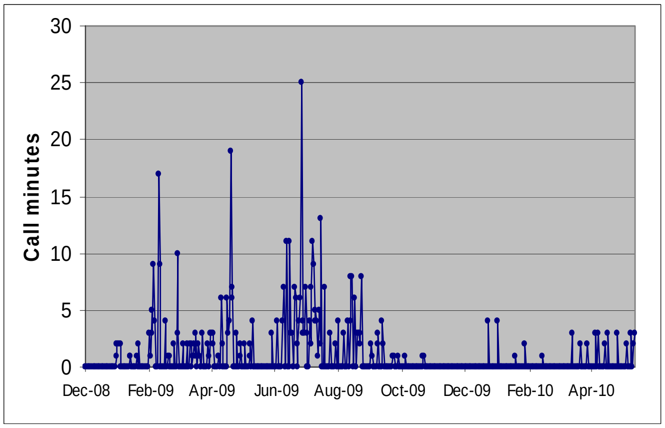


Mittry Lake Wildlife Area

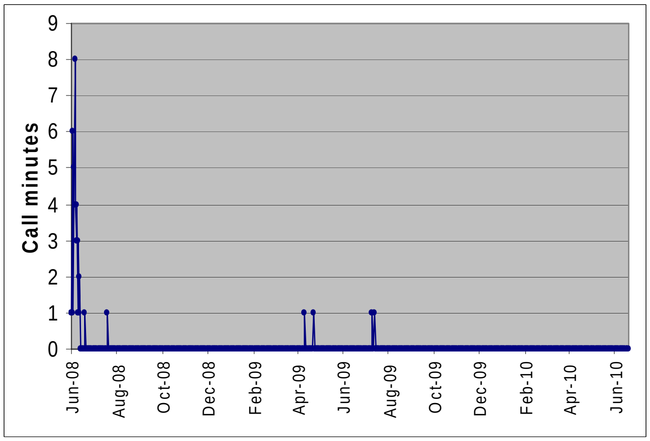
Figure 14. Numbers of call minutes recorded for Townsend's big-eared bats at permanent stations along the Lower Colorado River, 2007-2010.



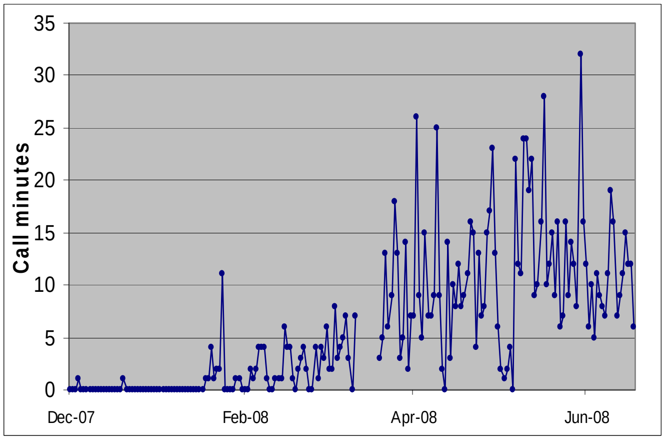
Bill Williams River NWR



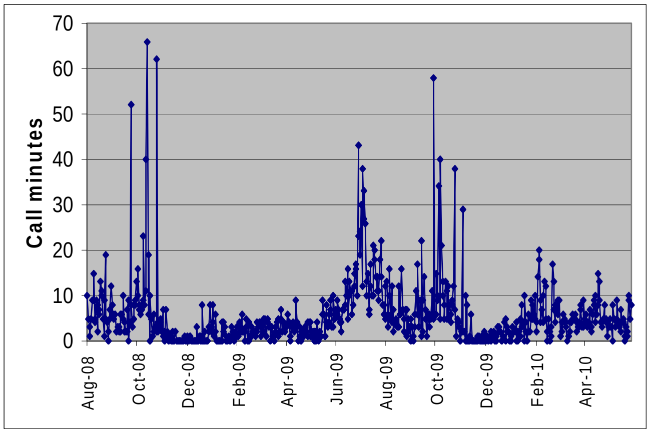
Cibola NWR



Picacho State Recreation Area



Imperial NWR



Mittry Lake Wildlife Area

Figure 15. Numbers of call minutes recorded for California leaf-nosed bats at permanent stations along the Lower Colorado River, 2007-2010.

Overall, total numbers of bat call minutes were generally low during the winter at all stations (Figures 16-20). Activity increased in February and March at most stations and remained high through the summer.

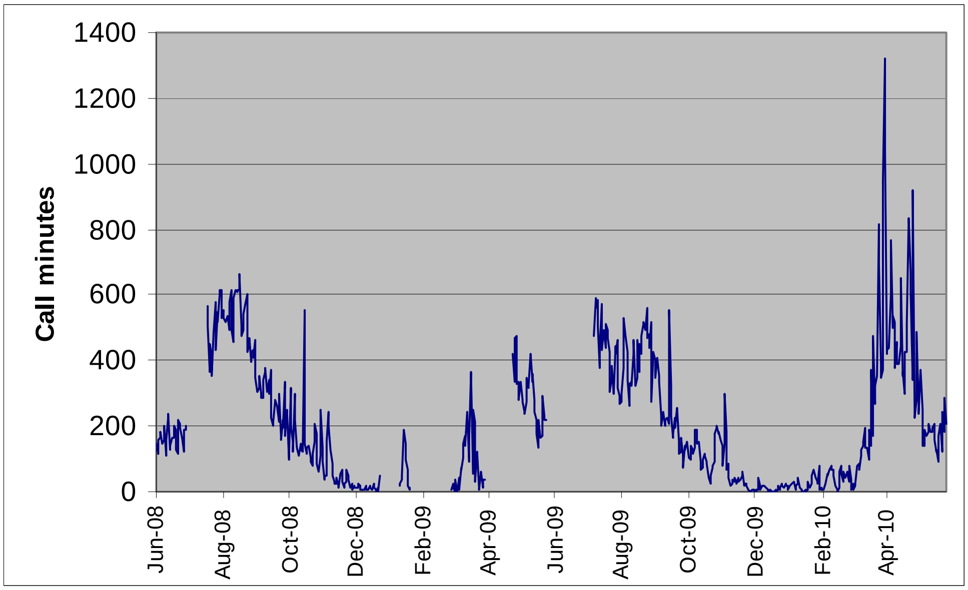


Figure 16. Total bat call minutes at the Bill Williams River NWR permanent station, 2008-2010.

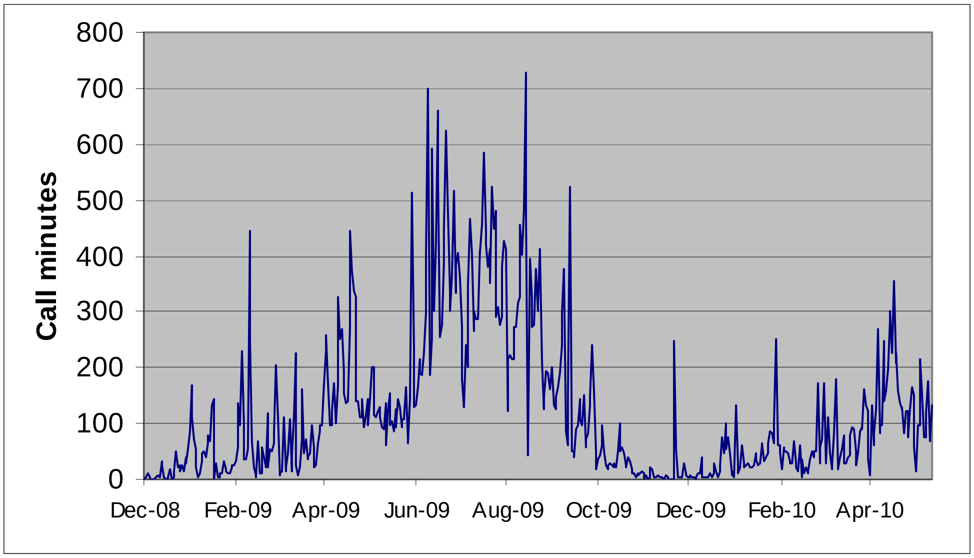


Figure 17. Total bat call minutes at the Cibola NWR permanent station, 2008-2010.

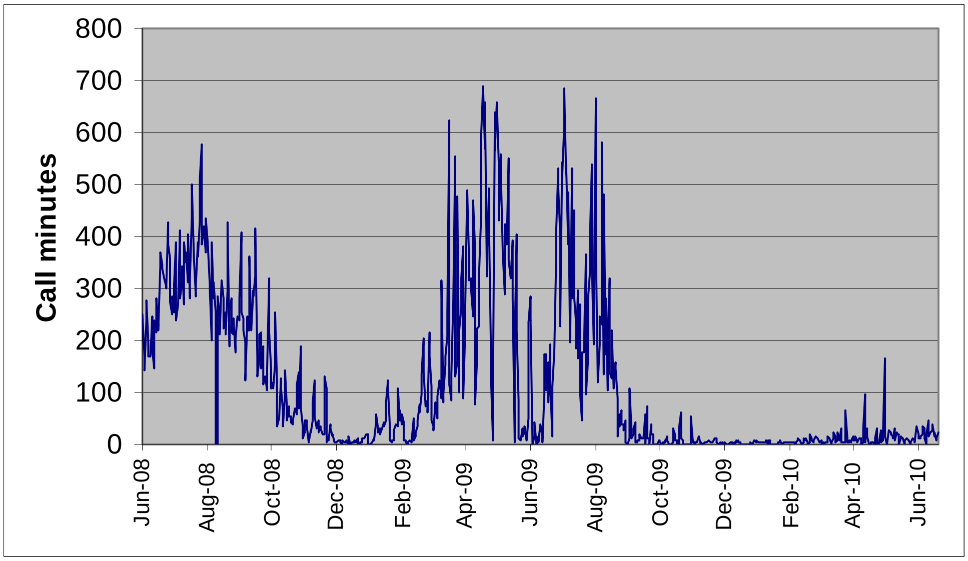


Figure 18. Total bat call minutes at the Picacho permanent station, 2008-2010.

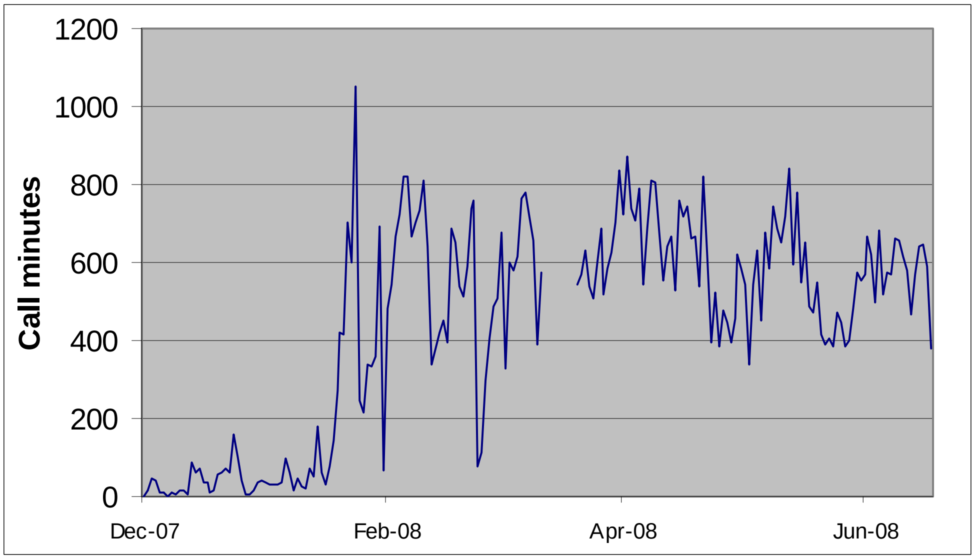


Figure 19. Total bat call minutes at the Imperial NWR permanent station, 2007-2008.

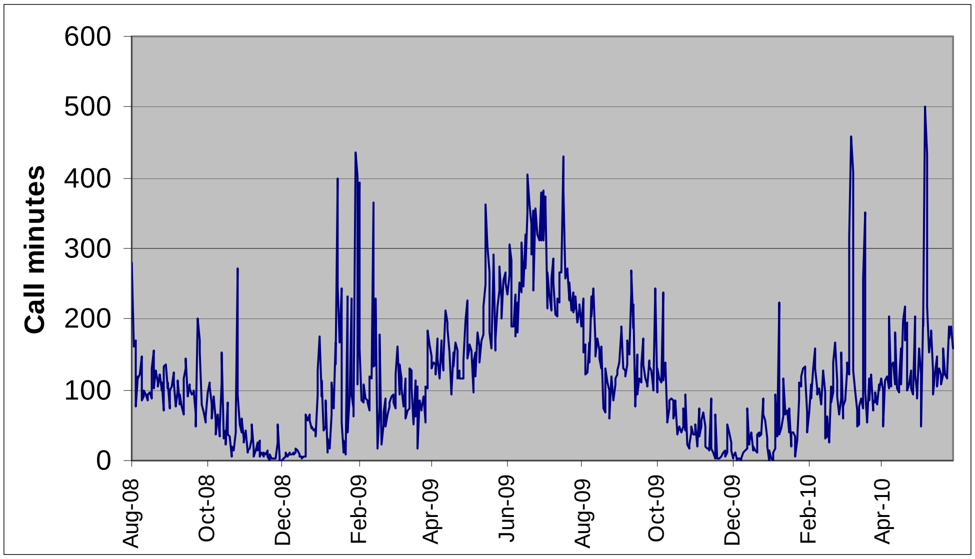


Figure 20. Total bat call minutes at the Mittry Lake permanent station, 2008-2010.

Season accounted for much of the variability in bat minutes for the focal species and for all species combined. Controlling for season allowed us to better isolate the contribution of the environmental variables. Temperature tended to be positively correlated with bat activity, even during the summer (Table 9). Humidity had weak, mixed affects, with positive affects during summer and negative affects during the rest of the year. Wind, particularly prior to midnight, had negative effects, especially on western red bats. We found a positive relationship between bat activity and moonlight for all species combined and each of the focal species, except western yellow bats, during at least some seasons. Variables tended to have greater affect when measured prior to midnight than when measured throughout the night. Despite the statistical significance of these environmental variables, coefficients of correlation were generally very low, due in large part to site variation. An individual analysis by site would be expected to improve the correlation of the remaining variables, as shown for example for the Bill Williams station in Table 10. Standard deviations of call minutes were generally lowest in the summer, indicating lower variability.

Table 9. Multiple linear regression relationships between bat call minutes and environmental variables at the permanent stations, Lower Colorado River, 2007-2010. Site was included in the regression but is not shown here. Figures in bold are statistically significant (P<0.05).

	All night				**Prior to midnight**			
	Temp.	**Humidity**	**Wind**	**Moon**	**Temp.**	**Humidity**	**Wind**	**Moon**
Spring								
LABL[1]	**0.051**	0.001	-0.002	0.002	**0.079**	0.002	-0.005	0.000
LAXA	**-0.009**	-0.004	0.001	-0.000	**-0.013**	**-0.014**	0.000	-0.003
COTO	-0.000	-0.000	0.004	0.000	-0.000	-0.001	0.001	-0.000
MACA	-0.000	-0.002	0.004	0.000	-0.001	-0.003	0.005	-0.000
All spp.	**0.022**	**-0.007**	0.001	0.001	**0.047**	-0.004	0.000	-0.001
Summer								
LABL	0.004	0.002	**-0.013**	0.003	0.002	**0.004**	**-0.006**	0.002
LAXA	**0.026**	0.002	-0.001	-0.000	**0.020**	0.004	-0.001	-0.003
COTO	0.001	-0.001	-0.003	0.000	0.000	-0.000	0.001	0.000
MACA	-0.001	-0.002	-0.004	-0.000	-0.003	-0.000	0.001	**0.006**
All spp.	**0.106**	**0.008**	-0.000	**0.015**	**0.076**	**0.020**	-0.001	**0.005**
Fall								
LABL	0.000	0.000	-0.002	0.004	0.001	-0.000	**-0.006**	0.003
LAXA	0.000	-0.002	0.002	0.003	0.000	-0.002	0.000	0.004
COTO	**0.048**	0.002	**-0.020**	**0.005**	**0.058**	0.001	**-0.015**	**0.005**
MACA	0.004	**-0.007**	-0.001	0.003	0.004	0.003	0.002	0.004
All spp.	**0.299**	0.002	-0.000	**0.022**	**0.329**	0.000	**-0.017**	**0.020**
Winter								
LABL	**0.026**	-0.000	**-0.006**	**0.014**	**0.030**	-0.000	**-0.010**	**0.009**
LAXA	0.005	**-0.005**	-0.001	0.000	0.004	-0.002	-0.001	0.004
COTO	**0.010**	-0.002	0.002	-0.000	**0.015**	-0.000	-0.000	0.004
MACA	**0.056**	-0.000	-0.004	-0.000	**0.070**	-0.000	**-0.012**	0.000
All spp.	**0.088**	**-0.004**	-0.003	-0.001	**0.097**	-0.002	**-0.005**	0.000
Total								
LABL	**0.006**	0.000	**-0.002**	**0.002**	**0.007**	0.001	**-0.003**	**0.001**
LAXA	-0.000	-0.001	0.000	0.000	-0.000	-0.002	0.000	-0.000
COTO	**0.003**	0.000	0.001	0.000	**0.002**	0.000	0.000	0.000
MACA	0.001	-0.000	0.001	0.000	0.000	-0.000	**0.003**	0.000
All spp.	**0.067**	0.001	0.000	**0.011**	**0.064**	**0.001**	-0.000	**0.001**

[1] LABL=western red bat, LAXA=western yellow bat, COTO=Townsend's big-eared bat, MACA=California leaf-nosed bat.

Table 10. Multiple linear regression relationships between bat call minutes and environmental variables at the Bill Williams NWR permanent station, 2008-2010. Figures in bold are statistically significant (P<0.05).

	All night				Prior to midnight			
	Temp.	**Humidity**	**Wind**	**Moon**	**Temp.**	**Humidity**	**Wind**	**Moon**
Spring								
LABL[1]	**0.170**	0.014	-0.000	0.009	**0.184**	0.016	-0.004	-0.001
LAXA	**-0.035**	-0.012	0.001	-0.001	**-0.053**	**-0.065**	-0.008	-0.010
COTO	-0.001	0.005	0.048	0.008	-0.008	0.000	0.016	0.000
MACA	-0.006	-0.001	0.018	0.001	-0.014	-0.000	**0.025**	-0.001
All spp.	0.022	0.008	**0.052**	0.001	0.007	0.000	0.006	-0.002
Summer								
LABL	**0.035**	**0.032**	**-0.072**	0.001	0.014	**0.056**	-0.005	0.028
LAXA	**0.104**	**0.094**	-0.002	-0.001	**0.067**	**0.133**	0.016	-0.007
COTO	0.001	0.004	0.015	0.001	-0.004	0.001	0.006	0.001
MACA	**-0.094**	**-0.075**	-0.007	-0.023	**-0.128**	-0.012	**0.044**	0.014
All spp.	**0.281**	**0.200**	-0.010	**0.022**	**0.215**	**0.234**	-0.008	0.012
Fall								
LABL	-0.003	-0.001	-0.005	0.014	-0.000	-0.007	-0.016	0.007
LAXA	0.002	0.001	**0.050**	-0.002	0.002	0.008	0.000	-0.006
COTO	**0.174**	0.008	-0.005	**0.022**	**0.210**	0.000	**-0.030**	0.017
MACA	**0.068**	**0.040**	0.000	**0.047**	**0.065**	**0.052**	0.002	**0.080**
All spp.	**0.560**	**0.019**	0.006	**0.020**	**0.623**	-0.000	**-0.033**	**0.019**
Winter								
LABL	**0.085**	0.000	-0.004	**0.104**	**0.114**	0.000	**-0.042**	**0.067**
LAXA	0.006	-0.015	0.004	0.001	0.019	-0.018	-0.004	-0.000
COTO	**0.069**	0.001	0.000	0.000	**0.076**	0.003	-0.000	0.000
MACA	**0.082**	0.001	-0.001	-0.008	**0.108**	0.003	**-0.028**	-0.005
All spp.	**0.284**	-0.006	**-0.041**	-0.003	**0.398**	0.000	**-0.157**	-0.005
Total								
LABL	**0.095**	-0.000	**-0.015**	**0.010**	**0.110**	0.002	**-0.020**	**0.008**
LAXA	0.004	0.000	0.003	-0.002	0.002	-0.006	-0.000	**-0.008**
COTO	**0.059**	0.001	**0.012**	0.004	**0.044**	0.000	0.001	0.000
MACA	0.001	**-0.010**	0.001	0.000	-0.000	-0.004	**0.011**	0.000
All spp.	**0.428**	**0.010**	0.003	0.002	**0.398**	**0.006**	0.003	0.000

[1] LABL=western red bat, LAXA=western yellow bat, COTO=Townsend's big-eared bat, MACA=California leaf-nosed bat.

Mist-netting

We mist-netted at 11 locations (Table 11) and captured 12 species, including each of the focal species. We had the most success at the Cliff Pond at Bill Williams NWR, where we captured 10 species. We captured 2 western red bats along the Bill Williams River, 1 at a beaver pond at the bottom end of Planet Ranch and 1 at the confluence of Mineral Wash. We captured single western yellow bats at the Planet Ranch swimming pool, the Cliff Pond, and the Nursery Stand at Imperial NWR. We captured California leaf-nosed bats at 7 locations, but captured Townsend's big-eared bats only at the Cliff Pond.

Table 11. Results of mist-netting along the Lower Colorado River, 2008-2010**.**

Location	**Date**	**Nets, h X l (m)**	**MACA[1]**	**MYYU**	**MYCA**	**MYVE**	**PAHE**	**EPFU**	**ANPA**	**COTO**	**LABL**	**LAXA**	**TABR**	**NYFE**	**TOTAL**
Havasu NWR, Pintail Slough	6/3/10	9 X 18 9 X 6 9 X 12		2	1	1	5	9							18
Planet Ranch swimming pool (PRSP)	7/25/08	6 X 9				1	13								14
PRSP	9/5/08	6 X 9	4			12	20								36
PRSP	11/9/08	6 X 9										1			1
PRSP	12/29/08	6 X 9			1		8								9
PRSP	1/21/09 1/22/09	6 X 9 (2)					9						1		10
PRSP	6/18/09	6 X 9	1			49	13						1		64
PRSP	9/21/09	6 X 9	13	1	3	6	43		1				4		71
PRSP	12/16/09	6 X 9	2		1		11								14
PRSP	2/23/10	6 X 9			1										1
Planet Ranch beaver pond	1/22/09	9 X 18		5			1				1		1		8
Planet Ranch beaver pond	2/11/10	9 X 12		1	3										4
Planet Ranch "End of Road"	1/22/09	9 X 12	1				8								9
Cliff Pond	8/20/08	6 X 12 3 X 6 3 X 12 9 X 12	29	6			12	7	28	3		1		2	88
Cliff Pond	8/11/09	6 X 9 3 X 6 (2) 3 X12(2)	4	4	1	2	54	12	5	1				3	86
Bill Williams River at Mineral Wash	6/2/10	9 X 6 9 X 18 6 X 6	1	2	21	15		3			1				43
Cienega Springs	6/21/08	6 X 9 6 X 6							7						7
CRIT 'Ahakhav	3/05/09 3/06/09	9 X 12 9 X 18 6 X 9	1												1
Imperial NWR Nursery Stand	6/1/10	9 X 9 9 X 12 12 X 18	6	3	1				4			1			15
Mittry Lake	7/31/08	6 X 12 7 X 30 9 X 18													0
Betty's Kitchen	2/26/09	3 X 6 (2) 6 X 18 6 X 12	3												3
Betty's Kitchen	4/16/09 4/17/09	9 X 12 9 X 18 3 X 6 (2) 6 X 9	6	2					3				1		12

Betty's Kitchen	1/15/10	6 X 18 6 X 9 (2) 3 X 6 (2)	2		1										3

[1] MACA=California leaf-nosed bat, MYYU=Yuma myotis, MYCA=California myotis, MYVE=cave myotis, PAHE=canyon bat, EPFU=big brown bat, ANPA=pallid bat, COTO=Townsend's big-eared bat, LABL=western red bat, LAXA=western yellow bat, TABR=Mexican free-tailed bat, NYFE=pocketed free-tailed bat, ,

DISCUSSION

Habitat selection.

Western red bats

According to our analysis, occupancy of western red bats in our study area was almost wholly dependent on the presence of cottonwood-willow. This was reflected in our prediction of a high probability of western red bat use at Bill Williams, Havasu, Imperial and Laguna Division relative to the majority of our study area. Shump and Shump (1982) and Pierson et al. (2004) found that western red bats roosted in foliage of trees and shrubs. Several studies have documented use of deciduous leaf litter for roosting by eastern red bats (*Lasiurus borealis)* (Moormon et al. 1999, Mager and Nelson 2001). Lacking floods or other mechanisms for litter removal, many riparian woodlands along the LCR have thick accumulations of litter which could provide additional roosting opportunities. Cottonwood-willow may harbor high densities of insects (Rosenberg et al. 1991), which may be an additional attractant for western red bats. Interestingly, it appears that even small stands of cottonwood-willow relative to other vegetation types encourage use by western red bats.

Due to the low abundance of existing mature stands of cottonwood-willow, we were unable to make comparisons of western red bat occupancy in mature versus immature stands. However, the use of mature deciduous vegetation by western red bats is well documented. For example, Pierson et al. (2004) found a preference for western red bats to roost in mature cottonwoods and sycamores in the Central Valley of California, roosting in the canopy foliage of the largest trees. We found that western red bats are using all ages of cottonwood-willow habitat, including younger stands associated with LCR MSCP restoration activities. Reclamation has also been finding western red bat use in these new stands (Susan Broderick, Reclamation, personal communication). This bodes well for increased prevalence of the species along the LCR as existing cottonwood-willow stands mature and additional stands are established.

Distance to river was negatively correlated with western red bat occupancy, indicating higher occupancy closer to the river. Western red bats typically feed on moths (Ross 1961), which are not aquatic associates, and so would not be expected to be attracted to aquatic habitats for foraging. However, Pierson et al. (2004) reported western red bats foraging along river edges and sandbars in the Central Valley of California, perhaps indicating they can be more opportunistic than previously thought. They may also be attracted to habitat edges for foraging (Mager and Nelson 2001) or for travel corridors. Other species have also been shown to use habitat edges as corridors (Krusic et al. 1996, Grindal and Brigham 1998).

Western yellow bats
Occupancy of our study area by western yellow bats was strongly associated with the abundance of cottonwood-willow. Additionally, we found them in close proximity to other forms of native vegetation, such as mesquite. The predicted distribution of western yellow bats was higher in the southern part of CRIT, Laguna Division and Bill Williams. This coincides with the abundance of mesquite and cottonwood- willow vegetation types. The dependence of western yellow bats on cottonwood-willow habitat for roosting and foraging has been documented elsewhere (Mumford and Zimmerman 1963, Higginbotham et al. 1999, Williams et al. 2006), and has been documented along the LCR by Brown (2006). Buecher and Sidner (2007) found that western yellow bats were much more likely to use cottonwood-willow habitats than saltcedar along the San Pedro River in Arizona. As noted for western red bats, even small areas of cottonwood-willow relative to other vegetation types resulted in high occupancy. We found a direct negative association between western yellow bats and saltcedar in our study, although the relationship was weak.

Few studies have suggested high use by any bat species of mesquite woodlands. Williams et al. (2006) found an intermediate level of bat activity in mesquite woodlands. He also found that California myotis spent more than 50% of its time in mesquite habitats. O'Farrell (2006a) found lower use of mesquite-saltcedar than a cottonwood-meadow habitat. Cohan et al. (1978) found low insect abundance in pure stands of mesquite but speculated that perhaps when mesquite was mixed with saltcedar it could harbor greater insect abundance.

Due to the lack of reliable information regarding the distribution of nonnative palms along our study area, we were unable to assess the importance of this vegetation type on western yellow bats. Other studies have found high use of palm skirts by roosting western yellow bats (Mumford and Zimmerman 1963, Williams 2001, O'Farrell et al. 2004, Brown 2006). Fan palms are common along the riparian areas of the LCR and are probably important as roost sites for western yellow bats. Brown (2006) suspected that populations of this species have increased with the increase of fan palms.

Townsend's big-eared bats
Our analysis suggested that Townsend's big-eared bats are the most widely distributed focal species throughout the study area. We estimated a high probability of use ($p>0.5$) for most of the portion of the LCR included in our surveys (Figure 11). This estimated widespread distribution can be attributed to the fact that Townsend's big-eared bat occupancy was most strongly correlated with mature saltcedar and mines, both of which occur widely along the LCR. However, the fact that we detected the species at the temporary stations at only 4 general locations throughout our study area (see Appendix E), combined with previous studies suggesting limited distribution of the species in our study area (Brown and Berry 2003), may indicate over-prediction by our model. It is possible that important variables that more strongly dictated Townsend's big-eared bat distribution were unavailable for inclusion in our analysis.

Factors that may have resulted in use of mature saltcedar by Townsend's big-eared bats are unclear. Saltcedar would not seem likely to be attractive as a source of prey. Townsend's big-eared bats are known to be moth specialists (Burford and Lacki 1998), and moths are conspicuously lacking in saltcedar habitats (Anderson et al. 2004). Saltcedar can host an abundance of other insects at times, however, such as leafhoppers (Knutson et al. 2003, Anderson et al. 2004, Wiesenborn 2005), which have been found to be important in the diets of other species of bats (Whitaker 1995, 1996, Sparks and Valdez 2003, O'Farrell et al. 2004). Townsend's big-eared bats may be sufficiently flexible in their diet to take advantage of available prey, and could be foraging on leafhoppers associated with saltcedar. Also, Townsend's big-eared bats could have been attracted to mature saltcedar because of its structural composition. They appear to be somewhat generalist in their foraging preferences (Hinman and Snow 2003), and can perhaps forage in whatever habitat is available near their roost. They may avoid stands of larger cottonwood-willow, preferring shrubbier habitats rather than tall forests (Sherwin et al. 2000).

Previous research indicated that the occurrence of Townsend's big-eared bats is strongly tied to the availability of roosts (Pierson and Rainey 1998). We did not find a direct relationship between the Townsend's big-eared bat and proximity to known roosts for the species. This result was not surprising, as only 3 Townsend big-eared bat roosts are known on the LCR (Brown 1996, Brown and Berry 2003), and we sampled near 2 only. We did find a strong relationship between the species and mines in our study area. This suggests that the Townsend big-eared bat is dependent on mines for roosting habitat. This is logical considering the specificity shown by Townsend's big-eared bats for mine roosts along the LCR (Brown and Berry 2003, 2004, Brown 1996, 2006) and elsewhere (Pierson and Rainey 1998). This result also indicates that at this time knowledge regarding the extent of the use of abandoned mines by the species along the LCR is incomplete.

We found a weak negative relationship between Townsend's big-eared bat occupancy and human population density. Considered with the correlation to mines, these two results would support findings by others that Townsend's big-eared bats are sensitive to human disturbance of their roosts and will move from areas as a result (Cross 1977, Kunz and Martin 1982, Pierson and Rainey 1998, Sherwin et al. 2000). Brown and Berry (2004) suggested that Townsend's big-eared bats are in decline along the LCR because of a combination of their restrictive roost needs and intolerance of roost disturbance. Development in general has been shown to have negative effects on Townsend's big-eared bats (Lacki et al. 1993) as well as other bat species (Kurta and Teramino 1992). Miner and Stokes (2005) noted a variety of negative impacts to bats from urbanization, including recreational activities and predation by cats. Kurta (1992) also suspected there are fewer insects in developed areas.

California leaf-nosed bats

California leaf-nosed bats were most likely to occur in our study area in close proximity to known roosts of this species. This finding was expected considering Brown et al. (1993) found that California leaf-nosed bats foraged within relatively short distances of their roosts, particularly in the winter. Also, considerable effort has been made to locate and monitor roosts of this species along the LCR (Brown 1996, Brown and Berry 2003), so most roosts in our study area were likely considered in our analysis. The lack of a significant relationship between California leaf-nosed bats and any particular vegetation type coincides with previous research that found no difference in use of riparian habitat types by the species (Williams et al. 2006).

We found that California leaf-nosed bats were more likely to occur further from the river in the study area. Though this species is known to use water sources, they are apparently not dependent on them and can derive their water requirements from their prey (Bell et al. 1986, Brown et al. 1993). In addition, the wide availability of water along the LCR would make this relationship difficult to detect. Our findings may reflect the fact that California leaf-nosed bats roosts and foraging habitat are typically in upland desert areas (Brown et al. 1993, Brown and Berry 2003), relatively far from the river. However, we note that this species is commonly captured at restoration sites and other riparian areas (Brown and Berry 2003, Calvert 2010, Piest, unpublished data), most likely when close to roosts. These areas may be particularly valuable during drought conditions when prey availability in desert uplands is low.

Distribution and seasonal activity patterns

We recorded each of the focal species throughout the length of the study area at the temporary stations, at each of the permanent stations, and during all seasons of the year. The Bill Williams permanent station consistently recorded the highest numbers of calls of the focal species and showed the highest occupancy at the temporary stations. Prior to this study, records of western red bats along the LCR were a mist-net capture in the winter from Bill Williams River NWR in 2002, and acoustic records from Havasu, Bill Williams, and Imperial NWRs during 2001-2002 (Brown and Berry 2003). We detected high activity at the Bill Williams and Imperial stations, in agreement with these previous findings. Other previous records of western red bats near the LCR were of 3 females collected in 1902 on Big Sandy Creek, a tributary of the Bill Williams River (Hoffmeister 1986), acoustic and capture records from the Muddy River (Williams 2001) in southern Nevada, and acoustic records from Las Vegas Wash (O'Farrell 2006a, b). Both of these sites are tributaries of the Colorado River in southern Nevada. Numerous captures have since occurred in this study and by Reclamation during monitoring at restoration sites (Calvert 2010, Allen Calvert, Reclamation, personal communication). At our temporary stations, detections of western red bats were lowest in the winter and highest during spring through fall. Higher activity of western red bats during the summer and mist-net captures are evidence of a summer-resident population of this species. No proof of breeding has been documented along the LCR, though Calvert (personal communication) has reported capture of scrotal males in August and September. Activity spikes we observed in the spring and late summer/fall could have resulted from migration movements. Otherwise, there was little evidence for a significant spring or fall migration, though this could have been masked by activity of the resident population. Williams (2001) and O'Farrell (2006a) found western red bats in the spring and summer in southern Nevada. The low number of winter records there would indicate that this population is migratory, and the LCR would be a logical path for this population and others to the north.

Western yellow bats were fairly common summer residents within the study area, as evidenced by high acoustic activity and mist-net captures. Numerous records were also documented prior to our study (Brown 1996, Brown and Berry 2003), and more recently (Calvert 2010, Allen Calvert, personal communication). This species apparently breeds along the LCR. A juvenile male was netted at Planet Ranch in October by Brown (1996), Reclamation biologists and Piest captured a juvenile female near Mittry Lake in July 2007, Piest captured a lactating female in May 2008 at Fortuna Wash within the MSCP Planning Area, about 10 km south of our study area, and Calvert (personal communication) recently captured a lactating female at 'Ahakhav Preserve. Other capture records along the LCR of which we are aware have been of adult males. Some males captured in the summer and fall were in reproductive condition (Calvert, personal communication; Piest, unpublished data). Williams (2001) and O’Farrell et al. (2004) documented a large population in the Moapa Valley, a LCR tributary in southern Nevada, including reproductive females. Also in southern Nevada, O’Farrell et al. (2006b) found western yellow bats throughout the year. Both of these studies found highest activity in the summer and little activity in the winter, agreeing with our results. They hypothesized that this species migrates through the LCR. Extreme peaks of activity in the spring at several of our permanent stations may have been migratory pulses. However, the population of western yellow bats north of the LCR may be too small to detect as they move through the LCR. O’Farrell et al. (2004) believed their records at Moapa in southern Nevada was the northernmost population, and they found few western yellow bats elsewhere during searches of suitable palm habitat in southern Nevada and along the northern extreme of the LCR. We detected the least amount of activity of western yellow bats during the fall, providing little evidence of migration during this period. Our occupancy models for this species included the 2-season variable, confirming different occupancy in spring/summer compared to fall/winter.

Townsend’s big-eared bats have apparently declined along the LCR during the past century, and the only known roosts along the LCR currently are in the Riverside Mountains southwest of Parker (Brown and Berry 2003) and near Planet Ranch on the Bill Williams River (Brown 1996). Recent acoustic detections had also been recorded from the Black Rock Mine north of Imperial NWR (Brown and Berry 2003). Despite our predicted widespread occurrence of this species based on our occupancy models, we detected them at our temporary stations only at Topock Marsh in Havasu NWR, Bill Williams River NWR, Cibola NWR, and near Imperial Dam. This limited occurrence, despite the widespread distribution of mature saltcedar and mines (habitat correlates for Townsend’s big-eared bats), may indicate that few mines along the LCR are actually suitable for this species. This is not surprising considering the specificity that has been documented for Townsend’s big-eared bats, particularly at their maternity and winter roosts (Pierson and Rainey 1998). Human disturbance may also limit the number of suitable sites along the LCR and may have resulted in abandonment of previously-occupied roosts (Brown and Berry 2003). This species may be further limited along the LCR by the loss of preferred foraging habitats and pesticide spraying in agricultural areas (Brown and Berry 2003). High activity of Townsend’s big-eared bats at the Bill Williams permanent station probably resulted from proximity to nearby roosts, documented by Brown (1996). Elsewhere, our acoustic detections did not correlate with known roosts, suggesting our knowledge of roost sites is incomplete. Townsend’s big-eared bats are known to breed within the study area and we detected them most commonly in the spring and summer. As expected for this hibernating species, activity was lower in the fall and winter though we did detect a few calls in winter at most permanent stations. We detected only one call during the winter at the temporary stations. Pate (2006) netted active Townsend’s big-eared bats in November and January at Organ Pipe Cactus National Monument and Hoffmeister (1986) reported that this species can become active on occasions during the winter. Williams (2001) and O’Farrell (2006a) found Townsend’s big-eared bats in the spring and summer at Colorado River tributaries in southern Nevada. Townsend’s big-eared bats shift seasonally between roosts but are apparently not long-distance migrants.

California leaf-nosed bats are year-round residents along the length of the LCR and numerous maternity and winter colonies are known (Brown 2006). Like Townsend's big-eared bats, they move only locally as they shift between seasonal roosts. Higher activity by California leaf-nosed bats in spring and summer than in fall (except at Mittry) and winter at both temporary and permanent stations is likely a result of reduced foraging distance during the winter (Bell et al. 1986, Brown et al. 1993).

Variability of activity of the focal species, and all species combined, was lowest in the summer, perhaps reflecting more stable weather conditions and less influence by migrants. More variable weather conditions in the fall and winter may account for increased variability of bat activity during those seasons. For all species combined, we recorded higher activity during the spring and summer than in the fall and winter. Bat activity was also found to be low during the winter by Brown and Berry (2003) along the LCR, O'Farrell (2006a, b) in southern Nevada, and Koprowski and Buecher (2008) near Tucson. For all species combined, activity was highest at the Imperial station and lowest at Cibola, Picacho, and Mittry.

Influence of weather and moon phase

We recorded much night-to-night variability of bat activity at the permanent stations. We examined data from some of the nights with the most abrupt changes in activity to see if we could identify causes. Some nights with abrupt decreases had unusually high wind readings. At least 1 night had high humidity readings, probably indicating rain. This could at least partially explain the negative relationships we found with humidity and bat activity in some analyses. Most nights with abrupt decreases in activity, however, did not show unusual environmental conditions and the decreases remain a mystery. Similarly, nights with abrupt increases in bat activity did not show unusual weather conditions, nor were they preceded by unfavorable conditions. Hayes (1997), Milne et al. (2005), and Mering and Chambers (2010) also noted extreme variation in their bat acoustic monitoring data.

At the permanent stations, temperature was correlated more frequently with bat activity than any of the other environmental variables. The relationship occurred for each of the focal species at least during some seasons, was almost always positive, and was especially prevalent in the winter. The only negative relationship was for western yellow bats in spring. We also found important positive relationships between temperature and detection rates for each of the focal species at the temporary stations. Wind was also a negative factor in our occupancy models for western yellow bats. Hayes (1997), Meyer et al. (2004), Milne et al. (2005), and Mering and Chambers (2010) also found positive relationships between bat activity and temperature. Rogers et al. (2006) found no correlation in northern Utah. Warmer temperatures are probably accompanied by higher insect activity (Hayes 1997), which would be expected to increase bat activity.

We recorded fewer relationships with humidity, and the relationships were mixed. Negative correlations occurred during fall, winter, and spring, and may have been related to rainfall events, as noted above. The unimportance of precipitation in our occupancy models may have resulted from the relatively small sample size of rain events or to local rainfall variation that caused discrepancies between the weather stations and our sampling sites. Positive relationships with humidity in the summer for western red bats and total bats may have been an autocorrelation with date. Late summer tends to be more humid than earlier and may have coincided with higher bat activity. Mering and Chambers (2010) found a negative relationship between bat activity and precipitation.

At the permanent stations, we found multiple negative correlations between wind, particularly prior to midnight, and bat activity. Correlations with western red bats occurred during all seasons except spring. Mering and Chambers (2010) also found lower activity with wind. Insects in general and flying insects in particular would be expected to be less active in wind and perhaps more difficult to detect and capture.

We found positive relationships between bat activity and moonlight. Hecker and Brigham (1999) reported that during full moons, bats sought out the better-lit forest canopies in British Columbia rather than the darker understories, apparently in response to insect availability. Milne et al. (2005) found reduced activity during the new moon. Mering and Chambers (2010) found a mixed affect, with activity by 35 kHz bats higher with 0-25% (dark) and 70-90% (light) moon phase. Hayes (1997), Karlsson et al (2002), and Rogers et al. (2006) found no correlation between bat activity and moon phase. Other studies have found a negative influence of moonlight on bat activity, but these have been of tropical bat species (Meyer et al. 2004, Milne et al. 2005) and the interpretation was avoidance of a higher predation risk in brighter moonlight. Karlsson et al (2002) hypothesized that bats in the tropics have been subjected to nocturnal predator pressure, whereas bats in temperate regions have not and so have not developed lunarphobia. Brown and Berry (2004) found a negative relationship between California leaf-nosed bats roost exit counts and moonlight. This species is the northernmost member of the tropical family Phyllostomatidae.

Coefficients of correlation for environmental variables were small. This was because variability in bat activity from site to site was high, and coefficients of correlation were therefore high for the site variable. This reduced the amount of correlation that was available for environmental variables. This could be improved using a site-by-site analysis.

MANAGEMENT IMPLICATIONS

We suggest that at present, the distribution of western red bats and western yellow bats are limited within the LCR MSCP project area. The viability of western red bats and western yellow bats along the LCR is dependent on the availability of cottonwood-willow habitat, although western yellow bats will likely benefit from the establishment of native mesquite bosques as well. It is likely, therefore, that further implementation of LCR MSCP conservation measures that address the establishment of cottonwood-willow habitat (e.g. WRBA2 and WYBA3), and to a lesser extent mesquite bosques, will result in a wider occurrence of both western red bats and western yellow bats along the LCR. Our results indicated that even small proportions of cottonwood-willow relative to other vegetation types have a large influence on occupancy for both species. Interestingly, this parallels findings from similar investigations of birds along the LCR (Rosenberg et al. 1991, Van Riper et al. 2008). We conclude that distribution and abundance of western red bats and western yellow bats may be better enhanced through the creation of numerous smaller restorations rather than fewer larger ones. Our study showed that high occupancy can be achieved through conversion of only a small percentage of saltcedar to cottonwood-willow. Our models indicated that western red bat occupancy was very high with as little as 5% coverage of cottonwood-willow within 300 m, or 1.4 ha. For western yellow bats, 10% coverage within 100 m, or 0.3 ha, resulted in a high probability of occupancy.

Our models suggested a correlation between Townsend's big-eared bats and mature saltcedar. However, we acknowledge potential weakness of this model in evaluating Townsend’s big-eared bat habitat use. Regardless of this issue, sufficient amounts of this habitat type are likely to remain without management since saltcedar will undoubtedly continue to dominate along the LCR. We also suggest that studies that document avoidance of saltcedar by other wildlife taxa cannot be automatically conferred to bats. Many of the negative aspects of saltcedar that make it unattractive to birds or other wildlife would not apply to most species of foraging bats. These include the sticky exudate, lack of thermal protection in summer, lack of seeds, and lack of cavity-nesting sites (Cohan et al. 1978, Hunter et al. 1988, Rosenberg et al. 1991). As discussed previously, saltcedar can instead harbor high densities of insects, particularly leafhoppers, which are important in the diets of bats. We suggest that this relationship needs further investigation and a good beginning would be an analysis of guano from mines along the LCR, particularly from Townsend's big-eared bats, to determine whether the species is foraging on saltcedar-dependent invertebrates.

Though not addressed in our study, we acknowledge the probable importance of non-native palm trees as roost sites for western yellow bats. We suggest that existing stands be maintained and that research be conducted to clarify the importance of this habitat component.

Our results and predictive models indicated that roosts are a critical habitat component for both Townsend’s big-eared bats and California leaf-nosed bats. Reclamation should continue to work to identify and protect important roosts for these and other species (e.g., Arizona myotis). All known roosts for any of these species should be prioritized for protective measures such as gating or access closure. Current monitoring of California leaf-nosed bat roosts should be continued to track population trends and to ensure that any problems can be identified and addressed in a timely manner. Our results also indicated that the current knowledge of mines used by Townsend’s big-eared bats is incomplete. Evaluation of mines within the LCR MSCP project area should continue to identify any unknown roosts of this species. Suggested areas are the Senator Mine in California (a historic roost), Imperial Refuge south of the Eureka Mine, and the Buckskin Mountains north of Parker (Patricia Brown, personal communication). We also detected Townsend’s big-eared bats at Havasu NWR, Cibola NWR, and areas around Mittry Lake, where no current roosts are known. If accessible to the public, any significant roosts should be properly gated to prevent entry and disturbance.

We could not explain much of the extreme nightly variation of bat activity that we observed at the permanent stations. Hayes (1997) and Kuenzi and Morrison (2003) discussed the difficulty this presents to monitoring programs for bats. The extreme variation, and the relatively low amount of activity by western red bats and western yellow bats, made it difficult for us to evaluate migratory activity of these species. The variation may also make population trends for any species difficult to identify. These limitations should be considered when designing future monitoring or evaluating existing data.

Correlations that we found between bat activity and environmental variables may have implications for monitoring efforts along the LCR. Our results confirmed expectations that nights with lower temperatures, higher humidity (suggesting precipitation), or higher winds have lower bat activity and so are not optimal times for surveys. Somewhat unexpected was our finding that moonlight apparently has positive effects on bat activity. Investigators have traditionally targeted dark moon phases when using capture methods such as mist-nets and harp traps, the logic being that bats are more capable of seeing and avoiding nets in moonlight. There also is an apparent misperception that there is less bat activity during those times, perhaps based on studies of tropical bats, which have been shown to be lunarphobic (Meyer et al. 2004, Milne et al. 2005). The issue of visual detection still applies, but this can be overcome by placing nets in shadows. The illumination differential between moonlit areas and shadows may make such placement particularly effective, especially when combined with higher bat activity.

Most components of our permanent stations functioned well. Exceptions were problems with the microphone and cable, perhaps as a result of moisture. Another issue was a tendency for the internal clock on the OWL datalogger to wander at 1 station, as much as 90 minutes during 1 5-month period. This would affect the timing of the detector operation as well as result in erroneous time values in the environmental data. The internal clock on our only SD1 detector also tended to wander, about 30 minutes every 6 months. We addressed these issues in our data by creating database routines that progressively corrected the data through time, but this assumed that the error occurred incrementally rather than in only 1 or a few events. Based on these experiences, we suggest that the internal timers on the detectors and the OWL dataloggers be checked and reset at least every 3 months. The OWL and Anabat data should be downloaded at least as often and inspected to ensure the environmental sensors, detector, and microphone are functioning properly.

The volume of call files collected at the permanent stations approached the limit that can reasonably be processed using current versions of Analook software. The high number of files necessitated the use of filters, which itself was a time-consuming process, particularly since the software often had difficulty completing the lengthy processing tasks. These problems would often require us to repeat the process several times. Also, call identification of Anabat files using filters is an inexact process and we acknowledge that many files were likely misidentified. Finally, having to exclude large files probably introduces biases since they are likely correlated with season (e.g., summer insect noise) or species (e.g., some large file sizes resulted from long call files of canyon bats rather than from external noise). More effort to refine filters and quantify error rates could alleviate some of these issues. Because of habitat differences at the various stations, bats seemed to vary their calls among stations. For example, a filter for Myotis species at Bill Williams seemed to perform much better than at Picacho, where many canyon bat call files were selected. Refining filters for each station should improve the accuracy of call analysis.

Consideration should be given to eventually replacing the Anabat units at the permanent stations with those using time expansion technology. The fuller spectrum that is captured for each call (amplitude and harmonics) by these systems enables more reliable call identification and a promising system of automated call analysis is being developed as part of SonoBat software. There are questions involved with this technology as well, however, particularly relating to storage and power requirements. And until tested, there are no guarantees that SonoBat can better handle files with external noise than Anabat, or will be less vulnerable to system errors resulting from the lengthy processing required for our volume of call files. Analysis of data from the Binary Acoustic Technology detector station maintained by Reclamation at the 'Ahakhav Preserve can help determine whether these systems can more effectively accomplish the monitoring objectives of the MSCP.

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APPENDICES

Appendix A. List of the 18 sampling segments along the Lower Colorado River, 2008-2010.

Segment name and code	River mile	Area covered
Reach 3		
Needles (NE)	276-241	Laughlin, Needles, upper Havasu NWR
Havasu (HA)	241-237	Central Havasu NWR
Topock Gorge (TG)	237-221	Lower Havasu NWR including Topock Gorge
Lake Havasu (LH)	221-192	Lake Havasu reservoir
Lower Bill Williams (LB)	--	Lower 5 miles, accessed from Highway 95 and refuge road
Upper Bill Williams (UB)	--	Upper 4 miles, accessed from Mineral Wash and Planet Ranch roads
Reach 4		
Parker Strip (PS)	192-171	Parker Strip and part of ‘Ahakhav Preserve
Parker Valley (PV)	171-121	CRIT and valley north of Blythe to I-10 (only ‘Ahakhav Preserve will be sampled on CRIT)
Cibola Valley (CV)	121-100	Palo Verde Valley and upper Cibola Valley
Upper Cibola (UC)	100-90	Upper portion of Cibola NWR
Lower Cibola (LC)	90-84	Lower portion of Cibola NWR
Upper Imperial (UI)	84-73	Upper river corridor of Imperial NWR
Reach 5		
Picacho (PI)	73-63	Picacho State Rec. Area and central river corridor of Imperial NWR
Lower Imperial (LI)	63-60	Lower river corridor and Red Cloud Mine road area of Imperial NWR
Martinez Lake (ML)	60-52	Imperial NWR farm fields, Martinez Lake, and upper Imperial Res.
Imperial West (IW)	59-46	Ferguson Lake, Senator Wash and NW Laguna Div.
Imperial Dam (ID)	52-46	Lower Imperial Res. and NE Laguna Div.
Lower Laguna (LL)	46-43	Mittry Lake

Appendix B. Procedures for selecting sampling points.

Using ArcView GIS, a 1-km^2 grid was overlaid upon the entire study area, following UTM 1000-m grid lines. We numbered the blocks defined by this grid sequentially from 1 at the northwest corner of the study area to 2880 at the southeast corner. We assigned each of the blocks a random number and these are listed in the file Block numbers.doc. Blocks were chosen for sampling using this procedure:

1. The segment of river to be sampled was determined.
2. We referred to printed maps to determine the sequence of block numbers included in that sampling segment.
3. We selected the block with the lowest random number from within the sequence. A new random sort was done for each sampling session in a segment.
4. If the entire block was determined to be inaccessible based on review of maps and discussion with local biologists, it was discarded and the block with the next lowest random number was chosen. This was repeated as necessary until a block was chosen that was at least partially accessible.
5. Some numbered blocks were completely outside the boundaries of the LCR MSCP boundary as delineated within the 2004 vegetation map and were excluded.

From within the chosen block, a random point was chosen from a grid of 100 points spaced at 100-m intervals. Sampling points within a chosen block were then processed using this procedure:

6. A random number from 1-100 was produced to select a sampling point.
7. The location of the selected point was located on the vegetation map.
8. We determined whether the point was accessible. If not, a new random number was chosen. This was repeated until a point was chosen that was determined to be accessible (could be reached within 20 minutes from a vehicle or boat).
9. The vegetation type at that point was noted.
10. If the selected point was outside the mapped vegetation area, or in a non-riparian habitat (agriculture, creosote, open water, unclassified desert), a new random number was chosen.

Sampling within each river segment was stratified to target 4 vegetation types: saltcedar, mesquite, cottonwood/willow, and marsh. Stratification was done using these procedures:

11. If a sampling point for a vegetation type had already been chosen, random numbers were chosen until a point was selected from within a vegetation type that had not been chosen.
12. If the block did not contain desired vegetation type (or was inaccessible), a new random block was chosen and step 11 was repeated.
13. This was repeated until there was a sampling point in each of the 4 target vegetation.
14. In case the selected block was found to be inaccessible during the field visit, alternative point for each vegetation type was selected.
15. If the selected point was found to be inaccessible during the field visit, the detector could be placed at a nearby location in an area of similar habitat.

Appendix B (cont.). Procedures for selecting sampling points.

Small patches sometimes did not include a possible sampling point (i.e., there were no 100-m UTM grid intersections within the patch). In these cases, a sampling point was chosen from within the center of the patch.

Appendix C. Expert panel questionnaire; participants were Bill Burger, Lin Piest, Tim Snow (Arizona Game and Fish Department), Carol Chambers (Northern Arizona University), Sybill Amellon (U.S. Forest Service), Allen Calvert (Reclamation), Jason Corbett (Bat Conservation International), and Pat Brown (Brown-Berry Biological Consultanting).

1. How much do you know about each species? Please rate 0 to 3; 0 = no knowledge, 1= some, 2 = extensive, and 3 = expert.

	Western yellow	Western red	Hoary	California leaf-nosed	Townsends big-eared	Cave myotis	Little brown	Pocketed free-tailed	Big free-tailed	Western bonneted
RATE										

2. Assuming that a species is present in the general area during a survey, what do you think affects the probability that it will be detected by an Anabat detector? Please rank 0 to 3; 0 = no affect, 1 = could affect, 2 = likely affect, 3 = will affect, and indicate “+” for positive affect and “–“ for negative affect.

	Western yellow	Western red	Hoary	California leaf-nosed	Townsends big-eared	Cave myotis	Little brown	Pocketed free-tailed	Big free-tailed	Western bonneted
Artificial light										
Moon light										
Precipitation										
Temperature										
Wind										
Other										

3. What do you think affects bat presence or habitat selection (for foraging, roosting, and migration) in an area? Please rank 0 to 3; 0 = no affect, 1 = could affect, 2 = likely affect, 3 = will affect, and indicate “+” for positive affect and “–“ for negative affect.

Appendix C (cont.). Expert panel questionnaire.

	Western yellow	Western red	Hoary	California leaf-nosed	Townsends big-eared	Cave myotis	Little brown	Pocketed free-tailed	Big free-tailed	Western bonneted
Vegetation maturity										
Native vegetation										
Non-native vegetation										
Canopy cover										
Canopy height										
Percent ground cover										
Open water										
Proximity to the river										
Rural/agriculture development										
Urban development										
Highways										
Back roads										
Roost availability										
Palm groves										
Predation										
Site fidelity										
Day[1]										
Week[1]										

Appendix C (cont.). Expert panel questionnaire

Month[1]										
Season[1]										
Other										

[1] This refers to how bat presence may be affected by temporal variation or timing of breeding chronology.

4. To your knowledge, do any of the species migrate through the Lower Colorado River? Please answer “Yes” or “No”.

	Western yellow	Western red	Hoary	California leaf-nosed	Townsends big-eared	Cave myotis	Little brown	Pocketed free-tailed	Big free-tailed	Western bonneted
Y/ N										

5. If yes, when does the species migrate? Mark “X”.

	Western yellow	Western red	Hoary	California leaf-nosed	Townsends big-eared	Cave myotis	Little brown	Pocketed free-tailed	Big free-tailed	Western bonneted
January										
February										
March										
April										
May										
June										
July										
August										
September										
October										
November										
December										

Appendix D. Descriptions and summary statistics for detection and habitat covariates (n=1,128 nights).

Covariate	**Description**	**AVG**	**STDEV**	**Range**	**Source**
AvgTemp	Average Temperature	72.32	19.00	28-101	NCDC-NOAA
MinTemp	Minimum Tempeature	60.10	3.00	35-90	NCDC-NOAA
MaxTemp	Maximum Temperature	91.26	3.30	40-117	NCDC-NOAA
PPT	Daily Precipitation	0.00	0.03	0-0.22	NCDC-NOAA
DistMine	distance (m) to mines; from GIS	7926.02	4212.88	1240-20585	USGS
DistMACARoost	Distance (m) to California leaf-nosed bats roosts; from GIS	9058.42	5462.67	1173-25808	Points provided by USBR-MSCP
DistCOTORoost	Distance (m) to Townsend’s big-eared bats roosts; from GIS	84662.93	40369.00	2975-135434	Points provided by USBR-MSCP
DistDam	Distance from Davis, Parker, and Imperial dams; from GIS	21670.33	16905.78	120-50827	National Inventory of Dams
DistRiv	Distance to river corridor; from GIS	1402.62	1904.96	10-7724	BiO-West (2006)
Pop_1000m	Number of people (Cell value 100m X 100m) within a 1000m radius	6.93	58.47	0-644	BiO-West (2006)
BW 100M	% area of Back water within 100m radius	2.13	6.16	0-37	BiO-West (2006)
OSOW 100M	% area of structured open water and open water within 100m radius	5.13	11.14	0-57	BiO-West (2006)
Water 100M	% area of All water sources within 100m radius	7.26	12.53	0-57	BiO-West (2006)

Appendix D (cont.). Descriptions and summary statistics for detection and habitat covariates (n=1,128 nights).

Covariate	**Description**	**AVG**	**STDEV**	**Range**	**Source**
AG 100M	% area of agricultural land within 100m radius	3.81	16.18	0-100	BiO-West (2006)
AAC 100M	% area of atriplex, arrowweed, creosote within 100m radius	3.91	12.76	0-78	BiO-West (2006)
SM-SH 100M	% area of salt cedar/honey msquite, and salt cedar/screwbean mesquite within 100m radius	12.37	25.19	0-92	BiO-West (2006)
CW_100M	% area of Cottonwood/willow within 100m radius	6.89	18.46	0-100	BiO-West (2006)
NAT 100M	% area of Native plants within 100m radius	19.31	28.60	0-100	BiO-West (2006)
MA_100M	% area of Marsh within 100m radius	13.50	22.31	0-96	BiO-West (2006)
SC_100M	% area of Salt-Cedar within 100m radius	35.42	32.46	0-100	BiO-West (2006)
(m)HM 100M	% area of Class I, II, III (mature) Honey mesquite within 100m radius	0.87	9.14	0-100	BiO-West (2006)
(m)SH-SM 100M	% area of Class I, II, III (mature) salt cedar/honey msquite, and salt cedar/screwbean mesquite within 100m radius	7.11	18.28	0-90	BiO-West (2006)
(m)CW 100M	% area of Class I, II, III (mature) Cottonwood/willow within 100m radius	0.52	3.70	0-73	BiO-West (2006)
(m) NAT100M	% area of Class I, II, III (mature) Native plants within 100m radius	8.50	20.26	0-100	BiO-West (2006)
(m)MA_100M	% area of Class I, II, III (mature) Marsh within 100m radius	6.41	15.38	0-72	BiO-West (2006)

Appendix D (cont.). Descriptions and summary statistics for detection and habitat covariates (n=1,128 nights).

Covariate	Description	AVG	STDEV	Range	Source
(m)SC_100M	% area of Class I, II, III (mature) Salt-Cedar within 100m radius	27.74	29.79	0-100	BiO-West (2006)
(i)HM_100M	% area of Class IV, V, VI (immature) Honey mesquite within 100m radius	0.00	0.00	0-0	BiO-West (2006)
(i)SM-SH 100M	% area of Class IV, V, VI (immature) salt cedar/honey msquite, and salt cedar/screwbean mesquite within 100m radius	4.52	16.08	0-87	BiO-West (2006)
(i)CW_100M	% area of Class IV, V, VI (immature) Cottonwood/willow within 100m radius	5.55	16.13	0-100	BiO-West (2006)
(i)MA_100M	% area of Class IV, V, VI (immature) Marsh within 100m radius	4.93	15.04	0-94	BiO-West (2006)
(i)SC_100M	% area of Class IV, V, VI (immature) Salt-Cedar within 100m radius	4.14	13.39	0-100	BiO-West (2006)
BW 300M	% area of Back water within 300m radius	2.41	5.08	0-24	BiO-West (2006)
OSOW 300M	% area of structured open water and open water within 300m radius	5.13	12.54	0-46	BiO-West (2006)
Water 300M	% area of All water sources within 300m radius	7.26	12.81	0-47	BiO-West (2006)
AG 300M	% area of agricultural land within 300m radius	3.81	18.15	0-96	BiO-West (2006)
AAC 300M	% area of atriplex, arrowweed, creosote within 300m radius	3.91	7.16	0-38	BiO-West (2006)
UD 300M	% area of undeveloped bare land within 300m radius	11.26	19.35	0-69	BiO-West (2006)

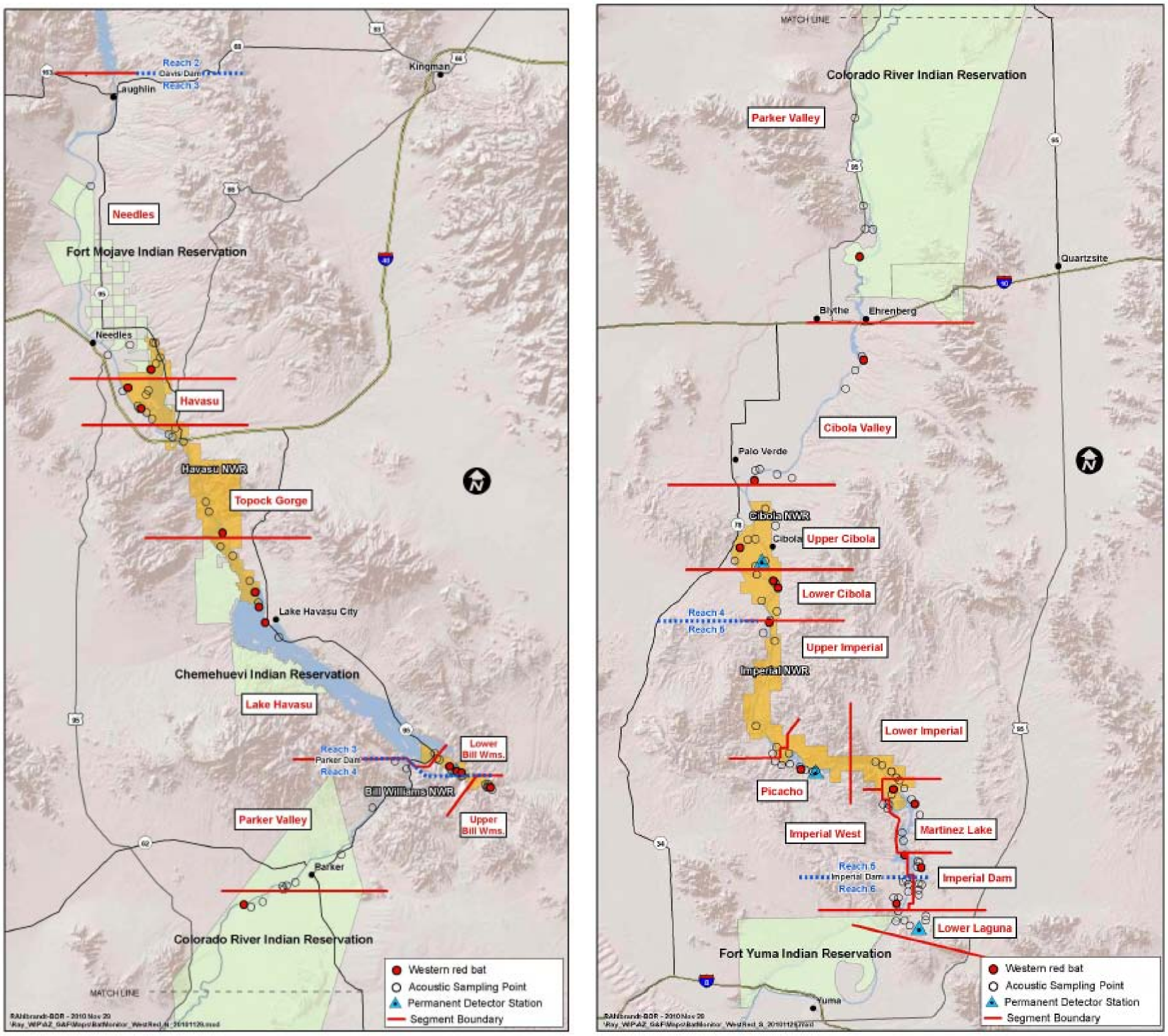
Appendix D (cont.). Descriptions and summary statistics for detection and habitat covariates (n=1,128 nights).

Covariate	**Description**	**AVG**	**STDEV**	**Range**	**Source**
HM_300M	% area of Honey mesquite within 300m radius	0.04	1.25	0-10	BiO-West (2006)
SM-SH 300M	% area of salt cedar/honey msquite, and salt cedar/screwbean mesquite within 300m radius	12.37	15.01	0-63	BiO-West (2006)
CW_300M	% area of Cottonwood/willow within 300m radius	6.89	11.27	0-88	BiO-West (2006)
NAT_300M	% area of Native plants within 300m radius	19.31	17.35	0-88	BiO-West (2006)
MA_300M	% area of Marsh within 300m radius	13.50	15.83	0-85	BiO-West (2006)
SC 300M	% area of Salt-Cedar within 300m radius	35.42	25.23	0-98	BiO-West (2006)
(m)SM-SH 300M	% area of Class I, II, III (mature) salt cedar/honey msquite, and salt cedar/screwbean mesquite within 300m radius	7.11	13.34	0-63	BiO-West (2006)
(m)CW 300M	% area of Class I, II, III (mature) Cottonwood/willow within 300m radius	0.52	4.02	0-43	BiO-West (2006)
(m)NAT300M	% area of Class I, II, III (mature) Native plants within 300m radius	8.50	13.51	0-63	BiO-West (2006)
(m)MA_300M	% area of Class I, II, III (mature) Marsh within 300m radius	6.41	11.75	0-68	BiO-West (2006)
(m)SC 300M	% area of Class I, II, III (mature) Salt-Cedar within 300m radius	27.74	23.44	0-98	BiO-West (2006)
(i)SM-SH 300M	% area of Class IV, V, VI (immature) salt cedar/honey msquite, and salt cedar/screwbean mesquite within 300m radius	2.05	7.24	0-58	BiO-West (2006)

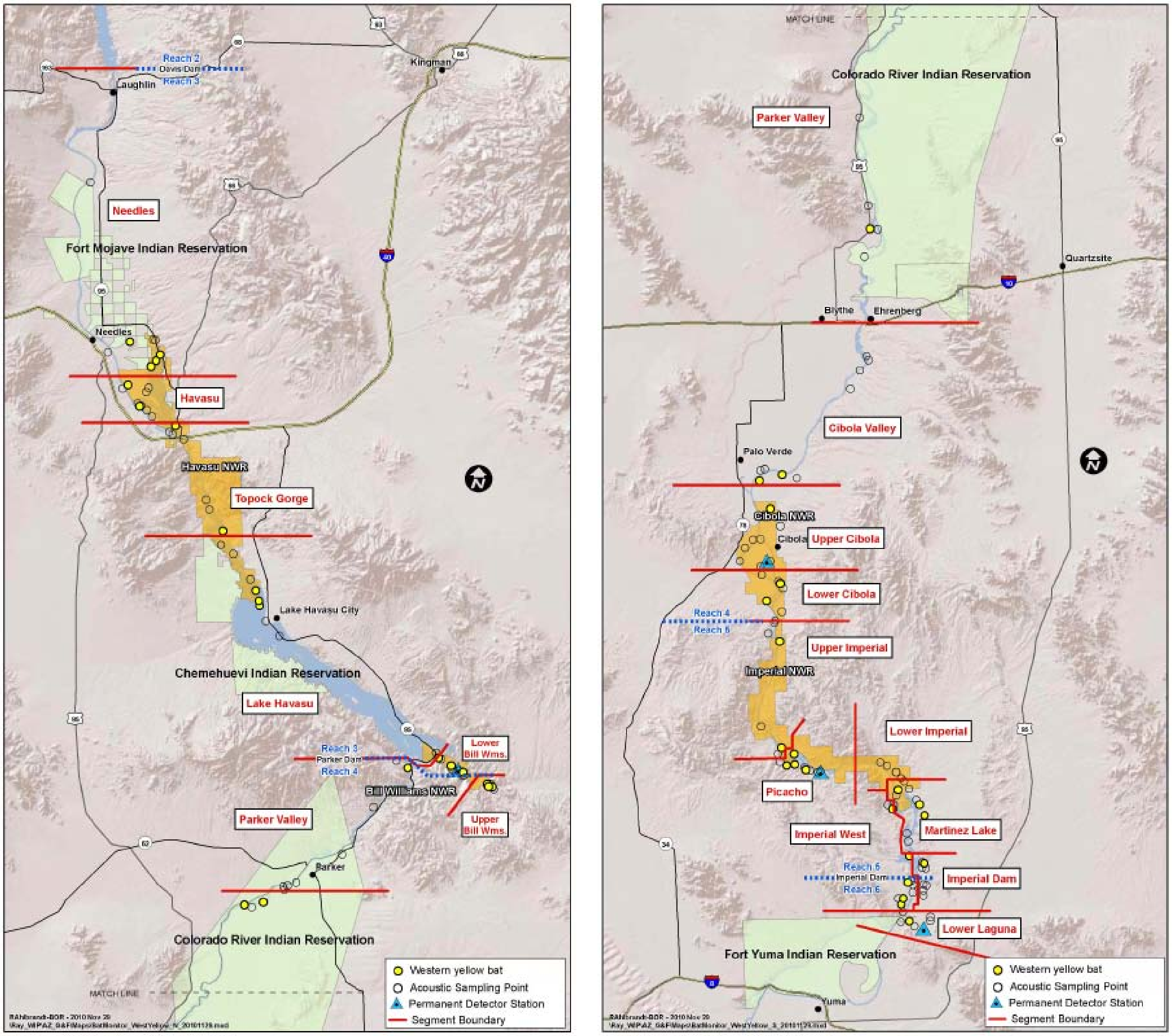
Appendix D (cont.). Descriptions and summary statistics for detection and habitat covariates (n=1,128 nights).

Covariate	**Description**	**AVG**	**STDEV**	**Range**	**Source**
(i)CW_300M	% area of Class IV, V, VI (immature) Cottonwood/willow within 300m radius	3.47	10.72	0-88	BiO-West (2006)
(i)MA_300M	% area of Class IV, V, VI (immature) Marsh within 300m radius	3.37	9.71	0-74	BiO-West (2006)
(i)SC_300M	% area of Class IV, V, VI (immature) Salt-Cedar within 300m radius	5.82	10.36	0-65	BiO-West (2006)

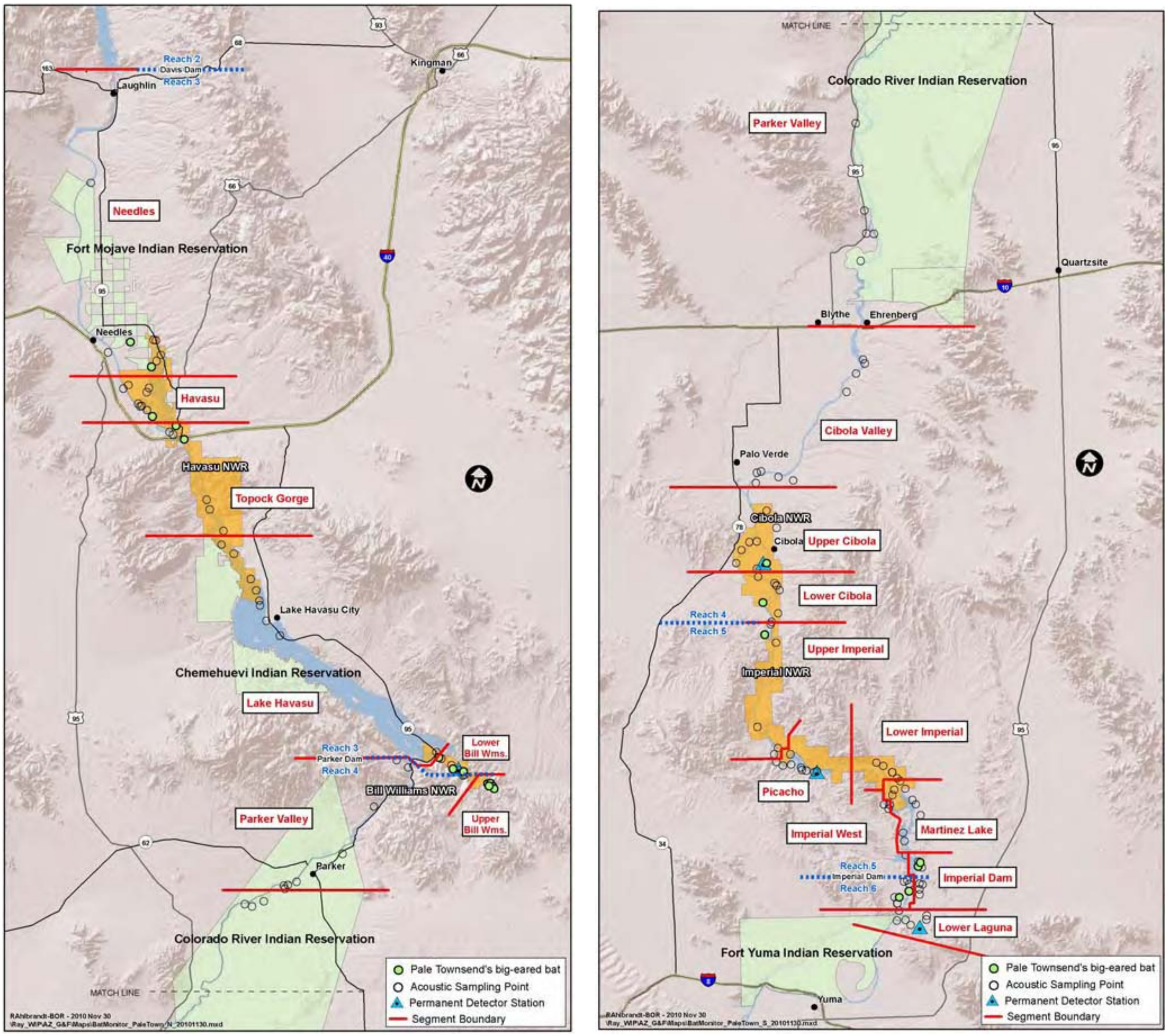
Appendix E. Locations of detections of the 4 focal species at the temporary stations; western red bats.



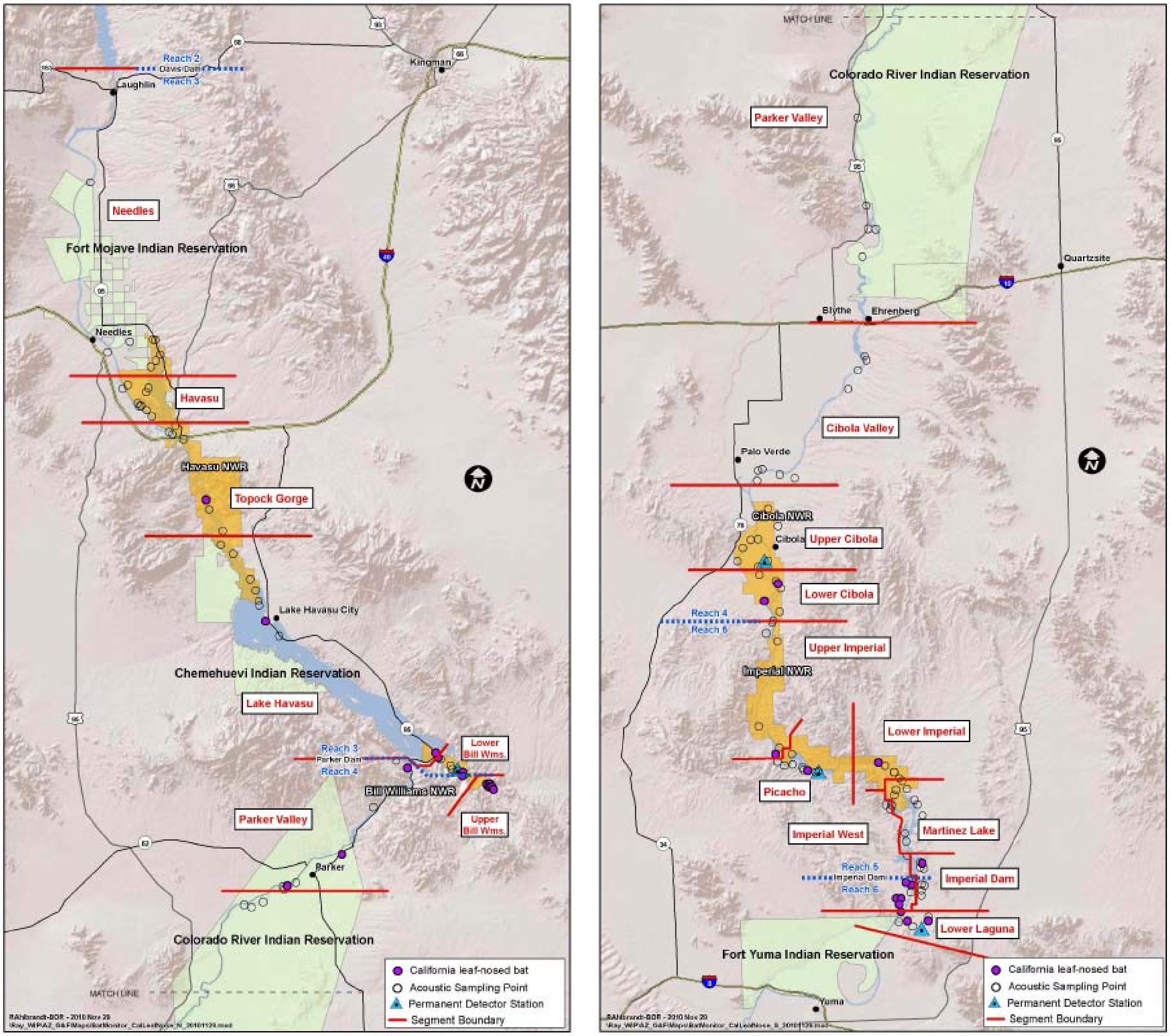
Appendix E (cont.). Locations of detections of the 4 focal species at the temporary stations; western yellow bats.



Appendix E (cont.). Locations of detections of the 4 focal species at the temporary stations; Townsend's big-eared bats.



Appendix E (cont.). Locations of detections of the 4 focal species at the temporary stations; California leaf-nosed bats.



Appendix F *A priori* models of detection probability for 4 focal species. Models included different forms of variation detection probability, while keeping occupancy constant ψ(.). All models were ranked against a null model, with the model with the lowest AICc value considered the “best” model of each species detection probability.

Western red bat	**AICc**	**ΔAICc**	**Model Weight**	**No. Of Parameters**
ψ(.),*p*(4Seasons+MinTemp)	362.71	0.00		4
ψ(.),*p*(4Seasons+MaxTemp)	364.29	1.58	0.31	4
ψ(.),*p*(4Seasons+WindSpeed)	381.46	18.75	0.00	4
ψ(.),*p*(4Seasons+PPT)	385.36	22.65	0.00	4
ψ(.),*p*(4Seasons+MoonPhase)	387.28	24.57	0.00	4
ψ(.),*p*(4Seasons)	387.99	25.28	0.00	3
ψ(.),*p*(2Seasons)	392.42	29.71	0.00	3
ψ(.),*p*(Year)	406.76	44.05	0.00	3
Null	410.54	47.83	0.00	2
Western yellow bat				
ψ(.),*p*(2Seasons+MinTemp)	509.19	0.00	0.66	4
ψ(.),*p*(2Seasons+MinTemp+WindSpeed)	510.56	1.37	0.33	5
ψ(.),*p*(2Seasons+MaxTemp)	517.05	7.86	0.01	4
ψ(.),*p*(2Seasons+MoonPhase)	537.85	28.66	0.00	4
ψ(.),*p*(2Seasons)	540.17	30.98	0.00	3
ψ(.),*p*(2Seasons+PPT)	540.48	31.29	0.00	4
ψ(.),*p*(4Seasons+MoonPhase)	545.86	36.67	0.00	4
ψ(.),*p*(4Seasons)	548.02	38.83	0.00	3
Null	551.64	42.45	0.00	2
ψ(.),*p*(Year)	553.45	44.26	0.00	3

Appendix F (cont.). *A priori* models of detection probability for 4 focal species.

Townsend's big-eared bat	**AIC_C**	**ΔAIC_C**	**Model Weight**	**No. Of Parameters**
ψ(.),p(2Seasons-a+MinTemp)	311.08	0.00	0.98	4
ψ(.),p(2Seasons-a+WindSpeed)	321.03	9.95	0.01	4
ψ(.),p(2Seasons-a)	321.52	10.44	0.01	3
ψ(.),p(Year+2Seasons-a+PPT)	322.29	11.21	0.00	5
ψ(.),p(Year+2Seasons-a)	322.39	11.31	0.00	4
ψ(.),p(Year+4Seasons)	322.97	11.89	0.00	4
ψ(.),p(PPT+2Seasons)	325.98	14.90	0.00	4
ψ(.),p(Year+2Seasons)	326.85	15.77	0.00	4
Null	337.93	26.85	0.00	2
ψ(.),p(Year)	338.73	27.65	0.00	3
California leaf-nosed bat				
ψ(.),p(4Seasons+AvgTemp)	387.12	0.00	0.27	4
ψ(.),p(4Seasons+MaxTemp)	387.43	0.31	0.23	4
ψ(.),p(4Seasons+WindSpeed+AvgTemp)	388.07	0.95	0.17	5
ψ(.),p(4Seasons+WindSpeed+MaxTemp)	388.33	1.21	0.15	5
ψ(.),p(4Seasons+MinTemp)	388.59	1.47	0.13	4
ψ(.),p(2Seasons+WindSpeed+AvgTemp)	390.16	3.04	0.06	5
ψ(.),p(4Seasons+MoonPhase)	395.69	8.57	0.00	4
ψ(.),p(4Seasons)	398.61	11.49	0.00	3
ψ(.),p(4Seasons+Year+PPT)	399.33	12.21	0.00	5
ψ(.),p(4Seasons+Year)	399.72	12.60	0.00	4
ψ(.),p(2Seasons+Year)	399.94	12.82	0.00	4
Null	415.16	28.04	0.00	2

Appendix G. *A priori* models of occupancy for 4 focal species. Models were ranked against a null model, with the model with the lowest AICc value considered the “best” model. Models within 4 AICc values the best models were considered to be competing, and model-averaged parameter estimates were used to estimate the distribution of each focal species along the LCR. Models included the most parsimonious form of variation in detection probability.

Western red bat[a]	**AICc**	**ΔAICc**	**Model Weight**	**No. Of Parameters**
ψ(CW300m),*p*(MinTemp+4Seasons)	323.25	0.00	0.70	5
ψ(CW300mDistRiv),*p*(MinTemp+4Seasons)	324.91	1.66	0.30	6
ψ(NAT300m+mNAT300m),*p*(MinTemp+4Seasons)	354.30	31.05	0.00	6
ψ(NAT300m+SC300m),*p*(MinTemp+4Seasons)	356.54	33.29	0.00	6
ψ(NAT300m+Water300m),*p*(MinTemp+4Seasons)	358.21	34.96	0.00	6
ψ(NAT300m+DistRiv+SC300m),*p*(MinTemp+4Seasons)	358.41	35.16	0.00	7
ψ(NAT300m+DistRiv+NearDam),p(MinTemp+4Seasons)	359.66	36.41	0.00	7
ψ(.),p(MinTemp+4Seasons)	362.71	39.46	0.00	4
ψ(MA300m+SC300m),*p*(MinTemp+4Seasons)	363.85	40.60	0.00	6
ψ(Pop1000m+SC300m),*p*(MinTemp+4Seasons)	365.74	42.49	0.00	6
ψ(SC300m+mNAT300m),*p*(MinTemp+4Seasons)	365.99	42.74	0.00	6
ψ(ACC300m+DistRiv),*p*(MinTemp+4Seasons)	366.29	43.04	0.00	6
ψ(Water300m+DistRiv),*p*(MinTemp+4Seasons)	366.46	43.21	0.00	6
ψ(SC300m+DistRiv),*p*(MinTemp+4Seasons)	366.48	43.23	0.00	6
Null	410.54	87.29	0.00	2
Western yellow bat				
ψ(CW100m+NAT100m),*p*(MinTemp+Seasons)	467.68	0.00	0.67	6
ψ(CW100m+SC100m),*p*(MinTemp+Seasons)	469.56	1.88	0.26	6
ψ(CW100m+DistRiv+Pop1000m),p(MinTemp+Seasons)	472.49	4.81	0.06	7
ψ(NAT100m+DistRiv+Pop1000m),*p*(MinTemp+Seasons)	480.76	13.08	0.00	7
ψ(NAT100m+MA100m),*p*(MinTemp+Seasons)	482.31	14.63	0.00	6
ψ(NAT100m+SC100m),*p*(MinTemp+Seasons)	483.30	15.62	0.00	6
ψ(DistRiv+NAT100m),*p*(MinTemp+Seasons)	483.89	16.21	0.00	6
ψ(SC100m),*p*(MinTemp+Seasons)	508.10	40.42	0.00	5
ψ(DistRiv+SC100m),*p*(MinTemp+Seasons)	508.53	40.85	0.00	6
ψ(mNAT100m),*p*(MinTemp+Seasons)	508.71	41.03	0.00	5
ψ(.),*p*(MinTemp+Seasons)	509.19	41.51	0.00	4
ψ(Water+AG100m),*p*(MinTemp+Seasons)	510.51	42.83	0.00	6
ψ(mCW100m+DistRiv+Pop1000m),*p*(MinTemp+Season)	511.51	43.83	0.00	7
ψ(Water100m+AAC100m),*p*(MinTemp+Seasons)	512.97	45.29	0.00	6
ψ(Water100m+DistRiv+Pop1000m),*p*(MinTemp+Season)	514.48	46.80	0.00	7
Null	551.64	83.96	0.00	2

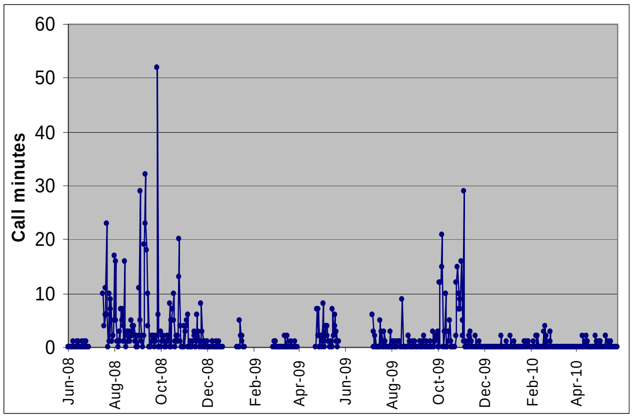
Appendix G (cont.). *A priori* models of occupancy for 4 focal species.

Townsend's big-eared bat	**AIC$_c$**	**ΔAIC$_c$**	**Model Weight**	**No. Of Parameters**
ψ(mSC100m+DistMine),*p*(MinTemp+2Seasons-a)-	303.38	0.00	0.57	6
ψ(Pop1000m+mSC100m),*p*(MinTemp+2Seasons-a)	305.74	2.36	0.17	6
ψ(Nat100m+SC100m),*p*(MinTemp+2Seasons-a)	308.30	4.92	0.05	6
ψ(mCW100m+DistMine),*p*(MinTemp+2Seasons-a)	308.35	4.97	0.05	6
ψ(MA100m+DistRiv,*p*(MinTemp+2Seasons-a)	308.83	5.45	0.04	6
ψ(DistCOTORoost+DistRiv),*p*(MinTemp+2Seasons-a)	308.89	5.51	0.04	6
ψ(NAT100m+DistMine),*p*(MinTemp+2Seasons-a)	309.76	6.38	0.02	6
ψ(CW100m+DistMine),*p*(MinTemp+2Seasons-a)	309.94	6.56	0.02	6
ψ(Pop1000m+AAC100m+DistMine),*p*(MinTemp+2Seasons-a)	310.34	6.96	0.02	7
ψ(.),*p*(MinTemp+2Seasons-a)	311.08	7.70	0.01	4
ψ(Pop1000m+AG100m+Water100m),*p*(MinTemp+2Seasons-a)	312.85	9.47	0.01	7
ψ(MA100m+NAT100m),*p*(MinTemp+2Seasons-a)	312.98	9.60	0.00	6
ψ(MA100m+Water100m),*p*(MinTemp+2Seasons-a)	313.35	9.97	0.00	6
ψ(CW100m+DistBridge+Pop1000m),*p*(MinTemp+2Seasons-a)	313.98	10.60	0.00	7
ψ(BW100m+AG100m)*p*(MinTemp+2Seasons-a)	314.08	10.70	0.00	6
Null	337.93	34.55	0.00	2
California leaf-nosed bat				
ψ(DistRiv+DistMACARoost),*p*(MinTemp+4Seasons)	355.68	0.00	0.88	6
ψ(SC100m+DistMACARoost),*p*(MinTemp+4Seasons)	361.05	5.37	0.06	5
ψ(MA100m+DistMACARoost),*p*(MinTemp+4Seasons)	362.77	7.09	0.03	6
ψ(MA100m+DistMACARoost+SC100m),*p*(MinTemp+4Seasons)	363.44	7.76	0.02	7
ψ(DistDam+DistMACARoost),*p*(MinTemp+4Seasons)	366.18	10.50	0.00	5
ψ(Water100m+DistMACARoost),*p*(MinTemp+4Seasons)	367.09	11.41	0.00	5
ψ(mNAT100m+DistMACARoost),*p*(MinTemp+4Seasons)	367.66	11.98	0.00	5
ψ(CW100m+DistMACARoost),*p*(MinTemp+4Seasons)	367.73	12.05	0.00	5
ψ(SC100m+NAT100m),*p*(MinTemp+4Seasons)	388.41	32.73	0.00	6
ψ(AG100m+Pop1000m),*p*(MinTemp+4Seasons)	396.84	41.16	0.00	5
ψ(DistRiv+MA100m),*p*(MinTemp+4Seasons)	402.48	46.80	0.00	5
ψ(DistRiv+SC100m),*p*(MinTemp+4Seasons)	404.92	49.24	0.00	5
ψ(SC100m+Water100m),*p*(MinTemp+4Seasons)	407.01	51.33	0.00	5
ψ(DistRiv+AAC100m),*p*(MinTemp+4Seasons)	407.58	51.90	0.00	5
Null	415.16	59.48	0.00	2

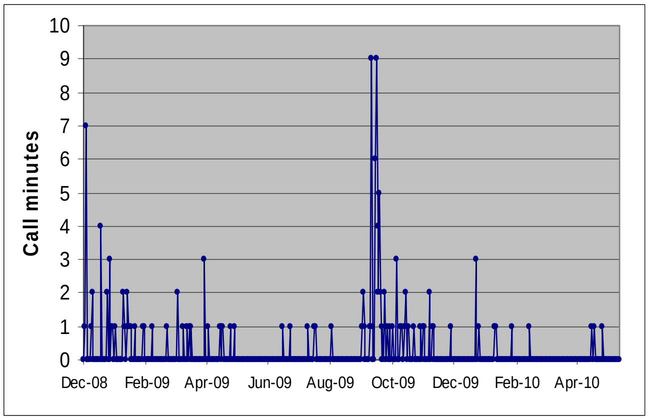
[a] Although we expected a 100-m buffer to be more biologically meaningful in dictating occupancy of focal species, models that included vegetation measurements using this buffer failed to converge properly for western red bats, and thus we measured all vegetation within a 300-m radius for this species.

Appendix H. Numbers of call minutes recorded for non-focal bat species at permanent stations.

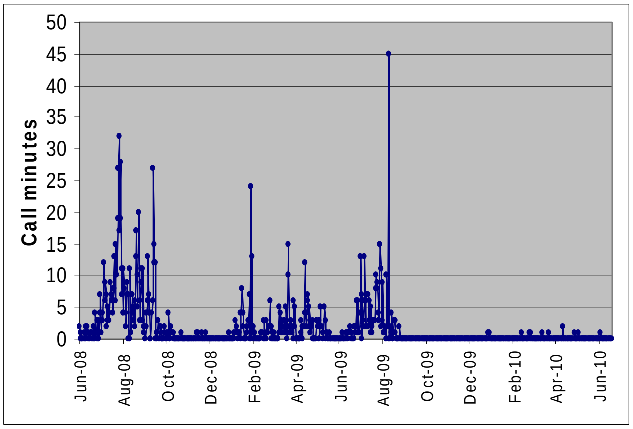
Bandwidth 7-15 kHz bats.



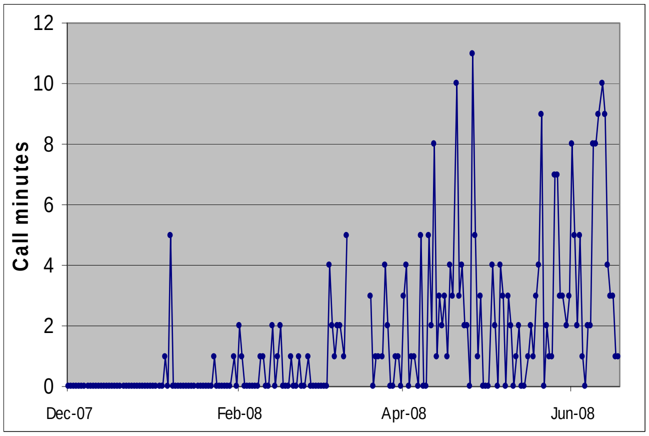
Bill Williams River NWR



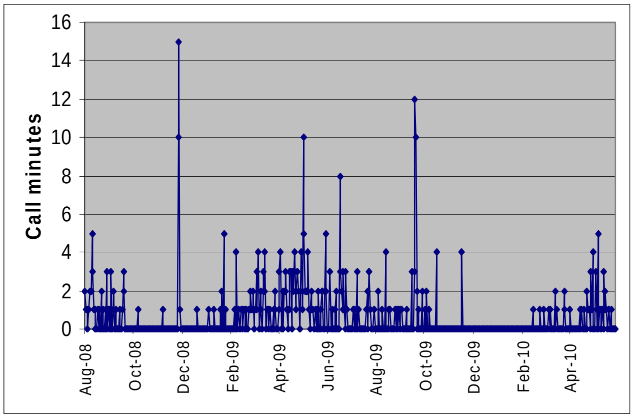
Cibola NWR



Picacho State Recreation Area



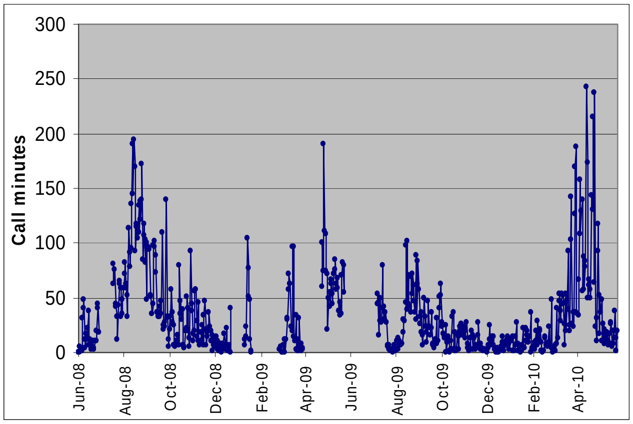
Imperial NWR



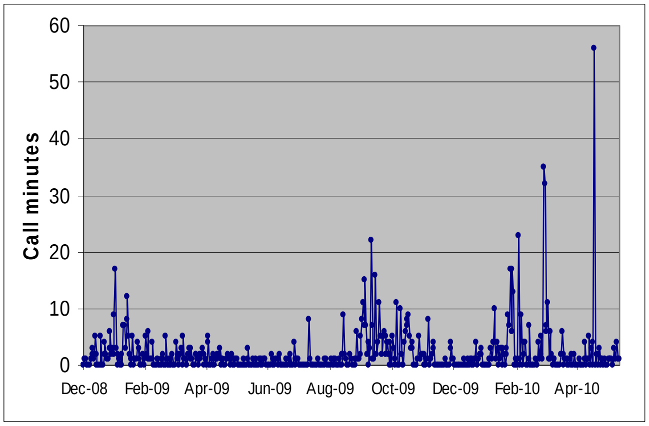
Mittry Lake Wildlife Area

Appendix H (cont.). Numbers of call minutes recorded for non-focal bat species at permanent stations.

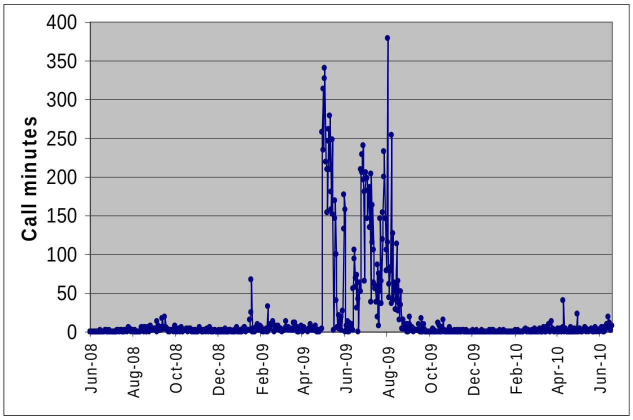
Bandwidth 15-24 kHz bats.



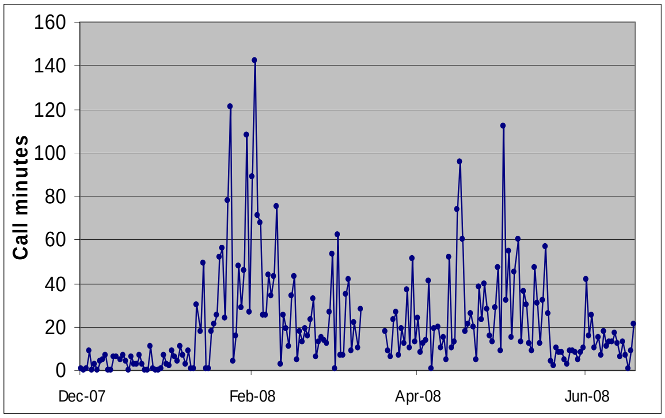
Bill Williams River NWR



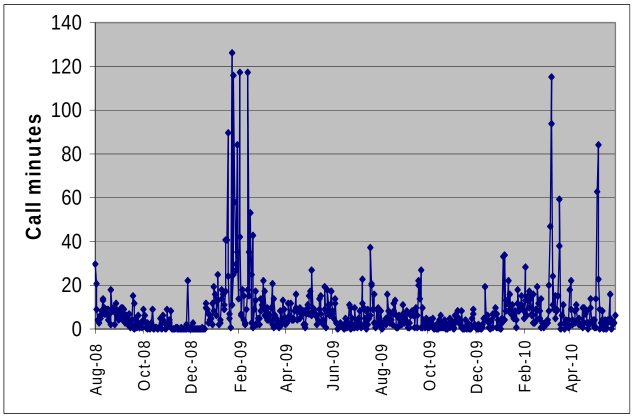
Cibola NWR



Picacho State Recreation Area



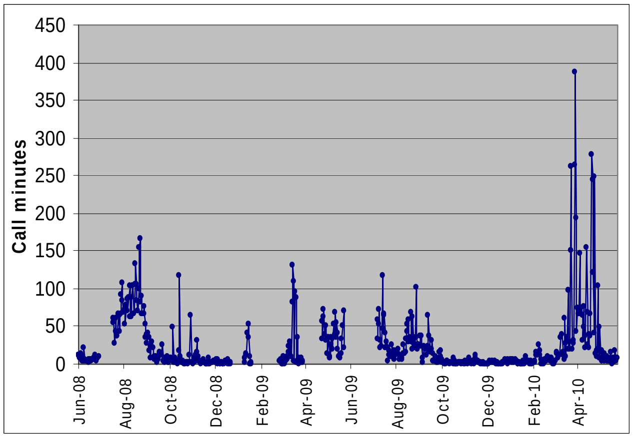
Imperial NWR



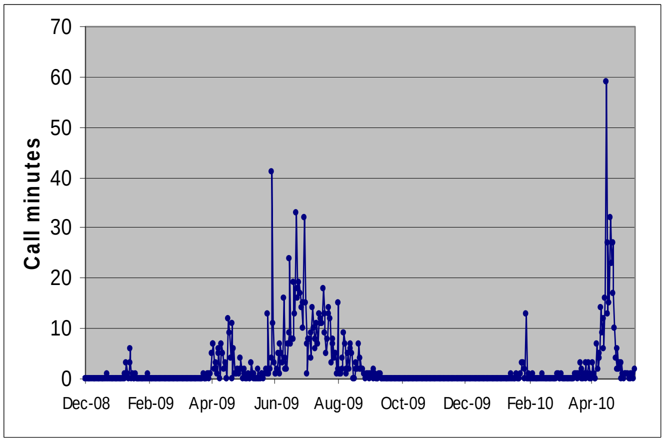
Mittry Lake Wildlife Area

Appendix H (cont.). Numbers of call minutes recorded for non-focal bat species at permanent stations.

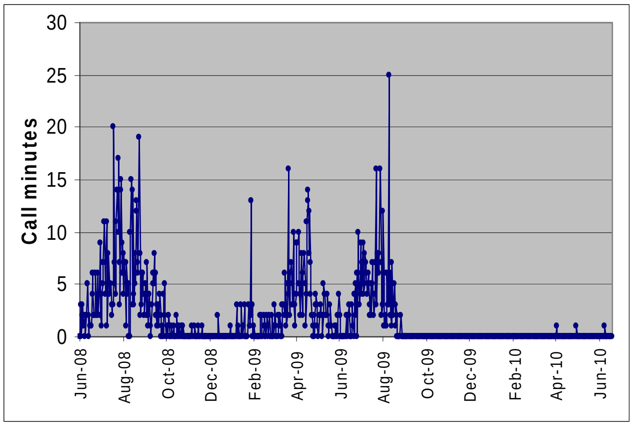
Bandwidth 24-30 kHz bats.



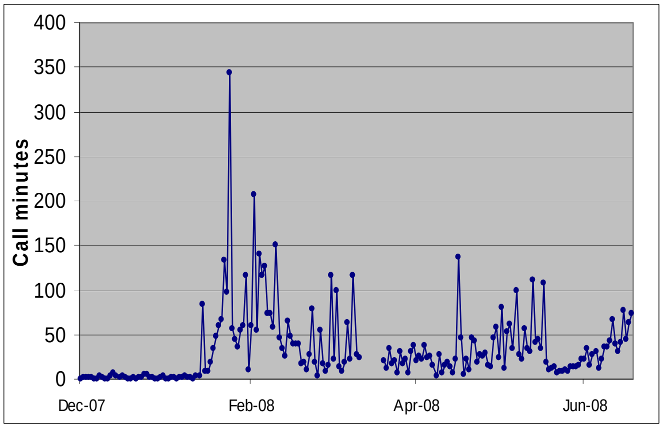
Bill Williams River NWR



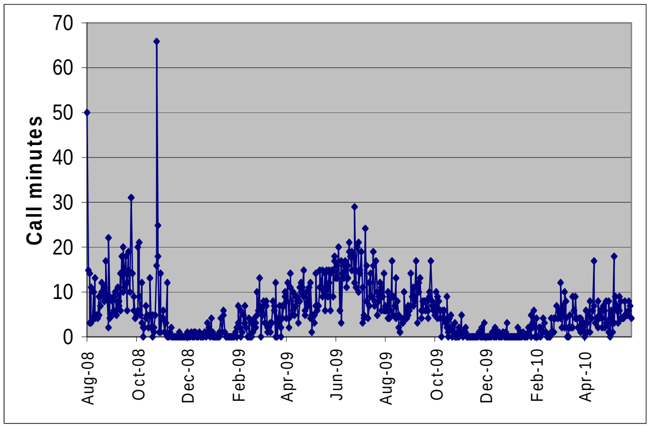
Cibola NWR



Picacho State Recreation Area



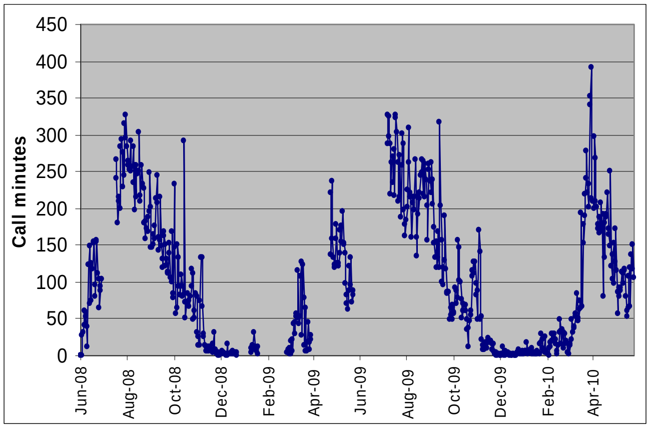
Imperial NWR



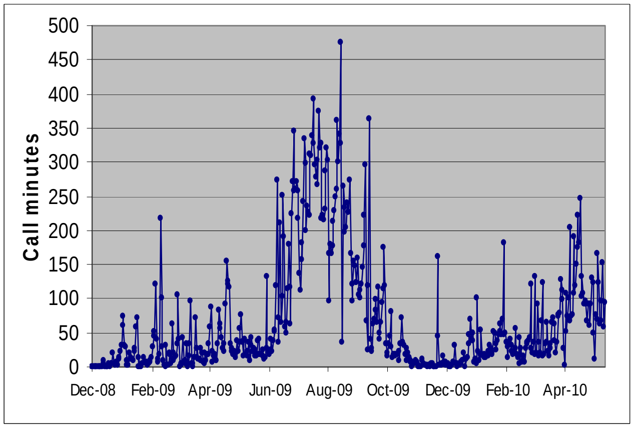
Mittry Lake Wildlife Area

Appendix H (cont.). Numbers of call minutes recorded for non-focal bat species at permanent stations.

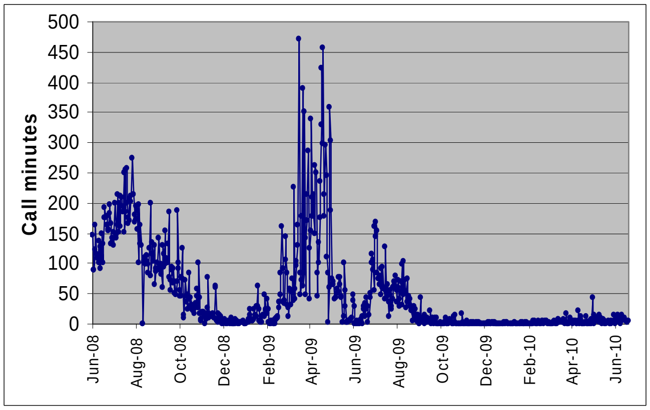
Myotis bats.



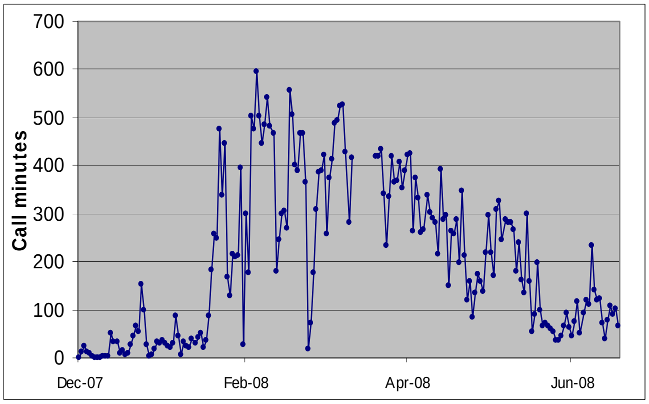
Bill Williams River NWR



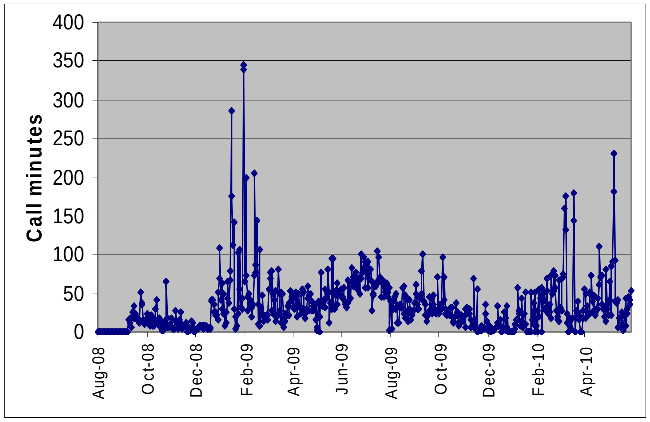
Cibola NWR



Picacho State Recreation Area



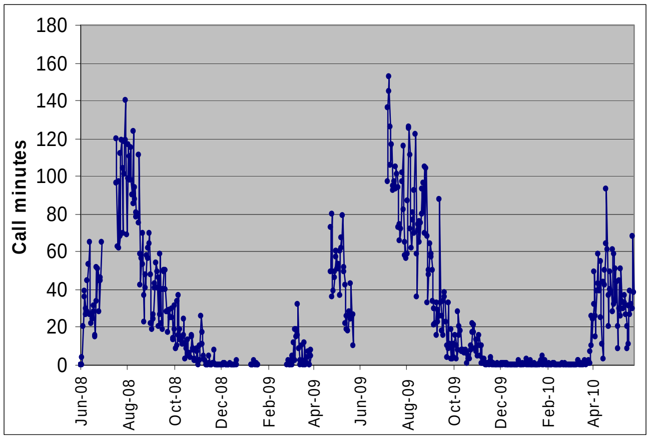
Imperial NWR



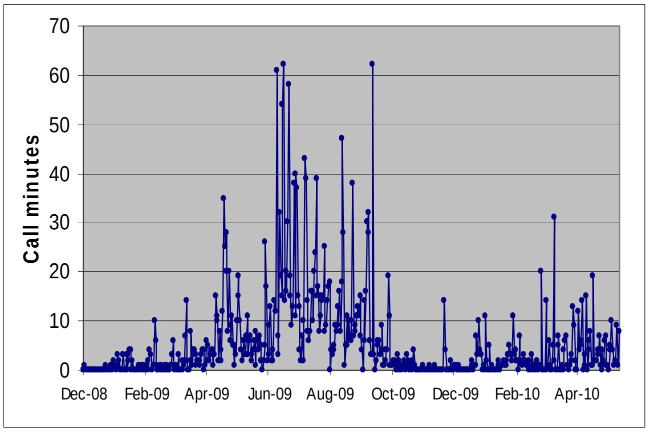
Mittry Lake Wildlife Area

Appendix H (cont.). Numbers of call minutes recorded for non-focal bat species at permanent stations.

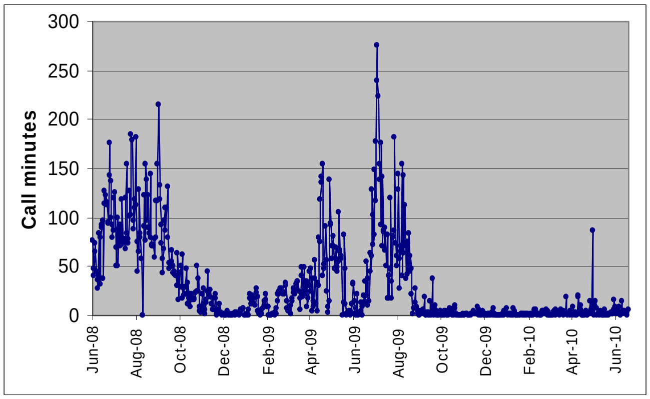
Canyon bats.



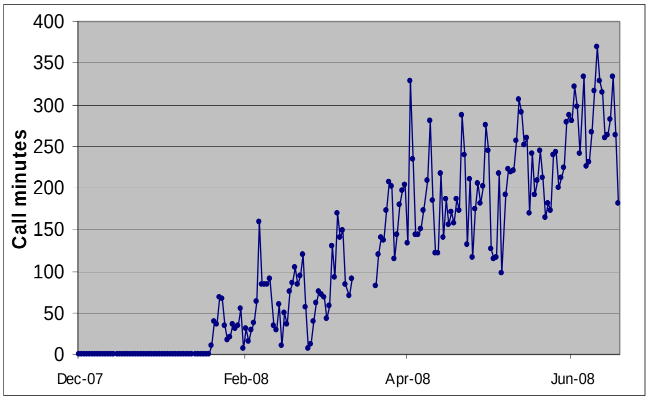
Bill Williams River NWR



Cibola NWR



Picacho State Recreation Area



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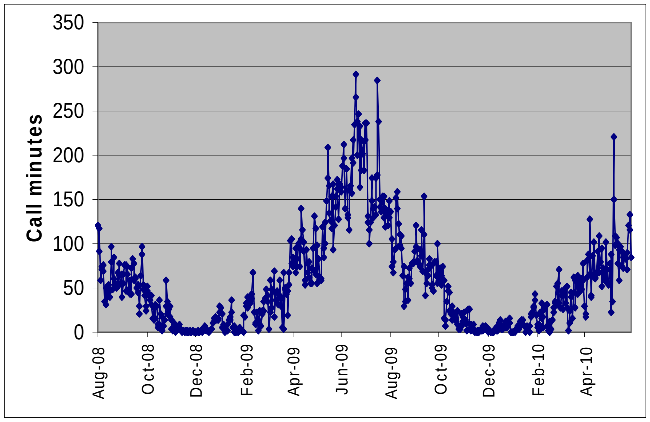
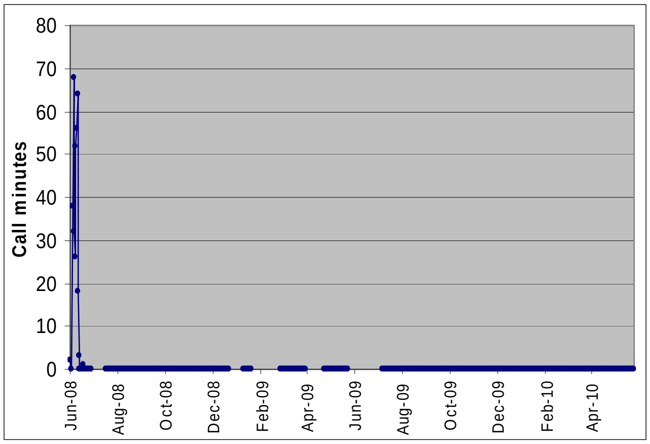
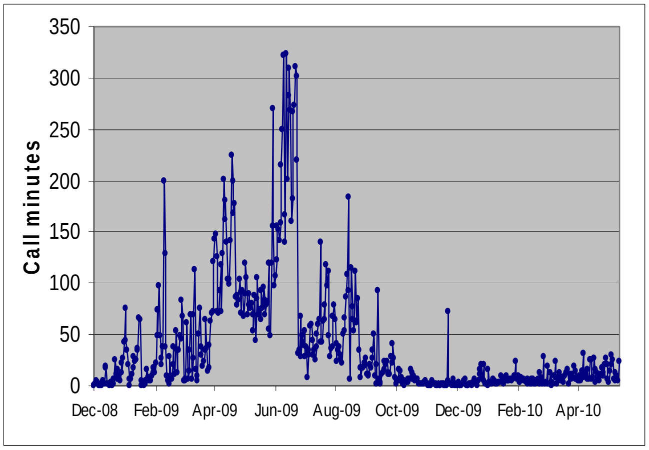


Mittry Lake Wildlife Area

Appendix H (cont.). Numbers of call minutes recorded for non-focal bat species at permanent stations.

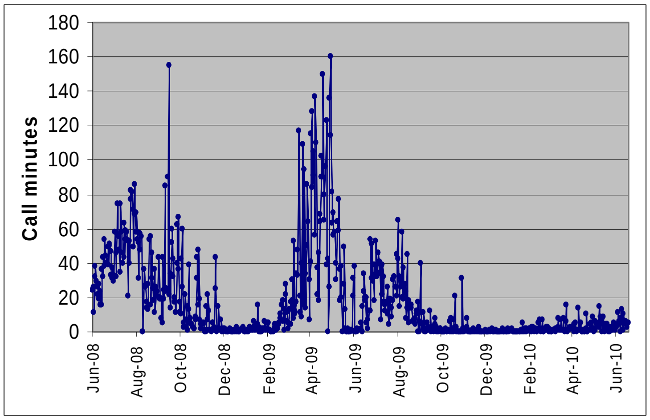
Unclassified calls.

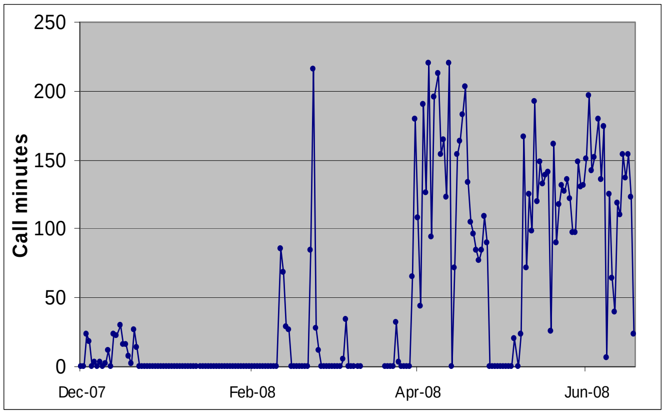




Bill Williams River NWR

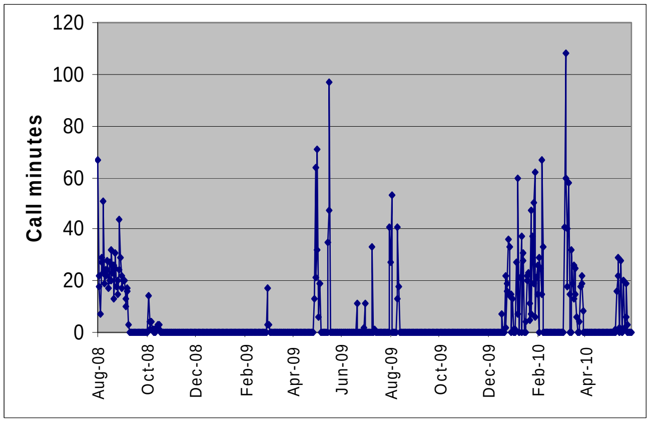
Cibola NWR





Picacho State Recreation Area

Imperial NWR



Mittry Lake Wildlife Area