USING ACOUSTIC SAMPLING OF BAT ASSEMBLAGES TO MONITOR ECOSYSTEM TRENDS

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1.0 INTRODUCTION

Analysis of recordings from ultrasound detectors is now widely applied to assessing bat distribution and activity over a range of time scales in various landscape contexts. At a national scale, recordings from labor intensive walking detector transects conducted by trained volunteers have provided the basis for annual distribution maps and records of changes in activity by species in the United Kingdom for several years (Bat Conservation Trust 2008) as part of multi-species biomonitoring programs. Statistically significant changes in bat species activity that suggest declining population trends or reveal limited ranges may warrant targeted investigation and shape allocation of conservation funding support. In the UK, Ireland, and continental Europe parallel volunteer based efforts implementing and evaluating designs for vehicle detector transects for roadside mammals and walking detector surveys adjacent to water bodies for water skimming bats are in progress (e.g., Roche et al. 2009).

A complementary approach to bat activity monitoring employs low power, unattended passive ultrasound recording systems deployed for intervals of nights to months (e.g., Duchamp et al. 2006, Frick et al. 2008, Gorresen et al. 2008, Johnson and Gates 2008). This approach has been widely used for inventory in the National Park system, but in the context of global change, it offers the possibility of relatively efficient simultaneous long term monitoring of population trends of otherwise cryptic highly mobile species that are a large fraction of mammalian diversity.

The objectives of the project were:

1. Complete development of a Windows™ interface for AnaLook software that will enable non-expert users to analyze and interpret long-term acoustic monitoring data.
2. Refine existing filters and develop new filters to automate the process of identifying individual bat species from acoustic detection records.
3. Develop an MS Access database application to store, manipulate, and prepare acoustic records for analysis.
4. Develop a statistically robust sampling framework that is capable of detecting changes in the species composition of the bat assemblage inhabiting a given area.
5. Identify statistical methods for analyzing data on presence/absence within bat assemblages to detect trends in species composition

Although the field trials that we ran to develop a sampling framework for long-term monitoring were conducted in Yosemite National Park in California, and were designed around site characteristics specific to that park (and by necessity provided data on the bat fauna specific to that area), our goal was to develop an approach that could be adapted to multiple habitats with different bat assemblages.

2.0 ACOUSTIC MONITORING EQUIPMENT

A passive acoustic monitoring system, for extended deployment was based on AnaBat system components (AnaBat II detector and ZCAIM zero-crossing analyzer; Titley

Electronics, Ballina, NSW, Australia) in a NEMA-rated gasketed weather tight enclosure (assembled EME Systems, Berkeley, CA). This system is powered by a 12V sealed lead acid battery, and provided with cables extending through the case wall for an external 5 watt solar panel, microphone extension, and (on four units from a prior project) a digital temperature/humidity sensor (Sensirion, Inc., prepared by EME systems) (Figure 1). The AnaBat II detector is a broadband frequency-dividing ultrasound detector with a companion data storage unit that uses Compact Flash memory cards. It has been widely employed for bat distribution and activity assessments, including multiple NPS site inventories (e.g., Gorresen et al. 2008, Rodhouse et al. 2005).

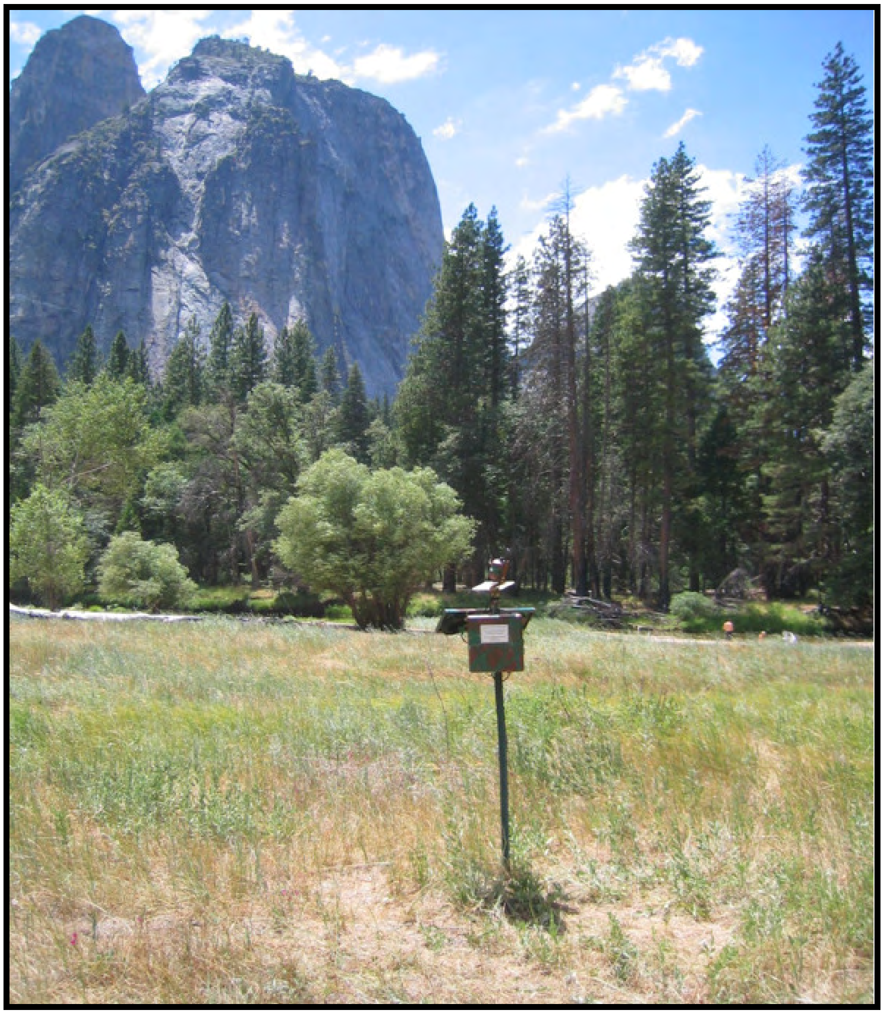


Figure 1. Acoustic monitoring system on floodplain at Woski Pond, Yosemite Valley, 18 July 2007.

For this project, EME Systems upgraded the detector 12 volt input to a higher efficiency low dropout regulator to reduce power drain (www.emesystems.com/bat-hat.htm). The ZCAIMs were also modified to allow external activation and shutdown by a multi-channel data logger/controller (OWL2pe) with custom firmware. Based on user entry (via a serial communications link) of the sampling site geographical coordinates, the logger firmware determines the monitoring schedule by calculating a local sunrise/sunset table, with a user selectable (positive or negative) offset from those values in minutes. Thus, either because of known patterns of local bat activity or topography and vegetation affecting light levels near sunset and sunrise, the user can, for example, begin sampling 20 minutes prior to sunset and end 20 minutes after sunrise. All systems in this project used that offset value.

Firmware allows logging internal enclosure temperature, battery voltage, ZCAIM activity status, and output from any external sensors at user selected intervals. The logging interval for project deployments was either 20 or 30 minutes. Several firmware enhancements were developed consultatively by EME Systems during the course of the project and uploaded to the monitors. One firmware upgrade for data quality was frequent testing of battery voltage. The firmware halts data collection until the next night if the voltage drops below a user-selected value thus avoiding sampling when low voltage would reduce detector sensitivity.

All systems were equipped by EME systems with a 5 m microphone extension cable, microphone weather shroud, 14 cm square plastic reflector plate and a bracket for attachment to a mast. The bracket maintains the microphone at a 45 degree angle to the reflector plate. The plate is pitched at 15 degrees from the horizontal to lessen accumulation of snow and ice. This arrangement orients the axis of the detection volume upward away from the microphone and the meadow surface at ca 30 degrees.

All microphones were Titley Lo-Mics that lack suppression components for audible range frequencies (20 Hz-20 kHz) typically incorporated in bat detector microphones or circuits. Much of western North America has one or more bat species that call predominantly in the audible and are more frequently recorded without the low frequency roll off. In Yosemite, these include spotted bats, mastiff bats and, to a lesser extent, hoary bats, plus social calls from several other species (e.g., pallid bats). To retain more detail in the structure of low frequency calls (and thus potentially enhance automated detection), the frequency division ratio of the detector was always set to 8 (i.e., the number of transitions of the input signal was divided by 8 in the output to the storage unit). The detection system suppresses frequencies below 4 kHz (with little impact on bat calls). A consequence of the low frequency microphone is that audible range insects, bird or mouse calls, and leaf rustle from wind or passing wildlife are also better detected.

The eight microphone extension assemblies purchased for the project include a low power, low output impedance ‘line driving’ preamplifier circuit potted in the shroud. This minimizes high frequency attenuation that might result from the 5m extension cable with the standard microphone. Prior testing demonstrated that the Lo-Mics show no high frequency loss with a 5m extension of this cable even without the preamplifier, but its presence assures that the equipment will perform similarly with either microphone in the future. Four of the twelve monitors used in this study were assembled by EME systems for a prior study and included microphone extension systems without the preamplifiers.

At the beginning of each field trial, each monitor was evaluated, both in terms of physical condition (e.g., animal bite marks on microphone cables, bear damage or vandalism of microphone bracket angles) and performance. The metalized Mylar™ microphone diaphragm is the most delicate element and is necessarily exposed to weather and sun. Damaged microphones (e.g. diaphragm wrinkled or losing metallization, physically intact, but noisy or low sensitivity) were replaced and all units (with the microphone on the extension cable) were simultaneously calibrated to a common sensitivity with a 40 kHz battery operated ultrasound emitter. Recalibration (requiring removing all installations from all sites for simultaneous comparison) was not done for microphone replacements or temporary detector or extension swaps for repairs during trials (e.g., ice accumulation or bear damage).

The initial trial extended through a winter and revealed several instrumentation issues. Most of the new lot of six detectors showed recorded signal anomalies (both gaps in low frequency calls and frequency offset 'ghosts' of bat calls). Extended investigation with the collaboration of EME Systems and Titley Electronics revealed these resulted from factory component changes with unforeseen consequences. Once repair procedures were identified, we sequentially exchanged defective detectors with a small set of non-project functional units, then repaired, tested, and replaced them.

With precipitation under cyclic freezing, we observed instances of ice accumulation on the sloping reflectors that rarely covered and apparently damaged microphones. The mechanism of damage is unclear, but the microphones sometimes filled data cards with static in a few nights, leading to data gaps in the initial field trial (Figure 2). We explored reducing accumulation first by smoothing the reflector edges, then by making the reflectors less wettable with a covering of Teflon film. As an alternative, we substituted reflectors of high density polyethylene sheet, a lower surface energy plastic than polycarbonate. Observations of large accumulations never recurred, perhaps because subsequent trials included no or fewer months of winter monitoring or the events were caused by atypical precipitation.

Figure 2. Ice accumulation on microphone reflector, Hodgdon Meadow, 28 November 2006.

Monitoring systems were downloaded periodically based on weather severity, storage card size, site, season and expected data accumulation rate. Cards were downloaded to a laptop on site and interpreted call files examined for quality and possible hardware problems. After data integrity was verified, cards were erased and reinstalled (Figure 3). Crystal controlled clocks in both the zcaim and the Owl logger were updated by serial link periodically. Clock drift was typically near 1minute/month fast. A serial GPS link to the zcaim added station coordinates to the file on the card. Data stored in the Owl memory was also downloaded periodically, more frequently in fall and winter to follow battery status. In warm seasons the panels were cleaned to remove pollen and bird guano. At sites where guano deposition was sufficient to impair solar recharging, the upper margin of the solar panel and the top of the microphone shroud were fitted with stainless steel spring wire helices (Figure 4) to reduce perching by birds.

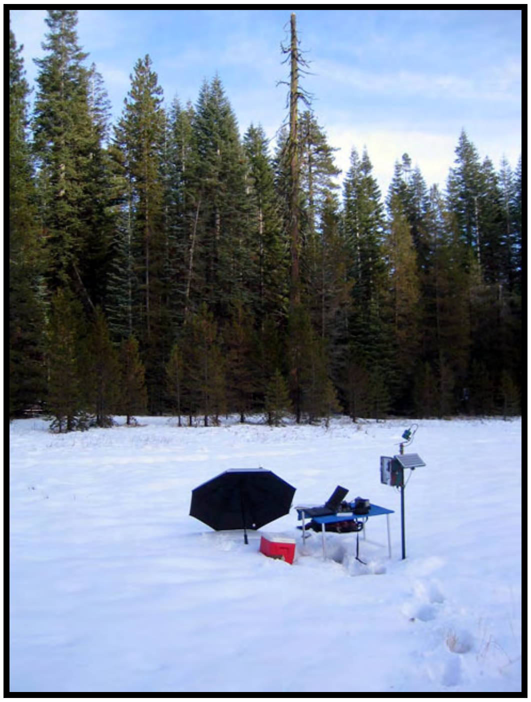


Figure 3. Doghouse Meadow data collection and system testing, 14 December 2006.

Figure 4. Spring wire helix on solar panel upper margin to lessen bird guano deposition, 19 Sept 2007.

Systems purchased for the project had larger NEMA enclosures that enclosed a 7 Ahr battery (Figure 1). This was adequate storage for low sun angle inclement weather episodes at open sites, but insufficient at meadow edge sites with marginal solar exposure in late Fall. Four monitors used were from an earlier project and had smaller enclosures, so either a 7 Ahr gel cell was mounted externally on top of the case or an 80 Ahr deep cycle battery in an outdoor enclosure was on the ground attached to the base of the 6 foot steel T-bar fence post used as a mast for all enclosures. Raising the microphone and reflector an additional several meters on a taller mast would likely have reduced recording of birds and insects and probably enhanced call distinctiveness for some bat species (Jensen and Miller 1999). Installation of the T-bar posts was simple and left minimal impact when removed. A taller, more robust mast and anchoring system raised concerns about visual intrusiveness of temporary installations. Enclosures, microphone shrouds, and the underside of the panels were painted green and brown and carried a label identifying the equipment as research bat monitors and providing local NPS contact information.

3.0 CALL ANALYSIS SOFTWARE

Project objective #1 was development of a Windows™ interface for AnalookW software that would enable non-expert users to analyze and interpret long-term acoustic monitoring data.

Design goals for the AnaBat™ detection system included minimizing data storage, electrical power requirements and device complexity while retaining adequate information for species identification from bat (and other predominantly ultrasonic) animal sounds. The mode of signal capture and representation chosen was frequency division without amplitude retention, in which the original frequency of the call is divided by a factor (4, 8,16, 32) chosen by the user prior to recording (see a brief discussion of system design, http://users.lmi.net/corben/anabat.htm#Anabat%20Contents). The system records the loudest sound at any instant over a wide frequency range (as determined by the microphone sensitivity and signal processing hardware). There are other approaches to ultrasonic vocalization recording and identification (heterodyning, time expansion, full spectrum recording) with different tradeoffs, but the current project addressed improvements and testing of this system already in wide use for long term passive monitoring.

Use of the system relies on two Windows™ programs – CFCread and AnalookW. These are available at:
http://www.titley.com.au/ViewContent-AnaBat-Systems-Software-by-Titley-Scientific

http://users.lmi.net/corben/anabat.htm#Latest%20ZCAIM%20Software

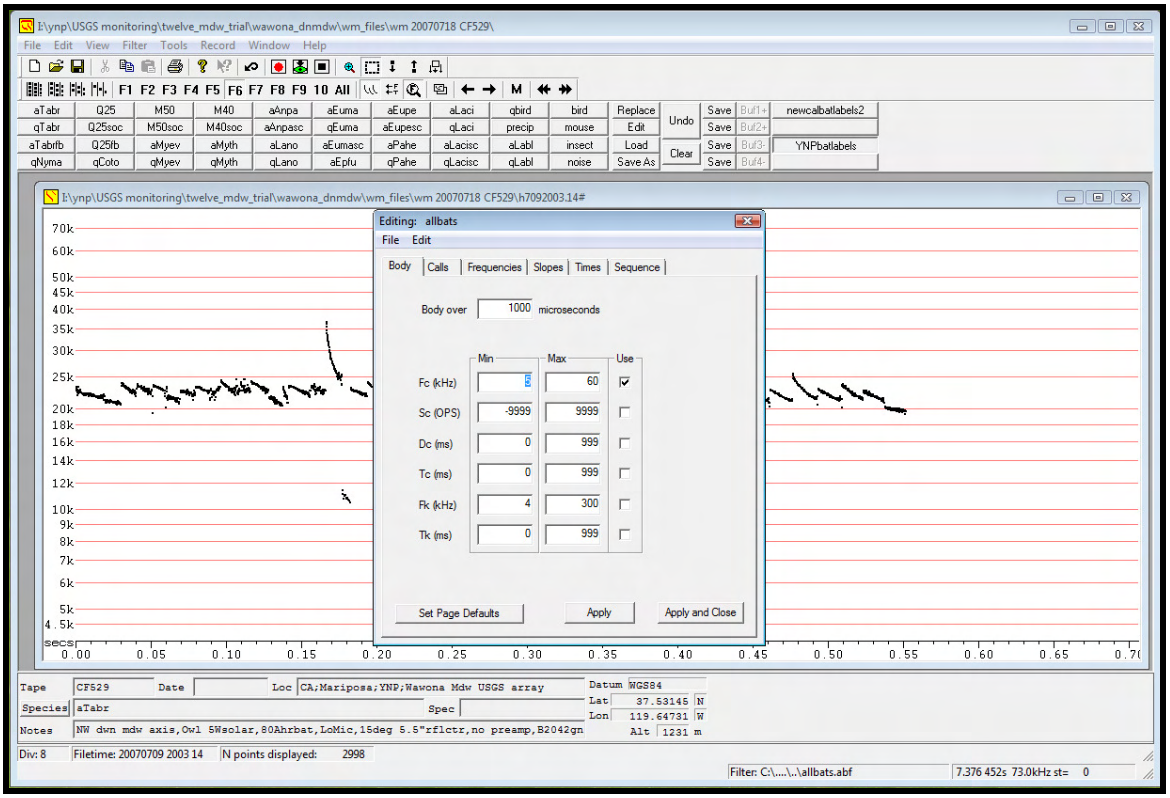
CFCread deals with several recurring tasks:

1. Transferring compressed files of acoustic events and their times of occurrence from the storage unit's CompactFlash card and, from user-selected parameter

settings, screening the compressed record and extracting intervals with presumptive bat calls for further analysis.
2. Initializing CompactFlash cards for data storage and setting sampling interval start and stop times if needed on the card to be read by the device.
3. Via a serial cable link to a computer, checking and updating the clock (maintained by an internal battery) in the storage zcaim.

Stepwise procedure for setting the clock is at:
http://users.lmi.net/corben/storage_zcaim.htm#Storage_ZCAIM_Contents

AnalookW is the analysis program applied to the call files that are the output from CFCread. AnalookW is compatible with current Windows versions (including 64 bit Vista). Additions and revisions are frequent and the most recent Beta version (3.7n) is available from the author, Chris Corben (www.hoarybat.com/Beta). It provides an extensive set of options via tabbed pages in a filter editor (Figure 5) that allows sequence file selection (filtering) based on quantitative call or call sequence parameters (e.g., characteristic frequency or slope, duration, inter-pulse interval). Both the parameter settings and the number of ‘identified’ calls or pulses required for a file to be accepted as identified allow varying stringency depending on how distinctive the call structure of a species (or group of acoustically similar species) is within the local species assemblage. For a targeted survey assessing the presence of a species thought to be rare, a less stringent filter might be desirable if there are difficult to implement identifying call or sequence characteristics that are visually identifiable in a reasonably small sample of calls.



I:\ynp\USGS monitoring\twelve_mdw_trial\wawona_dnmdw\wm_files\wm 20070718 CF529\

I:\ynp\USGS monitoring\twelve_mdw_trial\wawona_dnmdw\wm_files\wm 20070718 CF529\h7092003.14#

Editing: allbats

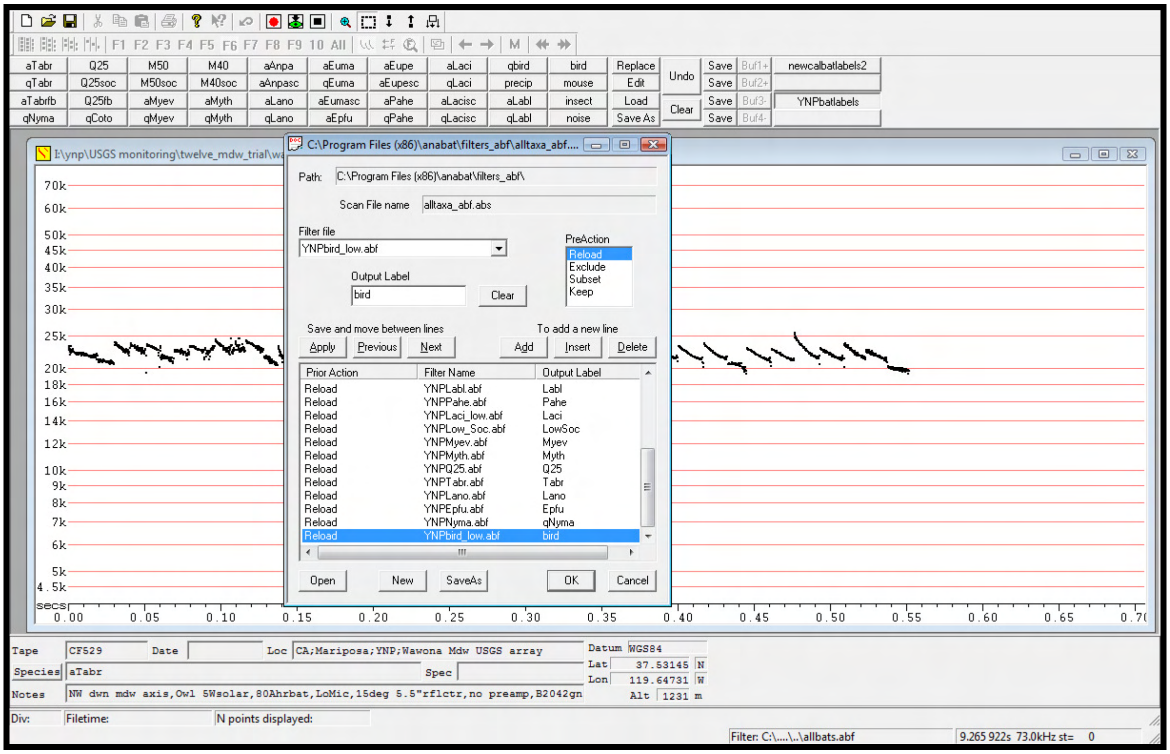
Body over 1000 microseconds

	Min	Max	Use
Fc (kHz)	5	60	☑
Sc (OPS)	-9999	9999	☐
Dc (ms)	0	999	☐
Tc (ms)	0	999	☐
Fk (kHz)	4	300	☐
Tk (ms)	0	999	☐

Tape CF529
Date
Loc CA;Mariposa;YNP;Wawona Mdw USGS array
Species aTabr
Spec
Notes NW dwn mdw axis,Owl 5Wsolar,80Ahrbat,LoMic,15deg 5.5"rflctr,no preamp,B2042gn
Datum WGS84
Lat 37.53145 N
Lon 119.64731 W
Alt 1231 m
Div: 8
Filetime: 20070709 2003 14
N points displayed: 2998
Filter: C:\....\..\allbats.abf
7.376 452s 73.0kHz st= 0

Figure 5. First page of AnalookW 3.7l filter editor for selecting call and call sequence parameters in a filter.

In AnalookW, the scan editor (Figure 6) is used to prepare a text file that applies to multiple filters to screen a directory or directory tree containing multiple sequence files. The output 'list file' from this process allows selective access to the subset of files identified by a filter or filter combination. Those sequence files can then either be further screened by the operator and individually labeled with the species name buttons near the top of the AnalookW window or marked and automatically labeled in large numbers. The list of species names associated with the buttons can be edited and several name lists can rapidly exchanged, if the number of labels required is more than 40.



C:\Program Files (x86)\anabat\filters_abf\alltaxa_abf....

Path: C:\Program Files (x86)\anabat\filters_abf\

Scan File name: alltaxa_abf.abs

Filter file: YNPbird_low.abf

Output Label: bird

PreAction: Reload / Exclude / Subset / Keep

Save and move between lines

To add a new line

Prior Action	Filter Name	Output Label
Reload	YNPLabl.abf	Labl
Reload	YNPPahe.abf	Pahe
Reload	YNPLaci_low.abf	Laci
Reload	YNPLow_Soc.abf	LowSoc
Reload	YNPMyev.abf	Myev
Reload	YNPMyth.abf	Myth
Reload	YNPQ25.abf	Q25
Reload	YNPTabr.abf	Tabr
Reload	YNPLano.abf	Lano
Reload	YNPEpfu.abf	Epfu
Reload	YNPNyma.abf	qNyma
Reload	YNPbird_low.abf	bird

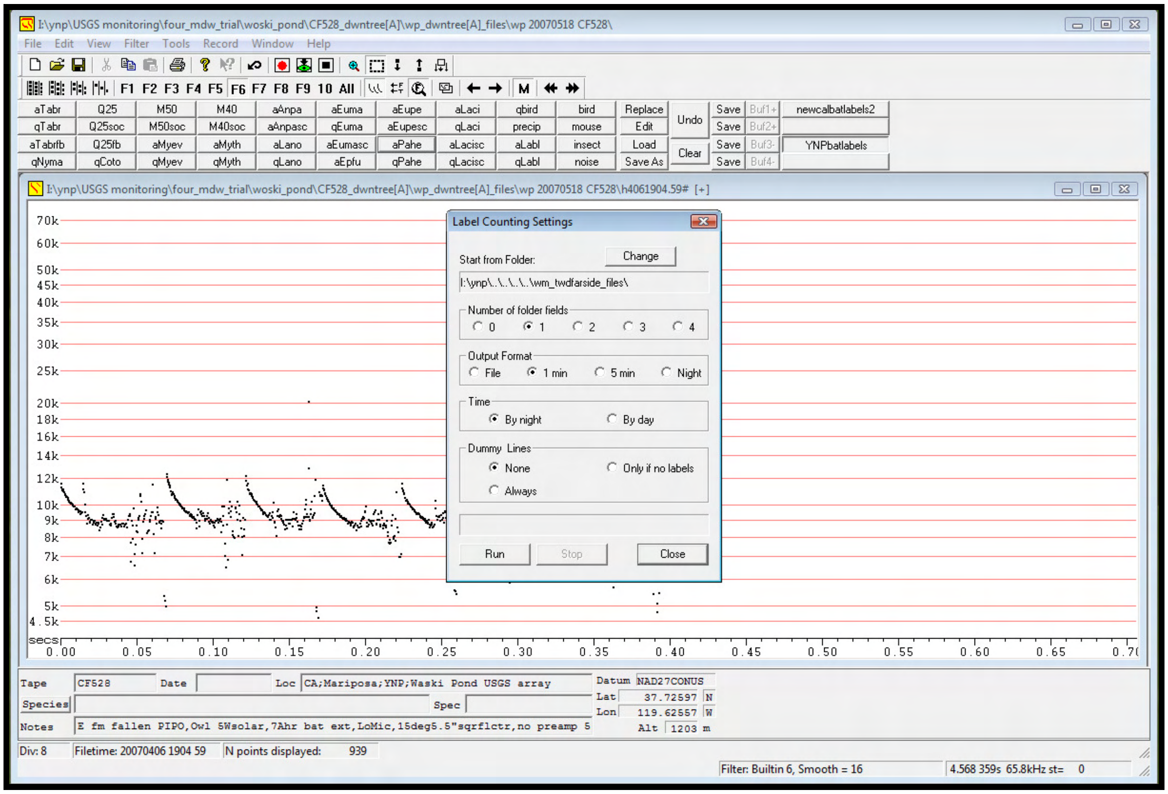
Tape: CF529
Date:
Loc: CA;Mariposa;YNP;Wawona Mdw USGS array
Species: aTabr
Spec:
Notes: NW dwn mdw axis,Owl 5Wsolar,80Ahrbat,LoMic,15deg 5.5"rflctr,no preamp,B2042gn
Datum: WGS84
Lat: 37.53145 N
Lon: 119.64731 W
Alt: 1231 m
Div:
Filetime:
N points displayed:
Filter: C:\....\..\allbats.abf
9.265 922s 73.0kHz st= 0

Figure 6. AnalookW 3.7l editor for scan files containing one or more filters.

With labeling of a sample of sequence files completed, a module in the Tools menu (Figure 7) can be used to extract counts of labels from a directory tree to a text file. The user can choose to list labels by individual sequence file or several aggregation intervals (1 minute, 5 minutes, entire night) and whether to identify counts by normal clock date and time (with a midnight date rollover) or by time since the previous noon, so that events within a night are grouped by date.

For transfer of sequence file data to other programs, another module in the Tools menu will export all header information shown at the bottom of the AnalookW window as one line of tab delimited text per sequence file selected. A database system in MS Access to manage this extracted data following NPS models is discussed below (see Section 5).

The AnalookW interface follows Windows™ conventions and the version described is currently employed by the user community. As with other bioacoustic analysis programs or other software used in natural resource inventory and monitoring (e.g., capture-mark-recapture and presence-absence analysis, GPS surveying, GIS), there is a learning curve for both the phenomena under study (parameter definitions, expected range of variation, cases of anomalies) and how to use the analytic software. For each of these topic areas there are options for organized training provided by equipment or software vendors, professional societies, consulting firms, universities and conservation groups. Titley Electronics conducts trainings at several levels on AnaBat hardware and software (http://www.titley.com.au/Training.aspx). Bat Conservation International (www.batcon.org) and regional sections of the Wildlife Society (e.g., www.tws-west.org) conduct trainings on bat field technique and bat call analysis that include presentation of several systems for acoustic monitoring, including AnaBat.



I:\ynp\USGS monitoring\four_mdw_trial\woski_pond\CF528_dwntree[A]\wp_dwntree[A]_files\wp 20070518 CF528\

I:\ynp\USGS monitoring\four_mdw_trial\woski_pond\CF528_dwntree[A]\wp_dwntree[A]_files\wp 20070518 CF528\h4061904.59# [+]

Label Counting Settings

Start from Folder: I:\ynp\..\..\..\..\wm_twdfarside_files\

Number of folder fields: ○ 0 ● 1 ○ 2 ○ 3 ○ 4

Output Format: ○ File ● 1 min ○ 5 min ○ Night

Time: ● By night ○ By day

Dummy Lines: ● None ○ Only if no labels ○ Always

Tape: CF528

Date:

Loc: CA;Mariposa;YNP;Waski Pond USGS array

Species:

Spec:

Notes: E fm fallen PIPO,Owl 5Wsolar,7Ahr bat ext,LoMic,15deg5.5"sqrflctr,no preamp 5

Datum: NAD27CONUS

Lat: 37.72597 N

Lon: 119.62557 W

Alt: 1203 m

Div: 8

Filetime: 20070406 1904 59

N points displayed: 939

Filter: Builtin 6, Smooth = 16

4.568 359s 65.8kHz st= 0

Figure 7. AnalookW 3.7l dialog to compile a text file listing all species labels by date and time for a selected directory tree.

4.0 ACOUSTIC FILTERS FOR YOSEMITE BATS

Project objective #2 was to refine existing filters and develop new filters to automate the process of identifying individual bat species from acoustic detection records.
The basic approach is to use the expanded, more user friendly filter definition options in AnalookW to select individual call and call sequence parameter values that identify a distinctive portion of the species or species group call repertoire. Repertoire overlap varies with the species in the local bat assemblage and so is site dependent. Insect, bird mouse and frog calls occur in the wide frequency range used by bats and are likely to be encountered in call analysis. Insect choruses in particular can override other animal sounds, but the elevation range of much of Yosemite makes this less common than it is in some other habitats.

Development of recognition filters for Yosemite in the new format was begun by translating the widely circulated DOS Analook filters using a spreadsheet system designed by Bruce Miller (pers. comm.). Subsequent parameter additions and adjustments were based on repeated trials with samples of Yosemite sequence files from multiple sites with differing numbers of calls from the target taxa and those it was feasible to separate. Filters for twelve species or acoustic categories provided are listed in Table 1. Aspects of individual filters are discussed below, but the selectivity obtained is adequate to follow activity of these species and categories through time.

It is important to remember that any system will record large numbers of unidentifiable or marginally identifiable call sequences. This can include bats at the edges of the detection volume or several bats well within it, but interacting acoustically to produce fragmented or non-diagnostic call sequences. It is also important to recognize that the knowledge of species call repertoires and discriminating characteristics can improve with additional data. Re-analysis of very large data sets is relatively quick if exploration of different filter parameter values or newly developed discriminatory methods is desired.

Table 1. Filters employed in the current study.

Filter name	**Taxa included**
YNPAnpaSc	*Antrozous pallidus* directive calls
YNPEuma	*Euderma maculatum*
YNPEupe	*Eumops perotis*
YNPLabl	*Lasiurus blossevillii*
YNPLacilow	*Lasiurus cinereus* (calls 18 kHz or lower)
YNPM50	*Myotis yumanensis, M. californicus*
YNPM40	*Myotis volans, M. lucifugus, M. ciliolabrum*
YNPMyev	*Myotis evotis*
YNPMyth	*Myotis thysanodes*
YNPPahe	*Parastrellus hesperus*
YNPQ25	*Tadarida brasiliensis, Eptesicus fuscus, Lasionycteris noctivagans*, small numbers of *Lasiurus cinereus* and rare *Antrozous pallidus*
YNPTabr	*Tadarida brasiliensis* (calls from 18.5 kHz -25), small numbers of *Lasiurus cinereus*

4.1. Pallid bat, *Antrozous pallidus*

Pallid bat directive calls are social communication calls first discussed in detail in the context of mother young interaction (Brown 1976). Bat field workers are typically familiar with the call type because they are audible and sometimes emitted on release of captured pallid bats. The sequences are high slope, short inter-pulse interval groups of irregular calls that extend from the ca. 25 kHz minimum of this species ultrasonic foraging calls down to ca. 8 kHz. In long term monitoring, these calls are rare, but structurally relatively distinctive. Because of intensity and lower attenuation by distance at low frequency, they may be recorded without associated echolocation calls. Some pallid bat open-air echolocation calls are distinctive with a combination of moderate overall slope (ca 80 octaves per second) and slight irregularities in slope within the calls. A substantial proportion of pallid calls lack these features. In a several month warm season sample from Yosemite, there are typically tens of thousands of calls from more common taxa with similar overall characteristics that are selected by available filter parameters, so that presently it is impractical to identify these foraging or commuting calls automatically.

4.2 Spotted bat, *Euderma maculatum*

Spotted bat open-air echolocation calls are largely distinctive in their low frequency and high slope and are readily identified by filters. The current filter also will select some high slope feeding buzz and interaction calls from mastiff bats (*Eumops perotis)* and some insects. The number of mastiff call files accepted is small and excluding them by limiting the pulse frequency range will discard substantial numbers of similarly wide frequency range spotted bat calls. High intensity low frequency insect chorusing has the potential for masking spotted bat calls.

4.3. Western mastiff bat, *Eumops perotis*

Western mastiff bat calls are abundant at many Yosemite sites and lower slope calls are largely distinctive. The filter also accepts similar segments from bird calls, but these are uncommon and episodic at most sites and can be largely excluded by limiting dawn and dusk sampling. Rare hoary bat social sequences include extended duration pulses down to 8-12 kHz and sometimes will trigger the mastiff filter.

4.4. Western red bat, *Lasiurus blossevillii*

Most western red bat calls observed in Yosemite are distinctive (rapidly varying pulse duration and frequency baseline, often with reverse-J shaped calls, as in other *Lasiurus* sp.) The filter discriminates from the patchily more common western pipistrelle (*Parastrellus hesperus*) by frequency range and duration (greater than 8 milliseconds for red bats). In samples with thousands of pipistrelle sequence files, some will have several pulses of 8 ms duration. A filter design trade-off is that many red bat sequences contain few pulses and pulse length varies, so that requiring a larger number of 8 ms pulses will lead to low red bat detection rates (an uncommon, also patchily distributed species). Generally the number of files the current filter selects is small enough that all can be examined.

4.5. Hoary bat, *Lasiurus cinereus*

Hoary bat files identified by the current filter (14-18 kHz low slope files) are largely distinctive in Yosemite. These sequences are at the lower frequency margin of the hoary bat call repertoire (O'Farrell et al. 2000), but higher calls are in the frequency range of more common 20-25 kHz species, notably the Mexican freetail. Uncommon or rare spotted and mastiff bat social calls in the 14-18 kHz range may also be selected by the filter. The number of these calls and the percent misidentification are small, but vary with the relative activity of the taxa at a site.

4.6. M50, California myotis, *Myotis californicus* & Yuma myotis, *M. yumanensis*

The M50 filter is relatively stringent in requiring several high slope, short duration calls with substantial frequency range over a short interval. This largely excludes higher slope western pipistrelle calls and fragments of the upper portion of M40 calls. M50 calls are common at many sites, so the stringency doesn't reduce detection unduly even though substantial numbers of visually recognizable M50 sequences are rejected. The filter does not accept lower slope 50 kHz *Myotis* sequences, because of their similarity to pipistrelle calls responding to prey or other bats.

4.7. M40, Long legged myotis, *Myotis volans,* Little brown bat, *M. lucifugus* & Western small-footed myotis, *M. ciliolabrum*

The M40 filter is structured similarly to the M50 to isolate moderately steep multiple pulse sequences with a characteristic frequency around 40 kHz. Little brown bat calls can attain lower slopes than the current filter allows. The elevation range of the little brown bat in Yosemite is almost entirely above that of pipistrelles and red bats as currently understood, so an M40 filter allowing lower slopes could be applied at sites above 1800-2000m.

4.8. Long-eared myotis, *Myotis evotis* & fringed myotis, *M. thysanodes*

The long-eared myotis and fringed myotis filters select multi-pulse sequences with high slope (100 octaves per second or above). For long-eared myotis the characteristic frequency is 30 kHz or above. For fringed myotis it is 25 kHz or below. Some fragmentary fringed myotis will have intermediate minimum frequencies, but neither species is common in these data sets, so inspection, even with months of data, is feasible. The primary non-Myotis sequences sometimes selected by the filter are feeding buzzes of Mexican free-tails (*Tadarida brasiliensis*) or other 25 kHz, larger bats (see table above). These are difficult to exclude using the obvious criterion of short inter-pulse intervals because the filter may detect only scattered pulses in the buzz (a consequence of pulse fragmentation) thus increasing the automated estimate of the inter-pulse interval.

4.9. Western pipistrelle, *Parastrellus hesperus*

Western pipistrelle sequences are relatively readily identified by filter and are usually numerous at sites where they are detected. The filter may also pick up enough pulses from some red bat sequences for recognition, but these are normally a small fraction of the total. The filter selects for multiple lower slope pulses to enhance separation from M50.

4.10. Q25, Mexican free-tailed bat, *Tadarida brasiliensis,* big brown bats, *Eptesicus fuscus* & silver-haired bats, *Lasionycteris noctivagans*

Q25 includes calls from several larger aerial pursuit foragers, Mexican free-tails (*T. brasiliensis*), big brown bats (*Eptesicus fuscus*), and silver haired bats (*Lasionycteris noctivagans*). Sequence files in this frequency range are very numerous in samples from Yosemite (often hundreds/night at lower elevations). Some may be assigned by inspection to big brown bats, but the numbers with structurally highly varied sequences that are free-tails, based on the fact that they extend to frequencies well below 25 kHz, favor a conservative interpretation for filter analyses of large data sets that are not fully edited by an observer. A small number of hoary bat feeding or social sequences also rise into this frequency range. These are recognizable visually from the steep reverse-J pulse shape and the wide ranging and rapidly changing minimum or characteristic frequency, but filter recognition isn't currently feasible.

4.11. Mexican free-tailed bat, *Tadarida brasiliensis*

The Mexican free-tail filter recognizes multiple pulse, lower slope sequences from ca 18.5 kHz to 25 kHz. Some moderate to low slope hoary bat sequences fall partly or, less frequently, wholly in this range, but there is no ready method to exclude them without potentially excluding a much larger number of free-tail sequences.

5.0 MS ACCESS DATABASE

Objective # 3 was to develop an MS Access database application to store, manipulate, and prepare acoustic records for analysis. Input is generated by an option in the AnalookW tools menu that produces a file containing the text headers of all call sequence files in a directory, including the file name, date and time, species or species group labels assigned, location data and notes. The database, through the use of a macro and several queries, imports header files and formats them so they can be appended to a permanent archive. Additional queries provide the ability to convert the sequence file entries that contain multiple species labels into individual records for each species and extract records for analysis by species or species group.

The database is built on the Natural Resources Database Template (NRDT3.2). The NRDT was developed by the NPS I&M office in Fort Collins and is the recommended relational database structure for long-term monitoring data. It is FGDC compliant and integrates into the NPS DataStor. The database provides a viable means for managing and analyzing the large amount of data generated by long-term deployment of passive monitors (2.9 million sequence files in this project, including noise files excluded from the analysis, but retained).

The acoustic monitoring database comprises 16 tables. Three of these are lookup tables (tblu_bat_spp, tblu_call_type, tblu_detection_type). A fourth table (xref_Event_Contacts) functions as a cross-reference table. Three other tables (tbl_blank_table, tblTmp_Import_New_Event_Data, tblTmplt_import_header) are used by queries and macros to temporarily store and parse raw data files. As consistent with the NRDT, two tables tblLocations and tblEvents form the core of the database (Figure 8). TblLocations stores information about the location of the sampling site. TblEvents records sampling events. Both core tables are linked to subsidiary tables using GUIDs, globally unique IDs that are automatically generated when a new location or event is added. The subsidiary tables provide additional descriptive information on the sampling site or details about the sampling event. The tbl_Event_Groups also provides a means of assigning a single night's acoustic detections to a single sampling event in tblEvents.

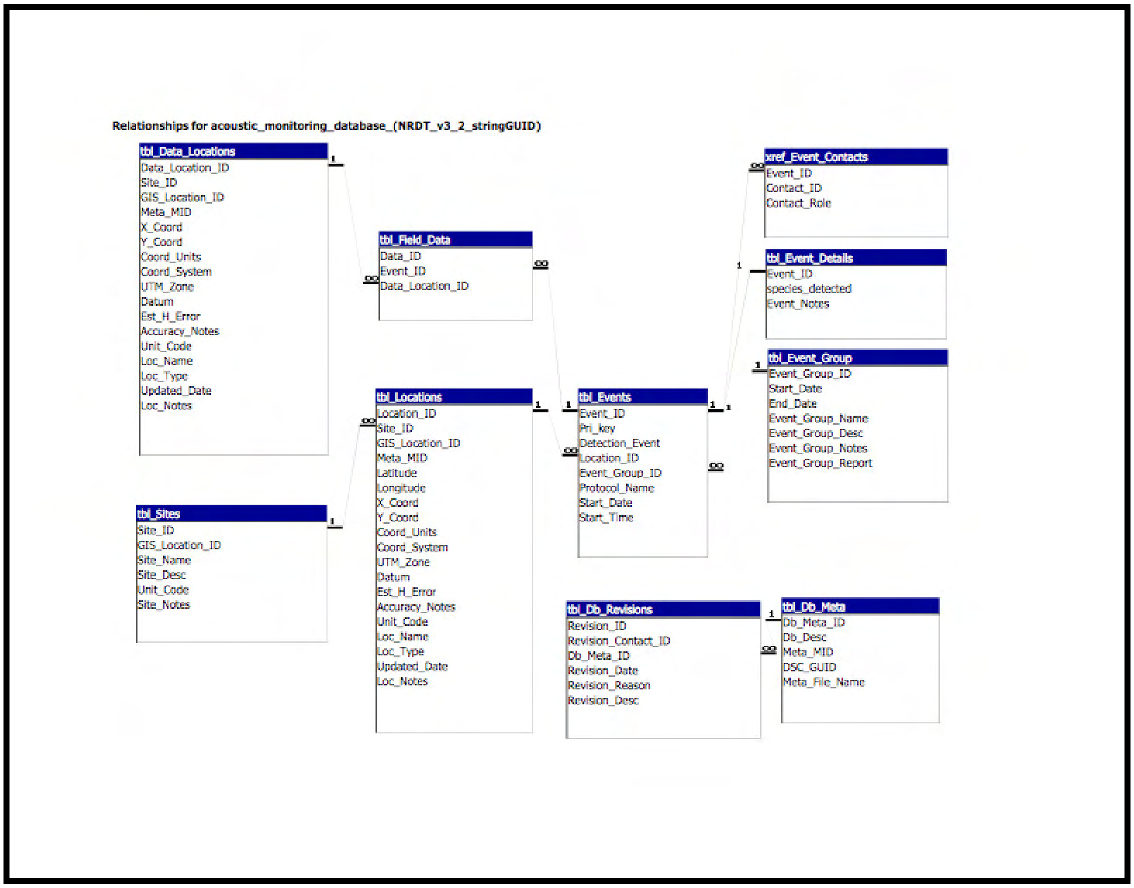


Figure 8. MS Access database primary table relationships and fields for managing large AnaBat file acoustic data sets.

6.0. DEVELOPING A SAMPLING FRAMEWORK

Objective #4 was to develop a statistically robust sampling framework capable of detecting changes in the species composition of the bat assemblages inhabiting a given area.

To meet this objective we designed a series of field trials. Our study area was Yosemite National Park, located in the central Sierra Nevada of California. The park is 3,081 km^2 and ranges in elevation from 320 to 4,007 m.

6.1. Site Selection and Experimental Design

We chose meadows as the test habitat for all trials conducted in this study for the following four reasons:

1. Many bat species respond acoustically to nearby objects (prey items, other bats, habitat structure, including vegetation) by decreasing the interval between calls or pulses, increasing the frequency range of each call, decreasing individual pulse duration, and, when very close, lowering call intensity (see Schnitzler and Kalko 2001 review). For North American temperate zone bats, these changes in response

to targets and obstacles in their detection volume increases call structure similarity among species (e.g., Broders et al. 2004). Open-air foraging calls generally show the greatest differences in individual pulse form and values for call (and multi-pulse call sequence) parameters among species and acoustic categories of several species, which cannot currently be separated.

2. In addition to reduced probability of call identification in sites where the detection volume includes substantial amounts of vegetative structure, the structure itself may alter ultrasound propagation and, with it, call detection or quality (Patriquin et al. 2003). In relatively high canopy forest, measuring among-site differences in the effects of vegetative structure on bats calls is an as yet unresolved issue, but it seems likely that those effects will vary seasonally with such factors as deciduous tree and shrub phenology and precipitation patterns.
3. In addition, earlier trials showed that, at low elevations in Yosemite, birds and chorusing insects (with frequencies extending into the ultrasonic) perched in trees in the detection volume, added to automated identification challenges. Some bird calls resemble some low frequency bat calls and are difficult to exclude by structure-based filters. Insect choruses covering wide frequency ranges for long intervals through the night can rapidly fill digital data storage cards and may be louder than some bat calls, so the latter are fragmented or unrecorded. North American bat calls are largely ‘low duty cycle’ sounds with a single bat emitting a 2-40 millisecond pulse every 100-500 milliseconds. Both insects and birds are present in meadows, but, with the detection volume of the monitor directed upward in open air, the amount of non-bat sound recorded is much less than if the volume includes extensive elevated perching sites.
4. A logistic reason to favor open sites for long term monitoring is that solar recharging of batteries (for the monitoring equipment and sites chosen) is feasible with a relatively small panel area (5 watts) at the monitor. A tree canopy above the monitor would likely require remote placement of the solar panel and connecting cables or regular battery exchange. An issue not addressed in this study, but relevant to long term monitoring is temporal patterns of vegetation change (e.g., succession in meadows).

All monitoring sites were open, with low relief and a seasonally varying cover of herbaceous vegetation that was, in most instances a low turf, but did not exceed 1 m in height. Monitor sites were typically several tens of meters away from forest margins, water body shores and paved roads, except in the meadow to center edge comparison. Permits for the project did not include wilderness areas, so all sites were within or adjacent to relatively concentrated human use areas, including Yosemite Valley floor, road corridors, trailheads, or zones around campgrounds and housing.

We used twelve monitors to conduct three different trials to examine activity variation at different spatial scales with differing levels of replication. Appendix I lists all sites with geographic coordinates and elevations.

Trial One: The first trial examined within and among site variation, and was conducted between November 2006 and early July 2007 in four meadows accessible in winter (Wawona Meadow, Hodgdon Meadow, a portion of the Crane Flat meadow system locally known as Doghouse Meadow, and a Yosemite Valley floor meadow/floodplain area at Woski Pond) (Figure 9).

We deployed three monitors at the corners of a 25 m equilateral triangle with microphones directed outward from the center (Figure 10). The placement of the triangle was based on local judgment, minimizing proximity to trees and other structure and effects of cliffs or tree horizons on panel insulation at low winter sun angles. From the perspective of long-term deployment for monitoring, a primary sampling design question addressed was the extent of variation in species activity among similarly deployed monitors at one location. Would a single monitoring device be adequate to represent a site in more extensive comparisons?

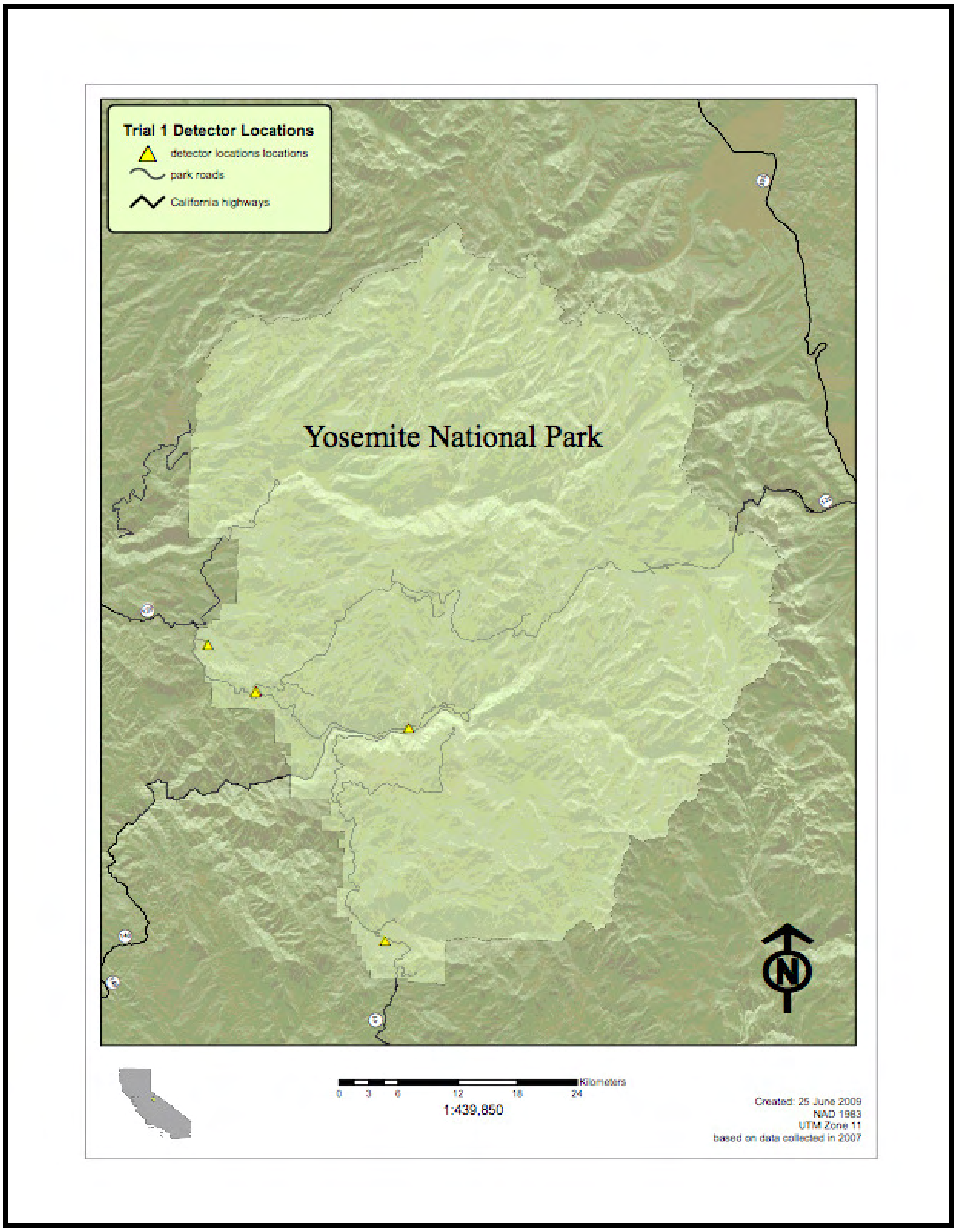


Figure 9. Trial 1 sites with 25 m triangular arrays of three monitors in four meadows.

Figure 10. Triangular array of monitors in Doghouse Meadow. 30 November 2006.

<u>Trial Two:</u> The second trial (July –November 2007) compared activity at single monitors in each of four meadows in three elevation strata (Figure 11). Low elevation meadows were Wawona, Hodgdon, Woski Pond and Yellow Pines. Moderate elevation sites were Monroe Meadow, Peregoy Meadow, Doghouse Meadow, and an unnamed roadside meadow below Gin Flat. High elevation meadows were at White Wolf, Snow Flat, Tenaya Creek and Tuolumne Meadow. Monitor placement similarly dealt with siting in largest available open area, obtaining a detection volume with few or no trees and maintaining adequate panel insulation (Figure 12). Trial duration was largely determined by the seasonal Tioga Road gate opening and closing times in 2007. This trial examined warm season elevation distributions and variation in species activity. Prior acoustic and capture studies in the park had indicated that several species were only active at low to moderate elevations, while one species, *Myotis lucifugus*, was restricted to moderate to high elevation.

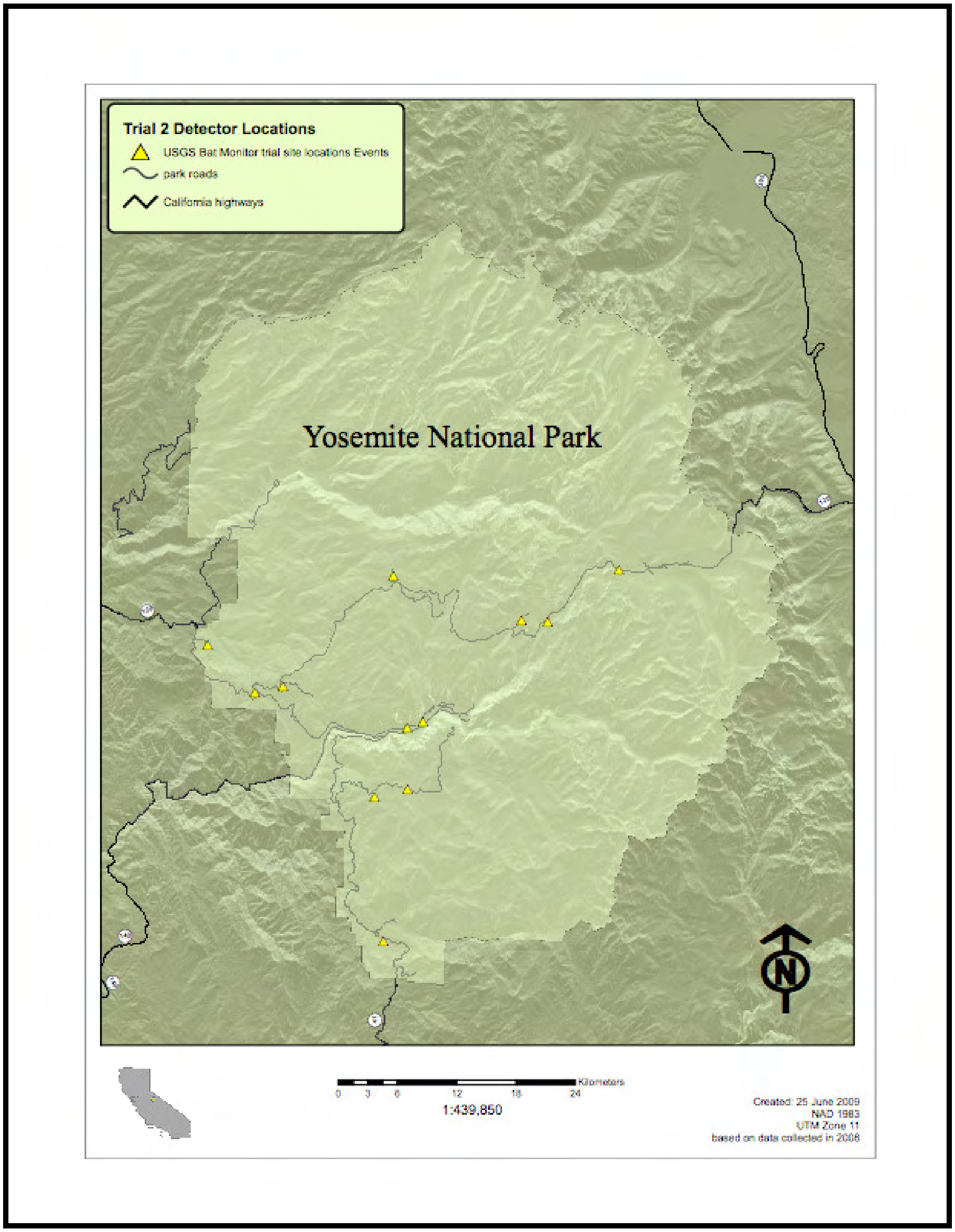


Figure 11. Trial 2 localities with single acoustic monitors in twelve meadows in three elevation strata along road corridors.

Figure 12. Monroe Meadow monitor station in view of inactive ski equipment, 5 July 2007.

Trial Three: The third trial (March-December 2008), with two monitors per meadow, compared the centers and edges of six low elevation meadows accessible in winter (Wawona, Hodgdon, Bridalveil, Woski Pond, Yellow Pines and Leidig; Figures 13-15). The meadow center microphone and reflector were oriented toward the most open aspect. The edge monitor was placed approximately 5 m from a tree meadow margin with the microphone oriented so that the detection volume was largely along the edge. The bat assemblage in Yosemite includes species with differing ecomorphology and habitat use. These range from very large fast flying open air foragers, such as the mastiff bat, to clutter tolerant species that likely both glean prey from surfaces and hunt aerially (represented by the long-eared and fringed myotis). Many of the bat species in Yosemite are generalist aerial pursuit foragers and may favor hunting along habitat edges where insects may be concentrated both passively by wind and by their behavior. With the marked seasonal pattern of temperature, moisture availability and primary productivity in Yosemite, the size spectrum and local distribution of insects likely varies greatly. The intent of this trial was to assess the seasonal pattern of acoustic activity at meadow center and edge. In considering a long term monitoring program, device deployment, maintenance, and data analysis were expected to require less time at meadow center sites, but more activity on edges by some species (or acoustic categories) was likely (e.g., Ford et al. 2005).

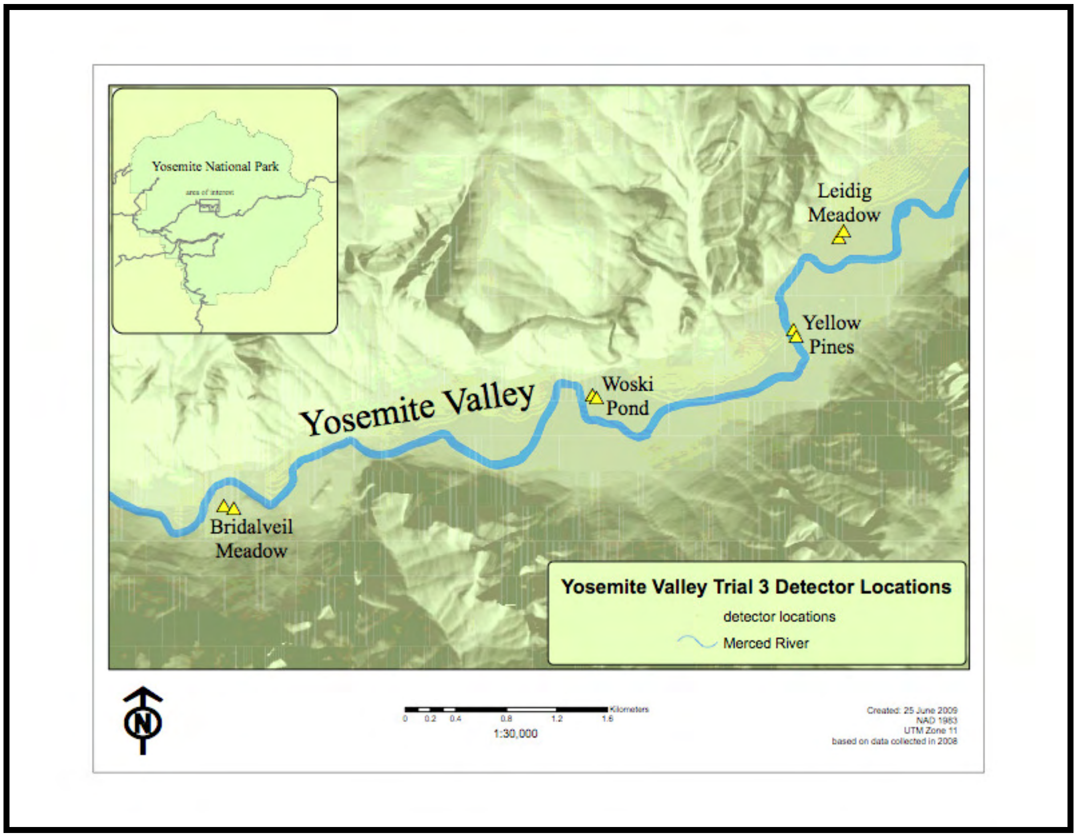


Figure 13. Trial 3 Yosemite Valley paired center and edge meadow acoustic monitor stations.

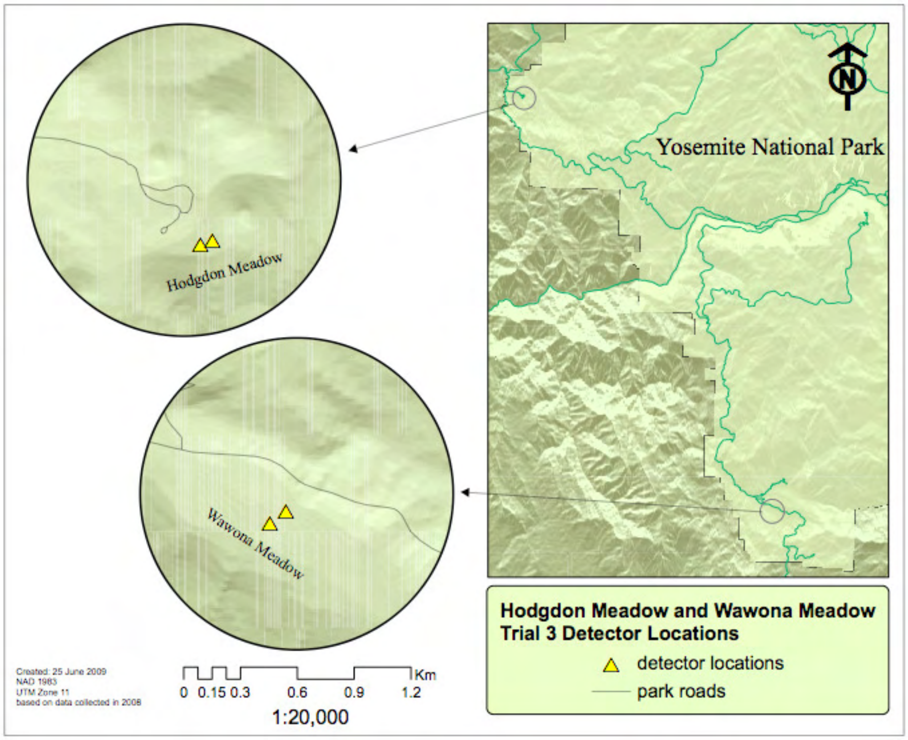


Figure 14. Additional Trial 3 stations in Hodgdon and Wawona meadows on the Yosemite park periphery.

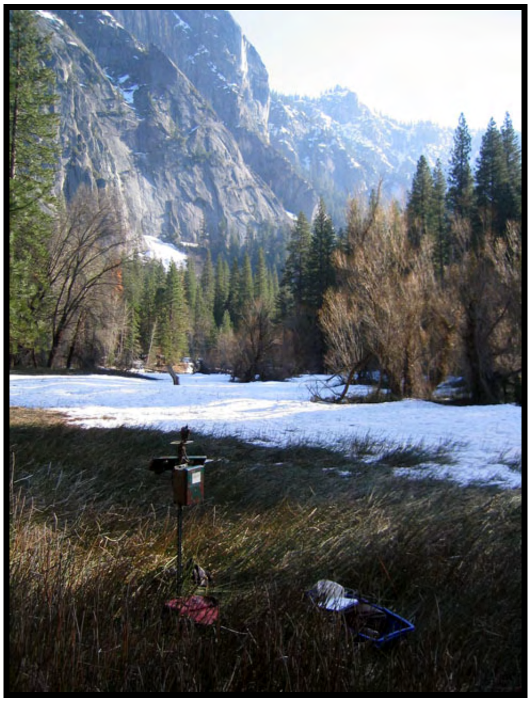


Figure 15. Monitor adjacent to forest edge near Yellow Pines Campground, Yosemite Valley, 5 March 2008.

6.2. Statistical Analysis

Project objective #5 was to identify statistical methods for analyzing data on presence/absence within bat assemblages to detect trends in species composition.

Miller (2001) reviewed approaches used to quantify bat acoustic activity from recordings, (e.g., call or pulse counts, counts of multi-pulse passes through the detection volume, counts of 15 second files generated by AnaBat software or bytes of recorded data). He concluded that the best option for variable duration, often active surveys (e.g., walking transects) was aggregating detections at very short time scales and analyzing counts of one minute intervals standardized by division by the sampling time in hours. We have employed a variant of this approach for these long- term analyses, using nightly counts for each species or acoustic category of one minute intervals with detections (not standardized for seasonal variation in night length).

Analysis of wildlife presence-absence and activity data has been changing rapidly with expanding use of increasingly sophisticated occupancy modeling, an approach initially addressing the issue that some fraction of apparent species absences in sequential sampling of study sites are detection failures (MacKenzie et al., 2006). Advances in newer occupancy models have relaxed some initial assumptions that constrained wider application. Recent studies (Gorresen et al. 2008, Yates and Muzika 2006) have applied occupancy models to repeated sampling of bat acoustic data.

While occupancy analysis is a key tool for cryptic, low vagility organisms, with the movement scale, call intensity and flight speed of bats (commonly movements of multiple km/night at ca 5 m/sec), many instances of acoustic non-detection are likely real. That is, the species was not present in the detection volume during that sampling interval, even at a scale of minutes. Gorresen et al. (2008) discuss dealing with this violation of the population closure assumption of simple occupancy models and, similarly, with partitioning extended sampling (with the potential of seasonal change) into short time blocks (1 week) in order to avoid a related assumption violation by having occupancy change during a sampling interval. Our approach here is that simpler analyses with fewer assumptions based on sums of minutes of presence per sampling night (analogous to catch per unit effort models) offer an adequate basis initially for using long-term monitor samples to compare species activity among years or sites.

Statistical analyses of the three Yosemite field trial data sets employed functions (lm for linear models, glm for generalized linear models, glmer for generalized linear mixed models, for AIC for model selection) of the R programming language, version 2.70 (R Development Core Team, 2008). Activity per night by species (or acoustic category) was compared by generalized linear mixed models (GLM—Nelder and Wedderburn, 1972), using a forward stepping model selection process via Akaike's information criterion (AIC—Akaike, 1973). Resampling was used to evaluate the number of sampling nights required for species detection and examine differing rates of detection with sampling effort between adjacent habitats and localities at different elevations.

Nightly count data sets for all species and acoustic categories were analyzed. Pallid bat social call were least frequently detected study 'target' in all trials and at most sites (e.g., less than 10 detections in a season), but are included in most analyses. A brief descriptive summary of the results and selected figures are included in the sections below. Each section has an appendix with the detailed model results and a plot for each species or acoustic category analyzed. There are almost inevitably large numbers of points in the plots and the wide range of count values with many of them low, results in many points clustered near the X (date) axis. We evaluated alternative presentations, but concluded that data were most accessible in a color coded plot of untransformed count data and recommend the files be viewed in color.

6.3. Results of Field Trials

Trial One: Within and Among Site Variation at Four Meadows

This trial (Nov 2006-Jul 2007) includes an entire winter with more no-to-low activity nights than the other trials. Replicate monitors in each meadow allow evaluation of interaction between date and location using a linear mixed effects model. Inspection of the figures and interaction terms in Appendix II shows that changes in activity with time differ significantly among study meadows for some species. For example, the spring to summer increases during 2007 in spotted bat and pipistrelle activity at the Woski Pond site and red bats at Hodgdon Meadow each clearly exceed other meadows (Figure 16, see also Appendix II). In contrast to nearly all other meadows and species, Q25 activity at Woski Pond declines from late Fall 2006 into 2007 in a linear plot.

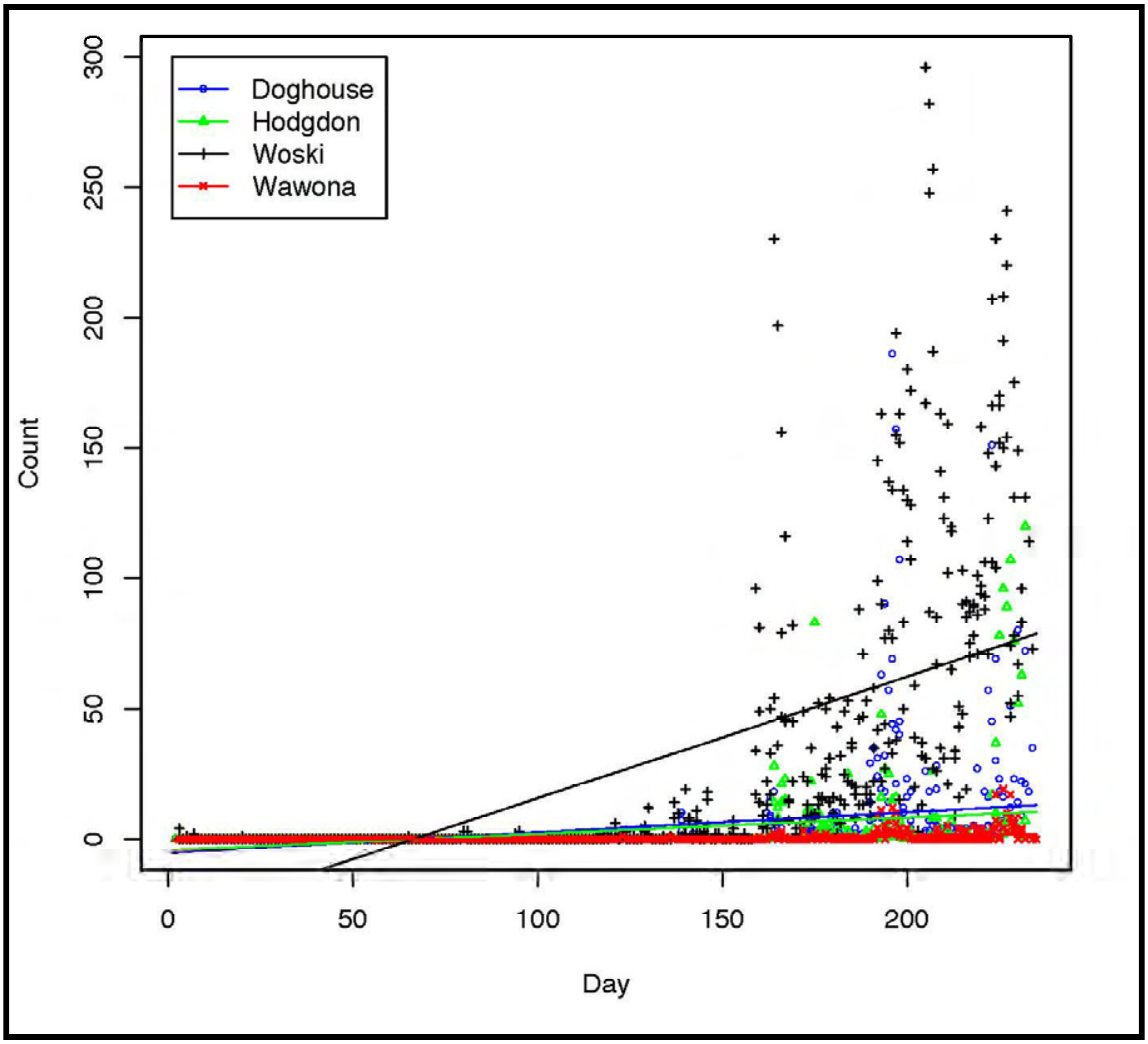


Figure 16. Spotted bat activity in Trial 1 (Nov-Jul) with significantly greater seasonal increase in activity at Woski Pond meadow than at other sites.

Resampling analyses comparing species detection with 600 random nights of single detector samples from this trial to random nights with a cluster of three detectors favors the cluster only for two species, when nights are not matched.

Because variation in activity by species is generally greater among sites than within sites (in this monitor configuration), and the number of available monitors is typically limiting, we conclude it is preferable for park wide bat community monitoring to maximize the number of sites sampled, and deploy one detector per site for long-term monitoring.

Trial Two: Twelve Meadows at Three Elevation Strata

Generalized linear model (GLM) analyses by species and acoustic categories for this trial comparing three elevation strata (July-Oct 2007) show a seasonal pattern (for those with sufficiently large numbers of detections) of higher activity at low (or low and mid) elevation, with activity declining into the Fall (see mastiff bat activity in Figure 17).

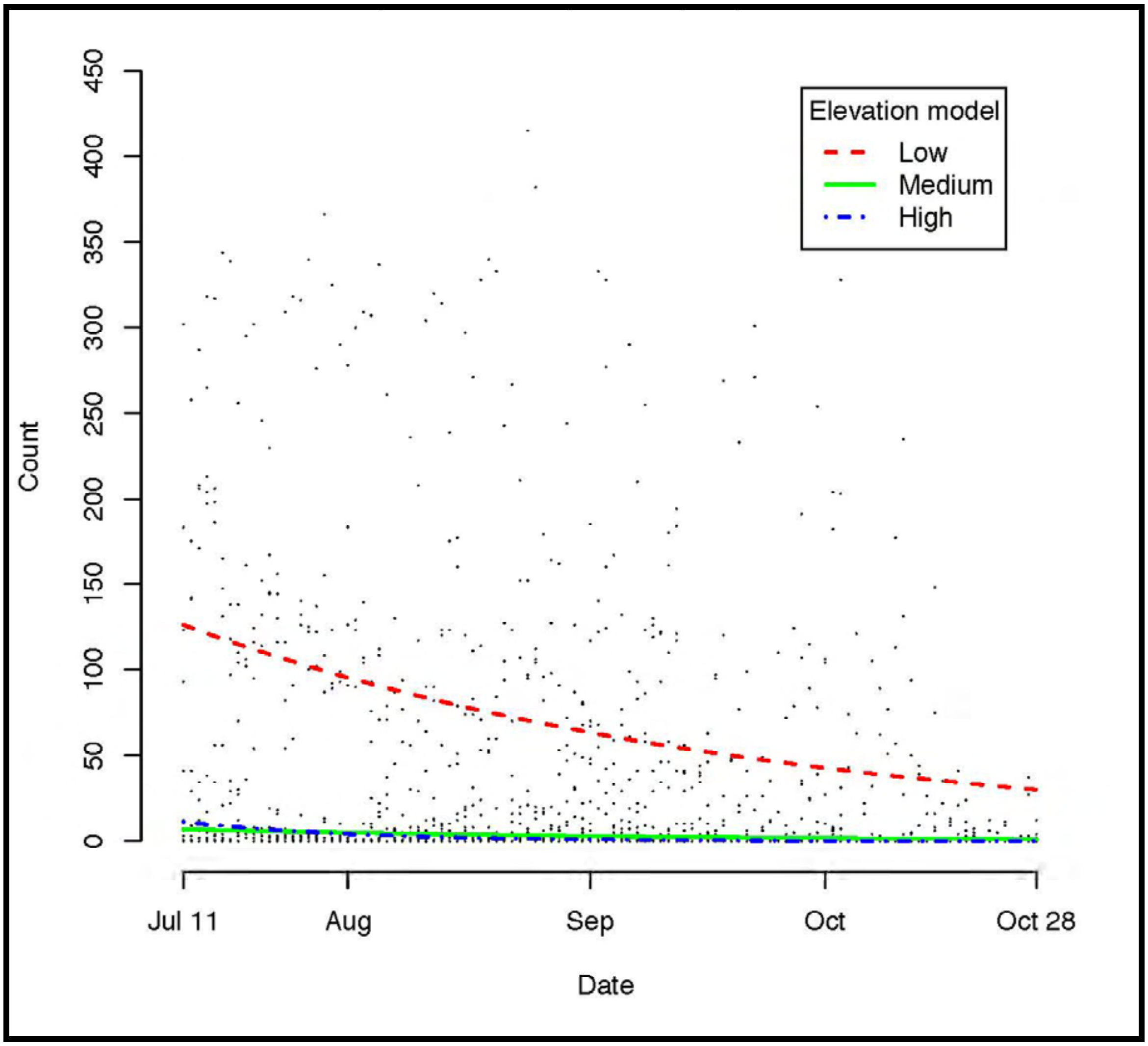


Figure 17. Mastiff bat activity in Trial 2 (Jul-Oct 2007) with significantly greater activity at mid and low elevations and activity declining into Fall.

For some species, activity decline proceeds more slowly at low (or low and mid) elevation. There are two notable exceptions to these patterns. M40 is most active at high elevation. A reasonable hypothesis is this is largely a consequence of the distinctive largely high elevation distribution of the little brown bat (one of the three 40 kHz *Myotis* species in Yosemite). Low elevation hoary bat activity rises rather than declines late in the trial. This may relate to seasonal migration in this species (Cryan 2000). All elevation GLM models and figures are in Appendix III.

To examine sampling effort required for species detection, we used the elevation trial data as most representative of the range of road accessible meadow habitats in Yosemite and drew 300 random samples of different numbers of nights to determine the probability of encountering a species or acoustic category, including calculation of the number of survey nights required to have a 90% of encountering the species at least once (Figure 18). Model terms were derived using the logit link function. Appendix IV contains the model data and plots for each species. Figure 19 is a similarly derived species/acoustic category accumulation curve for this data set.

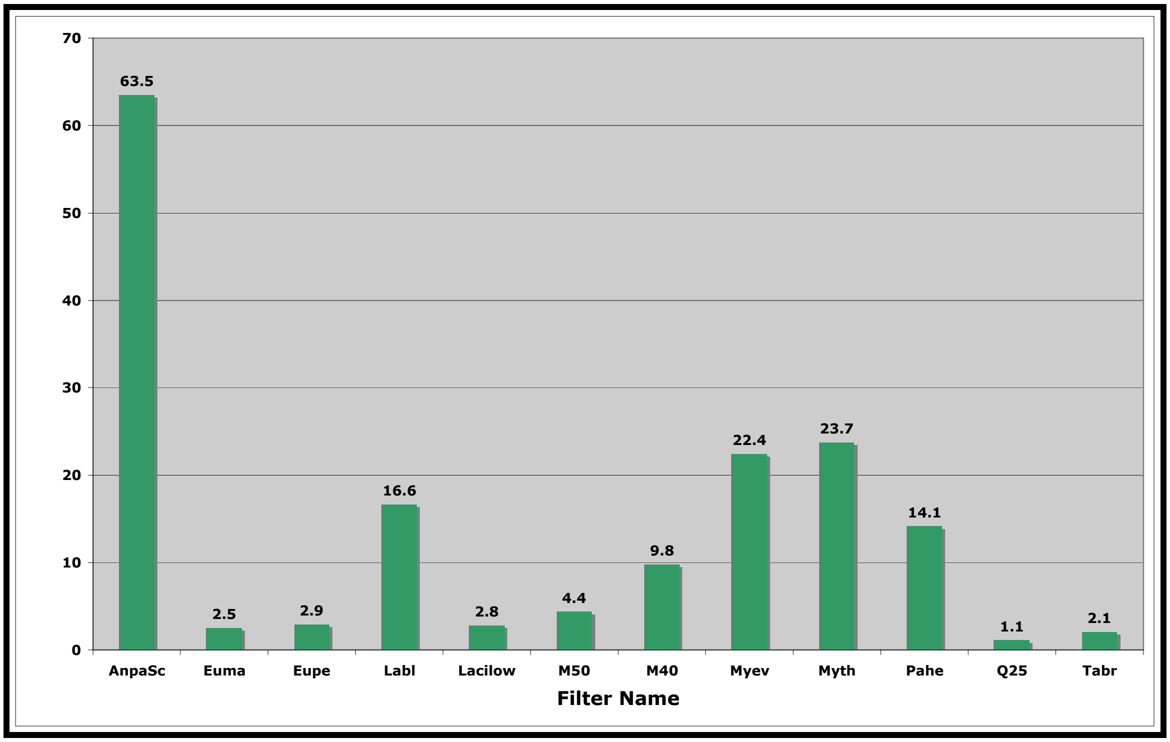


Figure 18. Estimated number of sample nights required for a 90% probability of detecting the species or acoustic category at least once based on Trial 2 data (twelve meadow sites in three elevation strata).

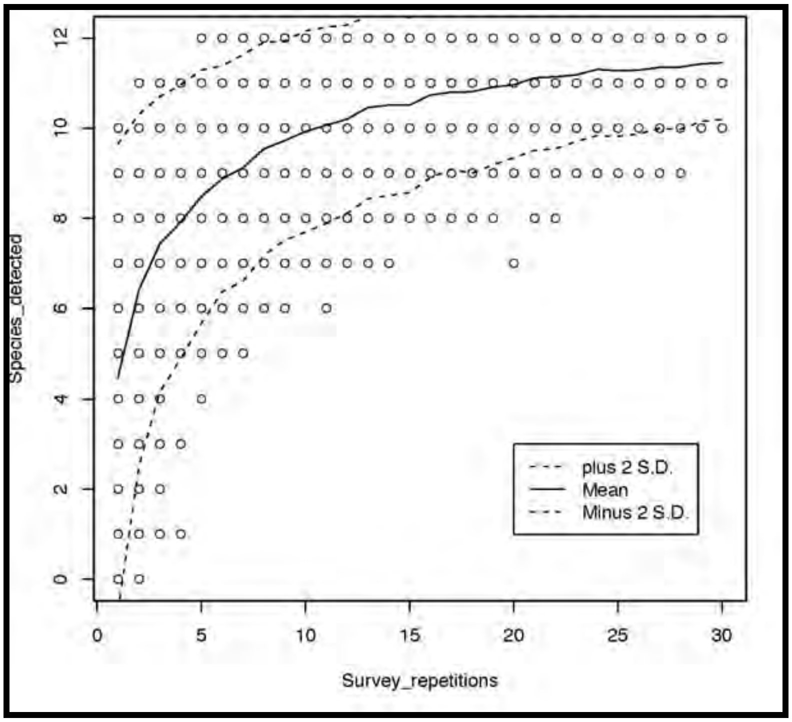


Figure 19. Resampling-based accumulation plot using the Trial 2 elevation data for species and acoustic category detection with increasing numbers of survey nights.

Several notable, if unsurprising, features from analysis of this trial are that overall activity is lower at higher altitude sites and, for most species, declines more steeply in the Fall than at lower sites. Several species present at low and moderate elevation are undetected at high elevation, so the overall probability of encounter for the trial for these species is lowered. The 40 kHz acoustic group shows a distinctive pattern in this trial almost certainly because the little brown bat is a significant component of bat activity at high elevation sites. It is different from all the other species in the park bat community, in being uncommon below that stratum and is absent from captures at low elevation.

Trial Three: Meadow Edge to Meadow Center Comparisons at Six Lower Elevation Meadows

The primary question for this trial was whether meadow edge monitor sites provided an analytically better sample of activity for the bat assemblage as a whole than meadow center sites. Meadow center sites were technically advantageous in having more consistent insulation for battery maintenance, lower levels of data storage consumed by birds and insects and (for ground level detection) low levels of bat acoustic response to structural clutter. Edge locations were more varied in vegetative structure, presented significant challenges at some sites in maintaining solar recharge (tall forest edges), and often had more non-bat sounds recorded. However, the potential for insect concentration along edges leading to more foraging activity and the possibility that clutter adapted or facultative gleaning species might be more frequently detected recommended assessment of edges (e.g., Celuch and Kropil 2008). Generalized linear model analyses by species and acoustic categories for this trial include a full activity season (Mar-Dec 2008) with peak activity for several species near the middle of the interval, paralleling seasonal temperature change and likely seasonal secondary productivity. Appendix V contains models and plots by species. Table 2 provides qualitative interpretation of results by species and acoustic category.

Table 2. Qualitative results from analysis of Trial 2 six meadow edge and center activity (Mar-Dec 2008).

Species	**Seasonal activity trend**	**Habitat preference**	**Interaction**
Spotted bat	No	Edge	No change
Mastiff bat	Increase in Fall	Center	Center preference increases in Fall
Hoary bat	No	No	Slight center preference in Fall
M50	No	Edge	Preference weakens in Fall
M40	Decrease in Fall	Edge	Preference weakens in Fall
Long-eared myotis	No	Edge	No change
Fringed myotis	No	No	Slight edge preference in Fall
Western pipistrelle	Increase in Fall	No	Shift to center preference in Fall
Q25	No	Edge	Shift to center preference in Fall
Mexican freetail	No	Center	Center preference increases in Fall

In this trial, two species, western mastiff bats and Mexican freetails, showing more activity at meadow centers, are aerial pursuit foragers with high aspect ratio wings adapted for fast flight. Both are also among the more commonly detected species at both meadow centers and edges. For the community as a whole, the meadow vs. edge activity differences are not large.

From these data, we conclude the preferred sampling site is one that has low vegetative or other fixed structural clutter in the detection volume, thus favoring recording of longer duration calls that are more readily assignable to species. The detector should be located to have enough solar exposure to power the monitoring system for the proposed sampling duration, but, at the same time be placed near a habitat structure edge (here a meadow/forest interface). This increases measured activity for several taxa without seriously reducing detection of the relatively abundant species that are more active in the open meadow center sites.

6.3 Inferences from field trials for Yosemite monitoring

Analyses of the three trials provide the basis for designing a long-term bat acoustic monitoring approach for Yosemite. Qualitatively, Trial 1 with a three monitor array in each meadow showed that, while within-meadow replication demonstrated marked differences among meadows in winter to summer seasonal increase in activity for several species, multiple monitors per meadow were not substantially better than a single unit in representing species activity in a meadow. Thus with limited hardware and staff time, spatially distributing monitors one per meadow would sample more of the apparent variation among meadows and better address the primary goal of monitoring bat community activity trends for the park.

Trial 2 with one monitor per meadow in three elevation strata showed that activity for most species declined with elevation and several species were not detected above the moderate elevation stratum. The shorter warm season at higher elevations (effectively determined by the Tioga Road access dates) substantially restricted the number of nights of sampling. Summary estimates of the probability of encounter based on all the elevation trial meadows were lowered for species absent from most or all of the high and moderate elevation sites. Thus, if the primary objective is the lowest feasible uncertainty estimate of year to year change in activity for bat multiple species, the best approach -- assuming relatively gradual climate change -- would restrict monitoring to low to moderate elevation sites below the gate. There the active season is longer (more sample nights) and the activity is higher (more nights with larger numbers of active minutes).

A significant tradeoff is that this approach will provide only limited evidence of activity expansion upslope for species now entirely or predominantly at low elevation. It also will not adequately monitor activity change in the little brown bat (*Myotis lucifugus*), which in Yosemite is the only bat species that appears largely restricted to moderate to high elevation. Of 89 capture records in our database, only two are below 2100 m. This is the only bat species in the park currently known to bear young above 2400 m. Declines in other, sometimes better known high elevation mammals in western North America (e.g., the Grinnell resurvey) suggest that continued climate warming is cause for concern about this montane species.

Another threat to western North American bats is the ongoing eastern U.S. expansion of hibernation site mortality from white nose fungus, *Geomyces destructans* (Blehert et. al. 2009, Gargas et al. 2009). Little brown bats at high elevation in Yosemite have a short active season and very probably a long hibernation interval in unknown low temperature sites. As a consequence, this pathogen may pose a higher risk for little brown bats than for congeners (e.g., Yuma myotis) that, at the elevation of Yosemite valley, are sporadically active in winter and may be encountered foraging in mid winter. We can speculate that by hibernating for shorter intervals possibly in warmer sites, they may experience less temperature dependent depression of immune function. Higher levels of immune system activity may make them less vulnerable to opportunistic infection by this expanding introduced pathogen.

Trial 3, with acoustic monitors at centers and edges of six low elevation meadows from Spring through Fall, showed some species had a center or edge habitat preference (i.e., higher activity) and the preference sometimes changed seasonally. Overall, however, center to edge activity differences were small. We can employ the low elevation center and edge monitor data sets from this trial in a simple power analysis (Figure 20) to estimate the minimum detectable change in mean activity between two years for the species and acoustic groups for various levels of sampling effort (detector nights) The relationship is given in the following formula (Zar, 1999, pg 107, Equation 7.9):

$$\delta = \sqrt{\frac{s^2}{n}}(t_{\alpha,\nu} + t_{\beta(1),\nu})$$

where δ is the minimum detectable difference between two means ($\delta = |\mu - \mu_0|$), s^2 is the variance, n is the sample size, and $t_{\alpha,\nu}$ is the quantile of the t distribution with probability α, and degrees of freedom ν. Parameter values are all calculated using data from the entire season and α=0.05.

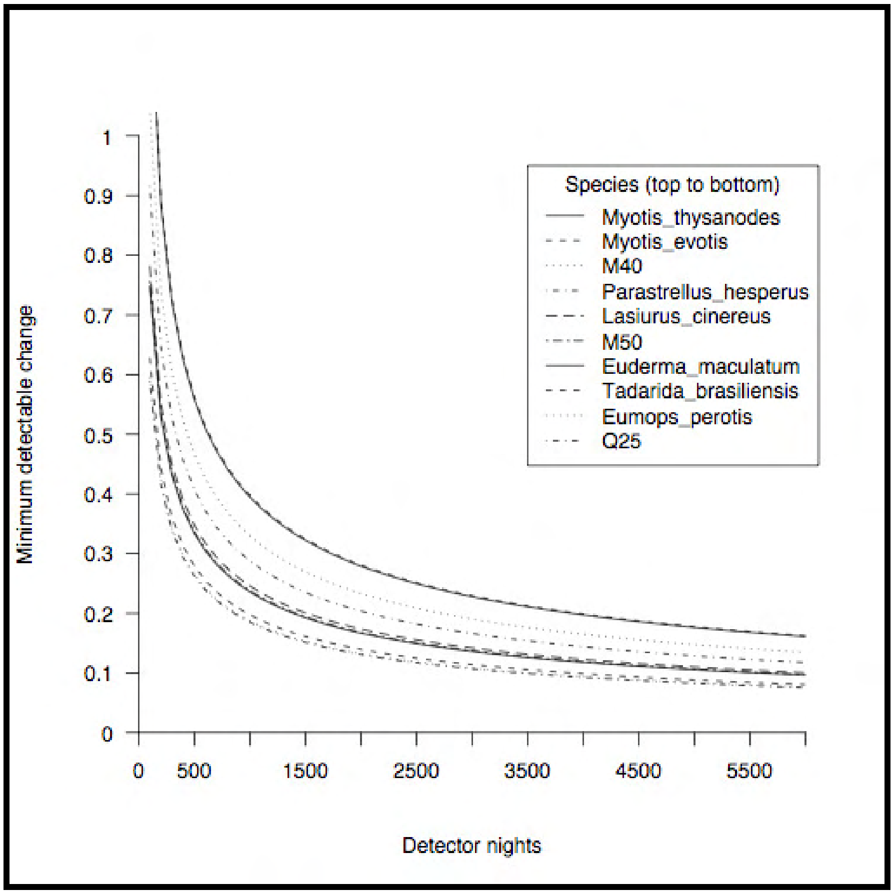


Figure 20. Minimum detectable change in mean activity (by species and acoustic group) between two years by T-test for various levels of sampling effort based on data from Trial 3 (twelve low elevation meadow center and edge monitors combined).

These data cover an interval of 236 nights for each of twelve monitors for an approximate total of 2800 nights (less hardware or bear-induced data gaps). At this level of effort, the graph indicates detection of year to year changes in activity of 20% or more for the more active (and likely abundant) species. For the less frequently recorded *M. evotis* and *M. thysanodes* minimum detectable change rises to somewhat below 30% change year to year.

Figure 21displays the temporal structure of the combined center edge data in detail for selected species and acoustic categories using the same equation parameters from a 30 day moving window, rather than the entire season. The date given on the graph is the starting date for the 30 day window and the mean activity count/night, activity variance and, minimum detectable change are all normalized.

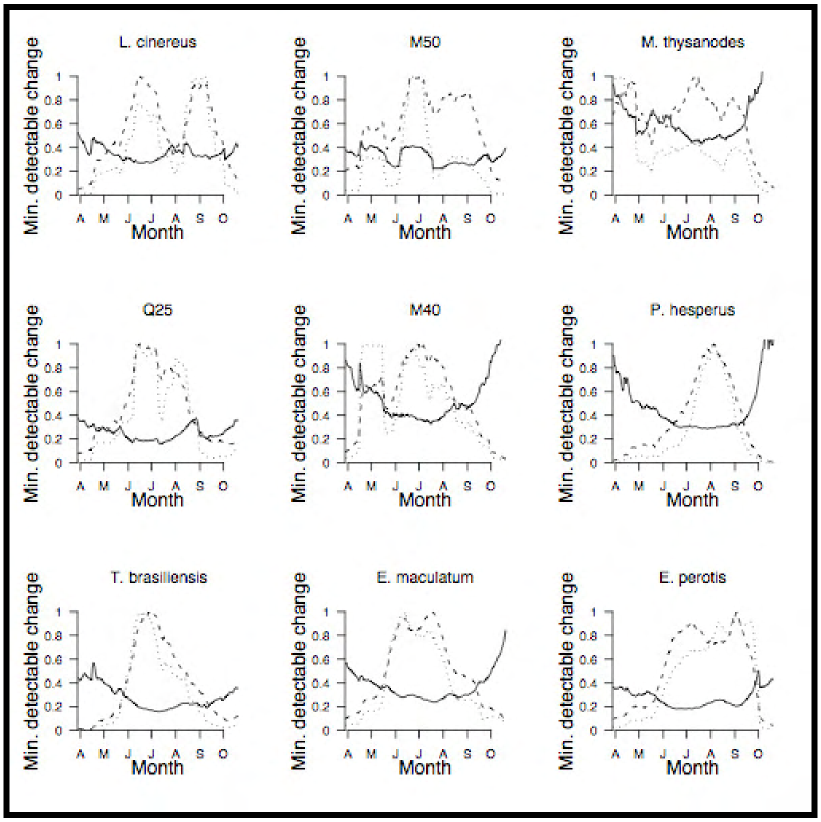


Figure 22. Normalized thirty day moving means from Trial 3 for selected species and species groups for nightly activity (dashed line), activity variance (dotted line) and minimum detectable year to year change (solid line) by T-test (Zar 1999).

While it may be argued that there are better tests for these data than simple t-tests, the demonstration of changes in power for the t-test reflects the relative changes in power for different species, at different times of the season, and for different sample sizes that we would expect to see with any test of differences in mean. Power has an inverse relationship with δ, so that as δ increases, power decreases. Power changes throughout the season, so that δ is high at the beginning and end of the warm season, when activity is low or erratic, and δ is sometimes sporadically high in mid-season during times associated with high variance in activity. Power increases (δ decreases) with increased sample size, but approaches an asymptote determined by species abundance and detectability.

Figure 21 makes it clear that for several species the monitoring interval in this trial was greater than the seasonal activity interval, so that more nights of monitoring effort would not improve the minimum detectable change value. Reducing minimum detectable change requires either more monitors (increasing total detections per night) or hardware/analytic changes that increase the activity detected per night.

7.0. CONCLUSIONS AND RECOMMENDATIONS

7.1. Recommendations for Yosemite monitoring

Our primary goal in this study was the development of a statistically robust sampling framework for acoustic monitoring that is capable of detecting changes in the species composition of the bat assemblage inhabiting a given area. As noted in the report introduction, particularly in the UK and elsewhere in Europe, surveys of various designs that estimate bat species activity using call identification are now widely used for inventory and monitoring of populations at large landscape scales. These differ from what is feasible in most U.S. national parks, because they rely on regular participation of large numbers of trained volunteer amateur surveyors. An alternative approach, already used for a number of years on National Park Service lands primarily for inventory, is deployment of passive monitors that record acoustic data which can be periodically downloaded and analyzed. This study pursued hardware additions and improved software for employing the AnaBat detection and data storage system as long-term passive monitors. Three field trials of durations greater than 100 days with the available twelve monitors examined questions relating to various scales of static spatial arrangement for long-term monitoring. The results from these trials lead us to recommend:

1. With limited equipment and operator time, the most effective deployment of detectors for monitoring would be one station per meadow. Placing the monitor so that the microphone direction and detection volume parallels and is close (5-10m) to a vegetation edge will slightly increase detected activity for several species and acoustic categories.
2. Because seasonal duration of activity, overall activity in meadows, and species number decline with elevation, the most effective use of limited resources for bat community monitoring would be to deploy all monitors at lower elevation meadows or structurally similar sites below the gates on the Tioga and Glacier Point roads. Six edge sites from this study could be re-occupied and six additional identified (on Yosemite Valley floor and along major park road corridors including Doghouse Meadow to make use of prior monitoring data from that site). This would allow a monitoring duration of 200 days or more. Operating the monitors through the winter provides information on phenology, but winter weather can degrade the acoustic equipment with minimal benefit to year to year comparison of warm season activity. Maintaining these monitors for several sequential annual cycles would provide empirical information on year to year activity variation and help to shape the design of longer term monitoring.
3. If the values for minimum detectable year to year change reported above (ca 20% for more active species and acoustic categories) need to be improved, the simplest solution would be to deploy additional monitors at additional sites. Figure 21 shows the expected trend in minimum detectable change with larger counts of detector nights. There is the possibility that larger reflectors could enhance detection rates and simultaneously somewhat reduce insect noise recording.

Monitoring activity of *M. lucifugus* that occurs primarily at higher elevations in Yosemite requires a separate monitoring effort. The season for observation is set to approximately 100 days by road access through the Tioga gate. Levels of 40 kHz *Myotis* activity in meadows at higher elevations is much lower than activity at sites with quiet surface water on rivers and some lakes. This species, like Yuma myotis, is a facultative skimmer of emerging aquatic insects and placing acoustic monitors at water body margins would obtain much higher per night activity and improved estimates of year to year detectible variation in activity.

7.2. A proposed framework for long-term monitoring

7.2.1. Conduct an inventory to characterize the bat fauna

Yosemite National Park was selected for this study because three of the participants had studied bats in Yosemite for up to 13 years, collecting both demographic and acoustic data. Consequently, the distribution, habitat associations, seasonal patterns, and acoustic call characteristics were fairly well known for most species. This avoided several preliminary steps that would be required to set up a long-term monitoring program in an area where the bat fauna had not been characterized.

Before a long-term acoustic monitoring program could be implemented, it would be important to conduct an initial inventory. Because some species are more readily identified by capture, and others are more readily detected acoustically, an inventory should include both capture and acoustic methods, and should be continued until at least 90% of the expected species are detected. An expected species list can be obtained from sources such as Hall (1981) or other regionally specific publications (*e.g*., Hoffmeister 1986, Schmidly 1991), from regional bat working groups (e.g., Western Bat Working Group, www.wbwg.org), and species accounts found on the web site of Bat Conservation International (www.batcon.org). This inventory should cover all habitat types in the study area, sampling each area until 90% of the expected species are detected.

7.2.2. Monitoring Equipment

There are an increasing number of ultrasound recording systems and bioacoustic or signal analysis software packages that are potentially useful for bat acoustic surveys. This project was designed to improve and evaluate the long term application of a weatherproof passive monitor based on the widely used AnaBat detector and ZCAIM CF card storage unit (Titley Electronics, Ballina, NSW, Australia) with an enclosure, microphone extension, solar power supply and data logging multi-channel controller (Owl2pe) adapted for scheduling recording (EME Systems, Berkeley, CA). Signal capture compressed by frequency division contributes to efficient data storage, and the external controller minimizes daytime power drain (approximately 0.5 amp hours/24hrs), so that the monitors can run for months in California without intervention, but more frequent site visits may be desirable if there are possible issues with human or animal damage.

The detector and storage zcaim combination used in this project has since been replaced by Titley Electronics with a single unit storage detector (SD1) that incorporates the functions of the separate detector and zcaim. An additional cost option is a cellular modem that allows monitors to upload data daily to a web site for remote download and offers remote control of detector settings (e.g., sensitivity). In Yosemite meadows, the amount of data per night would probably not require a larger battery and solar panel in the warm seasons to provide power for the several hours of daily operation of the communications link. Three and four season operation in California would require a larger panel and localities with different insulation regimes should review panel and battery sizing.

7.2.3. Selecting Sites

There are several important considerations in selecting monitoring sites: the number, their spatial distribution, and their habitat characteristics.

Typically the number of monitoring instruments available and time available for a project is determined by budget constraints rather than a desired level detectable activity (and inferred population) change from year to year. Examining Figures 20 and 21 above, it should be clear that the percent year to year change that can be detected is affected by the number of monitor nights, the level of activity (minutes/night), and the variance in nightly activity. Both the seasonal duration of activity and the number of monitoring stations determine the feasible number of monitor nights.

Localities with short bat activity seasons or low or highly variable nightly activity will require data from more monitoring instruments to attain the same level of activity change detection as a higher activity site. A season of reconnaissance sampling, moving monitors among sites, within and among broad habitat and elevation categories is a basic first step (in the absence of prior data) to assess what can be obtained from various scales of monitoring effort (including both equipment maintenance and analytic time).

Species (and acoustic category) accumulation rates are a useful metric to follow in reconnaissance monitoring. In the warm seasons in mesic parts of California, 5-7 days is usually enough to approach a species richness asymptote. At high elevations or in arid unproductive areas, monitoring at resource sites where bats concentrate (e.g., isolated surface water) maybe the best choice, but monitor siting may require several iterations, if high concentrations of bats lead to intense activity and poor species discrimination as consequence of altered call structure.

Spatial distribution of sampling sites. The spatial distribution of sampling sites should be determined by the primary focus of the monitoring program. If the goal is to monitor a large fraction of the bat species assemblage, then it should be determined where in the study area both species richness and activity are high. For example, in Yosemite, which covers a wide elevational range (320-4,007 m), species richness declines with elevation, and the maximum occurs below 1,800 m. If the goal were to monitor the community as a whole, we would recommend placing all systems below 1,800 m. If, however, because of climate change, there is an interest in tracking changes in the species assemblage over an elevational gradient, then detectors should be distributed over a wider elevational range, and include high elevation sites.

Habitat characteristics of sampling sites. For the four reasons stated earlier (Section 6.1), we selected meadows as our habitat type for acoustic monitoring. Not only did this habitat type meet all our acoustic criteria, it also was fairly abundant and distributed across an elevational gradient in Yosemite.

The most important characteristic of meadows was, however, that they provided an acoustically uncluttered environment. We thus recommend that an analogous open habitat be selected wherever a monitoring program is to be established, and that initial trials establish that bat species numbers are useful and acoustic interference (e.g., insect, frog, or bird calls, water noise) is acceptable. Low elevation oak grassland and chaparral sites in California can be particularly problematic for broadband insect choruses.

Sampling at the edge, with the detector oriented along the interface, appeared to maximize community activity in the Yosemite trials, but this may be compromised in sites with more intense canopy insect choruses. Thus we recommend selecting sites that are both as open as possible and initially close to an interface with more structural complexity. Preliminary trials should be conducted to demonstrate that several criteria are being met: the detection volume has minimal structural clutter, non-bat sound does not cause consistent interference, high species richness is being sampled, and bat activity is not so high that interactions (active clutter) substantially reduce call quality for identification.

7.2.4. Analytical methods

The statistical approach suggested here (Section 6.3) for monitoring change in year to year activity is based on a T-test using mean and variance of a season of nightly count of minutes with activity for each species or (unresolved multi-species acoustic category).

8.0. ACKNOWLEDGEMENTS

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Appendix I. Sampling Localities.

All coordinate data were collected with a Garmin GPSMap 60Cx. Datum for all tabled coordinates is NAD83. Coordinates for Trial 1 are means of 5-7 single fixes from multiple site visits (recorded as NAD27 CONUS and later converted). Trial 2 and 3 coordinates are instrument means from greater than 400 fixes on a single site visit (recorded as NAD83). Elevations were obtained by importing the geographical coordinates into ArcMap in the original datum and then reprojecting them to UTM NAD 1983 to ensure consistency with the current Yosemite digital elevation model. Elevations values below were then extracted from the 10X10 m cell underlying each point.

site	**stratum**	**latitude**	**longitude**	**elevation**
Triangle trial (1)				
Wawona	A	37.53149	119.64734	1238
Wawona	B	37.53141	119.64706	1238
Wawona	C	37.53164	119.64712	1239
Hodgdon	A	37.79600	119.85838	1399
Hodgdon	B	37.79592	119.85814	1400
Hodgdon	C	37.79577	119.85833	1399
Woski Pond	A	37.72593	119.62669	1204
Woski Pond	B	37.72608	119.62679	1204
Woski Pond	C	37.72589	119.62690	1204
Doghouse	A	37.75431	119.80291	1877
Doghouse	B	37.75442	119.80267	1877
Doghouse	C	37.75422	119.80263	1877
Elevation trial (2)				
Woski Pond	low	37.72588	119.62684	1203
Yellow Pines	low	37.73100	119.60897	1205
Wawona	low	37.53145	119.64730	1234
Hodgdon	low	37.79556	119.85838	1397
Doghouse	mid	37.75418	119.80262	1876
Below Gin Flat	mid	37.76027	119.77100	2101
Peregoy	mid	37.66967	119.62447	2127
Monroe	mid	37.66189	119.66184	2213
White Wolf	high	37.86340	119.64770	2420
Tenaya Creek	high	37.82525	119.46919	2485
Tuolumne	high	37.87504	119.38850	2610
Snow Flat	high	37.82660	119.49913	2655
Center edge trial (3)				
Wawona	center	37.53146	119.64737	1234
Wawona	edge	37.53201	119.64648	1239

Hodgdon	center	37.79556	119.85841	1397
Hodgdon	edge	37.79533	119.85773	1400
Woski Pond	center	37.72591	119.62685	1203
Woski Pond	edge	37.72570	119.62647	1203
Bridalveil	center	37.71720	119.65967	1186
Bridalveil	edge	37.71699	119.65872	1190
Leidig	center	37.73766	119.60518	1205
Leidig	edge	37.73816	119.60473	1205
Yellow Pines	center	37.73100	119.60900	1205
Yellow Pines	edge	37.73077	119.60847	1205

APPENDIX II. Trial 1, Three Detectors per Meadow Replicated Block Design

Within block replication in these models allows investigation of interaction between location and date. Note that the models generate NaN for certain P values. Since these terms are retained by AIC, these incalculable p values aren’t required.

II.1.Pallid bat, *Antrozous pallidus*

A. pallidus social vocalizations model selection

```
LMEANPASC1<-lme(ANPASC~1, random = ~1|Location, data = YNPbats2)
LMEANPASC2<-lme(ANPASC~1, random = ~1|Location/Day, data = YNPbats2)
LMEANPASC3<-lme(ANPASC~Day, random = ~1|Location, data = YNPbats2)
LMEANPASC4<-lme(ANPASC~Day, random = ~1|Location/Day, data = YNPbats2)
LMEANPASC5<-lme(ANPASC~Day + Location, random = ~1|Location, data =
YNPbats2)
LMEANPASC6<-lme(ANPASC~Day + Location, random = ~1|Location/Day, data =
YNPbats2)
LMEANPASC7<-lme(ANPASC~Day * Location, random = ~1|Location, data =
YNPbats2)
LMEANPASC8<-lme(ANPASC~Day * Location, random = ~1|Location/Day, data =
YNPbats2)
### 4 does not converge
```

AIC selects Model 8

Selection by AIC indicates that a full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that day, location and their interaction are all informative for explaining activity levels. Retention of both random effects indicates that day within location provides grouping that contributes to model information.

A. pallidus social vocalizations model terms

```
Linear mixed-effects model fit by REML
 Data: YNPbats2
        AIC       BIC   logLik
  -7898.592 -7835.556 3960.296

Random effects:
 Formula: ~1 | Location
        (Intercept)
StdDev:  0.00465402

 Formula: ~1 | Day %in% Location
         (Intercept)   Residual
StdDev: 7.004779e-06 0.04172081

Fixed effects: ANPASC ~ Day * Location
                               Value   Std.Error   DF    t-value p-
value
(Intercept)            -0.001440393 0.005777263 1356 -0.2493211
0.8032
```

```
Day                      0.000024384 0.000024636  921  0.9897971
0.3225
LocationHodgdon_Mdw     -0.006000047 0.008340158    0 -0.7194164
NaN
LocationWoski_Pond       0.001440393 0.008230526    0  0.1750062
NaN
LocationWawona_Mdw      -0.000269781 0.008142955    0 -0.0331306
NaN
Day:LocationHodgdon_Mdw  0.000075367 0.000037962  921  1.9853230
0.0474
Day:LocationWoski_Pond  -0.000024384 0.000035367  921 -0.6894706
0.4907
Day:LocationWawona_Mdw   0.000005825 0.000034546  921  0.1686056
0.8661
 Correlation:
                        (Intr) Day    LctH_M LctW_P LctW_M D:LH_M
D:LW_P
Day                     -0.521
LocationHodgdon_Mdw     -0.693  0.361
LocationWoski_Pond      -0.702  0.365  0.486
LocationWawona_Mdw      -0.709  0.369  0.491  0.498
Day:LocationHodgdon_Mdw  0.338 -0.649 -0.537 -0.237 -0.240
Day:LocationWoski_Pond   0.363 -0.697 -0.251 -0.527 -0.257  0.452
Day:LocationWawona_Mdw   0.371 -0.713 -0.257 -0.261 -0.508  0.463
0.497

Standardized Within-Group Residuals:
          Min            Q1           Med            Q3           Max
-3.763561e-01 -7.652339e-02 -1.041836e-02 -9.997296e-19  2.389116e+01

Number of Observations: 2285
Number of Groups:
         Location Day %in% Location
                4               929
Warning message:
In pt(q, df, lower.tail, log.p) : NaNs produced
```

For *A. pallidus*, the intercept of Doghouse at Day One is not significantly different from zero. The main effect for day is also insignificant. The main effect for each of the three sites relative to Doghouse is incalculable. Woski and Wawona, interacting with day, are not significantly different from Doghouse. However, Hodgdon increases significantly with day as compared to Doghouse (Figure AII.1).

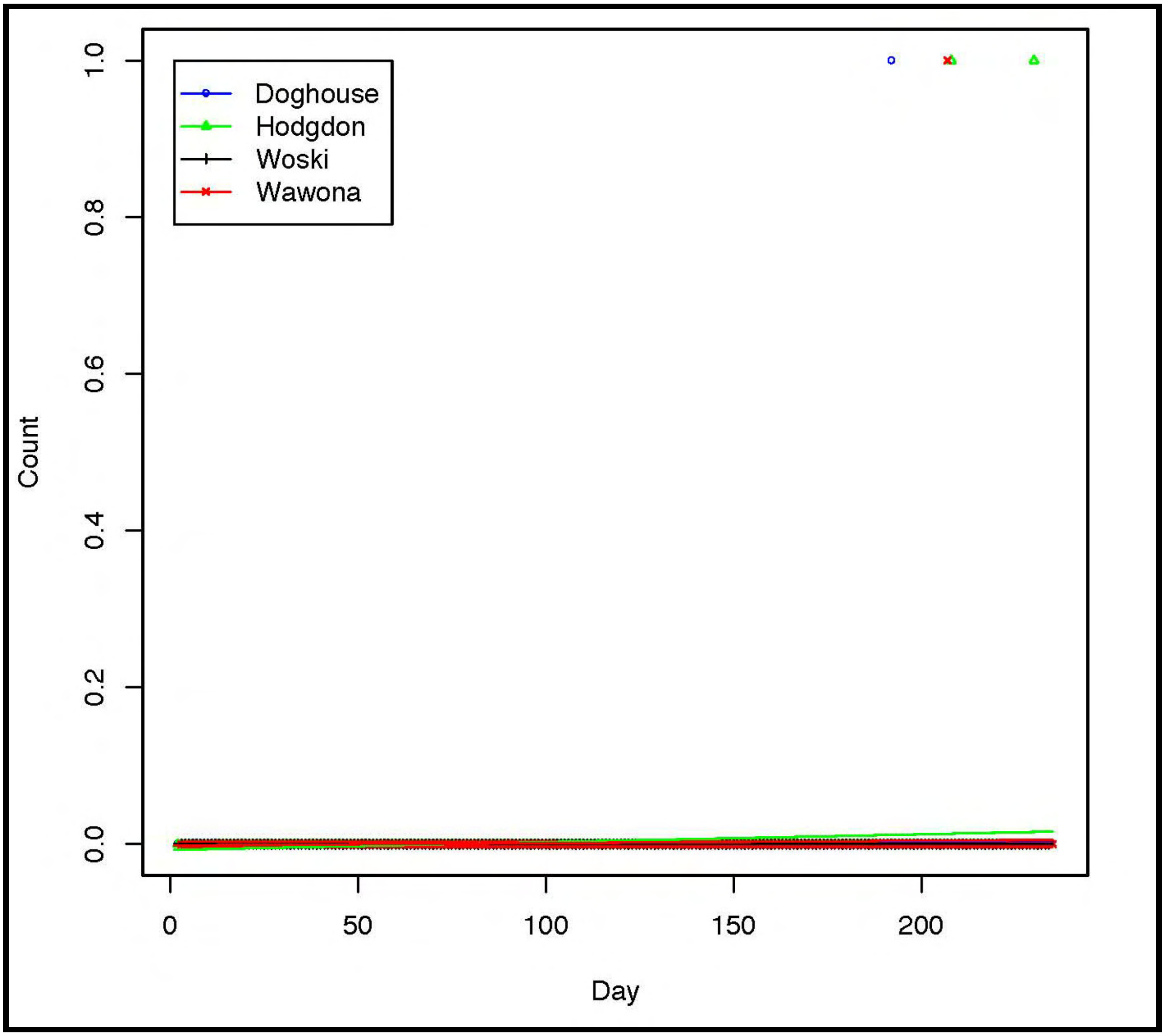

Figure AII.1. Interactions between day and location for *Antrozous pallidus* (social calls)

II.2. Spotted bat, *Euderma maculatum*

E. maculatum model selection

```
LMEEUMA1<-lme(EUMA~1, random = ~1|Location, data = YNPbats2)
LMEEUMA2<-lme(EUMA~1, random = ~1|Location/Day, data = YNPbats2)
LMEEUMA3<-lme(EUMA~Day, random = ~1|Location, data = YNPbats2)
LMEEUMA4<-lme(EUMA~Day, random = ~1|Location/Day, data = YNPbats2)
LMEEUMA5<-lme(EUMA~Day + Location, random = ~1|Location, data =
YNPbats2)
LMEEUMA6<-lme(EUMA~Day + Location, random = ~1|Location/Day, data =
YNPbats2)
LMEEUMA7<-lme(EUMA~Day * Location, random = ~1|Location, data =
YNPbats2)
```

```
LMEEUMA8<-lme(EUMA~Day * Location, random = ~1|Location/Day, data =
YNPbats2)
```

AIC selects Model 8

Selection by AIC indicates that a full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that day, location and their interaction are all informative for explaining activity levels. Retention of both random effects indicates that day within location provides grouping that contributes to model information.

E. maculatum model terms

```
Linear mixed-effects model fit by REML
 Data: YNPbats2
       AIC      BIC    logLik
  20363.79 20426.82 -10170.89

Random effects:
 Formula: ~1 | Location
        (Intercept)
StdDev:    1.855369

 Formula: ~1 | Day %in% Location
        (Intercept) Residual
StdDev:    14.93918 16.62932

Fixed effects: EUMA ~ Day * Location
                             Value Std.Error   DF   t-value p-value
(Intercept)              -5.215853  3.045559 1356 -1.712610  0.0870
Day                       0.077372  0.017645  921  4.384970  0.0000
LocationHodgdon_Mdw       0.899934  4.357817    0  0.206510     NaN
LocationWoski_Pond      -25.808072  4.332608    0 -5.956707     NaN
LocationWawona_Mdw        4.548098  4.305744    0  1.056286     NaN
Day:LocationHodgdon_Mdw  -0.014586  0.025721  921 -0.567106  0.5708
Day:LocationWoski_Pond    0.389435  0.025137  921 15.492768  0.0000
Day:LocationWawona_Mdw   -0.066832  0.024860  921 -2.688353  0.0073
 Correlation:
                        (Intr) Day    LctH_M LctW_P LctW_M D:LH_M
D:LW_P
Day                     -0.692
LocationHodgdon_Mdw     -0.699  0.484
LocationWoski_Pond      -0.703  0.486  0.491
LocationWawona_Mdw      -0.707  0.489  0.494  0.497
Day:LocationHodgdon_Mdw  0.475 -0.686 -0.695 -0.334 -0.336
Day:LocationWoski_Pond   0.486 -0.702 -0.339 -0.694 -0.344  0.482
Day:LocationWawona_Mdw   0.491 -0.710 -0.343 -0.345 -0.687  0.487
0.498

Standardized Within-Group Residuals:
        Min          Q1         Med          Q3         Max
-6.28037298 -0.11880882 -0.02125490  0.03284431  9.65533338

Number of Observations: 2285
Number of Groups:
         Location Day %in% Location
```

```
                  4              929
Warning message:
In pt(q, df, lower.tail, log.p) : NaNs produced
```

For *E. maculatum*, the intercept of Doghouse at Day One is not significantly different from zero. Activity increases significantly overall with day. The main effect for each of the three sites relative to Doghouse is incalculable. Hodgdon, interacting with day, is not significantly different from Doghouse. However, Woski increases significantly with day and Wawona decreases significantly with day as compared to Doghouse (Figure AII.2).

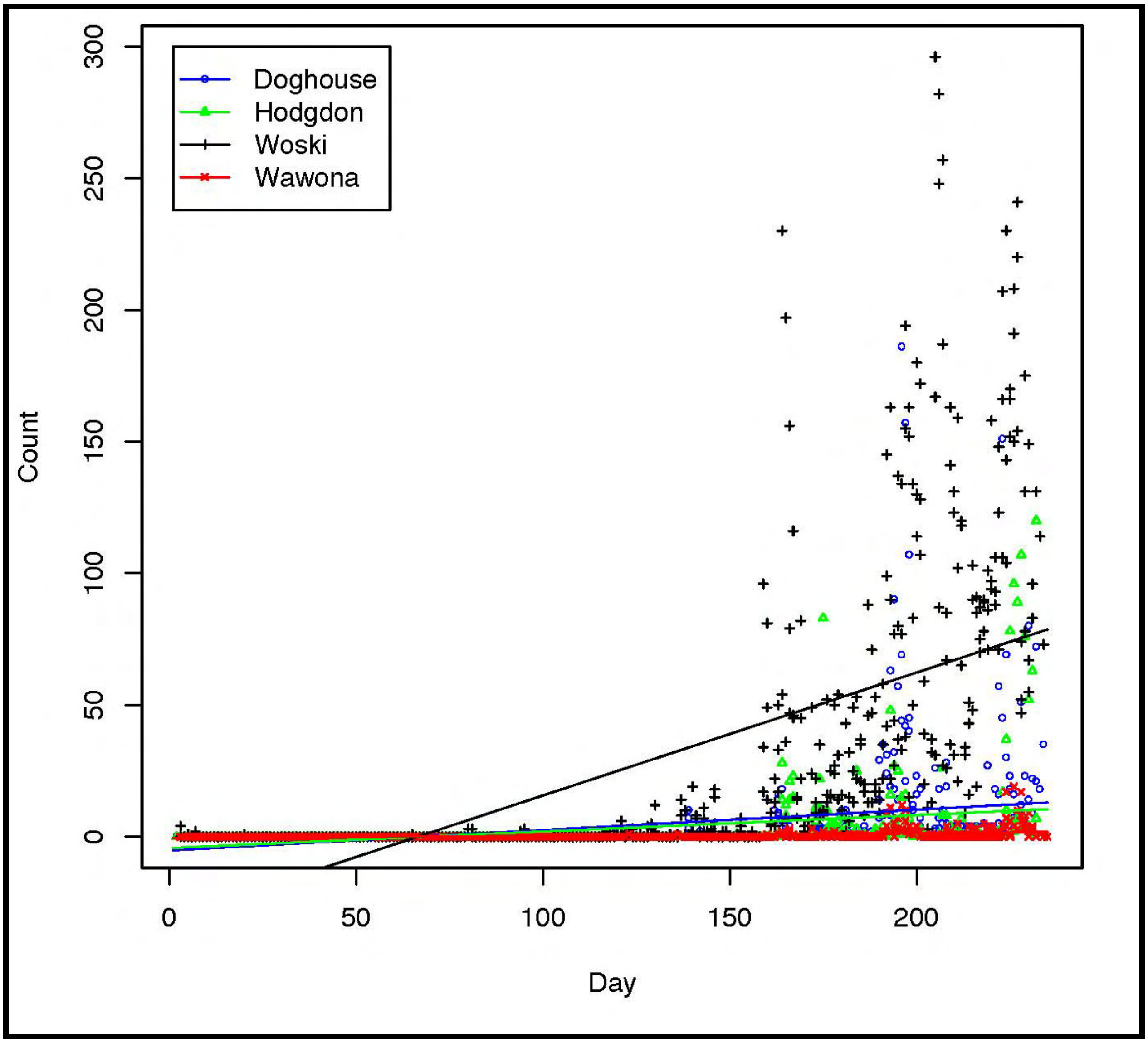

Figure AII.2. Interactions between day and location for *Euderma maculatum*

<u>II.3. Western mastiff bat, *Eumops perotis*</u>

E. perotis model selection

```
LMEEUPE1<-lme(EUPE~1, random = ~1|Location, data = YNPbats2)
LMEEUPE2<-lme(EUPE~1, random = ~1|Location/Day, data = YNPbats2)
LMEEUPE3<-lme(EUPE~Day, random = ~1|Location, data = YNPbats2)
LMEEUPE4<-lme(EUPE~Day, random = ~1|Location/Day, data = YNPbats2)
LMEEUPE5<-lme(EUPE~Day + Location, random = ~1|Location, data =
YNPbats2)
LMEEUPE6<-lme(EUPE~Day + Location, random = ~1|Location/Day, data =
YNPbats2)
LMEEUPE7<-lme(EUPE~Day * Location, random = ~1|Location, data =
YNPbats2)
LMEEUPE8<-lme(EUPE~Day * Location, random = ~1|Location/Day, data =
YNPbats2)
```

AIC selects Model 8

Selection by AIC indicates that a full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that day, location and their interaction are all informative for explaining activity levels. Retention of both random effects indicates that day within location provides grouping that contributes to model information.

E. perotis model terms

```
Linear mixed-effects model fit by REML
 Data: YNPbats2
       AIC      BIC    logLik
  19511.79 19574.83 -9744.894

Random effects:
 Formula: ~1 | Location
        (Intercept)
StdDev:    1.029544

 Formula: ~1 | Day %in% Location
        (Intercept) Residual
StdDev:    27.07844  9.22761

Fixed effects: EUPE ~ Day * Location
                            Value Std.Error   DF   t-value p-value
(Intercept)              -1.20131  3.807720 1356 -0.315492  0.7524
Day                       0.02434  0.026964  921  0.902808  0.3669
LocationHodgdon_Mdw       1.02695  5.406095    0  0.189961     NaN
LocationWoski_Pond      -23.33492  5.409670    0 -4.313557     NaN
LocationWawona_Mdw      -35.32809  5.398939    0 -6.543525     NaN
Day:LocationHodgdon_Mdw  -0.02195  0.038495  921 -0.570129  0.5687
Day:LocationWoski_Pond    0.44059  0.038277  921 11.510406  0.0000
Day:LocationWawona_Mdw    0.47961  0.038108  921 12.585428  0.0000
 Correlation:
                        (Intr) Day    LctH_M LctW_P LctW_M D:LH_M
D:LW_P
Day                     -0.837
LocationHodgdon_Mdw     -0.704  0.589
LocationWoski_Pond      -0.704  0.589  0.496
```

```
LocationWawona_Mdw      -0.705  0.590  0.497  0.496
Day:LocationHodgdon_Mdw  0.586 -0.700 -0.837 -0.413 -0.413
Day:LocationWoski_Pond   0.590 -0.704 -0.415 -0.838 -0.416  0.493
Day:LocationWawona_Mdw   0.592 -0.708 -0.417 -0.417 -0.837  0.496
0.498

Standardized Within-Group Residuals:
          Min            Q1           Med            Q3           Max
-7.6057414885 -0.0669828762 -0.0009293636  0.0383664901  5.9029690493

Number of Observations: 2285
Number of Groups:
         Location Day %in% Location
               4              929
Warning message:
In pt(q, df, lower.tail, log.p) : NaNs produced
```

For *E. perotis*, the intercept of Doghouse at Day One is not significantly different from zero. The main effect for day is also insignificant. The main effect for each of the three sites relative to Doghouse is incalculable. Hogdon, interacting with day, is not significantly different from Doghouse. However, the two other localities, Woski Pond and Wawona Meadow, increase significantly with day as compared to Doghouse (Figure AII.3).

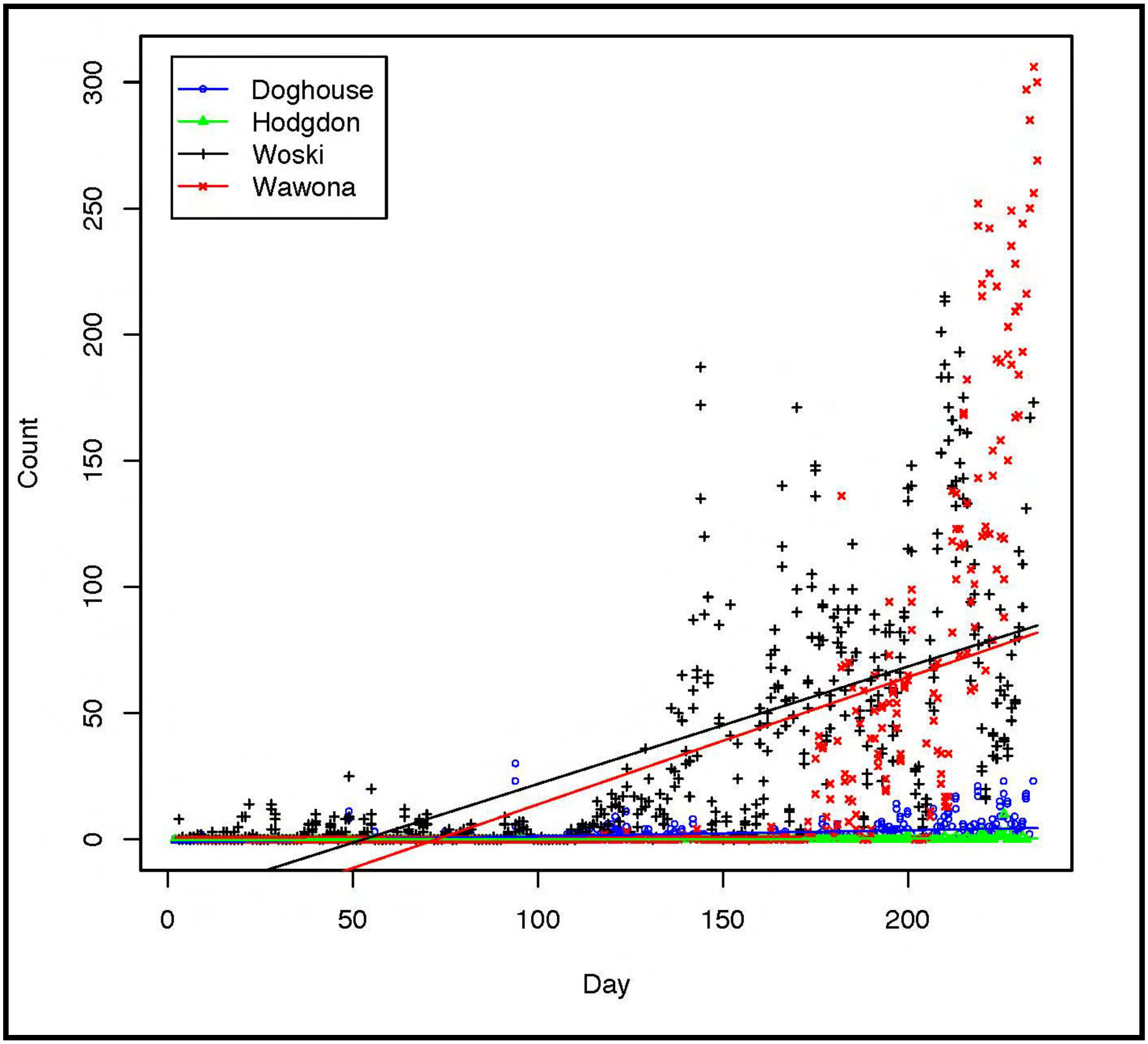

Figure AII.3. Interactions between day and location for *Eumops perotis*

II.4. Western red bat, *Lasiurus blossevillii*

L. blossevillii model Selection

```
LMELABL1<-lme(LABL~1, random = ~1|Location, data = YNPbats2)
LMELABL2<-lme(LABL~1, random = ~1|Location/Day, data = YNPbats2)
LMELABL3<-lme(LABL~Day, random = ~1|Location, data = YNPbats2)
LMELABL4<-lme(LABL~Day, random = ~1|Location/Day, data = YNPbats2)
LMELABL5<-lme(LABL~Day + Location, random = ~1|Location, data =
YNPbats2)
LMELABL6<-lme(LABL~Day + Location, random = ~1|Location/Day, data =
YNPbats2)
LMELABL7<-lme(LABL~Day * Location, random = ~1|Location, data =
YNPbats2)
```

```
LMELABL8<-lme(LABL~Day * Location, random = ~1|Location/Day, data =
YNPbats2)
```

AIC selects Model 8

Selection by AIC indicates that a full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that day, location and their interaction are all informative for explaining activity levels. Retention of both random effects indicates that day within location provides grouping that contributes to model information.

L. blossevillii model terms

```
Linear mixed-effects model fit by REML
 Data: YNPbats2
       AIC      BIC    logLik
  5961.886 6024.923 -2969.943

Random effects:
 Formula: ~1 | Location
        (Intercept)
StdDev:  0.07094672

 Formula: ~1 | Day %in% Location
        (Intercept)  Residual
StdDev:   0.8074011 0.6358823

Fixed effects: LABL ~ Day * Location
                             Value  Std.Error   DF   t-value p-value
(Intercept)              -0.0087320 0.13887248 1356 -0.062878  0.9499
Day                       0.0001225 0.00087494  921  0.139968  0.8887
LocationHodgdon_Mdw      -1.0574407 0.19810572    0 -5.337759     NaN
LocationWoski_Pond        0.0087320 0.19745396    0  0.044223     NaN
LocationWawona_Mdw       -0.0204731 0.19656202    0 -0.104156     NaN
Day:LocationHodgdon_Mdw   0.0153039 0.00126279  921 12.119135  0.0000
Day:LocationWoski_Pond   -0.0001225 0.00124443  921 -0.098410  0.9216
Day:LocationWawona_Mdw    0.0003153 0.00123430  921  0.255418  0.7985
 Correlation:
                         (Intr) Day    LctH_M LctW_P LctW_M D:LH_M
D:LW_P
Day                      -0.749
LocationHodgdon_Mdw      -0.701  0.525
LocationWoski_Pond       -0.703  0.527  0.493
LocationWawona_Mdw       -0.707  0.529  0.495  0.497
Day:LocationHodgdon_Mdw   0.519 -0.693 -0.750 -0.365 -0.367
Day:LocationWoski_Pond    0.527 -0.703 -0.369 -0.751 -0.372  0.487
Day:LocationWawona_Mdw    0.531 -0.709 -0.372 -0.373 -0.746  0.491
0.498

Standardized Within-Group Residuals:
          Min            Q1           Med            Q3           Max
-9.369747e+00 -9.586079e-03  4.567161e-18  1.517054e-17  1.579214e+01

Number of Observations: 2285
Number of Groups:
```

```
         Location Day %in% Location
                4                929
Warning message:
In pt(q, df, lower.tail, log.p) : NaNs produced
```

For *L. blossevillii*, the intercept of Doghouse at Day One is not significantly different from zero. The main effect for day is also insignificant. The main effect for each of the three sites relative to Doghouse is incalculable. Hogdon, interacting with day, increases significantly relative to Doghouse.The two other localities, Woski Pond and Wawona Meadow, interacting with day, show no significant difference from Doghouse (Figure AII.4).

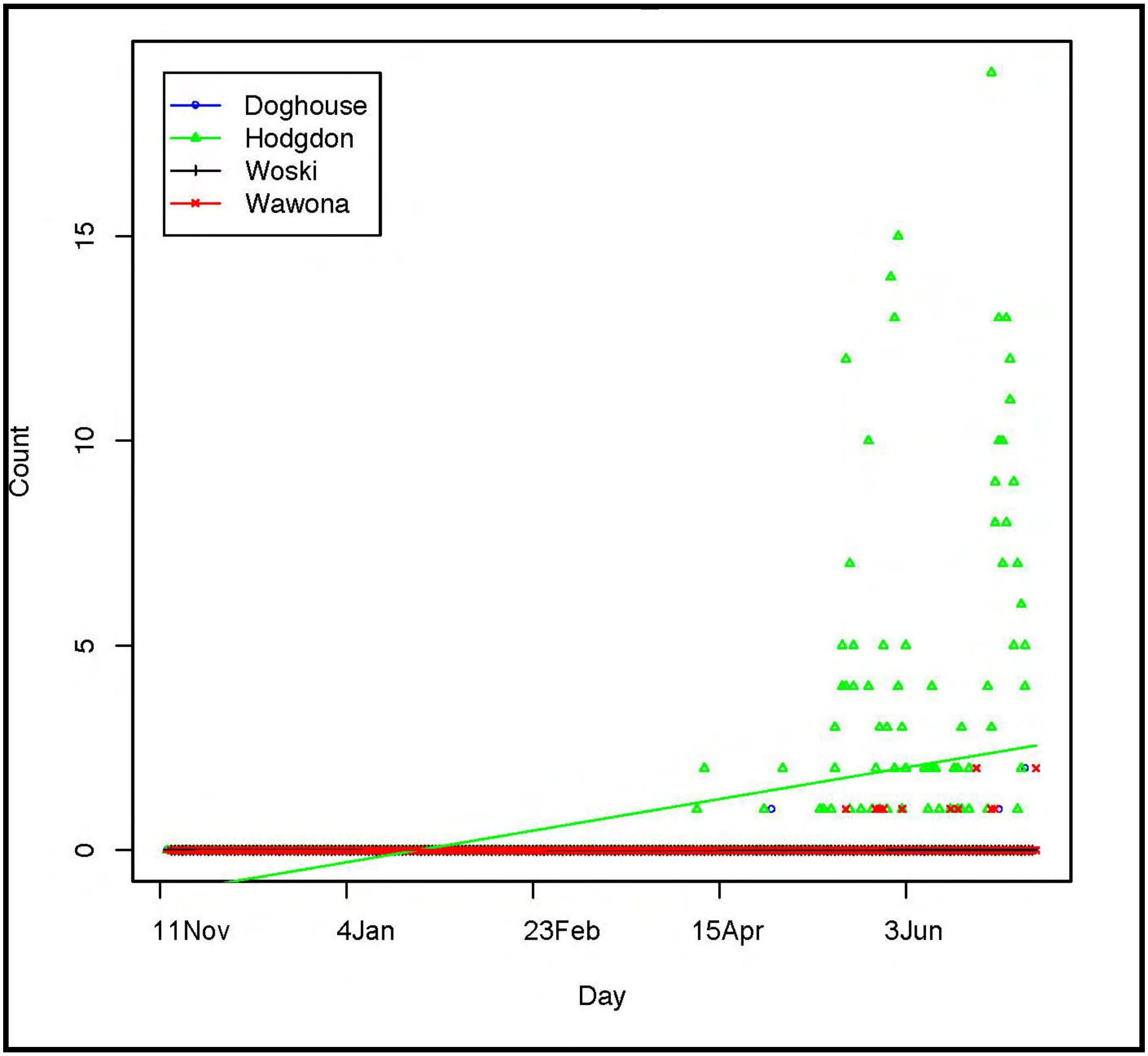

Figure AII.4. Interactions between day and location for *Lasiurus blossevillii*

II.5. Hoary bat, *Lasiurus cinereus*

L. cinereus model selection

```
LMELACI1<-lme(LACI~1, random = ~1|Location, data = YNPbats2)
LMELACI2<-lme(LACI~1, random = ~1|Location/Day, data = YNPbats2)
LMELACI3<-lme(LACI~Day, random = ~1|Location, data = YNPbats2)
LMELACI4<-lme(LACI~Day, random = ~1|Location/Day, data = YNPbats2)
LMELACI5<-lme(LACI~Day + Location, random = ~1|Location, data =
YNPbats2)
LMELACI6<-lme(LACI~Day + Location, random = ~1|Location/Day, data =
YNPbats2)
LMELACI7<-lme(LACI~Day * Location, random = ~1|Location, data =
YNPbats2)
LMELACI8<-lme(LACI~Day * Location, random = ~1|Location/Day, data =
YNPbats2)
```

AIC selects Model 8

Selection by AIC indicates that a full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that day, location and their interaction are all informative for explaining activity levels. Retention of both random effects indicates that day within location provides grouping that contributes to model information.

L. cinereus model terms

```
Linear mixed-effects model fit by REML
 Data: YNPbats2
       AIC      BIC    logLik
  21151.91 21214.95 -10564.96

Random effects:
 Formula: ~1 | Location
        (Intercept)
StdDev:    2.494953

 Formula: ~1 | Day %in% Location
        (Intercept) Residual
StdDev:    11.11001 22.36180

Fixed effects: LACI ~ Day * Location
                             Value Std.Error   DF    t-value p-value
(Intercept)             -21.550949  3.437012 1356  -6.270258       0
Day                       0.383093  0.017155  921  22.330730       0
LocationHodgdon_Mdw      17.020594  4.941230    0   3.444606     NaN
LocationWoski_Pond       18.770431  4.893503    0   3.835786     NaN
LocationWawona_Mdw       20.337364  4.850717    0   4.192651     NaN
Day:LocationHodgdon_Mdw  -0.307899  0.025584  921 -12.034745       0
Day:LocationWoski_Pond   -0.340728  0.024522  921 -13.894827       0
Day:LocationWawona_Mdw   -0.355241  0.024116  921 -14.730632       0
 Correlation:
                        (Intr) Day    LctH_M LctW_P LctW_M D:LH_M
D:LW_P
Day                     -0.602
LocationHodgdon_Mdw     -0.696  0.419
```

```
LocationWoski_Pond      -0.702  0.423  0.489
LocationWawona_Mdw      -0.709  0.427  0.493  0.498
Day:LocationHodgdon_Mdw  0.404 -0.671 -0.611 -0.284 -0.286
Day:LocationWoski_Pond   0.421 -0.700 -0.293 -0.606 -0.298  0.469
Day:LocationWawona_Mdw   0.428 -0.711 -0.298 -0.301 -0.593  0.477
0.498

Standardized Within-Group Residuals:
        Min          Q1         Med          Q3         Max
-2.99560183 -0.13901209 -0.03236050  0.03733516  9.37995740

Number of Observations: 2285
Number of Groups:
         Location Day %in% Location
                4               929
Warning message:
In pt(q, df, lower.tail, log.p) : NaNs produced
```

For *L. cinereus*, the intercept of Doghouse at Day One is significantly different from zero. Activity increases significantly overall with day. The main effect for each of the three sites relative to Doghouse is incalculable. Doghouse, interacting with day, shows a significant increase in activity relative to the other three sites (Figure AII.5).

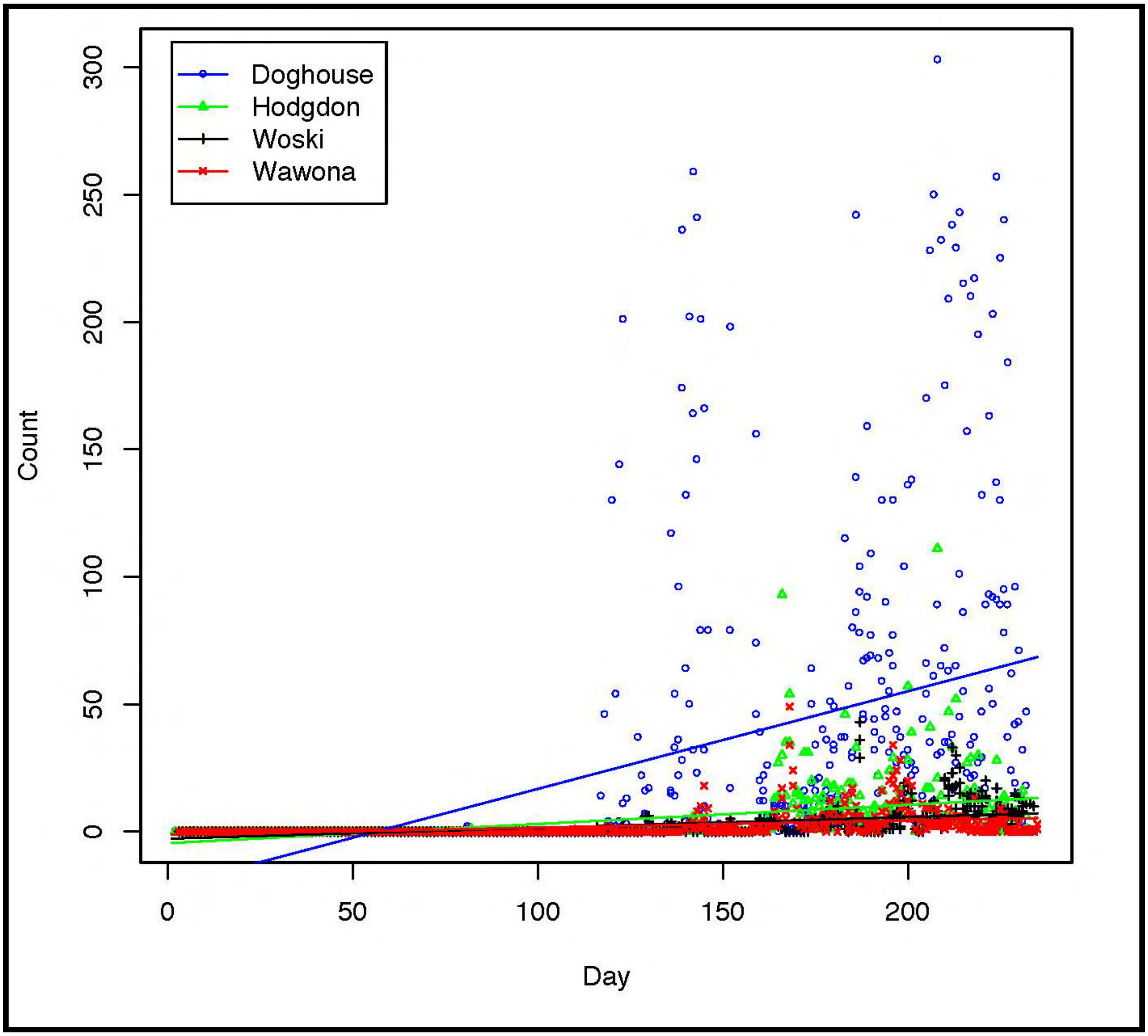

Figure AII.5. Interactons between day and location for *Lasiurus cinereus*

II.6. M40 *Myotis ciliolabrum*, *Myotis lucifugus*, and *Myotis volans*

M40 model selection

```
LMEM401<-lme(M40~1, random = ~1|Location, data = YNPbats2)
LMEM402<-lme(M40~1, random = ~1|Location/Day, data = YNPbats2)
LMEM403<-lme(M40~Day, random = ~1|Location, data = YNPbats2)
LMEM404<-lme(M40~Day, random = ~1|Location/Day, data = YNPbats2)
LMEM405<-lme(M40~Day + Location, random = ~1|Location, data = YNPbats2)
LMEM406<-lme(M40~Day + Location, random = ~1|Location/Day, data =
YNPbats2)
LMEM407<-lme(M40~Day * Location, random = ~1|Location, data = YNPbats2)
LMEM408<-lme(M40~Day * Location, random = ~1|Location/Day, data =
YNPbats2)
```

AIC selects Model 4

Selection by AIC indicates that a partial model, with a fixed effect for day and all random effects is the minimum adequate model. Only day is informative when explaining activity levels. Retention of both random effects indicates that day within location provides grouping that contributes to model information.

M40 model terms

```
Linear mixed-effects model fit by REML
 Data: YNPbats2
       AIC      BIC    logLik
  21396.30 21424.96 -10693.15

Random effects:
 Formula: ~1 | Location
        (Intercept)
StdDev:    10.65372

 Formula: ~1 | Day %in% Location
        (Intercept) Residual
StdDev:    14.67536 22.49309

Fixed effects: LACI ~ Day
                Value Std.Error   DF   t-value p-value
(Intercept) -7.671316  5.500272 1356 -1.394716  0.1633
Day          0.134175  0.010018  924 13.393759  0.0000
 Correlation:
    (Intr)
Day -0.216

Standardized Within-Group Residuals:
       Min         Q1        Med         Q3        Max
-2.9175336 -0.2659919 -0.0870348  0.1172886  9.2607165

Number of Observations: 2285
Number of Groups:
         Location Day %in% Location
                4               929
```

There are no interactions between day and location for the aggregated M40 group, which includes (and cannot distinguish among) *Myotis ciliolabrum*, *Myotis lucifugus*, and *Myotis volans* (Figure AII.6).

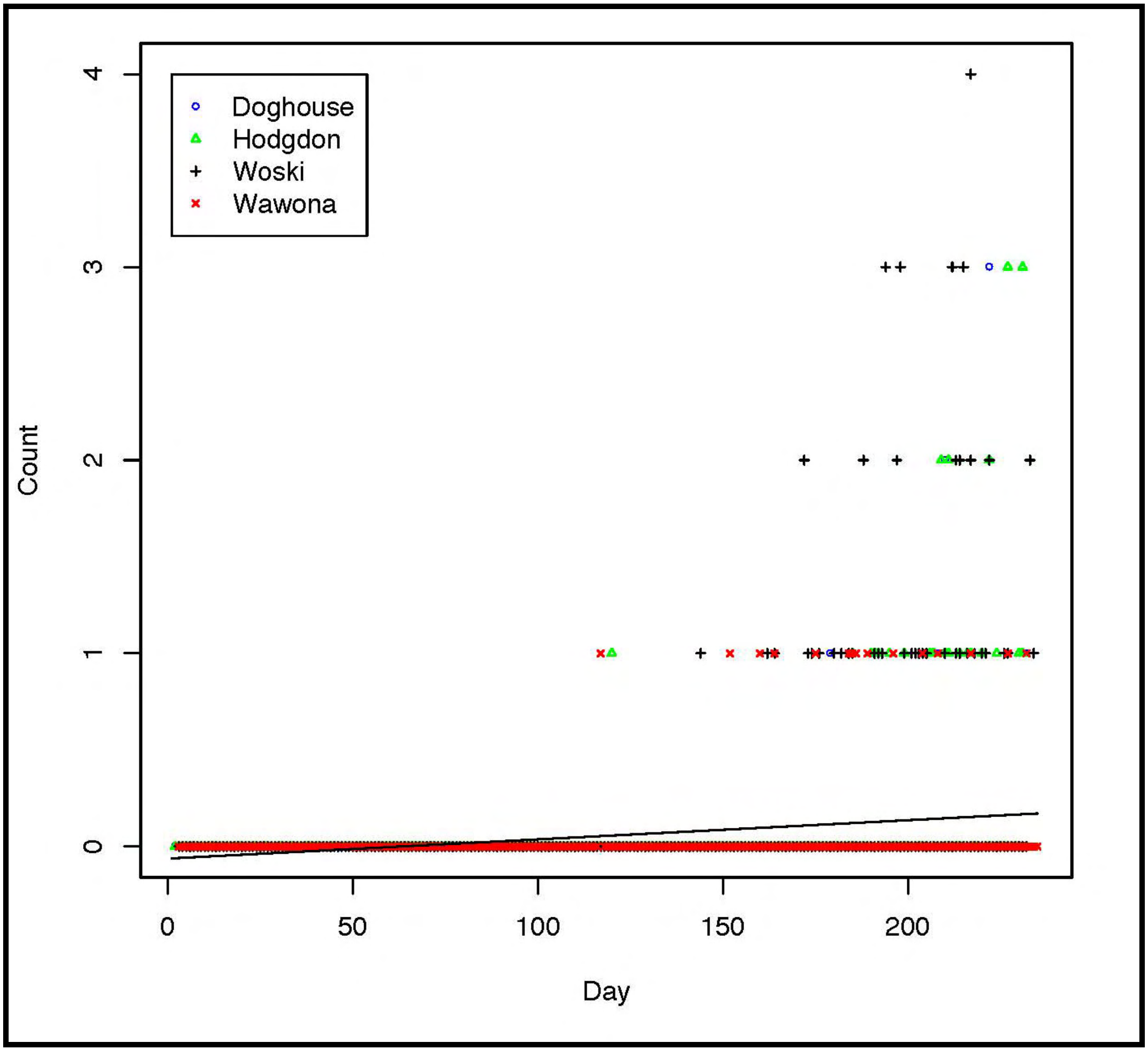

Figure AII.6. No interactions between day and location for M40 (*Myotis ciliolabrum*, *Myotis lucifugus*, and *Myotis volans*)

II.7 M50 – *Myotis californicus* and *Myotis yumanensis*

M50 model selection

```
LMEM501<-lme(M50~1, random = ~1|Location, data = YNPbats2)
LMEM502<-lme(M50~1, random = ~1|Location/Day, data = YNPbats2)
LMEM503<-lme(M50~Day, random = ~1|Location, data = YNPbats2)
LMEM504<-lme(M50~Day, random = ~1|Location/Day, data = YNPbats2)
LMEM505<-lme(M50~Day + Location, random = ~1|Location, data = YNPbats2)
LMEM506<-lme(M50~Day + Location, random = ~1|Location/Day, data =
YNPbats2)
LMEM507<-lme(M50~Day * Location, random = ~1|Location, data = YNPbats2)
LMEM508<-lme(M50~Day * Location, random = ~1|Location/Day, data =
YNPbats2)
```

AIC selects Model 8

Selection by AIC indicates that a full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that day, location and their interaction are all informative for explaining activity levels. Retention of both random effects indicates that day within location provides grouping that contributes to model information.

M50 model terms

```
Linear mixed-effects model fit by REML
 Data: YNPbats2
       AIC      BIC    logLik
  8640.649 8703.686 -4309.324

Random effects:
 Formula: ~1 | Location
        (Intercept)
StdDev:   0.1418890

 Formula: ~1 | Day %in% Location
        (Intercept) Residual
StdDev:    1.127576 1.271725

Fixed effects: M50 ~ Day * Location
                             Value Std.Error   DF   t-value p-value
(Intercept)             -1.0702137 0.2316258 1356 -4.620443  0.0000
Day                      0.0149732 0.0013374  921 11.196053  0.0000
LocationHodgdon_Mdw      1.0467083 0.3314670    0  3.157806     NaN
LocationWoski_Pond       0.0583210 0.3295174    0  0.176989     NaN
LocationWawona_Mdw       0.7092320 0.3274527    0  2.165906     NaN
Day:LocationHodgdon_Mdw -0.0114589 0.0019503  921 -5.875420  0.0000
Day:LocationWoski_Pond   0.0019020 0.0019053  921  0.998263  0.3184
Day:LocationWawona_Mdw  -0.0061850 0.0018841  921 -3.282712  0.0011
 Correlation:
                        (Intr) Day    LctH_M LctW_P LctW_M D:LH_M
D:LW_P
Day                     -0.690
LocationHodgdon_Mdw     -0.699  0.482
LocationWoski_Pond      -0.703  0.485  0.491
LocationWawona_Mdw      -0.707  0.488  0.494  0.497
Day:LocationHodgdon_Mdw  0.473 -0.686 -0.693 -0.332 -0.335
Day:LocationWoski_Pond   0.484 -0.702 -0.338 -0.692 -0.342  0.481
Day:LocationWawona_Mdw   0.490 -0.710 -0.342 -0.344 -0.685  0.487
0.498

Standardized Within-Group Residuals:
        Min          Q1         Med          Q3         Max
-5.70448491 -0.25074782 -0.06209248  0.09371989  9.96710723

Number of Observations: 2285
Number of Groups:
         Location Day %in% Location
                4               929
```

```
Warning message:
In pt(q, df, lower.tail, log.p) : NaNs produced
```

For the M50 group, which includes (and cannot distinguish between) *M. californicus* and *M. yumanensis*, the intercept of Doghouse at Day One is significantly different from zero. Also, activity increases significantly overall with day. The main effect for each of the three sites relative to Doghouse is incalculable. Doghouse, interacting with day, shows no significant differnce from Woski, but a significant increase in activity relative to the other two sites (Figure AII.7).

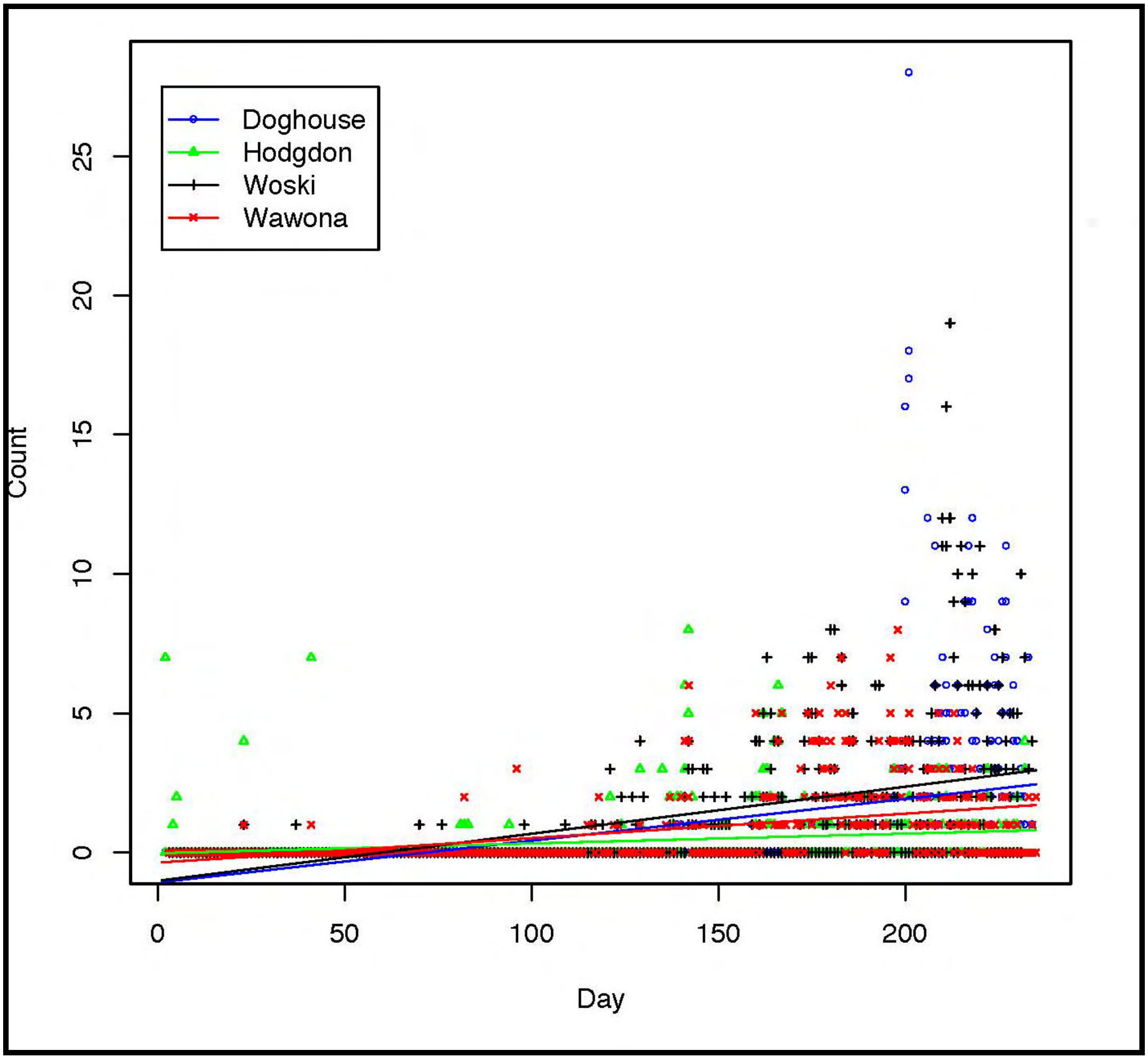

Figure AII.7. Interactions between day and location for M50 (*Myotis californicus* and *Myotis yumanensis*)

II.8. Long-eared myotis, *Myotis evotis*

M. evotis model selection

```
LMEMYEV1<-lme(MYEV~1, random = ~1|Location, data = YNPbats2)
LMEMYEV2<-lme(MYEV~1, random = ~1|Location/Day, data = YNPbats2)
LMEMYEV3<-lme(MYEV~Day, random = ~1|Location, data = YNPbats2)
LMEMYEV4<-lme(MYEV~Day, random = ~1|Location/Day, data = YNPbats2)
LMEMYEV5<-lme(MYEV~Day + Location, random = ~1|Location, data =
YNPbats2)
LMEMYEV6<-lme(MYEV~Day + Location, random = ~1|Location/Day, data =
YNPbats2)
LMEMYEV7<-lme(MYEV~Day * Location, random = ~1|Location, data =
YNPbats2)
LMEMYEV8<-lme(MYEV~Day * Location, random = ~1|Location/Day, data =
YNPbats2)
```

AIC selects Model 4

Selection by AIC indicates that a partial model, with a fixed effect for day and all random effects is the minimum adequate model. Only day is informative when explaining activity levels. Retention of both random effects indicates that day within location provides grouping that contributes to model information.

M. evotis model terms

```
Linear mixed-effects model fit by REML
 Data: YNPbats2
        AIC       BIC   logLik
  -899.3024 -870.6362 454.6512

Random effects:
 Formula: ~1 | Location
        (Intercept)
StdDev:  0.03297607

 Formula: ~1 | Day %in% Location
        (Intercept)  Residual
StdDev:  0.06492009 0.1868333

Fixed effects: MYEV ~ Day
                  Value   Std.Error   DF   t-value p-value
(Intercept) -0.03312068 0.018799428 1356 -1.761792  0.0783
Day          0.00053182 0.000065788  924  8.083797  0.0000
 Correlation:
    (Intr)
Day -0.417

Standardized Within-Group Residuals:
        Min          Q1         Med          Q3         Max
-3.30070801 -0.24166994 -0.11592890  0.04567547 12.75638376

Number of Observations: 2285
Number of Groups:
         Location Day %in% Location
```

```
            4                   929
```

There are no interactions between day and location for *M. evotis* (Figure AII.8). Note there are relatively few records for this species.

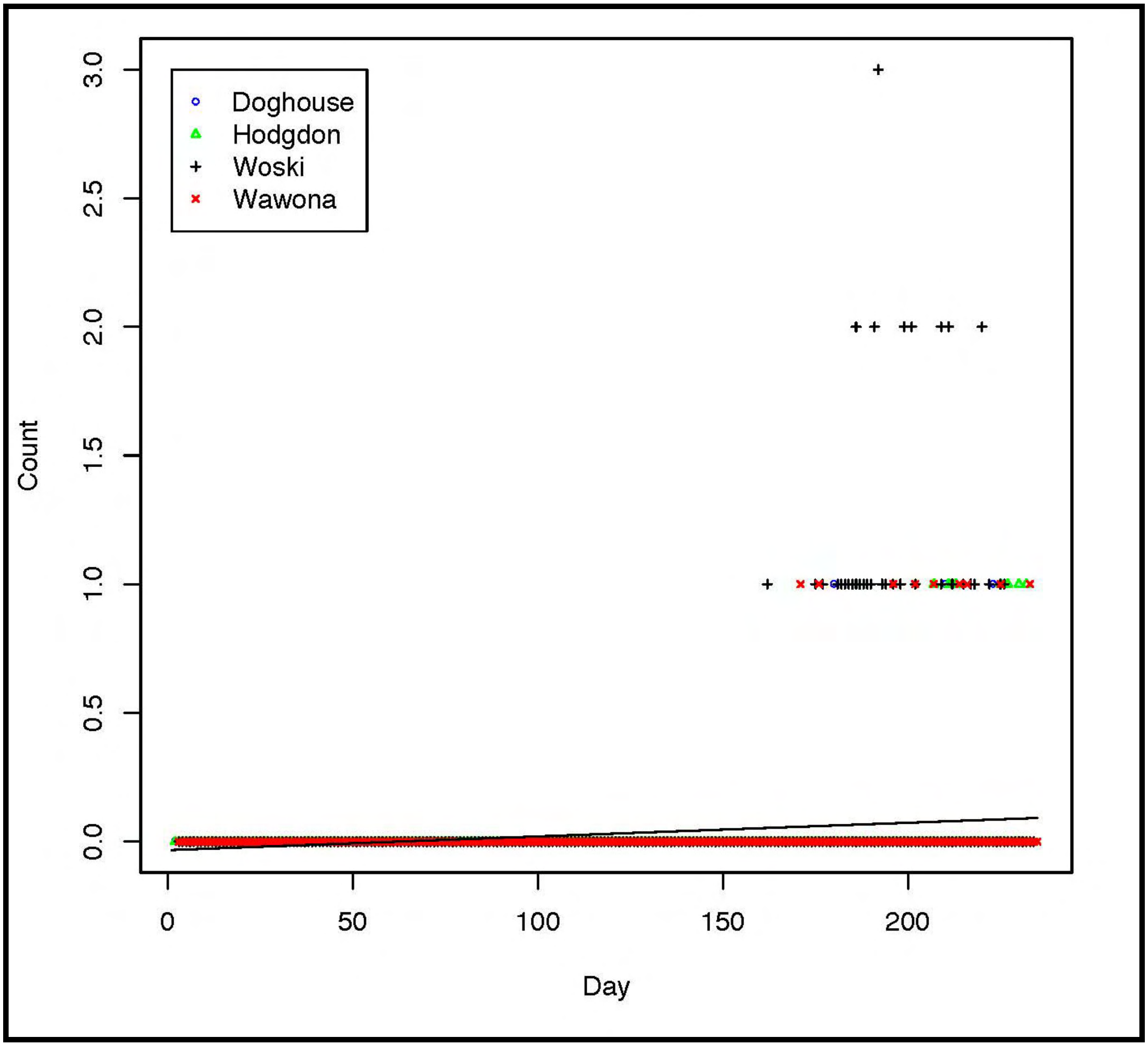

Figure AII.8. No interaction between day and location for *Myotis evotis*

II.9. Fringed myotis, *Myotis thysanodes*

M. thysanodes model selection

```
LMEMYTH1<-lme(MYTH~1, random = ~1|Location, data = YNPbats2)
LMEMYTH2<-lme(MYTH~1, random = ~1|Location/Day, data = YNPbats2)
LMEMYTH3<-lme(MYTH~Day, random = ~1|Location, data = YNPbats2)
LMEMYTH4<-lme(MYTH~Day, random = ~1|Location/Day, data = YNPbats2)
LMEMYTH5<-lme(MYTH~Day + Location, random = ~1|Location, data =
YNPbats2)
```

```
LMEMYTH6<-lme(MYTH~Day + Location, random = ~1|Location/Day, data =
YNPbats2)
LMEMYTH7<-lme(MYTH~Day * Location, random = ~1|Location, data =
YNPbats2)
LMEMYTH8<-lme(MYTH~Day * Location, random = ~1|Location/Day, data =
YNPbats2)
```

AIC selects Model 4

Selection by AIC indicates that a partial model, with a fixed effect for day and all random effects is the minimum adequate model. Only day is informative when explaining activity levels. Retention of both random effects indicates that day within location provides grouping that contributes to model information.

M. thysanodes model terms

```
Linear mixed-effects model fit by REML
 Data: YNPbats2
        AIC       BIC   logLik
  -991.5734 -962.9072 500.7867

Random effects:
 Formula: ~1 | Location
        (Intercept)
StdDev:  0.04289096

 Formula: ~1 | Day %in% Location
        (Intercept)  Residual
StdDev:  0.05991502 0.1840784

Fixed effects: MYTH ~ Day
                   Value  Std.Error   DF   t-value p-value
(Intercept) -0.020939934 0.02316897 1356 -0.903792  0.3663
Day          0.000453152 0.00006386  924  7.095974  0.0000
 Correlation:
    (Intr)
Day -0.328

Standardized Within-Group Residuals:
        Min          Q1         Med          Q3         Max
-2.24700083 -0.24426489 -0.11350282  0.04341166 14.05039863

Number of Observations: 2285
Number of Groups:
         Location Day %in% Location
                4               929
```

There are no interactions between day and location for *M. thysanodes* (Figure AII.9). Note there are relatively few records for this species.

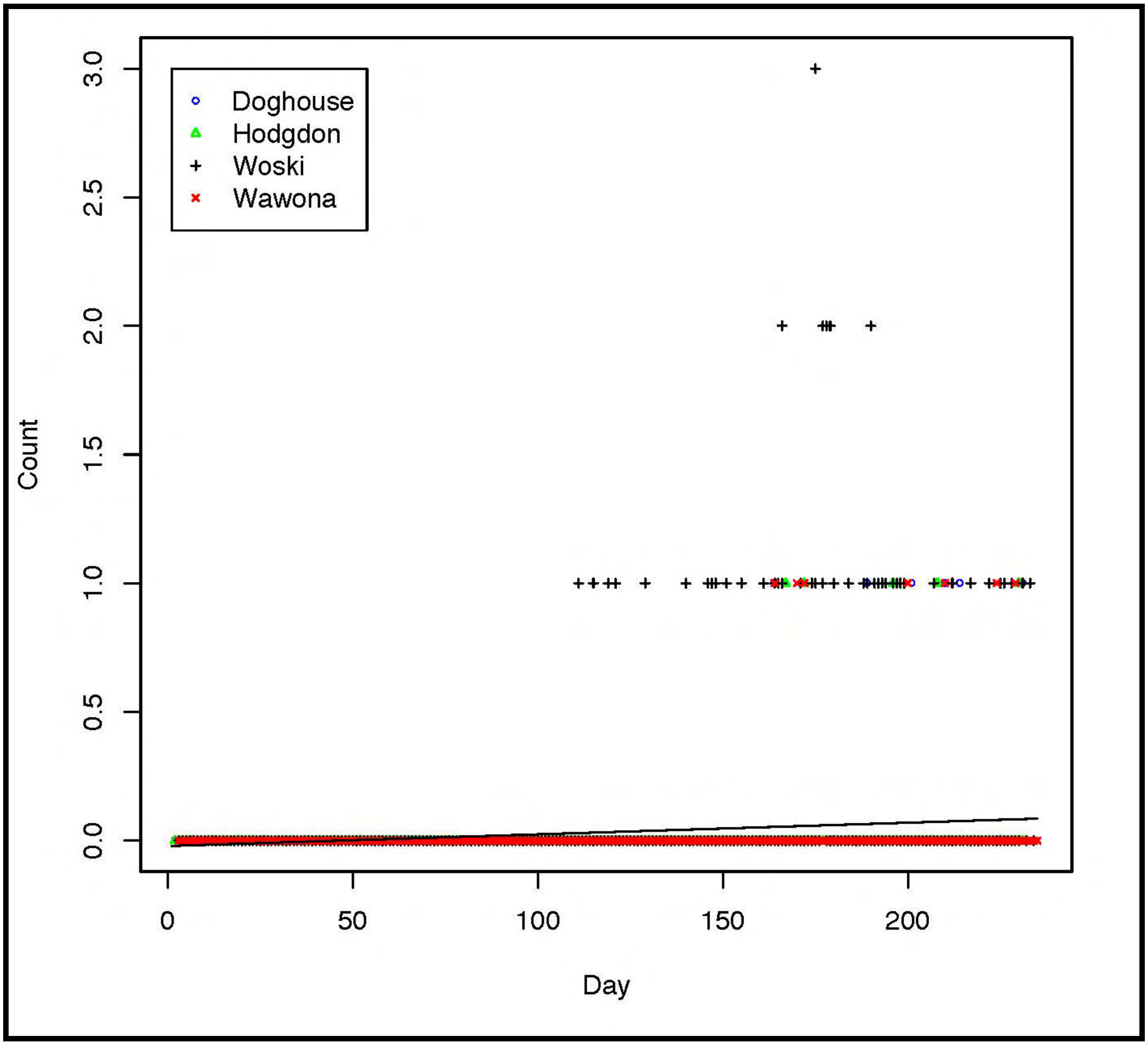

Figure AII.9. No interactions between day and location for *Myotis thysanodes*

II.10. Western pipistrelle, *Parastrellus hesperus*

P. hesperus model selection

```
LMEPAHE1<-lme(PAHE~1, random = ~1|Location, data = YNPbats2)
LMEPAHE2<-lme(PAHE~1, random = ~1|Location/Day, data = YNPbats2)
LMEPAHE3<-lme(PAHE~Day, random = ~1|Location, data = YNPbats2)
LMEPAHE4<-lme(PAHE~Day, random = ~1|Location/Day, data = YNPbats2)
LMEPAHE5<-lme(PAHE~Day + Location, random = ~1|Location, data =
YNPbats2)
LMEPAHE6<-lme(PAHE~Day + Location, random = ~1|Location/Day, data =
YNPbats2)
LMEPAHE7<-lme(PAHE~Day * Location, random = ~1|Location, data =
YNPbats2)
```

```
LMEPAHE8<-lme(PAHE~Day * Location, random = ~1|Location/Day, data =
YNPbats2)
```

AIC selects Model 8

Selection by AIC indicates that a full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that day, location and their interaction are all informative for explaining activity levels. Retention of both random effects indicates that day within location provides grouping that contributes to model information.

P. hesperus **model terms**

```
Linear mixed-effects model fit by REML
 Data: YNPbats2
       AIC     BIC    logLik
  6812.203 6875.24 -3395.102

Random effects:
 Formula: ~1 | Location
        (Intercept)
StdDev:  0.08168508

 Formula: ~1 | Day %in% Location
        (Intercept)  Residual
StdDev:    1.068937 0.7321281

Fixed effects: PAHE ~ Day * Location
                             Value  Std.Error   DF   t-value p-value
(Intercept)             -0.0028904 0.17449961 1356 -0.016564  0.9868
Day                      0.0000366 0.00113120  921  0.032337  0.9742
LocationHodgdon_Mdw      0.0028904 0.24865456    0  0.011624     NaN
LocationWoski_Pond      -1.2084364 0.24806271    0 -4.871496     NaN
LocationWawona_Mdw       0.0028904 0.24709170    0  0.011698     NaN
Day:LocationHodgdon_Mdw -0.0000366 0.00162784  921 -0.022471  0.9821
Day:LocationWoski_Pond   0.0229014 0.00160811  921 14.241190  0.0000
Day:LocationWawona_Mdw  -0.0000366 0.00159652  921 -0.022912  0.9817
 Correlation: 
                        (Intr) Day    LctH_M LctW_P LctW_M D:LH_M
D:LW_P
Day                     -0.769                                   
LocationHodgdon_Mdw     -0.702  0.540                            
LocationWoski_Pond      -0.703  0.541  0.494                     
LocationWawona_Mdw      -0.706  0.543  0.496  0.497              
Day:LocationHodgdon_Mdw  0.535 -0.695 -0.770 -0.376 -0.378       
Day:LocationWoski_Pond   0.541 -0.703 -0.380 -0.771 -0.382  0.489
Day:LocationWawona_Mdw   0.545 -0.709 -0.383 -0.383 -0.767  0.492
0.498

Standardized Within-Group Residuals:
          Min            Q1           Med            Q3           Max 
-9.029494e+00 -5.336394e-04  1.314380e-17  2.626119e-17  1.009284e+01 

Number of Observations: 2285
```

```
Number of Groups:
         Location Day %in% Location
                4              929
Warning message:
In pt(q, df, lower.tail, log.p) : NaNs produced
```

For *P. hesperus*, the intercept of Doghouse at Day One is not significantly different from zero. The main effect for day is also insignificant. The main effect for each of the three sites relative to Doghouse is incalculable. Woski, interacting with day, shows a significant increase in activity relative to Doghouse. Hodgdon and Wawona, interacting with day, are not significantly different from Doghouse (Figure AII.10).

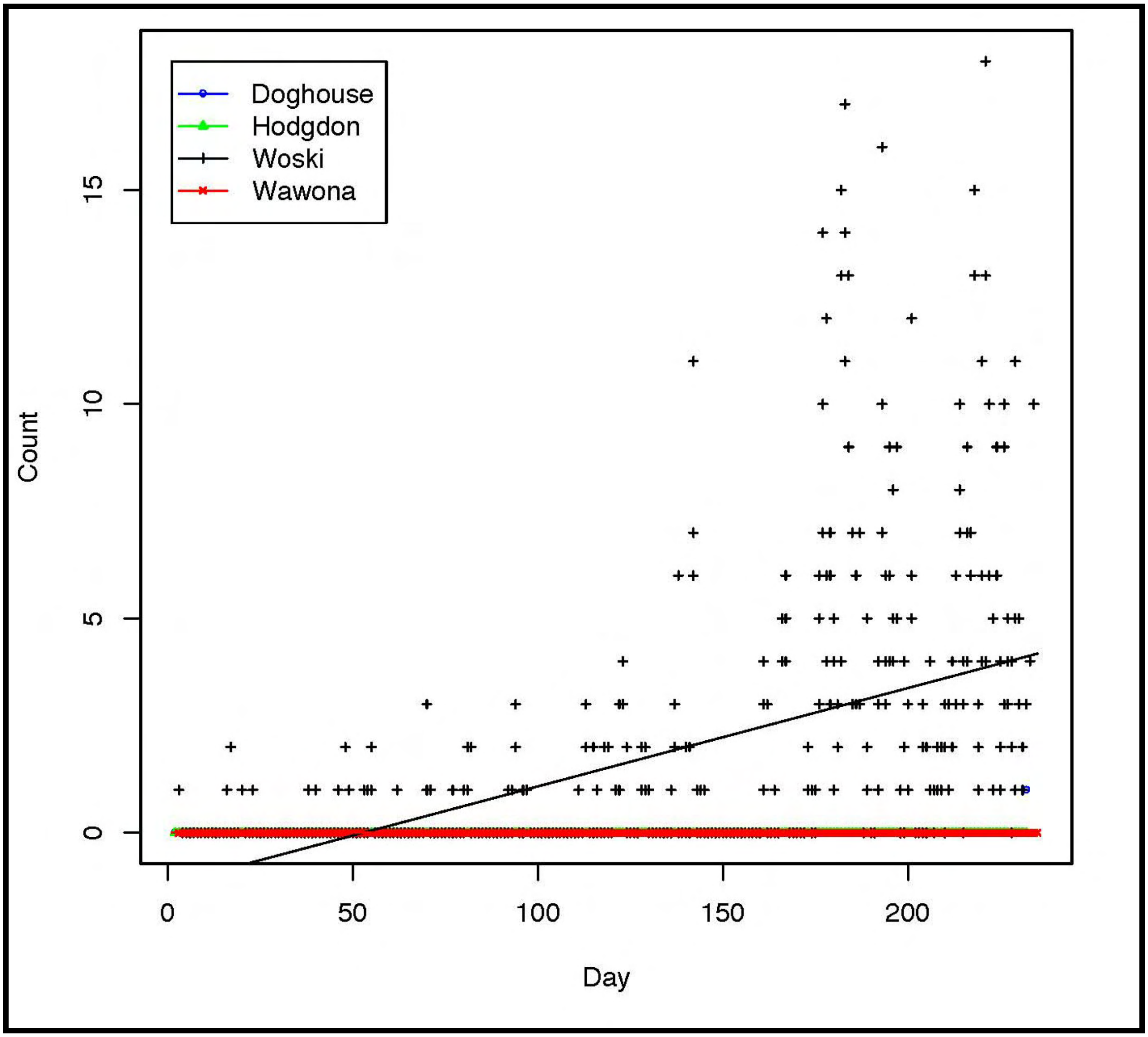

Figure AII.10. Interactions between day and location for *Parastrellus hesperus*

II.11. Q25 – *Eptesicus fuscus*, *Lasionycteris noctivagans*, and *Tadarida brasiliensis*

Q25 model selection

```
LMEQ251<-lme(Q25~1, random = ~1|Location, data = YNPbats2)
LMEQ252<-lme(Q25~1, random = ~1|Location/Day, data = YNPbats2)
LMEQ253<-lme(Q25~Day, random = ~1|Location, data = YNPbats2)
LMEQ254<-lme(Q25~Day, random = ~1|Location/Day, data = YNPbats2)
LMEQ255<-lme(Q25~Day + Location, random = ~1|Location, data = YNPbats2)
LMEQ256<-lme(Q25~Day + Location, random = ~1|Location/Day, data =
YNPbats2)
LMEQ257<-lme(Q25~Day * Location, random = ~1|Location, data = YNPbats2)
LMEQ258<-lme(Q25~Day * Location, random = ~1|Location/Day, data =
YNPbats2)
```

AIC selects Model 8

Selection by AIC indicates that a full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that day, location and their interaction are all informative for explaining activity levels. Retention of both random effects indicates that day within location provides grouping that contributes to model information.

Q25 model terms

```
Linear mixed-effects model fit by REML
 Data: YNPbats2
       AIC      BIC    logLik
  20701.94 20764.98 -10339.97

Random effects:
 Formula: ~1 | Location
        (Intercept)
StdDev:    1.591041

 Formula: ~1 | Day %in% Location
        (Intercept) Residual
StdDev:    26.26029  14.2602

Fixed effects: Q25 ~ Day * Location
                            Value Std.Error   DF    t-value p-value
(Intercept)             -24.81640  4.005043 1356  -6.196288       0
Day                       0.41114  0.026996  921  15.229663       0
LocationHodgdon_Mdw      20.76447  5.698083    0   3.644115     NaN
LocationWoski_Pond       67.19616  5.691929    0  11.805516     NaN
LocationWawona_Mdw       21.57410  5.674449    0   3.801972     NaN
Day:LocationHodgdon_Mdw  -0.28754  0.038704  921  -7.429333       0
Day:LocationWoski_Pond   -0.51049  0.038353  921 -13.310345       0
Day:LocationWawona_Mdw   -0.34751  0.038124  921  -9.115195       0
 Correlation:
                        (Intr) Day    LctH_M LctW_P LctW_M D:LH_M
D:LW_P
Day                     -0.798
LocationHodgdon_Mdw     -0.703  0.561
```

```
LocationWoski_Pond      -0.704  0.562  0.495
LocationWawona_Mdw      -0.706  0.564  0.496  0.497
Day:LocationHodgdon_Mdw  0.557 -0.698 -0.799 -0.392 -0.393
Day:LocationWoski_Pond   0.562 -0.704 -0.395 -0.800 -0.397  0.491
Day:LocationWawona_Mdw   0.565 -0.708 -0.397 -0.398 -0.797  0.494
0.498

Standardized Within-Group Residuals:
        Min          Q1         Med          Q3         Max
-8.22275671 -0.18807648 -0.04551748  0.06801834  8.04165101

Number of Observations: 2285
Number of Groups:
         Location Day %in% Location
                4              929
Warning message:
In pt(q, df, lower.tail, log.p) : NaNs produced
```

For the Q25 group, which includes (and cannot distinguish among) *Eptesicus fuscus*, *Lasionycteris noctivagans*, and *Tadarida brasiliensis*, the intercept of Doghouse at Day One is significantly different from zero. Activity also increases significantly overall with day. The main effect for each of the three sites relative to Doghouse is incalculable. Doghouse, interacting with day, shows a significant increase in activity relative to the other three sites (Figure AII.11).

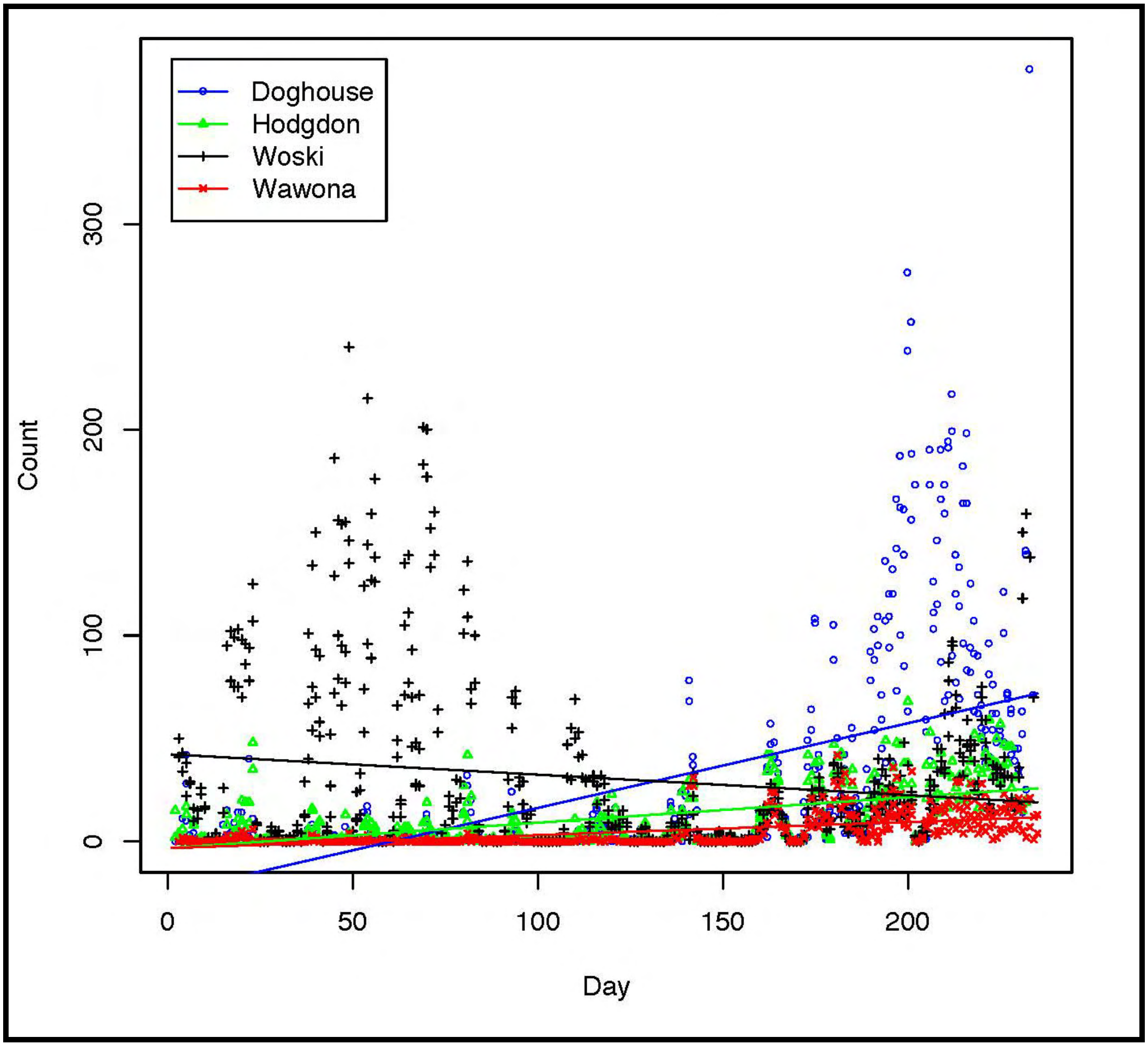

Figure AII.11. Interactions between day and location for Q25 (*Eptesicus fuscus*, *Lasionycteris noctivagans*, and *Tadarida brasiliensis*)

II.12. Mexican free-tailed bat, *Tadarida brasiliensis*

T. brasiliensis model selection

```
LMETABR1<-lme(TABR~1, random = ~1|Location, data = YNPbats2)
LMETABR2<-lme(TABR~1, random = ~1|Location/Day, data = YNPbats2)
LMETABR3<-lme(TABR~Day, random = ~1|Location, data = YNPbats2)
LMETABR4<-lme(TABR~Day, random = ~1|Location/Day, data = YNPbats2)
LMETABR5<-lme(TABR~Day + Location, random = ~1|Location, data =
YNPbats2)
LMETABR6<-lme(TABR~Day + Location, random = ~1|Location/Day, data =
YNPbats2)
LMETABR7<-lme(TABR~Day * Location, random = ~1|Location, data =
YNPbats2)
```

```
LMETABR8<-lme(TABR~Day * Location, random = ~1|Location/Day, data =
YNPbats2)
```

AIC selects Model 8

Selection by AIC indicates that a full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that day, location and their interaction are all informative for explaining activity levels. Retention of both random effects indicates that day within location provides grouping that contributes to model information.

T. brasiliensis model terms

```
Linear mixed-effects model fit by REML
 Data: YNPbats2
       AIC      BIC    logLik
  21877.03 21940.06 -10927.51

Random effects:
 Formula: ~1 | Location
        (Intercept)
StdDev:    2.364169

 Formula: ~1 | Day %in% Location
        (Intercept) Residual
StdDev:    25.94599 21.18961

Fixed effects: TABR ~ Day * Location
                             Value Std.Error   DF   t-value p-value
(Intercept)             -27.185784  4.530504 1356 -6.000609       0
Day                       0.409409  0.028316  921 14.458427       0
LocationHodgdon_Mdw      24.807290  6.464856    0  3.837253     NaN
LocationWoski_Pond       28.057840  6.441976    0  4.355471     NaN
LocationWawona_Mdw       21.774249  6.411803    0  3.395964     NaN
Day:LocationHodgdon_Mdw  -0.374405  0.040904  921 -9.153257       0
Day:LocationWoski_Pond   -0.199175  0.040280  921 -4.944742       0
Day:LocationWawona_Mdw   -0.325618  0.039941  921 -8.152377       0
 Correlation:
                        (Intr) Day    LctH_M LctW_P LctW_M D:LH_M
D:LW_P
Day                     -0.743
LocationHodgdon_Mdw     -0.701  0.521
LocationWoski_Pond      -0.703  0.523  0.493
LocationWawona_Mdw      -0.707  0.525  0.495  0.497
Day:LocationHodgdon_Mdw  0.515 -0.692 -0.745 -0.362 -0.364
Day:LocationWoski_Pond   0.522 -0.703 -0.366 -0.745 -0.369  0.487
Day:LocationWawona_Mdw   0.527 -0.709 -0.369 -0.371 -0.740  0.491
0.498

Standardized Within-Group Residuals:
        Min          Q1         Med          Q3         Max
-6.67649056 -0.21568546 -0.02861378  0.03134706  7.19823472

Number of Observations: 2285
Number of Groups:
         Location Day %in% Location
```

```
                4               929
Warning message:
In pt(q, df, lower.tail, log.p) : NaNs produced
```

For *T. brasiliensis*, the intercept of Doghouse at Day One is significantly different from zero. Also, activity increases significantly overall with day. The main effect for each of the three sites relative to Doghouse is incalculable. Doghouse, interacting with day, shows a significant increase in activity relative to the other three sites (Figure AII.12).

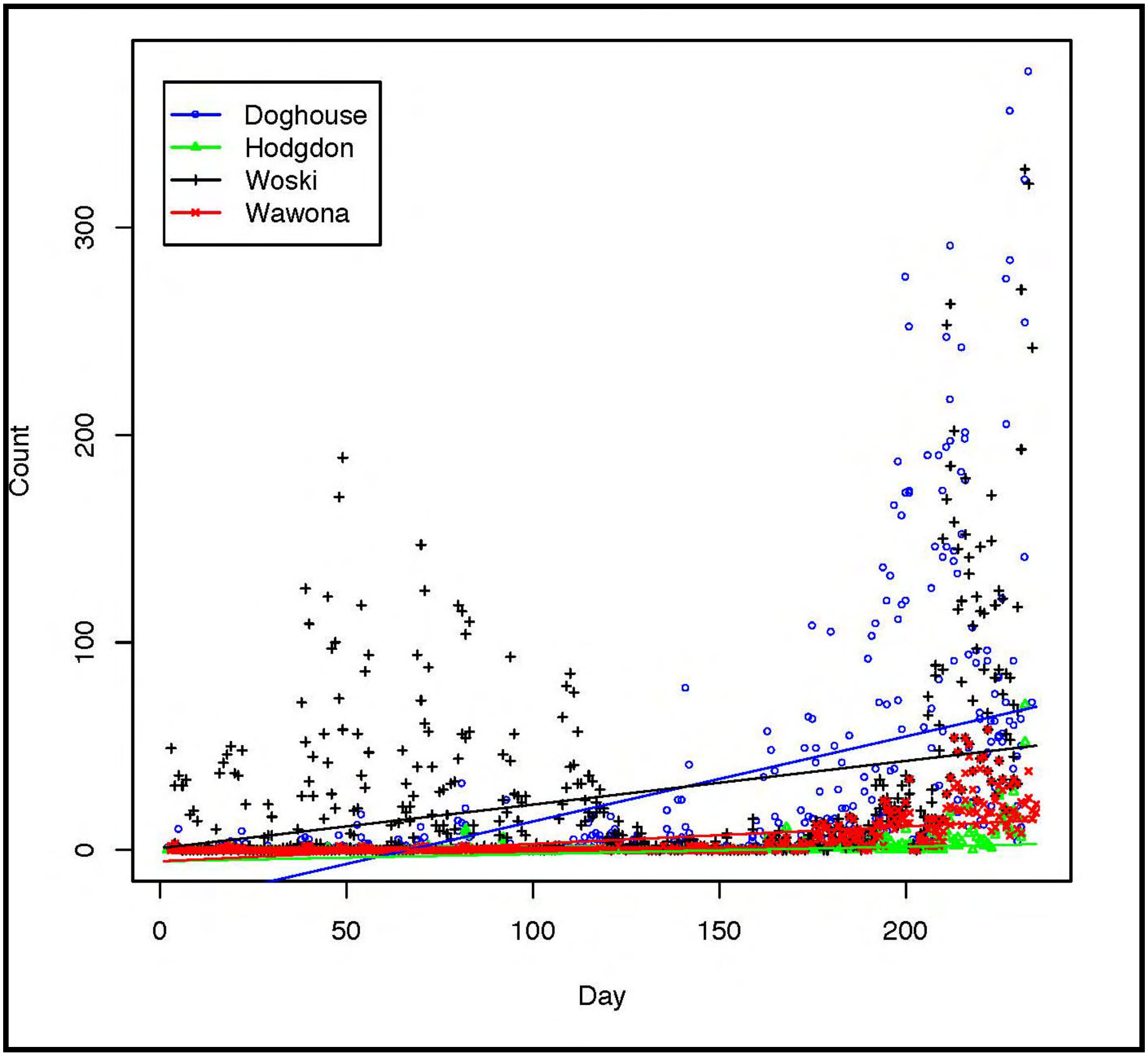

Figure AII.12. Interactions between day and location for *Tadarida brasiliensis*

APPENDIX III. Twelve Meadows in Three Elevation Strata

III.1.Pallid bat, *Antrozous pallidus*

```
mean(Antrozous_pallidus,na.rm=TRUE)
0.03787879
mean(Antrozous_pallidus[Elev=="Low"],na.rm=TRUE)
0.03409091
mean(Antrozous_pallidus[Elev=="Medium"],na.rm=TRUE)
0.07727273
mean(Antrozous_pallidus[Elev=="High"],na.rm=TRUE)
0.002272727

Models:
GLMERANPA1: Antrozous_pallidus ~ 1 + (1 | Location)
GLMERANPA2: Antrozous_pallidus ~ Elev + (1 | Location)
GLMERANPA3: Antrozous_pallidus ~ Elev + (Day | Location)
GLMERANPA4: Antrozous_pallidus ~ Elev * Day + (1 | Location)
GLMERANPA5: Antrozous_pallidus ~ Elev * Day + (Day | Location)

           Df     AIC     BIC  logLik   Chisq Chi Df Pr(>Chisq)
GLMERANPA1  2  268.89  279.27 -132.45
GLMERANPA2  4  267.27  288.01 -129.64  5.6217      2  0.0601548 .
GLMERANPA3  6  267.68  298.80 -127.84  3.5905      2  0.1660827
GLMERANPA4  7  258.56  294.86 -122.28 11.1196      1  0.0008542 ***
GLMERANPA5  9  262.08  308.75 -122.04  0.4869      2  0.7839137
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Selection by AIC indicates that a partial model, with all considered fixed but only a single random effect for location is the minimum adequate model. Retention of all fixed effects indicates that elevation and day are both important for explaining activity levels, and the interaction term indicates that the effect of elevation changes with day. Retention of one random effect indicates that location, but not day, has grouping that contributes to model information.

Antrozous_pallidus **Model Terms**

```
Generalized linear mixed model fit by the Laplace approximation
Formula: Antrozous_pallidus ~ Elev * Day + (1 | Location)
   Data: YNPbats
   AIC   BIC logLik deviance
 258.6 294.9 -122.3    244.6
Random effects:
 Groups   Name        Variance Std.Dev.
 Location (Intercept) 1.6768   1.2949
Number of obs: 1320, groups: Location, 12

Fixed effects:
                 Estimate Std. Error z value Pr(>|z|)
(Intercept)    -6.7308193  2.5216659 -2.6692   0.0076 **
ElevLow         4.5298448  2.6360760  1.7184   0.0857 .
ElevMedium      2.8836941  2.6505459  1.0880   0.2766
Day            -0.0004961  0.0379500 -0.0131   0.9896
```

```
ElevLow:Day    -0.0361551  0.0396268 -0.9124   0.3616
ElevMedium:Day -0.0016949  0.0383375 -0.0442   0.9647
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) ElevLw ElvMdm Day    ElvL:D
ElevLow     -0.957
ElevMedium  -0.951  0.910
Day         -0.828  0.792  0.787
ElevLow:Day  0.793 -0.790 -0.754 -0.958
ElevMedm:Dy  0.819 -0.784 -0.795 -0.990  0.948
```

Weakness in this model is likely attributable to sparseness of detections. The strongest effect is low elevation (see Figure AIII.1).

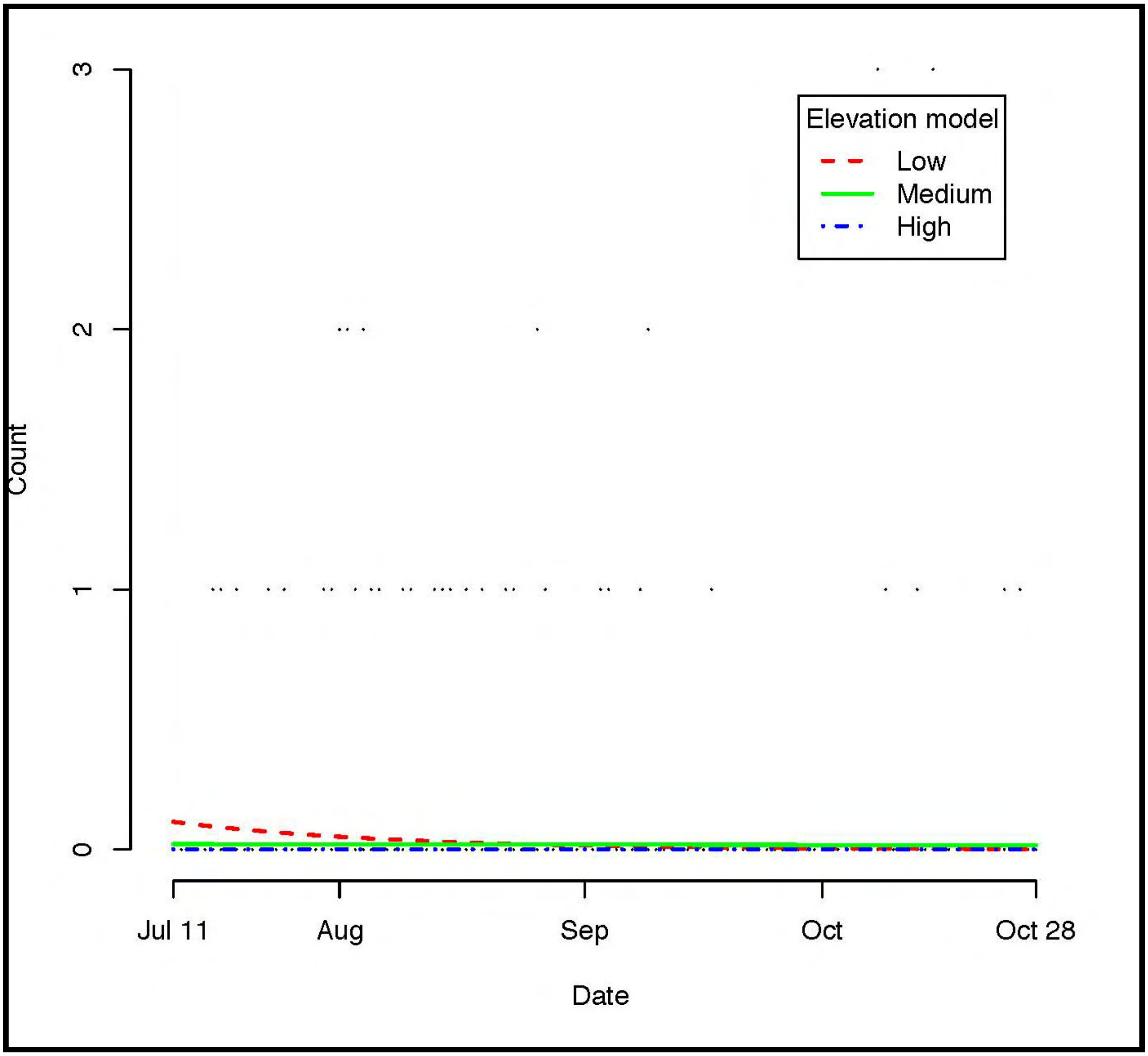

Figure AIII.1. Seasonal elevation preference by *Antrozous pallidus* (social calls)

III.2. Spotted bat, *Euderma maculatum*

```
mean(Euderma_maculatum,na.rm=TRUE)
40.79848
mean(Euderma_maculatum[Elev=="Low"],na.rm=TRUE)
57.55227
mean(Euderma_maculatum[Elev=="Medium"],na.rm=TRUE)
62.14773
mean(Euderma_maculatum[Elev=="High"],na.rm=TRUE)
2.695455

Models:
GLMEREUMA1: Euderma_maculatum ~ 1 + (1 | Location)
GLMEREUMA2: Euderma_maculatum ~ Elev + (1 | Location)
GLMEREUMA3: Euderma_maculatum ~ Elev + (Day | Location)
GLMEREUMA4: Euderma_maculatum ~ Elev * Day + (1 | Location)
GLMEREUMA5: Euderma_maculatum ~ Elev * Day + (Day | Location)
           Df   AIC   BIC logLik     Chisq Chi Df Pr(>Chisq)
GLMEREUMA1  2 62823 62833 -31410
GLMEREUMA2  4 62817 62838 -31405    10.014      2   0.006689 **
GLMEREUMA3  6 42037 42068 -21012 20784.067      2  < 2.2e-16 ***
GLMEREUMA4  7 42653 42689 -21319     0.000      1   1.000000
GLMEREUMA5  9 42015 42062 -20999   641.275      2  < 2.2e-16 ***
```

Selection by AIC indicates that the full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that elevation and day are both important for explaining activity levels, and the interaction term indicates that the effect of elevation changes with day. Retention of both random effects indicates that both day and location have grouping that contributes to model information.

Euderma_maculatum Model terms

```
Generalized linear mixed model fit by the Laplace approximation
Formula: Euderma_maculatum ~ Elev * Day + (Day | Location)
   Data: YNPbats
   AIC   BIC logLik deviance
 42015 42062 -20999    41997
Random effects:
 Groups   Name        Variance   Std.Dev.  Corr
 Location (Intercept) 2.1497e+00 1.4661974
          Day         4.0108e-05 0.0063331 -0.423
Number of obs: 1320, groups: Location, 12

Fixed effects:
                 Estimate Std. Error z value Pr(>|z|)
(Intercept)     1.0336874  0.7397212   1.397 0.162293
ElevLow         2.9062457  1.0418605   2.789 0.005279 **
ElevMedium      3.6212218  1.0415839   3.477 0.000508 ***
Day            -0.0223814  0.0037351  -5.992 2.07e-09 ***
ElevLow:Day     0.0060518  0.0049283   1.228 0.219460
ElevMedium:Day -0.0001673  0.0049109  -0.034 0.972823
---
```

```
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) ElevLw ElvMdm Day    ElvL:D
ElevLow     -0.710
ElevMedium  -0.710  0.504
Day         -0.406  0.289  0.289
ElevLow:Day  0.308 -0.412 -0.219 -0.758
ElevMedm:Dy  0.309 -0.219 -0.412 -0.761  0.576
>
```

Note that most *E. maculatum* are present at medium and low elevation and that activity declines into fall (see Figure AIII.2).

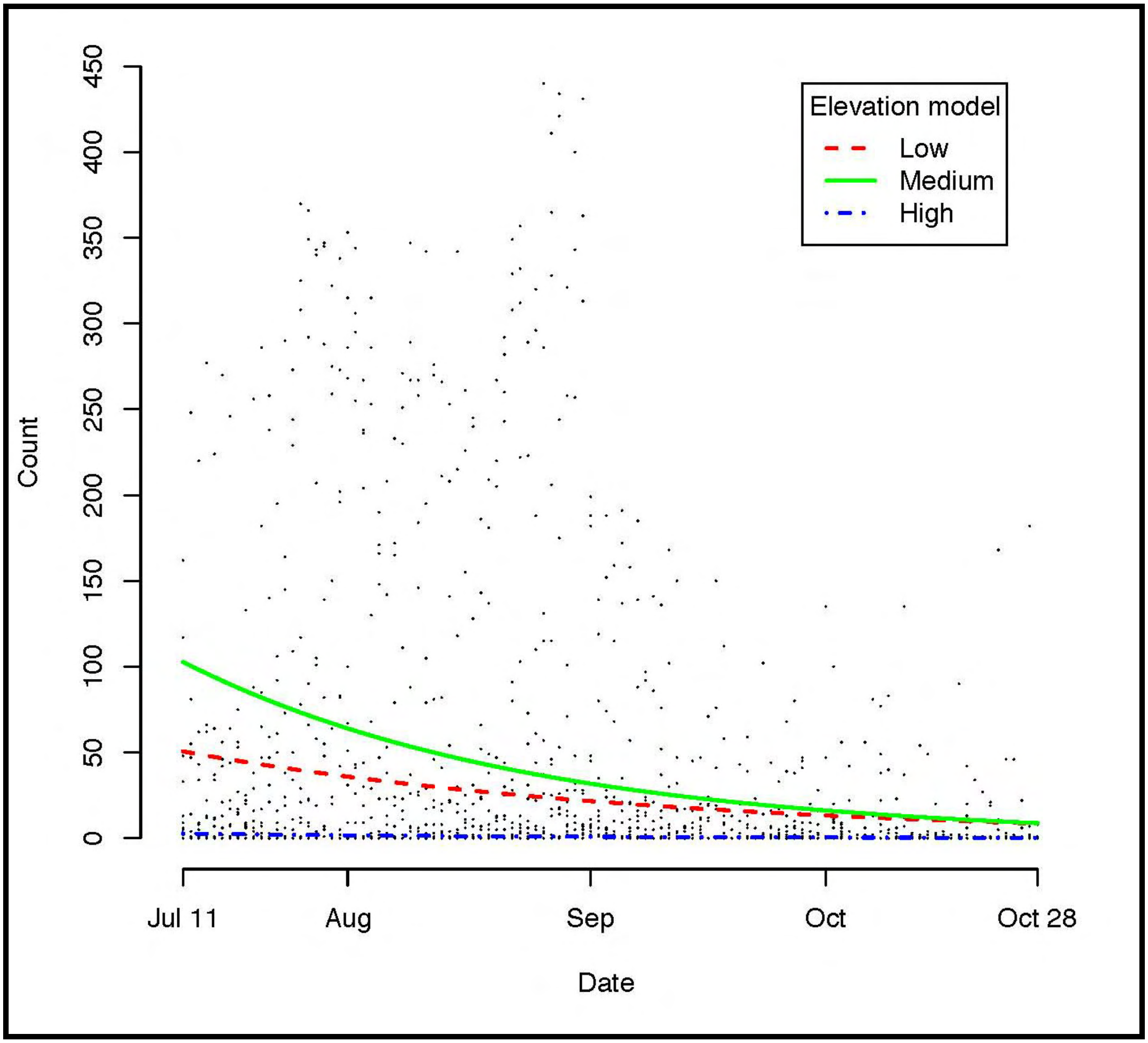

Figure AIII.2. Seasonal elevation preference by *Euderma maculatum*

III.3. Western mastiff bat, *Eumops perotis*

```
mean (Eumops_perotis,na.rm=TRUE)
35.6697
mean(Eumops_perotis[Elev=="Low"],na.rm=TRUE)
89.53864
mean(Eumops_perotis[Elev=="Medium"],na.rm=TRUE)
6.359091
mean(Eumops_perotis[Elev=="High"],na.rm=TRUE)
11.11136

Models:
GLMEREUPE1: Eumops_perotis ~ 1 + (1 | Location)
GLMEREUPE2: Eumops_perotis ~ Elev + (1 | Location)
GLMEREUPE3: Eumops_perotis ~ Elev + (Day | Location)
GLMEREUPE4: Eumops_perotis ~ Elev * Day + (1 | Location)
GLMEREUPE5: Eumops_perotis ~ Elev * Day + (Day | Location)
           Df    AIC    BIC logLik      Chisq Chi Df Pr(>Chisq)
GLMEREUPE1  2  45207  45217 -22601
GLMEREUPE2  4  45202  45222 -22597     8.9636      2    0.01131 *
GLMEREUPE3  6  24987  25018 -12487 20218.8869      2    < 2e-16 ***
GLMEREUPE4  7  28277  28313 -14131     0.0000      1    1.00000
GLMEREUPE5  9  24977  25023 -12479  3303.9079      2    < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Selection by AIC indicates that the full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that elevation and day are both important for explaining activity levels, and the interaction term indicates that the effect of elevation changes with day. Retention of both random effects indicates that both day and location have grouping that contributes to model information.

Eumops_perotis Model Terms

```
Generalized linear mixed model fit by the Laplace approximation
Formula: Eumops_perotis ~ Elev * Day + (Day | Location)
   Data: YNPbats
   AIC   BIC logLik deviance
 24977 25023 -12479    24959
Random effects:
 Groups   Name        Variance   Std.Dev. Corr
 Location (Intercept) 2.69637027 1.642063
          Day         0.00028134 0.016773 -0.618
Number of obs: 1320, groups: Location, 12

Fixed effects:
                Estimate Std. Error z value Pr(>|z|)
(Intercept)     2.449768   0.825972   2.966  0.00302 **
ElevLow         2.399642   1.164682   2.060  0.03937 *
ElevMedium     -0.506650   1.166179  -0.434  0.66396
Day            -0.046186   0.008671  -5.326 1.00e-07 ***
ElevLow:Day     0.032982   0.012066   2.734  0.00627 **
ElevMedium:Day  0.030273   0.012127   2.496  0.01255 *
---
```

```
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) ElevLw ElvMdm Day    ElvL:D
ElevLow     -0.709
ElevMedium  -0.708  0.502
Day         -0.614  0.436  0.435
ElevLow:Day  0.441 -0.616 -0.313 -0.719
ElevMedm:Dy  0.439 -0.311 -0.616 -0.715  0.514
```

Note that most *E. perotis* are present at low elevation and that activity declines into fall (see Figure 3a). The interactions are such that this decline proceeds more slowly at low and medium elevation (see Figure AIII.3).

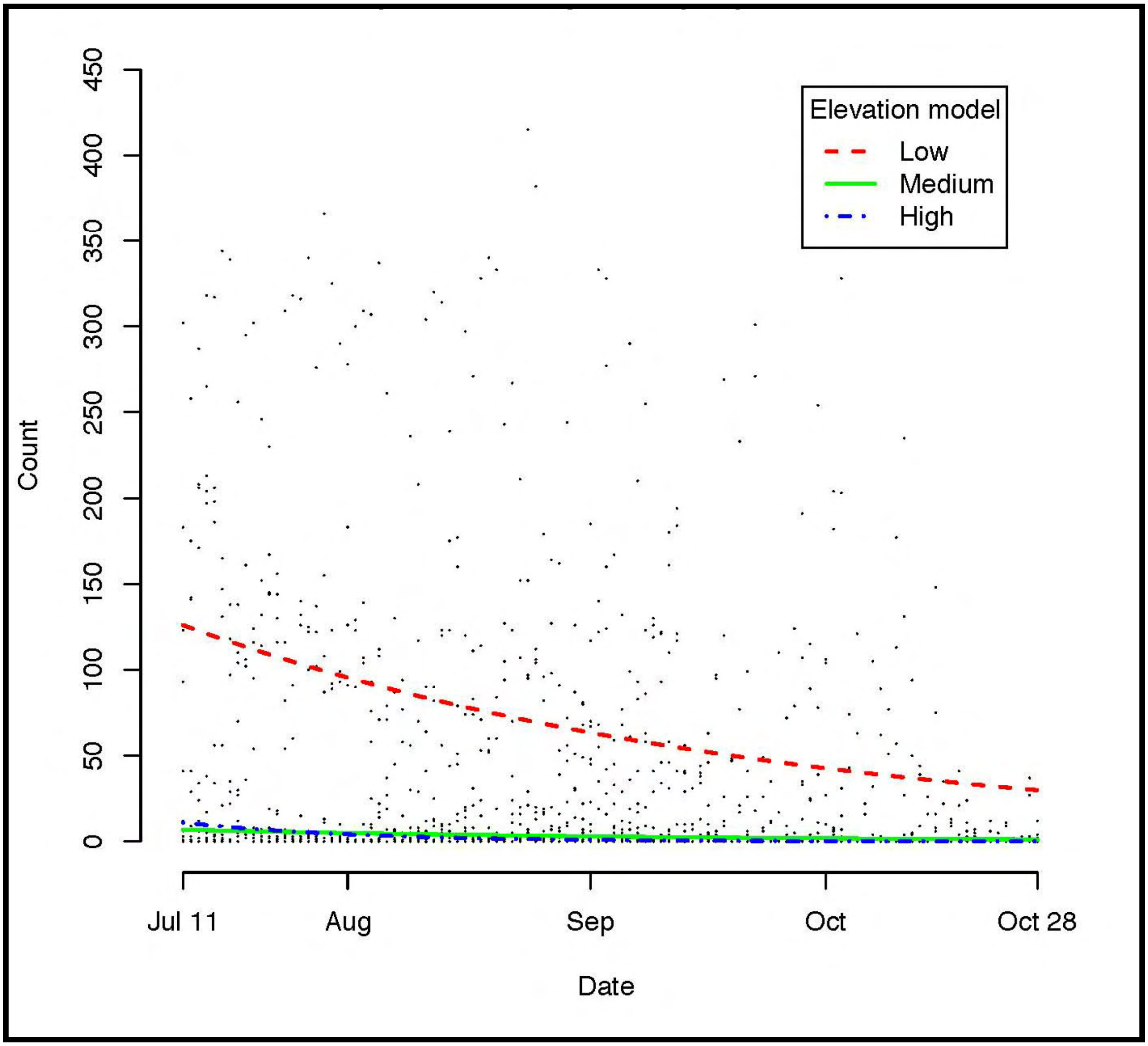

Figure AIII.3. Seasonal elevation preference by *Eumops perotis*

III.4. Western red bat, *Lasiurus blossevillii*

```
mean(Lasiurus_blossevillii,na.rm=TRUE)
0.3151515
mean(Lasiurus_blossevillii[Elev=="Low"],na.rm=TRUE)
0.5113636
mean(Lasiurus_blossevillii[Elev=="Medium"],na.rm=TRUE)
0.4227273
mean(Lasiurus_blossevillii[Elev=="High"],na.rm=TRUE)
0.01136364

Models:
GLMERLABL1: Lasiurus_blossevillii ~ 1 + (1 | Location)
GLMERLABL2: Lasiurus_blossevillii ~ Elev + (1 | Location)
GLMERLABL3: Lasiurus_blossevillii ~ Elev + (Day | Location)
GLMERLABL4: Lasiurus_blossevillii ~ Elev * Day + (1 | Location)
GLMERLABL5: Lasiurus_blossevillii ~ Elev * Day + (Day | Location)
           Df     AIC     BIC  logLik    Chisq Chi Df Pr(>Chisq)    
GLMERLABL1  2 1256.04 1266.41 -626.02                               
GLMERLABL2  4 1250.53 1271.27 -621.26   9.5120      2    0.00860 ** 
GLMERLABL3  6 1106.77 1137.89 -547.39 147.7534      2    < 2e-16 ***
GLMERLABL4  7 1105.45 1141.75 -545.73   3.3190      1    0.06849 .  
GLMERLABL5  9 1105.63 1152.30 -543.82   3.8229      2    0.14787    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Selection by AIC indicates that a partial model, with all considered fixed but only a single random effect for location is the minimum adequate model. Retention of all fixed effects indicates that elevation and day are both important for explaining activity levels, and the interaction term indicates that the effect of elevation changes with day. Retention of one random effect indicates that location, but not day, has grouping that contributes to model information.

***Lasiurus_blossevillii* Model Terms**

```
Generalized linear mixed model fit by the Laplace approximation 
Formula: Lasiurus_blossevillii ~ Elev * Day + (1 | Location) 
   Data: YNPbats 
  AIC  BIC logLik deviance
 1105 1142 -545.7     1091
Random effects:
 Groups   Name        Variance Std.Dev.
 Location (Intercept) 2.5417   1.5943  
Number of obs: 1320, groups: Location, 12

Fixed effects:
                Estimate Std. Error z value Pr(>|z|)    
(Intercept)    -5.725179   1.396959  -4.098 4.16e-05 ***
ElevLow         4.887796   1.618805   3.019  0.00253 ** 
ElevMedium      4.745955   1.619080   2.931  0.00338 ** 
Day            -0.001289   0.014653  -0.088  0.92989    
ElevLow:Day    -0.017331   0.014836  -1.168  0.24272    
ElevMedium:Day -0.020803   0.014890  -1.397  0.16240    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Correlation of Fixed Effects:
             (Intr) ElevLw ElvMdm Day    ElvL:D
ElevLow      -0.863
ElevMedium   -0.863  0.745
Day          -0.569  0.491  0.491
ElevLow:Day   0.562 -0.493 -0.485 -0.988
ElevMedm:Dy   0.559 -0.483 -0.493 -0.984  0.972
```

Note that most *Lasiurus blossevillii* are present at medium and low elevation. Activity declines into fall, but not significantly so. Detections of this species are sparse (see Figure AIII.4).

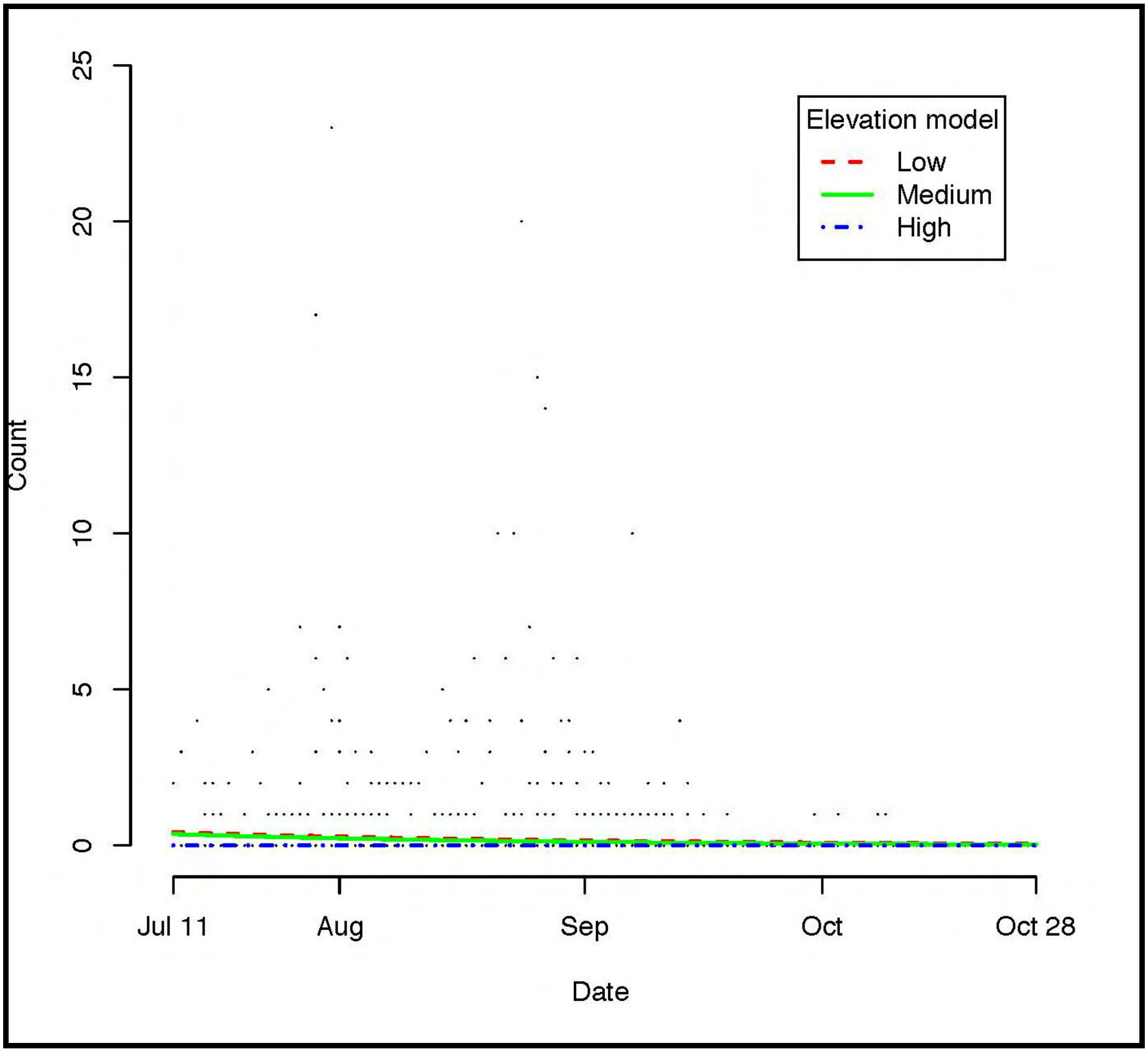

Figure AIII.4. Seasonal elevation preference by *Lasiurus blossevillii*

III.5. Hoary bat, *Lasiurus cinereus*

```
mean(Lasiurus_cinereus,na.rm=TRUE)
14.13712
mean(Lasiurus_cinereus[Elev=="Low"],na.rm=TRUE)
34.44318
mean(Lasiurus_cinereus[Elev=="Medium"],na.rm=TRUE)
7.193182
mean(Lasiurus_cinereus[Elev=="High"],na.rm=TRUE)
0.775

Models:
GLMERLACI1: Lasiurus_cinereus ~ 1 + (1 | Location)
GLMERLACI2: Lasiurus_cinereus ~ Elev + (1 | Location)
GLMERLACI3: Lasiurus_cinereus ~ Elev + (Day | Location)
GLMERLACI4: Lasiurus_cinereus ~ Elev * Day + (1 | Location)
GLMERLACI5: Lasiurus_cinereus ~ Elev * Day + (Day | Location)
           Df    AIC    BIC logLik    Chisq Chi Df Pr(>Chisq)
GLMERLACI1  2  27818  27828 -13907
GLMERLACI2  4  27808  27829 -13900   13.074      2   0.001449 **
GLMERLACI3  6  24818  24849 -12403 2994.413      2  < 2.2e-16 ***
GLMERLACI4  7  26700  26736 -13343    0.000      1   1.000000
GLMERLACI5  9  24815  24861 -12398 1889.579      2  < 2.2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Selection by AIC indicates that the full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that elevation and day are both important for explaining activity levels, and the interaction term indicates that the effect of elevation changes with day. Retention of both random effects indicates that both day and location have grouping that contributes to model information.

Lasiurus_cinereus Model Terms

```
Generalized linear mixed model fit by the Laplace approximation
Formula: Lasiurus_cinereus ~ Elev * Day + (Day | Location)
   Data: YNPbats
   AIC   BIC logLik deviance
 24815 24861 -12398    24797
Random effects:
 Groups   Name        Variance   Std.Dev.  Corr
 Location (Intercept) 1.9879e+00 1.4099312
          Day         9.7668e-05 0.0098827 -0.721
Number of obs: 1320, groups: Location, 12

Fixed effects:
                Estimate Std. Error z value Pr(>|z|)
(Intercept)     0.110647   0.715470  0.1546  0.87710
ElevLow         2.458005   1.004904  2.4460  0.01444 *
ElevMedium      1.316043   1.007341  1.3065  0.19140
Day            -0.013574   0.005420 -2.5045  0.01226 *
ElevLow:Day     0.021838   0.007345  2.9730  0.00295 **
ElevMedium:Day  0.002012   0.007461  0.2696  0.78747
---
```

```
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
             (Intr) ElevLw ElvMdm Day    ElvL:D
ElevLow      -0.712
ElevMedium   -0.710  0.506
Day          -0.705  0.502  0.500
ElevLow:Day   0.520 -0.712 -0.369 -0.738
ElevMedm:Dy   0.512 -0.364 -0.709 -0.726  0.536
```

Note that most *Lasiurus cinereus* are present at low elevation, and the interaction is such that the low elevation population grows significantly into fall (see Figure AIII.5).

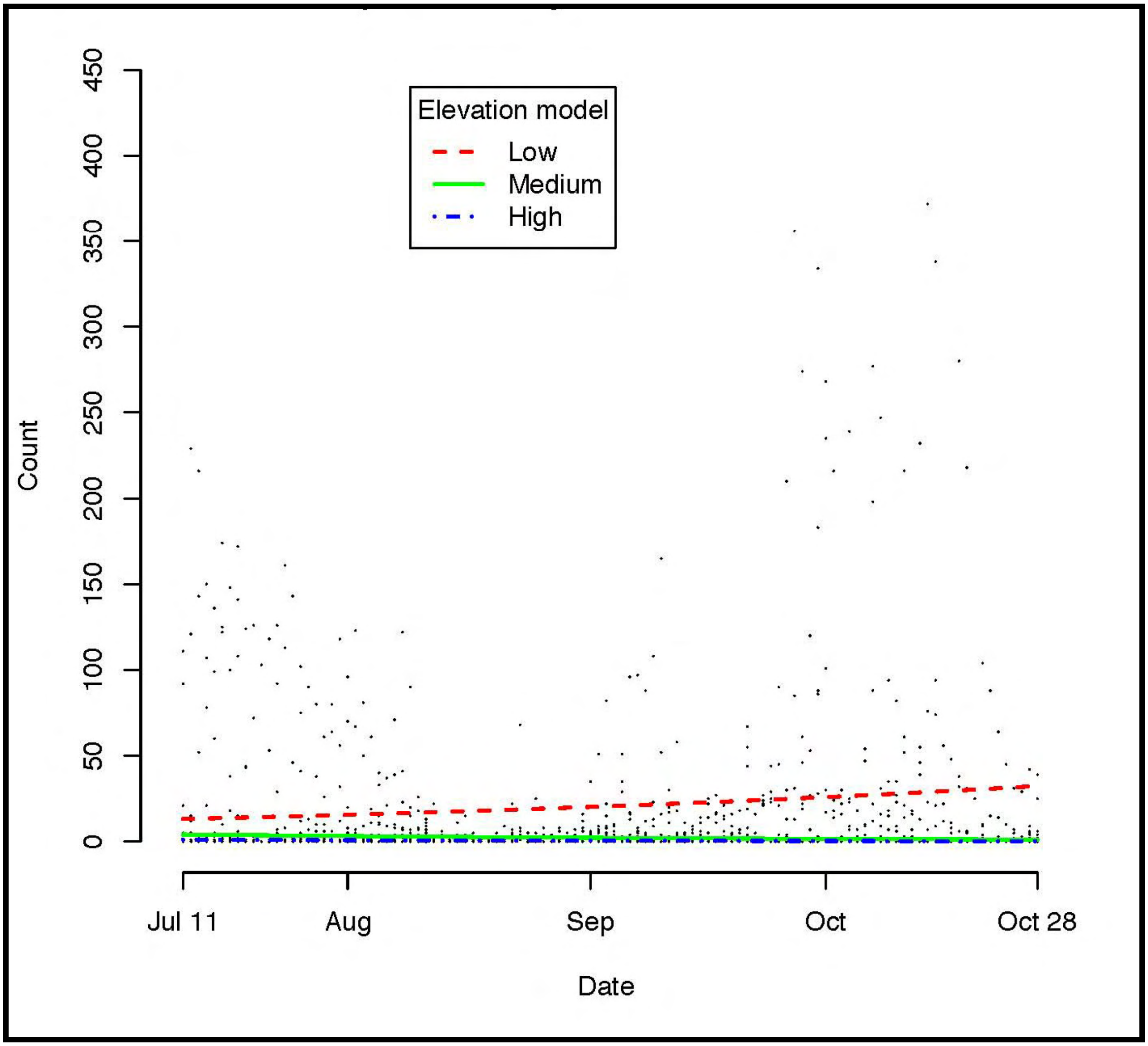

Figure AIII.5. Seasonal elevation preference by *Lasiurus cinereus*

III.6. M40 *Myotis ciliolabrum*, *Myotis lucifugus*, and *Myotis volans*

```
mean(M40,na.rm=TRUE)
0.4704545
mean(M40[Elev=="Low"],na.rm=TRUE)
0.3272727
mean(M40[Elev=="Medium"],na.rm=TRUE)
0.4818182
mean(M40[Elev=="High"],na.rm=TRUE)
0.6022727

Models:
GLMERM401: M40 ~ 1 + (1 | Location)
GLMERM402: M40 ~ Elev + (1 | Location)
GLMERM403: M40 ~ Elev + (Day | Location)
GLMERM404: M40 ~ Elev * Day + (1 | Location)
GLMERM405: M40 ~ Elev * Day + (Day | Location)
          Df     AIC     BIC  logLik    Chisq Chi Df Pr(>Chisq)
GLMERM401  2 1836.52 1846.89 -916.26
GLMERM402  4 1837.75 1858.49 -914.87   2.7696      2     0.2504
GLMERM403  6 1332.76 1363.87 -660.38 508.9867      2  < 2.2e-16 ***
GLMERM404  7 1294.43 1330.73 -640.22  40.3311      1  2.144e-10 ***
GLMERM405  9 1298.38 1345.05 -640.19   0.0498      2     0.9754
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Selection by AIC indicates that a partial model, with all considered fixed but only a single random effect for location is the minimum adequate model. Retention of all fixed effects indicates that elevation and day are both important for explaining activity levels, and the interaction term indicates that the effect of elevation changes with day. Retention of one random effect indicates that location, but not day, has grouping that contributes to model information.

M40 Model Terms

```
Generalized linear mixed model fit by the Laplace approximation
Formula: M40 ~ Elev * Day + (1 | Location)
   Data: YNPbats
  AIC  BIC logLik deviance
 1294 1331 -640.2     1280
Random effects:
 Groups   Name        Variance Std.Dev.
 Location (Intercept) 0.95163  0.97552
Number of obs: 1320, groups: Location, 12

Fixed effects:
                Estimate Std. Error z value Pr(>|z|)
(Intercept)     0.774517   0.497614   1.556 0.119598
ElevLow        -1.155566   0.712137  -1.623 0.104659
ElevMedium     -1.116266   0.717767  -1.555 0.119900
Day            -0.036070   0.002667 -13.526  < 2e-16 ***
ElevLow:Day     0.014001   0.004019   3.484 0.000495 ***
ElevMedium:Day -0.004422   0.004153  -1.065 0.286950
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
```

```
            (Intr) ElevLw ElvMdm Day    ElvL:D
ElevLow     -0.699
ElevMedium  -0.693  0.484
Day         -0.140  0.098  0.097
ElevLow:Day  0.093 -0.176 -0.064 -0.664
ElevMedm:Dy  0.090 -0.063 -0.144 -0.642  0.426
```

Most M40 are present at high elevation, and activity declines as the season advances. Interactions indicate that this decline is slower at low elevation. Detections are fairly sparse (see Figure AIII.6).

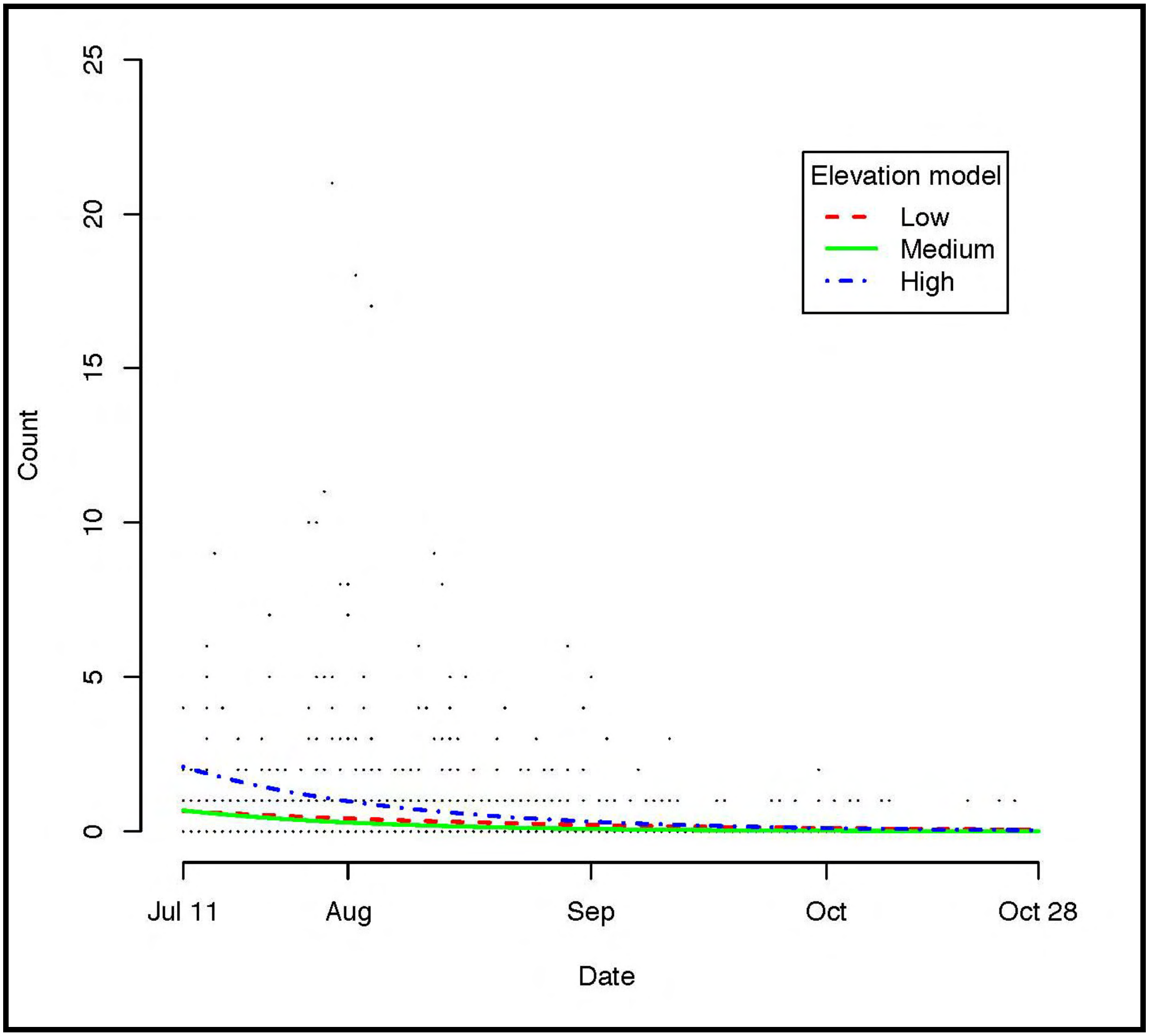

Figure AIII.6. Seasonal elevation preference by M40 (*Myotis ciliolabrum*, *Myotis lucifugus*, and *Myotis volans*)

III.7 M50 – *Myotis californicus* and *Myotis yumanensis*

```
mean(M50,na.rm=TRUE)
1.705303
mean(M50[Elev=="Low"],na.rm=TRUE)
2.468182
mean(M50[Elev=="Medium"],na.rm=TRUE)
2.529545
mean(M50[Elev=="High"],na.rm=TRUE)
0.1181818

Models:
GLMERM501: M50 ~ 1 + (1 | Location)
GLMERM502: M50 ~ Elev + (1 | Location)
GLMERM503: M50 ~ Elev + (Day | Location)
GLMERM504: M50 ~ Elev * Day + (1 | Location)
GLMERM505: M50 ~ Elev * Day + (Day | Location)
          Df    AIC    BIC  logLik    Chisq Chi Df Pr(>Chisq)
GLMERM501  2  5628.1  5638.5 -2812.1
GLMERM502  4  5621.6  5642.3 -2806.8   10.546      2   0.005128 **
GLMERM503  6  3102.0  3133.1 -1545.0 2523.608      2  < 2.2e-16 ***
GLMERM504  7  3336.9  3373.2 -1661.5    0.000      1   1.000000
GLMERM505  9  3095.1  3141.8 -1538.6  245.835      2  < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Selection by AIC indicates that the full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that elevation and day are both important for explaining activity levels, and the interaction term indicates that the effect of elevation changes with day. Retention of both random effects indicates that both day and location have grouping that contributes to model information.

M50 Model Terms

```
Generalized linear mixed model fit by the Laplace approximation
Formula: M50 ~ Elev * Day + (Day | Location)
   Data: YNPbats
  AIC  BIC logLik deviance
 3095 3142  -1539     3077
Random effects:
 Groups   Name        Variance  Std.Dev. Corr
 Location (Intercept) 2.0443854 1.429820
          Day         0.0005189 0.022779 -0.736
Number of obs: 1320, groups: Location, 12

Fixed effects:
               Estimate Std. Error z value Pr(>|z|)
(Intercept)    -1.46114    0.76924  -1.899  0.05750 .
ElevLow         2.67762    1.05178   2.546  0.01090 *
ElevMedium      2.91817    1.05969   2.754  0.00589 **
Day            -0.02651    0.01333  -1.988  0.04676 *
ElevLow:Day     0.01913    0.01757   1.089  0.27606
ElevMedium:Day -0.02454    0.01791  -1.370  0.17064
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Correlation of Fixed Effects:
             (Intr) ElevLw ElvMdm Day    ElvL:D
ElevLow      -0.731
ElevMedium   -0.726  0.531
Day          -0.730  0.534  0.530
ElevLow:Day   0.554 -0.732 -0.402 -0.759
ElevMedm:Dy   0.543 -0.397 -0.730 -0.744  0.565
```

M50 are present at mostly low and medium elevations and activity declines significantly as the season advances. The interaction term is such this seasonal decline is slow at low elevation (see Figure AIII.7).

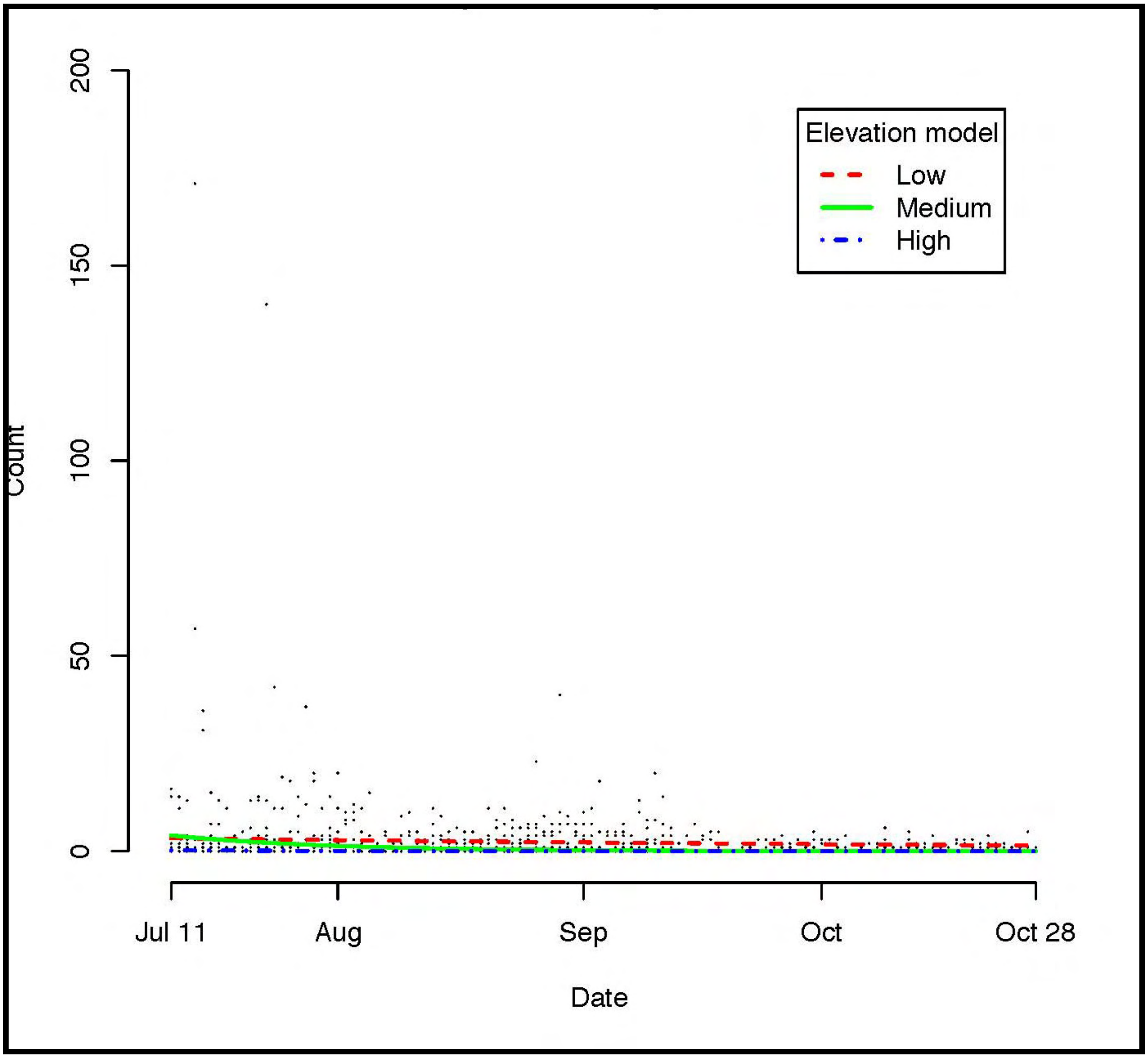

Figure AIII.7. Seasonal elevation preference by M50 (*Myotis californicus* and *Myotis yumanensis*)

III.8. Long-eared myotis, *Myotis evotis*

```
mean(Myotis_evotis,na.rm=TRUE)
0.1053030
mean(Myotis_evotis[Elev=="Low"],na.rm=TRUE)
0.1
mean(Myotis_evotis[Elev=="Medium"],na.rm=TRUE)
0.1363636
mean(Myotis_evotis[Elev=="High"],na.rm=TRUE)
0.07954545

Models:
GLMERMYEV1: Myotis_evotis ~ 1 + (1 | Location)
GLMERMYEV2: Myotis_evotis ~ Elev + (1 | Location)
GLMERMYEV3: Myotis_evotis ~ Elev + (Day | Location)
GLMERMYEV4: Myotis_evotis ~ Elev * Day + (1 | Location)
GLMERMYEV5: Myotis_evotis ~ Elev * Day + (Day | Location)
           Df     AIC     BIC  logLik   Chisq Chi Df Pr(>Chisq)
GLMERMYEV1  2  704.85  715.22 -350.43
GLMERMYEV2  4  707.01  727.75 -349.51  1.8411      2  0.3982976
GLMERMYEV3  6  686.11  717.22 -337.06 24.8996      2  3.918e-06 ***
GLMERMYEV4  7  677.20  713.50 -331.60 10.9085      1  0.0009572 ***
GLMERMYEV5  9  680.45  727.12 -331.23  0.7481      2  0.6879505
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Selection by AIC indicates that a partial model, with all considered fixed but only a single random effect for location is the minimum adequate model. Retention of all fixed effects indicates that elevation and day are both important for explaining activity levels, and the interaction term indicates that the effect of elevation changes with day. Retention of one random effect indicates that location, but not day, has grouping that contributes to model information.

Myotis_evotis Model Terms

```
Generalized linear mixed model fit by the Laplace approximation
Formula: Myotis_evotis ~ Elev * Day + (1 | Location)
   Data: YNPbats
   AIC   BIC logLik deviance
 677.2 713.5 -331.6    663.2
Random effects:
 Groups   Name        Variance Std.Dev.
 Location (Intercept) 0.28493  0.53379
Number of obs: 1320, groups: Location, 12

Fixed effects:
                Estimate Std. Error z value Pr(>|z|)
(Intercept)    -1.585129   0.386745  -4.099 4.16e-05 ***
ElevLow        -0.758934   0.560095  -1.355  0.17541
ElevMedium      0.237345   0.520753   0.456  0.64855
Day            -0.026861   0.006500  -4.133 3.59e-05 ***
ElevLow:Day     0.026388   0.008061   3.273  0.00106 **
ElevMedium:Day  0.010578   0.007850   1.348  0.17779
---
```

```
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) ElevLw ElvMdm Day    ElvL:D
ElevLow     -0.690
ElevMedium  -0.743  0.513
Day         -0.533  0.368  0.395
ElevLow:Day  0.429 -0.574 -0.319 -0.806
ElevMedm:Dy  0.441 -0.304 -0.517 -0.828  0.668
```

Detections are sparse for this species and the terms for the model, other than a decline in activity as the season advances, are weak. An interaction term is such that this decline is nearly absent at low elevation (see Figure AIII.8).

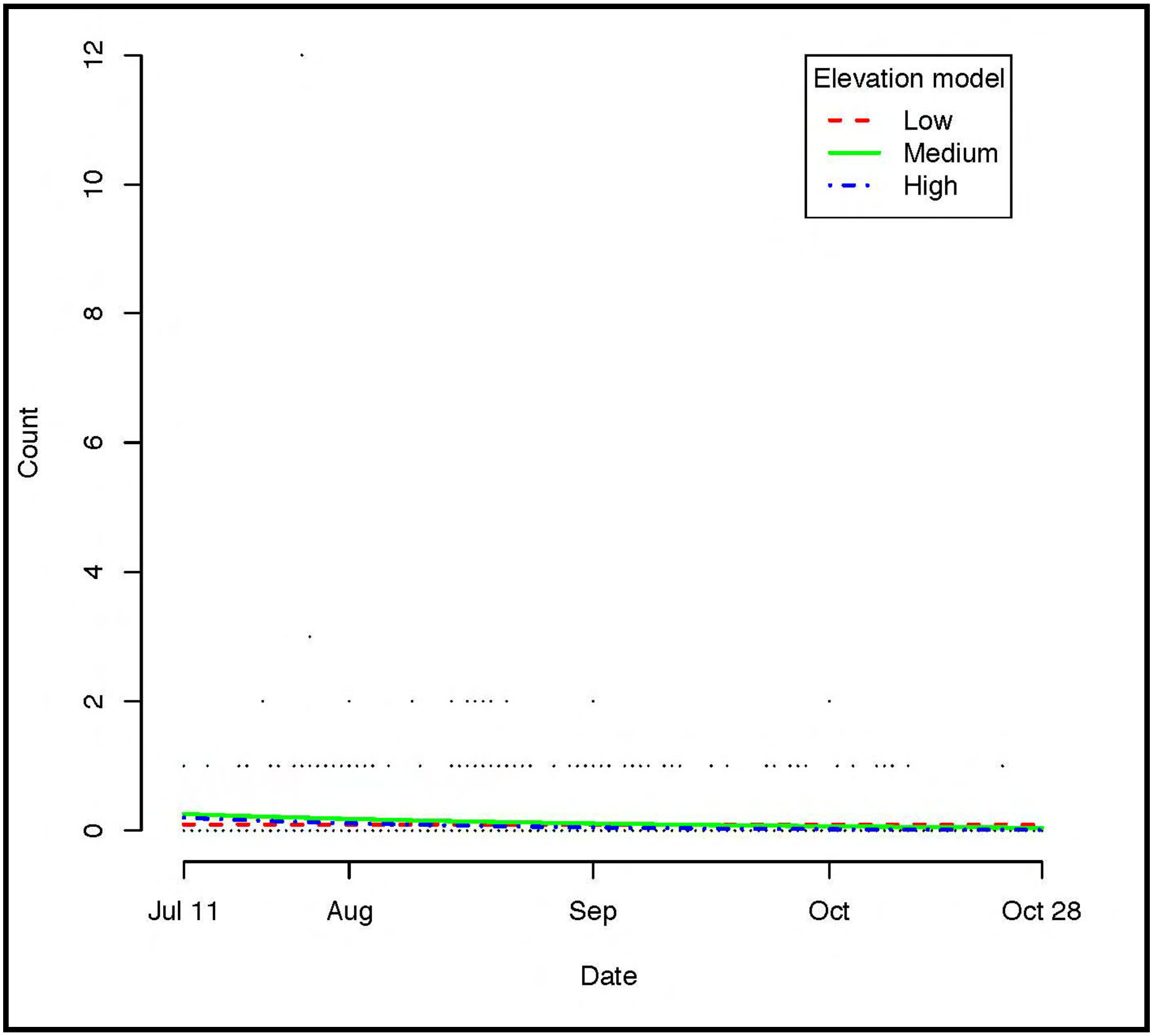

Figure AIII.8. Seasonal elevation preference by *Myotis evotis*

III.9. Fringed myotis, *Myotis thysanodes*

```
mean(Myotis_thysanodes,na.rm=TRUE)
0.1272727
mean(Myotis_thysanodes[Elev=="Low"],na.rm=TRUE)
0.2113636
mean(Myotis_thysanodes[Elev=="Medium"],na.rm=TRUE)
0.1704545
mean(Myotis_thysanodes[Elev=="High"],na.rm=TRUE)
0

Models:
GLMERMYTH1: Myotis_thysanodes ~ 1 + (1 | Location)
GLMERMYTH2: Myotis_thysanodes ~ Elev + (1 | Location)
GLMERMYTH3: Myotis_thysanodes ~ Elev + (Day | Location)
GLMERMYTH4: Myotis_thysanodes ~ Elev * Day + (1 | Location)
GLMERMYTH5: Myotis_thysanodes ~ Elev * Day + (Day | Location)
           Df    AIC    BIC  logLik    Chisq Chi Df Pr(>Chisq)    
GLMERMYTH1  2 644.81 655.18 -320.40                               
GLMERMYTH2  4 637.18 657.92 -314.59  11.6247      2   0.002990 ** 
GLMERMYTH3  6 502.68 533.79 -245.34 138.5066      2  < 2.2e-16 ***
GLMERMYTH4  7 506.38 542.68 -246.19   0.0000      1   1.000000    
GLMERMYTH5  9 506.96 553.62 -244.48   3.4264      2   0.180287    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Selection by AIC indicates that a partial model, with all considered random effects, but only elevation as a fixed effect is the minimum adequate model. Retention of only elevation as a fixed effect indicates that day is not important for explaining activity levels, nor does the effect of elevation change with day. Retention of both random effects indicates that both day and location have grouping that contributes to model information.

Myotis_thysanodes Model Terms

```
Generalized linear mixed model fit by the Laplace approximation
Formula: Myotis_thysanodes ~ Elev + (Day | Location)
   Data: YNPbats
   AIC   BIC logLik deviance
 502.7 533.8 -245.3    490.7
Random effects:
 Groups   Name        Variance   Std.Dev. Corr  
 Location (Intercept) 0.50521305 0.71078        
          Day         0.00080371 0.02835  -0.125
Number of obs: 1320, groups: Location, 12

Fixed effects:
            Estimate Std. Error  z value Pr(>|z|)
(Intercept)   -20.53    1370.68 -0.01498    0.988
ElevLow        18.92    1370.68  0.01380    0.989
ElevMedium     15.13    1370.68  0.01104    0.991

Correlation of Fixed Effects:
           (Intr) ElevLw
ElevLow    -1.000       
ElevMedium -1.000  1.000
```

Detections are very sparse for this species and all model terms are very weak (see Figure AIII.9).

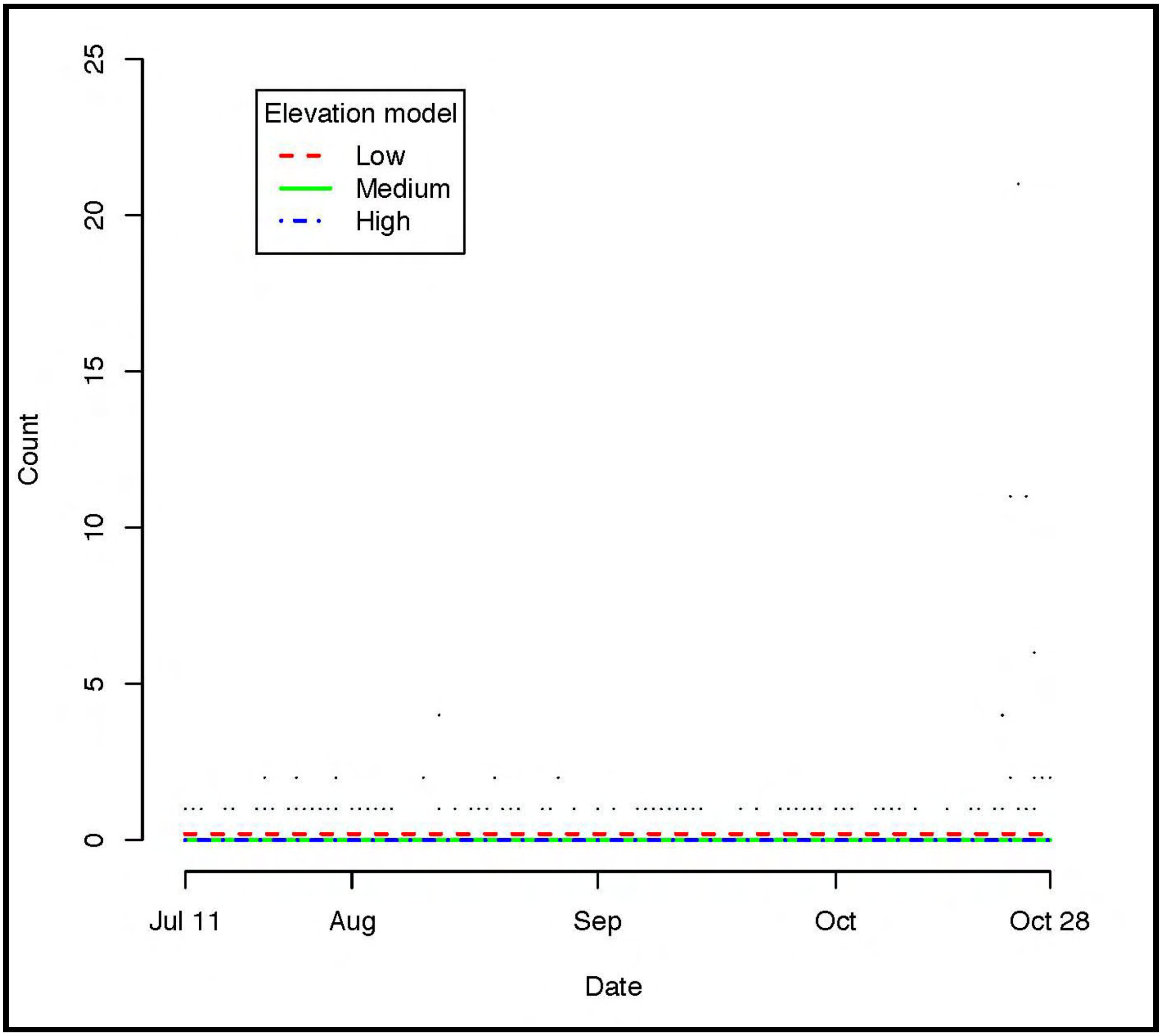

Figure AIII.9. Seasonal elevation preference by *Myotis thysanodes*

III.10. Western pipistrelle, *Parastrellus hesperus*

```
mean(Parastrellus_hesperus,na.rm=TRUE)
1.775758
mean(Parastrellus_hesperus[Elev=="Low"],na.rm=TRUE)
5.245455
mean(Parastrellus_hesperus[Elev=="Medium"],na.rm=TRUE)
0.08181818
mean(Parastrellus_hesperus[Elev=="High"],na.rm=TRUE)
0
```

```
Models:
GLMERPAHE1: Parastrellus_hesperus ~ 1 + (1 | Location)
GLMERPAHE2: Parastrellus_hesperus ~ Elev + (1 | Location)
GLMERPAHE4: Parastrellus_hesperus ~ Elev + Day + (1 | Location)
GLMERPAHE3: Parastrellus_hesperus ~ Elev + (Day | Location)
GLMERPAHE5: Parastrellus_hesperus ~ Elev * Day + (Day | Location)
           Df    AIC    BIC  logLik    Chisq Chi Df Pr(>Chisq)
GLMERPAHE1  2  2524.4  2534.8 -1260.2
GLMERPAHE2  4  2515.3  2536.1 -1253.7  13.0688      2   0.001453 **
GLMERPAHE4  5  2220.8  2246.7 -1105.4 296.5430      1  < 2.2e-16 ***
GLMERPAHE3  6  2220.8  2251.9 -1104.4   2.0208      1   0.155152
GLMERPAHE5  9  2223.1  2269.8 -1102.5   3.6824      3   0.297863
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Selection by AIC indicates that a partial model, with all considered random effects, but only elevation as a fixed effect is the minimum adequate model. Retention of only elevation as a fixed effect indicates that day is not important for explaining activity levels, nor does the effect of elevation change with day. Retention of both random effects indicates that both day and location have grouping that contributes to model information.

Parastrellus_hesperus **Model Terms**

```
Generalized linear mixed model fit by the Laplace approximation
Formula: Parastrellus_hesperus ~ Elev + (Day | Location)
   Data: YNPbats
  AIC  BIC logLik deviance
 2221 2252  -1104     2209
Random effects:
 Groups   Name        Variance   Std.Dev.  Corr
 Location (Intercept) 1.2060e+01 3.4728042
          Day         7.2431e-05 0.0085107 -0.995
Number of obs: 1320, groups: Location, 12

Fixed effects:
            Estimate Std. Error  z value Pr(>|z|)
(Intercept)   -19.18     698.27 -0.02747    0.978
ElevLow        17.36     698.27  0.02486    0.980
ElevMedium     14.86     698.28  0.02128    0.983

Correlation of Fixed Effects:
           (Intr) ElevLw
ElevLow    -1.000
ElevMedium -1.000  1.000
```

Detections are less sparse for this species, but model terms are still very weak, suggesting that these variables are not meaningful for predicting abundance of *P. hesperus* (see Figure AIII.10).

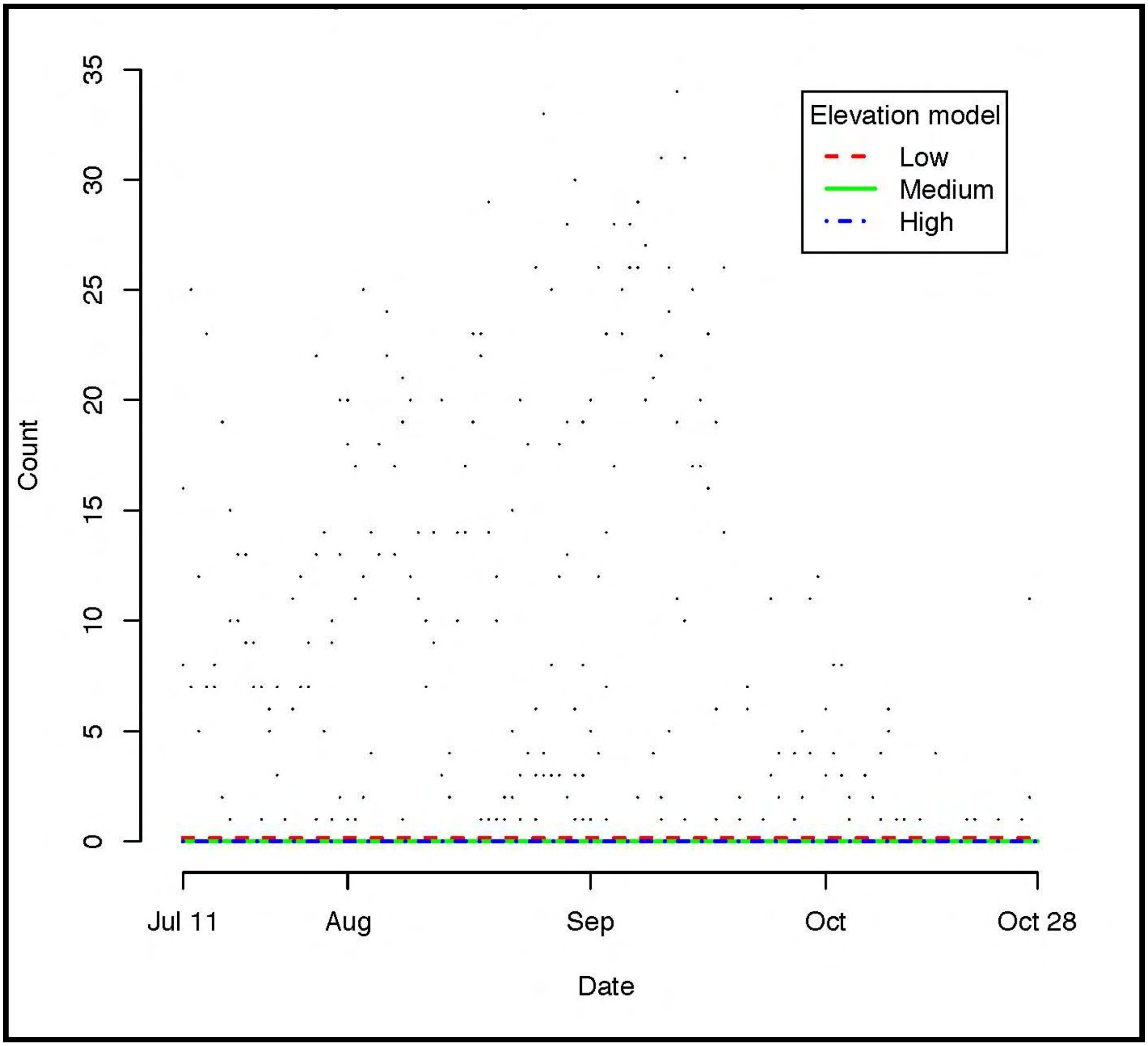

Figure AIII.10. Seasonal elevation preference by *Parastrellus hesperus*

III.11. Q25 – *Eptesicus fuscus*, *Lasionycteris noctivagans*, and *Tadarida brasiliensis*

```
mean(Q25,na.rm=TRUE)
22.02803
mean(Q25[Elev=="Low"],na.rm=TRUE)
22.925
mean(Q25[Elev=="Medium"],na.rm=TRUE)
25.93182
mean(Q25[Elev=="High"],na.rm=TRUE)
17.22727
```

Models:

```
GLMERQ251: Q25 ~ 1 + (1 | Location)
GLMERQ252: Q25 ~ Elev + (1 | Location)
GLMERQ253: Q25 ~ Elev + (Day | Location)
GLMERQ254: Q25 ~ Elev * Day + (1 | Location)
GLMERQ255: Q25 ~ Elev * Day + (Day | Location)
          Df    AIC    BIC logLik     Chisq Chi Df Pr(>Chisq)
GLMERQ251  2  29823  29833 -14910
GLMERQ252  4  29826  29847 -14909    0.7171      2     0.6987
GLMERQ253  6  20545  20576 -10266 9285.5843      2     <2e-16 ***
GLMERQ254  7  21475  21511 -10730    0.0000      1     1.0000
GLMERQ255  9  20523  20570 -10252  955.5485      2     <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Selection by AIC indicates that the full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that elevation and day are both important for explaining activity levels, and the interaction term indicates that the effect of elevation changes with day. Retention of both random effects indicates that both day and location have grouping that contributes to model information.

Q25 Model Terms

```
Generalized linear mixed model fit by the Laplace approximation
Formula: Q25 ~ Elev * Day + (Day | Location)
   Data: YNPbats
   AIC   BIC logLik deviance
 20523 20570 -10252    20505
Random effects:
 Groups   Name        Variance   Std.Dev.  Corr
 Location (Intercept) 0.13617230 0.3690153
          Day         0.00004673 0.0068359 0.264
Number of obs: 1320, groups: Location, 12

Fixed effects:
                Estimate Std. Error z value Pr(>|z|)
(Intercept)     3.907240   0.185479  21.066  < 2e-16 ***
ElevLow        -0.465171   0.262454  -1.772  0.07633 .
ElevMedium      0.219229   0.262177   0.836  0.40305
Day            -0.025402   0.003447  -7.370 1.71e-13 ***
ElevLow:Day     0.015825   0.004871   3.249  0.00116 **
ElevMedium:Day  0.001858   0.004873   0.381  0.70300
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) ElevLw ElvMdm Day    ElvL:D
ElevLow     -0.707
ElevMedium  -0.707  0.500
Day          0.250 -0.177 -0.177
ElevLow:Day -0.177  0.250  0.125 -0.708
ElevMedm:Dy -0.177  0.125  0.251 -0.707  0.501
```

Q25 are present at all elevations and activity declines as the season advances. Interaction terms are such that this decline is limited at low elevations (see Figure AIII.11).

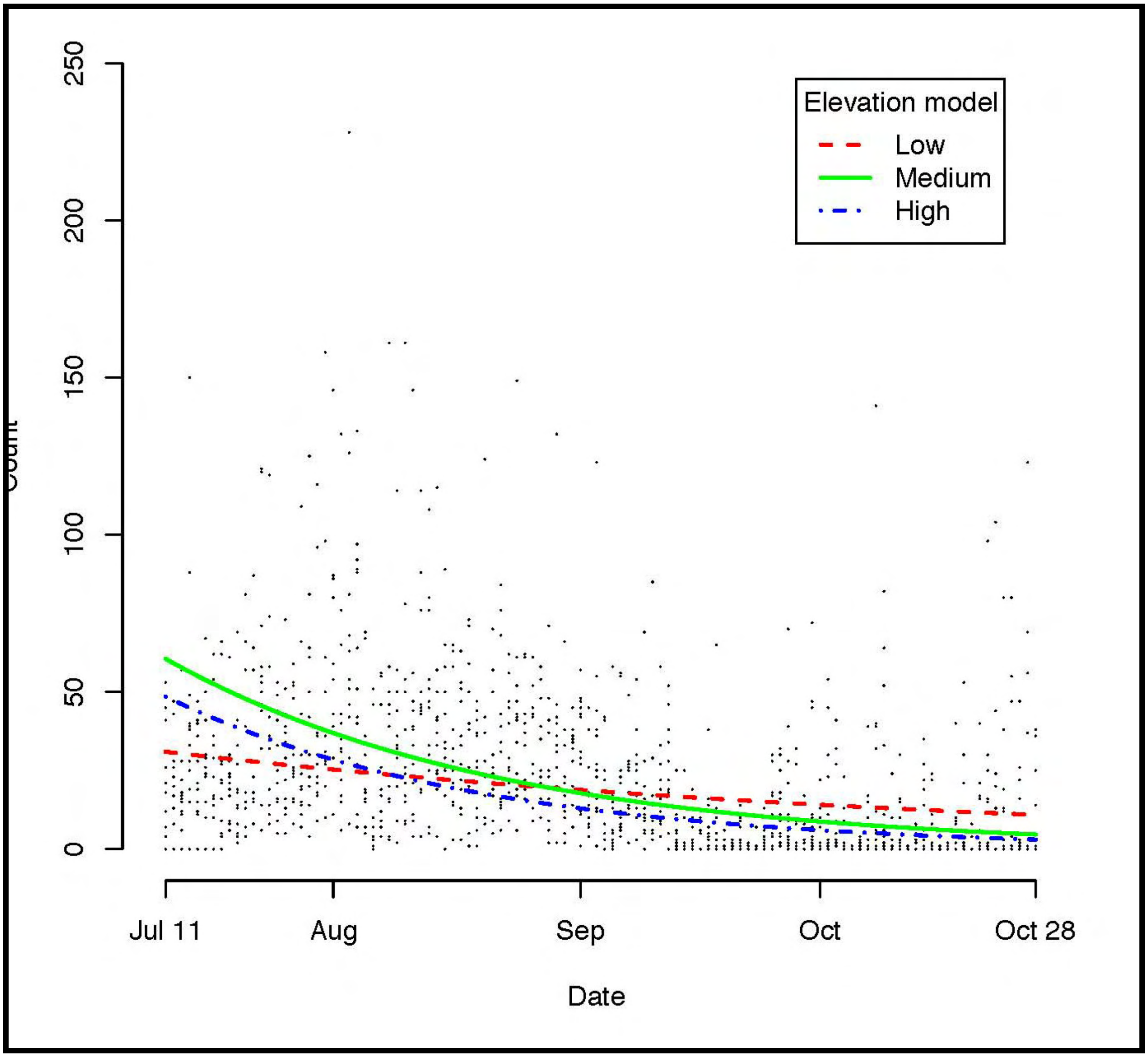

Figure AIII.11. Seasonal elevation preference by Q25 (*Eptesicus fuscus*, *Lasionycteris noctivagans*, and *Tadarida brasiliensis*)

<u>III.12. Mexican free-tailed bat, *Tadarida brasiliensis*</u>

```
mean(Tadarida_brasiliensis,na.rm=TRUE)
35.1697
mean(Tadarida_brasiliensis[Elev=="Low"],na.rm=TRUE)
52.17955
mean(Tadarida_brasiliensis[Elev=="Medium"],na.rm=TRUE)
40.91364
mean(Tadarida_brasiliensis[Elev=="High"],na.rm=TRUE)
```

```
12.41591

Models:
GLMERTABR1: Tadarida_brasiliensis ~ 1 + (1 | Location)
GLMERTABR2: Tadarida_brasiliensis ~ Elev + (1 | Location)
GLMERTABR3: Tadarida_brasiliensis ~ Elev + (Day | Location)
GLMERTABR4: Tadarida_brasiliensis ~ Elev * Day + (1 | Location)
GLMERTABR5: Tadarida_brasiliensis ~ Elev * Day + (Day | Location)
           Df   AIC   BIC logLik      Chisq Chi Df Pr(>Chisq)
GLMERTABR1  2 44208 44218 -22102
GLMERTABR2  4 44207 44227 -22099     5.4417      2    0.06582 .
GLMERTABR3  6 29074 29106 -14531 15136.1253      2    < 2e-16 ***
GLMERTABR4  7 29756 29793 -14871     0.0000      1    1.00000
GLMERTABR5  9 29040 29087 -14511   719.9603      2    < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Selection by AIC indicates that the full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that elevation and day are both important for explaining activity levels, and the interaction term indicates that the effect of elevation changes with day. Retention of both random effects indicates that both day and location have grouping that contributes to model information.

Tadarida_brasiliensis Model Terms

```
Generalized linear mixed model fit by the Laplace approximation
Formula: Tadarida_brasiliensis ~ Elev * Day + (Day | Location)
   Data: YNPbats
   AIC   BIC logLik deviance
 29040 29087 -14511    29022
Random effects:
 Groups   Name        Variance   Std.Dev.  Corr
 Location (Intercept) 5.2525e-01 0.7247421
          Day         2.2033e-05 0.0046939 0.140
Number of obs: 1320, groups: Location, 12

Fixed effects:
                Estimate Std. Error z value Pr(>|z|)
(Intercept)     3.675298   0.363112  10.122  < 2e-16 ***
ElevLow         0.714255   0.513165   1.392    0.164
ElevMedium      0.583042   0.513397   1.136    0.256
Day            -0.030921   0.002426 -12.745  < 2e-16 ***
ElevLow:Day     0.019557   0.003385   5.778 7.56e-09 ***
ElevMedium:Day  0.003256   0.003411   0.954    0.340
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) ElevLw ElvMdm Day    ElvL:D
ElevLow     -0.708
ElevMedium  -0.707  0.500
Day          0.123 -0.087 -0.087
ElevLow:Day -0.088  0.129  0.062 -0.717
ElevMedm:Dy -0.087  0.062  0.125 -0.711  0.510
```

Tadarida brasiliensis are present at all elevations and activity declines as the season advances. However, an interaction term is such that this species is still relatively abundant at low elevation late in the season (see Figure AIII.12).

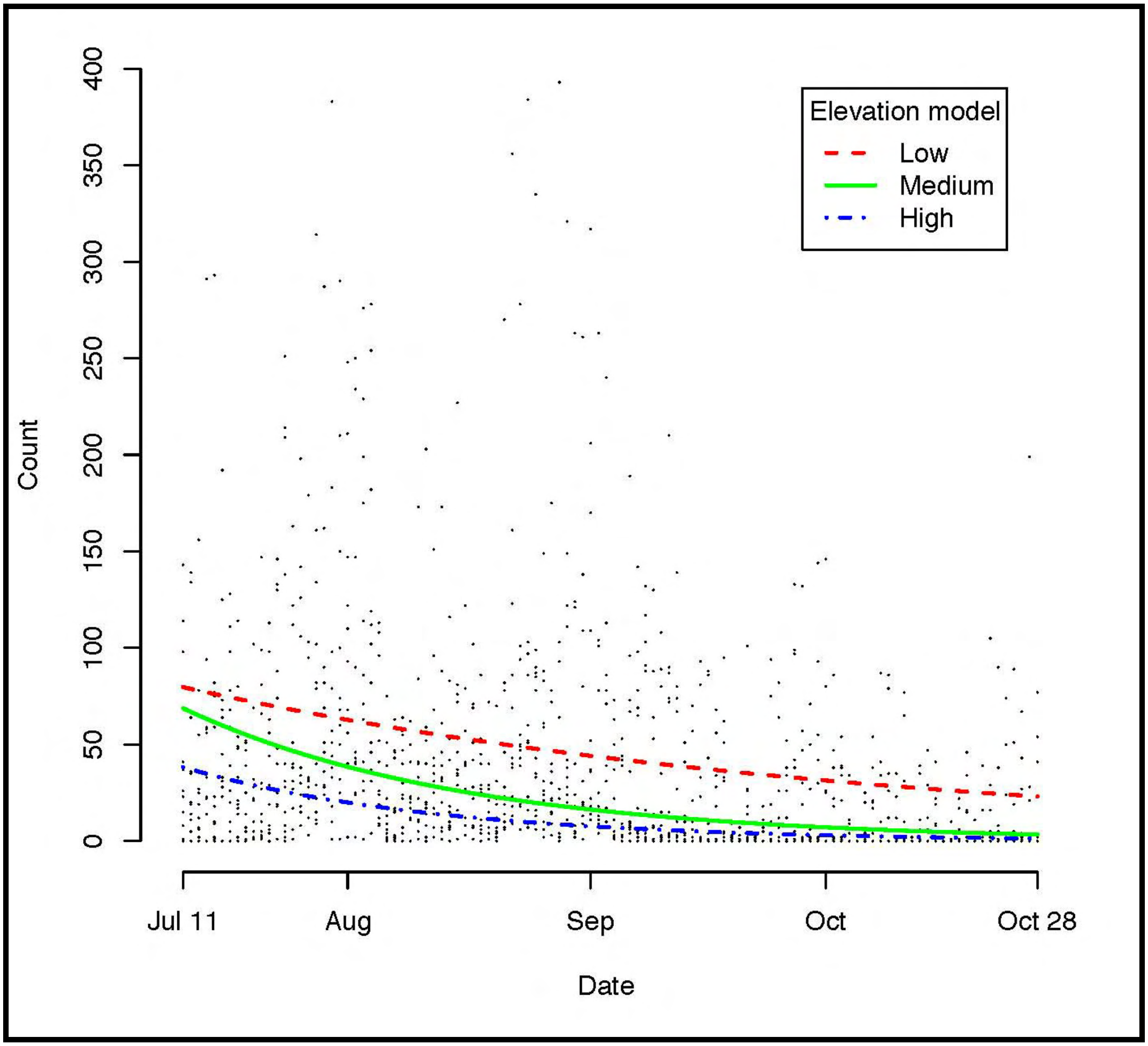

Figure AIII.12. Seasonal elevation preference by *Tadarida brasiliensis*

APPENDIX IV. Trial 2, Detection Probability per Unit Effort by Random Samples in the Elevation Data,

We used the following models to determine probabilities of encountering a species at least once in random samples of different sizes within the elevation data set. The results could be used as a general guideline to compare relative survey effort required for the different species at the meadows used for collecting the elevation data set. Model terms were derived using the logit link function. Note that we included a calculation of the number of survey nights needed to achieve a 90% probability of encountering species at least once.

IV.1. Pallid bat, *Antrozous pallidus*

A. pallidus, Model Selection

Analysis of Deviance Table

```
Model 1: A_pallidus_detected ~ 1
Model 2: A_pallidus_detected ~ Survey_repetitions
  Resid. Df Resid. Dev  Df Deviance
1       299     361.29
2       298     247.97   1   113.32
> AIC(GLMANPA1,GLMANPA)
         df      AIC
GLMANPA1  1 363.2910
GLMANPA   2 251.9698
```

Select the full model

A. pallidus, Terms of selected model

```
glm(formula = A_pallidus_detected ~ Survey_repetitions, family =
binomial)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.8805  -0.6789   0.3072   0.6024   1.8047

Coefficients:
                    Estimate Std. Error z value Pr(>|z|)
(Intercept)        -1.588716   0.295997  -5.367 7.99e-08 ***
Survey_repetitions  0.059598   0.007114   8.378  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 361.29  on 299  degrees of freedom
Residual deviance: 247.97  on 298  degrees of freedom
AIC: 251.97

Number of Fisher Scoring iterations: 5
```

Expected number of repetitions to achieve a 90% probability of detecting *A. pallidus* at least once: 63.5

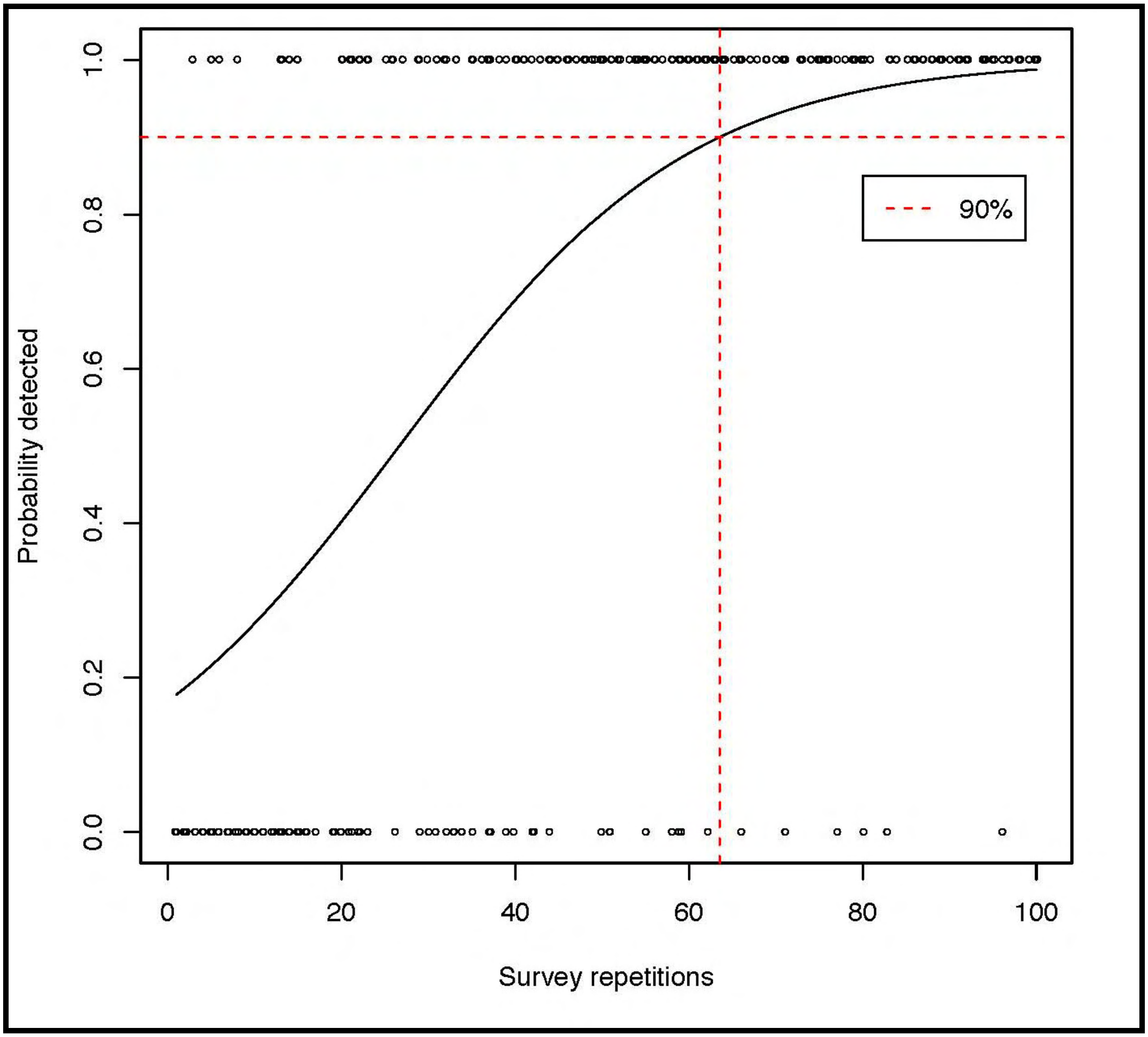

Figure AIV.1. Random survey effort and detection probability for *Antrozous pallidus*

IV.2. Spotted bat, *Euderma maculatum*

E. maculatum, Model Selection

Analysis of Deviance Table

```
Model 1: E_maculatum_detected ~ 1
Model 2: E_maculatum_detected ~ Survey_repetitions
  Resid. Df Resid. Dev  Df Deviance
```

```
1       299    146.958
2       298     88.143   1   58.815
> AIC(GLMEUMA1,GLMEUMA)
         df      AIC
GLMEUMA1  1 148.9580
GLMEUMA   2  92.1433
```

Select the full model

***E. maculatum*, Terms of selected model**

```
glm(formula = E_maculatum_detected ~ Survey_repetitions, family =
binomial)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-2.38752   0.01386   0.05430   0.18740   1.05095

Coefficients:
                   Estimate Std. Error z value Pr(>|z|)
(Intercept)         -0.9378     0.5603  -1.674   0.0942 .
Survey_repetitions   1.2428     0.2860   4.346 1.39e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 146.958  on 299  degrees of freedom
Residual deviance:  88.143  on 298  degrees of freedom
AIC: 92.143

Number of Fisher Scoring iterations: 8
```

Expected number of repetitions to achieve a 90% probability of detecting *E. maculatum* at least once: 2.5

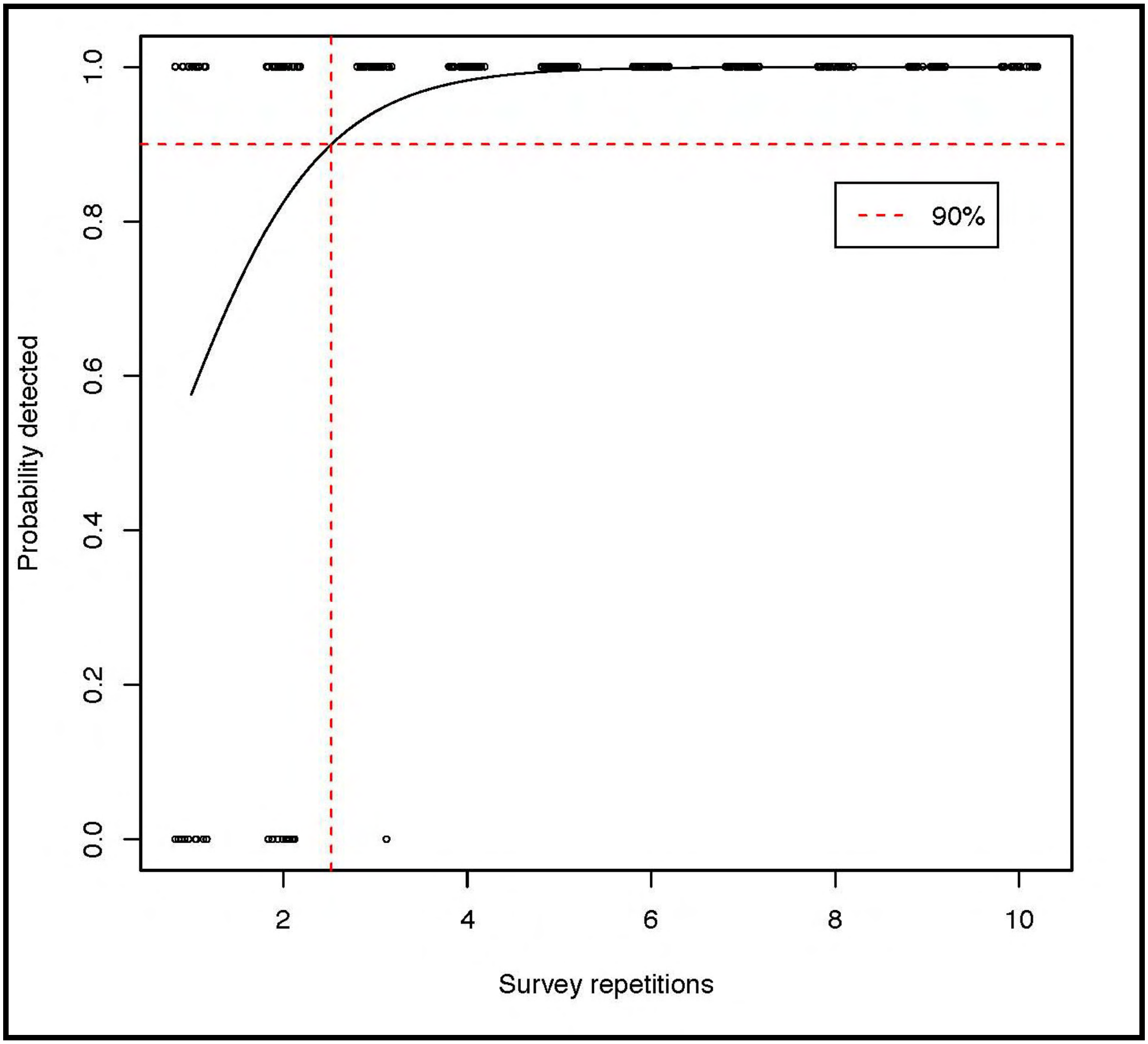

Figure AIV.2. Random survey effort and detection probability for *Euderma maculatum*

IV.3. Western mastiff bat, *Eumops perotis*

E. perotis, Model Selection

Analysis of Deviance Table

```
Model 1: E_perotis_detected ~ 1
Model 2: E_perotis_detected ~ Survey_repetitions
  Resid. Df Resid. Dev  Df Deviance
1       299    157.306
2       298    104.635   1   52.671
> AIC(GLMEUPE1,GLMEUPE)
```

```
         df      AIC
GLMEUPE1  1 159.3063
GLMEUPE   2 108.6349
```

Select the full model

E. perotis, Terms of selected model

```
glm(formula = E_perotis_detected ~ Survey_repetitions, family =
binomial)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-2.89885   0.02662   0.10882   0.27626   1.00202

Coefficients:
                   Estimate Std. Error z value Pr(>|z|)
(Intercept)         -0.5121     0.4775  -1.073    0.283
Survey_repetitions   0.9397     0.2020   4.652 3.29e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 157.31  on 299  degrees of freedom
Residual deviance: 104.63  on 298  degrees of freedom
AIC: 108.63

Number of Fisher Scoring iterations: 8
```

Expected number of repetitions to achieve a 90% probability of detecting *E. perotis* at least once:

2.9

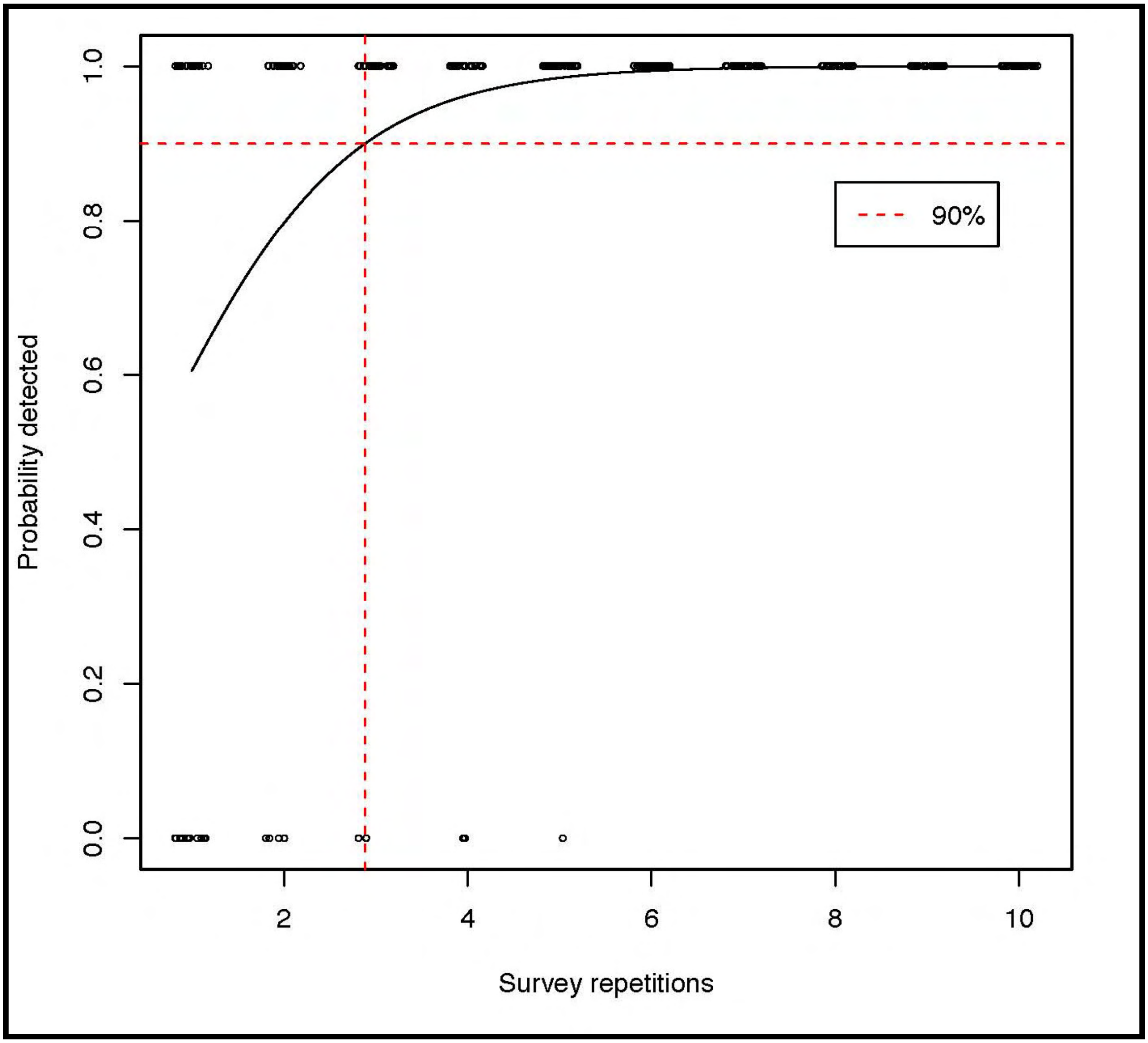

Figure AIV.3. Random survey effort and detection probability for *Eumops perotis*

IV.4. Western red bat, *Lasiurus blossevillii*

L. blossevillii, Model Selection

Analysis of Deviance Table

```
Model 1: L_blossevillii_detected ~ 1
Model 2: L_blossevillii_detected ~ Survey_repetitions
  Resid. Df Resid. Dev  Df Deviance
1       299     332.94
2       298     220.21   1   112.72
> AIC(GLMLABL1,GLMLABL)
         df      AIC
GLMLABL1  1 334.9351
```

```
GLMLABL   2 224.2135
```

Select the full model

L. blossevillii, Terms of selected model

```
glm(formula = L_blossevillii_detected ~ Survey_repetitions, family =
binomial)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-3.1758   0.1015   0.2527   0.6093   1.7989

Coefficients:
                   Estimate Std. Error z value Pr(>|z|)
(Intercept)        -1.62684    0.33176  -4.904 9.41e-07 ***
Survey_repetitions  0.22976    0.02972   7.732 1.06e-14 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 332.94  on 299  degrees of freedom
Residual deviance: 220.21  on 298  degrees of freedom
AIC: 224.21

Number of Fisher Scoring iterations: 6
```

Expected number of repetitions to achieve a 90% probability of detecting *L. blossevillii* at least once: 16.6

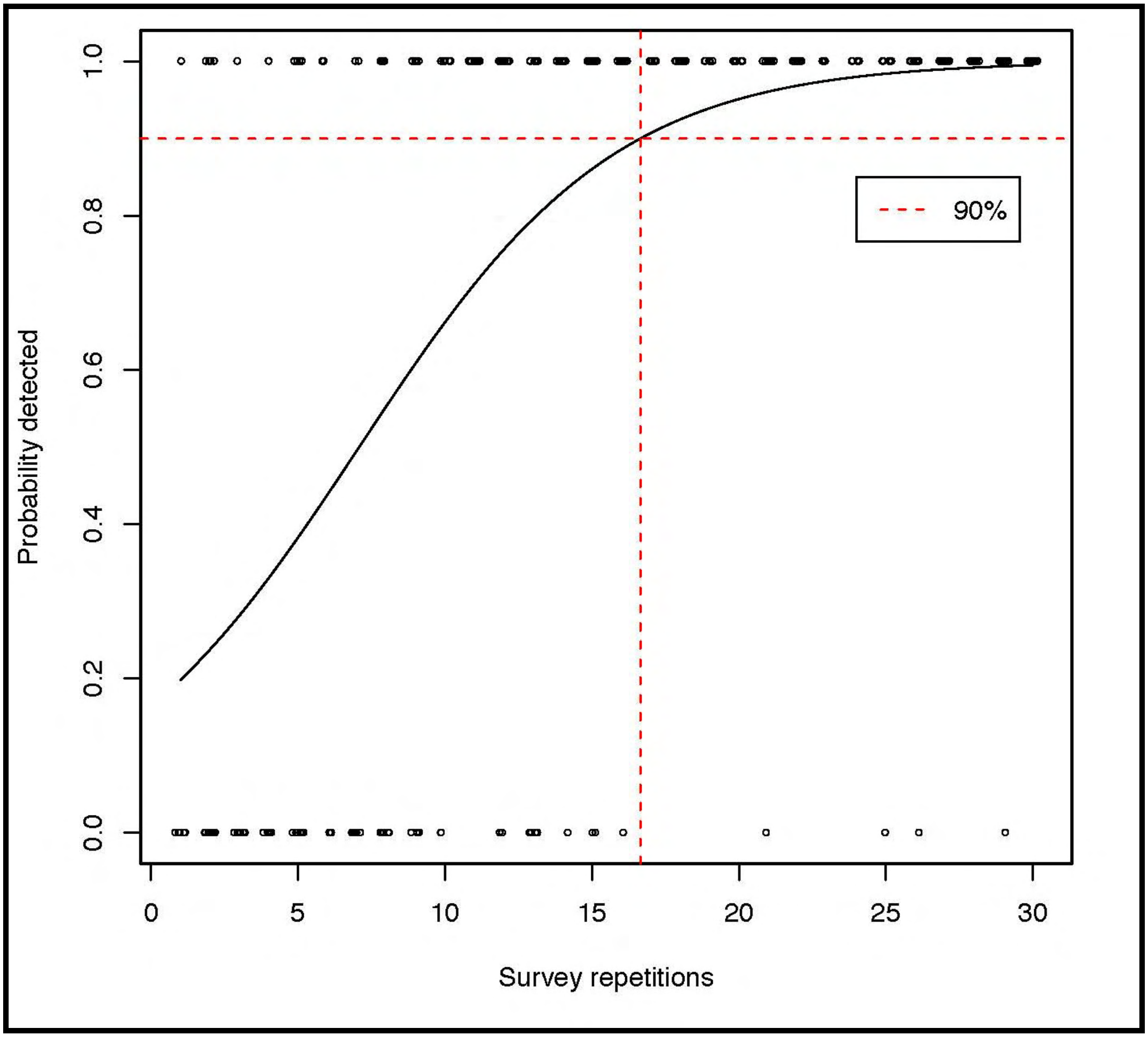

Figure AIV.4. Random survey effort and detection probability for *Lasiurus blossevillii*

IV.5. Hoary bat, *Lasiurus cinereus*

L. cinereus, Model Selection

Analysis of Deviance Table

```
Model 1: L_cinereus_detected ~ 1
Model 2: L_cinereus_detected ~ Survey_repetitions
  Resid. Df Resid. Dev  Df Deviance
1       299    162.331
2       298     99.074   1   63.257
> AIC(GLMLACI1,GLMLACI)
         df      AIC
```

```
GLMLACI1  1 164.3311
GLMLACI   2 103.0736
```

Select the full model

L. cinereus, Terms of selected model

```
glm(formula = L_cinereus_detected ~ Survey_repetitions, family =
binomial)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-2.24973   0.01401   0.07629   0.23475   1.09895

Coefficients:
                   Estimate Std. Error z value Pr(>|z|)
(Intercept)         -0.9428     0.5127  -1.839    0.066 .
Survey_repetitions   1.1302     0.2402   4.706 2.53e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 162.331  on 299  degrees of freedom
Residual deviance:  99.074  on 298  degrees of freedom
AIC: 103.07

Number of Fisher Scoring iterations: 8
```

Expected number of repetitions to achieve a 90% probability of detecting *L. cinereus* at least once: 2.8

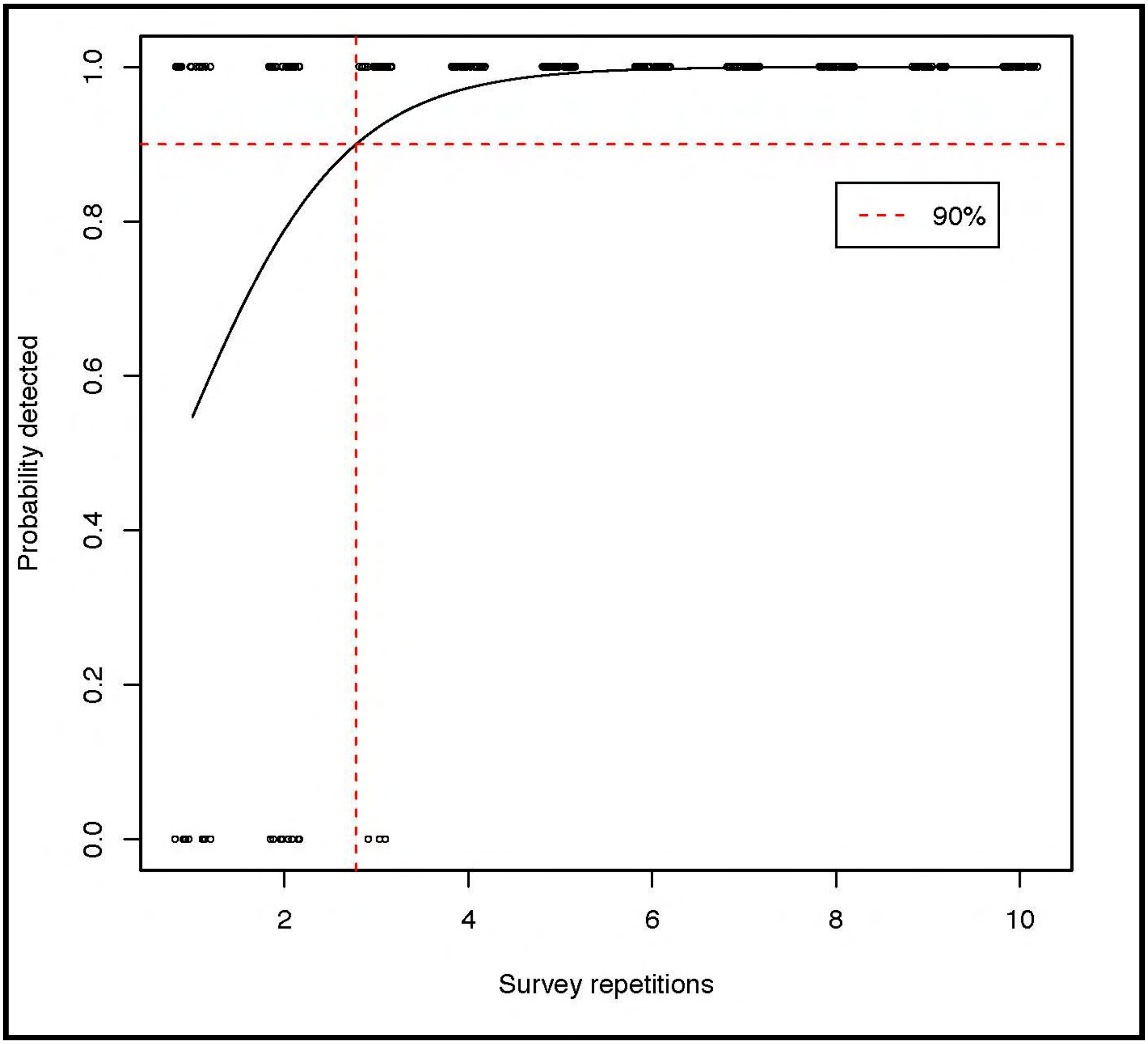

Figure AIV.5. Random survey effort and dtection probability for *Lasiurus cinereus*

IV.6. M40 *Myotis ciliolabrum*, *Myotis lucifugus*, and *Myotis volans*

M40, Model Selection

Analysis of Deviance Table

```
Model 1: M40_detected ~ 1
Model 2: M40_detected ~ Survey_repetitions
  Resid. Df Resid. Dev  Df Deviance
1       299     231.83
2       298     128.20   1   103.64
> AIC(GLMM401,GLMM40)
        df      AIC
GLMM401  1 233.8320
```

```
GLMM40   2 132.1956
```

Select the full model

***M40*, Terms of selected model**

```
glm(formula = M40_detected ~ Survey_repetitions, family = binomial)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-2.46170   0.02002   0.08925   0.31472   1.62795

Coefficients:
                   Estimate Std. Error z value Pr(>|z|)
(Intercept)        -1.37951    0.40139  -3.437 0.000589 ***
Survey_repetitions  0.36333    0.05725   6.347 2.20e-10 ***
---
Signif. Codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 231.83  on 299  degrees of freedom
Residual deviance: 128.20  on 298  degrees of freedom
AIC: 132.20

Number of Fisher Scoring iterations: 7
```

Expected number of repetitions to achieve a 90% probability of detecting *M40* at least once:

9.8

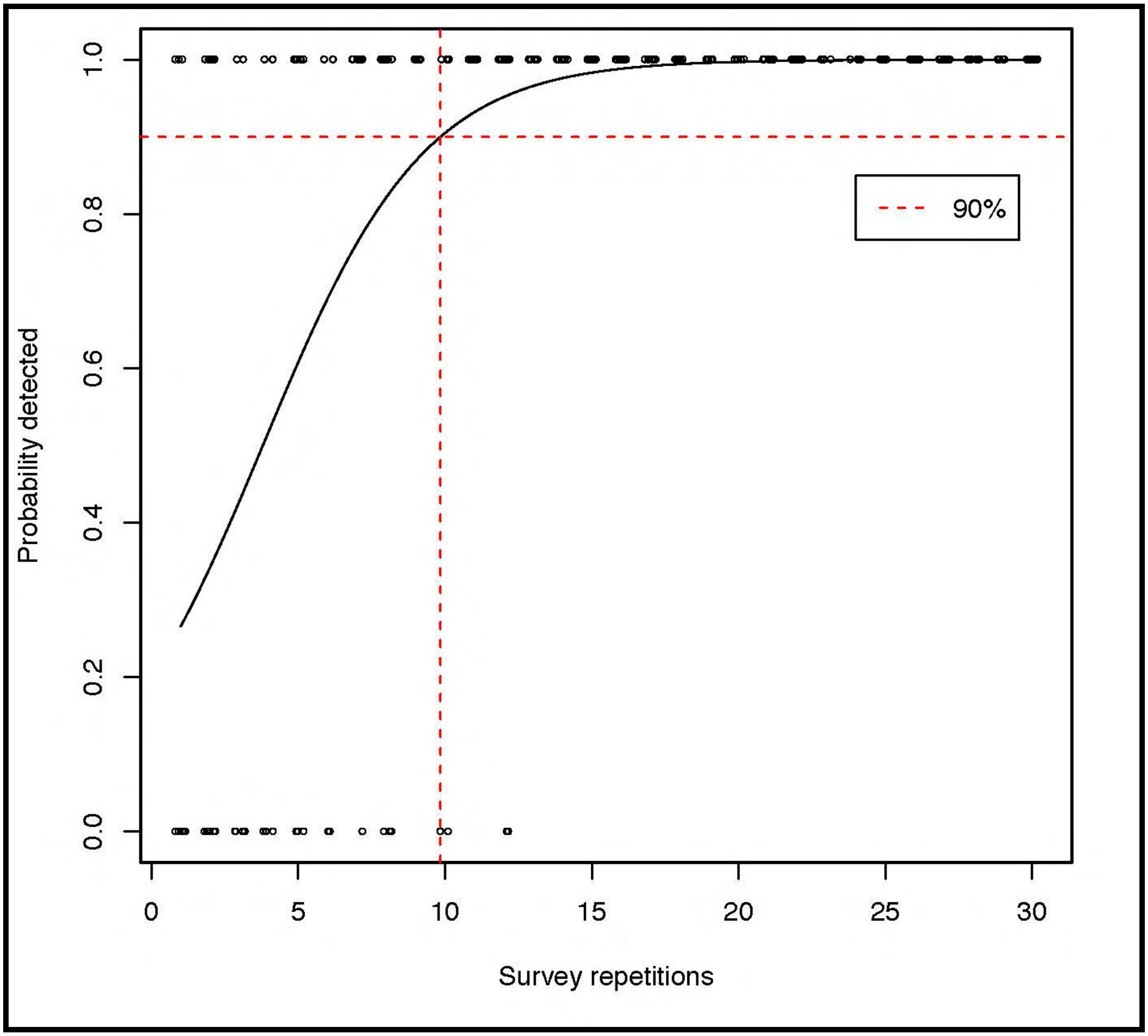

Figure AIV.6. Random survey effort and detection probability for M40 (*Myotis ciliolabrum*, *Myotis lucifugus*, and *Myotis volans*)

IV.7 M50 – *Myotis californicus* and *Myotis yumanensis*

M50, Model Selection

Analysis of Deviance Table

```
Model 1: M50_detected ~ 1
Model 2: M50_detected ~ Survey_repetitions
  Resid. Df Resid. Dev  Df Deviance
1       299     94.321
2       298     58.549   1   35.772
> AIC(GLMM501,GLMM50)
        df      AIC
```

```
GLMM501  1 96.32116
GLMM50   2 62.54887
```

Select the full model

M50, Terms of selected model

```
glm(formula = M50_detected ~ Survey_repetitions, family = binomial)

Deviance Residuals:
      Min         1Q     Median         3Q        Max
-2.599080   0.004896   0.036071   0.136295   0.905424

Coefficients:
                   Estimate Std. Error z value Pr(>|z|)
(Intercept)          0.2361     0.5439   0.434 0.664224
Survey_repetitions   0.4438     0.1323   3.355 0.000793 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 94.321  on 299  degrees of freedom
Residual deviance: 58.549  on 298  degrees of freedom
AIC: 62.549

Number of Fisher Scoring iterations: 9
```

Expected number of repetitions to achieve a 90% probability of detecting *M50* at least once: 4.4

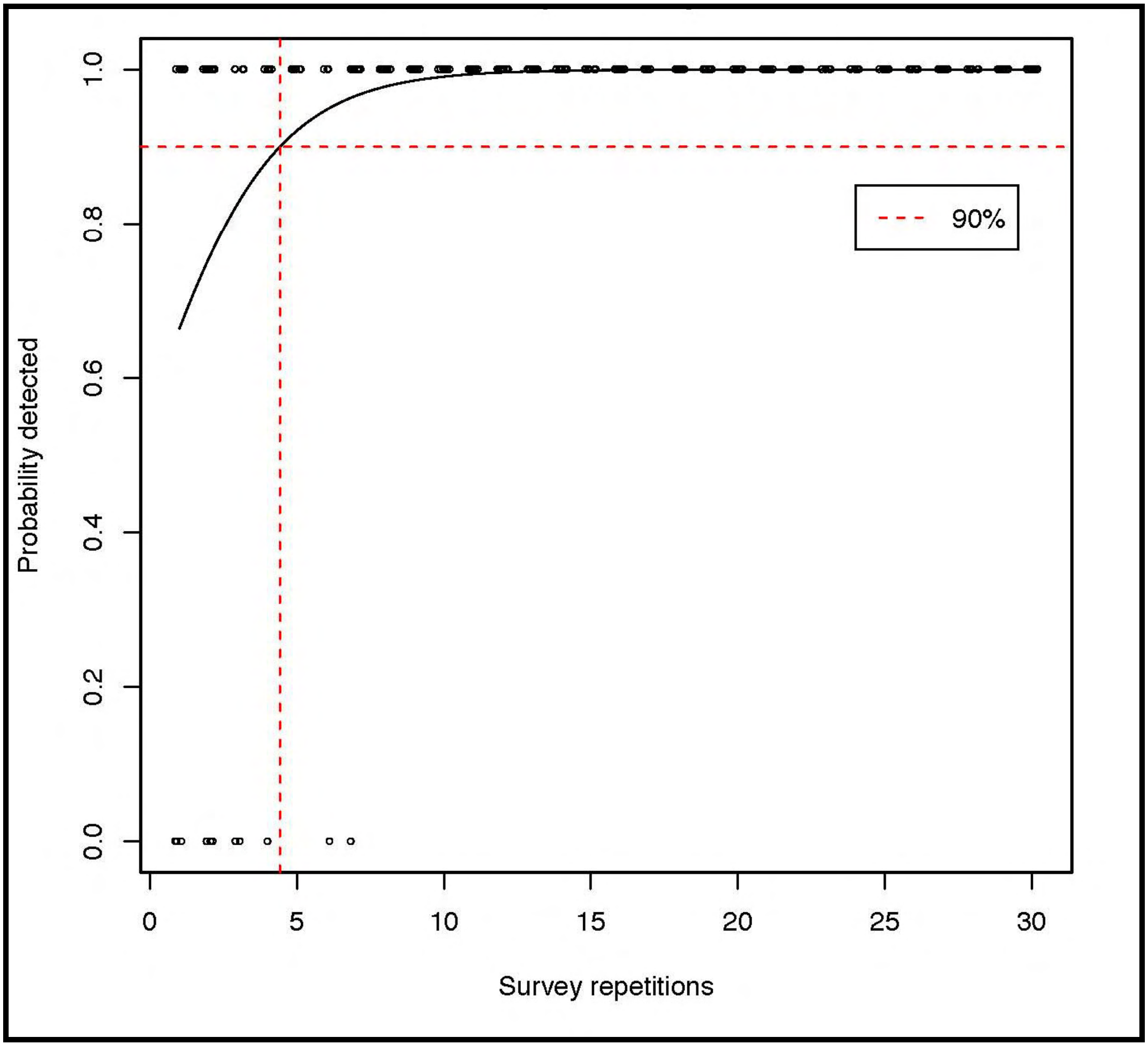

Figure AIV.7. Random survey effort and detection probability for M50 (*Myotis californicus* and *Myotis yumanensis*)

IV.8. Long-eared myotis, *Myotis evotis*

M. evotis, Model Selection

Analysis of Deviance Table

```
Model 1: M_evotis_detected ~ 1
Model 2: M_evotis_detected ~ Survey_repetitions
  Resid. Df Resid. Dev  Df Deviance
1       299    195.050
```

```
2       298     96.908   1   98.142
> AIC(GLMMYEV1,GLMMYEV)
         df      AIC
GLMMYEV1  1 197.0498
GLMMYEV   2 100.9079
```

Select the full model

M. evotis, Terms of selected model

```
glm(formula = M_evotis_detected ~ Survey_repetitions, family =
binomial)

Deviance Residuals:
      Min         1Q     Median         3Q        Max
-3.465785   0.004161   0.024807   0.158822   1.548700

Coefficients:
                   Estimate Std. Error z value Pr(>|z|)
(Intercept)        -1.13808    0.43244  -2.632   0.0085 **
Survey_repetitions  0.14878    0.02969   5.011  5.4e-07 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 195.050  on 299  degrees of freedom
Residual deviance:  96.908  on 298  degrees of freedom
AIC: 100.91

Number of Fisher Scoring iterations: 8
```

Expected number of repetitions to achieve a 90% probability of detecting *M. evotis* at least once:

22.4

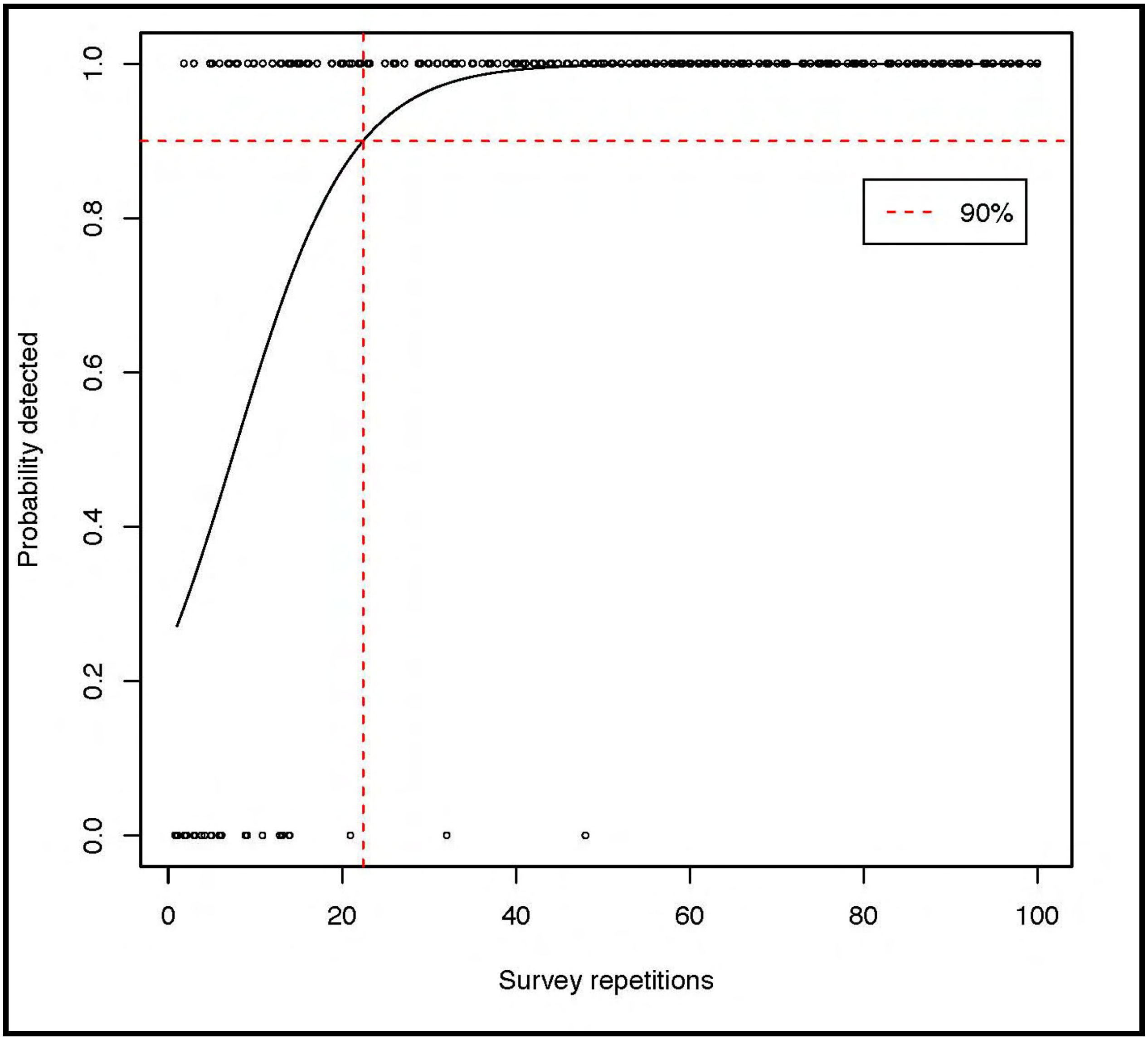

Figure AIV.8. Random survey effort and detection probability for *Myotis evotis*

IV.9. Fringed myotis, *Myotis thysanodes*

M. thysanodes, Model Selection

Analysis of Deviance Table

```
Model 1: M_thysanodes_detected ~ 1
Model 2: M_thysanodes_detected ~ Survey_repetitions
  Resid. Df Resid. Dev  Df Deviance
1       299     207.91
2       298     100.22   1   107.68
> AIC(GLMMYTH1,GLMMYTH)
         df      AIC
GLMMYTH1  1 209.9092
```

```
GLMMYTH   2 104.2248
```

Select the full model

***M. thysanodes*, Terms of selected model**

```
glm(formula = M_thysanodes_detected ~ Survey_repetitions, family =
binomial)

Deviance Residuals:
      Min         1Q     Median         3Q        Max
-2.467278   0.004185   0.026030   0.149654   1.635149

Coefficients:
                   Estimate Std. Error z value Pr(>|z|)
(Intercept)        -1.33044    0.43358  -3.068  0.00215 **
Survey_repetitions  0.14915    0.02851   5.231 1.68e-07 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 207.91  on 299  degrees of freedom
Residual deviance: 100.22  on 298  degrees of freedom
AIC: 104.22

Number of Fisher Scoring iterations: 8
```

Expected number of repetitions to achieve a 90% probability of detecting *M. thysanodes* at least once: 23.7

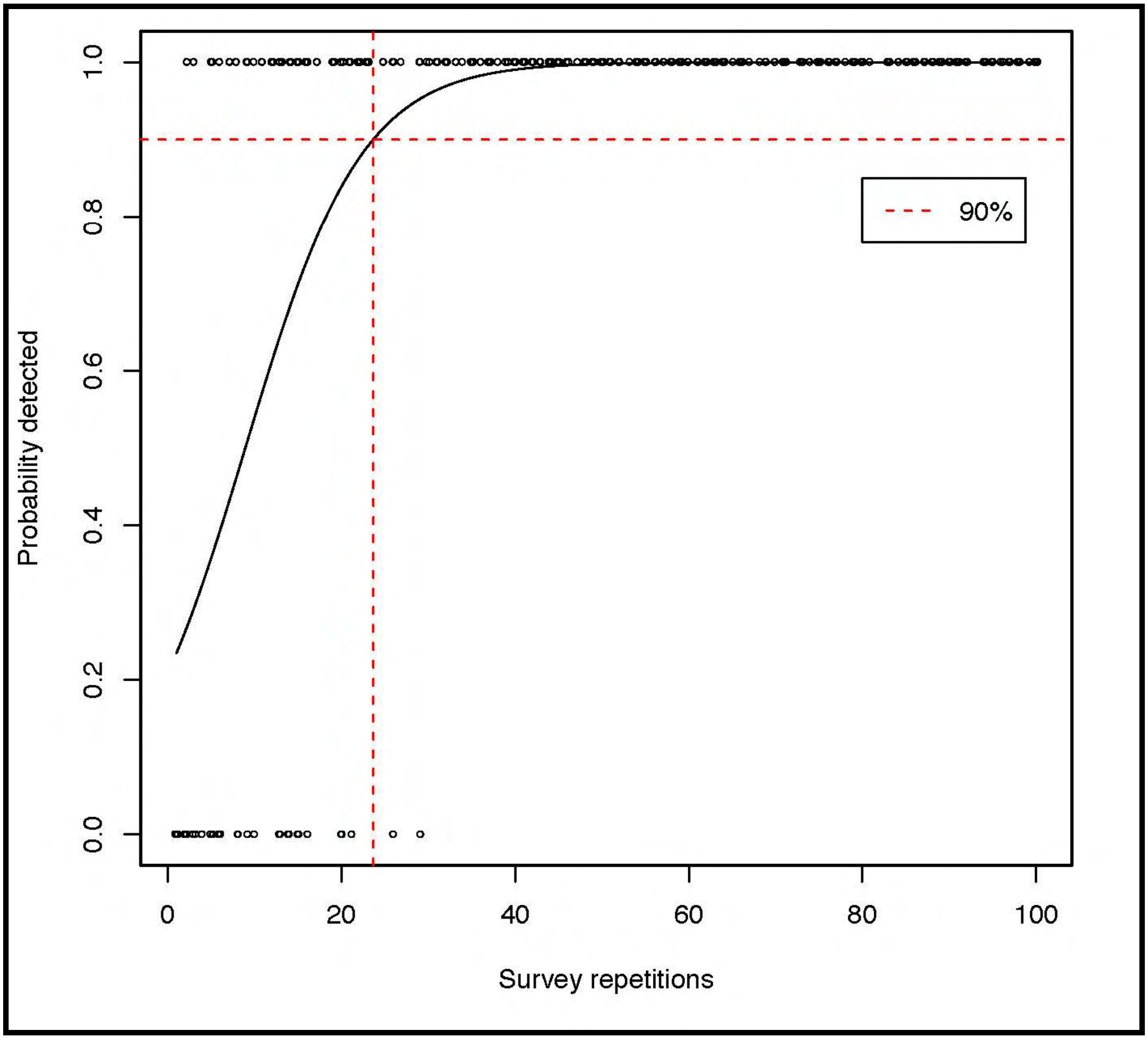

Figure AIV.9. Random survey effort and detection probability for *Myotis thysanodes*

IV.10. Western pipistrelle, *Parastrellus hesperus*

P. hesperus, Model Selection

Analysis of Deviance Table

```
Model 1: P_hesperus_detected ~ 1
Model 2: P_hesperus_detected ~ Survey_repetitions
  Resid. Df Resid. Dev  Df Deviance
1       299    257.069
2       298    194.814   1   62.255
> AIC(GLMPAHE1,GLMPAHE)
         df      AIC
GLMPAHE1  1 259.0687
```

```
GLMPAHE   2 198.8139
```

Select the full model

***P.hesperus*, Terms of selected model**

```
glm(formula = P_hesperus_detected ~ Survey_repetitions, family =
binomial)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-3.1074   0.1268   0.2672   0.5506   1.2893

Coefficients:
                   Estimate Std. Error z value Pr(>|z|)
(Intercept)        -0.44748    0.31336  -1.428    0.153
Survey_repetitions  0.18812    0.03042   6.185 6.21e-10 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 257.07  on 299  degrees of freedom
Residual deviance: 194.81  on 298  degrees of freedom
AIC: 198.81

Number of Fisher Scoring iterations: 6
```

Expected number of repetitions to achieve a 90% probability of detecting *P. hesperus* at least once: 14.1

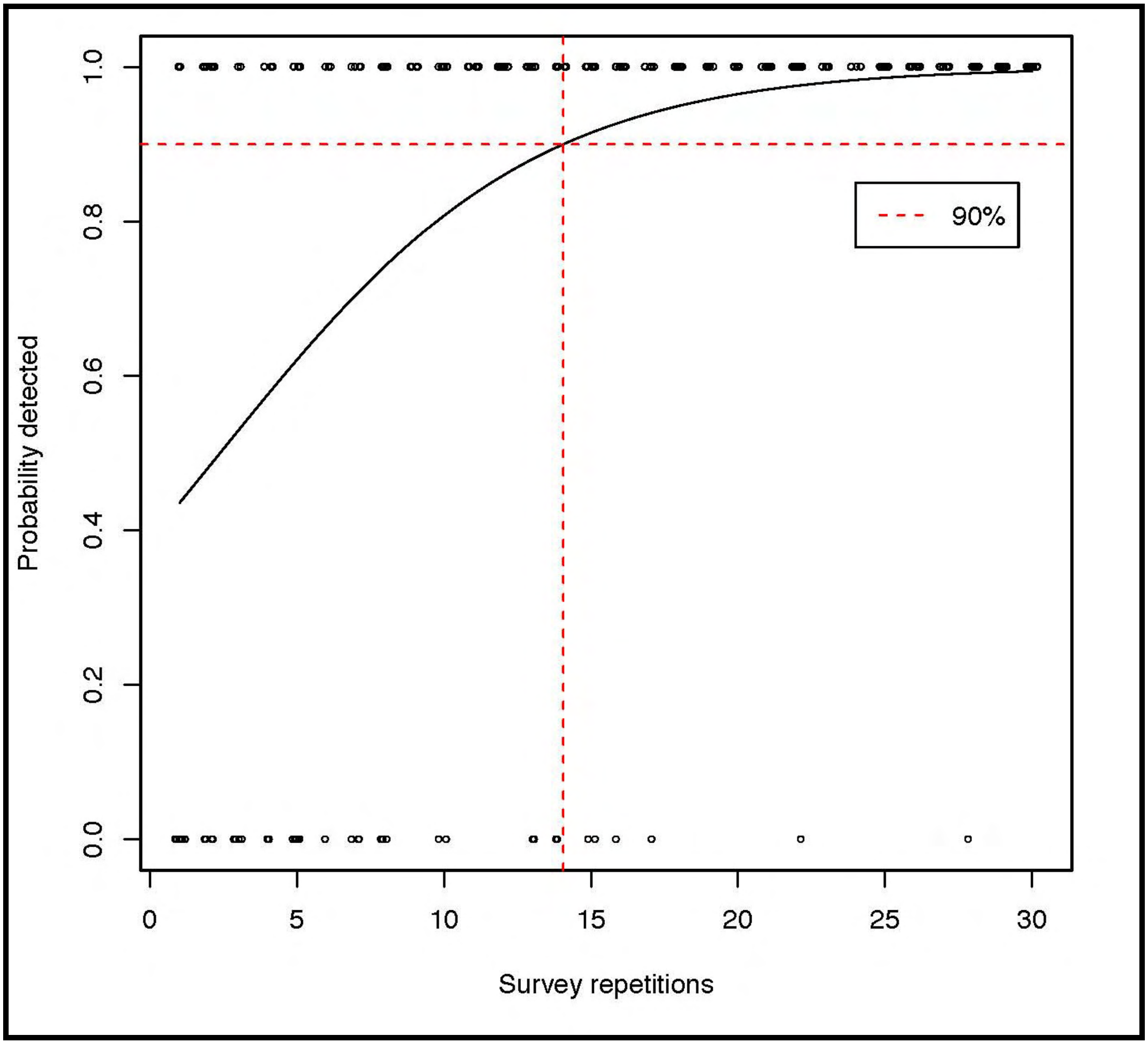

Figure AIV.10. Random survey effort and detection probability for *Parastrellus hesperus*

IV.11. Q25 – *Eptesicus fuscus*, *Lasionycteris noctivagans*, and *Tadarida brasiliensis*

Q25, Model Selection

Analysis of Deviance Table

```
Model 1: Q25_detected ~ 1
Model 2: Q25_detected ~ Survey_repetitions
  Resid. Df Resid. Dev  Df Deviance
1       299     50.860
2       298     37.865   1   12.994
```

```
> AIC(GLMQ251,GLMQ25)
        df      AIC
GLMQ251  1 52.85965
GLMQ25   2 41.86521
```

Select the full model

Q25, Terms of selected model

```
glm(formula = Q25_detected ~ Survey_repetitions, family = binomial)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-2.89508   0.01364   0.03787   0.17465   0.47334

Coefficients:
                   Estimate Std. Error z value Pr(>|z|)
(Intercept)          1.1110     0.8989   1.236   0.2165
Survey_repetitions   1.0215     0.4702   2.172   0.0298 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 50.860  on 299  degrees of freedom
Residual deviance: 37.865  on 298  degrees of freedom
AIC: 41.865

Number of Fisher Scoring iterations: 9
```

Expected number of repetitions to achieve a 90% probability of detecting *Q25* at least once: 1.1

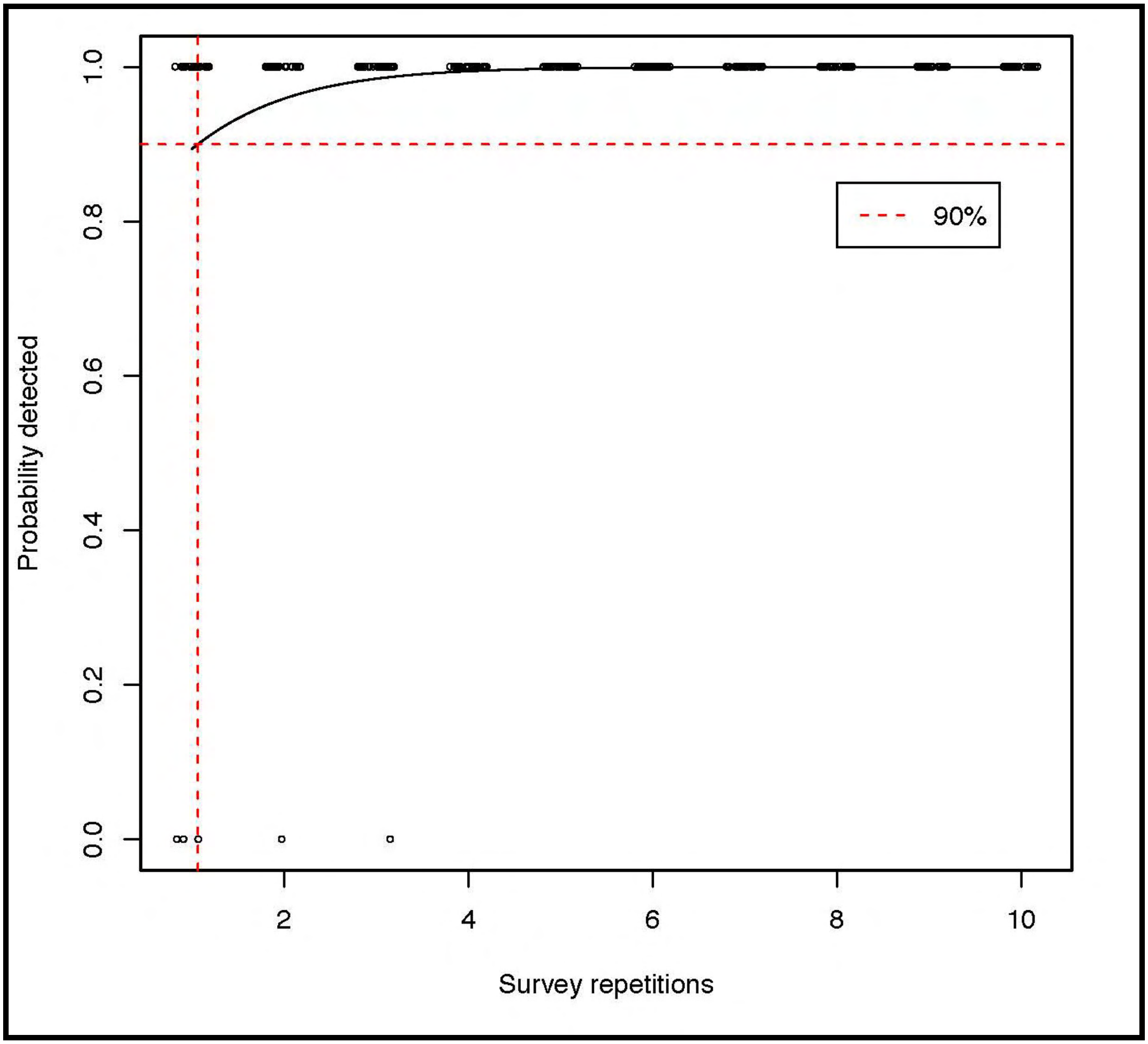

Figure AIV.11. Random survey effort and detection probability for Q25 (*Eptesicus fuscus*, *Lasionycteris noctivagans*, and *Tadarida brasiliensis*)

IV.12. Mexican free-tailed bat, *Tadarida brasiliensis*

T. brasiliensis, Model Selection

Analysis of Deviance Table

```
Model 1: T_brasiliensis_detected ~ 1
Model 2: T_brasiliensis_detected ~ Survey_repetitions
  Resid. Df Resid. Dev  Df Deviance
1       299    100.766
```

```
2       298     77.002   1   23.764
> AIC(GLMTABR1,GLMTABR)
         df       AIC
GLMTABR1  1 102.76649
GLMTABR   2  81.00237
```

Select the full model

T. brasiliensis, Terms of selected model

```
glm(formula = T_brasiliensis_detected ~ Survey_repetitions, family =
binomial)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-3.20345   0.05159   0.10888   0.33041   0.66868

Coefficients:
                   Estimate Std. Error z value Pr(>|z|)
(Intercept)          0.6360     0.5550   1.146 0.251863
Survey_repetitions   0.7482     0.2192   3.413 0.000643 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 100.766  on 299  degrees of freedom
Residual deviance:  77.002  on 298  degrees of freedom
AIC: 81.002

Number of Fisher Scoring iterations: 8
```

Expected number of repetitions to achieve a 90% probability of detecting *T. brasiliensis* at least once: 2.1

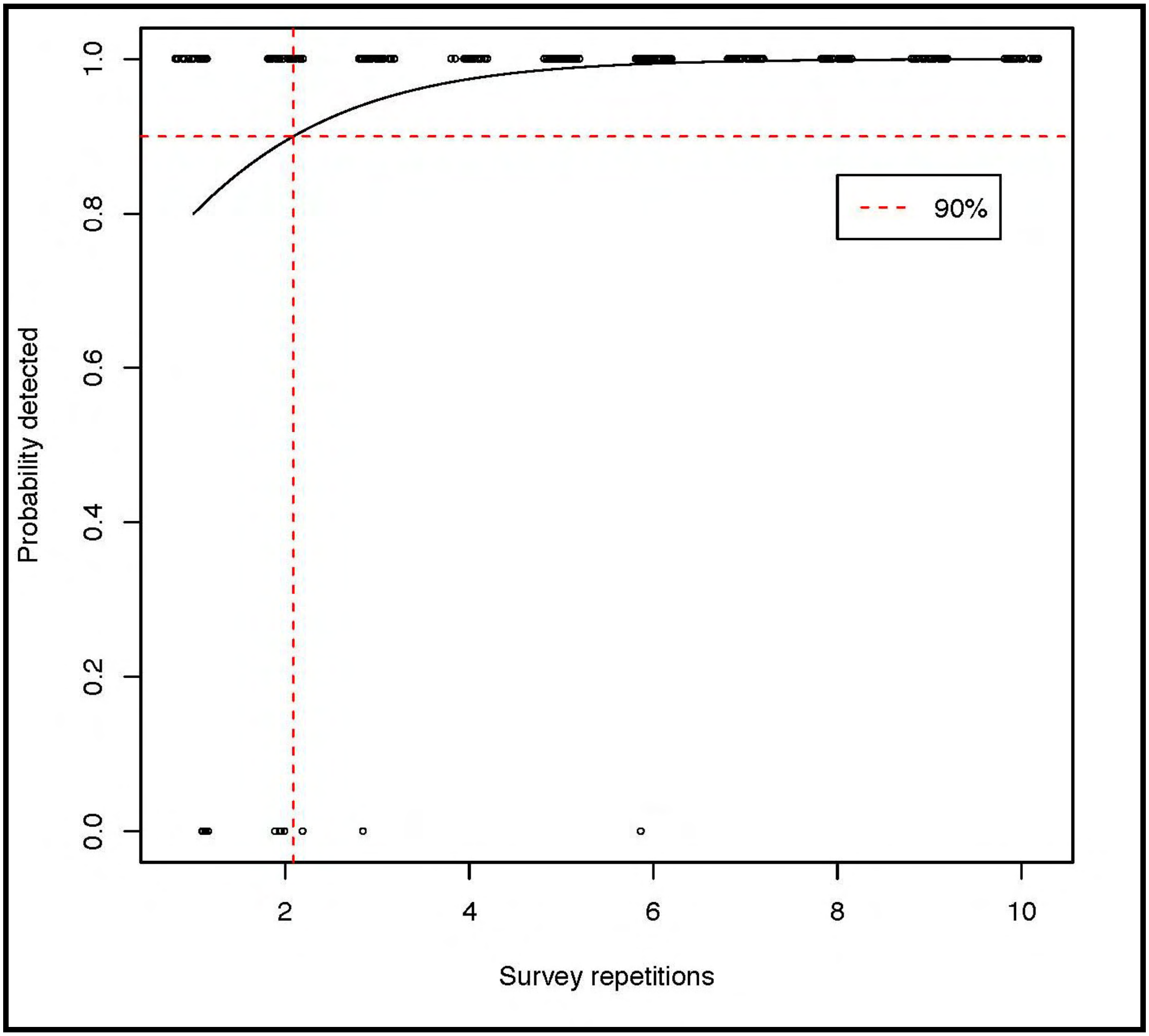

Figure AIV.12. Random survey effort and detection probability for *Tadarida brasiliensis*

APPENDIX V. Trial 3, Meadow Center-Edge Comparison in Six Lower Elevation Meadows

---

V.1. Spotted bat, *Euderma maculatum*

```
> mean(Euderma_maculatum,na.rm=TRUE)
[1] 30.05226
> mean(Euderma_maculatum[Habitat=="meadow"],na.rm=TRUE)
[1] 22.89477
> mean(Euderma_maculatum[Habitat=="edge"],na.rm=TRUE)
[1] 37.20975

Models:
GLMEREUMA1: Euderma_maculatum ~ 1 + (1 | Location)
GLMEREUMA2: Euderma_maculatum ~ Habitat + (1 | Location)
GLMEREUMA3: Euderma_maculatum ~ Habitat * Day + (1 | Location)
GLMEREUMA4: Euderma_maculatum ~ Habitat + (Day | Location)
GLMEREUMA5: Euderma_maculatum ~ Habitat * Day + (Day | Location)
           Df    AIC    BIC logLik  Chisq Chi Df Pr(>Chisq)
GLMEREUMA1  2 140525 140537 -70261
GLMEREUMA2  3 135653 135671 -67823 4874.4      1     <2e-16 ***
GLMEREUMA3  5 136621 136650 -68305    0.0      2          1
GLMEREUMA4  5 133963 133993 -66977 2657.5      0     <2e-16 ***
GLMEREUMA5  7 134084 134126 -67035    0.0      2          1
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
>
> # select the minimum adequate model
>
> GLMEREUMA4
```

Selection by AIC indicates that a partial model, with all considered random effects, but only habitat as a fixed effect is the minimum adequate model. Retention of only habitat as a fixed effect indicates that day is not important for explaining activity levels, nor does the effect of habitat change with day. Retention of both random effects indicates that both day and location have grouping that contributes to model information.

```
Generalized linear mixed model fit by the Laplace approximation
Formula: Euderma_maculatum ~ Habitat + (Day | Location)
   Data: YNPbats
    AIC    BIC logLik deviance
 133963 133993 -66977   133953
Random effects:
 Groups   Name        Variance   Std.Dev.  Corr
 Location (Intercept) 1.2038e+00 1.0971683
          Day         4.1688e-06 0.0020418 -0.377
Number of obs: 2832, groups: Location, 6

Fixed effects:
               Estimate Std. Error z value Pr(>|z|)
(Intercept)    3.178694   0.414983    7.66 1.86e-14 ***
Habitatmeadow -0.485703   0.007059  -68.81  < 2e-16 ***
```

```
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr)
Habitatmedw -0.006
```

There is no significant change in overall activity level. These data indicate a preference for edges that is consistent with season, by *Euderma maculatum* (see Figure AV.1).

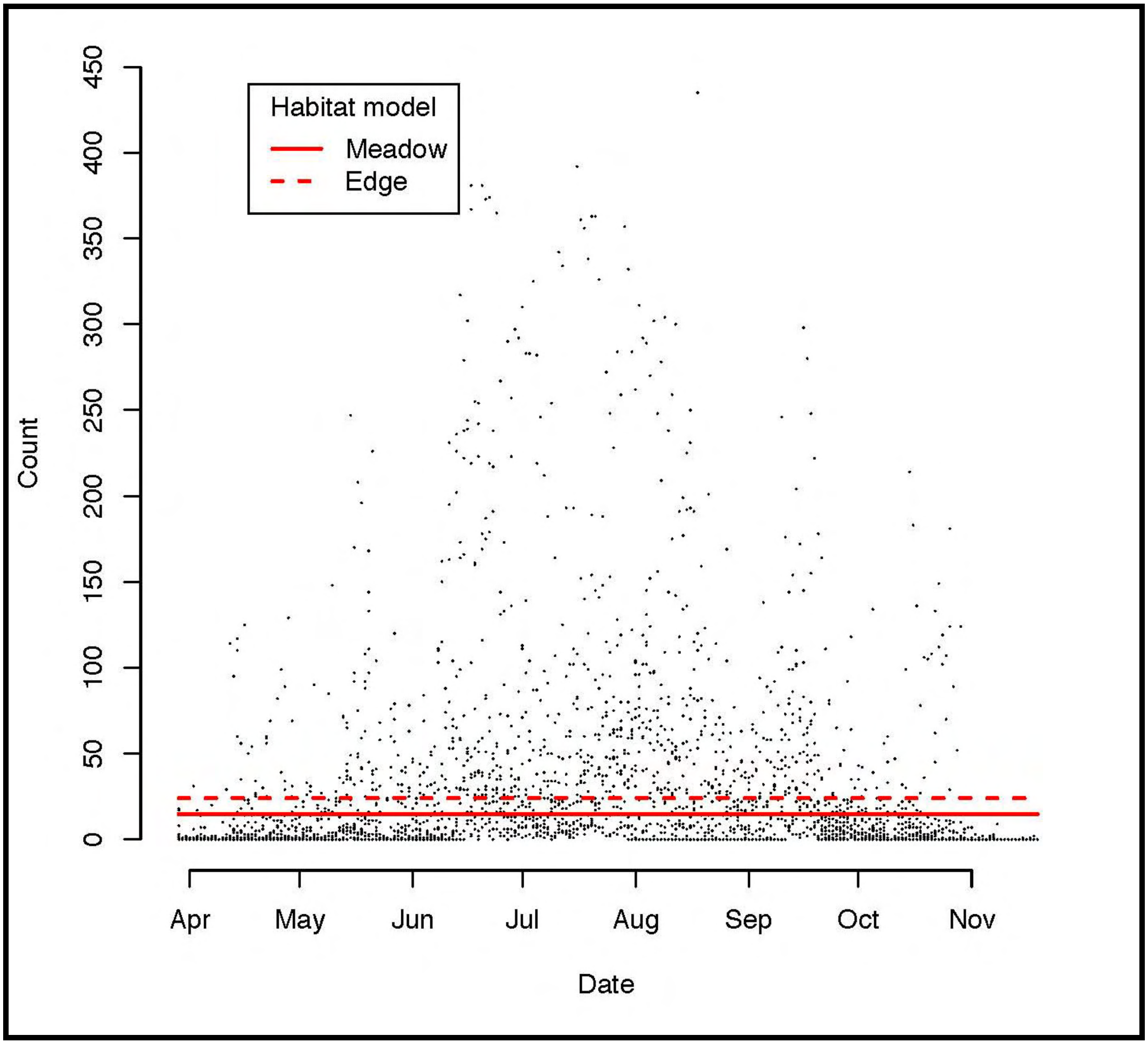

Figure AV.1. Seasonal habitat preference by *Euderma maculatum*

V.2. Western mastiff bat, *Eumops perotis*

```
> mean(Eumops_perotis,na.rm=TRUE)
[1] 81.40501
> mean(Eumops_perotis[Habitat=="meadow"],na.rm=TRUE)
[1] 90.85381
> mean(Eumops_perotis[Habitat=="edge"],na.rm=TRUE)
[1] 71.95621

Models:
GLMEREUPE1: Eumops_perotis ~ 1 + (1 | Location)
GLMEREUPE2: Eumops_perotis ~ Habitat + (1 | Location)
GLMEREUPE3: Eumops_perotis ~ Habitat * Day + (1 | Location)
GLMEREUPE4: Eumops_perotis ~ Habitat + (Day | Location)
GLMEREUPE5: Eumops_perotis ~ Habitat * Day + (Day | Location)
           Df    AIC    BIC  logLik    Chisq Chi Df Pr(>Chisq)
GLMEREUPE1  2  307088  307100 -153542
GLMEREUPE2  3  303977  303995 -151985 3112.968      1  < 2.2e-16 ***
GLMEREUPE3  5  299606  299636 -149798 4374.939      2  < 2.2e-16 ***
GLMEREUPE4  5  293365  293395 -146678 6240.427      0  < 2.2e-16 ***
GLMEREUPE5  7  293308  293350 -146647   61.498      2  4.426e-14 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
>
> # select the minimum adequate model
>
> GLMEREUPE5
```

Selection by AIC indicates that the full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that habitat and day are both important for explaining activity levels, and the interaction term indicates that the effect of habitat changes with day. Retention of both random effects indicates that both day and location have grouping that contributes to model information.

```
Generalized linear mixed model fit by the Laplace approximation
Formula: Eumops_perotis ~ Habitat * Day + (Day | Location)
   Data: YNPbats
    AIC    BIC  logLik deviance
 293308 293350 -146647   293294
Random effects:
 Groups   Name        Variance   Std.Dev.  Corr
 Location (Intercept) 1.2983e+00 1.1394410
          Day         1.0981e-05 0.0033137 -0.897
Number of obs: 2832, groups: Location, 6

Fixed effects:
                    Estimate Std. Error z value Pr(>|z|)
(Intercept)        3.578e+00  4.652e-01   7.691 1.46e-14 ***
Habitatmeadow      1.735e-01  8.947e-03  19.392  < 2e-16 ***
Day                3.272e-03  1.354e-03   2.417   0.0157 *
Habitatmeadow:Day 4.649e-04  6.163e-05   7.543 4.59e-14 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) Hbttmd Day
```

```
Habitatmedw -0.011
Day         -0.897  0.022
Habttmdw:Dy  0.009 -0.883 -0.025
```

There is a significant increase in activity as the season progresses into fall. These data indicate a preference for meadows that increases into fall, by *Eumops perotis* (see Figure AV.2).

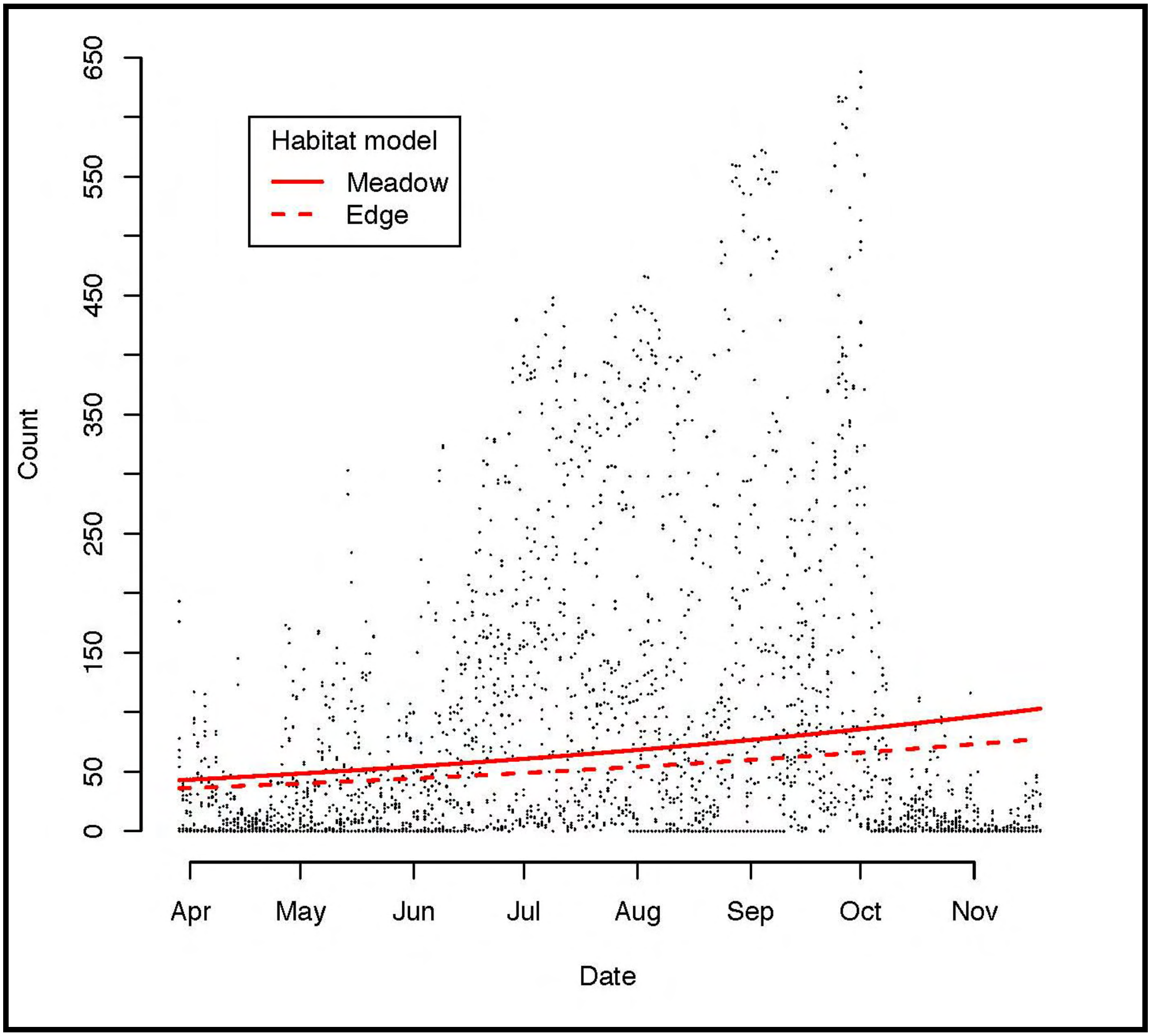

Figure AV.2. Seasonal habitat preference by *Eumops perotis*

V.3. Hoary bat, *Lasiurus cinereus*

```
> mean(Lasiurus_cinereus,na.rm=TRUE)
[1] 14.15466
```

```
> mean(Lasiurus_cinereus[Habitat=="meadow"],na.rm=TRUE)
[1] 15.25141
> mean(Lasiurus_cinereus[Habitat=="edge"],na.rm=TRUE)
[1] 13.05791
```

```
Models:
GLMERLACI1: Lasiurus_cinereus ~ 1 + (1 | Location)
GLMERLACI2: Lasiurus_cinereus ~ Habitat + (1 | Location)
GLMERLACI3: Lasiurus_cinereus ~ Habitat * Day + (1 | Location)
GLMERLACI4: Lasiurus_cinereus ~ Habitat + (Day | Location)
GLMERLACI5: Lasiurus_cinereus ~ Habitat * Day + (Day | Location)
           Df   AIC   BIC logLik   Chisq Chi Df Pr(>Chisq)
GLMERLACI1  2 82283 82295 -41140
GLMERLACI2  3 82044 82062 -41019 240.905      1  < 2.2e-16 ***
GLMERLACI3  5 81547 81576 -40768 501.427      2  < 2.2e-16 ***
GLMERLACI4  5 80812 80842 -40401 734.831      0  < 2.2e-16 ***
GLMERLACI5  7 80764 80806 -40375  51.699      2   5.94e-12 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
>
> # select the minimum adequate model
>
> GLMERLACI5
```

Selection by AIC indicates that the full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that habitat and day are both important for explaining activity levels, and the interaction term indicates that the effect of habitat changes with day. Retention of both random effects indicates that both day and location have grouping that contributes to model information.

```
Generalized linear mixed model fit by the Laplace approximation
Formula: Lasiurus_cinereus ~ Habitat * Day + (Day | Location)
   Data: YNPbats
   AIC   BIC logLik deviance
 80764 80806 -40375    80750
Random effects:
 Groups   Name        Variance   Std.Dev.  Corr
 Location (Intercept) 3.2477e-01 0.5698867
          Day         5.2655e-06 0.0022947 -0.763
Number of obs: 2832, groups: Location, 6

Fixed effects:
                   Estimate Std. Error z value Pr(>|z|)
(Intercept)       2.3000569  0.2332138   9.862  < 2e-16 ***
Habitatmeadow     0.0260296  0.0211317   1.232    0.218
Day               0.0015195  0.0009435   1.610    0.107
Habitatmeadow:Day 0.0010211  0.0001472   6.937 4.02e-12 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) Hbttmd Day
Habitatmedw -0.047
Day         -0.763  0.072
```

```
Habttmdw:Dy  0.042 -0.880 -0.084
```

There is no significant change in overall activity level. While habitat alone shows no significant preference, the significant interaction term indicates that a slight preference for meadows, by *L. cinereus*, develops as the season progresses into fall (see Figure AV.3).

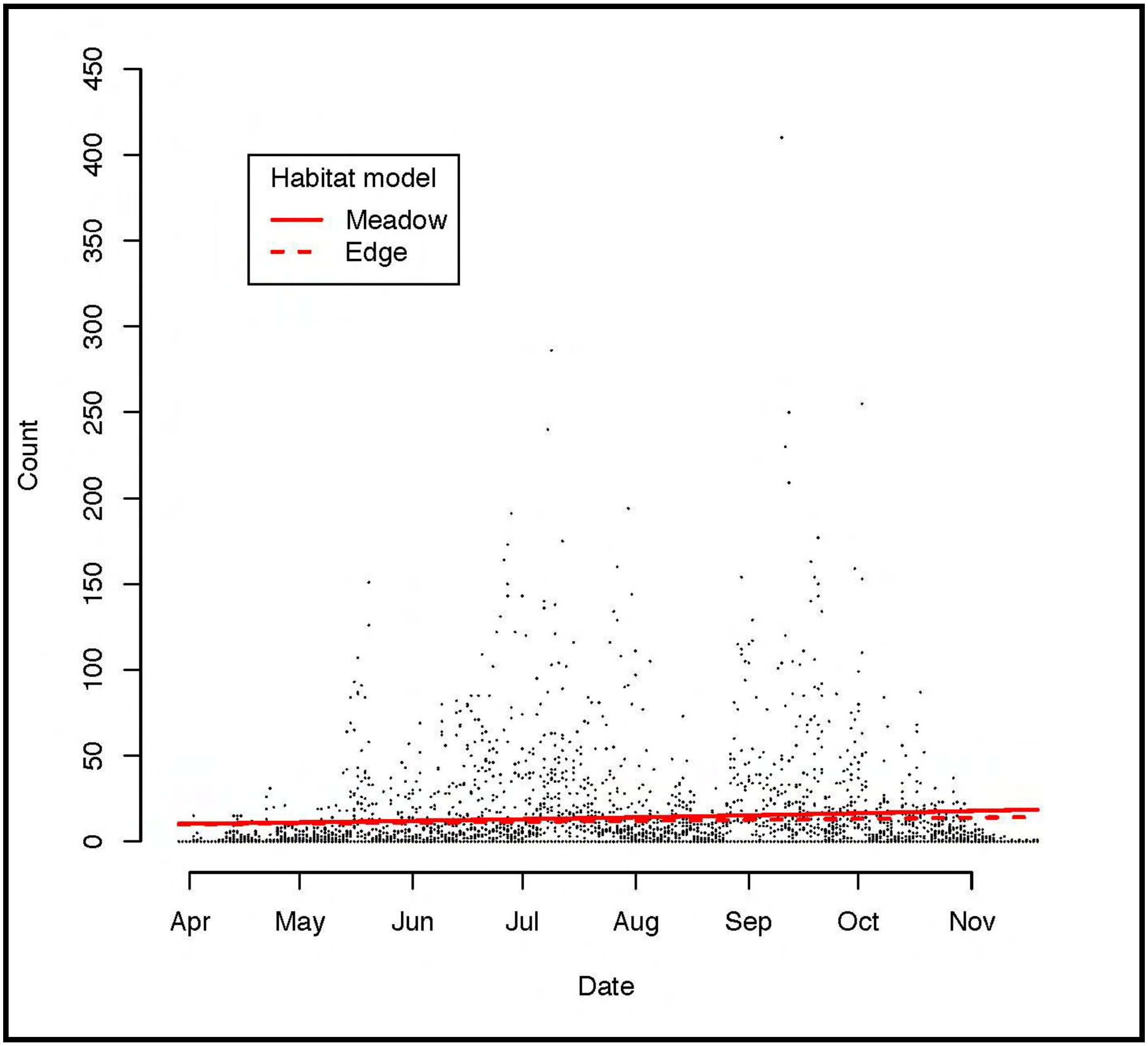

Figure AV.3. Seasonal habitat preference by *Lasiurus cinereus*

V.4. M40 *Myotis ciliolabrum*, *Myotis lucifugus*, and *Myotis volans*

```
> mean(M40,na.rm=TRUE)
[1] 0.4844633
> mean(M40[Habitat=="meadow"],na.rm=TRUE)
```

```
[1] 0.3227401
> mean(M40[Habitat=="edge"],na.rm=TRUE)
[1] 0.6461864

Models:
GLMERM401: M40 ~ 1 + (1 | Location)
GLMERM402: M40 ~ Habitat + (1 | Location)
GLMERM403: M40 ~ Habitat * Day + (1 | Location)
GLMERM404: M40 ~ Habitat + (Day | Location)
GLMERM405: M40 ~ Habitat * Day + (Day | Location)
          Df     AIC     BIC  logLik    Chisq Chi Df Pr(>Chisq)
GLMERM401  2  4312.5  4324.4 -2154.2
GLMERM402  3  4158.6  4176.4 -2076.3 155.8634      1  < 2.2e-16 ***
GLMERM403  5  4133.1  4162.8 -2061.5  29.5063      2  3.916e-07 ***
GLMERM404  5  4072.3  4102.1 -2031.2  60.7778      0  < 2.2e-16 ***
GLMERM405  7  4070.0  4111.6 -2028.0   6.3254      2    0.04231 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
>
> # select the minimum adequate model
>
> GLMERM405
```

Selection by AIC indicates that the full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that habitat and day are both important for explaining activity levels, and the interaction term indicates that the effect of habitat changes with day. Retention of both random effects indicates that both day and location have grouping that contributes to model information.

```
Generalized linear mixed model fit by the Laplace approximation
Formula: M40 ~ Habitat * Day + (Day | Location)
   Data: YNPbats
  AIC  BIC logLik deviance
 4070 4112  -2028     4056
Random effects:
 Groups   Name        Variance   Std.Dev.  Corr
 Location (Intercept) 1.0942e-01 0.3307830
          Day         8.6927e-06 0.0029483 0.268
Number of obs: 2832, groups: Location, 6

Fixed effects:
                    Estimate Std. Error z value Pr(>|z|)
(Intercept)       -0.1726851  0.1496849  -1.154  0.24864
Habitatmeadow     -0.7802713  0.1083113  -7.204 5.85e-13 ***
Day               -0.0039705  0.0013175  -3.014  0.00258 **
Habitatmeadow:Day  0.0007868  0.0008363   0.941  0.34681
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) Hbttmd Day
Habitatmedw -0.234
Day          0.076  0.176
Habttmdw:Dy  0.201 -0.849 -0.212
```

There is a significant decrease in activity as the season goes into fall. These data indicate a preference for edges, by M40. The preference weakens into fall (see Figure AV.4).

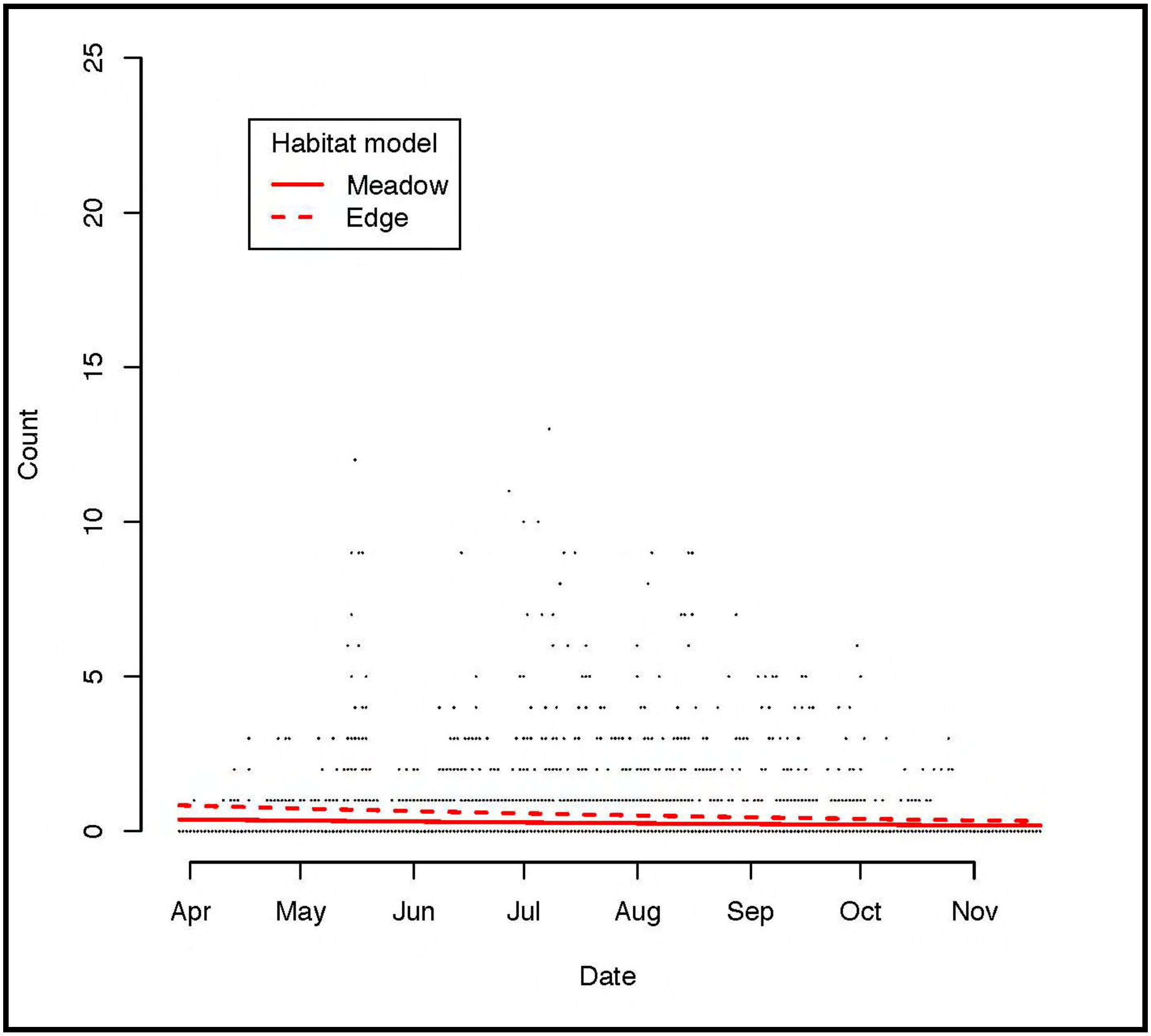

Figure AV.4. Seasonal habitat preference by M40 (*Myotis ciliolabrum*, *Myotis lucifugus*, and *Myotis volans*)

V.5. M50 – *Myotis californicus* and *Myotis yumanensis*

```
> mean(M50,na.rm=TRUE)
[1] 5.669845
> mean(M50[Habitat=="meadow"],na.rm=TRUE)
[1] 4.727401
> mean(M50[Habitat=="edge"],na.rm=TRUE)
[1] 6.612288
```

```
Models:
GLMERM501: M50 ~ 1 + (1 | Location)
GLMERM502: M50 ~ Habitat + (1 | Location)
GLMERM503: M50 ~ Habitat * Day + (1 | Location)
GLMERM504: M50 ~ Habitat + (Day | Location)
GLMERM505: M50 ~ Habitat * Day + (Day | Location)
          Df    AIC    BIC logLik   Chisq Chi Df Pr(>Chisq)
GLMERM501  2  27207  27219 -13601
GLMERM502  3  26763  26781 -13378 445.708      1  < 2.2e-16 ***
GLMERM503  5  26895  26925 -13443   0.000      2          1
GLMERM504  5  26317  26347 -13153 578.418      0  < 2.2e-16 ***
GLMERM505  7  26269  26311 -13128  51.899      2  5.374e-12 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
>
> # select the minimum adequate model
>
> GLMERM505
```

Selection by AIC indicates that the full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that habitat and day are both important for explaining activity levels, and the interaction term indicates that the effect of habitat changes with day. Retention of both random effects indicates that both day and location have grouping that contributes to model information.

```
Generalized linear mixed model fit by the Laplace approximation
Formula: M50 ~ Habitat * Day + (Day | Location)
   Data: YNPbats
   AIC   BIC logLik deviance
 26269 26311 -13127    26255
Random effects:
 Groups   Name        Variance   Std.Dev.  Corr
 Location (Intercept) 2.0765e-01 0.4556851
          Day         7.0070e-06 0.0026471 -0.334
Number of obs: 2832, groups: Location, 6

Fixed effects:
                    Estimate Std. Error z value Pr(>|z|)
(Intercept)        1.9360675  0.1872418  10.340  < 2e-16 ***
Habitatmeadow     -0.5327663  0.0319933 -16.652  < 2e-16 ***
Day               -0.0015173  0.0010928  -1.388    0.165
Habitatmeadow:Day  0.0016746  0.0002338   7.161 7.99e-13 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) Hbttmd Day
Habitatmedw -0.067
Day         -0.343  0.074
Habttmdw:Dy  0.059 -0.865 -0.089
```

There is no significant change in overall activity level. These data indicate a preference for edges, by M50, though the preference weakens as the season progresses into fall (see Figure AV.5).

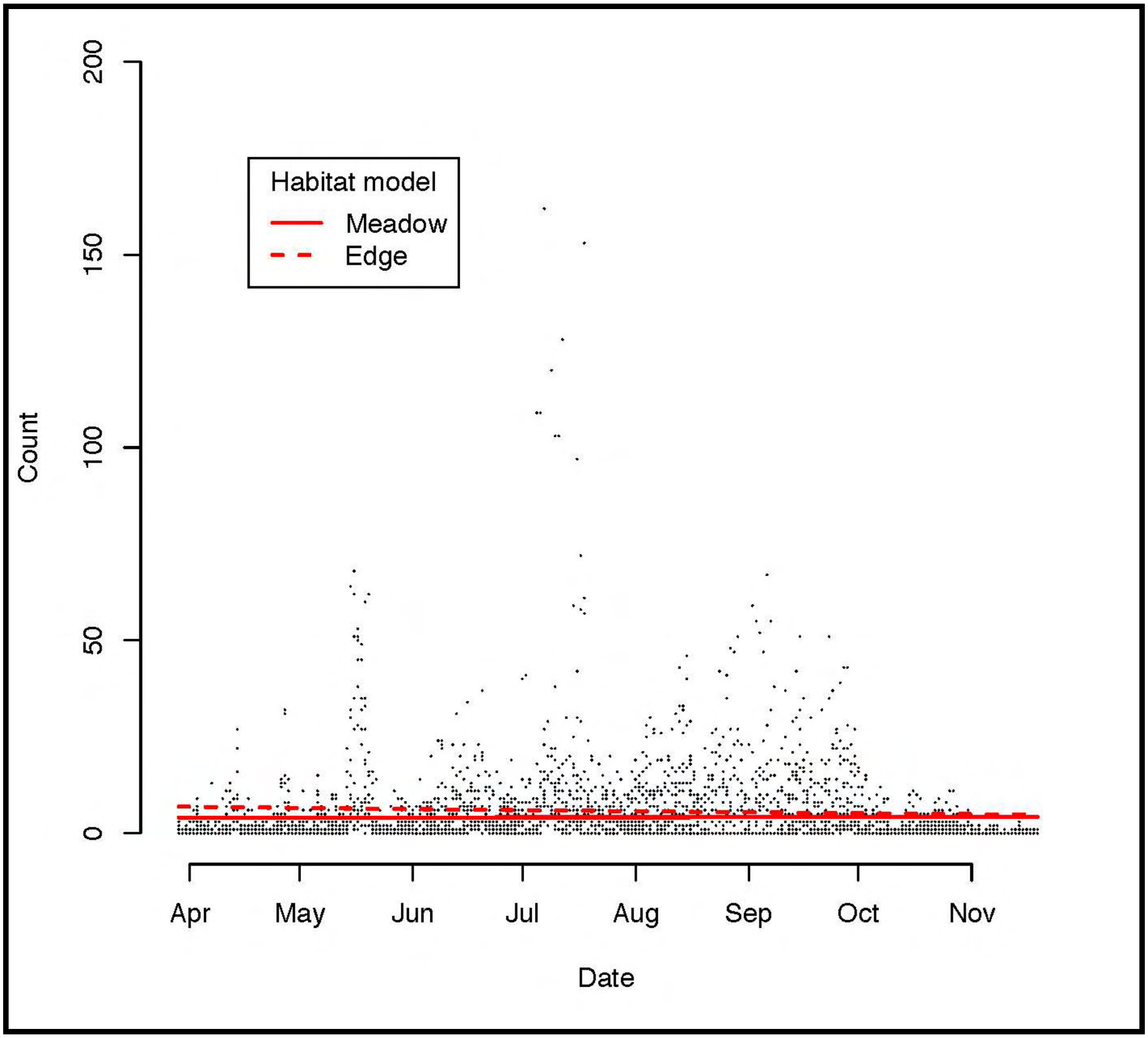

Figure AV.5. Seasonal habitat preference by M50 (*Myotis californicus* and *Myotis yumanensis*)

V.6. Long-eared myotis, *Myotis evotis*

```
> mean(Myotis_evotis,na.rm=TRUE)
[1] 0.1338277
> mean(Myotis_evotis[Habitat=="meadow"],na.rm=TRUE)
[1] 0.08757062
> mean(Myotis_evotis[Habitat=="edge"],na.rm=TRUE)
[1] 0.1800847
```

```
Models:
GLMERMYEV1: Myotis_evotis ~ 1 + (1 | Location)
```

```
GLMERMYEV2: Myotis_evotis ~ Habitat + (1 | Location)
GLMERMYEV3: Myotis_evotis ~ Habitat * Day + (1 | Location)
GLMERMYEV4: Myotis_evotis ~ Habitat + (Day | Location)
GLMERMYEV5: Myotis_evotis ~ Habitat * Day + (Day | Location)
           Df     AIC     BIC  logLik   Chisq Chi Df Pr(>Chisq)
GLMERMYEV1  2 1683.98 1695.87 -839.99
GLMERMYEV2  3 1639.75 1657.59 -816.87 46.2274      1  1.053e-11 ***
GLMERMYEV3  5 1638.09 1667.84 -814.05  5.6545      2    0.05917 .
GLMERMYEV4  5 1634.92 1664.67 -812.46  3.1719      0  < 2.2e-16 ***
GLMERMYEV5  7 1637.70 1679.35 -811.85  1.2171      2    0.54413
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
>
> # select the minimum adequate model
>
> GLMERMYEV4
```

Selection by AIC indicates that a partial model, with all considered random effects, but only habitat as a fixed effect is the minimum adequate model. Retention of only habitat as a fixed effect indicates that day is not important for explaining activity levels, nor does the effect of habitat change with day. Retention of both random effects indicates that both day and location have grouping that contributes to model information.

```
Generalized linear mixed model fit by the Laplace approximation
Formula: Myotis_evotis ~ Habitat + (Day | Location)
   Data: YNPbats
  AIC  BIC logLik deviance
 1635 1665 -812.5     1625
Random effects:
 Groups   Name        Variance   Std.Dev.  Corr
 Location (Intercept) 7.2150e-02 0.2686077
          Day         7.6369e-06 0.0027635 0.150
Number of obs: 2832, groups: Location, 6

Fixed effects:
              Estimate Std. Error z value Pr(>|z|)
(Intercept)    -1.9037     0.1537 -12.384  < 2e-16 ***
Habitatmeadow  -0.7210     0.1095  -6.583 4.61e-11 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr)
Habitatmedw -0.233
```

There is no significant change in overall activity level. These data indicate a preference for edges that is constant across the season, by *Myotis evotis* (see Figure AV.6). Note that records for this species are a bit sparse.

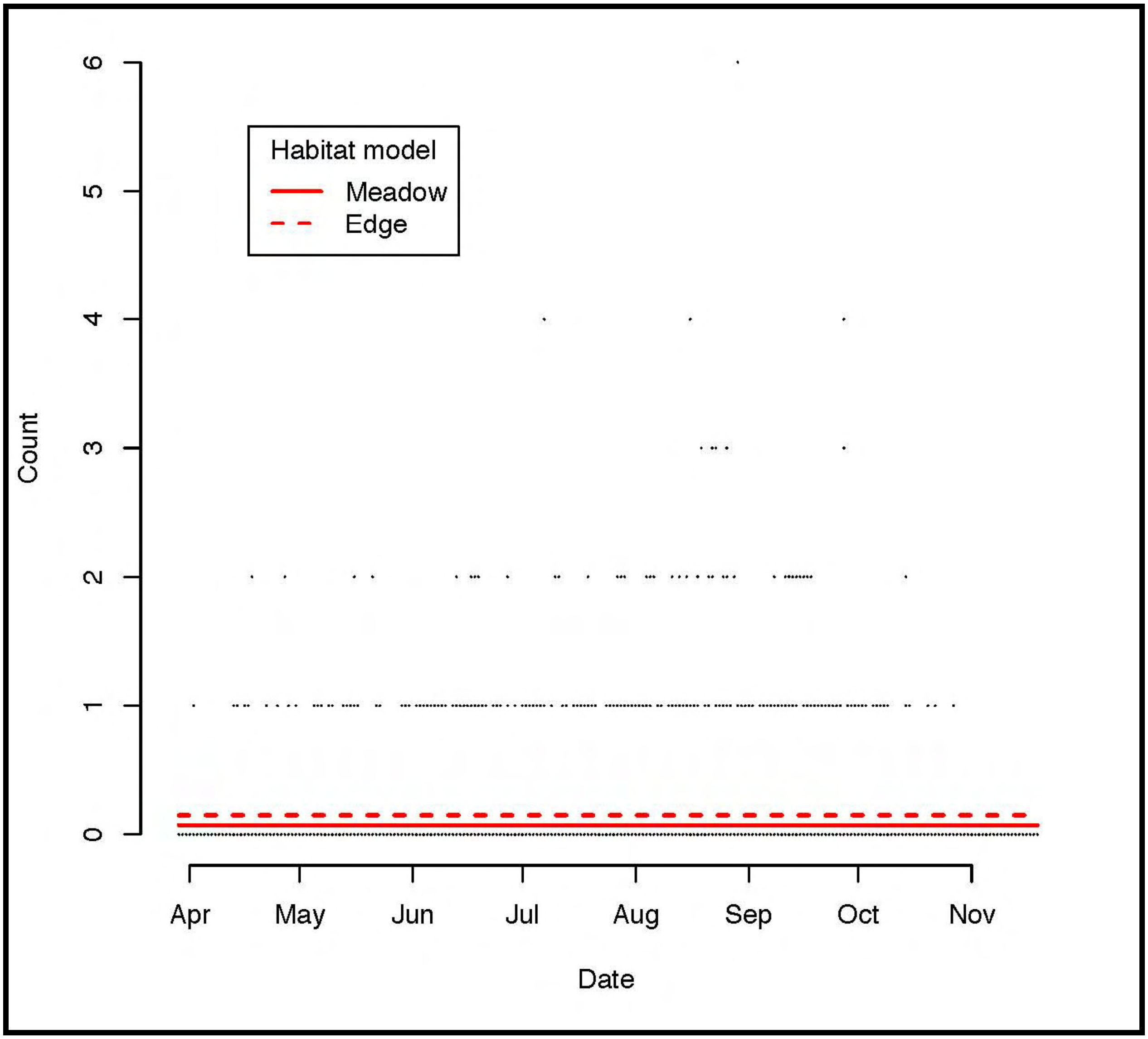

Figure AV.6. Seasonal habitat preference by *Myotis evotis*

V.7. Fringed myotis, *Myotis thysanodes*

```
> mean(Myotis_thysanodes,na.rm=TRUE)
[1] 0.1740819
> mean(Myotis_thysanodes[Habitat=="meadow"],na.rm=TRUE)
[1] 0.1483051
> mean(Myotis_thysanodes[Habitat=="edge"],na.rm=TRUE)
[1] 0.1998588

Models:
GLMERMYTH1: Myotis_thysanodes ~ 1 + (1 | Location)
GLMERMYTH2: Myotis_thysanodes ~ Habitat + (1 | Location)
GLMERMYTH3: Myotis_thysanodes ~ Habitat * Day + (1 | Location)
```

```
GLMERMYTH4: Myotis_thysanodes ~ Habitat + (Day | Location)
GLMERMYTH5: Myotis_thysanodes ~ Habitat * Day + (Day | Location)
           Df     AIC     BIC  logLik  Chisq Chi Df Pr(>Chisq)
GLMERMYTH1  2  2064.2  2076.1 -1030.1
GLMERMYTH2  3  2055.4  2073.2 -1024.7 10.849      1  0.0009884 ***
GLMERMYTH3  5  2024.0  2053.8 -1007.0 35.366      2  2.091e-08 ***
GLMERMYTH4  5  2026.1  2055.8 -1008.0  0.000      0  < 2.2e-16 ***
GLMERMYTH5  7  2019.4  2061.0 -1002.7 10.708      2  0.0047290 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
>
> # select the minimum adequate model
>
> GLMERMYTH5
```

Selection by AIC indicates that the full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that habitat and day are both important for explaining activity levels, and the interaction term indicates that the effect of habitat changes with day. Retention of both random effects indicates that both day and location have grouping that contributes to model information.

```
Generalized linear mixed model fit by the Laplace approximation
Formula: Myotis_thysanodes ~ Habitat * Day + (Day | Location)
   Data: YNPbats
  AIC  BIC logLik deviance
 2019 2061  -1003     2005
Random effects:
 Groups   Name        Variance   Std.Dev. Corr
 Location (Intercept) 4.3935e-01 0.662837
          Day         7.2199e-06 0.002687 -0.572
Number of obs: 2832, groups: Location, 6

Fixed effects:
                   Estimate Std. Error z value Pr(>|z|)
(Intercept)       -1.521310   0.295806  -5.143 2.70e-07 ***
Habitatmeadow      0.047972   0.164079   0.292   0.7700
Day               -0.001974   0.001432  -1.378   0.1681
Habitatmeadow:Day -0.003436   0.001368  -2.511   0.0120 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) Hbttmd Day
Habitatmedw -0.258
Day         -0.619  0.353
Habttmdw:Dy  0.205 -0.829 -0.390
```

There is no significant change in overall activity level. These data indicate no overall significant habitat preference, by *Myotis thysanodes*, but that a slight preference for edges develops as the season progresses into fall (see Figure AV.7). Note that records are a bit sparse.

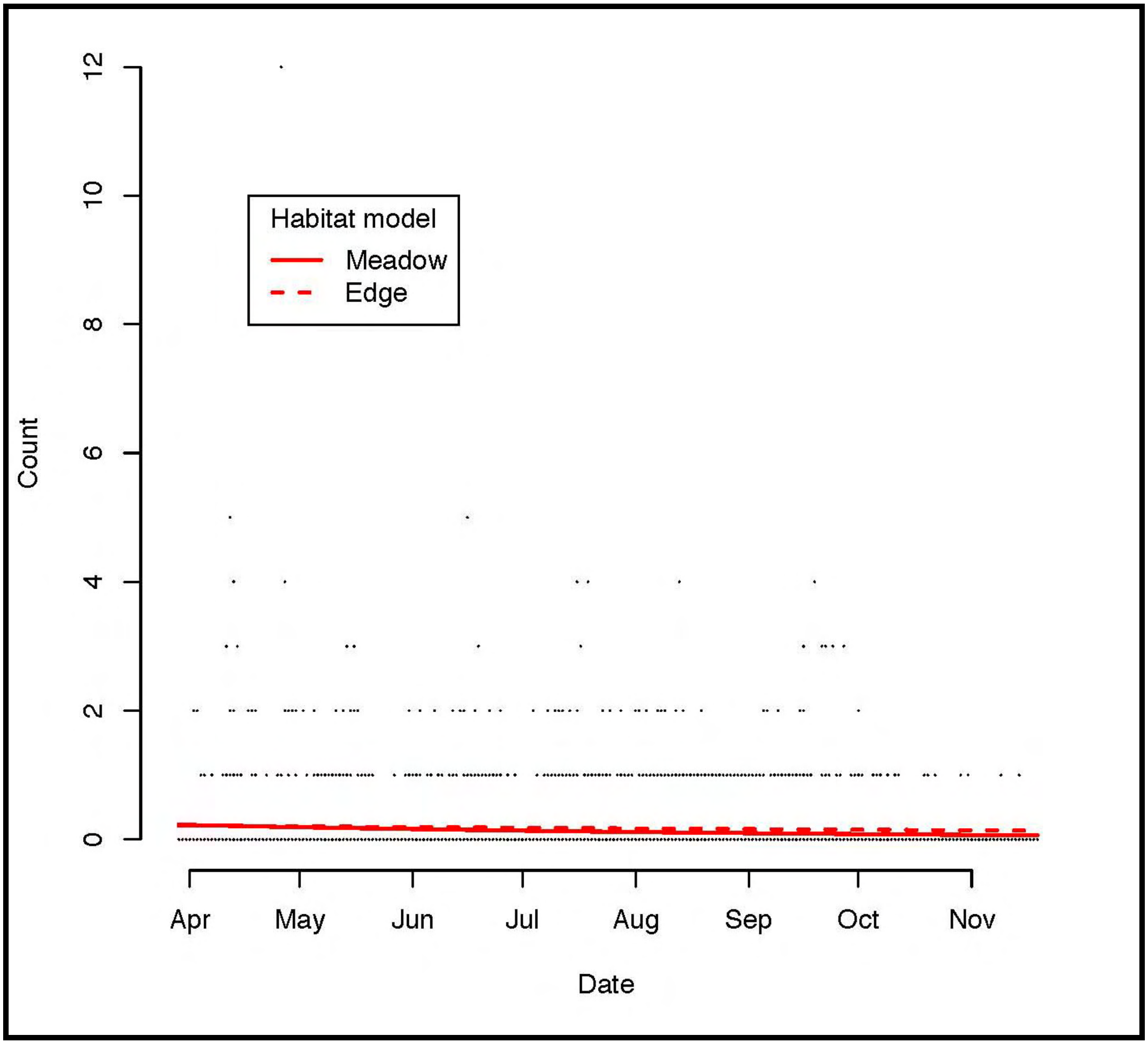

Figure AV.7. Seasonal habitat preference by *Myotis thysanodes*

V.8. Western pipistrelle, *Parastrellus hesperus*

```
> mean(Parastrellus_hesperus,na.rm=TRUE)
[1] 2.508828
> mean(Parastrellus_hesperus[Habitat=="meadow"],na.rm=TRUE)
[1] 2.97387
> mean(Parastrellus_hesperus[Habitat=="edge"],na.rm=TRUE)
[1] 2.043785
```

```
Models:
GLMERPAHE1: Parastrellus_hesperus ~ 1 + (1 | Location)
GLMERPAHE2: Parastrellus_hesperus ~ Habitat + (1 | Location)
GLMERPAHE3: Parastrellus_hesperus ~ Habitat * Day + (1 | Location)
GLMERPAHE4: Parastrellus_hesperus ~ Habitat + (Day | Location)
```

```
GLMERPAHE5: Parastrellus_hesperus ~ Habitat * Day + (Day | Location)
           Df     AIC     BIC  logLik   Chisq Chi Df Pr(>Chisq)
GLMERPAHE1  2 14466.1 14478.0 -7231.0
GLMERPAHE2  3 14222.5 14240.4 -7108.3 245.540      1  < 2.2e-16 ***
GLMERPAHE3  5 13904.0 13933.7 -6947.0 322.580      2  < 2.2e-16 ***
GLMERPAHE4  5 13953.8 13983.5 -6971.9   0.000      0  < 2.2e-16 ***
GLMERPAHE5  7 13907.1 13948.8 -6946.6  50.645      2  1.006e-11 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
>
> # select the minimum adequate model
>
> GLMERPAHE3
```

Selection by AIC indicates that a partial model, with all considered fixed but only a single random effect for location is the minimum adequate model. Retention of all fixed effects indicates that habitat and day are both important for explaining activity levels, and the interaction term indicates that the effect of habitat changes with day. Retention of one random effect indicates that location, but not day, has grouping that contributes to model information.

```
Generalized linear mixed model fit by the Laplace approximation
Formula: Parastrellus_hesperus ~ Habitat * Day + (1 | Location)
   Data: YNPbats
   AIC   BIC logLik deviance
 13904 13934  -6947    13894
Random effects:
 Groups   Name        Variance Std.Dev.
 Location (Intercept) 6.3514   2.5202
Number of obs: 2832, groups: Location, 6

Fixed effects:
                    Estimate Std. Error z value Pr(>|z|)
(Intercept)       -0.8817438  1.0344987  -0.852    0.394
Habitatmeadow      0.0605309  0.0524888   1.153    0.249
Day                0.0015059  0.0002737   5.502 3.76e-08 ***
Habitatmeadow:Day  0.0024015  0.0003582   6.705 2.01e-11 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) Hbttmd Day
Habitatmedw -0.028
Day         -0.033  0.654
Habttmdw:Dy  0.025 -0.887 -0.764
```

There is a significant increase in overall activity level, as season progresses into fall. These data indicate no significant overall preference, by *Parastrellus hesperus*, but the effect of the interaction is such that a preference for meadows develops in fall (see Figure AV.8).

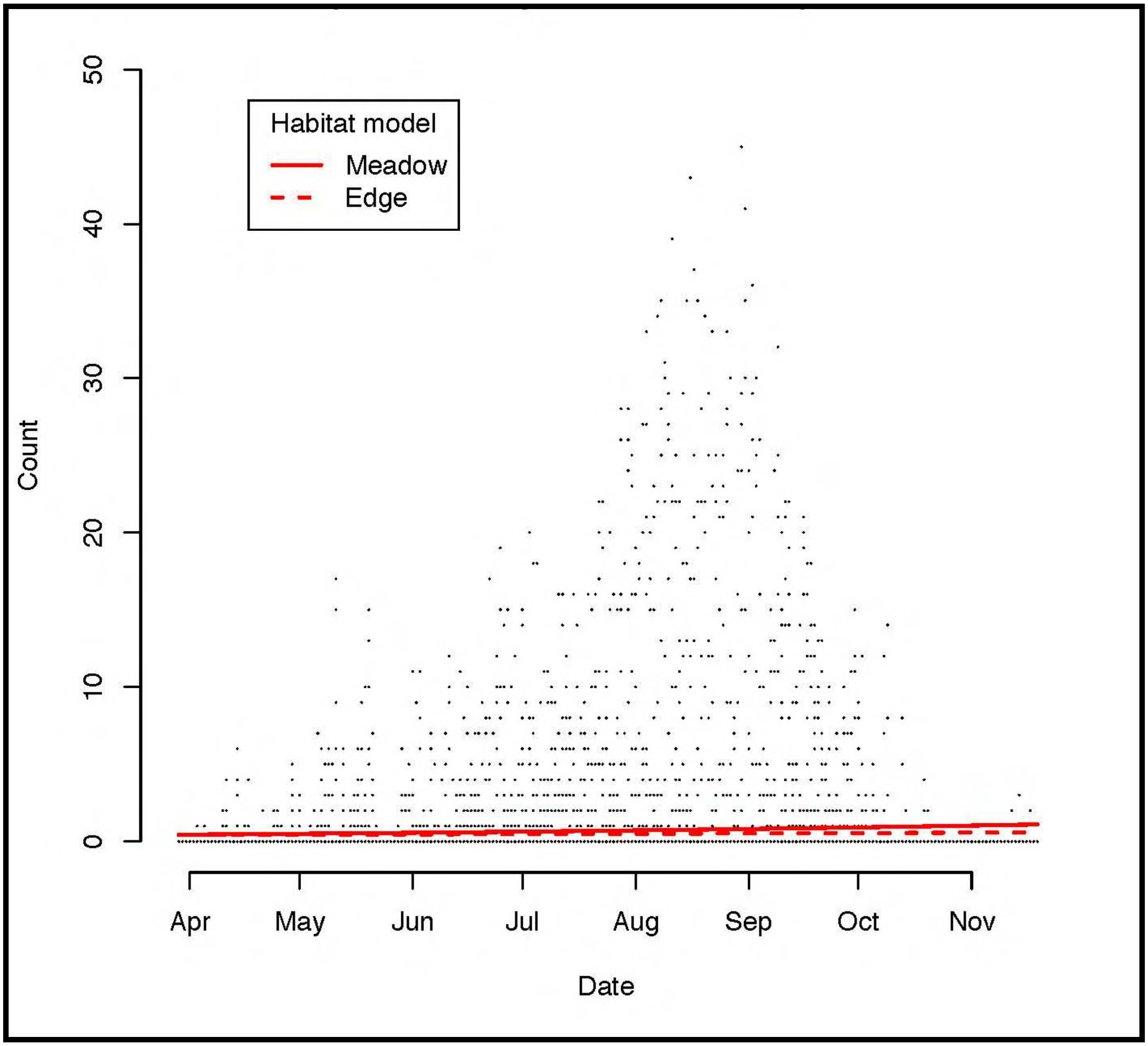

Figure AV.8. Seasonal habitat preference by *Parastrellus hesperus*

V.9. Q25 – *Eptesicus fuscus*, *Lasionycteris noctivagans*, and *Tadarida brasiliensis*

```
> mean(Q25,na.rm=TRUE)
[1] 22.42232
> mean(Q25[Habitat=="meadow"],na.rm=TRUE)
[1] 21.28107
> mean(Q25[Habitat=="edge"],na.rm=TRUE)
[1] 23.56356

Models:
GLMERQ251: Q25 ~ 1 + (1 | Location)
GLMERQ252: Q25 ~ Habitat + (1 | Location)
GLMERQ253: Q25 ~ Habitat * Day + (1 | Location)
```

```
GLMERQ254: Q25 ~ Habitat + (Day | Location)
GLMERQ255: Q25 ~ Habitat * Day + (Day | Location)
          Df   AIC   BIC logLik  Chisq Chi Df Pr(>Chisq)
GLMERQ251  2 96352 96364 -48174
GLMERQ252  3 96189 96207 -48092 164.57      1  < 2.2e-16 ***
GLMERQ253  5 95802 95832 -47896 391.23      2  < 2.2e-16 ***
GLMERQ254  5 95053 95083 -47522 748.53      0  < 2.2e-16 ***
GLMERQ255  7 94636 94678 -47311 421.20      2  < 2.2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
>
> # select the minimum adequate model
>
> GLMERQ255
```

Selection by AIC indicates that the full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that habitat and day are both important for explaining activity levels, and the interaction term indicates that the effect of habitat changes with day. Retention of both random effects indicates that both day and location have grouping that contributes to model information.

```
Generalized linear mixed model fit by the Laplace approximation
Formula: Q25 ~ Habitat * Day + (Day | Location)
   Data: YNPbats
   AIC   BIC logLik deviance
 94636 94678 -47311    94622
Random effects:
 Groups   Name        Variance   Std.Dev.  Corr
 Location (Intercept) 1.2110e-02 0.1100434
          Day         5.6437e-06 0.0023757 -0.496
Number of obs: 2832, groups: Location, 6

Fixed effects:
                    Estimate Std. Error z value Pr(>|z|)
(Intercept)        3.3100376  0.0461686   71.69   <2e-16 ***
Habitatmeadow     -0.3849328  0.0159751  -24.10   <2e-16 ***
Day               -0.0015995  0.0009733   -1.64    0.100
Habitatmeadow:Day  0.0023869  0.0001165   20.49   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) Hbttmd Day
Habitatmedw -0.152
Day         -0.497  0.047
Habttmdw:Dy  0.135 -0.867 -0.057
```

There is no significant change in overall activity level. These data indicate an overall preference for edges, by Q25, but note that as the season progresses, the effect of the habitat:day interaction term is strong enough to reverse this preference, so that Q25 prefers meadows in fall (see Figure AV.9).

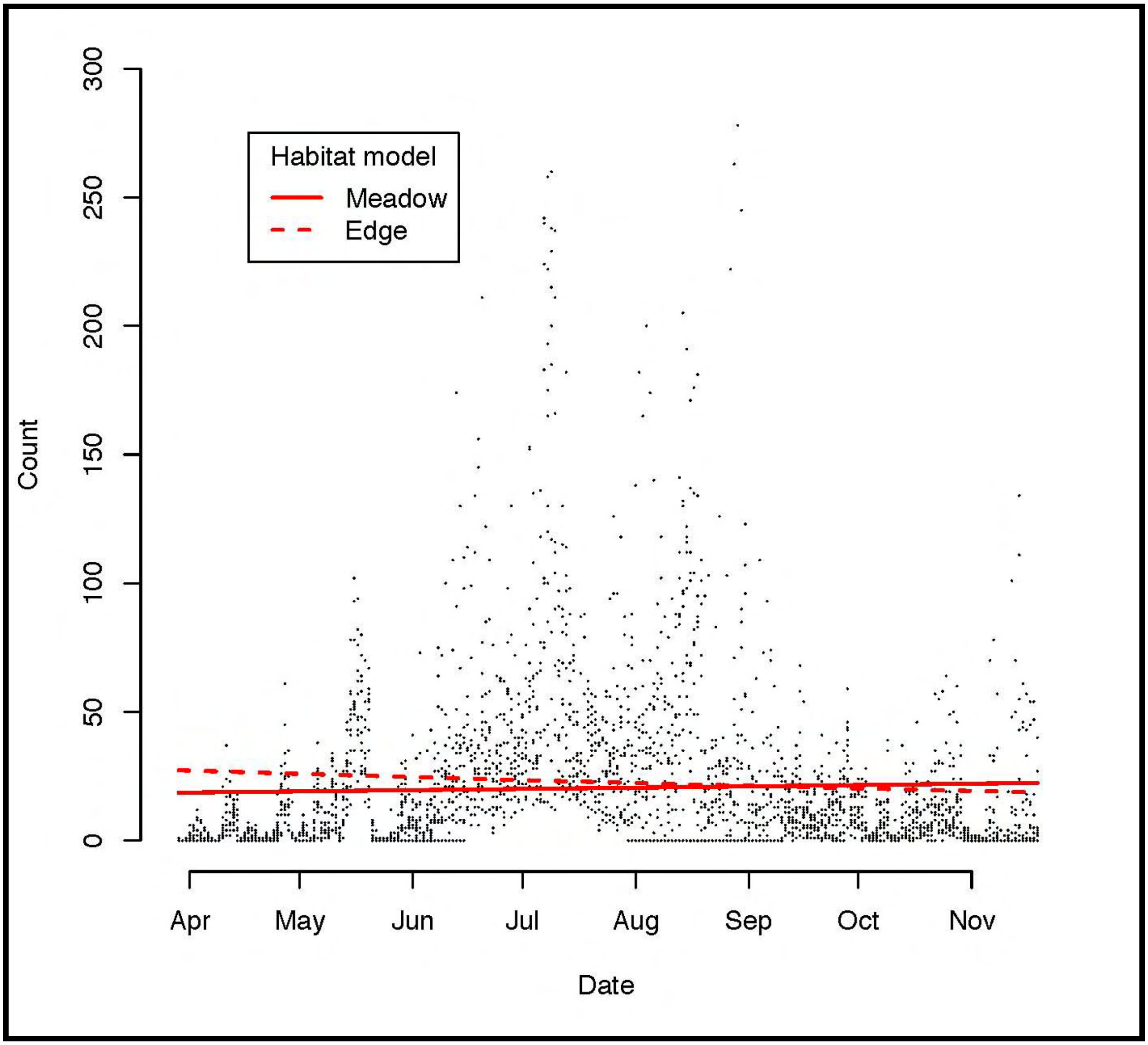

Figure AV.9. Seasonal habitat preference by Q25 (*Eptesicus fuscus*, *Lasionycteris noctivagans*, and *Tadarida brasiliensis*)

V.10. Mexican free-tailed bat, *Tadarida brasiliensis*

```
> mean(Tadarida_brasiliensis,na.rm=TRUE)
[1] 30.16808
> mean(Tadarida_brasiliensis[Habitat=="meadow"],na.rm=TRUE)
[1] 35.10876
> mean(Tadarida_brasiliensis[Habitat=="edge"],na.rm=TRUE)
[1] 25.2274

Models:
GLMERTABR1: Tadarida_brasiliensis ~ 1 + (1 | Location)
GLMERTABR2: Tadarida_brasiliensis ~ Habitat + (1 | Location)
GLMERTABR3: Tadarida_brasiliensis ~ Habitat * Day + (1 | Location)
```

```
GLMERTABR4: Tadarida_brasiliensis ~ Habitat + (Day | Location)
GLMERTABR5: Tadarida_brasiliensis ~ Habitat * Day + (Day | Location)
           Df    AIC    BIC logLik   Chisq Chi Df Pr(>Chisq)
GLMERTABR1  2 132155 132167 -66076
GLMERTABR2  3 129856 129873 -64925 2301.85      1  < 2.2e-16 ***
GLMERTABR3  5 129468 129497 -64729  392.02      2  < 2.2e-16 ***
GLMERTABR4  5 129178 129208 -64584  289.23      0  < 2.2e-16 ***
GLMERTABR5  7 128895 128937 -64441  287.34      2  < 2.2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
>
> # select the minimum adequate model
>
> GLMERTABR5
```

Selection by AIC indicates that the full model, with all considered fixed and random effects is the minimum adequate model. Retention of all fixed effects indicates that habitat and day are both important for explaining activity levels, and the interaction term indicates that the effect of habitat changes with day. Retention of both random effects indicates that both day and location have grouping that contributes to model information.

```
Generalized linear mixed model fit by the Laplace approximation
Formula: Tadarida_brasiliensis ~ Habitat * Day + (Day | Location)
   Data: YNPbats
    AIC    BIC logLik deviance
 128895 128937 -64441   128881
Random effects:
 Groups   Name        Variance   Std.Dev.   Corr
 Location (Intercept) 5.0761e-01 0.71246833
          Day         6.3628e-07 0.00079767 -0.709
Number of obs: 2832, groups: Location, 6

Fixed effects:
                   Estimate Std. Error z value Pr(>|z|)
(Intercept)       2.9885585  0.2911045  10.266   <2e-16 ***
Habitatmeadow     0.1205860  0.0143100   8.427   <2e-16 ***
Day               0.0004421  0.0003365   1.314    0.189
Habitatmeadow:Day 0.0017024  0.0001020  16.692   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) Hbttmd Day
Habitatmedw -0.027
Day         -0.695  0.149
Habttmdw:Dy  0.024 -0.874 -0.176
```

There is no significant change in overall activity level. These data indicate a preference for meadows that increases into fall, by *Tadarida brasiliensis* (see Figure AV.10).

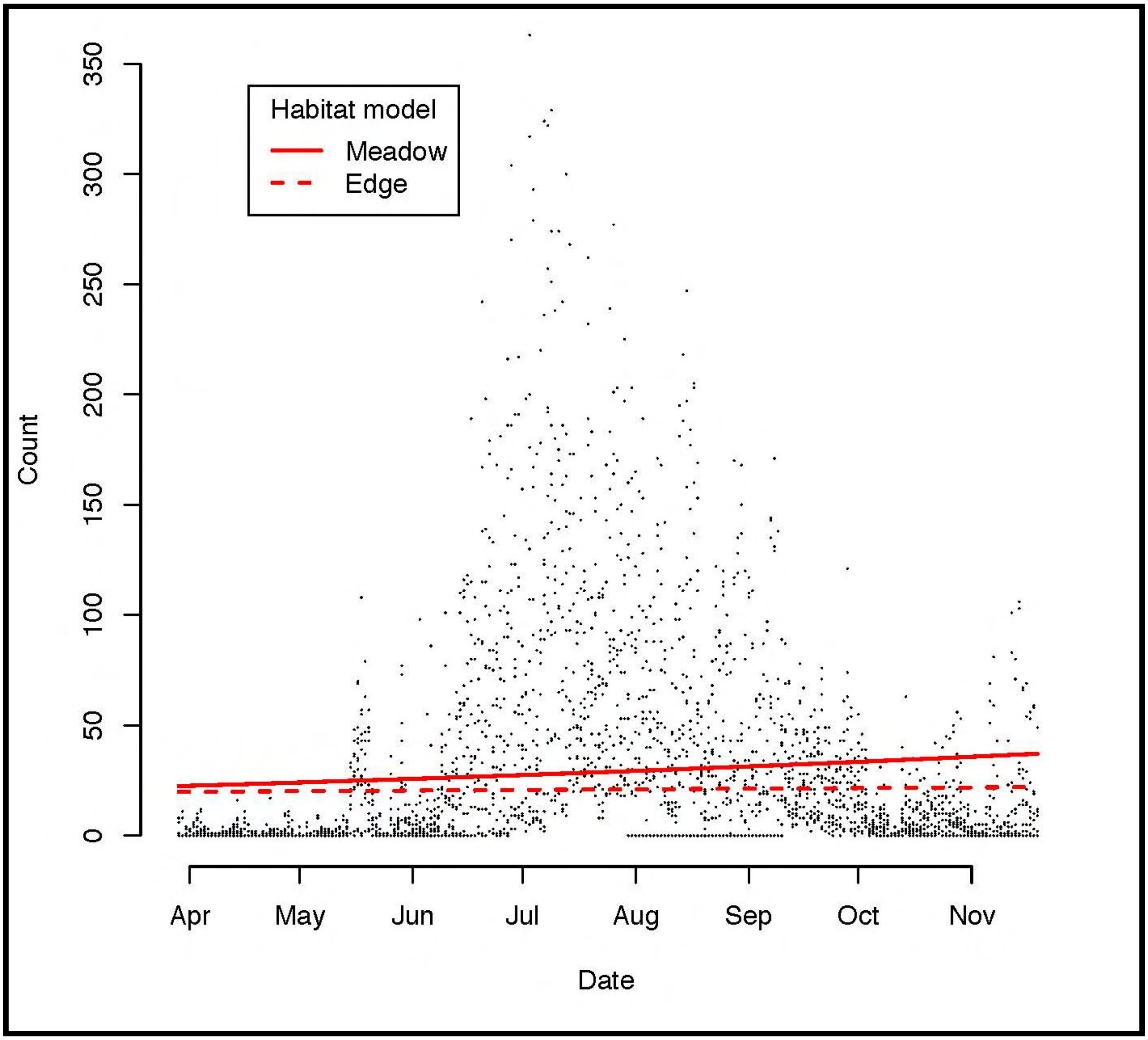

Figure AV.10. Seasonal habitat preference by *Tadarida brasiliensis*