INVESTIGATING COAST REDWOODS AS REFUGIA FOR BATS UNDER GLOBAL CHANGE

FINAL REPORT

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I. PROJECT SUMMARY

Previous studies have demonstrated the value of coast redwood forest habitat for sensitive bat populations, but the focus of much of this work has been on mature, protected forests. We selected twenty redwood forest sites representing diverse management contexts across Mendocino and Sonoma counties to investigate how bat community composition and activity patterns relate to stand maturity and forest management. Because bats are highly sensitive to temperature and humidity, we chose study sites that represented the coastal gradient of fog-influenced climate to also investigate how microclimate influences bat activity (*see figure 1*). Our study relied on passive acoustic monitors, a technology which, despite promising innovations, is still limited by detection range. To extend our investigation across the full vertical habitat of a redwood forest while studying seasonal changes in bat activity, we selected a subset of five study sites *(figure 2*), including old-growth groves and commercial timber properties, for a 12-month canopy study. We installed passive acoustic monitors simultaneously at the top of coast redwood trees and nearby at ground level. We detected significant winter bat activity at all sites, as well as seasonal activity peaks for known migratory species. Treetop deployment methods significantly increased our capacity to detect tree-roosting species (*Lasiurus blossevillii*, *Lasiurus cinereus* and *Lasionycteris noctivagans*), as well as the additional migrant *Tadarida brasiliensis*, across all forest management types. These results suggest that standard survey methods underrepresent the value of redwood forest habitat for bat species that overwinter on the California coast or migrate through the ecosystem.

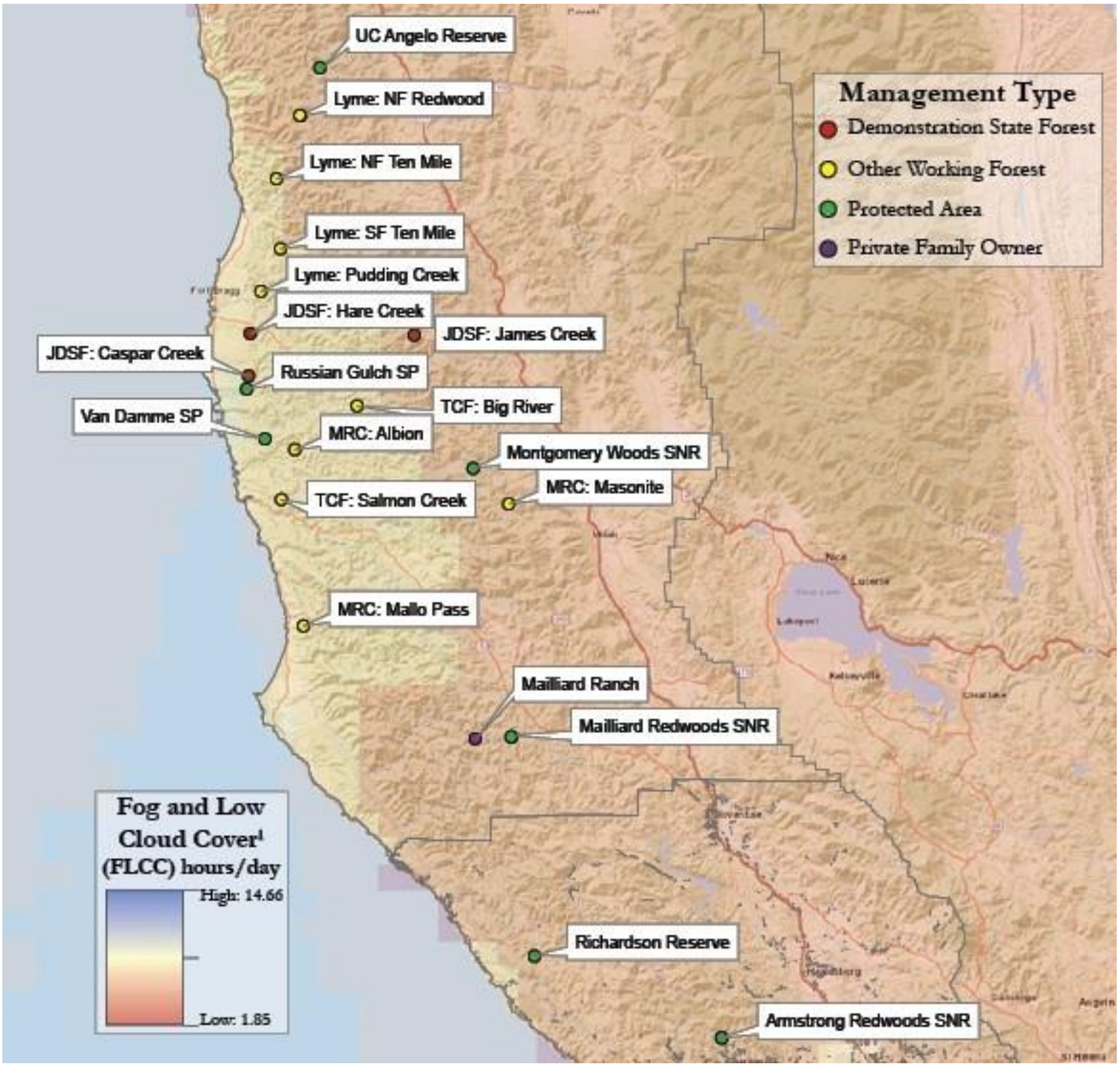


Figure 1: Full landscape study includes 20 sites representing 8 ownerships.

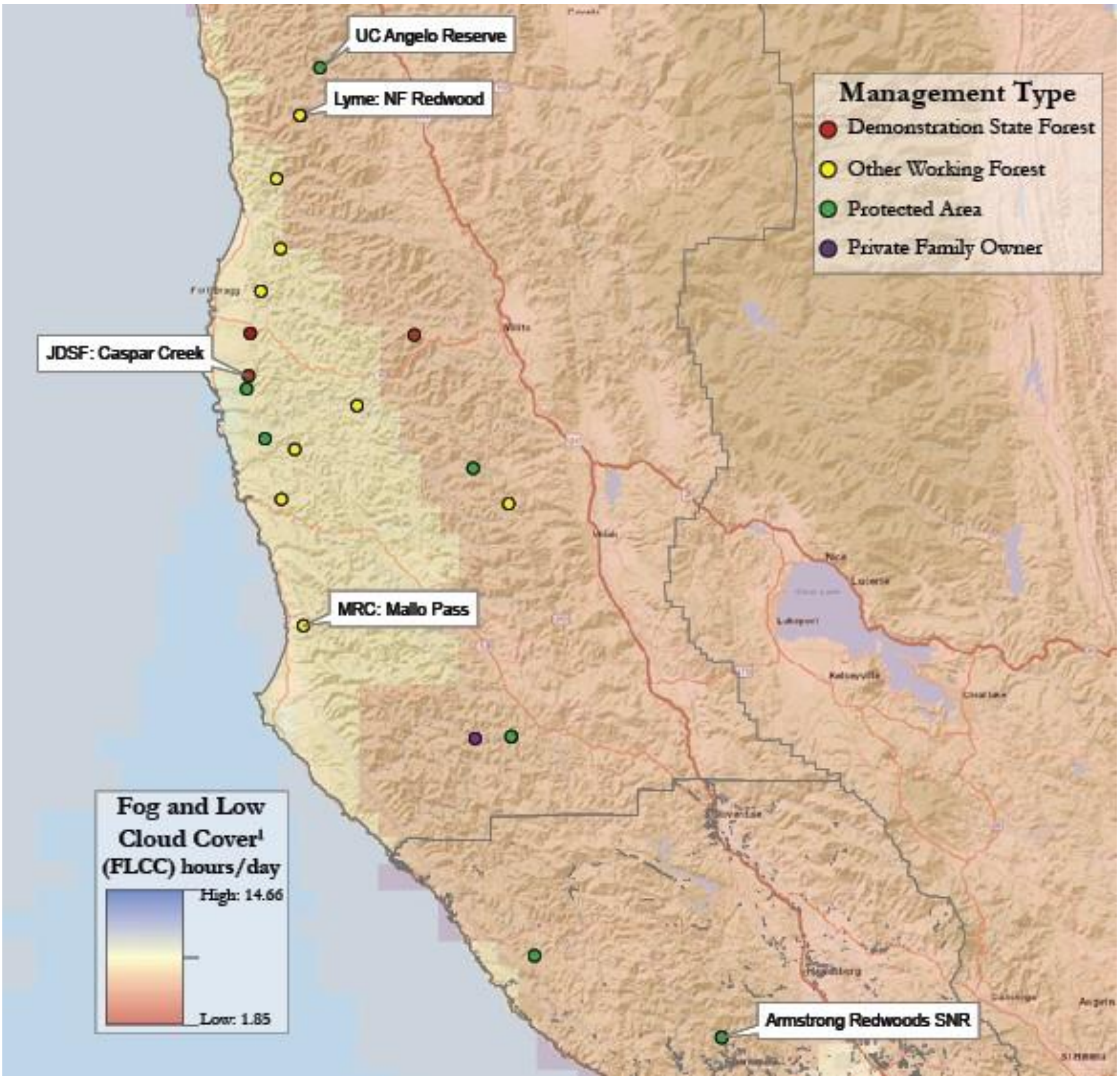


Figure 2: Year-round study sites, including paired ground-level and treetop-level monitoring.

II. Research questions

- *How do bat species distribution, abundance, and activity patterns in coast redwood forests vary with two key environmental variables that significantly influence habitat conditions in this ecosystem: (i) a fog-dominated climate, and (ii) forest management practices?*
  a) *How do bat species abundance and activity patterns of bat species vary with the unique microclimate conditions associated with summer fog?*
  b) *Do bat species abundance and activity patterns differ between protected and working forest areas?*
  c) *How are the above findings informed by surveying bats at different levels of their vertical habitat, including canopy height?*

d) *Which bat species are active in coast redwood forests during the winter, and which habitat conditions are associated with the highest winter activity levels?*

- *Is there evidence that fog supplies any type of supplemental freshwater resource for bats like it does for plants?*
- *Based on these findings, where and how might coast redwood forest function as refugium for bats from forecasted impacts of climate change and white-nose syndrome disease?*

III. DIFFERENCES BETWEEN PROPOSED WORK AND EXECUTED PROJECT

Sometimes aspects of the proposed work needs to change due to unforeseen circumstances or new information. If this occurred, please describe any differences between what was proposed and what was done.

Despite significant unexpected challenges presented by the COVID-19 pandemic, we are grateful to report that the project has mostly proceeded according to plan and that all field data collection has been accomplished.

We were fortunate to have already launched our year-round bat acoustic monitoring project, including detectors at both ground and canopy-level, at five redwood forest sites in October 2019. Because we were observing interesting differences between the ground and treetop detectors, including substantially more detections of migratory species at treetop, we decided to leave this study up for a full 12 months, instead of closing the project before our summer field season as initially planned. We retrieved all of the equipment at the beginning of October 2020 and are now in the process of analyzing the data. In many cases, an individual detector recorded over 20,000 calls over the course of the month so we still have some work to do classifying bat calls to species before we can comment on the statistical significance of our findings.

One notable challenge that we did suffer at the end of this project is that our monitoring site at Armstrong Redwoods State Natural Reserve was heavily impacted by the Walbridge fire in late August. Fortunately, we had visited the site a few days before the fire and were able to collect the last of our summer data on August 16. Data for the 6 weeks after this has been lost due to the fire incinerating our ground detector. Also, a neighboring tree fell against our rigged tree and brought down the pull cord that enabled us to climb up to our treetop detector. As a result, this equipment is currently stuck 78 m above the ground, but we are continuing to be in conversation with our contacts at California State Parks to determine whether it will be safe next year to re-rig the tree and retrieve the equipment. The silver lining is that we hope our year of pre-fire bat data can serve as a valuable baseline comparison for future post-fire bat monitoring at Armstrong Redwoods State Natural Reserve.

Our final season of acoustic monitoring at our twenty summer field sites proceeded remarkably similarly to summer 2019. This is significant because the COVID-19 pandemic upended the fieldwork of many graduate students at our university. Fortunately, Chelsea was able to receive permission to continue this field project because she was able to visit field sites and complete all of the ground-level acoustic monitoring on her own, including two monitoring rounds of at least 4 consecutive nights each at twenty field sites between June 18 – August 11, 2020.

However, we were unable to do mist netting in summer 2020 because the California Department of Fish & Wildlife placed a moratorium on non-essential bat handling due to concerns of transmitting COVID-19 to California bats. Similarly, we were planning to recruit an undergraduate field assistant for summer 2020 to help assess available insect prey abundance at our study sites. That part of the project became infeasible given the Shelter in Place and other COVID-19 safety protocols, as well as the regulations of our university. Chelsea did attempt to put out sticky traps to assess insect composition at study sites, but we abandoned this effort when we decided that the potential benefits did not outweigh the risk of unintentionally catching a bat or other unintended animal in the stick traps.

One significant roadblock that we are still contending with is completing the proposed lab research. We were planning to do stable isotope analysis on bat fur and blood samples collected during mist netting. However, lab work planned for spring 2020 was halted when the university closed in March, and we lost access to campus facilities. The blood samples collected in summer 2019, when we last did mist netting, are no longer viable, but the hair samples could still be analyzed at a later date.

IV. Introduction/Background

Western bat populations are increasingly at risk from the unprecedented threats of climate change and white-nose syndrome (WNS), a disease that has decimated eastern North American bat populations and is considered one of the worst wildlife diseases in modern times[1,2]. At least thirteen species of bats, including three California Species of Concern and seven additional "species at risk"[3], inhabit coast redwood ecosystems. Six of these species have been elsewhere identified with WNS symptoms, and three additional species have been found to carry the causative fungal pathogen[2]. These numbers already demonstrate an increase in the threat of WNS to California bats since this study was first proposed, when only four of these species had been identified elsewhere with WNS symptoms and the pathogen had not yet been detected in California, which occurred in July 2019. Also, climate change is predicted to cause significant bat population declines in the western United States, especially in arid areas with warming temperatures and limited water resources[4], which may cause coastal forests to offer important climate refugia for western bat populations. Consequently, there is heightened urgency to increase our understanding of bat ecology and the role forest management can play in coast redwood forests to inform proactive conservation. Species presence and activity patterns vary significantly across these forests, but the mechanisms behind bat distribution patterns are largely unknown[5]. To better understand the susceptibility of coast redwood bat populations to current threats, we have been investigating how spatial distribution and activity patterns are influenced by the coastal fog-dominated climatic conditions (moist and cool) as well as current forest management practices.

Bats are a valuable indicator for monitoring climate change impacts on ecosystems because of their sensitivity to environmental stresses, including their susceptibility to temperature, humidity, and precipitation patterns[6,7,4]. In part this is because bats have high rates of evaporative water loss[4,6], and their reproductive success can decline dramatically when local water sources drop below a critical threshold[7]. Consequently, the higher temperatures and longer dry periods that are forecasted for California may lead to significant population declines[8,9]. However, coast redwood forests might offer bats protection against the impacts of climate change. Coastal effects on air temperature buffer the coast redwood range against extreme weather events and contribute to a high degree of environmental stability year-round[10]. Fog drip is known to provide a vital freshwater resource for biota and to reduce streamflow decline[11,12,13], but little is known about how fog affects terrestrial fauna species distribution and behavior. Exploring this influence on bat species distribution may illuminate the value of the coast redwoods as a climate refugium for terrestrial mammals.

We lack critical knowledge of the community composition and the behavioral ecology of western bats, especially the winter ecology of forest bats[14]. A few studies reveal that some species are active year-round in coast redwood forests[5,15,16]. This is significant because WNS decimates North American bat populations by inducing physiological changes that disrupt normal winter hibernation[16]. Infected bats arouse from torpor more frequently and, if they cannot successfully forage in the winter, fatally deplete their fat reserves[17]. If bats can actively forage during the winter, such as may be the case in coastal habitats, then we hypothesize that these populations might be able to avoid starvation and thus not be as susceptible to WNS. This hypothesis is supported by results of a 2016 study conducted in North Carolina which found that bat activity levels in coastal habitat with slightly higher winter temperatures sustained more consistent, year-round activity than inland populations, suggesting that coastal bat populations, unlike elsewhere in their range, were not hibernating and might therefore be less susceptible to WNS[18]. Considering that northeastern bat populations have declined over 80% since WNS emerged in New York in 2006[19], winter-active coastal populations could become critical source populations for the persistence of North American bat populations as WNS continues to spread[18].

Both summer and winter activity patterns likely vary significantly depending on microhabitat conditions related to forest maturity and disturbance history[15,16]. Given that only 5% of old-growth coast redwood forest remains[20], and that the majority of redwood forest habitat is in commercial timber production[21], we need to better understand the habitat value of working forests and how we might manage these lands to better support biodiversity and conserve the redwood ecosystem. Working lands can provide vital accessory habitat and resources to wildlife, as well as connect otherwise isolated protected areas[22]. Working lands conservation might be particularly important for a mammal such as a bat which forages over long distances and seasonally shifts roosting habitat to meet thermoregulatory requirements. Timber companies in the coast redwood ecosystem are already promoting biodiversity conservation, such as through stream protection zones. However, most bat research in the coast redwood forests has focused on protected areas, especially mature forests, and it is unknown how findings from these studies apply across the larger coast redwood landscape. We investigated a large number of study sites across multiple management contexts to allow the results to be generalized and confer broader impacts for conservation.

Another important variable influencing bat species distribution is vertical forest structure. Bat activity within the forest canopy and above treetop is largely unobserved with standard survey methods due to the limitations of ground-based detection methods, which underrepresent bats that prefer open habitat above treetop or emit quieter calls that do not penetrate to the ground. Thus, our understanding of bat community assemblage and foraging habitat use is biased toward the species that occupy the lower canopy[23]. As evidence of this, the first, and only, study to investigate how bat activity varied from ground to treetop in a California redwood forest found two bat species (*Lasiurus blossevillii* and *Tadarida brasiliensis*) which were not previously documented to occur in coast redwood forests[5]. However, this study was only conducted at one site with old growth trees[5]. We conducted a multi-site comparison to explore how canopy-level activity patterns in this ecosystem are influenced by stand maturity and forest management practices. Our landscape-scale study was designed to increase our understanding of how different management regimes and the coastal gradient of fog-influenced climate affect bat community composition and behavior with data from the full vertical habitat of the Earth's tallest forests.

V. Methods

To investigate across the two environmental variables, fog-influenced climate and forest management type, we used available spatially explicit data and ground truthing to assess the conditions of potential study sites (Step 1, *see Figure 3*). High and low fog sites, including both young, working forests and mature, protected forests, were identified using fog and low cloud cover (FLCC) indices derived from decadal satellite data[29]. Five study sites were selected for each of four treatment groups: (High Fog, Low Fog) x (Protected Area, Working Forest) (Step 2, *Fig. 3*).

A passive acoustic monitor was deployed in the riparian corridor because, based on the results of our pilot season and conferring with other bat researchers, we found that location to be optimal for detecting bats as they foraged and moved through the landscape (Step 3, *Fig. 3*). Placing the detectors at the riparian corridor also helped us to standardize detector placement across study sites. A second detector was later placed at canopy level at five sites to observe how site activity patterns vary across vertical habitat. Canopy detectors were paired with nearby ground-based detectors and deployed for 12 continuous months (October 2019 – October 2020). During summer 2019 and summer 2020, ground detectors were rotated between sites after a minimum of four nights, the survey length recommended by North American Bat Monitoring Protocol[30]. To relate bat activity to microclimate conditions and further characterize the sites, temperature and humidity were actively logged using iButton sensors attached to the outside of the acoustic detector case (Step 4, *Fig. 3*).

Echolocation calls detected through acoustic monitoring are analyzed using SonoBat call analysis software and classified by species (Step 5, *Fig. 1*). When a confident species identification is not possible, calls are instead identified by acoustic guild or not identified. Generalized linear mixed models will be used to analyze how bat species activity varies with environmental variables. Mist netting was done at each site during summer 2019 to corroborate acoustic detection results (Step 6, *Fig. 3*). Also, capture data provided important information on bat sex, age and reproductive status that cannot be obtained from acoustic monitoring. Capturing bats also enabled us to take blood and fur samples for stable isotope analysis; however, as described above, this corollary part of the study was not carried out due to complications related to the COVID-19 pandemic.

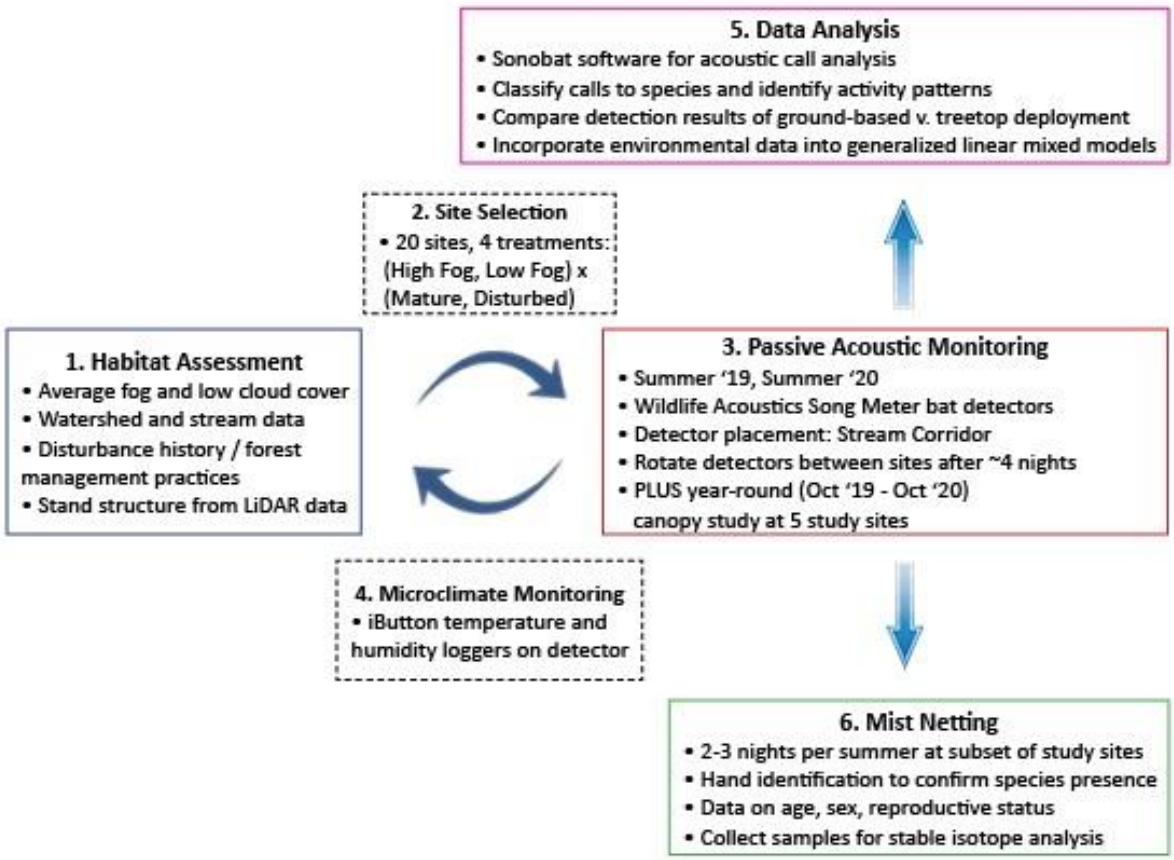


Figure 3: Schematic of research activities and methods.

VI. RESULTS

<u>Twenty-Site Summer Study</u>

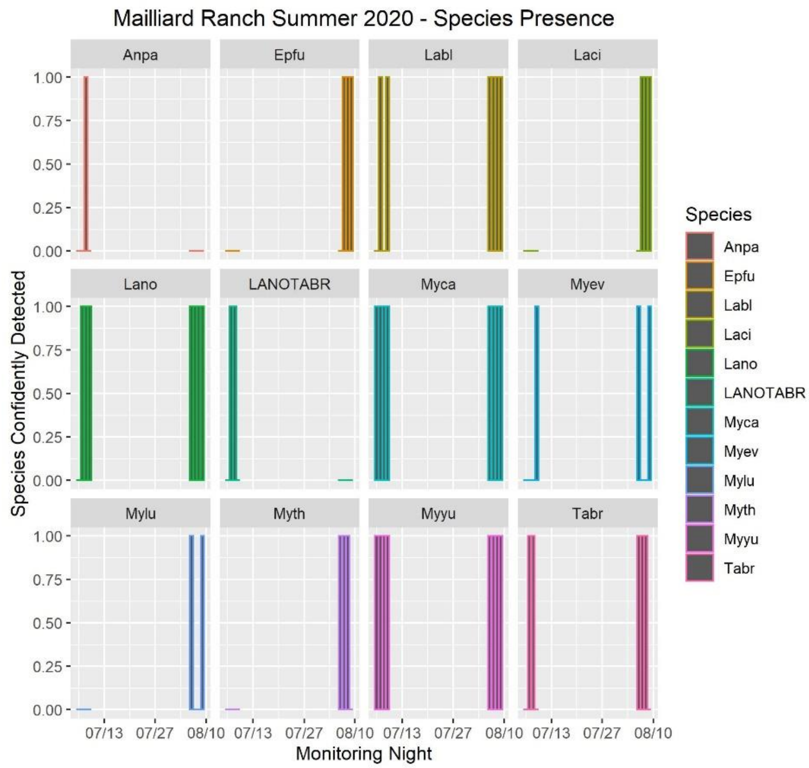
Our study design has proved to be highly effective at monitoring bat species presence and activity patterns in coast redwood forests. At many of our data sites, over 1,000 bat calls were recorded in a single monitoring night. Given that we monitored at each of twenty sites at least four nights per summer monitoring round and had two monitoring rounds in each of our summer field seasons, it has taken longer than anticipated to manually vet our summer data to confidently identify bat calls to species. Also, we recently upgraded our bat call analysis software to SonoBat 4.4.5 because we realized when attending an advanced acoustics master class in January that there had been significant advancements in the software since we had last updated it, and we needed to re-classify all data using the upgraded software in order to be confident in our findings.

However, we have used SonoBat's autoclassification capabilities to take a preliminary look at the species results for all of our study sites for each monitoring round, and we have finished manually vetting several of our sites. Based on these preliminary results, certain trends are emerging. Although overall bat activity was often high on sites with younger forest habitat that are actively managed for timber, the majority of these calls were attributed to a couple of commonly detected species, *Myotis yumanensis (Myyu)* and *Myotis californicus (Myca)*. Protected sites with mature groves tended to have higher species diversity, even when the total number of bat calls detected was lower. Species which we detected on more monitoring nights and with higher activity levels at mature, protected sites than young, working forest sites include *Antrozous pallidus (Anpa)*, *Corynorhinus townsendii (Coto)*, *Myotis evotis (Myev)*, *Myotis thysanodes (Myth)*, and *Myotis volans (Myvo)*.

An anecdotal example of this trend are the species presence and activity results of Mailliard Redwoods State Natural Reserve and Mailliard Ranch. These two study sites are located 5 km apart as the crow flies and thus have similar climate (*see figure 4)*. The monitoring points were located at different waterways: our monitoring point at Mailliard Redwoods SNR was on Mill Creek and our monitoring at Mailliard Ranch was on Garcia River. The immediate habitat around the Mailliard Ranch monitoring location included a history of unevenaged management with selection harvest as recent as 2008 according to public THP records. Mailliard Redwoods State Natural Reserve was part of the original Mailliard Ranch property but has been part of the California State Parks system since 1954 and the closest publicly available THP record is on the adjacent Mailliard Ranch property approx. 400 m from our monitoring point. The habitat at Mailliard Redwoods SNR is noticeably more mature, including taller redwood trees than Mailliard Ranch and less riparian understory vegetation. Despite only being a 243-acre parcel, the Mailliard Redwoods SNR seemed to provide critical habit for sensitive bat species. *Corynorhinus townsendii* and *Myotis volans* were both confidently identified at Mailliard Redwoods SNR, despite no detections of these species at Mailliard Ranch. *Myotis evotis* and *Myotis thysanodes* were detected at both sites, but detection numbers were significantly higher at Mailliard Redwoods SNR, despite total nightly bat activity detected at Mailliard Redwoods SNR being notably less than Mailliard Ranch. In contrast, *Myotis lucifugus (Mylu)* and *Tadarida brasiliensis (Tabr)* were only detected at Mailliard Ranch (*see figures 5 and 6*).

Interestingly, the differences between these two monitoring locations were even more stark when mist netting. We were able to conduct two nights of mist netting at each site during summer 2019 (*see figure 7*). Only two common species, *Myotis yumanensis (Myyu)* and *Myotis californicus (Myca)*, were captured at our Mailliard Ranch study site. Seven species were captured at Mailliard Redwoods SNR, including the only *Corynorhinus townsendii* captured at any site during our study. We were also surprised to capture three *Myotis thysanodes* during a single monitoring night at Mailliard Redwoods SNR and an additional *Myotis thysanodes* on the second night because this was the only site that we captured this species at in summer 2019, despite doing a total of 17 nights of mist netting at ten study sites. Comparing these capture results with the acoustic detection results illustrates the value of conducting mist netting to corroborate the findings of bat acoustic monitoring. Even though we have been unable to do our planned lab analysis on bat hair and blood samples collected during mist netting nights, the additional insights that we gained on bat activity at our study sites by being present at nights made the extra effort invested in mist netting worthwhile.

Figure 4: Map showing monitoring point at Mailliard Ranch (-123.392763 W, 38.901994 N) on left and Mailliard Redwoods SNR (-123.33605 W, 38.904369 N) on right. Hatched line areas show all Timber Harvest Plans documented since 1997.



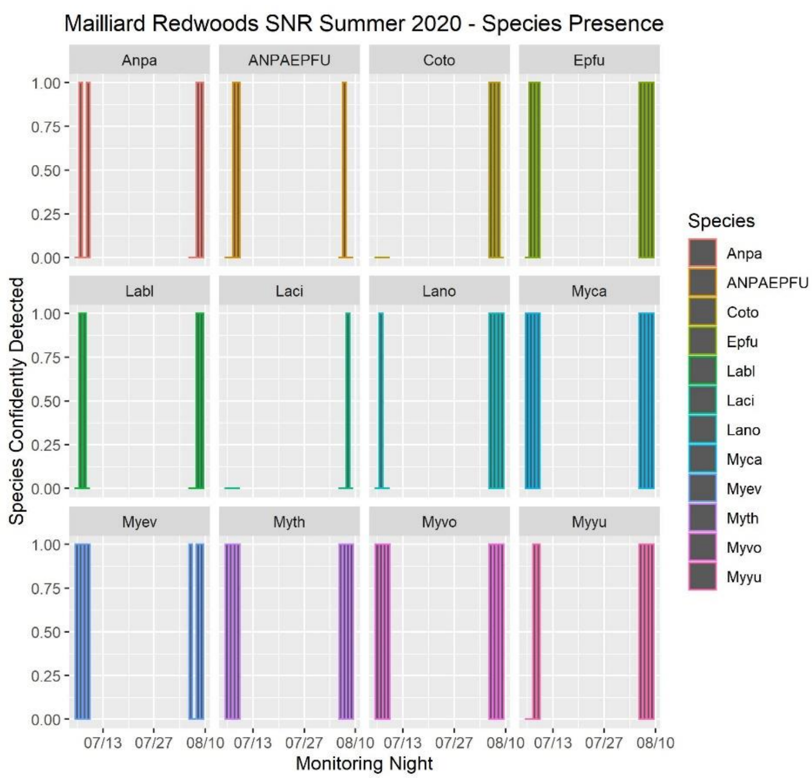
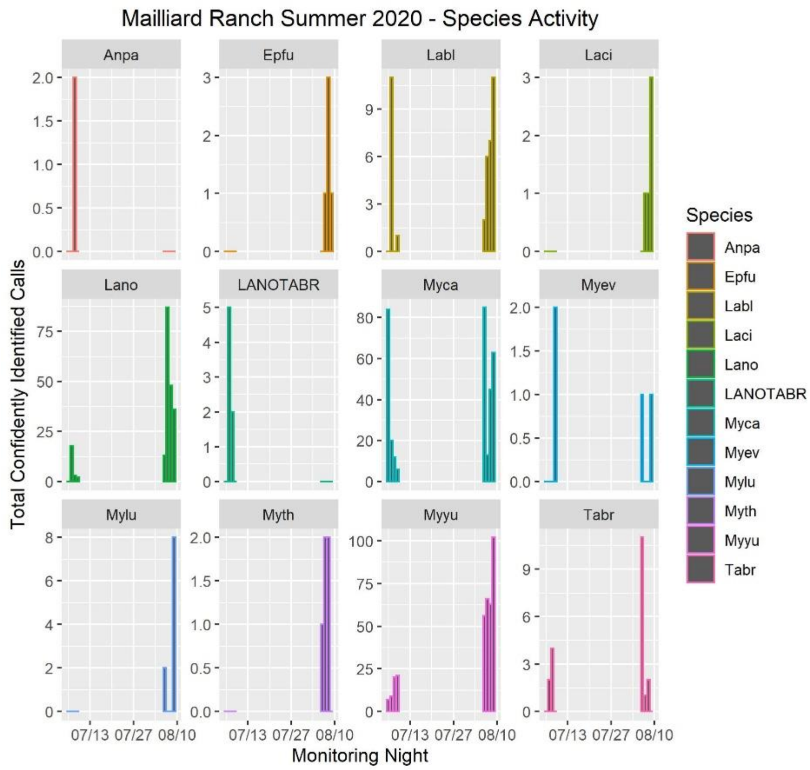


Figure 5: Acoustic data collected for Mailliard Ranch and Mailliard Redwoods SNR was auto-classifed then manually vetted using SonoBat 4.5.5. Only calls that we confidently identified to species are included in these results. If a species was confidently detected on that monitoring night, it is indicated by the value "1".



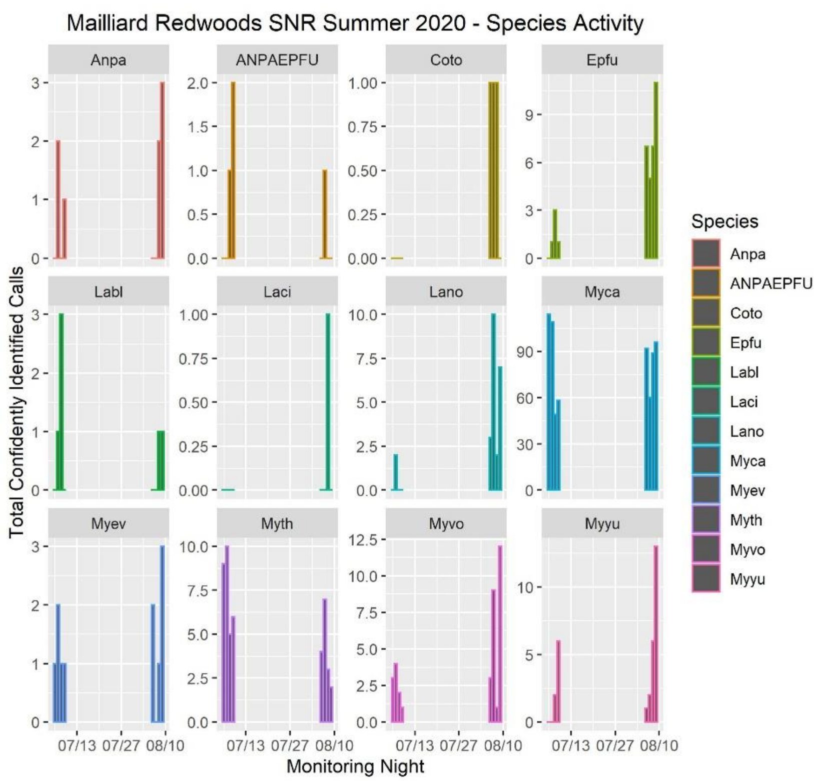


Figure 6: Acoustic data collected for Mailliard Ranch and Mailliard Redwoods SNR was auto-classifed then manually vetted using SonoBat 4.5.5. Only calls that we confidently identified to species are included in these results. Activity is measured in total confidently identified calls per monitoring night.

Date: 7/19/2019 **Net Open:** 20:50
Site: Mailliard Ranch - Garcia River **Net Close:** 0:15

#	Time	Net	Spp Code	Species	Sex	Repro Status	Age
1	21:26	3	MYCA	Myotis californicus	F	LACT	A
2	21:28	1	MYCA	Myotis californicus	F	LACT	A
3	21:30	1	MYCA	Myotis californicus	F	NON	**A**
4	21:30	1	MYYU	Myotis yumanensis	M	NON	J
5	22:35	1	MYCA	Myotis californicus	M	NON	A
6	22:50	2	MYYU	Myotis yumanensis	M	NON	A
7	23:09	2	MYYU	Myotis yumanensis	M	NON	A
8	23:37	1	MYCA	Myotis californicus	M	NON	A

Date: 8/7/2019 **Net Open:** 20:40
Site: Mailliard Ranch - Garcia River **Net Close:** 1:15

#	Time	Net	Spp Code	Species	Sex	Repro Status	Age
1	20:45	1	MYYU	Myotis yumanensis	F	NEV	A
2	20:45	1	MYYU	Myotis yumanensis	F	NEV	J
3	20:45	1	MYYU?	*species was not confirmed*	F	POST	A
4	21:05	1	MYCA	Myotis californicus	F	LACT	A
5	21:55	1	MYCA	Myotis californicus	M	NON	A
6	21:55	1	MYYU	Myotis yumanensis	F	NEV	A
7	21:55	1	MYCA	Myotis californicus	M	NON	A
8	21:55	1	MYCA	Myotis californicus	F	NEV	J
9	21:55	1	MYCA	Myotis californicus	M	NON	J
10	21:55	1	MYCA	Myotis californicus	F	NEV	A
11	23:16	1	MYYU	Myotis yumanensis	F	PREV	A
12	0:18	3	MYYU	Myotis yumanensis	M	NON	A

Date: 8/2/2019 **Net Open:** 20:30
Site: Mailliard Redwoods SNR **Net Close:**

#	Time	Net	Spp Code	Species	Sex	Repro Status	Age
1	20:50	1	MYTH	Myotis thysanodes	F	LACT?	A
2	20:50	1	MYVO	Myotis volans	M	NON	A
3	21:13	2	MYTH	Myotis thysanodes	F	LACT?	A
4	21:20	2	MYCA	Myotis californicus	M	NON	A
5	23:25	2	MYTH	Myotis thysanodes	M	NON	A
6	23:35	1	ANPA	Antrozous pallidus	F	NON	A
7	0:10	3	EPFU	Eptesicus fuscus	M	NON	A
8	0:10	3	EPFU	Eptesicus fuscus	M	NON	A

Date: 8/26/2019 **Net Open:** 19:48
Site: Mailliard Redwoods SNR **Net Close:** 0:35

#	Time	Net	Spp Code	Species	Sex	Repro Status	Age
1	20:32	2	COTO	Corynorhinus townsendii	F	NEV	A
2	20:35	3	MYYU	Myotis yumanensis	F	NEV	A
3	21:25	3	MYYU	Myotis yumanensis	F	NEV	A
4	23:15	2	MYYU	Myotis yumanensis	M	NON	A
5	23:46	1	MYYU	Myotis yumanensis	M	NON	A
6	23:46	3	MYTH	Myotis thysanodes	escaped from net		
7	0:35	1	MYYU	Myotis yumanensis	F	NEV	A

Figure 7: Records of bats captured during summer 2019 mist netting nights at Mailliard Ranch and Mailliard Redwoods SNR. Five more species were captured at Mailliard Redwoods SNR, including the only Corynorhinus townsendii captured at any site during our study.

Another interesting finding from our site-level acoustic detection results is that it often took more than one monitoring round to detect the presence of rarer species at a site. For example, at Harold Richardson Redwood Reserve, there were two species detected and confidently identified during our summer 2020 monitoring season that were not detected in our summer 2019 monitoring rounds: *Antrozous pallidus (Anpa)* and *Corynorhinus townsendii (Coto) (see figure 8)*. In both cases, very few calls were confidently identified (1 Coto call and 5 Anpa calls) but these calls contained diagnostic characteristics which were sufficient to confirm species presence.

In cases where we cannot confidently identify a call to species, we can often identify it to an acoustic guild following species groupings that have been standardized by other bat research for our region. Figure 9 shows how these groupings represent presence and activity results for Harold Richardson Redwoods Reserve. This will enable us to include more data in our ultimate landscape scale analysis with more confidence, so that we can better investigate how bat presence and activity patterns relate to the covariates of interest, including forest management and climate.

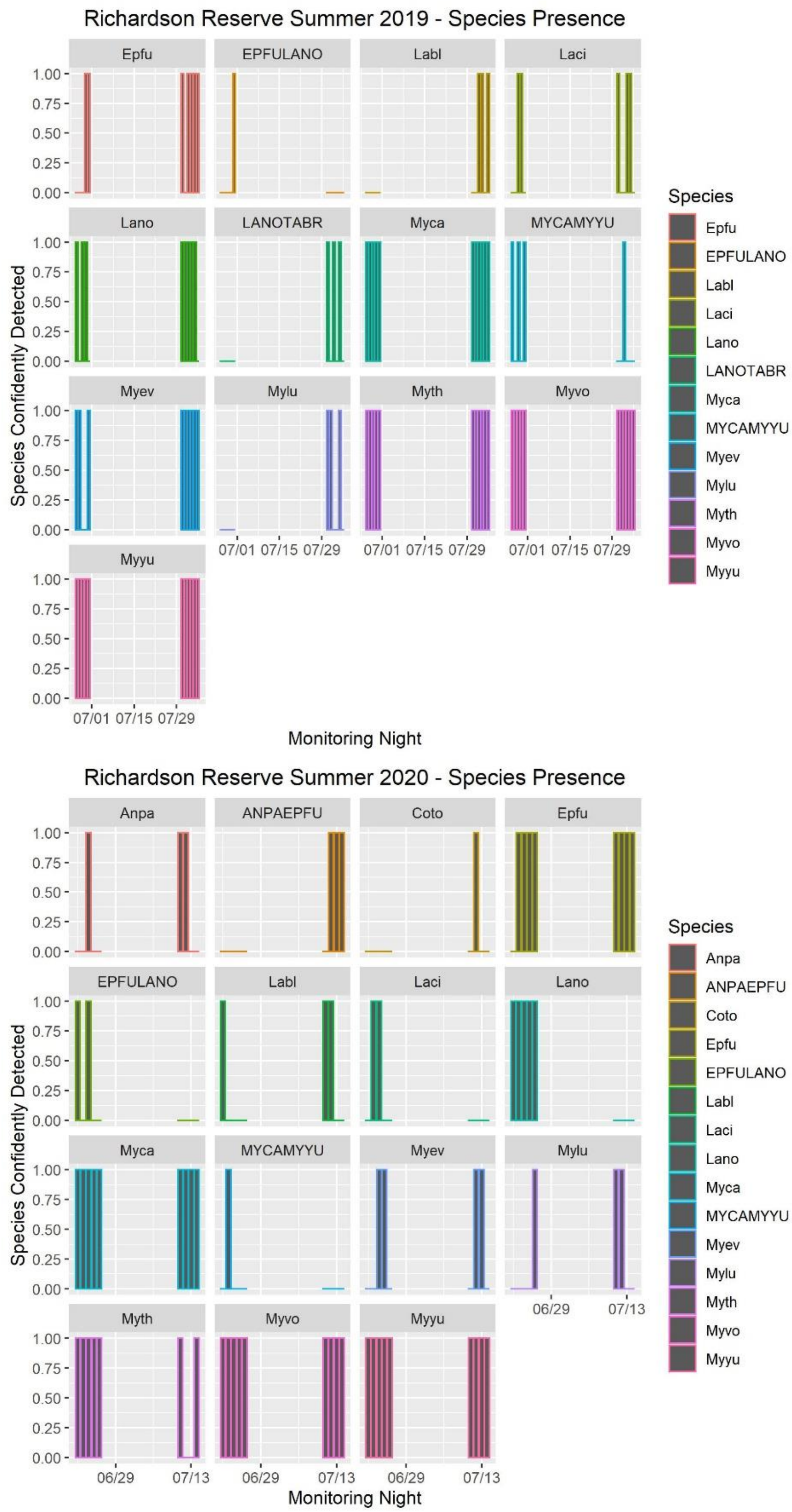


Figure 8: Acoustic data collected for Harold Richardson Redwoods Reserve was auto-classifed then manually vetted using SonoBat 4.5.5. Only calls that we confidently identified to species are included in these results. (a) Two rare species (Anpa and Coto) were confidently identified in summer 2020 that were not detected during summer 2019 monitoring rounds.

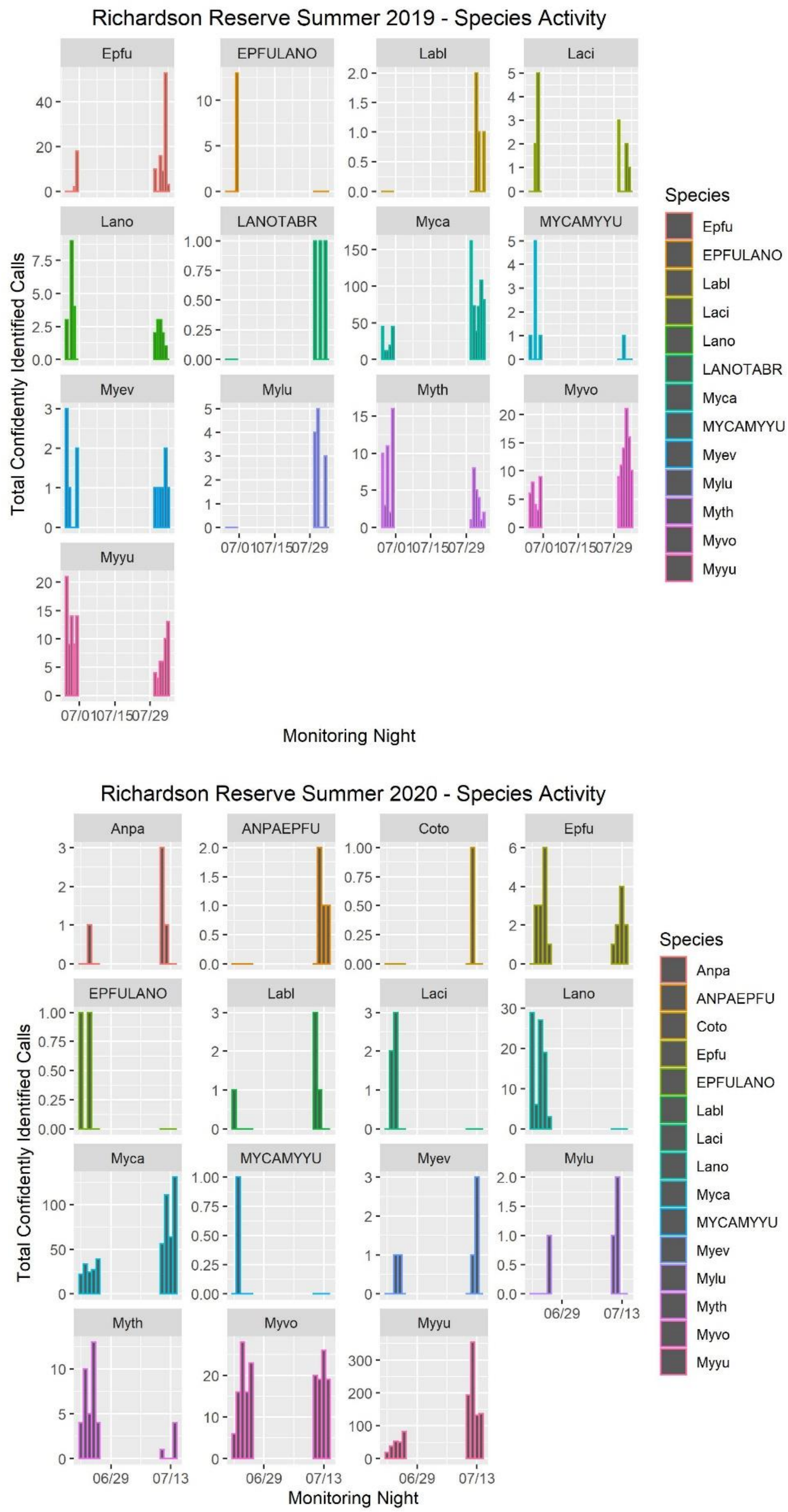


Figure 8(b): Activity is measured in total confidently identified calls per monitoring night.

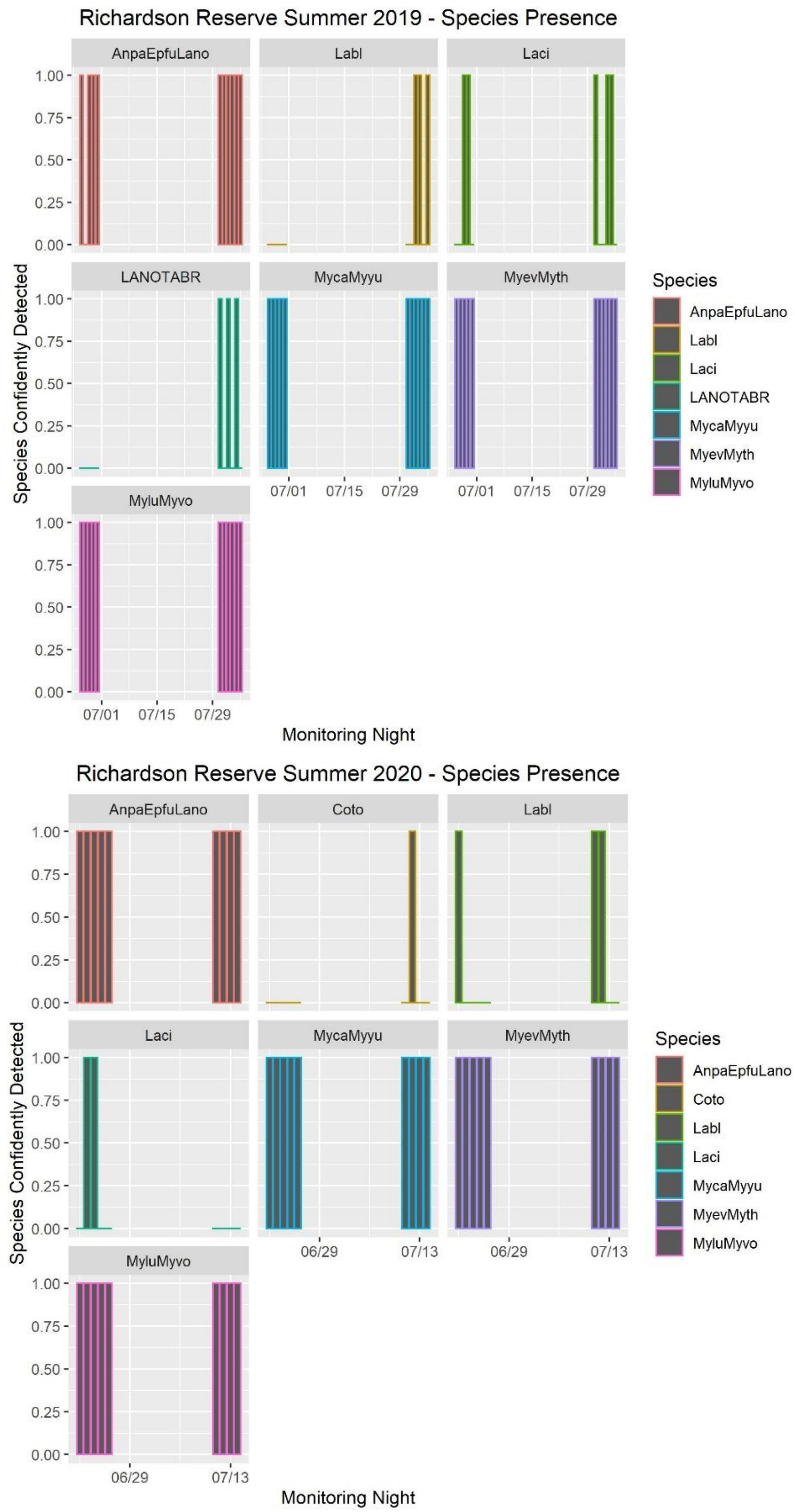


*Figure 9: Acoustic data collected for Harold Richardson Redwoods Reserve was auto-classifed then manually vetted using SonoBat 4.5.5. (a) Presence data has been binned into accepted **acoustic guilds.** For example, for AnpaEpfuLano, detected presence means at least one call was confidently identified that was either Anpa, Epfu or Lano, or AnpaEpfu or EpfuLano.*

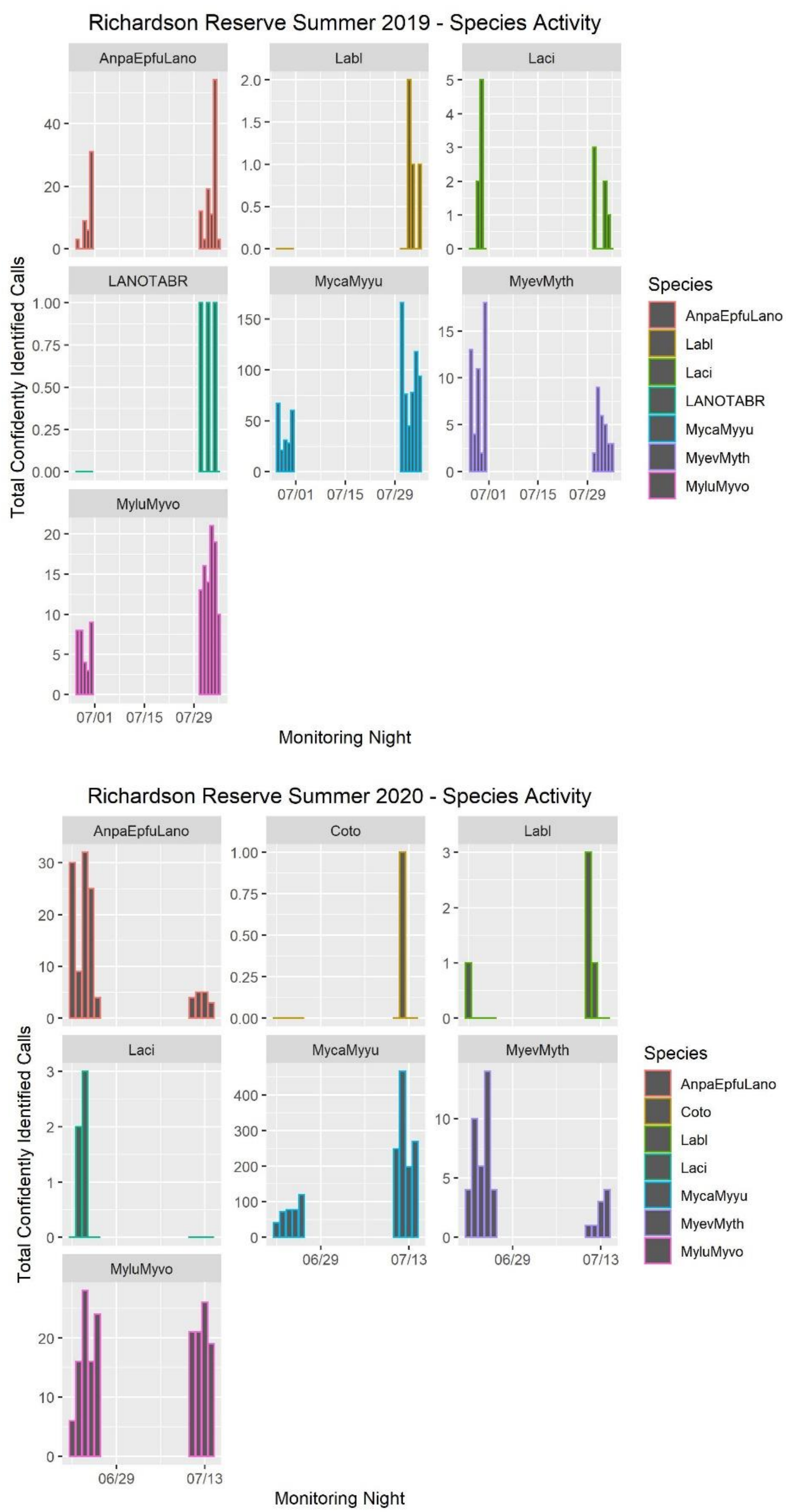


Figure 9(b): Activity is measured in total confidently identified calls per monitoring night for each acoustic guild. For example, for the guild AnpaEpfuLano, this includes calls confidently identified as Anpa, Epfu, or Lano, as well as ambiguous calls that were confidently identified as AnpaEpfu or EpfuLano.

Year-Round Paired Ground and Treetop Study

We are excited to share the preliminary results of our year-round study. Although we aimed to continuously monitor every other night or every third night (depending on the power efficiency of the bat acoustic detector model used at that site) from the time we installed the detectors at the five study sites in early October 2019 until we took down the project in October 2020, actual monitoring nights ended up being fewer due to equipment failures related to precipitation and water infiltrating the microphones. We had multiple incidents in which either a ground or a treetop microphone failed for several monitoring nights then dried out or stopped functioning completely and needed to be replaced. When manually vetting the data for each site and monitoring position, we noted when these failures occurred. The data for that site was then filtered to only include monitoring nights when we were confident that paired ground and treetop detector were both functional. This resulted in a range of 58 (Angelo Reserve) to 98 (MRC: Mallo Pass) total monitoring nights for each year-round study site.

Similar to our summer study, we used SonoBat 4.5.5. to auto-classify the bat acoustic data for each monitoring round (data was collected approximately monthly when batteries were changed). We manually vetted the auto-classified calls. When we were unable to confidently identify a call to species, we instead classified it to acoustic guild or marked it as unidentified so that it would not be included in species presence and activity analysis. When comparing treetop and ground-level presence and activity results for each site, we found that treetop deployment methods significantly increased capacity to detect tree-roosting species *Lasiurus blossevillii*, *Lasiurus cinereus* and *Lasionycteris noctivagans*, as well as the additional migrant *Tadarida brasiliensis*. When examining the data for each monitoring night, we were able to identify significant peaks in species activity that suggest migration events. See Figures 10 and 11 for an example of these peaks for *Lasionycteris noctivagans* and *Tadarida brasiliensis* at Armstrong Redwoods SNR. The activity peaks are much more noticeable with treetop deployment methods than with standard ground-level deployment.

Interestingly, trends in differences between ground and treetop deployment methods held in young forests, as well as in old-growth and other mature stands. For example, our study site Mallo Pass is a working forest logged by Mendocino Redwood Company. We installed our treetop detector as high as possible, but it was still only 33 m above the ground. This is in contrast to the detector at Armstrong Redwoods SNR which was installed 78 m above the ground. Yet, treetop deployment methods still detected activity peaks for *Lasionycteris noctivagans* and *Tadarida brasiliensis* that were not discernable from standard ground-level deployment methods (*see figure 12*).

To better understand how species composition and activity patterns changed over the year, we have been analyzing the data based on seasons (e.g. winter = monitoring nights 12/21/2019 to 3/18/2020), with a particular interest in winter activity (*see winter presence and activity plots below*). During the winter, *Lasiurus cinereus* was detected at one site only by using the treetop detector, and at the other sites, it was detected on average 5.6 times more monitoring nights by the treetop detector than the ground detector. Similarly, during both winter and spring, *Tadarida brasiliensis* was detected at three sites only by treetop deployment methods; and at one site, an average of 30 calls per winter monitoring night were confidently identified, despite no *Tadarida brasiliensis* calls being detected at ground-level for the same monitoring nights.

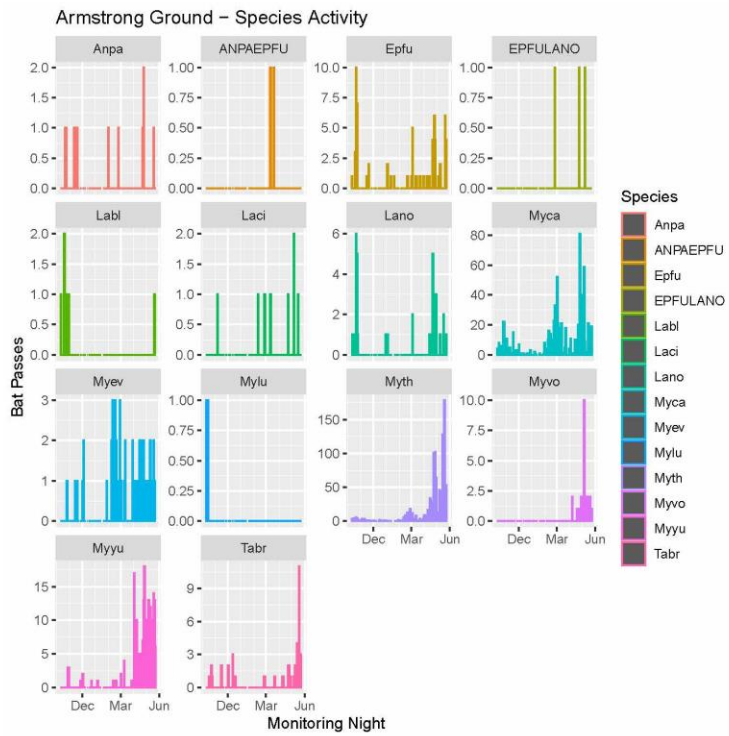


Figure 10: An example of species presence and activity results using confidently identified calls vetted in SonoBat 4.5.5. The ground monitoring location was functional for the entire duration of the study until the Walbridge fire in August 2020.

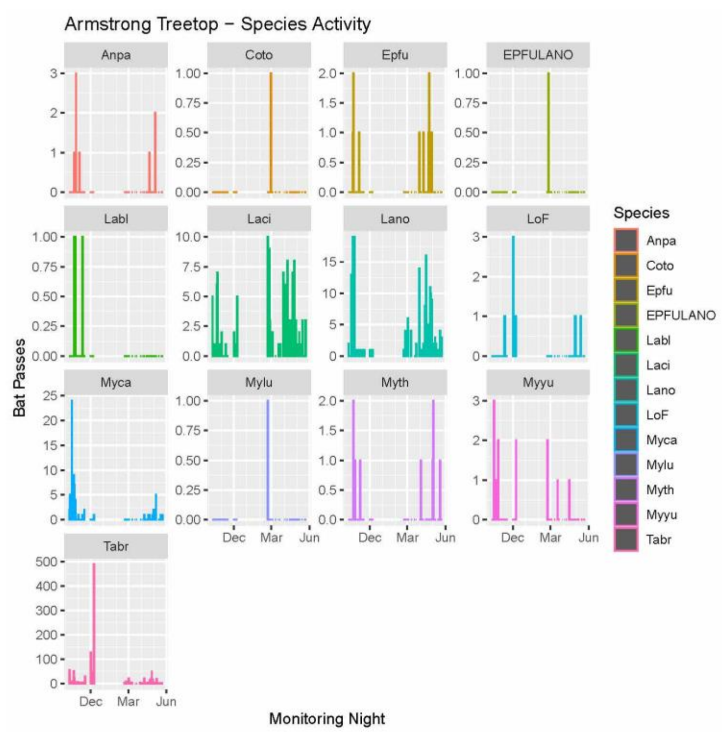


Figure 11: The treetop microphone ceased functioning on 12/11/2019 and was not replaced until 2/19/2020, resulting in a significant gap in monitoring at this location. Treetop data was not retrievable after the Walbridge fire in August 2020.

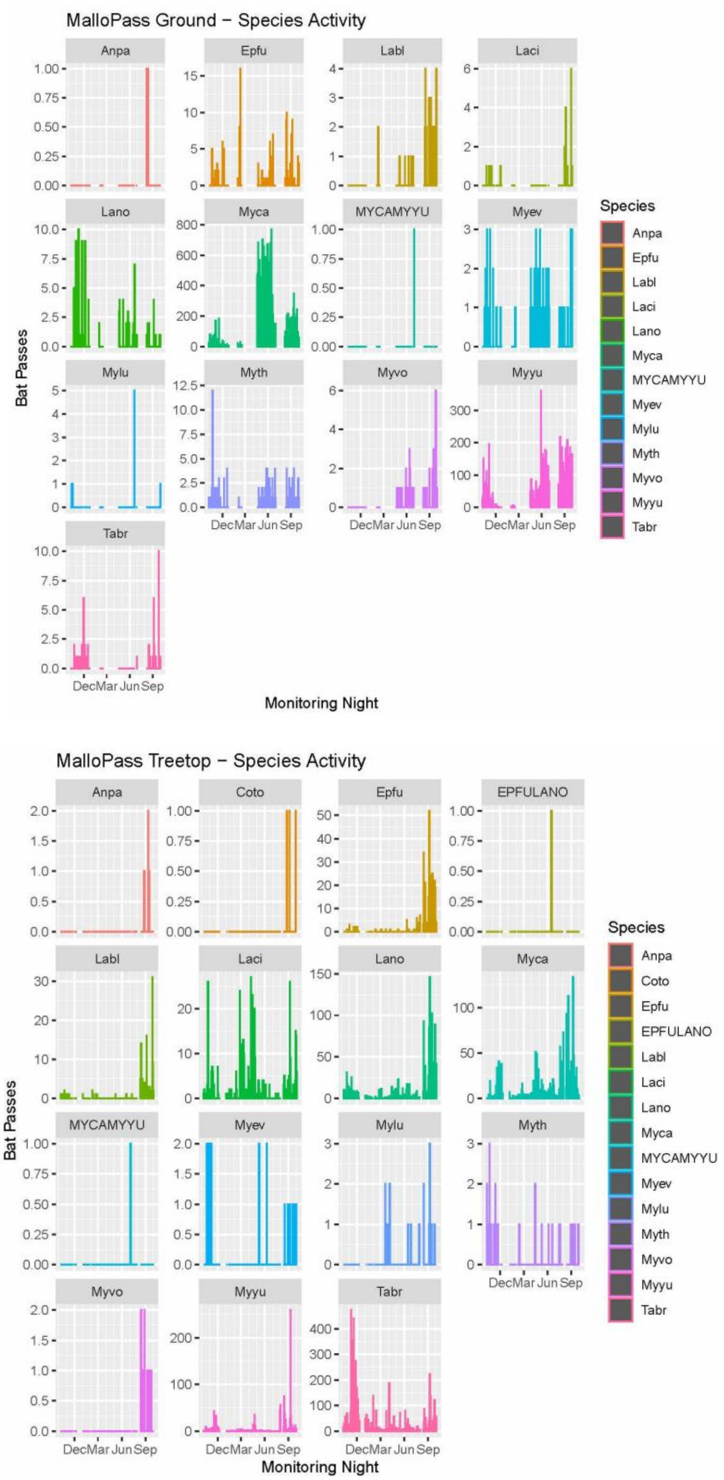
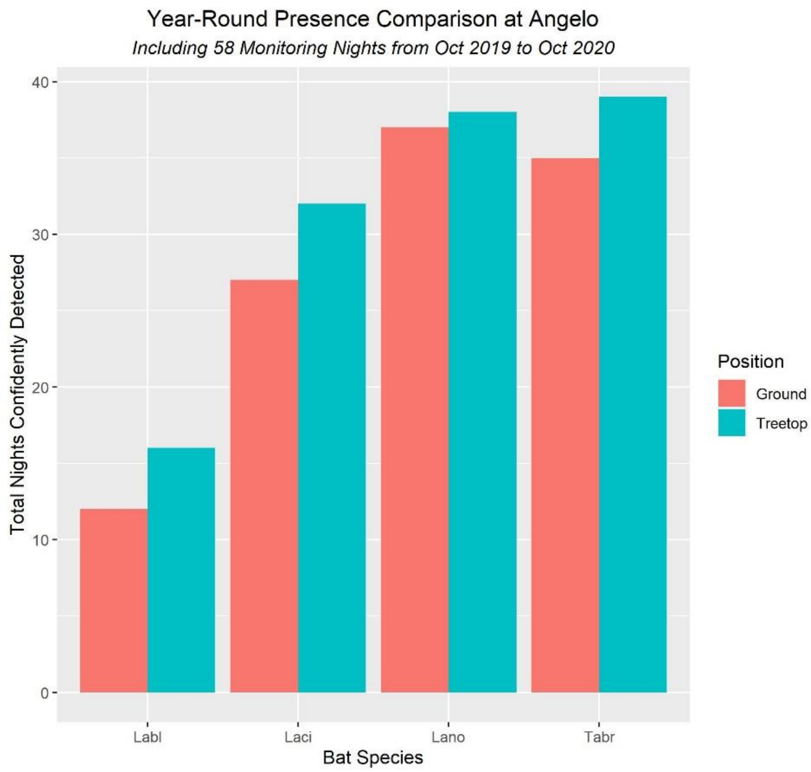
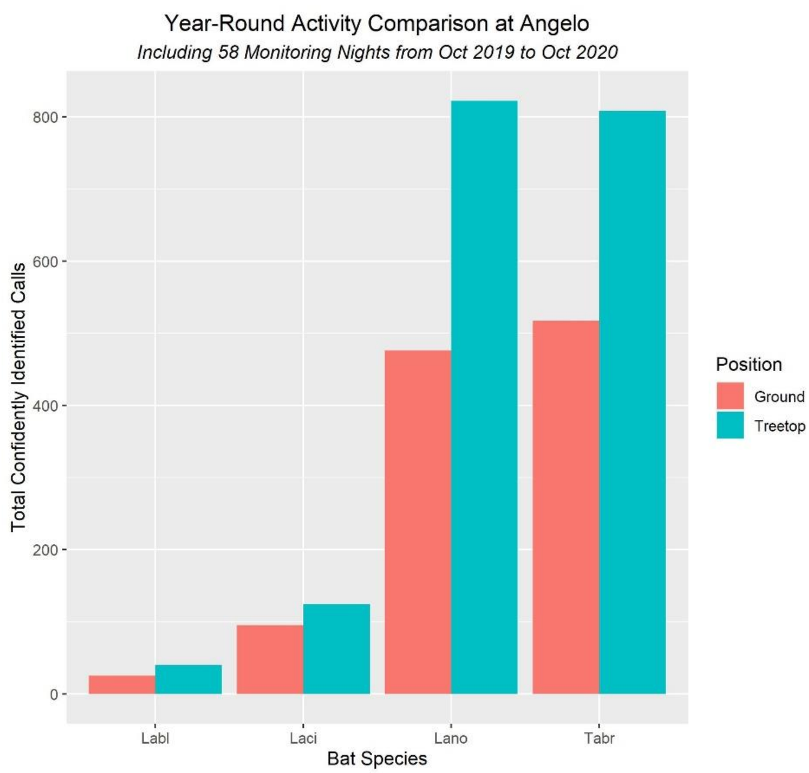
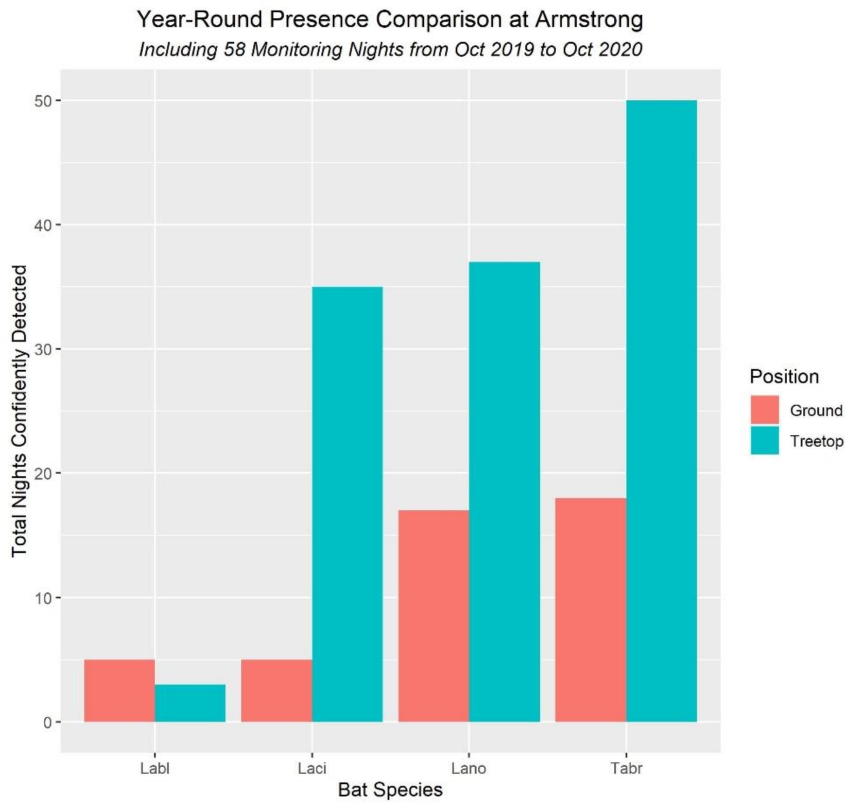
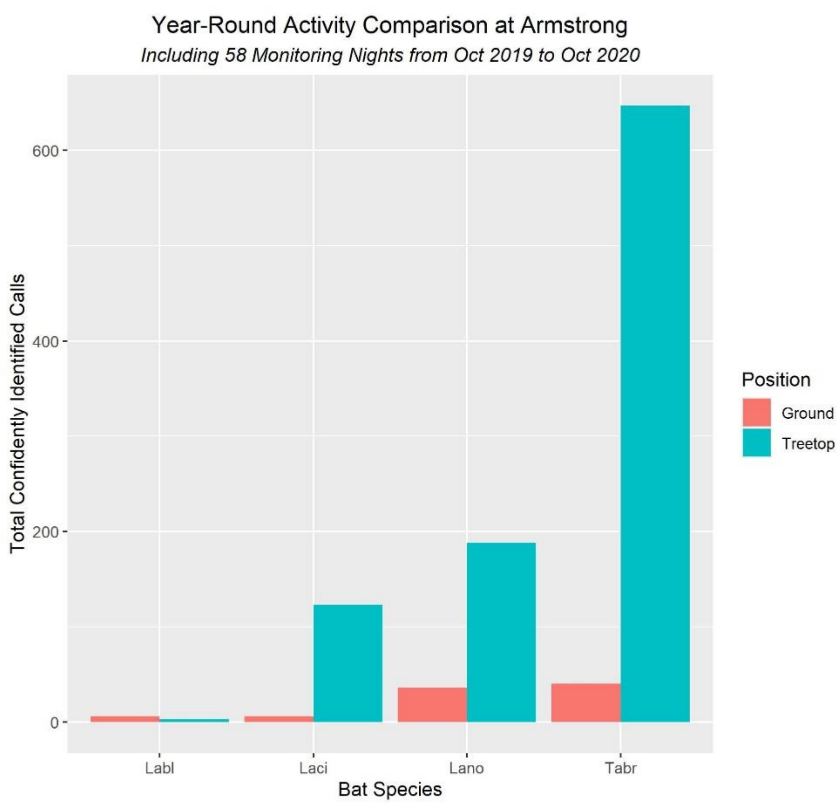


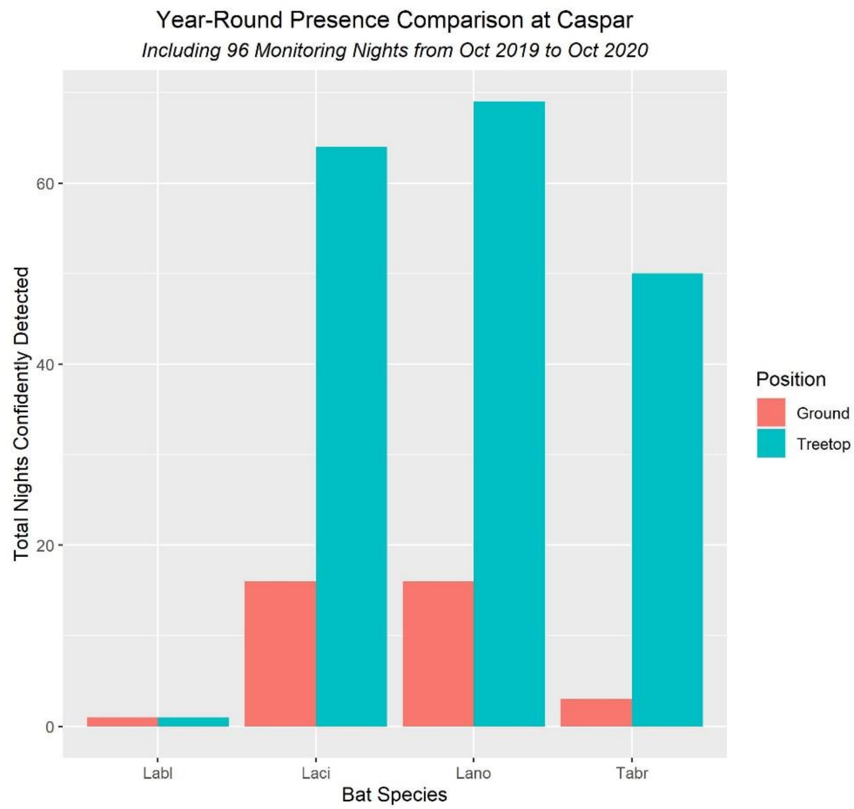
Figure 12: Species presence and activity results at MRC's Mallo Pass property. Differences in detection between paired ground and treetop detectors were evident even in a younger stand when the treetop detector was only 33 m above the ground.

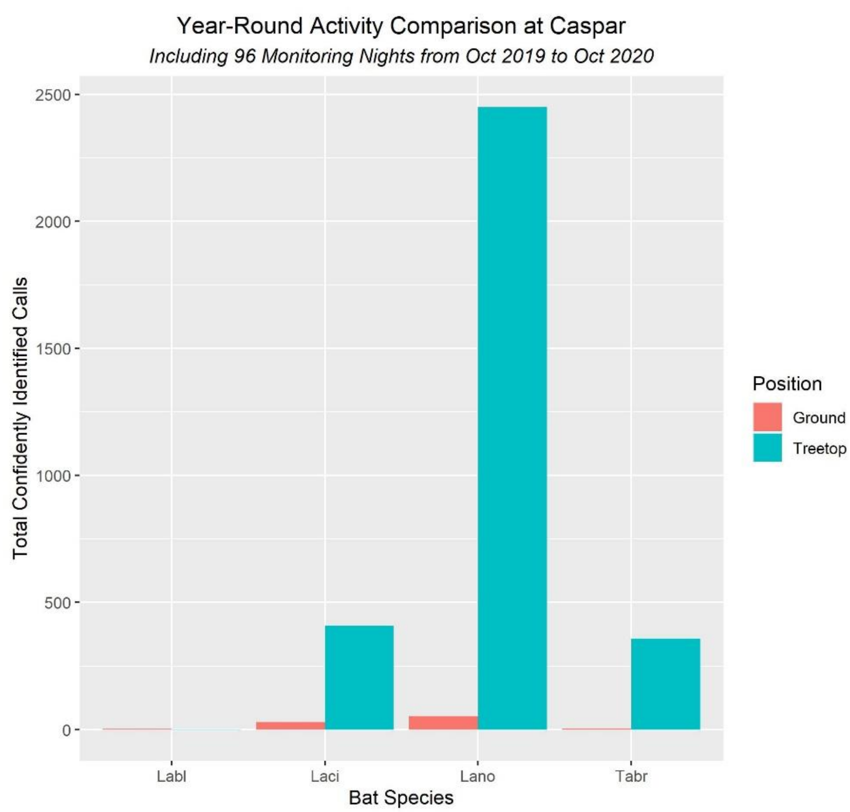

Year-Round Presence Comparison at Angelo
Including 58 Monitoring Nights from Oct 2019 to Oct 2020
Total Nights Confidently Detected
40
30
20
10
0
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop

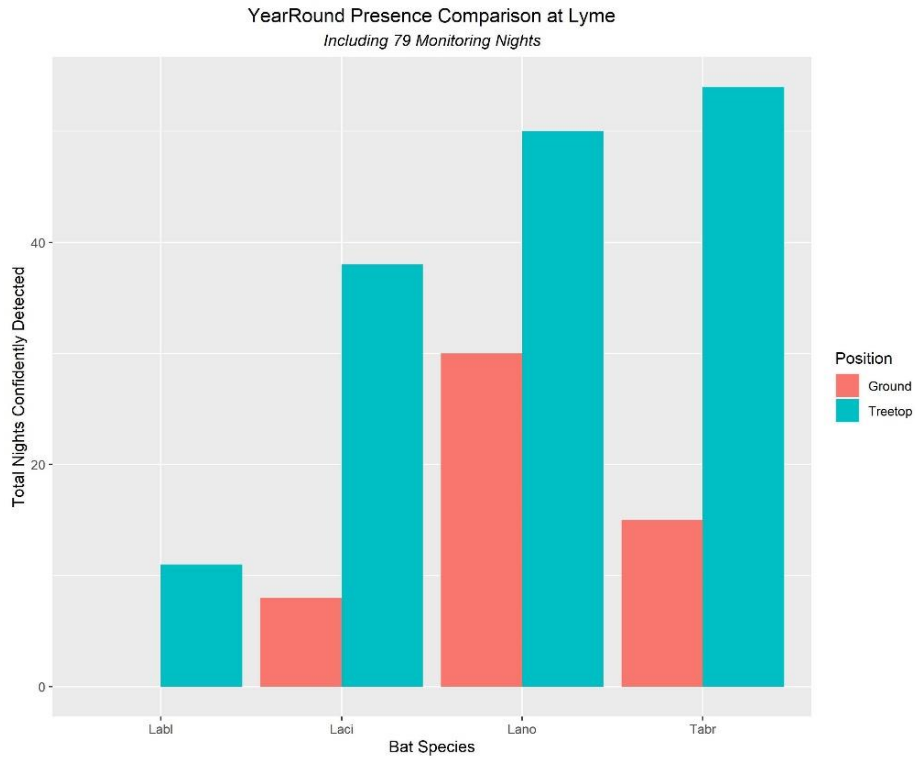

Year-Round Activity Comparison at Angelo
Including 58 Monitoring Nights from Oct 2019 to Oct 2020
Total Confidently Identified Calls
800
600
400
200
0
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop

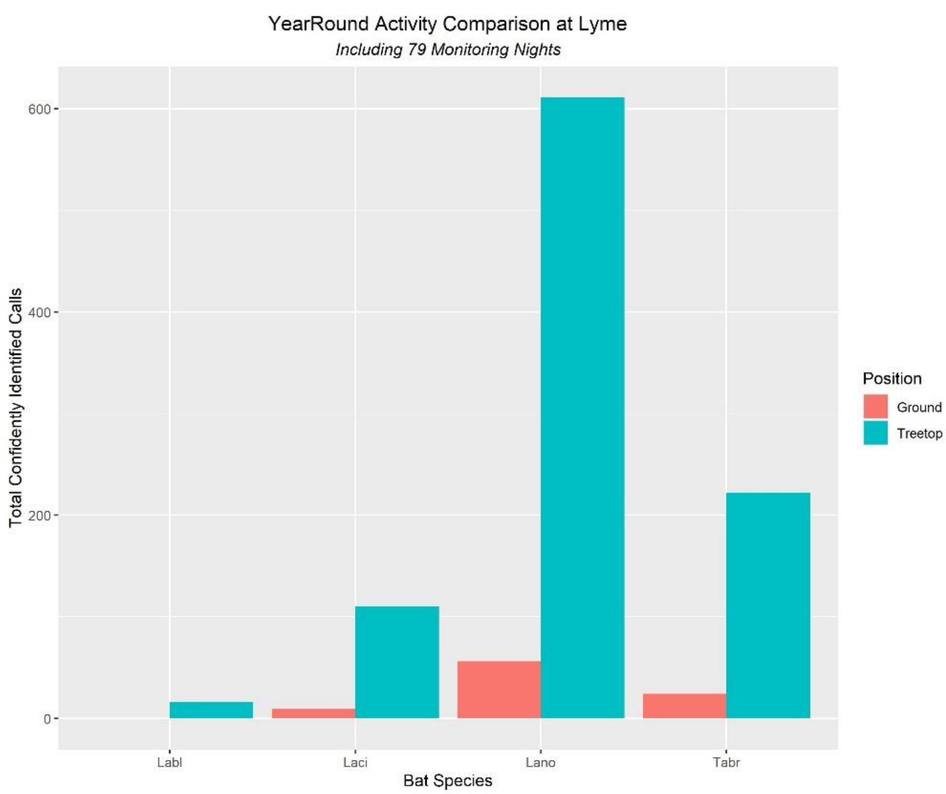

Year-Round Presence Comparison at Armstrong
Including 58 Monitoring Nights from Oct 2019 to Oct 2020
Total Nights Confidently Detected
0
10
20
30
40
50
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop

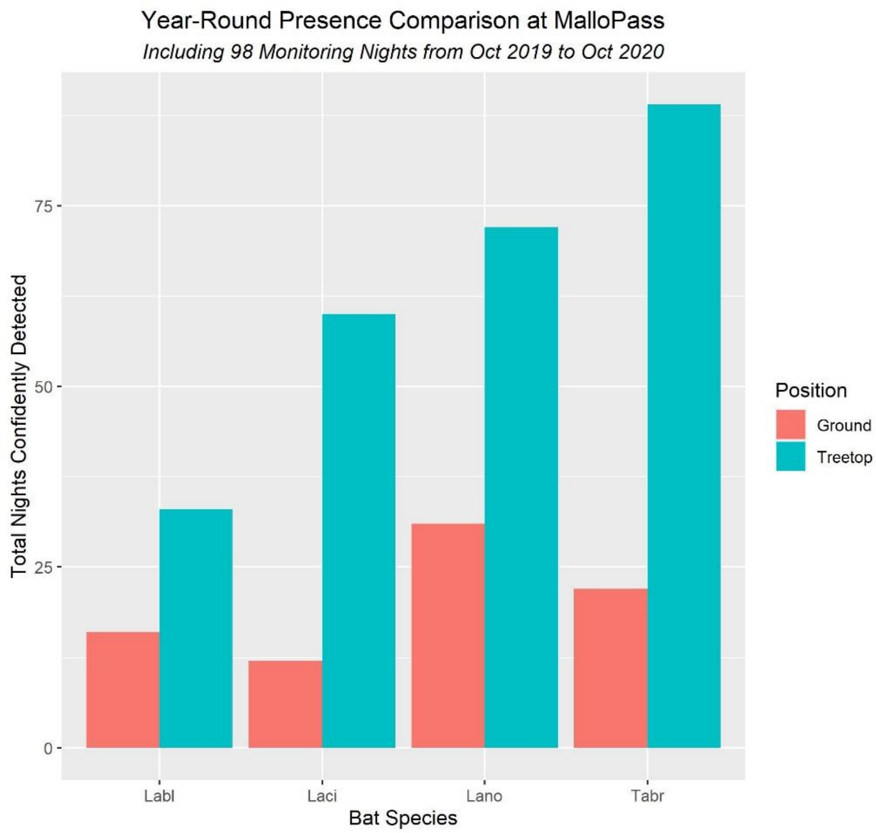

Year-Round Activity Comparison at Armstrong
Including 58 Monitoring Nights from Oct 2019 to Oct 2020
Total Confidently Identified Calls
0
200
400
600
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop

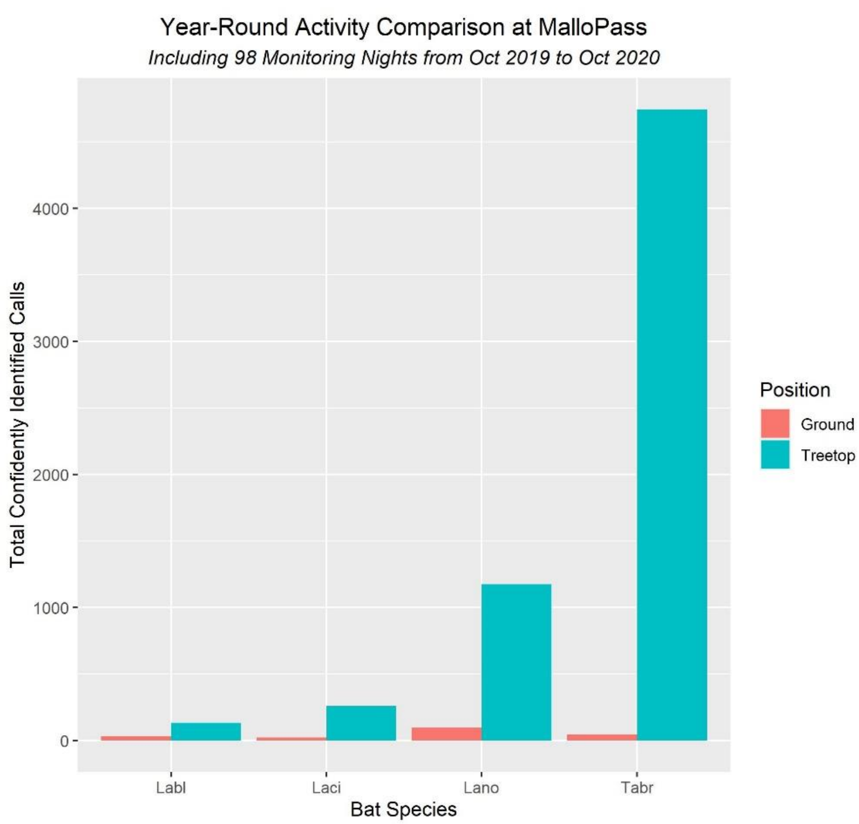

Year-Round Presence Comparison at Caspar
Including 96 Monitoring Nights from Oct 2019 to Oct 2020
Total Nights Confidently Detected
0
20
40
60
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop

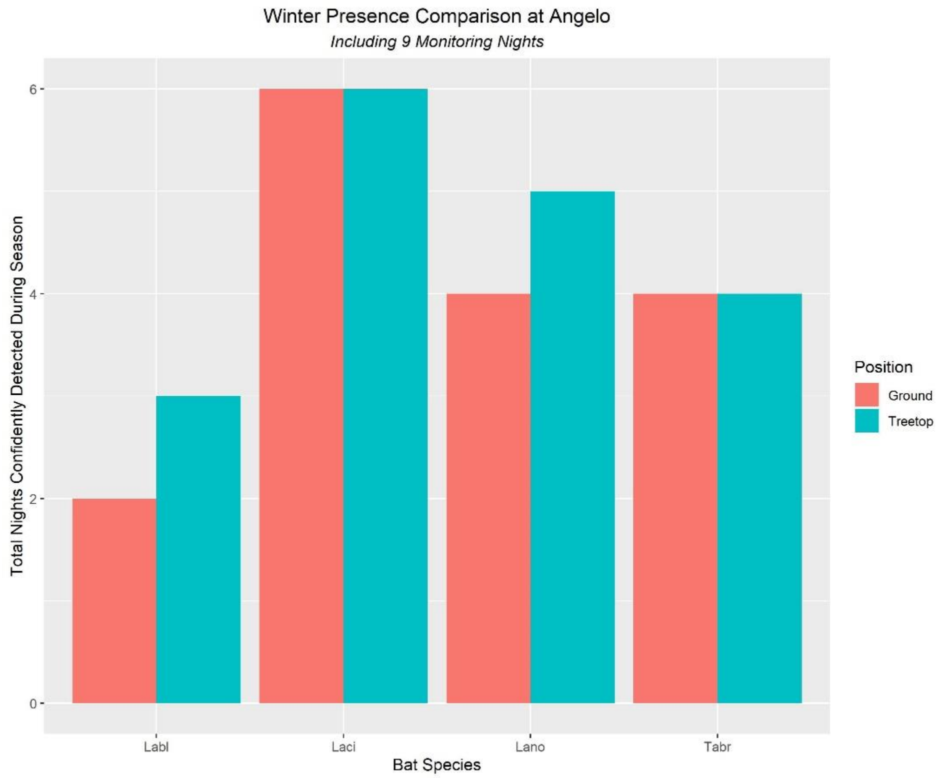

Year-Round Activity Comparison at Caspar
Including 96 Monitoring Nights from Oct 2019 to Oct 2020
Total Confidently Identified Calls
0
500
1000
1500
2000
2500
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop

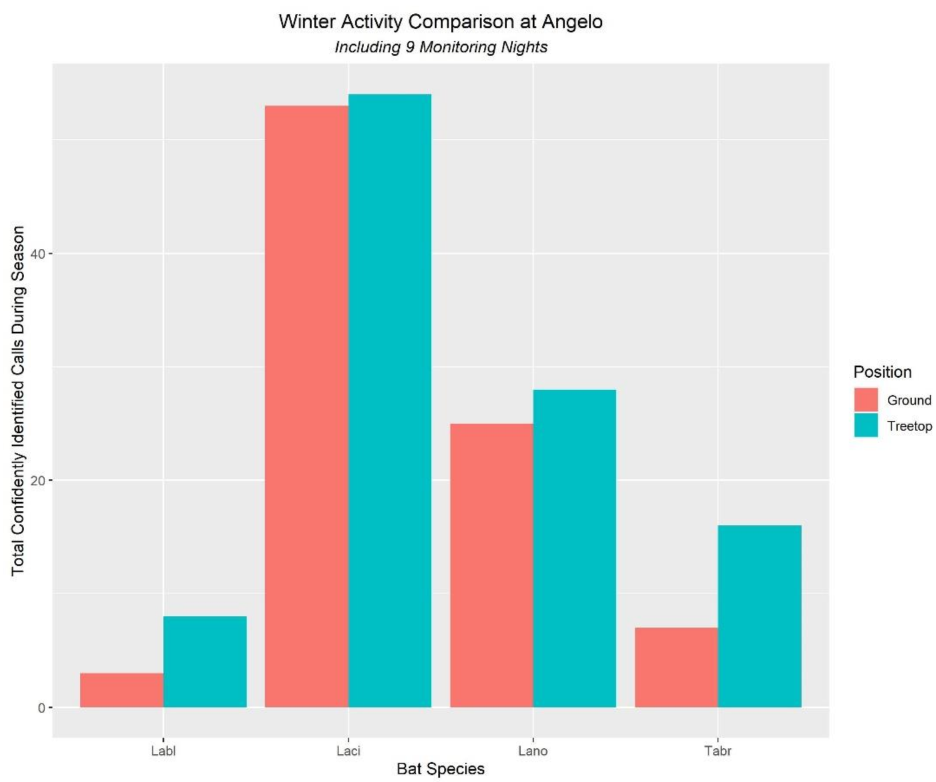

YearRound Presence Comparison at Lyme
Including 79 Monitoring Nights
Total Nights Confidently Detected
0
20
40
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop

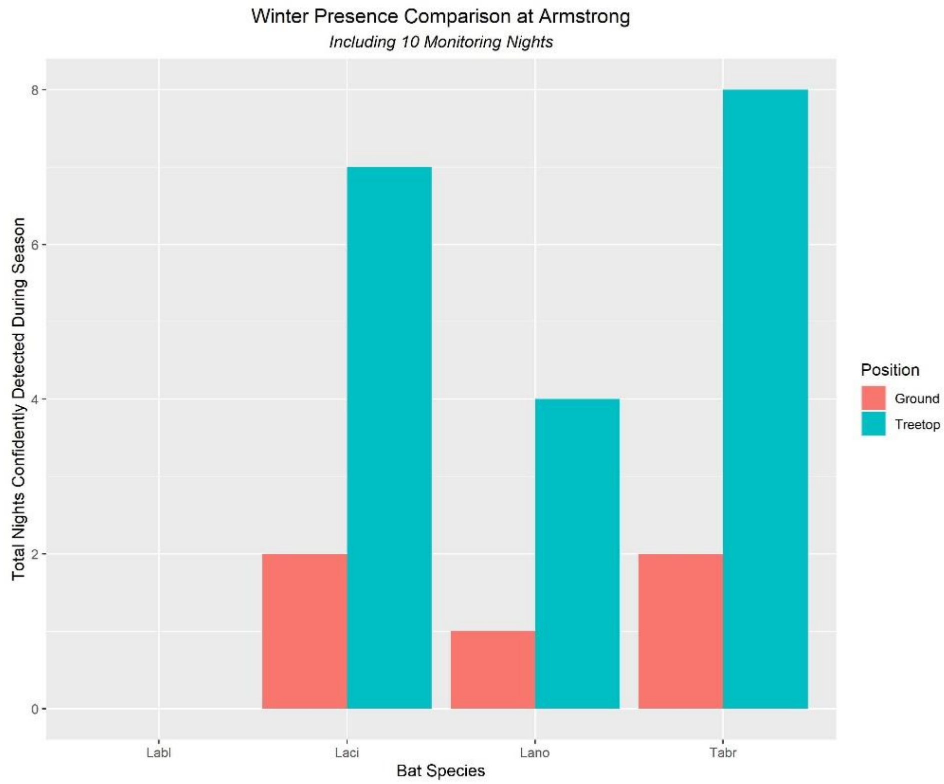

YearRound Activity Comparison at Lyme
Including 79 Monitoring Nights
Total Confidently Identified Calls
0
200
400
600
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop

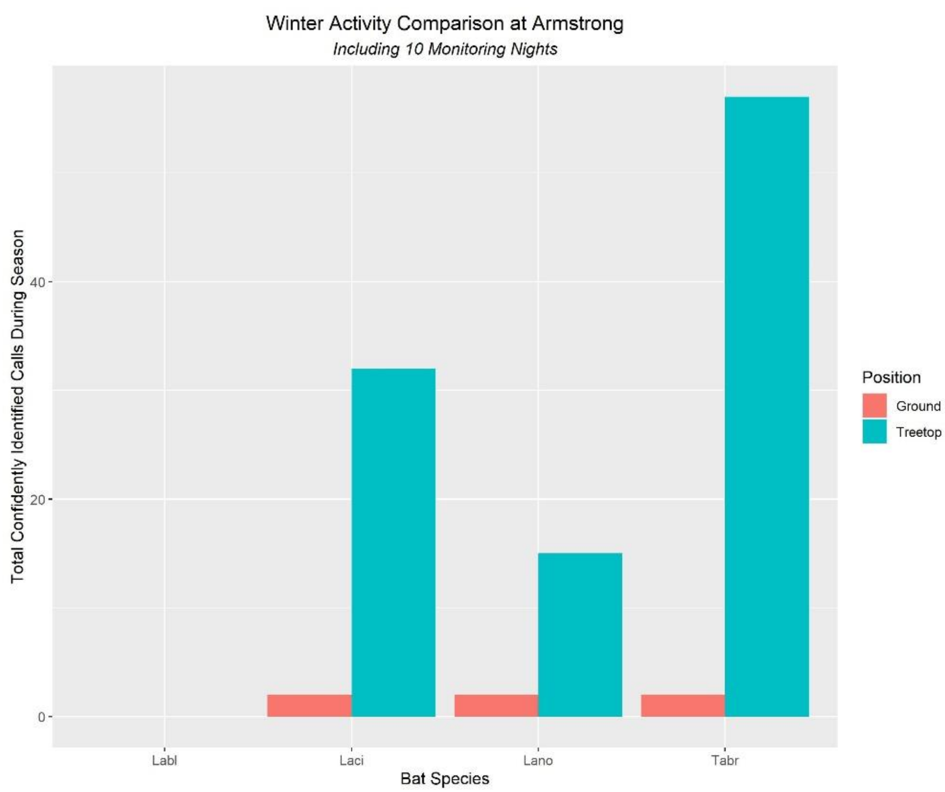

Year-Round Presence Comparison at MalloPass
Including 98 Monitoring Nights from Oct 2019 to Oct 2020
Total Nights Confidently Detected
0
25
50
75
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop

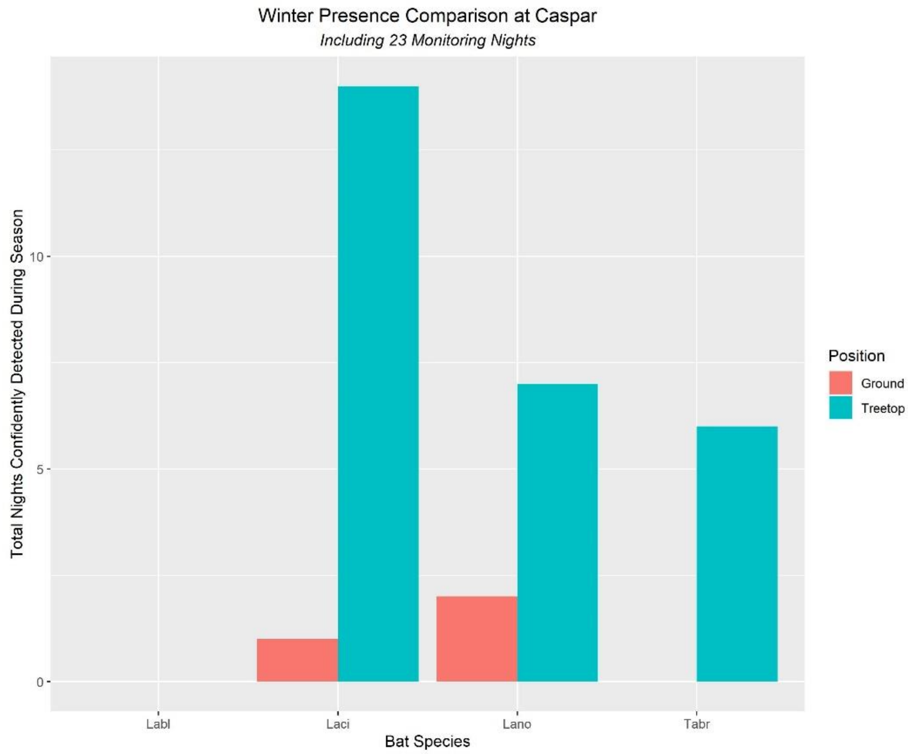

Year-Round Activity Comparison at MalloPass
Including 98 Monitoring Nights from Oct 2019 to Oct 2020
Total Confidently Identified Calls
0
1000
2000
3000
4000
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop

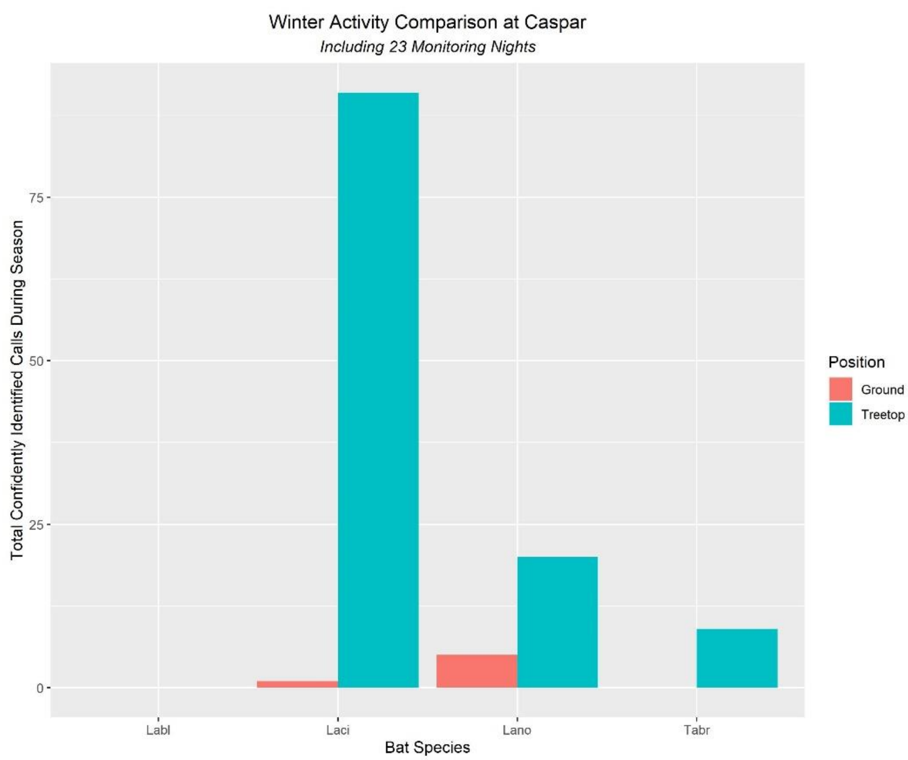

Winter Presence Comparison at Angelo
Including 9 Monitoring Nights
Total Nights Confidently Detected During Season
0
2
4
6
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop

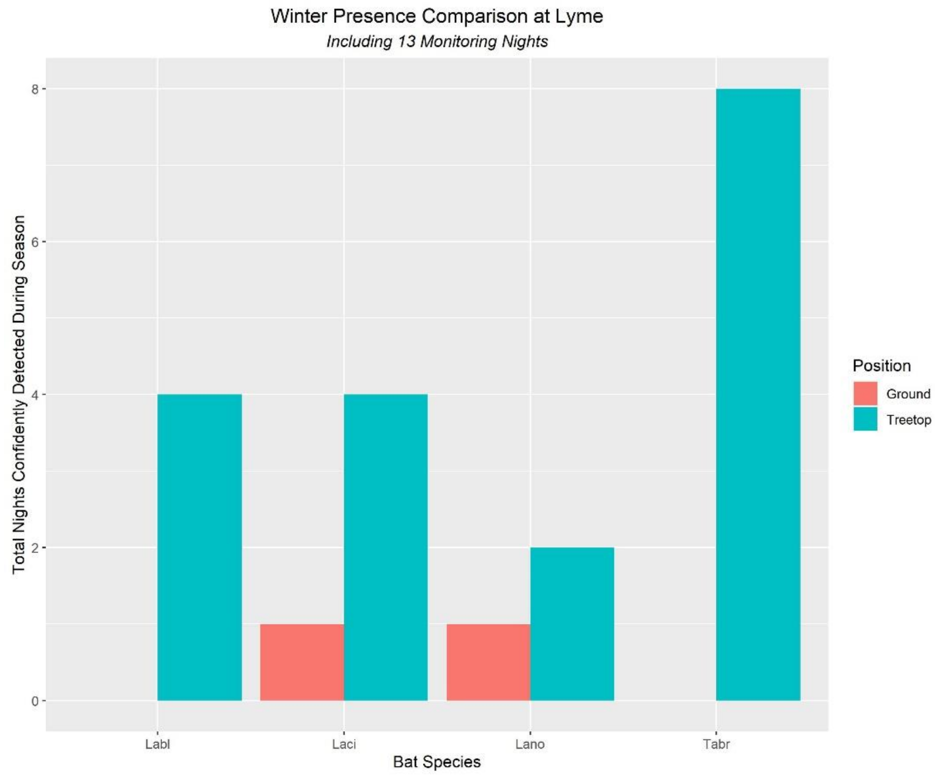

Winter Activity Comparison at Angelo
Including 9 Monitoring Nights
Total Confidently Identified Calls During Season
0
20
40
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop

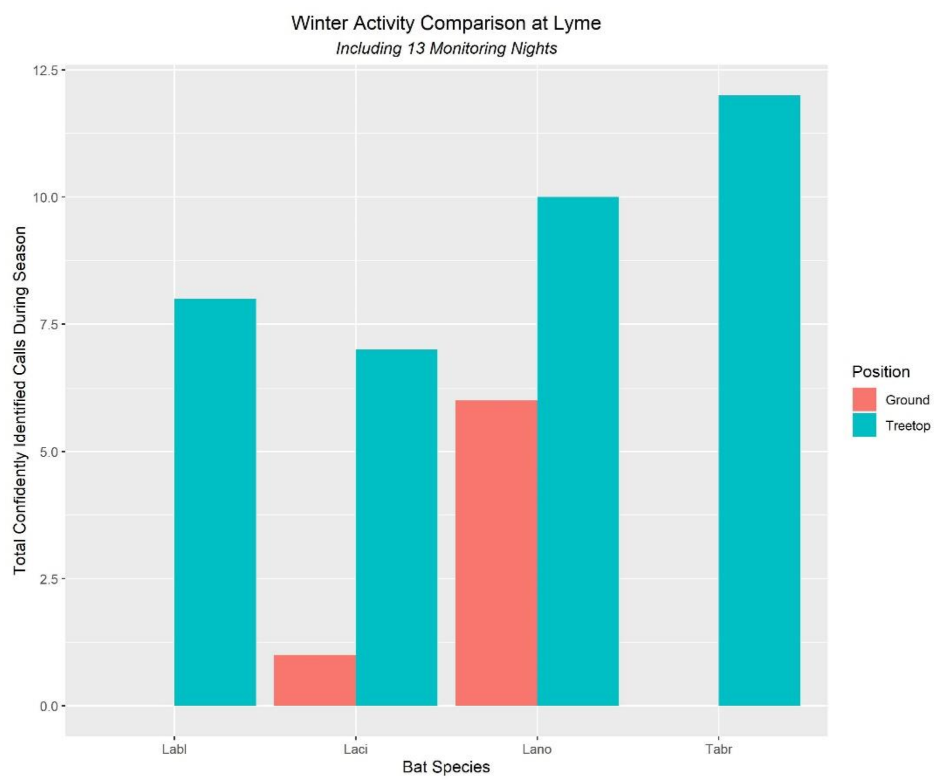

Winter Presence Comparison at Armstrong
Including 10 Monitoring Nights
Total Nights Confidently Detected During Season
0
2
4
6
8
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop

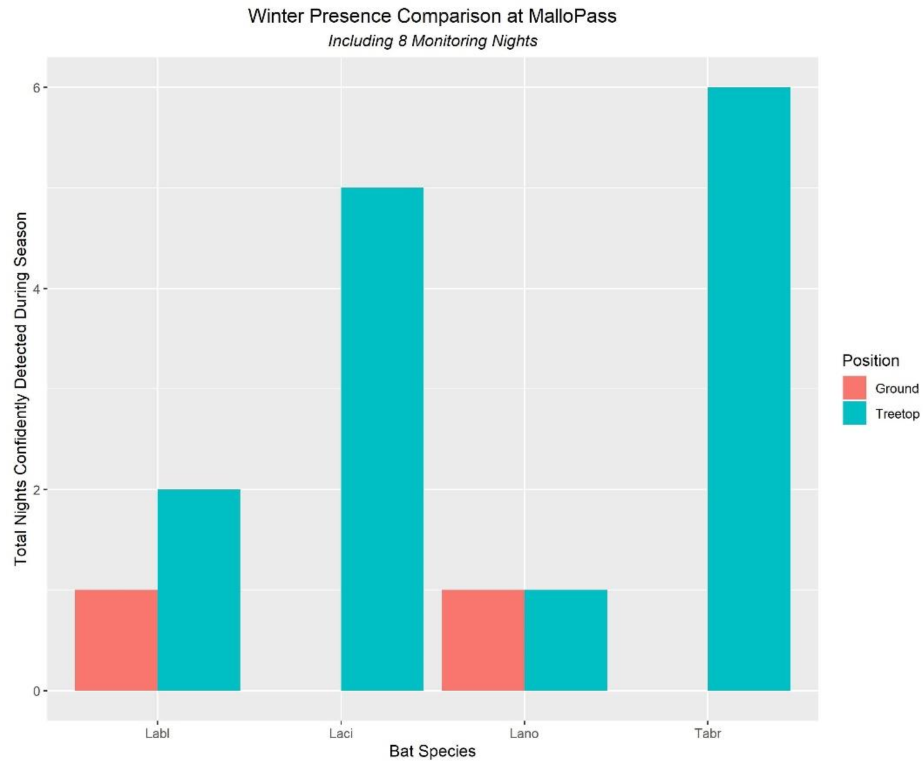

Winter Activity Comparison at Armstrong
Including 10 Monitoring Nights
Total Confidently Identified Calls During Season
0
20
40
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop

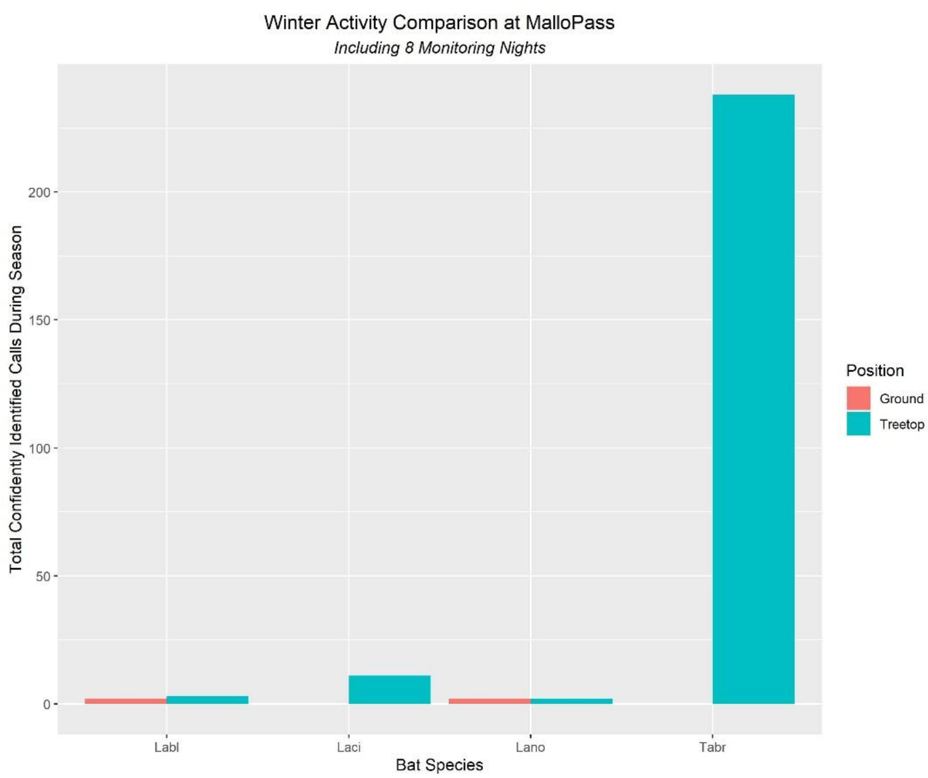

Winter Presence Comparison at Caspar
Including 23 Monitoring Nights
Total Nights Confidently Detected During Season
0
5
10
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop


Winter Activity Comparison at Caspar
Including 23 Monitoring Nights
Total Confidently Identified Calls During Season
0
25
50
75
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop


Winter Presence Comparison at Lyme
Including 13 Monitoring Nights
Total Nights Confidently Detected During Season
0
2
4
6
8
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop


Winter Activity Comparison at Lyme
Including 13 Monitoring Nights
Total Confidently Identified Calls During Season
0.0
2.5
5.0
7.5
10.0
12.5
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop


Winter Presence Comparison at MalloPass
Including 8 Monitoring Nights
Total Nights Confidently Detected During Season
0
2
4
6
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop


Winter Activity Comparison at MalloPass
Including 8 Monitoring Nights
Total Confidently Identified Calls During Season
0
50
100
150
200
Labl
Laci
Lano
Tabr
Bat Species
Position
Ground
Treetop

VII. Discussion

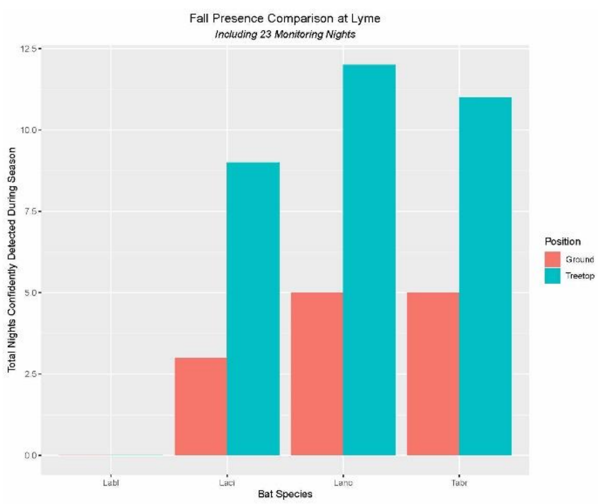
A key objective of this project was to investigate how the understanding of bat species presence and activity patterns in redwood forests that was based largely on studies in old-growth and other mature forests applies to younger, working forests. Only one previous study, Kennedy et al. 2014, has been published using treetop-based acoustic monitoring in a redwood forest. This study included two old-growth redwood trees in Humboldt Redwoods State Park and treetop detectors were installed 108 m above the ground[5]. By applying similar methods to a variety of forest management types in Mendocino and Sonoma counties, we have been able to show that the findings of the earlier study hold in younger, working forests, as well as other mature, protected groves. As found in Kennedy et al. 2014, ground-based deployment methods are highly effective at detecting *Myotis* species calls, but often fail to detect the presence of non-*Myotis* species, especially migratory species, relative to treetop detection methods.

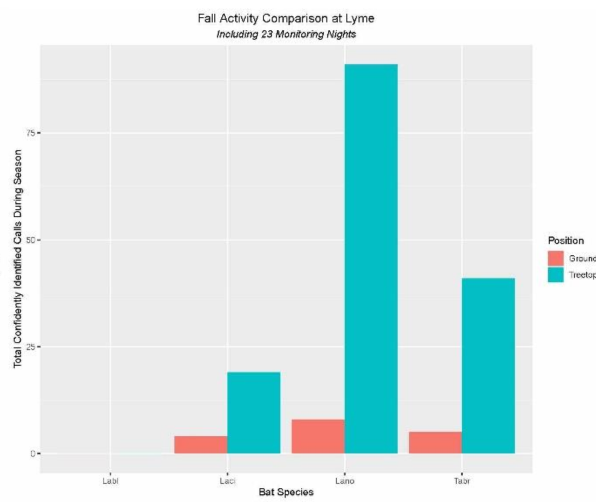
Kennedy et al. detected two species, *Lasiurus blossevillii and Tadarida brasiliensis*, that had no prior documented presence in coast redwood forests[5]. However, fieldwork for this study was conducted from April 2008 to November 2009, and there have been significant advancements in acoustic monitoring technology since this study was conducted. We have since found that these species, especially *Lasiurus blossevillii,* are regularly detected in coast redwood habitat using ground-based deployment methods, suggesting that our own detectors with their upgraded microphones are able to detect bats more effectively than what was used in the Kennedy et al. 2014 study. Total echolocation sequences recorded for their entire study were 3,769[5]. In contrast, in our study, each detector recorded 5,751 to 55,217 calls over the duration of the study (*see figure 13*). Given these demonstrated advancements in acoustic monitoring technology, it is even more notable that the findings of the earlier study still hold. Modern microphones are able to detect quieter calls and detect calls from further distances from the microphone, but standard ground-based deployment methods still fail to detect bat activity in the canopy and above treetop, even in relatively short redwood forests. This is likely biasing forest management to support *Myotis* species and undervaluing the importance of redwood forest habitat for tree-roosting species, including *Lasiurus blossevillii*, *Lasiurus cinereus* and *Lasionycteris noctivagans*, as well as the additional migrant *Tadarida brasiliensis*.

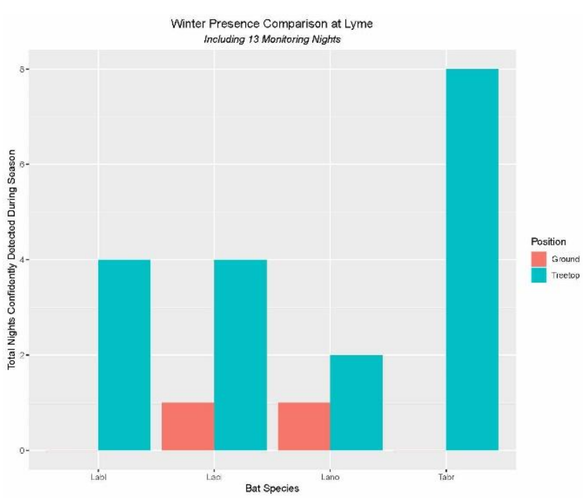
Treetop detectors were not only more effective at detecting high-flying species during migration periods. The differences between paired ground and treetop detection results held during all four seasons *(see figure 14 for an example)*. This also supports the finding from Kennedy et al. 2014 that the presence of larger, migratory species during November, February and March suggests that resident populations or inland migrants overwinter in redwood forests[5]. Furthermore, our study included the December-January monitoring period that the earlier study excluded, and we continued to see significant activity from not only known migratory species, but also a variety of other species, including *Myotis* species, during these months when bat activity levels have previously been presumed to be low.

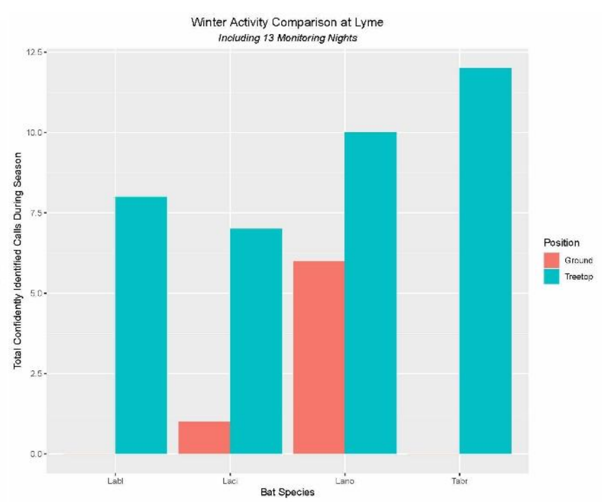
Site	Position	Total Nights	Total Calls Recorded
Angelo	Ground	114	29,089
Angelo	Treetop	166	19,244
Armstrong	Ground	106	5,751
Armstrong	Treetop	60	6,908
Caspar	Ground	99	10,201
Caspar	Treetop	102	16,180
Lyme	Ground	103	25,010
Lyme	Treetop	119	15,345
MalloPass	Ground	114	55,217
MalloPass	Treetop	155	23,426

Figure 13: Total functional monitoring nights and total bat passes recorded by each detector including the entire October 2019 to October 2020 monitoring period.









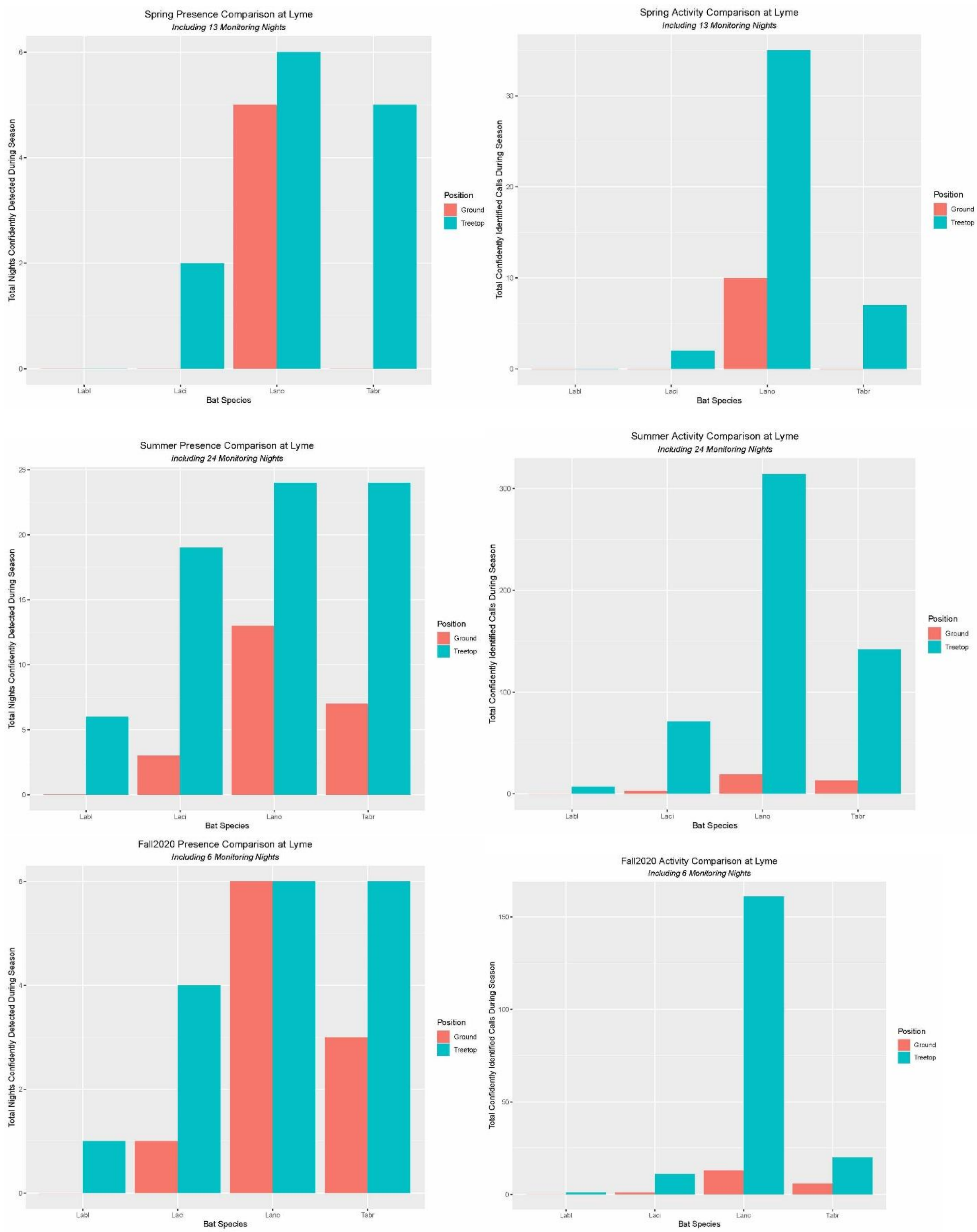


Figure 14: Using the treetop detector, we identified species presence on significantly more monitoring nights and identified more calls in all monitoring seasons (Fall 2019, Winter, Spring, Summer, Fall 2020), not only migration seasons.

VIII. Relevance to Conservation

Addressing concerns surrounding bat conservation is becoming increasingly important for forest managers as WNS spreads and climate disruption continues to worsen across the west[34]. For example, one of the species that was commonly found throughout the United States until the emergence of WNS, the little brown bat (*Myotis lucifugus*), is now at high risk of regional extinction in affected areas[35]. This species was frequently detected at our study sites, as were five other species known to be susceptible to WNS: *Eptesicus fuscus, Myotis thysanodes, Myotis volans, Myotis evotis and Myotis yumanensis*[2]. Rapid population collapses observed from emerging disease, and additional population declines predicted to result from climate change, have brought bats to the attention of landowners who may be facing Endangered Species Act regulations in the not-too-distant future. Our study has provided baseline monitoring of bat community composition and occupancy patterns in North Coast forestlands where no previous bat monitoring record existed. In particular, the species detection and activity results of our study sites have demonstrated that young, working forests also serve as critical habitat for sensitive bat populations, and managing these forests for bats may thus be as important as managing in mature, protected areas.

Furthermore, the results of our paired ground and treetop monitoring study indicate that bat researchers may have previously underestimated the value of coastal habitat in Northern California for the winter season. By monitoring at treetop, significantly more activity was detected in the winter from not only the presumed migratory species, *Lasiurus blossevillii*, *Lasiurus cinereus*. *Lasionycteris noctivagans*, and *Tadarida brasiliensis*, but also *Myotis* species. We will continue to analyze these results to investigate how activity patterns relate to microclimate conditions by using the temperature and humidity data that we actively recorded at out monitoring sites. If bats are actively foraging in the winter at these coastal locations, these populations may be more resilient to WNS and conserving coastal habitat for bats may therefore be particularly important as WNS increasingly impacts western bat populations.

We are continuing to analyze the results of our study. In particular, our next steps include applying statistical models to investigate how bat species presence and activity relate to climate, forest management and other environmental variables. In addition to the temperature and humidity data that we actively logged at each monitoring site, we will use historical climate data to better understand species presence across the coast redwood range. To study the relationship between bat activity and forest management, we are using LiDAR data to derive canopy height models and using Timber Harvest Plans that are publicly available as GIS records to quantify forest disturbance at study sites. Because the size of the stream channel seems to significantly influence bat movement and foraging activity, and our capacity to detect bat calls increases in open space such as a large riparian corridor, we are also in the process of deriving metrics for the stream channel width at each monitoring location. Once we have finished building our Generalized Linear Mixed Models with these covariates, we hope to have a better understand of the drivers of bat species presence and activity patterns in coast redwood forests. These findings can then be applied to identify priority redwood habitat to support bat conservation and to predict the impact of climate change on North Coast bat populations.

IX. Future Work

Because our study was limited to monitoring at the riparian corridor, our research has raised additional questions regarding how bats are using the interior forest habitat, especially in young, working forests. It was unclear from our acoustic monitoring design whether bats detected in young, working forests were merely passing through while foraging or moving between roost sites, opposed to roosting on the property. Next steps for investigating this might include roost assessment and radio tracking of individual bats, as well as additional acoustic monitoring at both ground-level and treetop farther from the riparian corridor.

Similarly, how does prey availability compare between young, working forests and mature, protected sites? This was a research component that we had intended to include in this study, but we did not have the capacity for incorporating this after covid-19 complicated our summer 2020 field season. Understanding how prey availability compares not only between actively logged and protected sites, but also across the coastal gradient from high fog to low fog areas, would provide additional insights into what is driving bat species occupancy patterns across the redwood ecosystem.

We are using publicly available LiDAR data to derive canopy height models because we expect this to also serve as a proxy for forest maturity, but there are other metrics of redwood habitat that influence bat activity. If other structural assessments of redwood habitat, such as tree density, DBH, tree and vegetation composition, and stand age, were available, these could also be incorporated into statistical models to understand how bat activity relates to forest habitat.

Also, we are using publicly available Timber Harvest Plan records as a metric of forest disturbance, but the CalFire GIS database does not include records before 1997[36]. That means that some of our “mature, protected” study sites may have been logged in recent history and we are not accounting for this in our current analysis. How do our findings of the relationship between bat activity and forest disturbance compare when historical logging records are also included? What value does old-growth redwood habitat provide that even relatively old, second-growth redwood habitat does not fulfill before truly mature features have developed?

There are other more direct impacts of forest management practices on bats that might also be studied in the future. How does logging change the microclimate at a site? How do timber harvest and silvicultural practices influence insect prey availability?

Finally, using findings from this study on how bat species occupancy relates to climate and microclimate variables of temperature and humidity, what changes in species ranges are predicted with climate change projections?

X. DELIVERABLES

Deliverable	Planned Completion Date
Hosting property owner/staff at bat mist netting events	Completed for summer 2019
Data shared with property owners and League	Completed for summer 2019. Ongoing for 2019/2020, to be completed in Spring '21
Popular articles and short videos on bats in redwoods for public	Personal social media on fieldwork November 2019 – October 2020. Social media posts for natural history museum in February 2021. ESRI story map planned for summer 2021.
Peer-reviewed scientific manuscript(s)	Fall '21
Data uploaded to Bat Acoustic Monitoring Portal for other researchers	Fall '21

COVID-19 significantly impacted our planned outreach as we have not been able to bring additional property owners/staff to bat mist netting events since summer 2019. We did have Forest Service and CalFire staff check out our canopy research project at Jackson Demonstration State Forest as we set it up in October 2019, and we have been able to informally engage with California state park staff and public visitors while at Armstrong Redwoods State Natural Reserve over the course of the year-round project.

We already shared the results of mist netting and acoustic analysis from our summer 2019 fieldwork with each property owner. We provide all property owners with the preliminary analysis of species detected and number of bat passes per species per monitoring night at their site. We are in the process of doing this again with our summer 2020 fieldwork data and our year-round project data, and we will make all of these reports available to the League once that is finished.

During November 2019 – October 2020, we actively maintained an Instagram account (@fieldnotes_chiroptera) documenting our fieldwork on bats in redwood forests, including photos and videos from the year-round canopy research and our summer study sites. In February 2021, we contributed blog-style social media posts (Facebook and Instagram) about bat field research in California redwood forests to a natural history museum based in Wyoming, Buffalo Bill Center of the West. This was part of a public outreach effort by one of the UC Berkeley lab groups with which Chelsea is affiliated. However, we would still like to do something similar for an organization in California. If the League is interested, we could discuss whether an entry on this topic is appropriate to submit for the League's Giant Thoughts blog or for the League's social media. We intend to create an ESRI Story Map on this project because we believe that multimedia format would be effective for communicating the story of this landscape scale research and its findings to a broader audience, and we believe that could be shared to the public in summer 2021.

In addition to the outreach efforts originally proposed for the grant award, we have also been presenting on our research at various conferences and bat researcher/professional meetings. We have presented on this project at the North American Society for Bat Research (October 2018), The Western Section of the Wildlife Society (February 2019), and the Bay Area Conservation Biology Symposium (April 2019). Our planned conference presentations for 2020 were unfortunately cancelled due to the COVID-19 pandemic, but many meetings are now resuming in a virtual format. We will be presenting at the California Bat Working Group meeting on March 2, and recently submitted an abstract for the Western Bat Working Group meeting (April 2021).

XI. BUDGET

What	**Proposed**	**Actual**
Acoustic bat detectors w/ mics	$4,912	$1,792.01
Accessory detector supplies	$639	$1,194.41
Power supplies for canopy	$1,611	$1,086.61
Set up supplies for canopy detectors	$600	$1,118.46
Professional assistance for tree rigging and canopy project set up	$0	$2,327.85
iButton hygrochron sensors	$700	$638.54
Mist nets (12 m)	$331	$0
Transportation to field sites	$3,411	$11,042.28
O-18 & H-2 isotope analyses	$4,752	$0
Part-time undergraduate assistant	$3,300	$0
25% GSR summer salary (Chelsea)	$4,621	$4,707.12
1.55% GAEL	$123	$71.24
Shipping Fees		$117.80
Campus stockroom purchases		$199.40
Other field supplies		$704.28
Total	$25,000	$25,000.00
Total to be reimbursed to the League		$0.00

Budget Justification

We spent the full amount ($25,000) awarded for this project, but we did have a few changes in how our budget was ultimately allocated. As explained above, we were unable to do the proposed stable isotope analyses or hire an undergraduate assistant for summer 2020 as planned, which is why the actual funding spent on these items is $0.

The funding spent on mist nets and for acoustic bat detectors is similarly much lower than budgeted, but that is because we were able to leverage the results of our summer 2018 pilot season funded by Save the Redwoods League and this full study proposal to also receive an award from the Carol Baird Fund to Support Graduate Field Research. The Carol Baird award supports field research at the Berkeley Natural History Field Stations, including Angelo Coast Range Reserve, which had been included in our full study since our pilot season in summer 2018. By including components of the year-round canopy research project under this grant, we were able to cover some fixed equipment costs, such as the mist nets, acoustic detectors, and climbing gear for the canopy research project. That has been quite fortunate because the expenses for the canopy research project were significantly more than we had originally budgeted. This included needing to hire professional assistance to rig a redwood tree at each of our five year-round canopy study sites. We hired Anthony Ambrose of Canopy Dynamics, LLC to do this critical work, and Anthony helped Chelsea to install the equipment at treetop in such a way that she would be able to afterward do monthly data collection and equipment maintenance with only a volunteer for ground support.

The transportation costs also ended up being significantly more than we had anticipated. This budget item included personal vehicle mileage reimbursement for Chelsea, as well as for essential volunteers. The increase expenses reflect the extended study which ultimately included two summer field seasons involving at least four site visits to each of 20 sites in Sonoma and Mendocino counties for summer acoustic monitoring plus additional mist netting nights, as well as the 12-month study which required a monthly round of visits from Berkeley to the five field sites. Although Chelsea was based in Mendocino for the summer field seasons and strategized rotation of acoustic monitors to be efficient as possible, the mileage required to conduct this research made us appreciate the full extent of our two-county landscape study design.

XII. References

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