

# Temporal and spatial variation in aquatic insect emergence and bat activity in a restored floodplain wetland

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## 1.0. INTRODUCTION

### 1.1. Preface of Study and Task Intent

As we restore floodplains, we need to learn how their spatial and temporal characteristics affect ecological function, so we can maximize the ecological services, and minimize the ecological disservices they provide. River floodplains provide crucial ecological values and services. Other reports address beneficial effects on water supplies that protect downstream users and ecosystems, such as dissipation of flood waters, ground water recharge, and retention and assimilation of nutrients, which otherwise would eutrophy water bodies downstream. In addition, floodplain ecosystems are productive habitats that have high potential and may often be essential for sustaining and recovering prized resident and migratory populations of native plants and animals. Floodplain habitat in California may be required for the recovery of threatened or endangered populations of fish (e.g., Ribeiro *et al.* 2004), reptiles and amphibians (Brode and Bury 1984), birds (Riparian Habitat Joint Venture 2004), and mammals (Williams and K.S. Kilburn 1984). Populations of less desirable species (non-native black rats, bullfrogs, carp, mosquitoes and biting midges) can also thrive in floodplain habitats. A challenge for floodplain restoration and management in regions near human population centers is to configure floodplains and their food webs so that populations of species considered beneficial thrive, and pest populations are suppressed.

There are two approaches for ‘engineering’ a floodplain food web in the attempt to maximize ecosystem services and minimize disservices. Both involve the management of hydrologic factors (timing and amount of discharges that inundate the floodplain) and floodplain structures (pool depressions, breach configuration, vegetation) that affect floodplain habitat and water retention. First, environmental factors that directly affect the performance (growth, survival, or reproduction) of desirable versus undesirable organisms can be manipulated. Crain *et al.* (2004) indicated that inundating floodplains during earlier, colder seasons favored the production of native salmonids, whereas inundation during later, warmer summer months supported massive recruitment of undesirable invasive carp. Second, factors that affect the interactions of other members of food webs with target organisms can be manipulated. Of particular interest here are factors that enhance the ability of predators, pathogens, or competitors to suppress pest or invasive species. Collins and Resh (1989) proposed that water depths of coastal wetlands could be manipulated on a weekly or daily basis to disrupt the ability of mosquito larvae to hide from visual predators (odonates, insectivorous fish) in the menisci formed where emergent aquatic vegetation intercepts the water surface. Clearly for both approaches, methods that require the least sustained intervention (‘passive restoration’—letting the ecosystem self-organize following early intervention) are preferable to major continued

engineering ('active restoration'), both for aesthetics and cost/benefit ratios, if passive restoration methods can accomplish the goals.

Here we report preliminary results from a study that examined how spatial and temporal factors influenced emergence of aquatic insects (primarily nematocerans, the midge and mosquito suborder) and the activity of insectivorous bats on a Central Valley floodplain restoration site. Specifically, we looked at how patterns of insect emergence and bat activity varied across geomorphically distinct floodplain habitats (and different types of emergent vegetation in these habitats) over three annual cycles that also varied considerably in the timing and duration of local precipitation and flooding. In addition to describing variation in the composition and abundance/activity of the insect and bat assemblages, a goal was to provide suggestions about combinations of factors that could enhance the ability of insectivorous bats to limit populations of night-flying aquatic insects, as well as habitat characteristics that can sustain bats populations long term as important, and increasingly appreciated components of native biodiversity.

## **1.2. Background: Insectivorous bat diets**

While adult odonates and birds like swallows are likely the dominant diurnal volant insectivores on floodplains, bats are the primary consumers of night-flying insects. The bat assemblage (9-13 species at the study site) is ecologically diverse, and includes species with a range of dietary preferences (moth specialists, beetle specialists, and aquatic emergent consumers), but recent studies have shown that bat foraging activity for many species is generally concentrated in association with water (either directly over water or in the riparian zone) (Grindal *et al.* 1999, Pierson *et al.* 2001). Despite dietary preferences, most bat species are opportunistic, and will feed on a diverse insect assemblage, often tracking insect hatches (Whitaker 1994). A study conducted in the 1990's on the upper Sacramento River identified a regional termite hatch that was tracked by multiple species at two sites tens of kilometers apart (Rainey and Pierson 1996).

Studies conducted in California and elsewhere have documented bat species (*Eptesicus fuscus* and *Tadarida brasiliensis*, both of which occur at the study site) feeding on important agricultural pests (*e.g.*, corn-borer moth, codling moth, tomato ear-worm). At high densities, these species likely play a role in insect control (Hogan 2000, Johnston 1998, McCracken 1996, Whitaker 1993, Whitaker *et al.* 1996). Bats have high energy demand and dietary throughput in warm seasons, with pregnant and/or lactating females processing up to 100% of their body weight (ca. 4-14 g) in insects each night. From a public health perspective on emerging aquatic insects, several mosquito taxa are important as vectors of human and animal diseases in California (*e.g.*, encephalitis, potentially malaria, dog heart worm, and more recently West Nile virus). Morphological analyses of insect remains in bat guano have shown that bats consume mosquitoes, but these studies are quite limited, so much remains to be done in assessing their contribution to vector control.

### 1.3. Background: Bat Life History

While the focus of this study is on bat foraging activity, it is important to consider this in relation to other life history parameters that also influence daily and seasonal patterns of activity. Bats differ significantly from many birds of similar body mass in that there is frequently a significant geographic separation (5-50 km) between roosting and foraging areas (Brown and Berry 2004, Pierson 1998). Thus bats that are monitored acoustically in a foraging area may, or may not, be roosting close by. There is mounting evidence that intact riparian forests with older defective trees, provide suitable roosting sites (*e.g.*, bole cavities, loose bark, vine tangles) for many species, and where such habitat is available bats may commute shorter distances to foraging areas (Pierson et al. 2000)

Because many bat roosts are cryptic (especially tree and rock crevice roosts), it is generally not possible without radio-tracking to determine the relationship between bat activity at a foraging site and distance to an individual or colonial roost site. However, a few species roost in very large and conspicuous aggregations, particularly in anthropogenic features like bridges and buildings, and, assuming a uniform distribution of prey, a reasonable hypothesis would be that the closer you are to a roost the more individuals of this species will be detected in a foraging study (*i.e.*, halo effect as bats disperse from a central roost site).

The bat species assemblage at the study site is highly variable in both roost site preferences and in degree of coloniality. There are highly adaptable species that in the Central Valley would most likely be found in anthropogenic structures (*e.g.*, *Tadarida brasiliensis*), others that could roost in human structures or in tree cavities/crevices (*e.g.*, *Antrozous pallidus*, *Eptesicus fuscus* and *Myotis lucifugus*), and those that are obligate foliage-roosting bats (*e.g.*, *Lasiurus blossevillii* and *Lasiurus cinereus*). There are species, like the two lasiurines, that are typically non-colonial, and others that form maternity colonies ranging in size from a few bats (*e.g.*, *Myotis californicus*) to many thousands (*e.g.*, *T. brasiliensis*).

There are also important differences in seasonal patterns of activity. All the vespertilionid bats are capable of hibernating. While it is not known where they go in the winter, their activity generally ceases in the Central Valley by late October and does not resume until the spring (March-May depending on annual weather patterns). The molossids (*T. brasiliensis* and *Eumops perotis*) can employ short-term torpor, but remain active year round. *T. brasiliensis*, some populations of which are known to be migratory, disappears from many large transportation structure roosts in the Central Valley in the winter, and densities appear to decline. Nevertheless, this species still present and active in the Central Valley. Available information suggests that the foliage bats are typically migratory, and that the Central Valley may serve as a spring and fall migratory flyway.

Temperate zone bats follow a predictable reproductive pattern, with mature females becoming pregnant in the spring. After a long (90-100 day) pregnancy, individuals of most species produce a single young, although multiple births are common in a few. The

young begin flying about three weeks after they are born, and this influx into the foraging population is generally detectable in both acoustic and capture data.

#### 1.4. Bat Assemblage on Cosumnes Preserve

Relatively little information is available on the distribution of bat species in the Central Valley of California. Most studies have focused on individual localities (Johnson 2000, Johnston *et al.* 2004, Stillwater Sciences 2003), particular species (Dalquest 1946), or specific ecological questions (Hogan 2000, Johnston 1998). The only published regional survey that includes a number of localities from the Sacramento Valley is a late 1920s transect by the Museum of Vertebrate Zoology at the University of California, Berkeley (Grinnell *et al.* 1930). This study sampled 43 localities from the Valley floor (260 ft. elevation at Mill Creek) to Lake Helen at 8,200 ft, with 10 localities below 500 ft. Although specimens were collected for thirteen species, only three were identified from localities below 500 ft.

Grinnell (1918) provided an early review of bat distribution in California, and included records from the Central Valley. The most recent edition of the California Department of Fish and Game's Mammal Species of Special Concern, currently under review for revision, provides the most up-to-date compilation of distributional information for those species proposed for Special Concern status. A recent publication providing range extensions for ten species in California includes a few new records for the Central Valley (Constantine 1998). A five-year survey conducted in the early 1990s provided distributional information for the upper Sacramento River drainage (Rainey and Pierson 1996). A recent study in the Sutter Buttes has contributed significantly to information on bat distribution in that unique locality (Johnson 2000). A study conducted in 2002, using largely passive acoustic monitoring to compare Nature Conservancy's proposed or active riparian restoration sites provided the initial trial for bat field methods on this project (Stillwater Sciences 2003). Also, a recent status review for the western red bat reported on multiple sites in the Sacramento Valley (Pierson *et al.* 2000).

A search of museum collection records nationwide yielded a total of 649 bat specimens of 15 species from localities in a nine county area (Tehama, Glenn, Butte, Colusa, Sutter, Yolo, Sacramento, Solano, San Joaquin) in the Central Valley, with only 21 records from Sacramento County. Three colonial species, *Myotis yumanensis*, *Tadarida brasiliensis*, and *Eptesicus fuscus*, account for 32, 20, and 10 percent of all the records respectively. *Lasiurus blossevillii* and *Myotis californicus* each account for 9 percent of the records. The remaining ten species are represented by relatively few specimens and together comprise 21 percent of all records. When the analysis of museum records is restricted to localities at or below 500 ft elevation, two species (*Myotis thysanodes* and *Myotis volans*) drop out. The thirteen remaining species could all occur at the Cosumnes Preserve. Most museum records were acquired between May and October, consistent with peak activity occurring during summer breeding and fall migration. There are only 13 winter (December–February) records for the Sacramento Valley below 500 ft elevation, including seven species: *Corynorhinus townsendii*, *L. blossevillii*, *Eumops perotis*, *Myotis californicus*, *M. yumanensis*, *Pipistrellus hesperus*, and *T. brasiliensis*.



**Table 1. Records of species potentially occurring in the Central Valley (below 500 ft.), from museum records, literature records, and this study (adapted from Stillwater Sciences 2003).**

Species	Type of Record <sup>1</sup>
Family Molossidae (free-tailed bats)	
Western mastiff bat <i>Eumops perotis</i>	M, A
Mexican free-tailed bat <i>Tadarida brasiliensis</i>	M, A, V
Family Vespertilionidae (mouse-eared bats)	
Pallid bat <i>Antrozous pallidus</i>	M, A
Townsend's big-eared bat <i>Corynorhinus townsendii</i>	M
Big brown bat <i>Eptesicus fuscus</i>	M, A, V
Silver-haired bat <i>Lasionycteris noctivagans</i>	M
Red bat <i>Lasiurus blossevillii</i>	M, A, V
Hoary bat <i>Lasiurus cinereus</i>	M, A
California myotis <i>Myotis californicus</i>	M, A
Small-footed myotis <i>Myotis ciliolabrum</i>	(Johnson 2000)
Long-eared myotis <i>Myotis evotis</i>	M
Little brown myotis <i>Myotis lucifugus</i>	M, A, V
Fringed myotis <sup>2</sup> <i>Myotis thysanodes</i>	M
Long-legged myotis <i>Myotis volans</i>	M
Yuma myotis <i>Myotis yumanensis</i>	M, A, V
Western pipistrelle <i>Pipistrellus hesperus</i>	M

<sup>1</sup> All records, except museum and records, refer to data collected in this study:  
M = museum records, A = acoustic detection, V = visual observation

## 1.5. Hypotheses

The secondary production of insects in the floodplain depends on the duration of inundation, the number of degree-days for development during this period (which in turn depends on the seasonal temperature regime during inundation as well as the hydrograph), and the quality and supply rate of primary production and detrital food sources available to support insect larval growth and development. An additional variable is the state of development of the insect when it reaches the floodplain (i.e., floodborne larvae or local oviposition?). Flood events both deliver nutrients and detritus to the floodplain, but if they are of sufficient volume they may also flush local production, including insects, from the floodplain.

Cold season rains wetting and sharply altering the thermal suitability of bat roost sites in tree bole cavities, bark flakes, and dense elevated leaf clusters (along with low insect availability at the end of the dry season), probably play a large role in the fall and winter low in bat activity at Central Valley alluvial riparian sites with no nearby elevated rock roosting habitat. While winter and early spring floods may influence later floodplain primary and secondary production by recharging groundwater, stimulating rooted plant growth and delivering nutrients and detritus, a reasonable hypothesis is that warm season bat populations, like many migrant birds, are uncoupled from variation in aquatic insect emergence from late October through February. Extended late rain (March-May) can still affect roost thermal suitability and foraging time, leading to bat reproductive delay or failure for the year. Later floods, perhaps typically snowmelt driven, provide aquatic insect resources that bats are present to exploit. Bat roost sites are high in trees so that roost flooding is not an issue. Thus we would expect late, long duration floods to correlate with elevated levels of insect prey and foraging activity.

## 2.0 METHODS

### 2.1. Study Site

Florsheim and Mount (2002) describe and illustrate flood mediated landscape and vegetation change on a floodplain restoration site managed by the Cosumnes River Preserve consortium. This study is one of several continued on the same site, employing similar or identical local feature names for continuity (Figure 1). References to the Cosumnes channel near Wendell's and the Corps Breach are the same locality.

Booth *et al.* (*submitted*) examined a long-term record of floods on the Cosumnes to develop a flood classification. For our study years 2003-2005, the last is notable in that it alone includes an event classed as a 'long' flood. For interpretive context, Figure 2 and Figure 3 show the three-year local minimum temperature and precipitation records from the UC Davis IPM meteorology network Thornton station immediately south of the Cosumnes Preserve (<http://www.ipm.ucdavis.edu/>). Both are plotted with the intervals of connection (= flooding) between the Cosumnes R. channel and the study floodplain as detected by the depth and flow sensor in the Triangle South levee breach (E. Booth, pers. comm.).

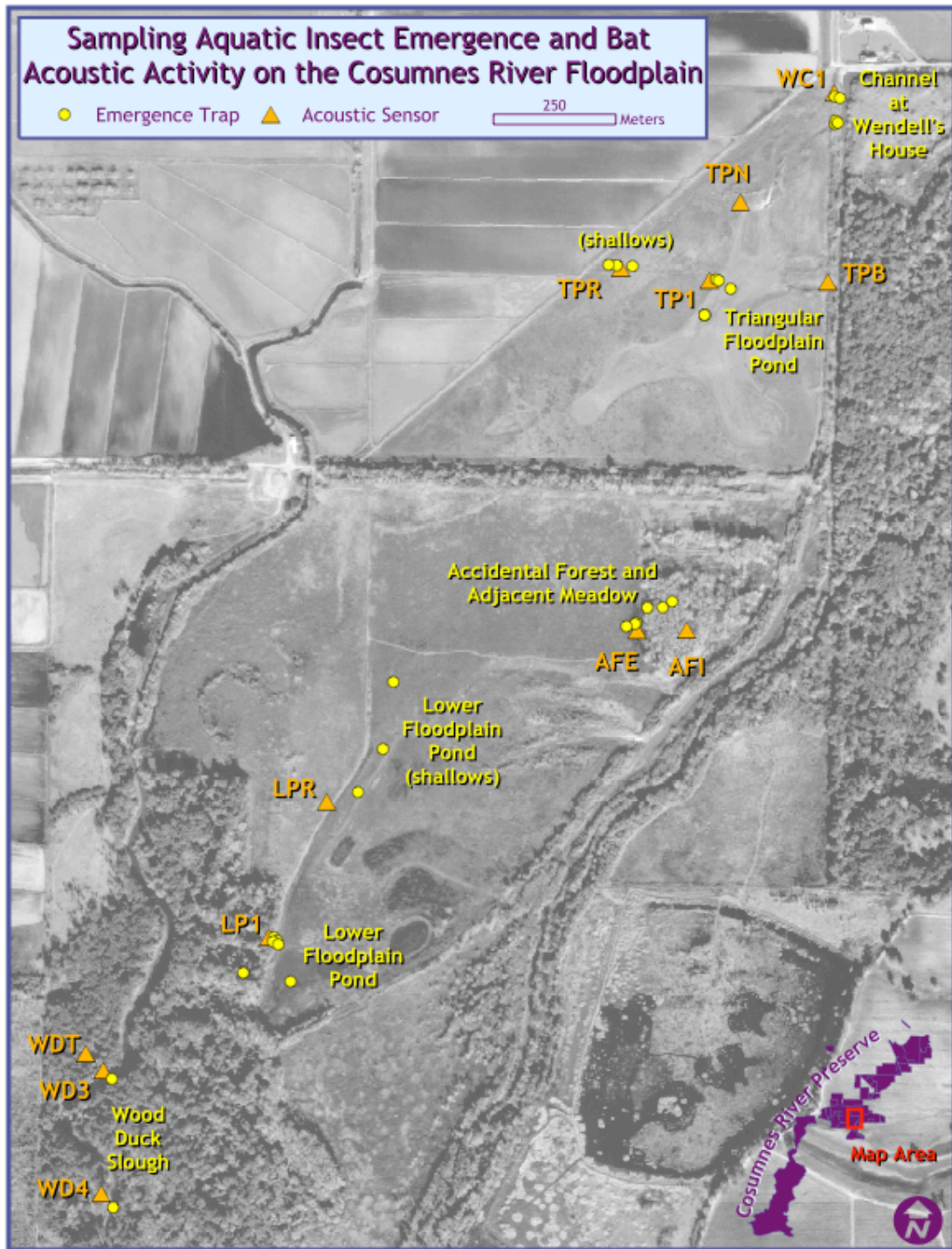


Figure 1. Floodplain bat acoustic monitoring stations (triangles) and approximate locations of aquatic insect emergence trap transects.

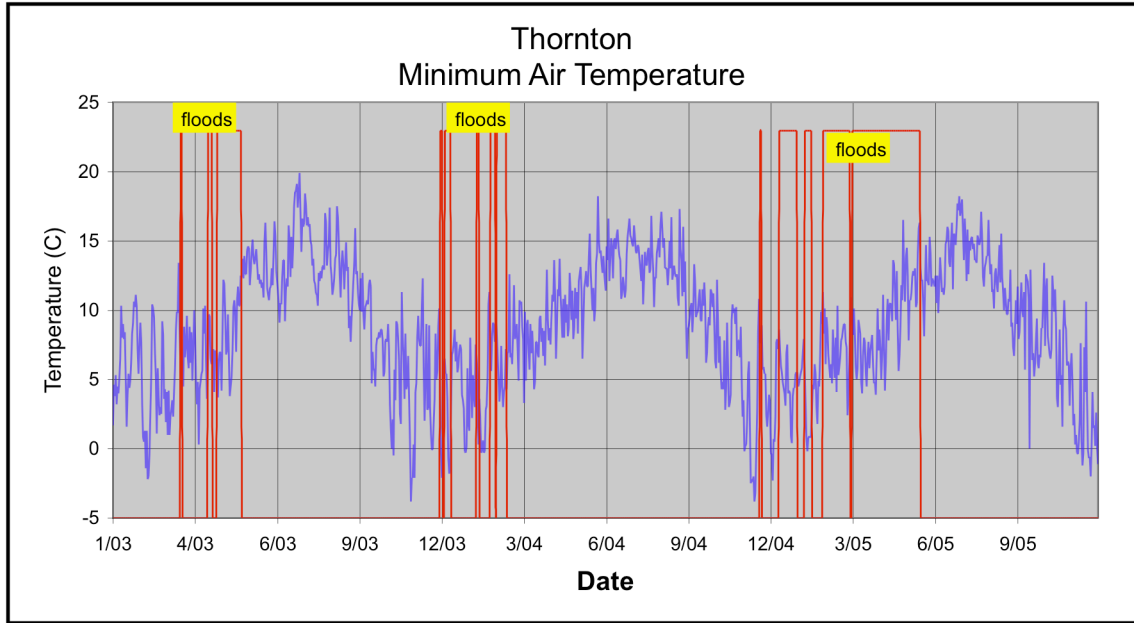


Figure 2. Minimum daily air temperature at Thornton immediately south of the Cosumnes River Preserve. Vertical red lines delineate intervals of floodplain connection with the river based on a breach sensor.

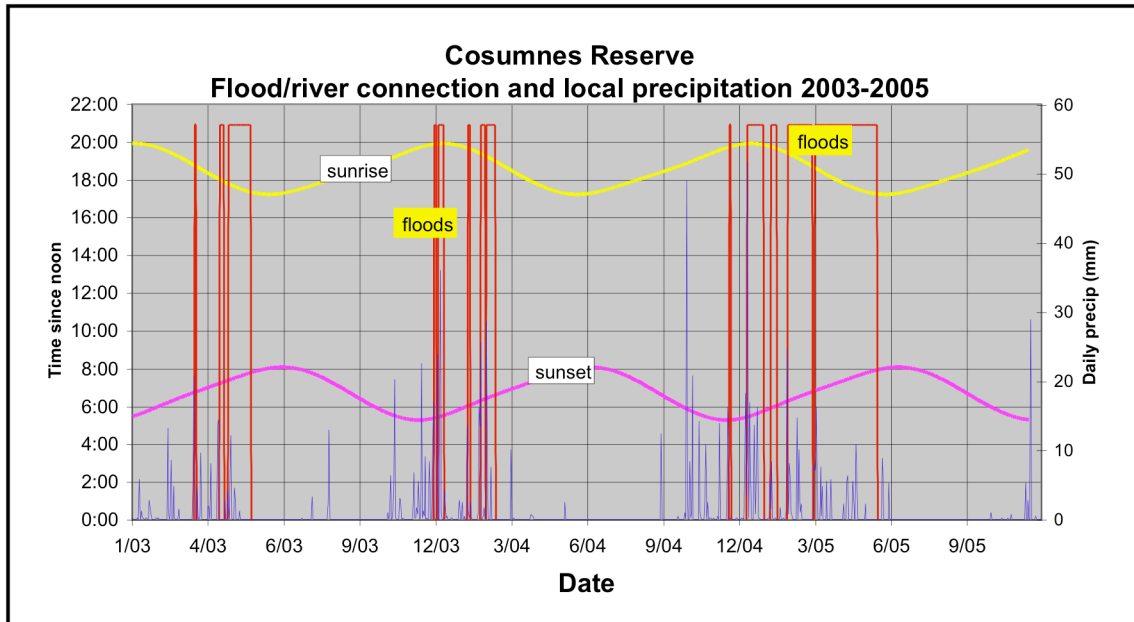


Figure 3. Daily precipitation at Thornton immediately south of the Cosumnes River Preserve. Vertical red lines delineate intervals of floodplain connection with the river based on a breach sensor. Sunrise and sunset lines show variation in day length.

Subsequent to disconnection, considerable surface water is retained by floodplain topography, both longer term in the Triangular and Lower Floodplain Ponds and other inundated areas at least minimally suitable for aquatic insect production. Seasonal changes in insolation, plant transpiration, local precipitation and presumably local

sediments are major controls on rate of clearance of residual flood water. The Lower Floodplain Pond and, particularly, water levels in Wood Duck Slough are actively manipulated seasonally by pumping and valve closures in association with irrigation. Typically both floodplain ponds were either dry or nearly so, terminating aquatic emergence and generating a thanatocoenose of aquatic organisms (carp, crayfish, tadpoles, insects) several months prior to onset of the subsequent rainy season.

The Sacramento-Yolo mosquito control personnel monitor for disease vector mosquitoes throughout the county and applied formulations of *Bti*, a mosquito control agent compatible with organic agriculture, on the Preserve, when dictated by their program guidelines. The establishment of West Nile virus in Sacramento County during this study raised additional concerns about mosquito abatement and discussion of additional intervention methods.

Sampling was distributed across Triangular and Lower Floodplain sites and the Tall Forest (a mature riparian forest remnant) to the south. Over the duration of this study, vegetation change in former agricultural fields that now are open floodplain was notably dynamic, with infill and height increases in woody vegetation. The gradual addition of a meter or more of vegetation structure changed both the insect emergence and aerial aggregation environment and foraging conditions for bats.

## 2.2. Emergence trapping

To estimate rates of emergence of adult aquatic insects from inundated habitats, we deployed anchored, round, floating 0.25 sq m traps constructed of 0.3 mm white mesh “No See-um netting” for 24 h (Figure. 4). Emergence within these traps was collected with oral aspirators and preserved in 70% ethanol for measurement and identification in the laboratory. Body mass of the adult aquatic insects collected was computed from regressions of body length to dry mass (Sabo *et al.* 2002).



Figure 4. Emergence traps deployed overnight at Corps levee breach near Wendell's during minimal flow from the Cosumnes channel (left) onto the floodplain.

We deployed emergence traps each in of five persistently wetted habitats: Triangular Flood Plain Pond (TP), Wood Duck Slough (WD), Cosumnes R. channel at the Corps levee breach (WC), and the Lower Floodplain Pond (LP). During floods, we also placed three traps in the floodplain shallows at three sites: adjacent to the NW-SE track from the cross levee to the Triangular Pond (TPR), in the swale east of the N-S track to the Lower Floodplain Pond and on an E-W transect across the west margin of the Accidental Forest. In this location three traps extended out from the edge into open meadow at 10, 20 and 30 m with an additional three at equivalent positions when submerged extending into the forest (AFE/AFI) (Figure 1).

Floodplains undergoing spillover and reconfinement of river water are among the most dynamic of habitats. A number of measurement challenges arise in this setting, particularly the challenge of moving boundaries between inundated and dry habitat, and the depth of water and strength of flow over a particular site. We devised the following scheme for sampling this variation. For each of the four main habitats (TP, WD, WC, and LF), we set out two transects of emergence traps. Each transect had one trap set at the shoreline (“shore” the most spatially shifting location), at “deepest”, the deepest accessible point in the water body (up to a maximum of 1.2-4 m, as constrained by sample collectors of variable height wearing waders), and a point midway between these in depth “1/2 depth”. The deep and half depth traps were always floating, anchored to the bottom by three length of chain, when deployed.

The shore trap was intended to partly sample crawling emergents (S. Nakano, pers. comm.), so that half the trap perimeter was floating and a portion of the other half rested on emergent shoreline sediment or matted vegetation. A mesh fabric skirt extended from the trap perimeter and was anchored to the shore with weights so that the trap lower margin was in contact with either shore or water surface. At steep shoreline sites on the river channel riprap and the excavated margins of Wood Duck Slough, the shore trap deployments were vulnerable to rapid changes in water level. In instances where trap placements covered floating aquatic macrophytes, the surfaces were disturbed to flush pre-existing insect accumulations.

This scheme let us compare emergence rates from sites that had short, intermediate, and long inundation periods during a given flood event (shore, 1/2 depth, and deepest, respectively). The period of inundation might vary inversely with benthic productivity, if for example this were higher in shallower habitats, as might be the case for light limited organisms.

Near the peaks of flood events, high flows in the levee constrained river channel and through the Corps Breach made emergence sampling at that site both impractical (given a low to moderate flow trap design) and unsafe, so there are data gaps at those events. During extensive floods, shoreline deployment sites did not exist at several stations.



### 2.3. Bat acoustic detection

Monitoring of bat activity on the floodplain relied on up to twelve solar powered passive ultrasound monitors (Figure 5). Each unit contained a broadband frequency-dividing Anabat II ultrasound detector and a storage ZCAIM --- a data processing device which schedules daily recording and stores compressed bat calls on removable Compact flash memory card (Titley Electronics, Ballina, NSW, Australia). These items were in a waterproof enclosure with 1.2 Amp hour battery and solar panel regulator (EME Systems, Berkeley, CA). The detectors with the extension cable and microphone were calibrated to a common sensitivity by ear using a pulsed 40-kHz source (Nevada Bat Technology; Las Vegas, NV). All components were attached near the top of a T-bar fence post.



Figure 5. Solar powered bat ultrasound monitor on the Lower Floodplain.

Systems were downloaded approximately monthly and checked for component degradation and bio-fouling. Because the systems were vulnerable to submersion, and the depth of flooding was typically not predictable, stations at lower elevations on the floodplain were removed prior to the first substantial flood and replaced later in the spring as circumstances permitted. Some elevated stations could be maintained longer (e.g. the levee slope adjacent the river at the Corps Breach [WC]), but were still periodically removed.

Analysis of the very large data set (over 2.4 million 15 second compressed acoustic sample files) relied upon software filters based on species or acoustic guild call characteristics. At present not all species can be separated acoustically. In this study the three species for which species-specific filters could be used were *Lasiurus blossevillii*, *Lasiurus cinereus*, and *Tadarida brasiliensis*. Particularly for the latter two, the filter extracts a subset of calls that overlap minimally with other species. Both *L. cinereus* and

*T. brasiliensis* have a varied vocal repertoire which includes both a distinctive subset of call and others which are similar to both one another and additional species common on this site, *Eptesicus fuscus*. Thus one of the acoustic guilds or phonotypes used was “25 kHz bats”. The category labelled “My40” could include three *Myotis* species that echolocate at 40 kHz (*M. ciliolabrum*, *M. lucifugus*, and *M. volans*). Although the category “My40” acknowledges that three species could occur locally, we are confident, based on visual observations with night vision equipment and spotlights and on habitat use, that the most of the My40 calls are from *M. lucifugus*.

Much of the analysis of acoustic data was automated, but it was necessary to visually scan portions of the data to remove broadband noise files generated by rain, ice formation or microphone failures, as well as birds or insect sounds that overlapped in frequency with lower frequency bat calls. Particular attention was given to data that appeared anomalous (*e.g.*, all peaks in activity were checked to make certain they reflected bat activity). Processing of the data will continue after submission of this report.

### 3.0 RESULTS

#### 3.1. Spatial and seasonal patterns in insect emergence

Nematocerans (Diptera) dominated emergence by number at most sampling sites on most dates (Figures 6-9). Brachycerans (Diptera) were the second most numerous group, followed by stoneflies (Plecoptera). In February 2005, we sampled an emergence peak of capniid stoneflies (“winter stoneflies”) at all sites, with the strongest emergence at the Triangular Floodplain pond. This emergence pulse of capniids occurred in February 2004 and possibly in February 2003 as well, as copious exuviae of these stoneflies were noted on emergent structures above water levels and by the field observations of Carson Jeffries. These small, short winged, black stoneflies are of possible nutritional significance for bats, as the order contains some species with more calcium than is typical for other insects (Studier and Sevick 1992). Calcium may be a limiting nutrient for bats, especially lactating females (Keeler and Studier 1992).



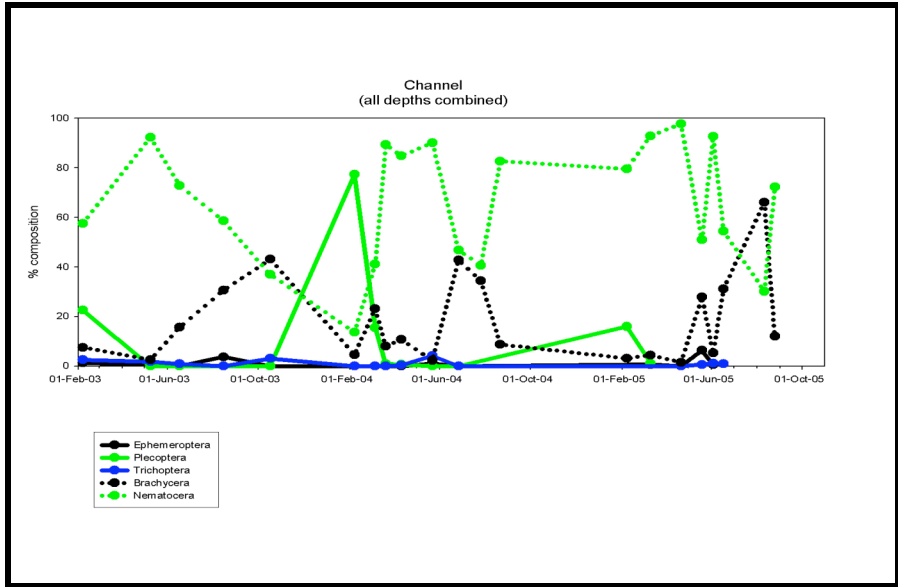


Figure 6. Percent composition of insect taxa in the river channel.

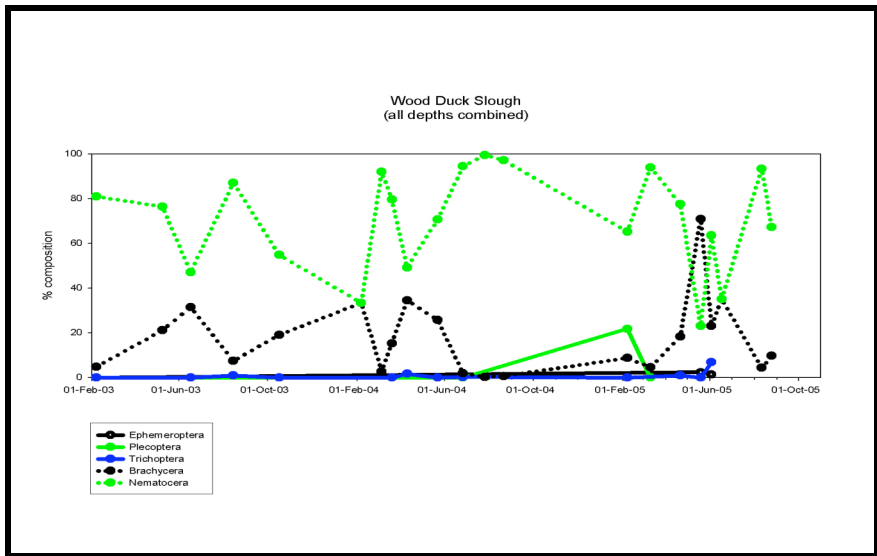


Figure 7. Percent composition of insect taxa at Wood Duck Slough.

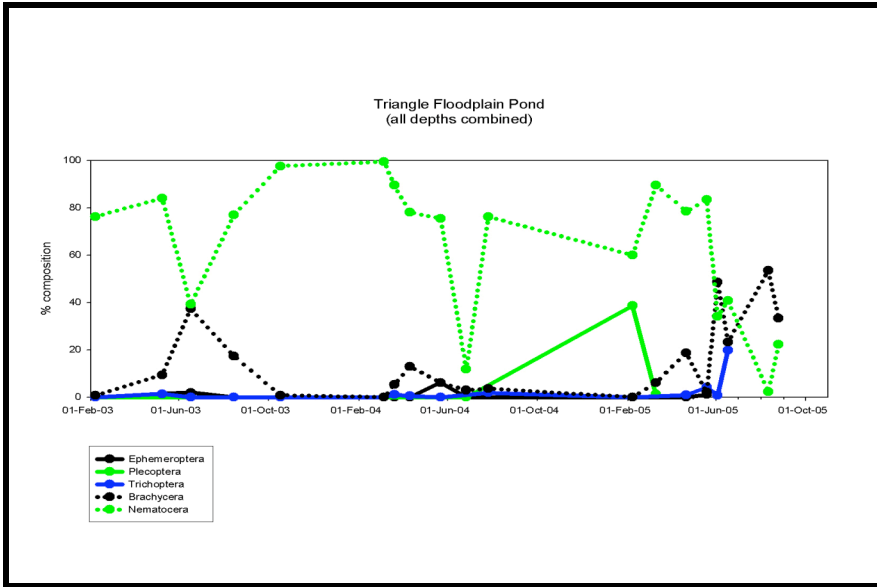


Figure 8. Percent composition of insect taxa at Triangle Floodplain pond.

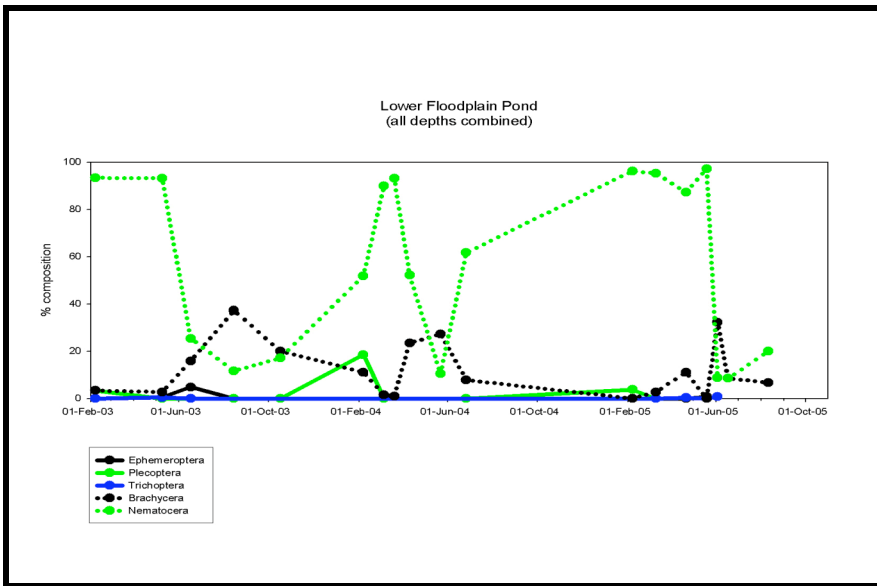


Figure 9. Percent composition of insect taxa at Lower Floodplain Pond.

The relative depth of water over which traps were set had no effect on the biomass or abundance of emergence (Figures 10-15). There was no strong consistent difference in emergence rates from the four main habitats, but Wood Duck Slough (one of the two channelized sites with permanent water) showed the strongest peak emergence in July 2004, with a maximum trap catch of 1006 individuals  $0.25 \text{ m}^{-2}$  (Figure 11, 16). Emergence from the inundated floodplain was considerably higher than emergence from the permanent channels on the same dates by abundance (Figure 16), but not by biomass

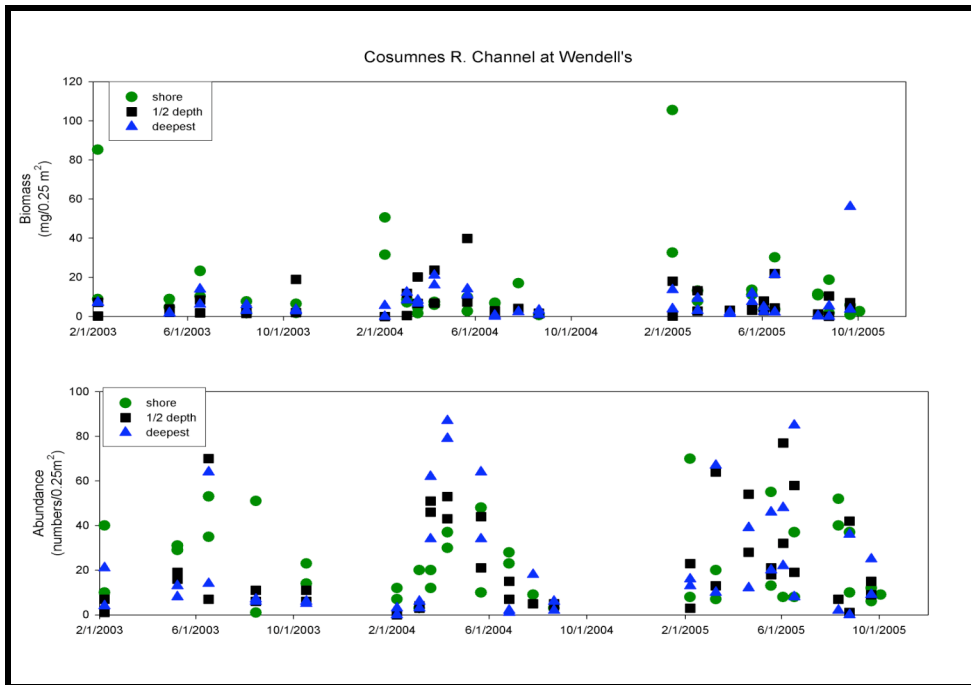


Figure 10. Biomass (mg/0.25m<sup>2</sup>) and abundance of insects (numbers/0.25m<sup>2</sup>) by date at River Channel near Wendell's.

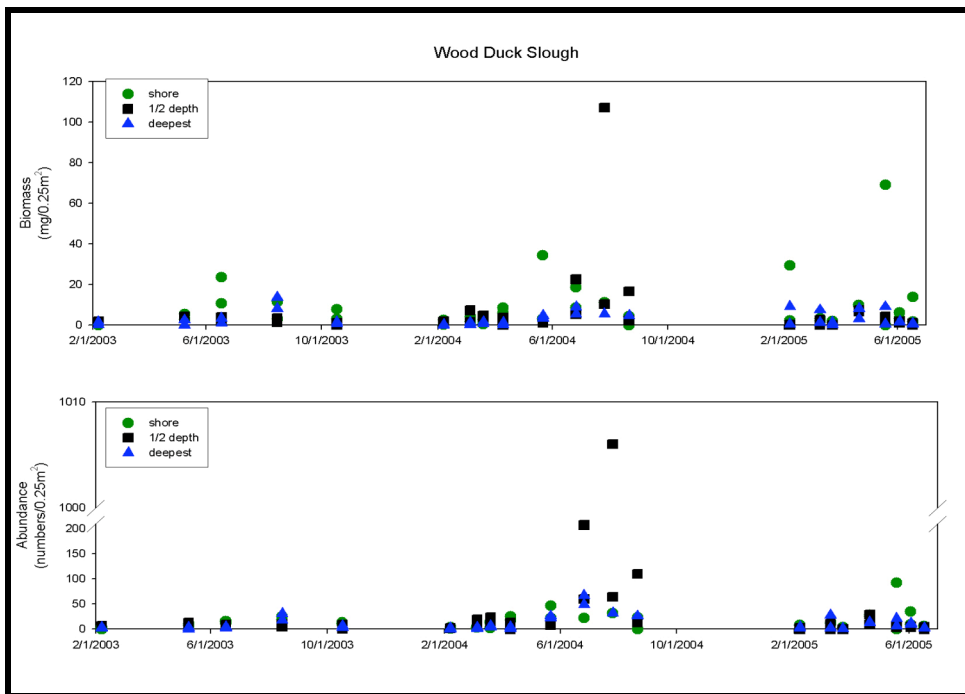


Figure 11. Biomass (mg/0.25m<sup>2</sup>) and abundance of insects (numbers/0.25m<sup>2</sup>) by date at Wood Duck Slough.

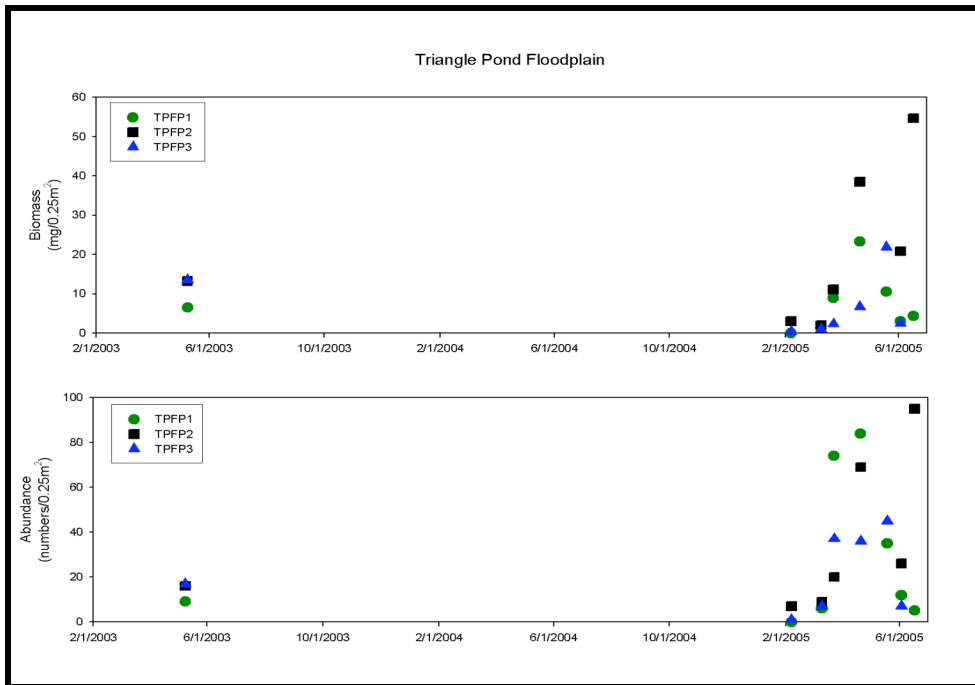


Figure 12. Biomass (mg/0.25m<sup>2</sup>) and abundance of insects (numbers/0.25m<sup>2</sup>) by date at Triangle Pond Floodplain.

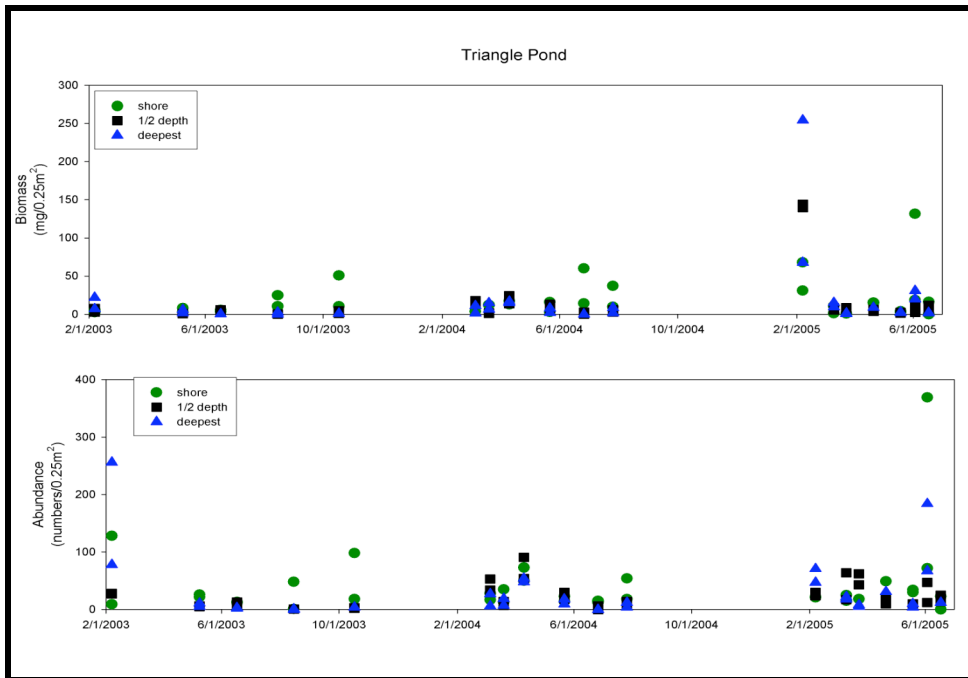


Figure 13. Biomass (mg/0.25m<sup>2</sup>) and abundance of insects (numbers/0.25m<sup>2</sup>) by date at Triangle Pond.

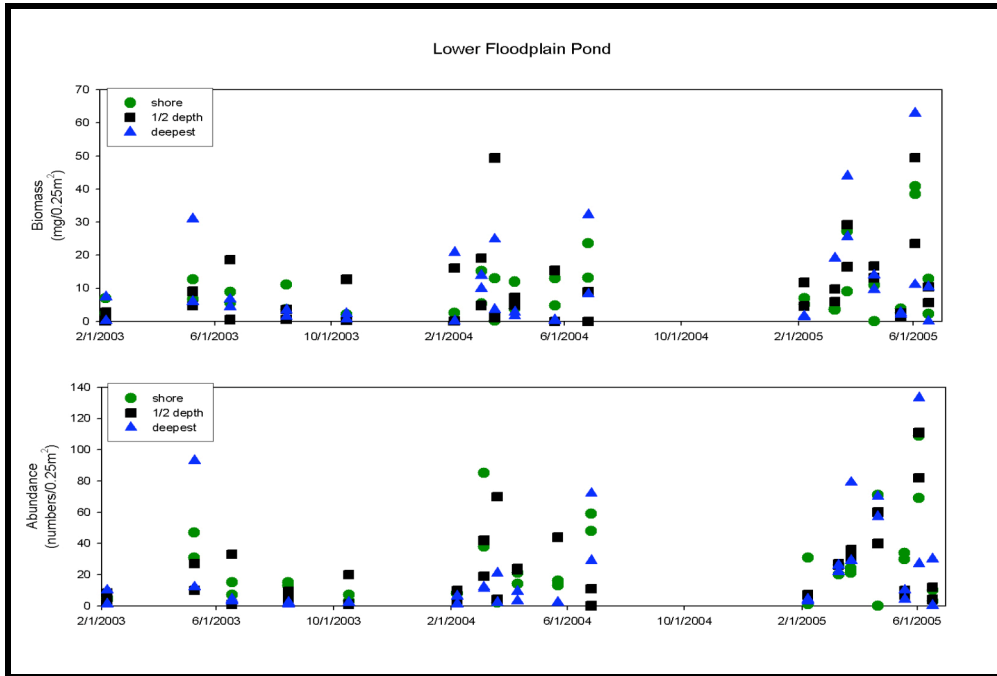


Figure 14. Biomass ( $\text{mg}/0.25\text{m}^2$ ) and abundance of insects ( $\text{numbers}/0.25\text{m}^2$ ) by date at Lower Floodplain Pond.

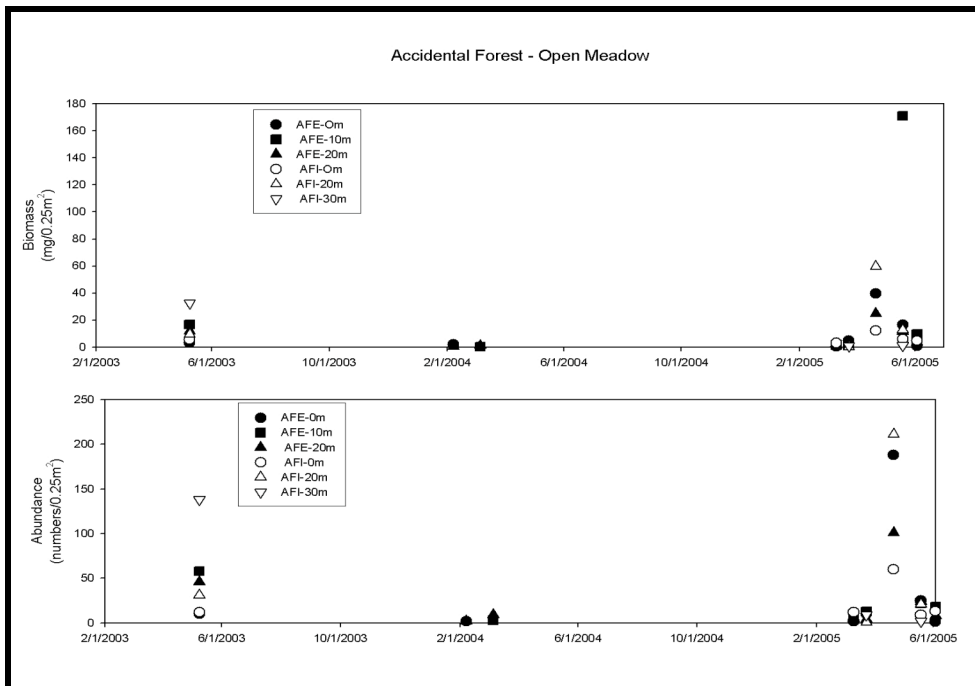


Figure 15. Biomass ( $\text{mg}/0.25\text{m}^2$ ) and abundance of insects ( $\text{numbers}/0.25\text{m}^2$ ) by date at Accidental Forest – Open Meadow.

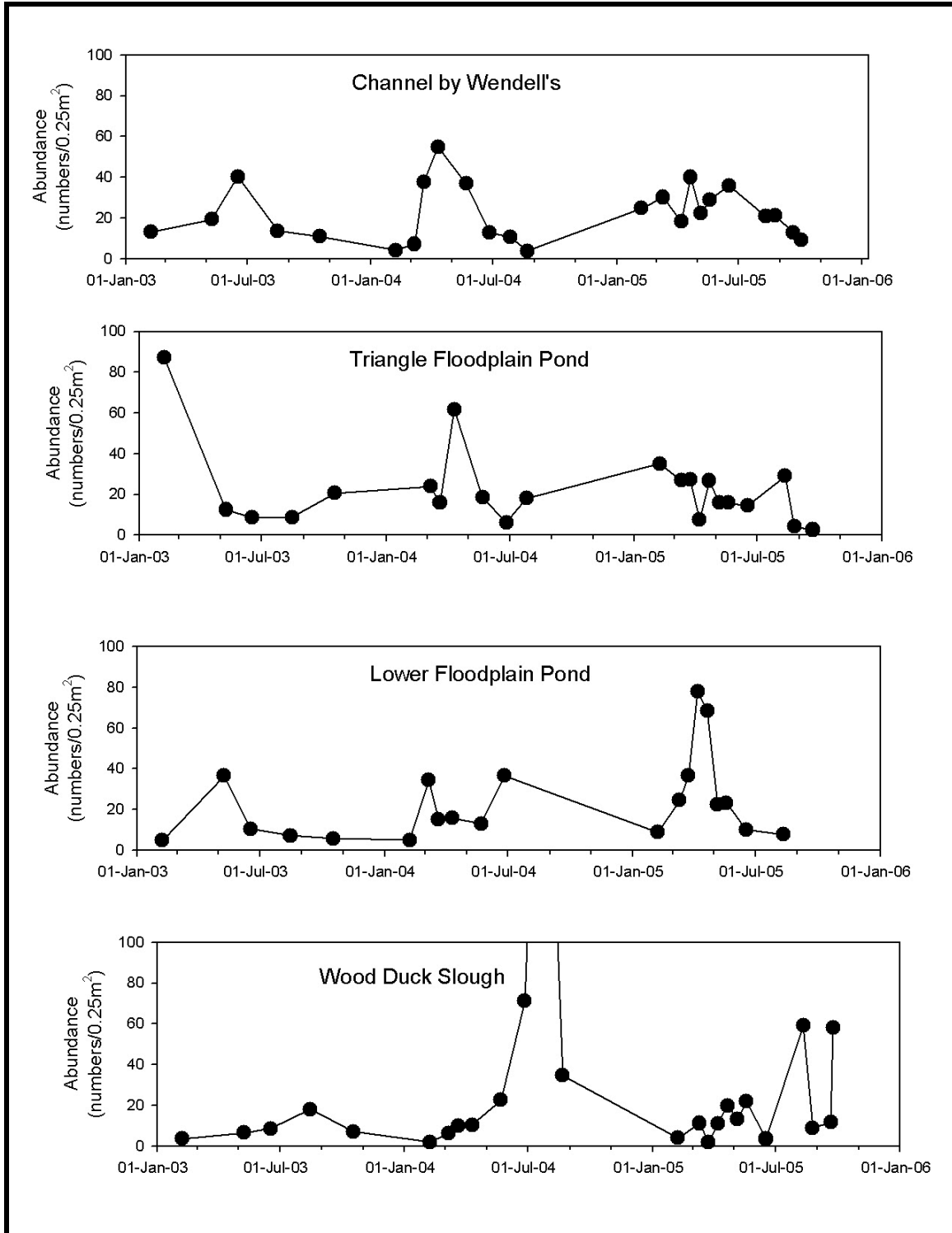


Figure 16. Abundance of insects (numbers/0.25m<sup>2</sup>) by date at four sampling sites.

(Figure 17, 18), likely due to the requirement of longer-lived larvae of large taxa like odonates for longer-lasting aquatic habitat. Biomass data have been plotted for all aquatic taxa (Figure 17) and for taxa omitting odonates (Figure 18), because the occurrence of a few large dragonflies in some samples greatly increased the spatial-temporal variability

in the data. Wood Duck Slough seemed the most seasonal of the four habitats, with emergence by numbers peaking in mid-summer during all three years (Figure 16). The maximum emergence from Wood Duck Slough (on July 26 2004) by

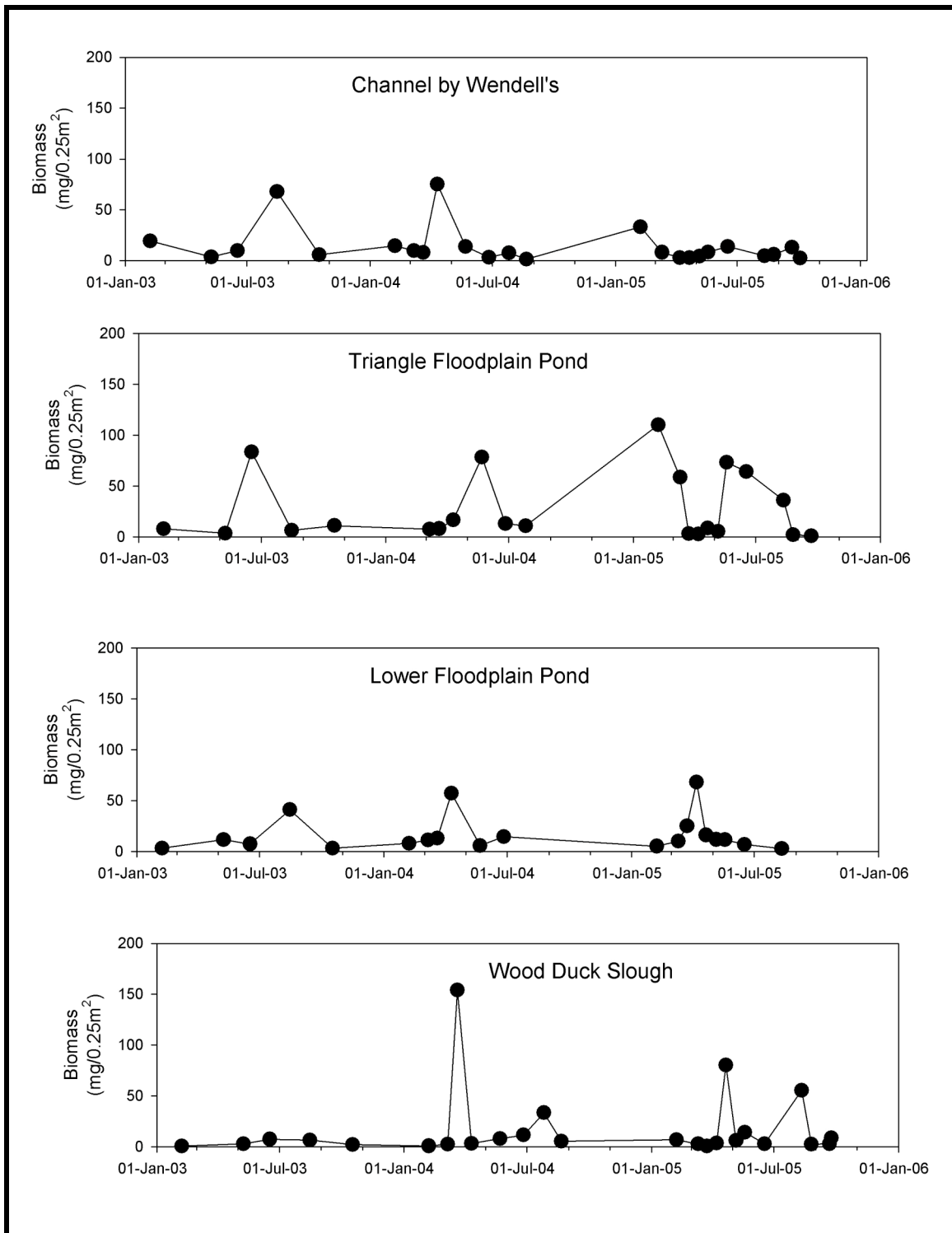


Figure 17. Biomass of all insects (mg/0.25m<sup>2</sup>) by date at four sampling sites.

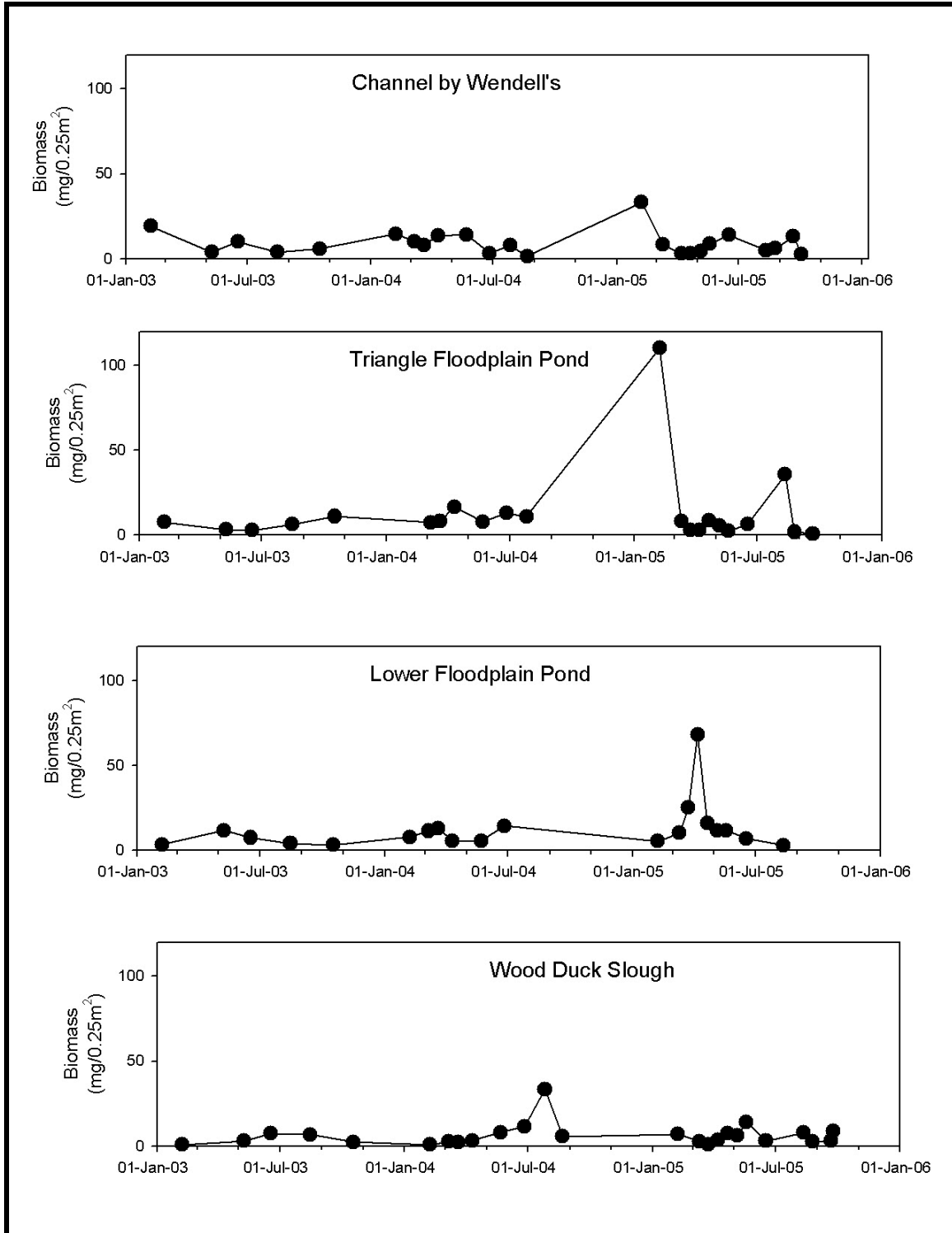


Figure 18. Biomass of insects (mg/0.25m<sup>2</sup>), without odonates, by date at four sampling sites.

numbers was 1006 individuals 0.25 m<sup>-2</sup>, corresponding to the maximum biomass emergence of 107 mg dry weight 0.25 m<sup>-2</sup>. The River Channel emergence peaks tended to begin earlier in the spring, and in 2003 and 2004, were waning by July. Maximum



channel emergence by numbers was 87 individuals  $0.25 \text{ m}^{-2}$  on April 10 2004, and the biomass peak on February 7, 2005 was 105 mg dry weight  $0.25 \text{ m}^{-2}$ . At the Lower Floodplain, the peak biomass and abundance of emergence coincided in a trap over the deepest habitat on June 3 2005: 63 mg dry weight  $0.25 \text{ m}^{-2}$  and 133 individuals mg dry weight  $0.25 \text{ m}^{-2}$ , respectively. On the Triangular Pond habitat, emergence peaks began earlier in the year, and subsided as the floodplain dried during the summer (Figure 16). Peak emergence biomass from this habitat was 254 mg dry weight  $0.25 \text{ m}^{-2}$  on February 7, 2005, while peak numbers emerging were 369 individuals  $0.25 \text{ m}^{-2}$  on June 3, 2005. On the Triangular Pond floodplain (Figure 1), where six traps were deployed when the habitat was inundated, the peak biomass and abundance of emergence occurred on June 17, 2005 (55 mg dry weight  $0.25 \text{ m}^{-2}$  and 95 individuals  $0.25 \text{ m}^{-2}$ , respectively). Along the Accidental Forest to Open Meadow Transect (Figure 15), distance into the forest from the meadow edge did not consistently correspond to higher emergence. The peak emergence in terms of biomass (171 mg dry weight  $0.25 \text{ m}^{-2}$ ) occurred 10 m into the forest on May 19 2005, and the peak emergence by abundance (211 individuals  $0.25 \text{ m}^{-2}$ ) occurred 20 m into the forest on April 21 2005 (Figure 15).

In our three years of sampling, the maximum abundance of insects sampled emerged from Wood Duck Slough, the permanent, often stagnant channel in the Tall Forest, while the maximum biomass emerged from the Triangular Pond, which was considerably more sunlit. We have chosen to emphasize maxima for comparing emergence among dates and times, as we believe most of the biases in our emergence trapping cause us to underestimate rates of insect emergence, sometimes severely.

## **3.2. Patterns of Bat Acoustic Activity**

### **3.2.1. All Bats**

Figures 19a,b & c depict the overall pattern of bat acoustic activity by year for all sampling sites, all species combined. These data are counts/night of approximately 15 second samples containing at least two bat calls. It shows the expected seasonal pattern of an increase in activity in March that continues to a peak in August, and then gradually declines until the end of October. With a few dramatic exceptions discussed in more detail below, there is relatively little bat activity between October and March.

A primary focus of this project was to examine seasonal patterns of bat foraging activity over the floodplain (semi-permanent or seasonal water) and sources of permanent water (the main channel of the Cosumnes River and Wood Duck Slough). A comparison of patterns of activity by year at floodplain sites (Figs. 20a,b & c) and permanent water sites (Figs. 21a,b & c) reveals that in 2003 and 2004 the permanent water sites had more bat foraging activity than the floodplain, with activity more evenly distributed between two habitat types in 2005, an unusually wet year. In 2004 and 2005, Wood Duck Slough received overall and more consistently more bat foraging activity than any other site. Bat activity at this site was comparable to that on the main channel at Wendell's in 2003. Bat activity at the floodplain sites was highly pulsed, with increases in activity broadly corresponding to flooding.

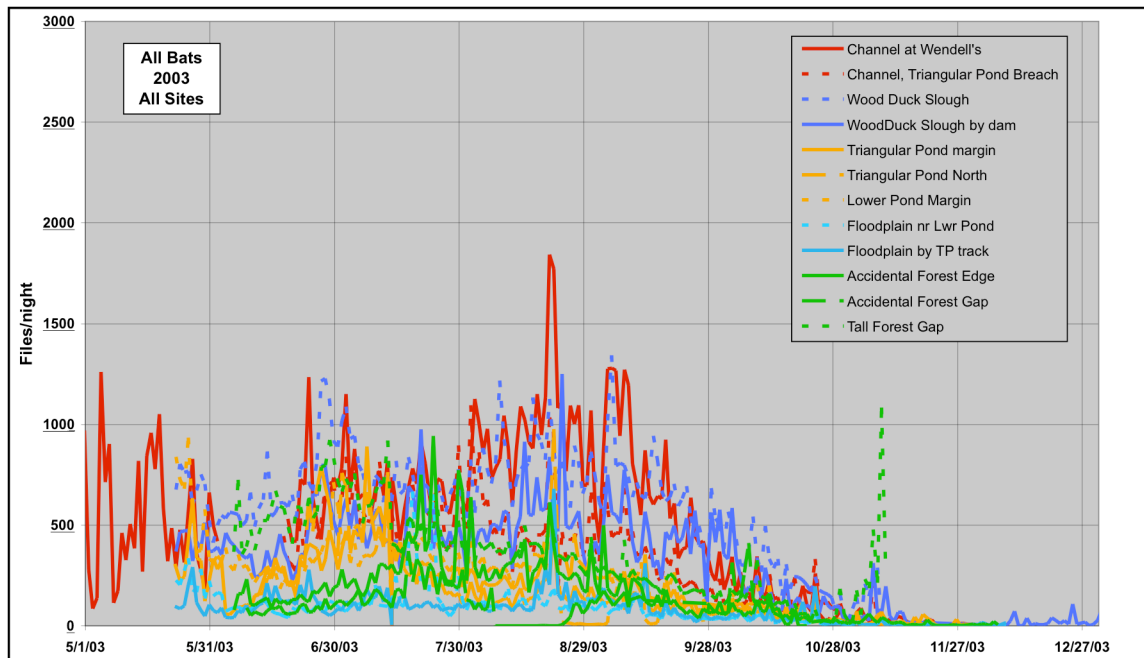


Figure 19a. Acoustic activity, all bats at all sampling sites for 2003.

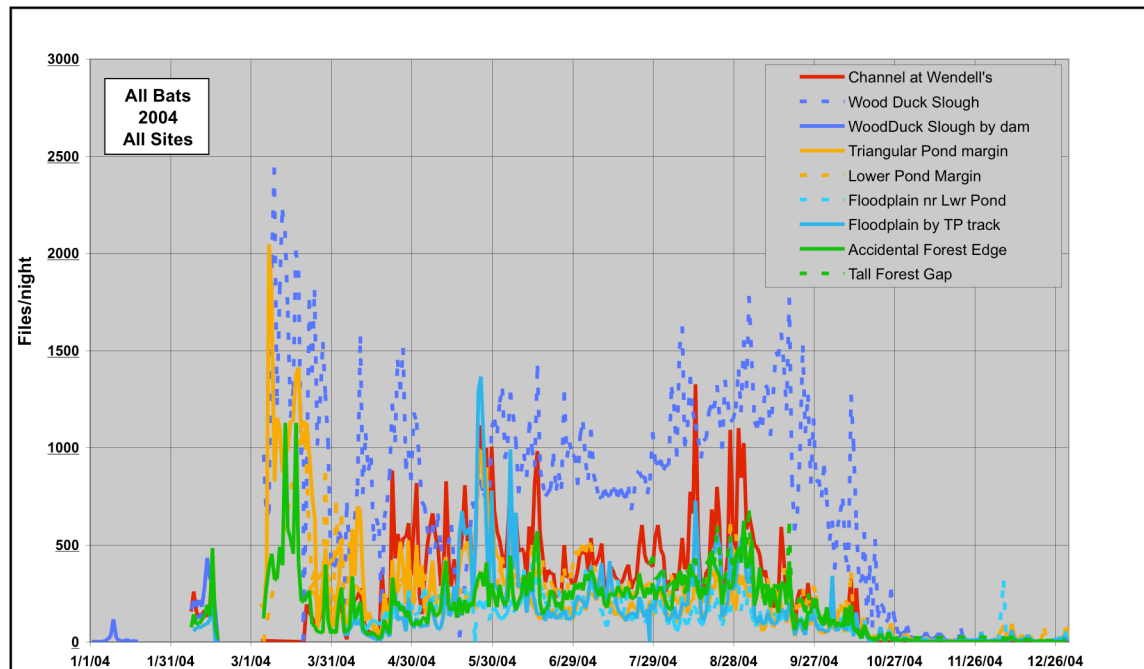


Figure 19b. Acoustic activity, all bats at all sampling sites for 2004.

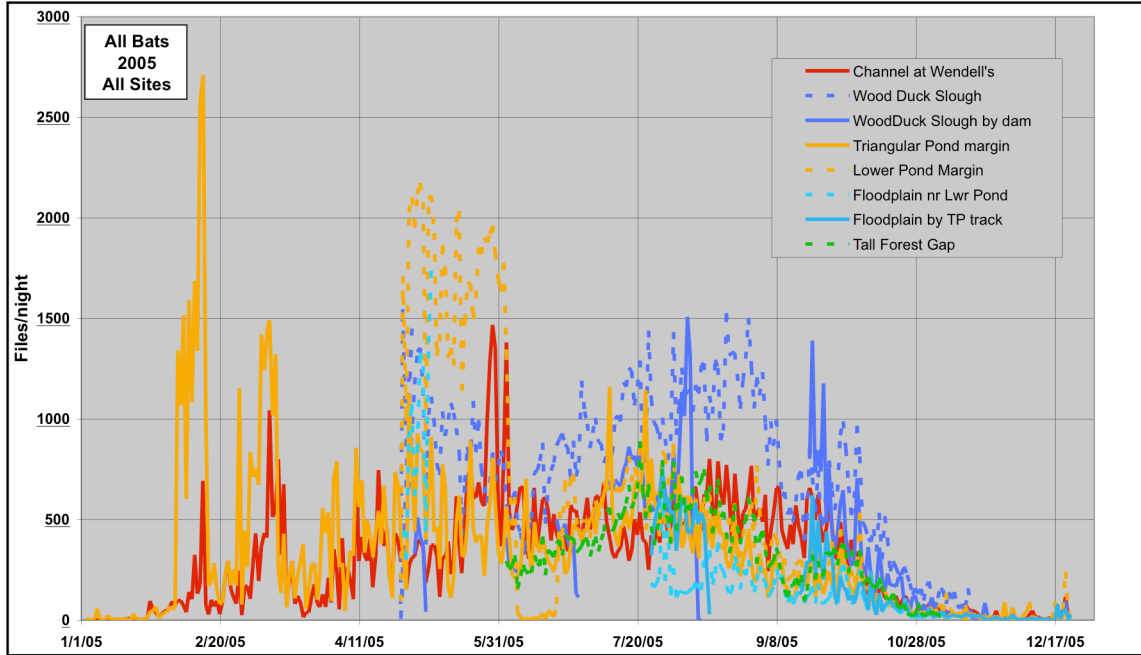


Figure 19c. Acoustic activity, all bats at all sampling sites for 2005.

Because different species have different requirements for roosting and foraging, we have divided the bat assemblage into three categories relevant to the goals of this project: 1) species that rely heavily or exclusively on aquatic emergent insects and often forage close to or in contact with the water surface; 2) open-air foragers that feed on a variety of insects, generally at greater than 10 m above the ground; and 3) foliage-roosting bats that also tend to be open-air foragers, but cover a large vertical range (from close to the water surface to high above the ground), and also forage along vegetation edges.

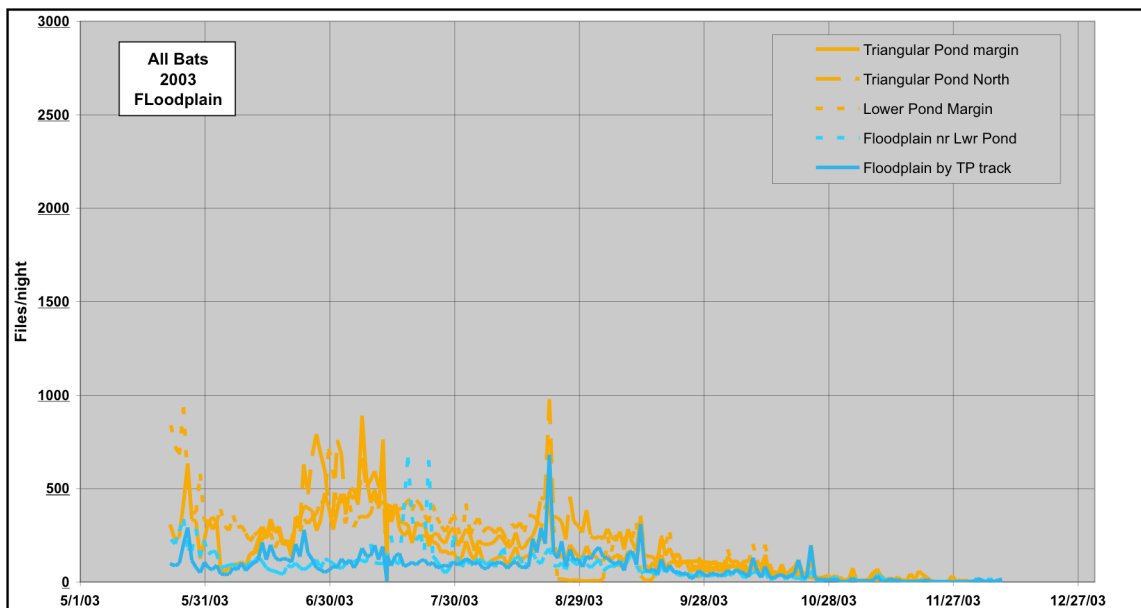


Figure 20a. Acoustic activity, all bats at floodplain sites for 2003.

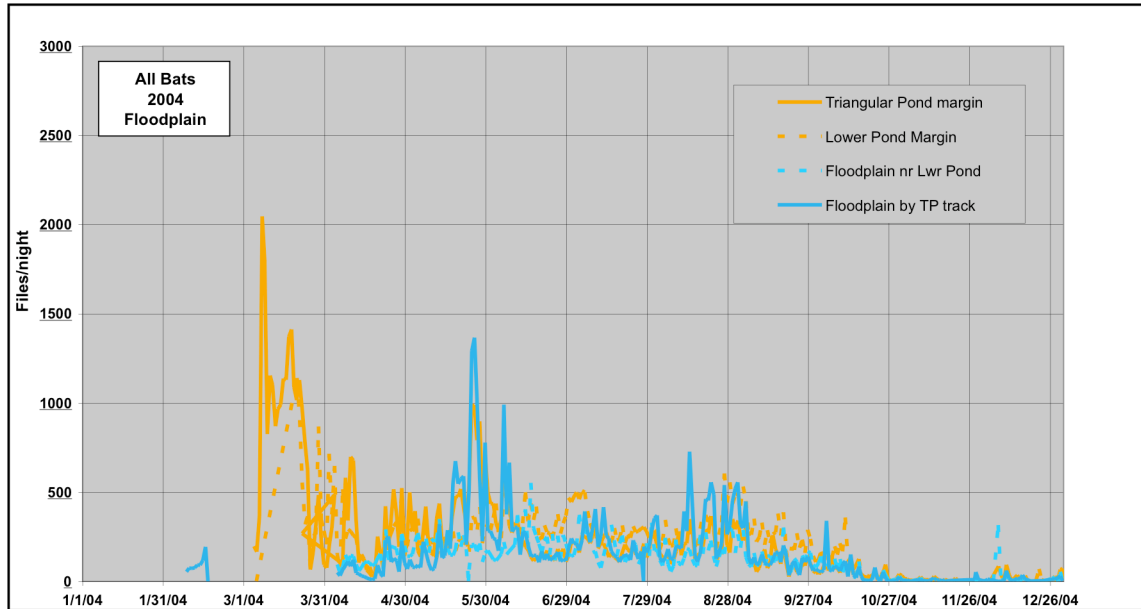


Figure 20b. Acoustic activity, all bats at floodplain sites for 2004.

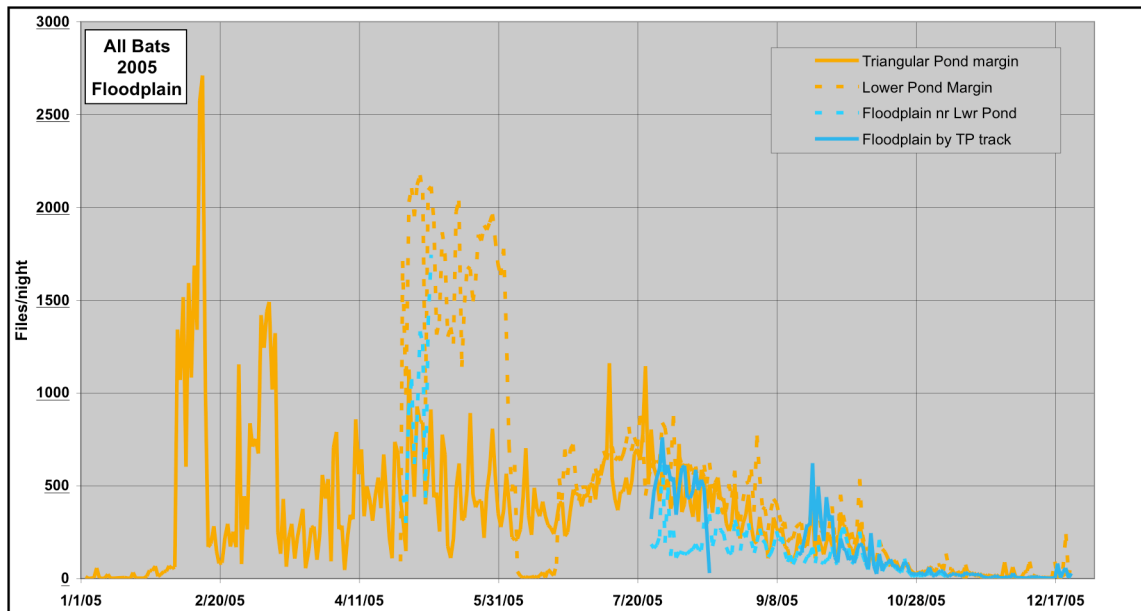


Figure 20c. Acoustic activity, all bats at floodplain sites for 2005.

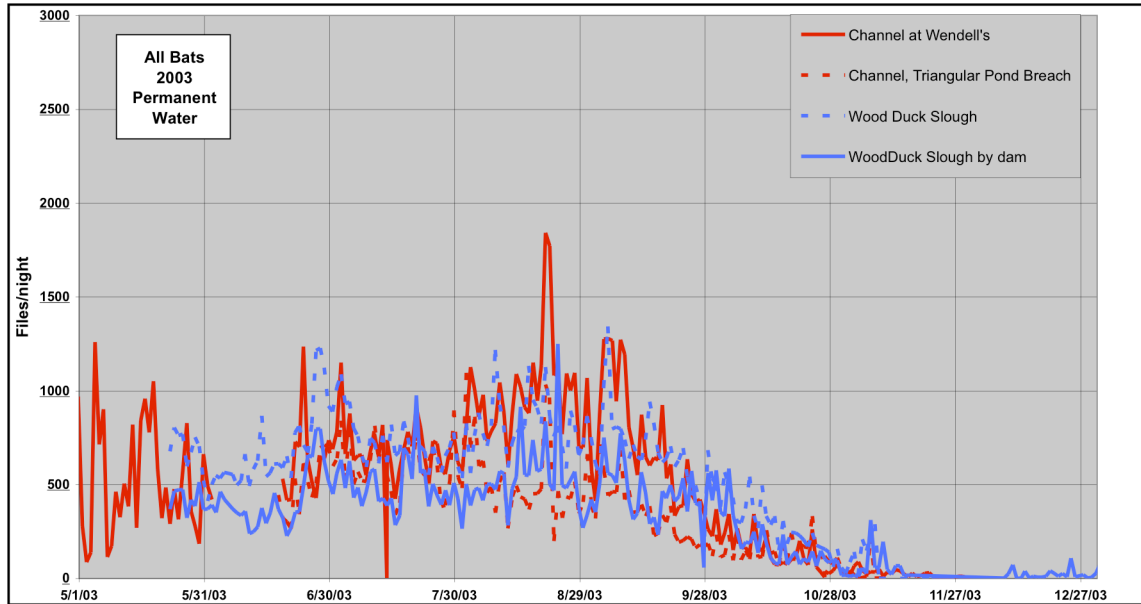


Figure 21a. Acoustic activity, all bats at permanent water sites for 2003.

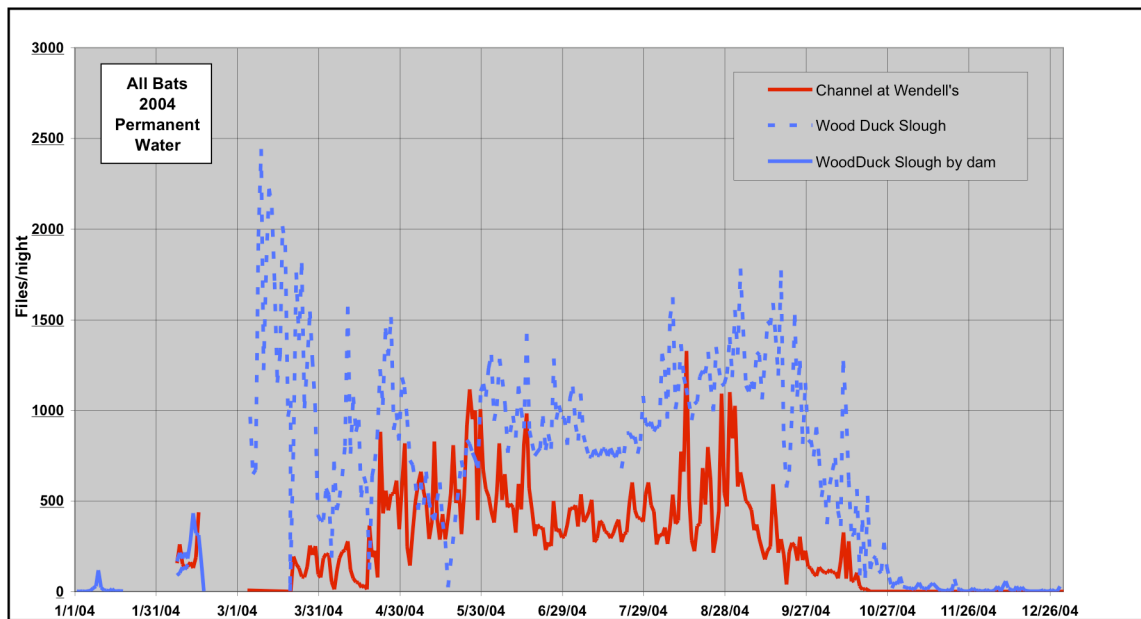


Figure 21b. Acoustic activity, all bats at permanent water sites for 2004.

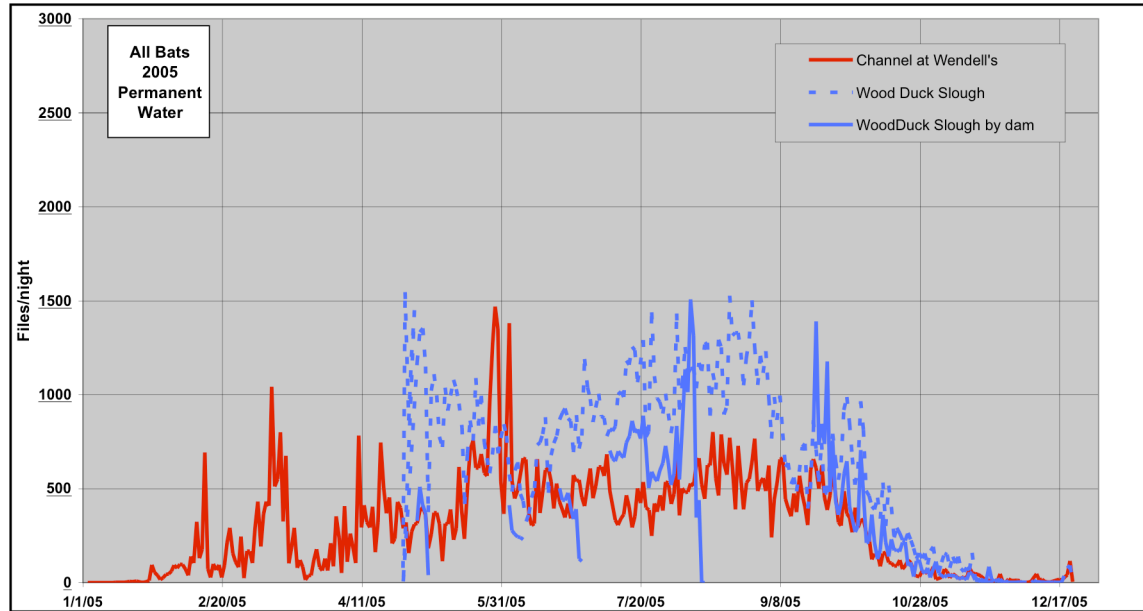


Figure 21c. Acoustic activity, all bats at permanent water sites for 2005.

### 3.2.2. Aquatic Dependent Bats

The most prevalent aquatic dependent species at the site was a *Myotis* echolocating at 40 kHz. Because there are three species that echolocate at this frequency and all could occur at the site, we have labeled this taxon My40. We are confident, however, based on visual observations at multiple sites, that most of the detections are for *Myotis lucifugus*, a species known in other localities to rely heavily on aquatic emergent insects, particularly chironomids and caddis flies (Belwood and Fenton 1976, Anthony and Kunz 1977, Fenton and Barclay 1980). Although it has been frequently been documented feeding over both water and land (e.g., Barclay 1991), it is generally regarded as favoring aquatic habitats.

Figures 22a,b & c show the patterns of activity for 40 kHz *Myotis* for the two and a half years (May 2003–December 2005) of the study. A significant feature of activity for this category is it is restricted to non-winter months. Thus the winter floods would potentially influence the foraging activity of this species only to the extent that they provide an environment for insect production a number of months later. Activity for this species was observable beginning in March in 2004, and not until late April in 2005, a year with a colder and later spring. There is a striking correlation between the peak in My40 acoustic activity in May 2005 at the Lower Pond Margin and a corresponding peak in insect abundance and biomass at the Lower Floodplain Pond (Figures 16-17). Likewise, there is a large peak in abundance of insects at Wood Duck Slough in June and July 2004 (Figure 16), and this site is used by My40 in preference to all others during the corresponding period.

Bodies of both permanent (Wood Duck Slough) and seasonal to highly transient (Triangular Pond, Lower Pond and the Floodplain sites) water on the floodplain are overall more important to this species than the river channel at the breach (Wendell's) or

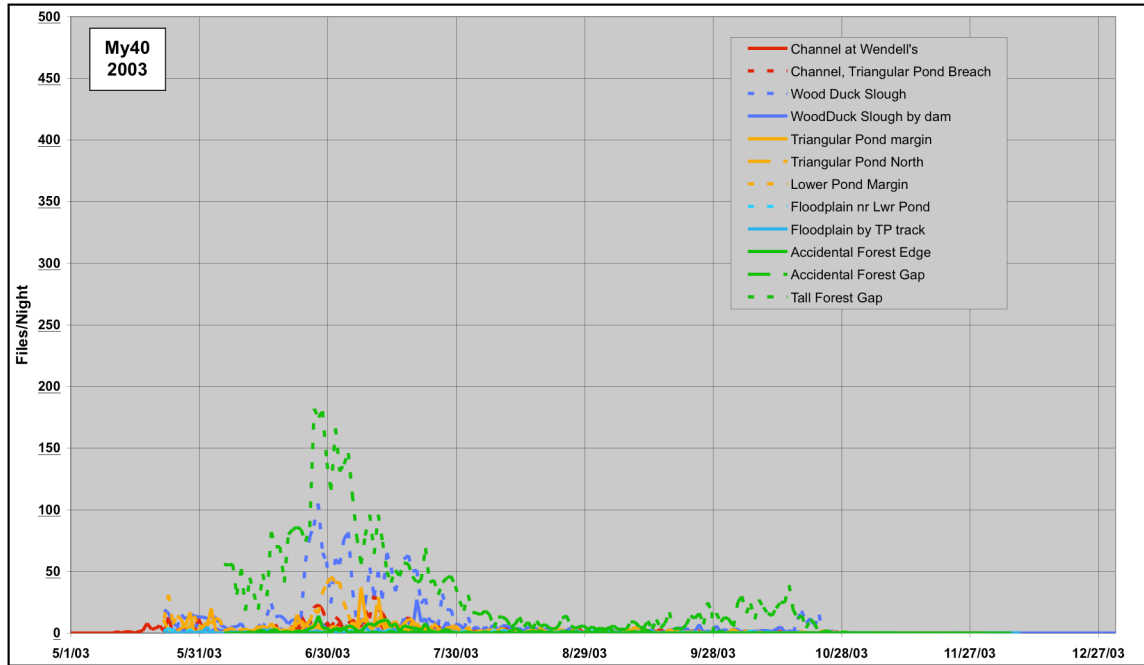


Figure 22a. Acoustic activity for 40 kHz *Myotis* at all sites in 2003.

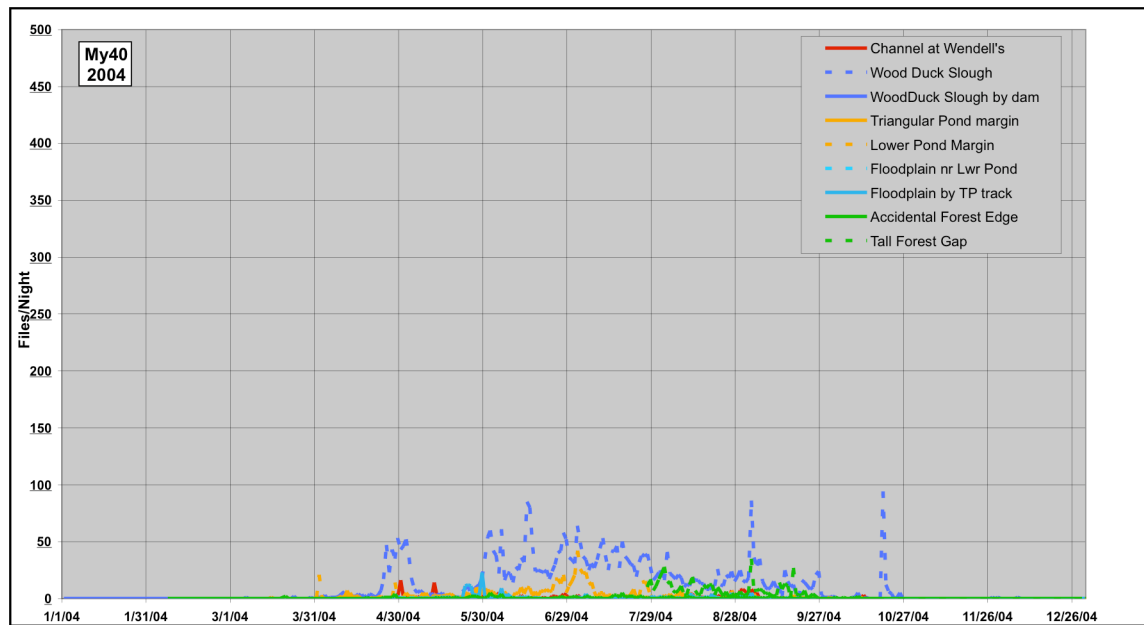


Figure 22b. Acoustic activity for 40 kHz *Myotis* at all sites in 2004.

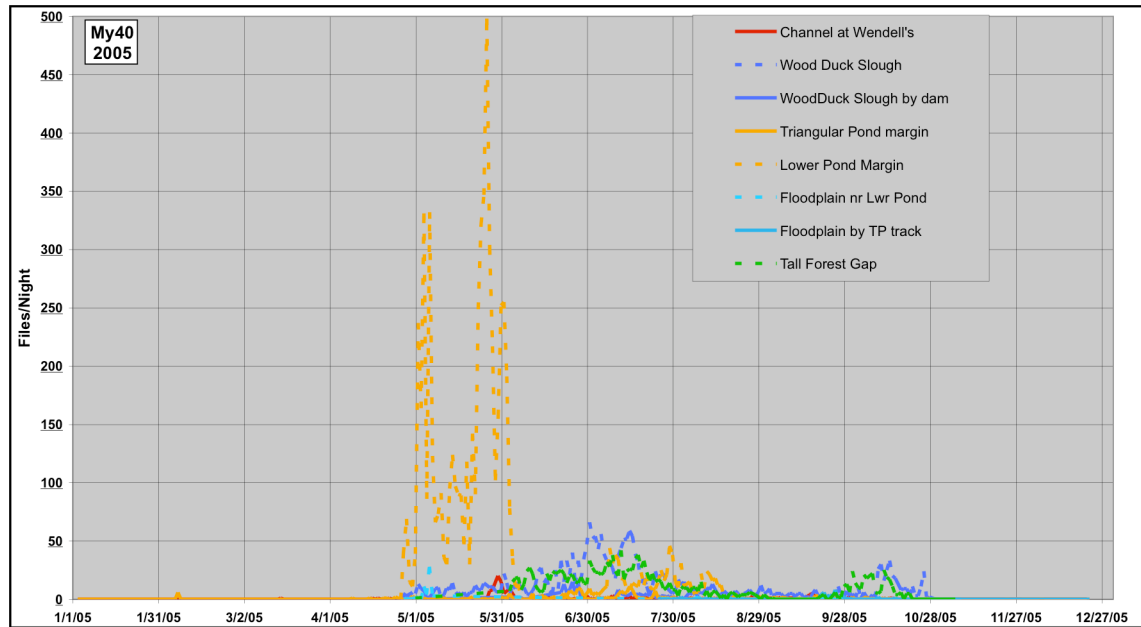


Figure 22c. Acoustic activity for 40 kHz *Myotis* at all sites in 2005.

the forest sites (with the notable exception of a peak in activity in the Tall Forest Gap in June 2003). Because terrestrial insects were not collected we are unable to correlate this increase in acoustic activity with insect abundance.

Evidence of substantial *M. lucifugus* activity at this site is consistent with data collected in the Sacramento River riparian in 2002 (Stillwater Sciences 2003), but contrasts with museum collections that there are only seven specimens from the Valley and no records from Sacramento County. *M. lucifugus* is one of the most widely distributed species in the United States and Canada, and is generally regarded as a “building bat” because of its propensity to form large colonies in human structures. While recent radio-tracking studies in multiple localities have also documented tree-roosting, it is striking that no colonies have been identified in the Central Valley for an apparently prevalent riparian species.

More detailed time/activity plots for *M. lucifugus* at selected stations (Figures 23a-e) strongly suggest that this species is roosting in the mature forest near Wood Duck Slough. These plots group the acoustic detection times in 5 minute presence/absence points with each dot indicating one or more detection files. At both Tall Forest Gap and Wood Duck Slough there is a concentration of activity at dawn and dusk. There are no such corresponding peaks at Triangular Pond (floodplain), Cosumnes channel (open river), or Accidental Forest Edge (younger forest). While the dusk and dawn activity at Wood Duck Slough could represent both emergence from a roost and foraging at water sites very near to a roost, foraging at these times could only occur close to a roost site. The most likely roost sites would be in the mature forest. The more prolonged concentration of foraging activity in late June and early July at Wood Duck Slough would be consistent with extended foraging by reproductive females trying to meet the energetic demands of lactation.



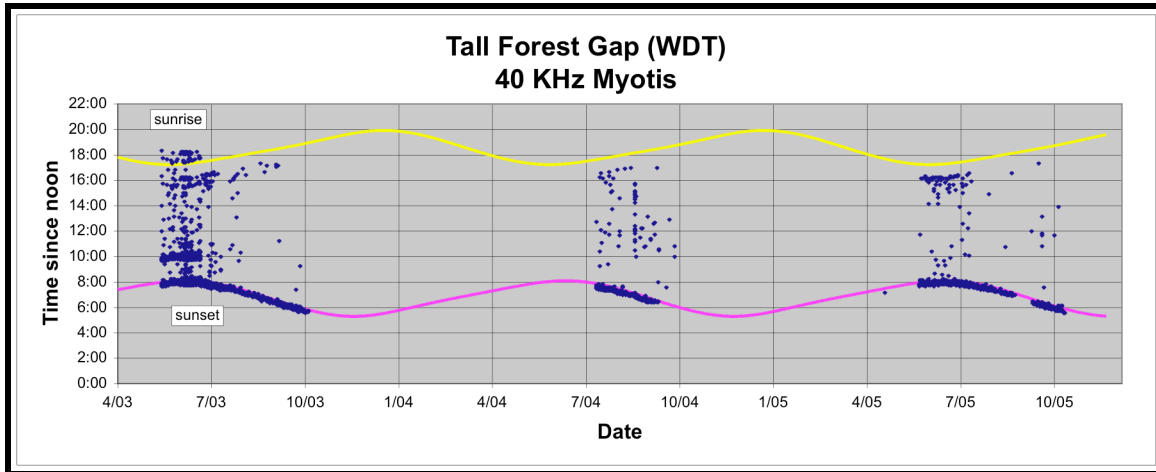


Figure 23a. Timing of acoustic activity by date in Tall Forest Gap for 40 kHz *Myotis*.

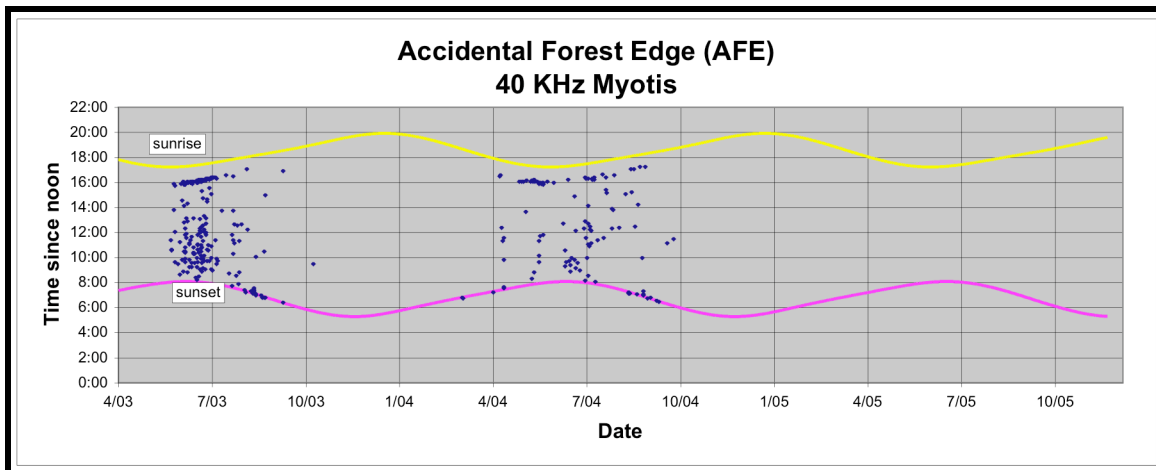


Figure 23b. Timing of acoustic activity by date at Accidental Forest Edge for 40 kHz *Myotis*. This station was not monitored in 2005.

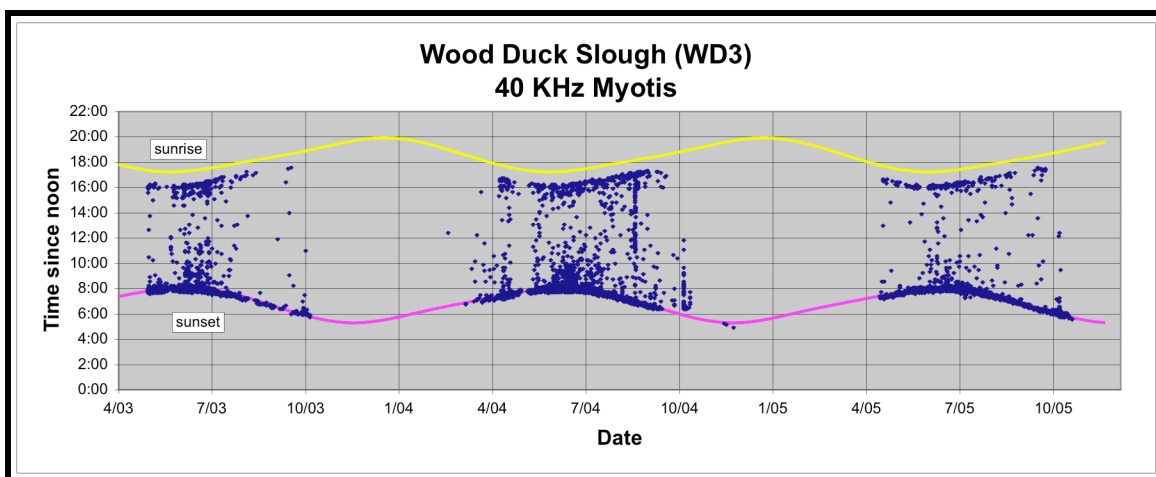


Figure 23c. Timing of acoustic activity by date at Wood Duck Slough for 40 kHz *Myotis*.

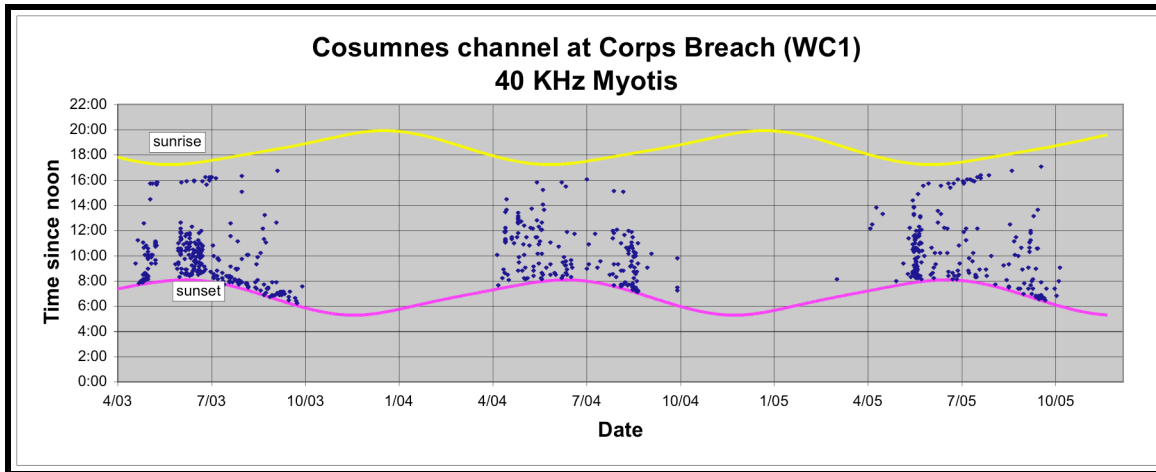


Figure 23d. Timing of acoustic activity by date at main river channel at Corps Breach for 40 kHz *Myotis*.

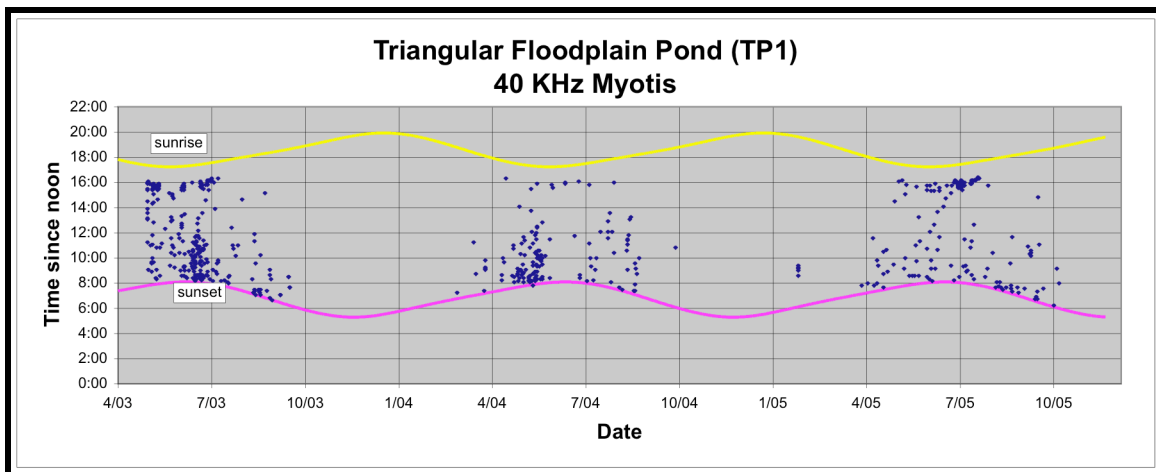


Figure 23e. Timing of acoustic activity by date at Triangular Floodplain Pond for 40 kHz *Myotis*.

### 3.2.3. Aerial Foraging Bats

The species that best fits the category of open air pursuit foraging, can be identified acoustically, and was relatively abundant at the study site is *Tadarida brasiliensis*. We were also interested in tracking the activity of this species, because unlike most of the other species potentially occurring at the site, this species is active in numbers in the winter. Also, replacement of the Franklin Boulevard Causeway during the study offered an opportunity to monitor the relationship between changing numbers in a large roost and activity at nearby foraging sites. A large colony (estimated at 60,000) was displaced in 2002 from the causeway, located less than 2 km from the study site. Replacement habitat was provided in a new bridge and made available to the bats by the end of 2004. Over 15,000 bats (almost entirely *T. brasiliensis*) had reoccupied the bridge two months after the completion of construction (Johnston et al. 2004).

Figures 24a,b & c display the seasonal distribution of acoustic activity for *T. brasiliensis* between May 2003 and December 2005. This fast-flying, highly mobile species shows peaks of activity at a wider range of sites than My40 – The main river channel in May 2003, the forest edge in July 2003, and the Triangle Pond, Floodplain, and Wood Duck Slough at various other times. Overall, the broad open areas offered by the floodplain and Triangle Pond are favored. In 2003 and 2004 activity is high at the Triangle Pond and the Floodplain during times when these areas were flooded. The peak of activity in early February 2005 at the Triangle Floodplain Pond corresponds to a peak in insect biomass and follows a period of intense precipitation.

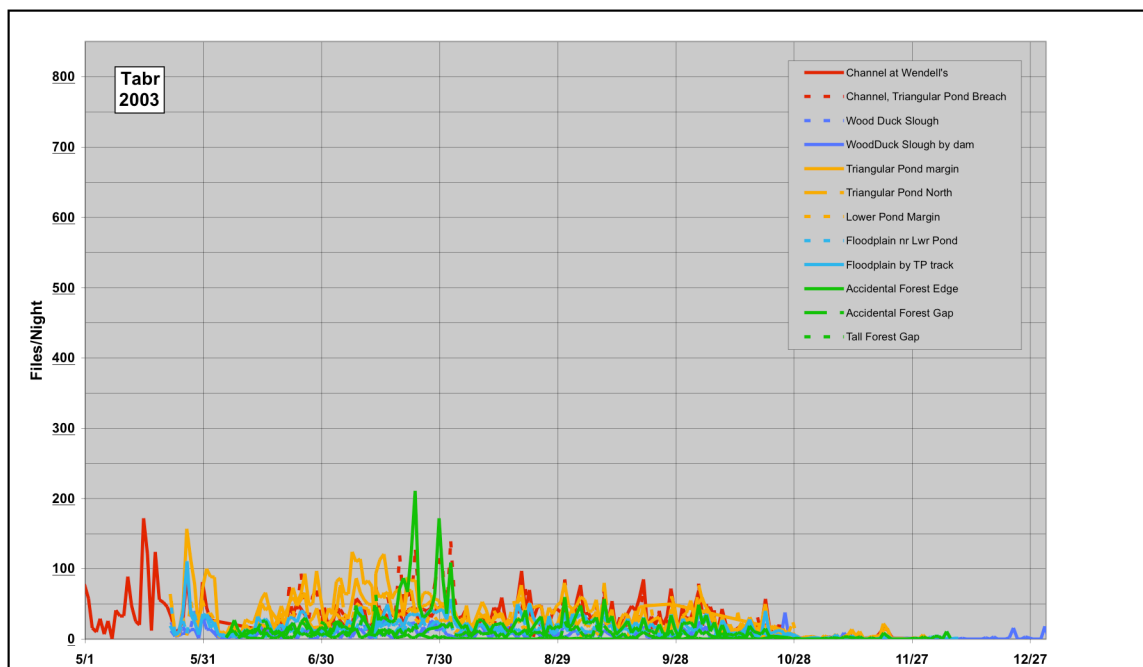


Figure 24a. Acoustic activity for Mexican free-tailed bat, *Tadarida brasiliensis* at all sites in 2003.

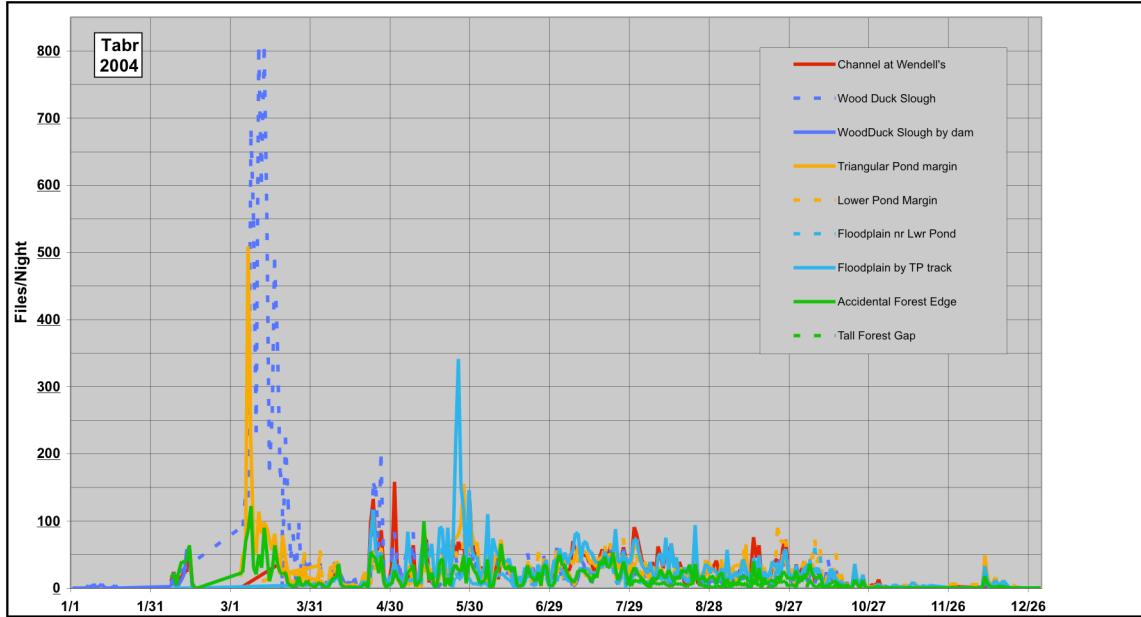


Figure 24b. Acoustic activity for Mexican free-tailed bat, *Tadarida brasiliensis* at all sites in 2004.

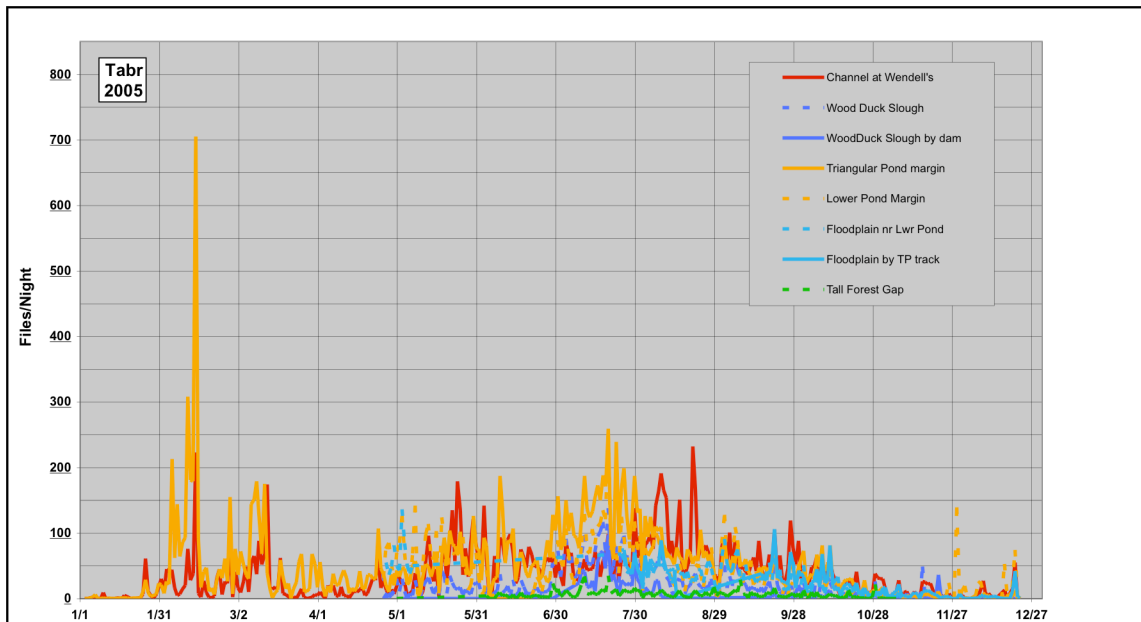


Figure 24c. Acoustic activity for Mexican free-tailed bat, *Tadarida brasiliensis* at all sites in 2005.

Time activity maps (Figures 25a-f) show high activity throughout the night for this species, with particularly intense activity on the floodplain and main river channel and the least amount of activity in the Tall Forest Gap. Also, *T. brasiliensis* activity appears higher in 2005 than in prior years. this may be linked by the re-establishment of substantial roosting in mitigation habitat incorporated in the replacement Franklin Boulevard Causeway.

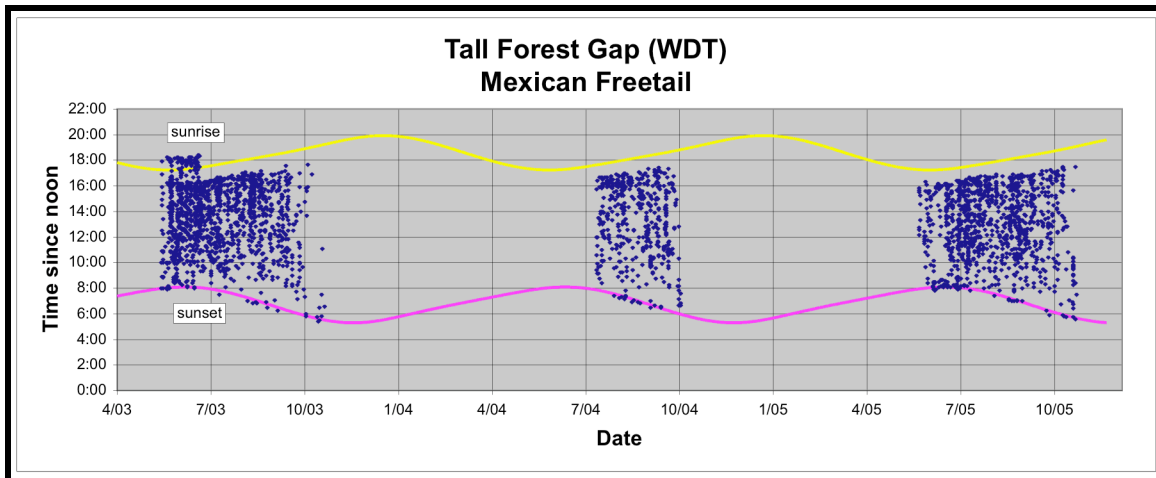


Figure 25a. Timing of acoustic activity by date at Tall Forest Gap for Mexican free-tailed bat, *Tadarida brasiliensis*.

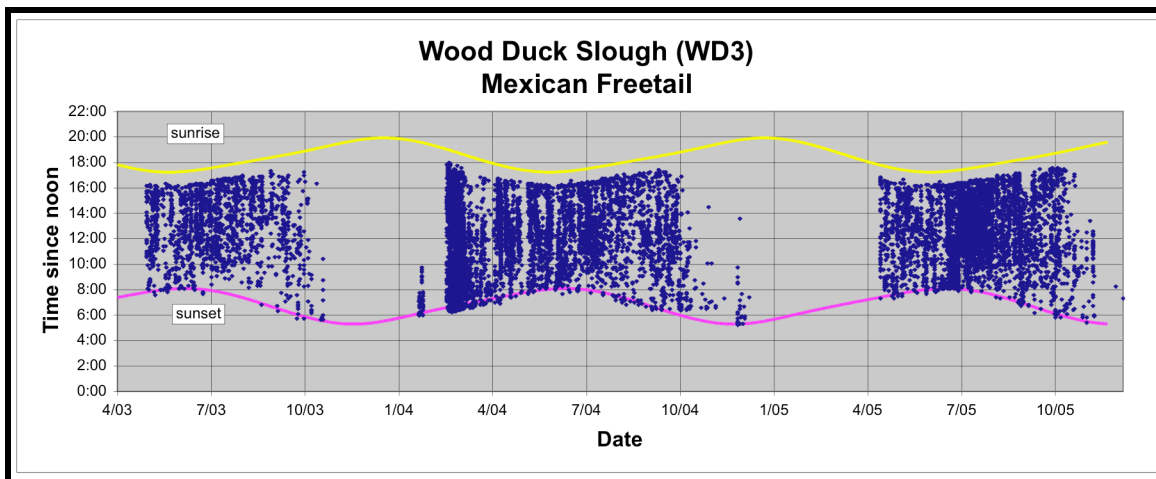


Figure 25b. Timing of acoustic activity by date at Wood Duck Slough for Mexican free-tailed bat, *Tadarida brasiliensis*.

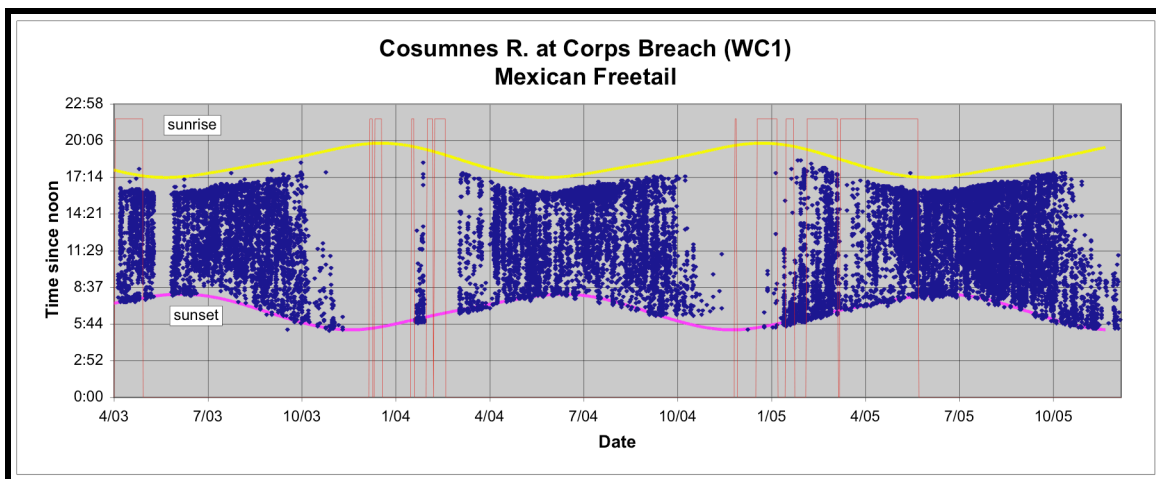


Figure 25c. Timing of acoustic activity by date at Corps Breach in main river channel for Mexican free-tailed bat, *Tadarida brasiliensis*. Flood events indicated.

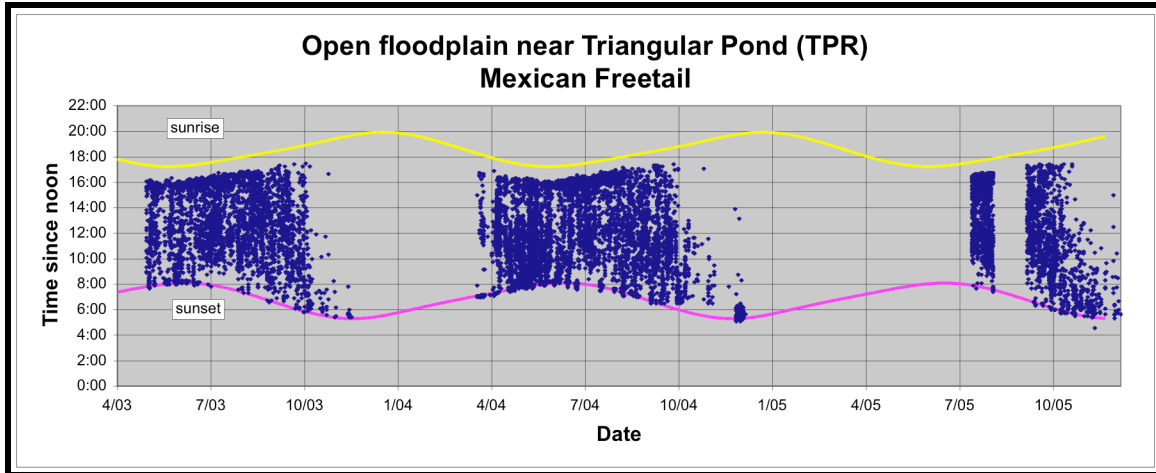


Figure 25d. Timing of acoustic activity by date at the open floodplain near Triangle Pond for Mexican free-tailed bat, *Tadarida brasiliensis*.

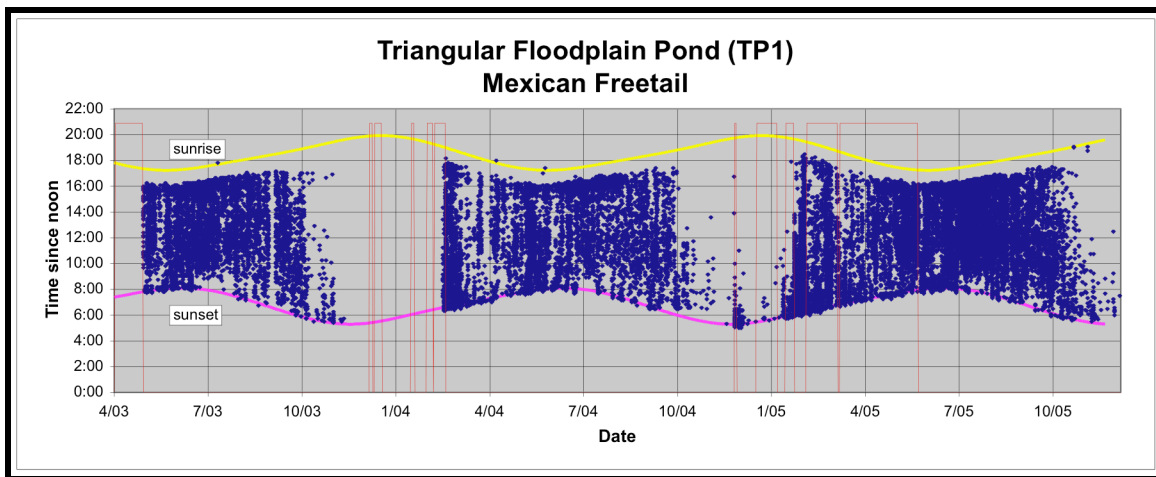


Figure 25e. Timing of acoustic activity by date at Triangular Floodplain Pond for Mexican free-tailed bat, *Tadarida brasiliensis*. Flood cycles indicated.

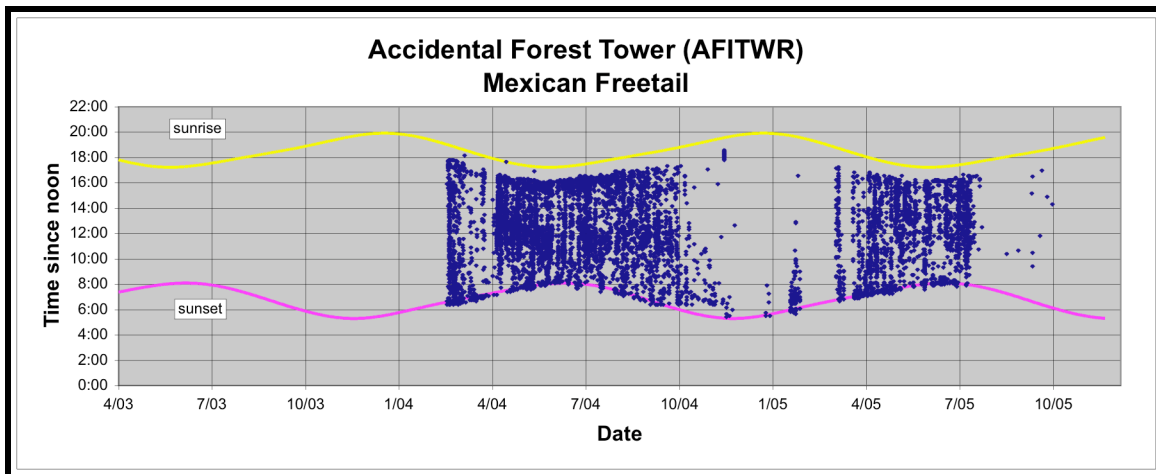


Figure 25f. Timing of acoustic activity by date at Accidental Forest Tower for Mexican free-tailed bat, *Tadarida brasiliensis*. Canopy monitor installed 2004, removed in 2005.

### 3.2.4. Foliage-roosting Bats

We tracked activity for both foliage roosting species, *Lasiurus blossevillii* and *Lasiurus cinereus* (Figures 26a,b & c and 28a,b and c). A study conducted in 2002 at other Nature Conservancy sites on the Sacramento River strongly suggested that red bats, *L. blossevillii*, were likely early responders to restoration of riparian forest (Stillwater Sciences 2003). Because there is evidence that both these species are associated with gallery cottonwood forests, and also use the Sacramento River Valley as a significant migratory flyway (Cryan 2003), they were of high interest for this project.

Although both foliage-roosting and migratory, they display interesting differences in patterns of acoustic activity suggesting that they differ considerably in their foraging behavior. *L. blossevillii* shows a peak in acoustic activity in mid to late August all three years. In 2003, this occurs on the Cosumnes river channel (Wendell's/Corps Breach), and in 2004 and 2005 there are peaks at Wood Duck Slough and the Tall Forest Gap (sites separated by trees and perhaps 100m map distance). These peaks do not correlate with insect abundance, and almost certainly reflect migratory events. The relatively low levels of activity that occur throughout the summer are associated primarily with the open river channel, the slough, and forest edge, and not with the floodplain.

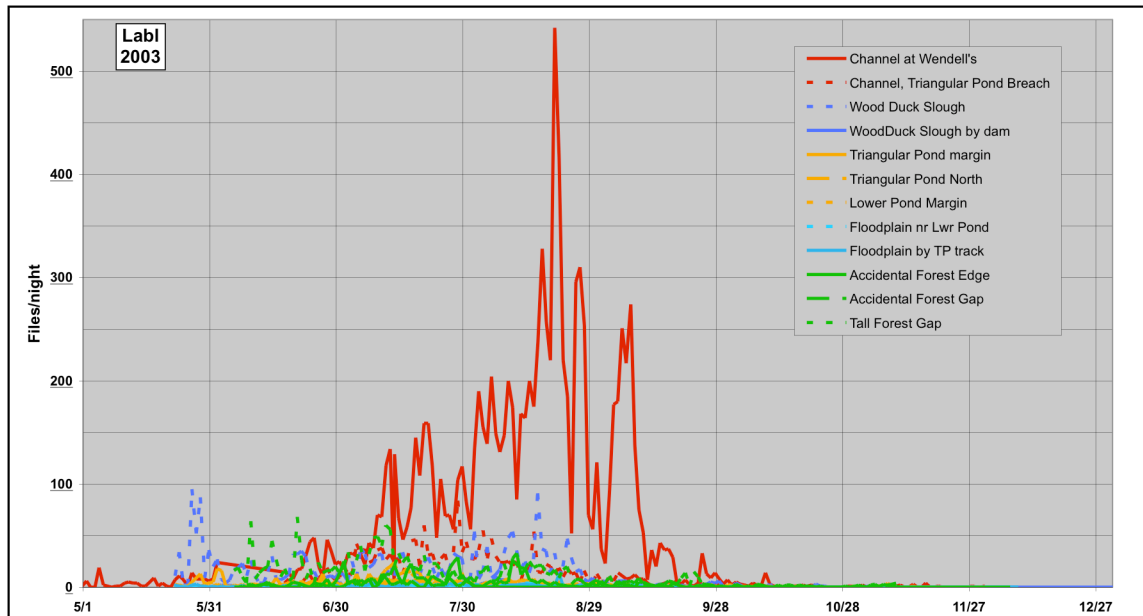


Figure 26a. Acoustic activity for western red bat, *Lasiurus blossevillii* at all sites for 2003.

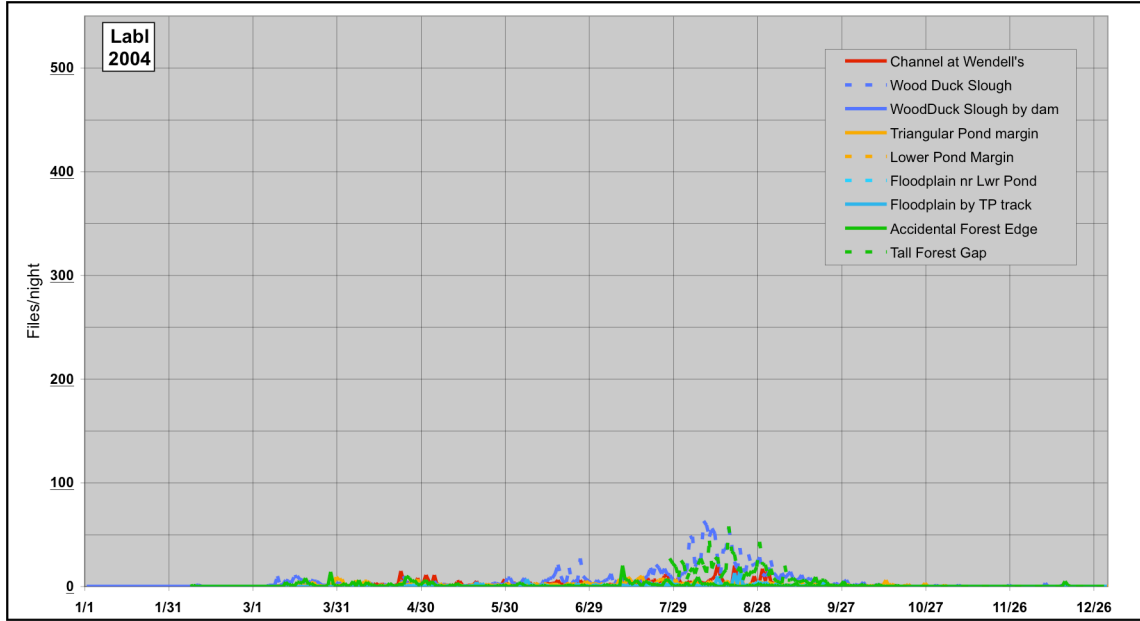


Figure 26b. Acoustic activity for western red bat, *Lasiurus blossevillii* at all sites for 2004.

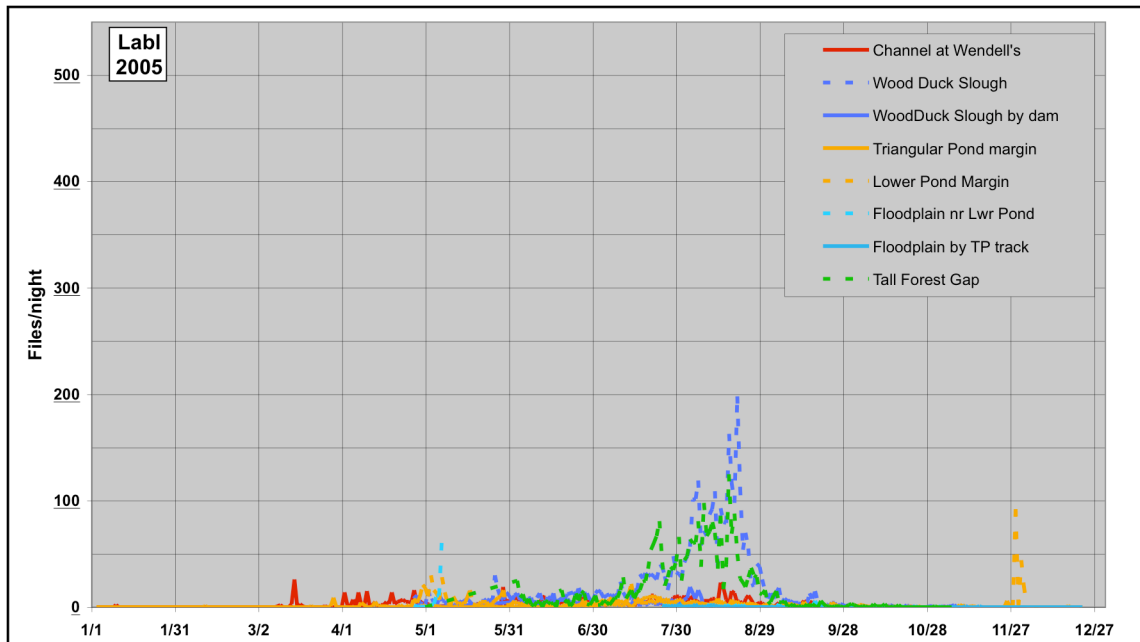


Figure 26c. Acoustic activity for western red bat, *Lasiurus blossevillii* at all sites for 2005.

Time/ activity maps for red bats (Figures 27a-e) suggest that this species prefers the mature forest (Tall Forest Gap) to young forest (Accidental Forest Edge) for both roosting and foraging. At the mature forest site, concentrations of activity at dusk suggest the bats are roosting in this habitat, and to a much lesser extent in the Accidental Forest. These data are consistent with data collected in other studies in the Central Valley involving this species (Pierson et al. 2000, Stillwater Sciences 2003). The greatest



amount of activity during the time interval when animals are likely foraging (after dusk until pre-dawn) occurs at Wood Duck Slough and in the nearby Tall Forest Clearing. Acoustic sampling for this species in the Sierra Nevada has shown that this species often forages over land as well as water (E.D. Pierson and W.E. Rainey, unpublished data).

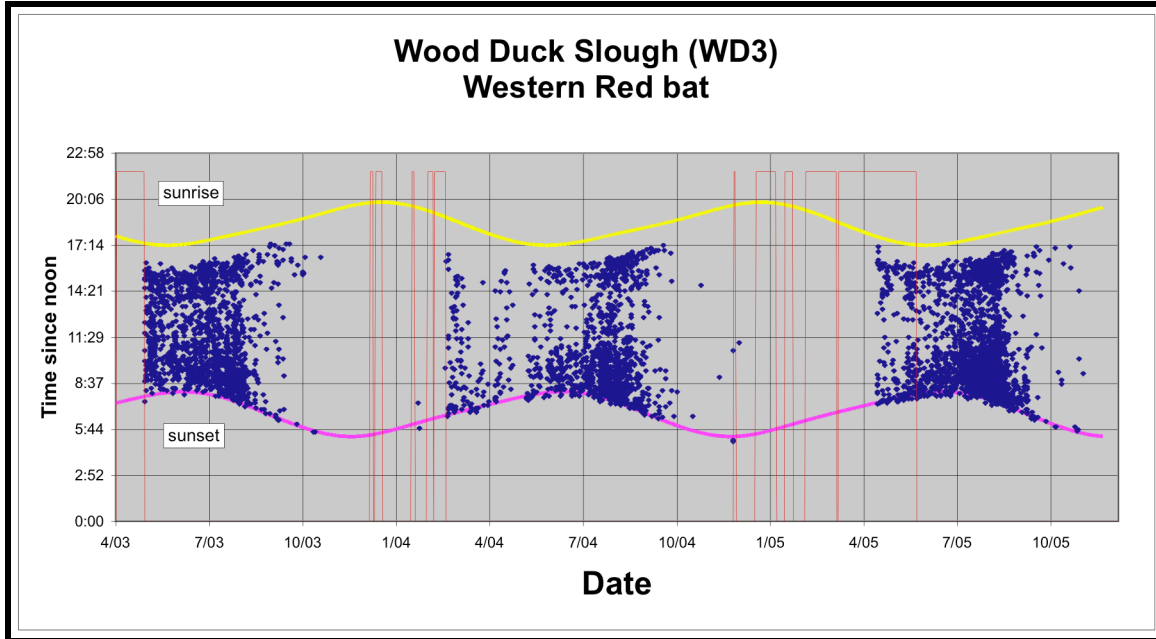


Figure 27a. Timing of activity by date for western red bat, *Lasiurus blossevillii*, at Wood Duck Slough.

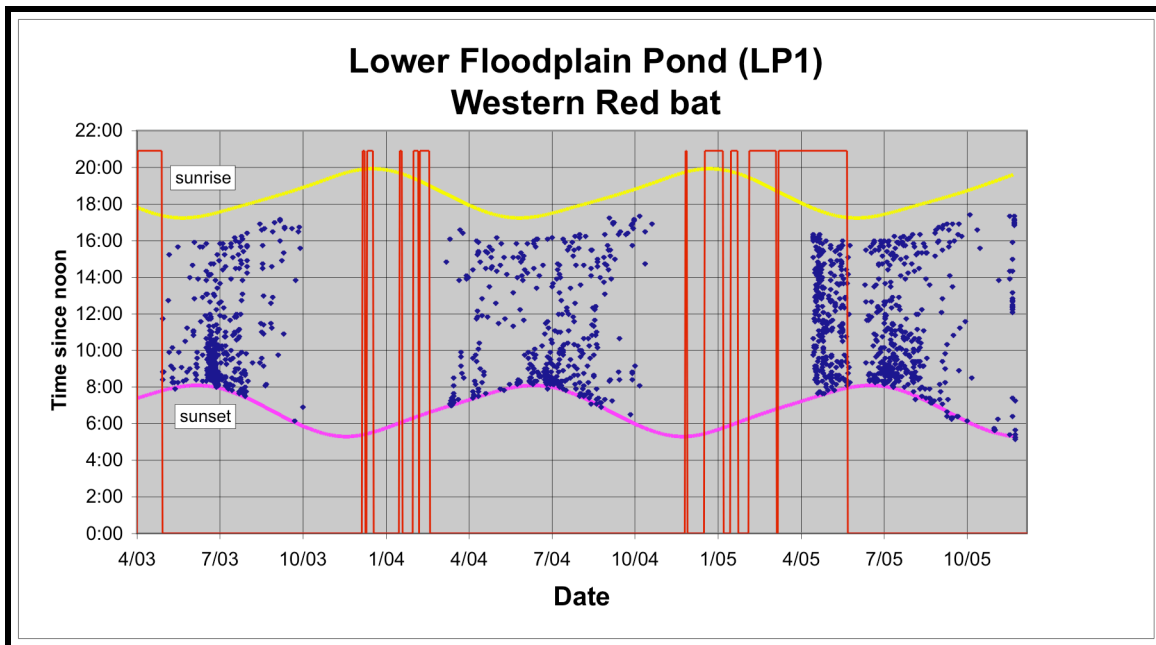


Figure 27b. Timing of activity by date for western red bat, *Lasiurus blossevillii*, at Lower Floodplain Pond.

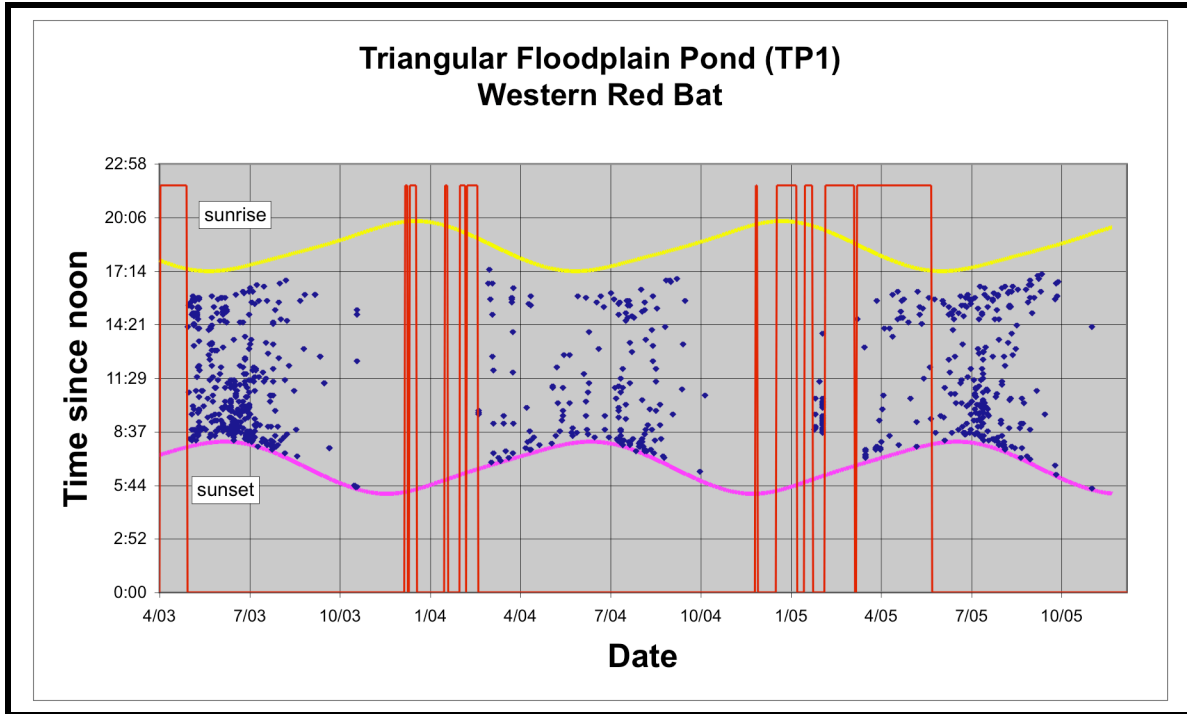


Figure 27c. Timing of activity by date for western red bat, *Lasiurus blossevillii*, at Triangular Pond Margin.

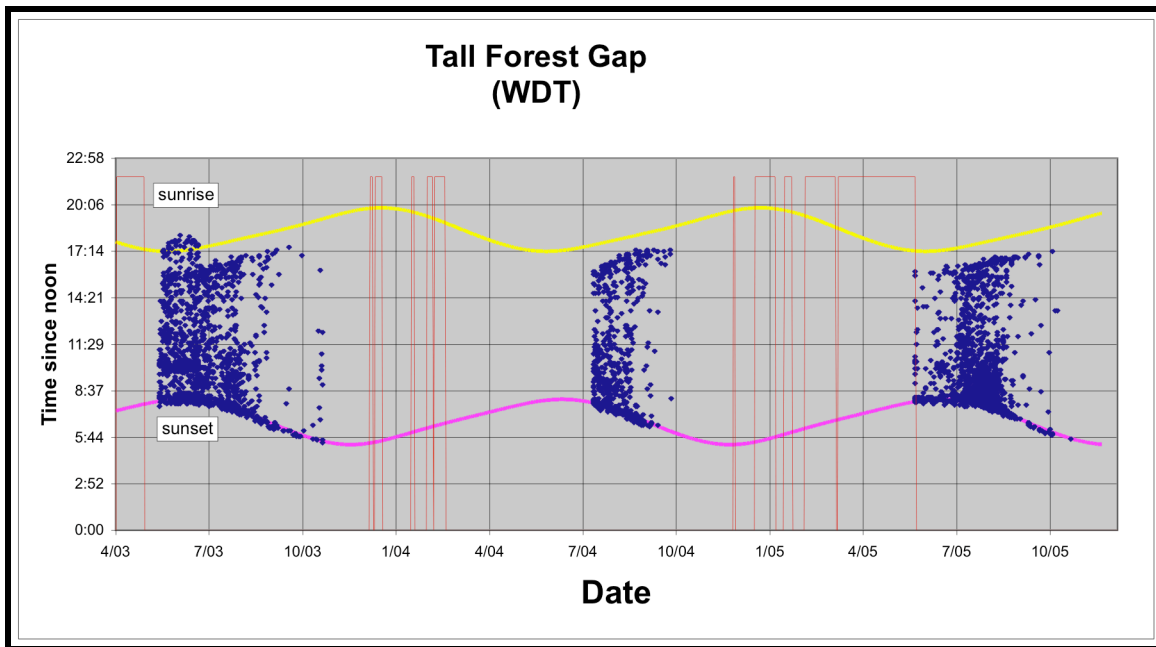


Figure 27d. Timing of activity by date for western red bat, *Lasiurus blossevillii*, at Tall Forest Gap.

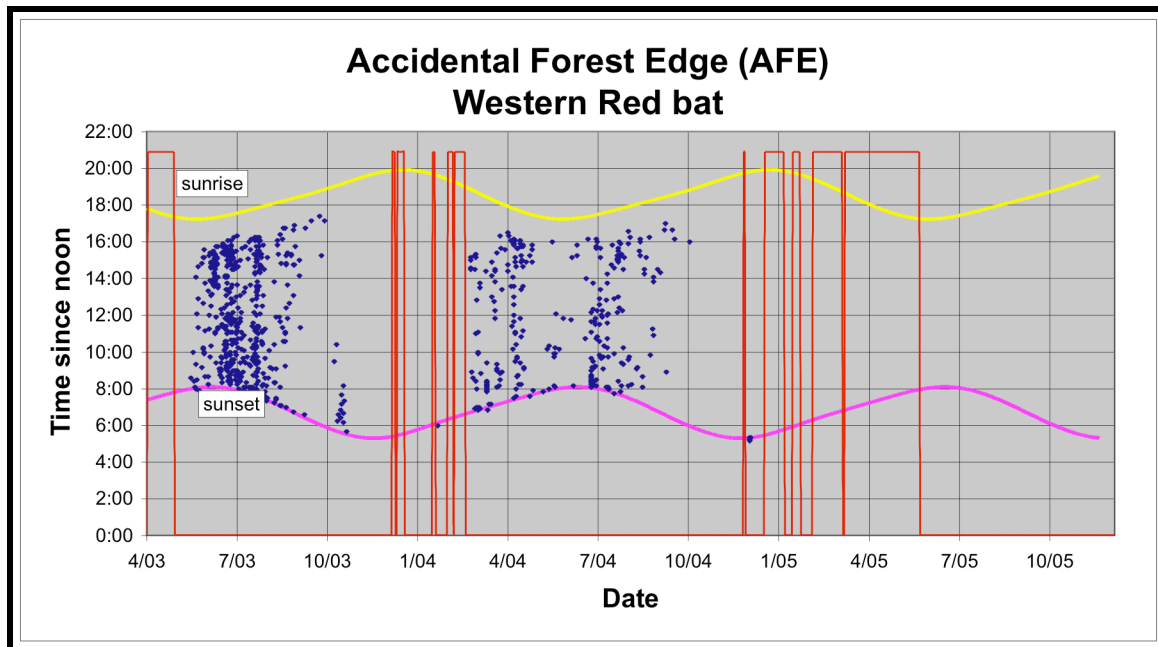


Figure 27e. Timing of activity by date for western red bat, *Lasiurus blossevillii*, at the Accidental Forest Edge. Monitor not deployed here in 2005.

Though most museum records of red bats are obtained in warmer seasons, and show a concentration of this species along the California coast in the winter, these data reveal red bat activity during the winter, including a peak in activity in late November 2005. Radio-tracking studies on the closely related eastern red bat have documented this species hibernating in leaf-litter (Saughey et al. 1998), even under snow (L. Robbins, pers. comm.). There are also isolated late fall, winter and early spring detections for the other foliage roosting species, *L. cinereus*. Because there is no suitable green foliage habitat for either species during this interval, in the absence of recent rain, it is possible they are roosting in leaf-litter like their eastern congener.

In 2005, hoary bats show a similar pattern to the red bats, with a peak in activity in both the Wood Duck Slough and the Tall Forest Gap between mid-August and mid-September, during the time they are inferred to be migrating down the Sacramento River (Figures 28a,b & c). There also are spring peaks in activity that could correspond to northward migration events. The primary floodplain habitat use difference between the hoary and red bats is that the hoaries make extensive use of the Triangular Pond, especially in May.

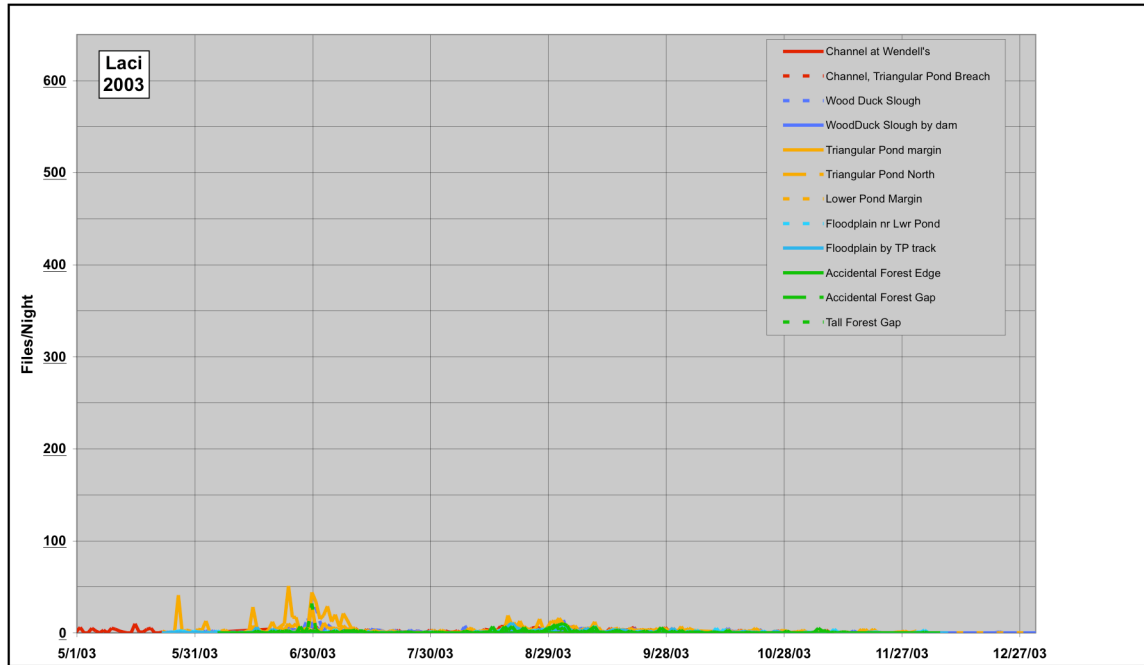


Figure 28a. Acoustic activity for hoary bat, *Lasiurus cinereus* at all sites for 2003.

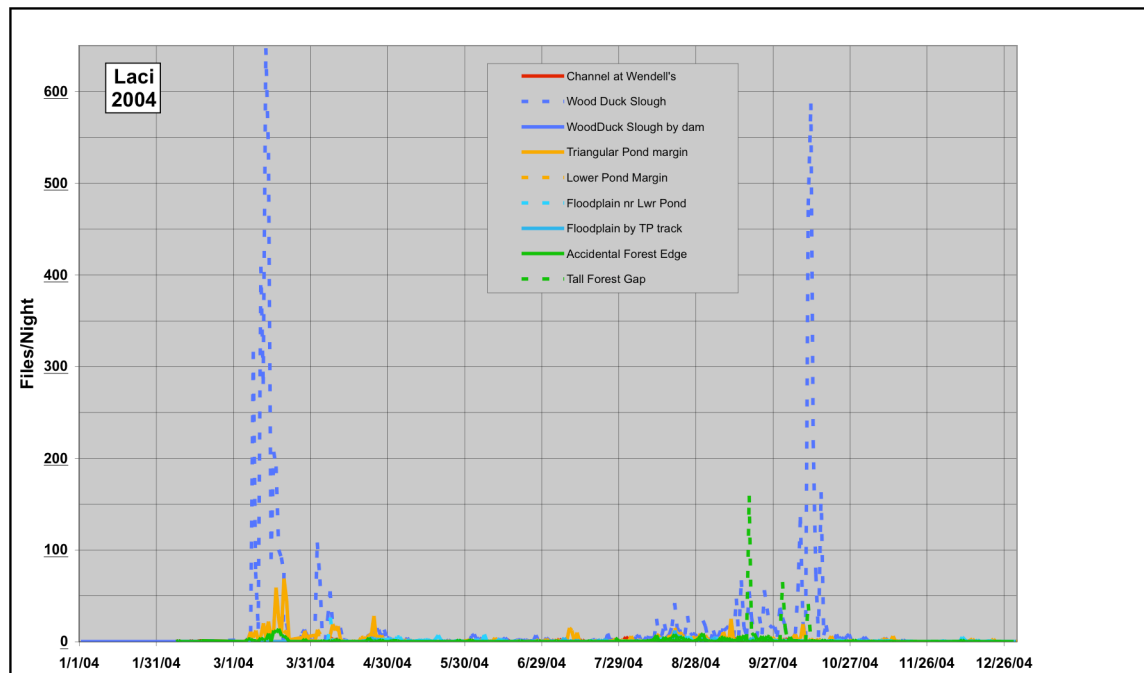


Figure 28b. Acoustic activity for hoary bat, *Lasiurus cinereus* at all sites for 2004.

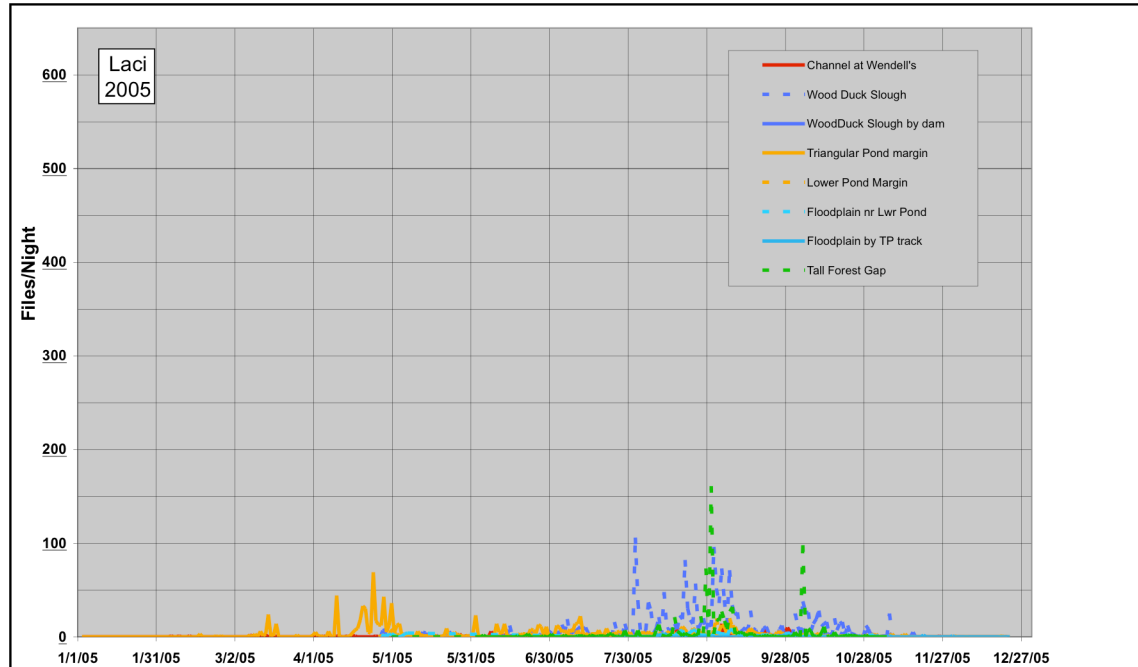


Figure 28c. Acoustic activity for hoary bat, *Lasiurus cinereus* at all sites for 2005.

### 3.3. Bat Species Accounts

Species accounts are provided for the nine species confirmed by acoustic and/or visual records as occurring on the study site.

#### 3.3.1. *Antrozous pallidus*, Pallid Bat

The pallid bat is a state and federal special-status species (CDFG - MSSC; FSS). There are 24 museum records for pallid bats from 14 localities in the nine county area. There are two records from two localities for Sacramento County. Also, while not common, this species was detected at Nature Conservancy sites along the Sacramento River near Chico, particularly in association with cottonwoods (Stillwater Sciences 2003).

*A. pallidus* occurs throughout California in a variety of habitats from true desert areas to the moister oak woodlands and redwood forests of the coastal regions, and to >2,000 m elevation in the Sierra Nevada. It is associated with ponderosa pine in the mountains, and shows a particularly strong association with oak habitat (both oak savannah and black oak and oak grasslands) at low to mid-elevations (Rainey and Pierson 1996).

*A. pallidus* is a colonial species, with a typical colony size of 50-300 (Barbour and Davis 1969, Hermanson and O'Shea 1983, Orr 1954). In natural settings pallid bats roost in tree hollows, in rock crevices on cliffs or rock outcrops, and sometimes caves. Pallid bats are, however, also frequently associated with human structures, particularly abandoned buildings, old mine workings, and bridges. This is one of the species most frequently found roosting in bridges in the Central Valley and western Sierran foothills (Pierson et al. 2001). Colony size is typically 50-300.

Pallid bats forage primarily on large ground-dwelling arthropods (e.g., scorpions and Jerusalem crickets), but also feed on large flying insects (e.g., long-horned beetles, such as *Prionus californicus*, and katydids), and can sometimes be seen flying less than 1 m above the ground in oak savannah (Barbour and Davis, 1969; Hermanson and O'Shea, 1983, Johnston and Fenton 2001). It has been observed in the Napa Valley feeding on tomato hornworm (*Manduca quinquemaculata*) caterpillars in gardens, suggesting it may also take other large insect larvae (Patricia Winters, pers. comm.).

A single acoustic record attributable to a pallid bat was detected in the Tall Forest Gap, suggesting this species is rare at this site. It would be expected to benefit, however, from restoration of riparian forest. A colony was located in a riparian cottonwood tree in Amador County (E. Pierson, pers. comm.).

### **3.3.2. *Eptesicus fuscus*, Big Brown Bat**

The big brown bat has no state or federal listing status. There are 60 museum records for big brown bats from 26 localities in the nine county area. There are two records from one locality for Sacramento County. Big brown bats were common at Nature Conservancy properties along the Sacramento River near Chico (Stillwater Sciences 2003).

The big brown bat is one of the most widely distributed and commonly detected species in a variety of habitats throughout California. It is primarily a crevice roosting species. Common diurnal roost sites are trees (particularly snags), old buildings, bridges, rock crevices, caves, and mines (Barbour and Davis 1969, Brigham 1991, Kurta and Baker 1990). Big brown bats are colonial, with a typical colony containing 25-75 adults, although colonies up to 700 have been found (Kurta and Baker 1990). Big brown bats are foraging habitat generalists, feeding aerially over both water and land, in forested and edge situations. They often emerge early (prior to dark) and can be seen foraging very high (up to 50 m. above the ground), descending later in the evening to 10-15 m (Whitaker et al. 1977). In some habitats they feed predominantly on beetles (Coleoptera), including such important agricultural pests (Whitaker 1995). In other localities they may feed primarily on aquatic insects, such as caddisflies (Trichoptera) (Brigham 1991, Verts et al. 1999), and have been known to consume a variety of other insect groups (e.g., Hemiptera, Hymenoptera, Diptera, Plecoptera, a few Lepidoptera). In northern California, radiotracking and netting data suggest individuals follow watercourses to forage, often flying above canopy level, and not traveling more than a few kilometers from their roosts. They feed over both open river corridors and in much more cluttered settings beneath the riparian canopy of small streams (E.D. Pierson and W.E. Rainey unpubl. data).

This species is very commonly found in bridge roosts in the Central Valley, but disappears from these roosts by mid-August. This species was common at the study site. While it may be roosting primarily off-site, suitable roosting habitat is found in the mature oak forest.

### 3.3.3. *Eumops perotis*, Western Mastiff Bat

The western mastiff bat is a state and federal special-status species (CDFG - MSSC; USFWS-SC). There are two museum records for western mastiff bats from two localities in the nine county area, with no records from Sacramento County. This species was detected acoustically at multiple sites in the Central Valley in a status review conducted in the late 1990s (Pierson and Rainey 1998), and at Nature Conservancy sites along the Sacramento River (Stillwater Sciences 2003). Contrary to expectations, this species was detected only once in this study at the Triangular Floodplain Pond.

Although generally regarded as a desert bat, recent surveys have documented a distribution in California that is far broader than was previously realized (Pierson and Rainey 1998). Once thought to occur primarily in southern California, it is now known to occur almost as far north as the Oregon border, with roosts in the Sierra Nevada up to 1,400 m, and foraging animals up to 3,000 m. The distribution of *E. perotis* is likely geomorphically determined, with the species only roosting where there are significant fractured rock features. Its roosts are found, however, in a variety of habitats, from desert scrub to chaparral, oak woodland, and the ponderosa pine belt.

*E. perotis* is primarily a crevice dwelling species. Natural roosts are often found under large exfoliating slabs of granite or sandstone, on cliff faces or in large boulders (Barbour and Davis 1969, Best et al. 1996, Krutzsch 1955, Pierson and Rainey 1998), but nearly half of all known roosts in California are in appropriately proportioned cracks in buildings (Barbour and Davis 1969). Unlike some molossid species (e.g., *Tadarida brasiliensis*) that undergo long distance seasonal migrations, *E. perotis* appears to move relatively short distances seasonally. It does not undergo prolonged hibernation, and appears to be periodically active all winter, and thus may seek winter refugia that are protected from prolonged freezing temperatures.

Mastiff bats forage over large open meadows in the Sierra, in blue oak/grey pine habitat at lower elevations in the Sierra, and over reservoirs, and in desert washes and drying creek beds in more xeric portions of the state. The mastiff bat is a strong, fast flier, and its foraging range is likely extensive. This species appears to feed predominantly on moths (Lepidoptera), but is known to take Hymenoptera, Homoptera, and Orthoptera.

Mastiff bats emit an audible echolocation call (at ca. 7-20 kHz), and can be heard flying every hour of the night. The 'normal' detector microphones used in this study have substantially decreased sensitivity in the audible range to reduce recordings of insects and birds. A microphone with increased low frequency would substantially improve detection of mastiff bat calls (along with other audio range input). However, in the comparable prior study in Sacramento River riparian a substantial number of mastiff detections were obtained with 'normal' detector microphones ((Stillwater Sciences 2003).

### 3.3.4. *Lasiurus blossevillii*, Western Red Bat

*L. blossevillii* is considered a sensitive species by the Forest Service, and is proposed for State Special Concern status (CDFG - MSSC; FSS). There are 61 museum records for western red bats from 30 localities in the nine county area. There are three records from three localities for Sacramento County. In a recent status review, this species was detected at multiple sites in the Central Valley, along both the Sacramento and San Joaquin rivers as well as at valley sites along major feeder drainages (*e.g.*, the Merced and Stanislaus rivers) (Pierson *et al.* 2000). It also was a focal species in a study conducted at Nature Conservancy reserves near Chico (Stillwater Sciences 2003).

Western red bats have been recorded primarily at lower elevations in California, with breeding females and young found in cottonwood/sycamore riparian, fruit and nut orchards, and planted windbreaks, close to major river corridors, in the Central Valley. Recent studies in the Central Valley found that summering populations are more abundant in remnant stands of cottonwood/sycamore riparian that extend >50 m back from the river than they are in younger, less extensive stands (Pierson *et al.* 1999). Grinnell (1918) suggested that red bats in California were sexually segregated in summer, with males moving to higher elevations, a pattern more recently noted in other species (*e.g.*, Cryan *et al.* 2000). Recent acoustic surveys have documented that western red bats, while relatively rare, are broadly distributed up to >2,500 m in the Sierra Nevada (Pierson *et al.* 2000 & 2001). This species is migratory, and winter records for both sexes are concentrated along the central and southern California coast (Pierson *et al.* 2000).

This species typically roosts non-colonially, in foliage, beneath overhanging leaves (Constantine 1959, Shump and Shump 1982a). Animals discovered in winter in Golden Gate Park in San Francisco were roosting in *Sparmannia africana*, a large-leaved, exotic, evergreen plant planted in Bay Area gardens (Orr 1950). A recent radiotracking study of the eastern red bat documented, however, that, when temperatures dropped, some individuals moved from trees to hibernate in leaf litter (Saugey *et al.* 1998). Red bats apparently arouse from hibernation on warm days to feed (Shump and Shump 1982a), and Orr's observations suggest that this species forages periodically during the winter in the San Francisco Bay area (Orr 1950). Red bats forage on a number of insect taxa, flying at both canopy height and low over the ground (Shump and Shump 1982a). One diet sample from California suggests this species feeds primarily on small moths, but takes a variety of other insects, particularly orthopterans.

While not common, this species was detected at a number of stations on the floodplain, appearing to be more active in mature forest and over nearby surface water. The species was present at the site over the summer, with increases in activity in the late summer due most likely to pulses of migrating animals. A few individuals were detected at Cosumnes in late November.

### **3.3.5. *Lasiurus cinereus*, Hoary Bat**

The hoary bat has no state or federal listing status. There are nine museum records for hoary bats from eight localities in the nine county area, with no records from Sacramento County. With improvements in acoustic technology, this species is readily detected if



present in an area. It was detected at multiple sites in the Central Valley in two recent studies (Pierson et al. 2000, Stillwater Sciences 2003). A single male of this species was captured along the Sacramento River in the Stillwater Sciences study.

*L. cinereus* is a foliage roosting species with a very broad distribution in North America (Barbour and Davis 1969, Shump and Shump 1982b). Breeding females are concentrated in the plains states and Canadian provinces. There are no records of females raising young in California. Adult males, however, are widely distributed within the state. In the southwestern U.S., this species is frequently associated with riparian habitats (Hoffmeister 1986, Pierson et al. 2000), and is presumed to roost in trees such as cottonwood, sycamore and mature willow. It occurs also, however, in mixed deciduous and coniferous forest, and has been recorded up to >3,000 m elevation in the Sierra Nevada. This species is known to undergo long distance seasonal migrations, with increased numbers of animals appearing along the California coast in the fall (Dalquest 1943, Tenaza 1966) and in southern California in the winter (Vaughan and Krutzsch 1954). Data obtained recently in the Central Valley and the Sierra foothills (Pierson et al. 2000, Pierson et al. 2001a) suggest that this species migrates through the Central Valley and adjacent foothills in the spring and the fall.

*L. cinereus* forages along river and stream corridors, over open bodies of water, meadows, and in open forest habitats. It feeds primarily on 6-30 mm moths, but is also known to consume Coleoptera, Hymenoptera, Isoptera, and Odonata.

This species was commonly detected in this study. It appeared to be resident at the site in the summer, with pulses of activity in the spring and fall suggesting aggregated movement of migrants.

### **3.3.6. *Myotis californicus*, California myotis**

The California myotis has no state or federal special status. There are 51 museum records for California myotis from 21 localities in the nine county area. There are five records from two localities for Sacramento County.

This species, which may be either solitary or form small colonies (generally fewer than 30 animals), is widely distributed throughout most of California at low to moderate elevation. It roosts in crevices (rocks, trees, and a variety of man-made structures including buildings, bridges, and abandoned mines) (Barbour and Davis 1969, Brigham et al. 1997, Simpson 1993). While it is found in a wide variety of habitats, it is often detected foraging around the canopy of oak trees or along riparian corridors in association with cottonwood, sycamore and willow. Diet data indicate this species is a generalist aerial forager consuming a wide variety of small insects. O'Farrell et al. (1967) observed that this was one of several species which were at least periodically active all winter at a Nevada desert spring, even at temperatures close to freezing. There are no data to suggest aggregated migration or long distance movements.

While the 50 kHz *Myotis* (*M. californicus* and *M. yumanensis*) were not as common as the 40 kHz bats, they present on the property. Those 50 kHz calls recorded at terrestrial sites (e.g., forest edge and gaps) were presumed to be largely *M. californicus*.

### 3.3.7. *Myotis lucifugus*, Little Brown Bat

*M. lucifugus* has no state or federal listing status. There are seven museum records for little brown bats from seven localities in the nine county area, with no records from Sacramento County. Despite the paucity of museum records, this species was found to be one of the more commonly detected species along the Sacramento River near Chico (Stillwater Sciences 2003).

*M. lucifugus* is one of the most widely distributed bats in North America (Humphrey and Cope 1976, Schowalter et al. 1979, Fenton and Barclay 1980), occurring from tree line in Canada and Alaska to the southern United States. It is generally forest associated, being absent from the largely treeless Great Plains and lowland desert. In California, it is found predominantly at higher latitudes or altitudes. *M. lucifugus* is a highly colonial species, forming colonies up to several thousand, and is one of the species that most commonly associated with human structures. Yet a number of studies have now documented tree roosting by this species (Barclay and Cash 1985, Kalcounis and Hecker 1996). Foraging studies have shown this species to feed heavily on aquatic emergent insects, particularly chironomids and caddis flies (Belwood and Fenton 1976, Anthony and Kunz 1977, Fenton and Barclay 1980). Although it has been documented feeding over both water and land (Barclay 1991), it is generally regarded as favoring aquatic habitats.

As a species that feeds largely on aquatic emergent insects it was one of the species most closely tracked in this study. It was common on the site, and foraged predominantly at still water sites (the floodplain ponds and slough).

### 3.3.8. *Myotis yumanensis*, Yuma Myotis

Although *M. yumanensis* is listed as a USFWS Species of Concern (because of issues elsewhere in its range), it is widely distributed throughout much of California. There are 186 museum records for Yuma myotis from 22 localities in the nine county area. There are three records from two localities for Sacramento County.

While this species occurs from sea level to >2,500 m in the Sierras, its maternity colonies (which are typically comprised of 300-1,000 females) are generally confined to elevations below 1,500 m (Barbour and Davis 1969, Pierson et al. 2000 & 2001). This is one of the species most commonly associated with human structures, including barns and bridges, although it will also roost in caves, abandoned swallow nests, defects in living trees and under flaking bark of large snags (Barbour and Davis 1969). *M. yumanensis* is more highly associated with water than any other species. It flies low over relatively the water (reservoirs, ponds, or slowly flowing reaches and pools of rivers and streams), feeding primarily on small, emergent aquatic insects, such as midges, mayflies and caddis flies (Barbour and Davis 1969, Rainey and Pierson 1996, van Zyll de Jong 1985).

This species was present in the study area, but was not as common as *M. lucifugus*, the other western U.S. species which skims emerging insects from the surface of relatively flat water.

### **3.3.9. *Tadarida brasiliensis*, Mexican Free-tailed Bat**

The Mexican free-tailed bat has no state or federal listing status. There are 150 museum records for Mexican free-tailed bats from 26 localities in the nine county area. There are four records from three localities for Sacramento County. This species occurs frequently in farm buildings and bridges in the Central Valley, and one of the largest known roosts in the state is in the Franklin Boulevard Causeway, less than 2 km from the project area (Johnston et al. 2004).

This is one of the most widely distributed and commonly encountered species in California. While breeding populations occur primarily at low to mid-elevations, this species is found all the way to the crest of the Sierra Nevada (Pierson et al. 2001). *T. brasiliensis* is found in a range of habitats, is the species most tolerant of urbanization, and is among the bats most likely to be found in association with man-made structures.

Mexican free-tailed bats form maternity colonies of up to several million in some caves in Texas, but in California, with the exception of one population of about 250,000 (in a lava cave in northern California), most colonies in California range in size from a few hundred to a few thousand. Although some populations of Mexican free-tailed bats migrate large distances (e.g., Texas populations overwinter in Mexico), seasonal movement patterns and population structure within California are poorly understood. Free-tailed bats can tolerate torpor during cold weather, but do not hibernate.

Mexican free-tailed bats are crevice or cavity dwellers, and can fit in cracks smaller than one inch wide. While this species roosts in a number of natural features (rock crevices, caves, and abandoned swallow nests), it is also the species most often found in man-made structures, including buildings, bridges, and mines (Barbour and Davis 1969, Wilkins 1989). Colonies also appear to be more mobile than many bat species, apparently displaying less loyalty to particular roost sites, with the exception of major maternity sites which are occupied year to year.

Mexican free-tailed bats are aerial foragers, and feed on a wide variety of flying insects (Whitaker et al. 1996). This is the species most likely to include a variety of agricultural pests in its diet, including the corn earworm moth (*Heliothis zea*) (McCracken 1996), and most likely the codling moth (*Cydia pomonella* L.) (Hogan 2000). Year-round diet studies conducted at Lemoore Naval Air Station in the San Joaquin Valley showed that this species foraged primarily over cotton fields and other agricultural areas, and included flies, moths, true bugs (mostly plant hoppers) and beetles in their diet (Johnston 1998).

This species was detected at all sampling stations on the floodplain and was the source of a large fraction of the total bat activity detected, particularly at open floodplain sites.

#### 4.0. RECOMMENDATIONS FOR MANAGEMENT AND MONITORING

Restoration of floodplains in the Central Valley of California is already bringing back a remarkable and productive ecosystem, albeit one which now includes a range of invasive species. River floodplains support highly valued species and ecosystem services, but can also facilitate the production and spread of non-native vertebrates (e.g. black rats, bullfrogs, and carp in California) and invertebrates (crayfish, emergent insects including mosquitoes and biting midges) which, native or non-native, may be pests or disease vectors from a human perspective. If restored floodplains provide conditions and resources that favor consumers of these pests, then their impact may be reduced. A primary ecological goal of floodplain restoration is habitat enhancement for native salmonids. To the extent that manipulation is possible, the flood regime ‘prescription’ is early season, cold water events, emptying the floodplain before it warms seasonally and favors carp and other aliens (Crain *et al.* 2004).

We infer that early season floods may have low short-term impact on insect prey available to bats active later in the same season. While long, likely pulsed, late season floods with repeated input of nutrients to the floodplain might maximize insect emergence available to aerial insectivores, this pattern seems undesirable both from production of alien fish and mosquitoes.

It is important to step back in both time and space, and note that, arguably, the primary constraint on populations of most bat species in the alluvial Central Valley is suitable roosting habitat in defects in mature trees in the very small remnants of riparian forest currently remaining. Thus, in the long term, a flood regime (and multiple distributed restoration sites) that episodically permits native forest tree recruitment (oak, cottonwood, sycamore) is one key to maintaining bat and other riparian vertebrate diversity. Bats are the most mobile Central Valley native riparian mammals and can be expected to recruit to new habitat relatively readily along river corridors. Artificial structures are useful mitigation for removal of prior artificial structure habitat, but, as currently designed, these attract largely a subset of generalist species. These colonies may provide significant ecological services in terms of insect control, but from the point of view of diversity, neither concrete nor orchards are a substitute for riparian forest.

Presumably most Central Valley riparian forest remnants, like the Cosumnes Preserve, support high densities of black rats. These emerge as effective nest predators in avian studies, but the impact of black rat predation on cavity and crevice roosting forest bat recruitment is unknown. Bat young are initially flightless and defenseless and female give birth only once in a year (i.e., there is no equivalent to re-nesting). The presence of substantial bat activity from several taxa at dusk and dawn over several years suggests

that the Tall Forest is not a ‘black hole’ for bat reproduction, but the topic of rat predation and reproductive success deserves attention.

We suggest that acoustic monitoring offers, over long intervals, a relatively low cost, low effort tool for exploring landscape patterns of bat migration. Over shorter intervals, it has application in assessing ‘progress’ in habitat restoration from the perspective of one relatively diverse group of native mammals.

A well known problem encountered in this and other ecological studies is that collecting and processing insect samples is so time and labor intensive that few samples can be handled. Consequently the high temporal and spatial variability of emergence is not captured with the same resolution as other variables of interest. To get closer to continuous real time assessment of flying insect activity near the water surface, it may be useful to temporarily abandon taxonomic resolution and address the development of an IR beam modulation sensor sampling at a sufficient rate to measure insect wing beat frequencies as a correlate of body size. From the perspective of aerial insectivores feeding on aquatic emergents, taxonomy likely has no role in prey capture decisions.

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## 6.0 LITERATURE CITED

- Anthony, E. L. P. and T. H. Kunz. 1977. Feeding strategies of the Little brown bat, *Myotis lucifugus*, in southern New Hampshire. *Ecology* 58(4): 775-786.
- Barbour, R. W. and W. H. Davis. 1969. *Bats of America*. University of Kentucky Press, Lexington, Ky, 286 pp.

Barclay, R. M. R. 1991. Population structure of temperate zone insectivorous bats in relation to foraging behavior and energy demand. *Journal of Animal Ecology* 60:165-178.

Barclay, R. M. R. and K. J. Cash. 1985. A non-commensal maternity roost of the little brown bat *Myotis lucifugus*. *Journal of Mammalogy* 66(4): 782-783.

Belwood, J. J. and M. B. Fenton. 1976. Variation in the diet of *Myotis lucifugus* (Chiroptera: Vespertilionidae). *Canadian Journal of Zoology* 54(10): 1674-1678.

Best, T. L., W. M. Kiser, and P. W. Freeman. 1996. *Eumops perotis*. *American Society of Mammalogists, Mammalian Species* 534:1-8.

Booth, E. G., J. F. Mount, and J. H. Viers (*Ms submitted*) Characterizing hydrologic variability of the Cosumnes River floodplain using a flood type/water year type classification. *San Francisco Estuary & Watershed Science*

Brigham, R. M. 1991. Flexibility in foraging and roosting behaviour by the big brown bat (*Eptesicus fuscus*). *Canadian Journal of Zoology* 69(1):117-121.

Brigham, R. M., M. J. Vonhof, R. M. R. Barclay, and J. C. Gwilliam. 1997. Roosting behavior and roost-site preferences of forest-dwelling California bats (*Myotis californicus*). *Journal of Mammalogy* 78:1231-1239.

Brode, J. M. and Bury, R. B. 1984. The importance of riparian systems to amphibians and reptiles. Pp. 30-36 *in*: Warner, R. E. and Hendrix, K. M., (eds.). *California riparian systems: ecology, conservation, and productive management*. University of California Press, Berkeley and Los Angeles.

Brown, P. E. and R. D. Berry 2004. Foraging habitat and home range of Allen's big-eared bat (*Idionycteris phyllotis*) in the Arizona desert as determined by radio-telemetry. *Bat Research News* 45:207-208.

Collins, J. N., and V. H. Resh. 1989. Guidelines for the ecological control of mosquitoes in non-tidal wetlands of the San Francisco Bay Area. Sacramento: California Mosquito Vector Control Association, Inc., and University of California Mosquito Research Program. 93p.

Constantine, D. G. 1959. Ecological observations on lasiurine bats in the north Bay area of California. *Journal of Mammalogy* 40(1):13-15.

Cryan, P. M. 2003. Seasonal distribution of migratory tree bats (*Lasiurus* and *Lasionycteris*) in North America. *Journal of Mammalogy* 84:579-593.

Crain, P. K., K. Whitener, P. B. Moyle, F. Feyrer, L. R. Brown, R. L. Brown and J. J. Orsi 2004. Use of a restored Central California floodplain by larvae of native and alien

fishes. American Fisheries Society Symposium 39: 125-140.

Cryan, P.M., M.A. Bogan, and J.S. Altenbach. 2000. Effect of elevation on distribution of female bats in the Black Hills, South Dakota. *Journal of Mammalogy* 81:719-725.

Dalquest, W. W. 1943. Seasonal distribution of the hoary bat along the Pacific coast. *Murrelet* 24(2):21-24.

Dalquest, W. W. 1946. The daytime retreat of a California mastiff bat. *Journal of Mammalogy* 27(1): 86-88.

Fenton, M. B. and R. M. R. Barclay. 1980. *Myotis lucifugus*. American Society of Mammalogists, *Mammalian Species* 142: 1-8.

Florsheim, J. L. and Mount, J. F. 2002. Restoration of floodplain topography by sand-splay complex formation in response to intentional levee breaches, Lower Cosumnes River, California. *Geomorphology* 44(1-2): 67-94.

Grindal, S. D., J. L. Morissette, and R. M. Brigham. 1999. Concentration of bat activity in riparian habitats over an elevational gradient. *Canadian Journal of Zoology* 77:972-977.

Grinnell, H. W. 1918. A synopsis of the bats of California. University California Publications in Zoology 17(12):223-404.

Grinnell, J., J. Dixon, and K.M. Linsdale. 1930. Vertebrate natural history of a section of northern California through the Lassen Peak region. University of California Press, Berkeley, 594 pp.

Hermanson, J. W. and T. J. O'Shea. 1983. *Antrozous pallidus*. American Society of Mammalogists, *Mammalian Species* 213:1-8.

Hoffmeister, D. F. 1986. The mammals of Arizona. University of Arizona Press, Tucson, AZ, 602 pp.

Hogan, B. C. 2000. A study of bat foraging activity and its relation to codling moth activity on four Yolo County walnut orchards. Unpublished Master's Thesis. California State University, Sacramento.

Humphrey, S. R. and J. B. Cope. 1976. Population ecology of the little brown bat, *Myotis lucifugus*, in Indiana and north-central Kentucky. Special Publications, American Society of Mammalogists 4: 1-81.

Johnson, H. 2000. Roosting and foraging ecology of bats in the Sutter Buttes, Sutter Co., California. Unpublished Masters Thesis, California State University, Sacramento, 114 pp.

Johnston, D. S. 1998. The Diet and Population Fluctuations of Mexican free-tailed bats in San Joaquin Valley - Can bats be effective for pest management? In Practical applications for wildlife and habitat management on farms and ranches. The Wildlife Society - San Joaquin Valley and the Society for Ecological Restoration, California Chapter. Visalia, California.

Johnston, D. S., and M. B. Fenton 2001. Individual and population-level variability in diets of pallid bats (*Antrozous pallidus*). *Journal of Mammalogy* 82:362-373.

Johnston, D.S., G. Tatarian, and E.D. Pierson. 2004. California bat mitigation: techniques, solutions, and effectiveness. Contract Report for California Department of Transportation and The California State University Sacramento Foundation, 164 pp.

Kalcounis, M. C. and K. R. Hecker. 1996. Intraspecific variation in roost-site selection by little brown bats (*Myotis lucifugus*). Pp. 81-90, in R. M. R. Barclay and M. R. Brigham, ed. Bats and Forest Symposium, October 19-21, 1995, Victoria, British Columbia, Canada, Research Branch, B.C. Ministry of Forests, Victoria, British Columbia, Working Paper 23/1996.

Keeler, J. O. and E. H. Studier 1992. Nutrition in pregnant Big Brown bats (*Eptesicus fuscus*) feeding on June beetles. *Journal of Mammalogy* 73:426-430.

Krutzsch, P. H. 1955. Observations on the California mastiff bat. *Journal of Mammalogy* 36:407-414.

Kurta, A. and R. H. Baker 1990. *Eptesicus fuscus*. *American Society of Mammalogists, Mammalian Species* 356:1-10.

McCracken, G. F. 1996. Bats aloft: a study of high-altitude feeding. *Bats* 14:7-10.

O'Farrell, M. J., W. G. Bradley and G. W. Jones 1967. Fall and winter bat activity at a desert spring in southern Nevada. *The Southwestern Naturalist* 12:163-171.

Orr, R. T. 1950. Notes on the seasonal occurrence of red bats in San Francisco. *Journal of Mammalogy* 31:457-458.

Orr, R. T. 1954. Natural history of the pallid bat, *Antrozous pallidus* (LeConte). *Proceedings of the California Academy of Sciences* 28:165-246.

Pierson, E. D. 1998. Tall trees, deep holes, and scarred landscapes: conservation biology of North American bats. Pp. 309-324, in T. H. Kunz and P. A. Racey, ed. *Bats: phylogeny, morphology, echolocation, and conservation biology*, Smithsonian Institution Press, Washington, D.C., 365 pp.

Pierson, E. D. and W. E. Rainey. 1998. Distribution, habitat associations, status and survey methodologies for three molossid bat species (*Eumops perotis*, *Nyctinomops*



*femorosaccus*, *Nyctinomops macrotis*) and the vespertilionid (*Euderma maculatum*). California Dept. of Fish and Game. Bird and Mammal Conservation Program. 61pp.

Pierson, E.D., W.E. Rainey, and C. Corben. 2000. Distribution and status of red bats, *Lasiurus blossevillii* in California. Report to Species Conservation and Recovery Program, Habitat Conservation Planning Branch, California Department of Fish and Game, Sacramento, CA, 37 pp.

Pierson, E. D., W. E. Rainey, and C. J. Corben. 2001. Seasonal Patterns of Bat Distribution along an Altitudinal Gradient in the Sierra Nevada. Report to California State University at Sacramento Foundation, Yosemite Association, and Yosemite Fund, 70 pp.

Ribeiro, F., P. K. Crain and P. B. Moyle 2004. Variation in condition factor and growth in young-of-year fishes in floodplain and riverine habitats of the Cosumnes River, California. *Hydrobiologia* 527:77-84.

Riparian Habitat Joint Venture 2004. The riparian bird conservation plan: a strategy for reversing the decline of riparian associated birds in California. California Partners in Flight. <http://www.prbo.org/calpif/pdfs/riparian.v-2.pdf>. Point Reyes Bird Observatory. Stinson Beach, California 156pp.

Rainey, W. E. and E. D. Pierson. 1996. Cantara spill effects on bat populations of the upper Sacramento River, 1991-1995. Report to California Department of Fish and Game, Redding, CA, (Contract # FG2099R1). 98 pp.

Sabo, J. L., J. L. Bastow, and M.E. Power (2002). Length-mass relationships for adult aquatic and terrestrial invertebrates in a California watershed. *Journal of the North American Benthological Society* 21(2): 336-343.

Saughey, D. A., B. G. Crump, R.L. Vaughan, G.A. Heidt. 1998. Notes on the natural history of *Lasiurus borealis* in Arkansas. *Journal of the Arkansas Academy of Science* 52: 92-98.

Schowalter, D. B., J. R. Gunson, and L.D. Harder. 1979. Life history characteristics of Little brown bats (*Myotis lucifugus*) in Alberta. *Canadian Field Naturalist* 93(3): 243-251.

Shump, K. A., Jr. and A. U. Shump. 1982a. *Lasiurus borealis*. *American Society of Mammalogists, Mammalian Species* 183:1-6.

Shump, K. A., Jr. and A. U. Shump 1982b. *Lasiurus cinereus*. *American Society of Mammalogists, Mammalian Species* 185:1-5.

Simpson, M. R. 1993. *Myotis californicus*. *American Society of Mammalogists, Mammalian Species* 428:1-4.

Statzner, B., and V. H. Resh. 1993. Multiple-Site and Multiple-Year Analyses of Stream Insect Emergence - a Test of Ecological Theory. *Oecologia* 96:65-79.

Stillwater Sciences, W. Rainey, E. Pierson, C. Corben, and M. Power. 2003. Sacramento River ecological indicators pilot study. Prepared by Stillwater Sciences, Berkeley, California for The Nature Conservancy, Chico, California. Available online: [http://www.sacramentoriverportal.org/reports/chico\\_landing/apdx11/final\\_text.pdf](http://www.sacramentoriverportal.org/reports/chico_landing/apdx11/final_text.pdf).

Studier, E. H. and S. H. Sevick 1992. Live mass, water content, nitrogen and mineral levels in some insects from south-central lower Michigan. *Comparative Biochemistry & Physiology A-Comparative Physiology* 103:579-595.

Tenaza, R. R. 1966. Migration of hoary bats on South Farallon Island, California. *Journal of Mammalogy* 47(3):533-535.

Vaughan, T. A. and P. H. Krutzsch. 1954. Seasonal distribution of the hoary bat in southern California. *Journal of Mammalogy* 35(3):431-432.

Verts, B. J., L. N. Carraway, and J. O. Whitaker. 1999. Temporal variation in prey consumed by big brown bats (*Eptesicus fuscus*) in a maternity colony. *Northwest Science* 73(2):114-120.

Whitaker, J. O., Jr. 1993. Bats, beetles, and bugs. *Bats* 11:23.

Whitaker, J. O., Jr. 1994. Food availability and opportunistic versus selective feeding in insectivorous bats. *Bat Research News* 35(4):75-77.

Whitaker, J. O., Jr. 1995. Food of the big brown bat *Eptesicus fuscus* from maternity colonies in Indiana and Illinois. *American Midland Naturalist* 134(2):346-360.

Whitaker, J. O., Jr., C. Maser, and L. E. Keller. 1977. Food habits of bats of Western Oregon. *Northwest Scientist* 51(1):46-55.

Whitaker, J. O., Jr., C. Neefus, and T. H. Kunz. 1996. Dietary variation in the Mexican free-tailed bat (*Tadarida brasiliensis mexicana*) during evening and morning feeding bouts. *Journal of Mammalogy* 77:716-724.

Wilkins, K. T. 1989. *Tadarida brasiliensis*. *American Society of Mammalogists, Mammalian Species* 331:1-10.

Williams, D.F., and K.S. Kilburn. 1984. Sensitive, threatened, and endangered mammals of riparian and other wetland communities in California. Pp. 950-956, in R.E. Warner and K.M. Hendrix, (eds.) *California riparian systems: ecology, conservation, and productive management*. Univ. California Press, Berkeley, 1035 pp.