

**Cantara Spill Effects on Bat Populations
of the
Upper Sacramento River
1991-1995**

FINAL Report for Contract # FG2099R1

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EXECUTIVE SUMMARY

This study, conducted in 1991-1995, was designed to assess impacts on bat populations along the upper Sacramento River resulting from the Cantara Spill on 14 July 1991. In the absence of pre-spill data for the region, several approaches were employed in parallel to identify changes resulting from the spill against a background of seasonal and inter-annual variations in abundance, activity, juvenile development and other parameters.

- All seventeen bat species expected from vicinity of the spill corridor were detected within the upper Sacramento River canyon. Four of these are Department of Fish and Game (DFG) Mammal Species of Special Concern and eight were Candidate 2 taxa under the Federal Endangered Species Act until that designation was eliminated in 1995. For several species, notably *Euderma maculatum*, a sensitive species not previously known from the coast ranges north of Ventura County, these observations are state range extensions. *Myotis yumanensis* and *Lasiorycteris noctivagans* were the most abundant species in mist net captures on both the Sacramento River and the nearby control drainage, Squaw Creek, although there is substantial variation in relative abundance from year-to-year. More species were encountered in netting at both spill and control sites in July-August 1992-1994 than in samples taken in the fall (September 1991 and 1995). Relative abundance also shows seasonal variation; presumably migrant *Tadarida brasiliensis* and *Lasiurus cinereus* are more common in September than in mid-summer. The number of species netted in September 1991 was lower than in September 1995.
- Estimates of bat numbers (by exodus count or capture) at spill and control *M. yumanensis* colonies, which have been sampled to monitor survival and reproduction, indicate two aggregations within the spill corridor have either increased or remained approximately stable since late 1991 or 1992.
- Sampling at bridge night roosts proved a relatively time-efficient way monitor populations of some species over several years. With notable exceptions (e.g., obligate tree roosting species are absent), bridge night roost bat samples were similar to those netted over the river. Banding and recapture at *M. yumanensis* and *Antrozous pallidus* night roosts showed high inter-annual site fidelity and thus permitted studies of reproductive maturation of juveniles and survival.
- Radiotracking of the tree roosting *L. noctivagans* in 1994 identified 14 roosts in 8 species of trees, with colony size varying from 1 to 69. All roosts were at least 5.5 m above ground and located in tree cavities or under the flaking bark in snags or the dead parts of living trees. Roosts varied in distance from the capture site on the river from 1.0 to 17.4 km. These data are consistent with earlier pilot radiotracking studies in indicating bats of several species come from a habitat corridor many km wide to forage over the river, and thus would be influenced by events such as the spill.
- Recapture of banded bats provided limited long term data on movement scale. Most recaptures are the most common species, *M. yumanensis*, with 72 % being

at the site of original capture (mostly at roost sites), and only 1.6 % being recaptured more than 5.0 km from the site of original capture. No movements between the spill and control drainages were detected. No trend over years suggests changes in the geographical scale of individual foraging movements in response to the spill. Recapture rates from netting over water are low for all species. This includes recaptures of the second most common species, *L. noctivagans* (none on the Sacramento River and 3 on Squaw Creek). This may reflect the large individual foraging ranges observed in radiotracking, low year-to-year fidelity to foraging areas, and/or large local populations.

- An analysis of reproductive patterns, based on mist netting surveys conducted from 1992-1995 shows a greater proportion adult females reproduced in 1994 and 1995 than in prior years. Additionally, recapture of banded adult female *M. yumanensis* at spill and control maternity roosts suggests reduced reproductive success in spill populations through 1994. Recapture data on animals originally captured as juveniles also suggests reduced survivorship through 1994, and possibly 1995, for *M. yumanensis* in the spill drainage.
- Non-intrusive observations of bat activity and flying insects (using night vision devices) at fixed stations and along transects on the Sacramento River and Squaw Creek in 1991 and 1992 suggested a less predictable prey base and prolonged feeding times on the Sacramento River relative to the control sites. Variability in these data were high and this approach was not continued in subsequent years. Insect captures on small sticky traps deployed over water during observations are heavily dominated by chironomids, have higher counts on Sacramento River stations and parallel the observational data in showing somewhat lower insect counts in 1992.
- Aquatic insects (primarily caddisflies) were a significant proportion of the diet of the three most abundant bat species in net captures over water. For the most common species, *M. yumanensis*, aquatic insects were more than 70% of the prey volume for all sampling periods on the Sacramento River. Changes in prey proportions from 1991-95 typically occur in parallel on the Sacramento River and Squaw Creek, indicating that regional scale patterns of interannual variation (*e.g.*, timing and magnitude of winter rains) exert major controls on prey availability. For the common bat species, diet diversity generally increases over the study period. For the community as a whole, mean differences among species in the relative proportions of prey eaten by bats caught on the same drainage in the same month (*i.e.*, the same prey present) indicate considerable specialization. Overall, no spill effects on diet composition are evident, but effects on foraging might not be apparent from composition alone, if bats responded by foraging longer hours in non-preferred habitat for similar prey.
- Assessment of year-to-year reproductive success and juvenile survivorship from 1991-1995 in *M. yumanensis* populations suggest spill related injuries are detectable, although the effects of year-to-year variation (primarily weather and climatic fluctuations) on sampling roost aggregations has made resolving that

question difficult. We speculate that a population level effect from the spill is unlikely to be detectable beyond 6-7 years.

- Quantitative data on species composition and abundance (*e.g.*, foraging bats per km of river) for a sample of sites with varying land use regimes on other major drainages in northern California would provide part of the baseline missing when this study was initiated and simplify future damage assessment efforts.
 - Bats are major consumers of night flying insects and may perform other quantitatively significant but little known ecosystem services (*e.g.*, basinwide up slope nutrient dispersal). From an analysis of restoration options, we suggest that the key issue for the long term persistence of viable bat populations is maintenance of a diverse (in size, age, and species) standing stock of defective trees and snags in the watershed.
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Adult year-to-year survival in bats is much higher than in other small mammals and most birds of similar mass (Pomeroy 1990). Recaptures of wild banded individuals more than 20 years old have been reported for several species (*e.g.*, Caubère *et al.* 1984). Bat maternity colonies are frequently multi-generation groups of related females; daughters remain with their mothers at maturity, while male offspring disperse. The primary source of natural mortality appears to be failure of the young to survive their first winter (*e.g.*, Pearson *et al.* 1952). Natural predation is apparently low and active defense against predators (snakes, small carnivores and raptors) is minimal. Bats rely for their survival on being able to escape detection by predators, both in the timing and mode of foraging and diurnally in their hidden roosting sites. Concentration of a large fraction of a local population at one site makes maternity colonies particularly vulnerable to disturbance or destruction. Because of the relatively low reproductive rate, bat populations are slower to recover from acute population reductions than more rapidly reproducing small mammals, such as mice.

1.1.2 Seasonal Activity Patterns

All bats in northern California eat insects and other arthropods (*e.g.*, scorpions [Hermanson and O'Shea 1983]); insect availability peaks in the warmer seasons. Gestation and juvenile development in bats are prolonged for mammals of this body size and occupy most of the seasonal window of high insect abundance. After weaning in midsummer, reproductive females and their newly volant young feed and accumulate fat until falling temperatures and declining insect abundance in autumn make foraging energetically unproductive.

During the colder portion of the year, insect availability and bat activity are low. Species that remain resident in highly seasonal areas may hibernate for extended periods, though episodes of activity by some species during warm intervals are likely, particularly at lower elevations. Bats are vulnerable to disturbance during winter, since arousal from torpor depletes energy reserves which may be essential for their survival until insect availability increases in the spring (Speakman *et al.* 1991). Juveniles generally enter hibernation with less fat and are, even in the absence of disturbance, at greater risk than adults of depleting their energy reserves (Ewing *et al.* 1970, Brigham 1987). Some species, including those which typically roost in foliage (*e.g.*, the hoary bat, *Lasiurus cinereus*), migrate out of colder regions in the winter.

1.1.3 Day Roost Selection

Day roosts for bats include tree cavities, caves, abandoned mines and building attics, but more restrictive, dark sites, such as rock crevices and loose bark or their manmade analogs (*e.g.*, roof tiles and bridge expansion joints) are favored by a substantial number of species (Kunz 1982a). A few, such as both species of *Lasiurus*, conceal themselves in foliage. Individual fidelity to day roost sites, both within a single season and between years seems to be generally high, even for foliage roosting species. Most maternity colonies appear to have alternatives to their preferred site and there may be within-season shifts among sites, particularly after disturbance. In a few cases that have been studied, exclusion from preferred sites in buildings has led to declines in reproductive success (Brigham and Fenton 1986).

The winter (≈hibernating) and summer (maternity) roost sites for a single bat colony are frequently geographically separate, in large part because different temperature regimes are required. Relatively secure roosts for hibernation (November-March) and raising young (April-October) are essential for the viability of any resident population. For a number of species, including some listed by State or Federal agencies as sensitive, the availability of suitable roost sites appears to

1.0 INTRODUCTION

A partial train derailment on the Cantara Loop north of Dunsmuir, California, on 14 July 1991 led to the release of large volumes of metam sodium solution, a soil sterilant, into the upper Sacramento River. This spill created a toxic plume which killed submerged macroscopic animals and aquatic plants in the river down to Shasta Lake, 41.6 miles (66.9 km) south (Brett *et al.* 1995 California Department of Fish and Game 1993, De Rosario *et al.* 1994; see Figure 1). Decomposition of the sterilant generated a persistent cloud of toxic gases in the river canyon which damaged terrestrial organisms, as well as posing a public health hazard which restricted access for evaluation of short-term impact (Cone *et al.* 1994).

In July 1991 the Redding office of the California Department of Fish and Game (DFG) requested assistance in evaluating injury to bat populations as part of assessment of the overall spill impact on terrestrial wildlife. Lack of prior bat population data in the spill area argued for parallel sampling of the spill and unaffected control sites over time. Based on the species assemblage expected in the area and timing of the spill relative to seasonal activity patterns, methods were designed to test hypotheses about both direct and indirect injury to the bat community.

The late initiation of investigations in 1991 relative to the annual reproductive cycle of bats and the hypothesis that a primary element of spill injury would be lowered overwinter survival led to selective studies in the summer and fall of 1992 and 1993, with a subset of investigations continued in 1994 and 1995. The following analysis incorporates results of the entire study 1991-1995 which relate to spill injury and recovery.

1.1 BAT BIOLOGY

Since bats may be unfamiliar organisms to many readers, natural history features which determined the study design are reviewed.

1.1.1 Reproduction and Demography

At mid-latitudes and above in the U.S., reproduction in bats is highly seasonal. For vespertilionid bats (most of the species in the upper Sacramento fauna; see Table 1), insemination takes place in winter refugia (see below); fertilization and embryonic development take place in the spring on emergence from hibernation. Most species form maternity aggregations (predominantly composed of adult females and, subsequently, their newborn young) in the spring and summer. In temperate latitudes females of colonial species typically bear one young per year in late spring or early summer. Births in a colony are relatively synchronous within a species. Females which lose an embryo late in development (or a young after birth) experience reproductive failure for the year (*i.e.*, there is no analog to renesting in birds). The duration of lactation is about six weeks (Tuttle and Stevenson 1982), but maternal care lasts through much of the summer and may include accompanying the young to foraging areas.

Bats are unusual among mammals in that they attain adult skeletal dimensions before they are sexually mature. Females of North American vespertilionid species commonly mature sexually in their first winter at about four months old, so that they emerge pregnant in the following spring. However, there is variation with latitude, locality, and even from year-to-year at the same locality in the proportion of these young females which are pregnant in the spring following their birth. The expectation is that surviving females not pregnant in their first spring will be pregnant in their second spring and in subsequent years. Reported pregnancy rates for parous females (those which have previously given birth) are typically close to 100%, but environmental stress can lower these values (Grindal *et al.* 1992).

limit populations. Roost disturbance or destruction by man is a significant cause of population decline (McCracken 1988). Substantial declines in known populations of Townsend's big-eared bat, *Corynorhinus townsendii*, in California are partly a consequence of roost destruction and disturbance (Graham 1966; Pierson 1988; Pierson *et al.* 1991).

1.1.4 Foraging Activity

Daytime roosting sites and primary foraging habitat may not be contiguous. The distance travelled between roosting sites and foraging areas may be several kilometers for relatively sedentary species (*e.g.*, the big brown bat, *Eptesicus fuscus* [Brigham 1991] or pallid bat, *Antrozous pallidus*, [Brown 1982; Pierson unpubl. obs.]) or many kilometers for long distance fliers such as the Mexican free-tail, *Tadarida brasiliensis* (Barbour and Davis 1969, Williams *et al.* 1973) or the mastiff bat *Eumops perotis* (Vaughan 1959). Many species also occupy solitary or aggregated night roosts. These sites are generally close to foraging areas and are used for eating large prey, resting and social interaction between foraging bouts (Kunz 1982a, Lewis 1994) and, as with day roosts, both natural sites and manmade analogs are occupied. Some North American species (*e.g.*, the spotted bat, *Euderma maculatum* [Wai-ping and Fenton 1989]) are generally presumed to fly continuously when away from their day roost.

At high insect densities, prey ingestion rates of some aerial foraging bats exceed assimilation rates, so that satiated animals may arrive at the night roost within an hour of departure from the day roost. Temporal activity patterns vary significantly among species, localities and seasons, but foraging activity is often bimodal (*i.e.*, concentrated within a few hours after sunset and, to a lesser extent, immediately prior to dawn), matching nocturnal insect activity (Kunz 1973, Erkert 1982). For several species, there is evidence for regularly occupied foraging territories or beats which are sometimes defended against some other bats and nocturnal birds (*e.g.*, Kunz 1973, Kurta and Baker 1990, Leonard and Fenton 1983, Rydell 1986), though opportunistic exploitation of insect aggregations is also well documented (Bell 1980, Vaughan 1980). Not surprisingly, resource defense may be more intense in times of scarcity.

Acoustic monitoring of bat activity from forest habitats in the Pacific Northwest suggests that bats preferentially roost in old growth settings (which have higher abundance of snags, trees with hollow limbs or boles and other potential refuge sites than younger forests), but forage primarily elsewhere (Thomas and West 1988, 1991). Several species, such as the Yuma myotis, *Myotis yumanensis*, the little brown bat, *Myotis lucifugus*, and the silver-haired bat, *Lasionycteris noctivagans*, frequently forage in habitats associated with surface water, exploiting emergent aquatic insects or those from adjacent vegetation (Fenton and Barclay 1980, Herd and Fenton 1983, Kunz 1982a, Manning and Jones 1989). The foraging style of *M. yumanensis* and *M. lucifugus* often bring them into contact with the water's surface. Prior to the current survey, community level studies in northern California identifying the bat species assemblage which forages over water or riparian habitats were lacking.

Bats may lose considerable water in warm, dry roosts during the day (up to 20% of hydrated body mass [Studier and O'Farrell 1980]) and, after emergence, most species drink while in flight from both natural and man-made bodies of water. Wing morphology and wing loading vary considerably among bats and influence flight speed and maneuverability (Norberg and Rayner 1987) so that, while large areas of open water (rivers, lakes) are potentially available to all species for drinking, vegetation-cluttered tributary streams or pools may be inaccessible to some. Limited surface water resources in dry habitats or seasons may attract bats from substantial areas of surrounding habitat, even when insect production is absent at these sites. Cyanide-charged process water from heap leach gold mining operations has lead to significant bat mortality (*e.g.*, Clark and

Hothem 1991, Sturgess *et al.* 1991), demonstrating that bats will approach and apparently consume chemically contaminated water with potentially aversive odor and elevated pH.

2.0 SURVEY DESIGN

2.1 SPILL INJURY TO BATS

While there is a substantial body of both experimental and observational toxicological data on bats emphasizing chlorinated hydrocarbons (*e.g.*, Clark 1981, Mitchell Jones 1989), no information on effects specifically on bats or their behavioral response to exposure was obtained for metam sodium and or the degradation products (methyl isothiocyanate, hydrogen sulfide, methylamine, carbon disulphide, N, N' dimethyl thiuram disulphide) identified in documents provided by DFG to the contractor. Other contract investigations were to address the movement and composition of the spill plume and toxicant effects on spill area organisms. This study focused on possible ecologic and demographic effects on bats, assuming from the preliminary data provided that spill components dispersed or degraded quickly and there was minimal residual toxicity (see Del Rosario *et al.* 1995, Geddes *et al.* 1995). As model for discussion, two intergrading phases of the spill and its aftermath should be distinguished:

1. An acute period when emergent aquatic insect prey from the river was eliminated and contamination of the river water and immediately overlying atmosphere was, at least locally, high enough to be dangerous, aversive, or both to bats.
2. A much longer period after chemical contamination dropped below the thresholds for aversion or acute injury, during which the prey base still was initially absent, then subsequently recovering, but altered in composition.

The following classes of possible spill injuries to bats were considered in designing field surveys.

2.1.1 Direct Mortality or Morbidity

Mortality or morbidity could have resulted from drinking or attempting to drink contaminated river water, from contact or respiratory uptake during attempted foraging at traditional sites along the river course while contamination was intense, or from fumigation by spill volatiles of bat roosts close to the river. To conserve energy, roosting bats may be in torpor especially during the early part of the day. During the day, the most common behavioral response of bats to threatening stimuli such as mechanical disturbance is to retreat further into the restricted dark areas they occupy, rather than fly out into daylight where they are highly vulnerable to diurnal aerial predators. This response pattern might lead to even higher exposure to irritating gaseous toxicants in bats than would be tolerated by many other mammals.

Some colonies of cave dwelling bats tolerate concentrations of naturally occurring gases (*e.g.*, CO₂, ammonia, depressed O₂) which are irritating or dangerous to humans (Constantine 1988). Hydrogen sulphide, one of the decomposition products of metam sodium, sometimes occurs at elevated levels in mines or in association with decomposing organic matter (Constantine 1988). While some elevation of tolerance for this gas may be present or inducible in cave dwelling bats, it is not known whether the adaptations of these species also occur in other bats and whether these adaptations influence response to more toxic compounds (*e.g.*, methyl isothiocyanate and carbon disulphide) derived from metam sodium.

It is important to note that even if chemical injury directly killed few bats, a decrement in performance (*e.g.*, increased pulmonary water loss; lowered burst speed for predator escape) could lead to increased mortality from natural causes. Particularly for naturally stressed developing juveniles, such loss of condition could contribute to less efficient prey acquisition (sometimes a matter of hundreds of insect captures per hour) leading to reduced fat stores and, in turn, to failure to survive hibernation. The injury potentially occurred in July, but the animal may not die (effectively of starvation) until January (the interacting effect of prey reduction is treated below). For surviving juveniles, lowered condition can lead to delayed reproduction (*e.g.*, Speakman and Racey 1986).

2.1.2 Indirect Mortality or Morbidity via Adult Ingestion or Inhalation

The spill occurred in mid-July 1991 when maternity colonies of some bat species along the upper Sacramento River would be expected to have non-flying young which were dependent on milk. Loss of parental condition from toxicant uptake could have led to reduced foraging efficiency and consequent reduced ability to provide adequate nutrition to dependent young. It is also possible that uptake of toxicants by lactating females may have permitted transfer of toxic compounds to the young in milk. These effects could have caused mortality, developmental alterations including reduced growth or marginal nutrition in young of the year. Most births likely preceded the spill, but for any remaining females which were in late pregnancy, exposure to toxic compounds and reduced food availability could have altered fetal development and increased perinatal mortality. A number of studies (*e.g.*, Ransome 1990) indicate that juvenile bats born late are typically compromised in many ways (low body mass, lowered first year and subsequent survival and reproductive success).

2.1.3 Indirect Mortality or Decreased Reproductive Success from Prey Base Alteration

2.1.3.1 Interaction of the spill, seasonal patterns of productivity, and bat reproductive energetics

The upper Sacramento, like other northern California rivers, has a seasonal regime of winter flooding with falling discharge and rising water temperatures in late spring and summer (Figure 2). Abundant algal growth on the rocky bed in the clear water of the sunlit channel supports a productive community of invertebrate herbivores and predators, and fish (Power 1990a). Destruction by the spill of both the standing crop of algae and associated aquatic insect community presumably eliminated or drastically altered the summer peak in flying aquatic insect production on which some bat species may rely to complete growth of the young and to obtain sufficient energy stores to survive low insect abundance in winter by hibernation. Fumigation of the riparian vegetation likely affected terrestrial insect prey and their food base with the severity of damage declining at increasing distance from the water.

The time of peak nutritional stress for both the female bat and her offspring is when the juvenile begins to fly. At that time, in at least some species foraging on aquatic insects, adults leave the open water areas which accommodate the limited foraging abilities of the developing young and, instead, begin to forage more heavily in cluttered habitats (Adams 1990, 1992). The high nutritional demands of the newly volant young combined with foraging microhabitat restrictions imposed by their limited flying skills likely make them differentially vulnerable to severe reductions in emergent aquatic insects.

2.1.3.2 Acute reduction in prey availability by the spill: behavioral responses and effects on bats

Possible responses of bats to locally reduced prey availability include extending the duration of foraging while remaining in the same area. However, females in late lactation may have already extended their foraging time substantially (*e.g.*, minimum 73% increase in *L. cinereus* [Barclay 1989], greater than 100% for *Eptesicus nilssonii* [Rydell 1993]). Another response is moving to more distant alternative foraging areas. Presumably this response would have been likely in the early acute phase of the spill when gases irritating to mammals were volatilizing from the river.

Though bats are highly mobile and the energetic costs of a limited increase in commuting distance are probably moderate at least for adults with fully developed flight morphology, it is important to remember that many tens of kilometers of what was likely the most productive corridor in the area was affected. Nearby higher gradient, shaded tributary streams of the Sacramento support less aquatic primary production and are more acoustically and physically cluttered, so that foraging for even adults of several species is likely prevented and others experience reduced efficiency (von Freckell and Barclay 1987, Mackey and Barclay 1989). Refugee bats from the spill area could face increased competition among themselves and with any resident bats in a new area. Tuttle (1976) found growth rate of volant juvenile *M. grisescens* among colonies was negatively correlated with the distance between the roosts and the bodies of water where they foraged over a scale of a few kilometers. Likely consequences of a sudden persistent reduction in prey availability include slowed growth and reduced within-season survival of young (particularly for those born late), reduced late season fat deposits for both adults and young, decreased overwinter survival and delayed reproduction, particularly for juvenile females.

2.1.3.3 Mechanisms of multi-year effects by the spill: alterations in aquatic food webs, prey size structure, elemental nutrition and the consequences of developmental injury

While benthic communities of northern California rivers are to some extent 'reset' annually by winter flooding and scour under normal rainfall regimes, chemical extirpation of the aquatic community in the main channel could have effects on primary production and the aquatic food web interactions which continue to influence local bat population survival and reproductive success for several years. Experiments in the nearby Eel River have shown that removal of larger predatory fish which consume smaller fish and invertebrate predators strongly affects populations of smaller herbivorous insects, who in turn control the standing crop of benthic algae (Power 1990b). Spill removal of larger predatory fish and their slow recovery may trigger substantial shifts in the abundance and species composition of the emergent aquatic insects available to bats.

Aquatic insect assemblages of equal total biomass, but different body size or taxonomic composition may not be equivalent to foraging bats. The lower echolocation frequencies (and generally lower maneuverability) of larger aerial pursuit foraging bats preclude efficient detection and capture of smaller, nonpredatory insects (Barclay 1986) which would likely be the first to reappear as the aquatic insect fauna recovers. In addition, slow recovery of populations of larger or longer generation-time insects, which are relatively less abundant, but are nutritionally significant to bats, may influence bat growth and survival. For example, physiological studies show that adult female *M. lucifugus* in late lactation are in calcium deficit (Kwiecinski *et al.* 1987). They mobilize their bone mass to supply calcium to their growing young, but rebuild their skeletons after the young are weaned. Analyses of *E. fuscus* guano and insects indicate that several elemental nutrients, including calcium, are limiting in insectivorous bat diets and that, among insects tested in central Michigan, only plecopterans (stoneflies) appear to be adequate calcium sources (Studier and Seveck 1991, Studier *et al.* 1991a, 1991b, Keeler and Studier 1992). Barclay (1995) argues that calcium rather than energy in the diet may limit reproduction in bats.

Even in the absence of persistent alterations to the resource base, bats (as noted above in section 2.12) and other animals (including humans) subject to unusual or intense environmental stress (*e.g.*, restricted food availability or quality, exposure to toxicants) during development may experience permanent alterations which influence their survival and reproductive success. The sum of these effects on individuals, even from single acute events, may affect population trajectories, especially of long-lived animals with a low reproductive output, for several years. Highly compromised individuals subject to subsequent 'more normal' environmental selective forces may survive only a short time. Those surviving longer may show reduced body size, reduced body mass for the same body size, reduced survival and reduced lifetime reproductive output. More subtle changes such as decreases in normal bilateral symmetry of body parts (termed fluctuating asymmetry) are another morphological indicator of developmental stress (both natural and anthropogenic) which has been experimentally linked to lower reproductive success, particularly in males (*e.g.*, Hill 1995).

2.2 BAT RESEARCH TECHNIQUES

North American bats are typically small, dark colored, disturbance sensitive animals which conceal themselves during the day and move rapidly over large distances at night to hunt insects using vocalizations which are largely inaudible to the human ear. This combination of features makes bats considerably more difficult to study than many other small vertebrates and knowledge of their population biology, ecology and the effects of interaction with man is concomitantly less advanced. Several innovations in techniques for capture (mist nets and harp traps) and, more recently, reliable, minimally intrusive electronic equipment for acoustic and visual survey (light amplification and ultrasound conversion devices) have greatly improved success in monitoring the composition and activity patterns of bat communities (Kunz 1988a, Thomas and West 1989, Rainey 1995). A key problem for many species is identification of concealed maternity roost sites and miniaturization of wildlife radio transmitters has been particularly important in allowing tracking of reproductive females back to their roosts. This technique and shorter-lived chemiluminescent tags also offer information on the timing and spatial pattern of foraging activity (Wilkinson and Bradbury 1988), but interpretation of behaviour of small flying organisms carrying tags which are a significant fraction of their body weight requires caution (*e.g.*, Calvo and Furness 1992).

The bat assemblage in California is diverse and, because the morphology and habits of species within the assemblage differ considerably, no one sampling method alone offers a complete assessment of species composition, status, and habitat use (Pierson, *et al.* In press). A combination of methods is usually obligatory and data interpretation must incorporate at least qualitatively the differential detectability of individual species or guilds.

2.3 SURVEY TASKS

Against this biological and technical background, a series of tasks were defined to test the most feasible elements of the hypothesis that bat populations in the spill area were negatively affected (altered foraging behavior, increased mortality, reduced growth or reproduction relative to nearby uncontaminated areas or to species norms derived from the literature). Some emphasis was placed on identifying populations in the survey area of sensitive species (*i.e.*, candidates for listing under Federal ESA or DFG mammals of special concern), but the study sought to evaluate the status of and evidence for impact on the entire bat community. The spill was an acute event with impact presumed to gradually decline over time in a seasonal environment with substantial inter-annual variation, which also influenced the status of wildlife populations. In the absence of prior

local data on bats, identifying spill effects after the actual event required studies which would also resolve the magnitude and pattern of natural fluctuation.

3.0 METHODS AND MATERIALS

3.1 ROOST SITE SURVEYS

Based on guidance from the contractor during the post-spill period in 1991, DFG personnel and subsequently BioSystems technicians identified natural and manmade structures which might serve as sites for aggregated bat roosting in the zone of influence of the spill. They: (1) reviewed documents and interviewed public agency personnel regarding the location of abandoned or active mines, tunnels, bridges, and caves from Riverview Drive (the upper limit of inundation by Lake Shasta) to Cantara Loop (see Fig.1); (2) conducted a helicopter reconnaissance of the survey area to both evaluate the previously identified features and locate additional manmade or natural features (cliffs, hollow trees, etc.) and (3) inspected the accessible features identified for bats or bat sign (guano, staining). In the course of these diurnal field inspections, observers walked a substantial portion of this segment of the Sacramento River and attempted to identify additional less conspicuous natural or manmade features within a few hundred meters of the river which might harbor bat roosts. Bats roosting at sites close to the river were most likely to manifest effects from the spill. Bridges were of particular interest as they commonly provide sites for crevice or cavity roosting bats (Davis and Cockrum 1963, Frazee and Wilkins 1990). Human-occupied structures close to the river (*e.g.*, in Dunsmuir) were not canvassed, but possible roost sites identified by interested residents or noted incidental to other activities were investigated if they had reasonable proximity to the river. Subsequently, additional roosts were identified in the course of radiotracking, and nocturnal surveys of bridges.

3.2 BAT ACTIVITY OBSERVATION

3.2.1 Site Selection

Bat activity observations were designed to permit DFG and Biosystems wildlife personnel to nonintrusively obtain an objective short-term index of bat activity over multiple sites on the river and a control drainage. Site selection for observation stations was made in 1991 by DFG personnel subsequent to discussions with the contractor. Sites were distributed along the affected reach of the Sacramento River and accessible portions of Squaw Creek, selecting for localities with substantial areas of relatively smooth surface flow favored by foraging bats (von Frenckell and Barclay 1987, Mackey and Barclay 1989), but addressing the practical problem of reliable night time road access during a period of extensive highway alteration. Thirteen sites (see Fig.1; Appendix 1 for site location descriptions; elevation range \approx 865-340 m) were selected along the Sacramento River, including one above Cantara Loop and twelve below, extending down the drainage to Vollmers. Note that the stations are numbered sequentially in the order that an observer traveling south along Interstate Highway 5 (I-5) would be obliged to visit them. This is consistent with the order downstream except that 8 is south of 9. Limited access between the Sims and Gibson Interstate 5 interchanges requires doubling back along the highway to reach sites in this segment.

The single site above Cantara Loop was tentatively incorporated as a control, with the recognition that events within the spill zone were likely to have influenced it. After review of other options, Squaw Creek was chosen as a control site (paralleling similar use in other wildlife contract surveys). This smaller drainage has a discharge into Shasta Lake comparable to that of the Sacramento River near Mount Shasta City (see Fig. 2, noting that the periods of record are not identical). Six observational monitoring sites (numbered consistently upstream; elevation range

≈455-340 m) were distributed along the relatively accessible portions of the drainage. The multiple sites on both drainages offer within-drainage replication, but are not formally paired between drainages on microhabitat or other criteria.

At each observation site a highway reflector was glued to a stable substrate (rock, large log, cemented area, etc.) and a complementary reflector was similarly glued to a rock at or close to the opposite shoreline, generally within a meter of the water's surface. The range finder distance to the near shoreline and the far reflector were recorded to obtain survey path length. The magnetic bearing from the observation point to the far reflector and one or more photographs were obtained to permit relocation, if markers were lost to flood damage or vandalism. Damaged or missing reflectors were replaced as needed.

3.2.2 Fixed Station Observations

Observers occupied a site prior to sunset, placing a tripod with night vision device (NVD), red filtered battery powered spotlight and suspended armored thermometer over the observation point. The axis of the spotlight beam, and the optical axis of the NVD were pointed at the reflector on the opposite bank. At approximately half-hour intervals, starting at local sunset (to the nearest minute from published tables for Mount Shasta), the observer would turn on the light and NVD, record on a tally the number of bats entering or passing through the field of view for one minute, turn off the light, wait one minute, then repeat this process twice. Immediately subsequent to this, the same method was used to obtain three insect counts. In the earliest observations only single one minute counts of bats and of insects were made. Observations generally continued for at least five hours. In some instances observations were initiated at one half hour after sunset. The observer recorded air temperature at the sampling times, weather conditions and moon rise.

Prior to initiation of the counts, observers set up a sticky trap array to collect samples of insects over the water in the foraging areas used by bats. The array held 3 Bulldog® clips hung from cords on a rod extending out them out approximately 3m from the shore near the observation site. For each night of observation an 8.5"X 11" sheet of acetate film rolled to form a cylinder and covered with Shell Darina® grease (an alternative to Tangletrap®; see Brigham and Smishek 1991, Kalcounis *et al.* 1992) was attached to the clips (one each at heights of 1.5m, 0.75m and near the the water surface) until the observations ended for the night. Difficulties with sporadic loss of the sheets to gusty winds lead shortly to a slightly altered procedure in which the sheets were attached to 12" lengths of 4" diameter cylindrical light gauge aluminum duct with clips and double-faced adhesive tape. Labelled trap sheets with insects were placed in acetate sleeves and stored in binders. The sheets were catalogued and, in a preliminary analysis the numbers of trapped insects were visually counted up to a maximum of sixty (uncounted high values coded as '>50').

Insects from the sheets were identified under a separate contract and summary results are presented below. The units of analysis are the individual sticky traps sheets (generally 3 per station per night). While the statistical independence of the three sheets from one site and night may be open to question in the context of some confirmatory statistical analyses, the approach taken to analysis here is instead exploratory and the pattern of variation at a survey site, relative to variation among sites or years is potentially informative.

Fixed observations were conducted at all six Squaw sites and a geographically distributed subset of the Sacramento sites (1,2,3, 5, 7,8,10,13), though Station 9 was sampled once by error. On each fixed observation night, two sites were monitored, either one site on Squaw Creek and one site on the Sacramento or sites 1 and 2 on the Sacramento. Each fixed observation site was generally surveyed twice each year on or near the same day in August and September 1991 and 1992. To minimize standardization efforts, the same NVD was used on each drainage in each year.

Between surveys batteries were systematically replaced or recharged as required to maintain proper operation. Any equipment malfunctions were logged in the observation record.

3.2.3 Transect Observations

During transect surveys, visual observations at each site were conducted as described for the fixed station observations above. The fundamental difference was that the observer moved from site to site within a drainage in the less than half hour interval between observations, so that all sites were sampled in numerical order at approximately half hourly intervals on a single night. Transects were conducted simultaneously on both drainages on twelve nights in August and September 1991 and 1992.

3.2.4 Roost Emergence Counts

To estimate colony size, seasonal duration of occupancy, and direction of exit flights at maternity roosts, as well as the exit location of some tree roosts identified by radiotracking (see below), roost emergence counts were conducted as described by Thomas and LaVal (1988). Early emerging species were generally counted with multiple observers counting non-overlapping sectors using unaided vision or binoculars, tally counters and sometimes bat detectors. With species which emerge in near total darkness, some or all observers used NVDs when available.

3.3 CAPTURE-RELEASE SURVEYS

3.3.1 Mist Netting

Mist net capture of bats over water along the spill affected segment of the Sacramento River and Squaw Creek permitted monitoring over time of species feeding or commuting on these corridors, assessment of reproductive condition and age and banding to examine maturation, survival and local movement. Following the procedures outlined by Kunz and Kurta (1988), 1.5 inch mesh black nylon or polyester nets of a size appropriate to the location (7' or 10' height; lengths of 18', 30', 42' and 60') were set on sectional poles from shoreline vegetation out into the river or creek. Where possible, nets extended completely across the watercourse, but at some sites water depth, heavy flow, or hazardous footing in darkness on loose cobbles and boulders restricted nets to the margins of the channel. Net area varied with site constraints (e.g., narrow sub-canopy streams vs. open river reaches). Though we tried to deploy similar numbers, sizes and spatial patterns of nets at particular sites across years for comparability, the dynamic nature of the habitat (changing flow and thus width, altered vegetation, scour creating deep areas impractical to net) and changes in the numbers of rabies immunized personnel available to remove bats lead to differences in the net area deployed (see Table 2A & B and discussion of effort standardization below)

To minimize captures of late flying birds, nets were generally opened 0.5 hrs after local sunset and remained open and closely tended for at least four hours. Bats were removed as rapidly as possible to numbered cloth holding bags, generally logging the time and net for each individual or aggregate capture. Bats were held suspended in the bags (usually individually, but occasionally pooled by species and time of capture) for several hours in a larger container prior to processing. This interval facilitated collection of guano samples for diet analysis and prevent repeated netting. Examples of large insects incidentally netted were retained (labelled and air dried) to aid in identification of fragmentary material in guano analysis.

On-site processing of netted bats involved species identification (see van Zyll de Jong 1985 for keys); weighing (to 0.1 or 0.01g) in temporary confinement on a portable electronic balance

foraging activity (*i.e.*, did radio location data indicate that the bat foraged directly over open water along the river, in or over riparian vegetation along the river, along the axis tributary streams, at middle elevations within the canyon away from streams, or along ridge lines). Movements were rapid and of large scale (several km in minutes) and simultaneous bearings from two or more observers were frequently not available. Analyses of radiotracking *L. noctivagans* are incorporated in a draft manuscript submitted to DFG (Pierson and Rainey 1996a)

3.4 DIET ANALYSIS

Bat diet analysis in this survey is based on analysis of guano from roost site deposits or from animals captured for mark and release, rather than the gut contents of sacrificed animals. Experimental studies indicate that results of fecal analysis are generally comparable to gut content analysis, although soft bodied insects (*e.g.*, mayflies) may be under-represented in fecal material (see Whitaker 1988 for discussion). As noted above, samples from various sources were air or oven dried to prevent degradation in storage and held in labelled plastic containers prior to microscopic analysis.

Fecal pellets were examined microscopically following the methods of Whitaker (1988), except that identifiable materials from the samples were initially retained to permit reanalysis. Arthropod prey identification (to the family or ordinal level) was based on higher taxon traits which persist highly fragmented material and guided in part by reference specimens from the spill area. The taxonomic resolution possible varies among orders partly because of prey handling practices by bats (frequently only the abdomens of moths are consumed and the remainder of the body with its wider array of diagnostic features is discarded) and partly because some groups are more resistant to fragmentation or distinctively ornamented (*e.g.*, beetles). Most analyses in the report are based on pooling prey taxa at the level of order.

Pellets in samples from individual bats taken from nets over water or nearby night roosts were counted and the percent volume (prey taxon volume/total volume for the pool*100) for each prey taxon present in the pooled sample of pellets was estimated visually. Thus the unit of analysis for these samples is the bat. For each year on the spill and control drainages we reviewed the available samples (without reference to localities within drainages) to obtain five adult and juvenile males and female samples (total of twenty) in which the number of relatively normal size pellets was five or greater. This goal was approached on both drainages only for the two most common species (*M. yumanensis* and *L. noctivagans*). For less common species, smaller available numbers of individual samples were analysed and in a few instances lower pellet count samples were analysed. For *T. brasiliensis*, Whitaker *et al* (in press) conclude that a minimum of five pellets were required to identify all the insect families present in the diet of an individual, but even single pellets typically contained the three most common prey taxa. While the numerical relationships may vary among species and localities, this finding suggests that inferences about common prey types for less commonly captured bat species can reasonably be made from small numbers of pellets. Mean number of pellets per bat is shown in all graphs to allow some assessment of rarefaction effects. For all years, netting and some bridge night roost collections on both drainages were conducted in a short intensive interval and samples for diet analysis within these intervals were selected without reference to date. Opportunistic samples from night roosts along the Sacramento River which offered additional information on seasonal variation in diets of *M. yumanensis* and *A. pallidus* are also labelled by collection month and year and incorporated in the analysis. For roost accumulations, up to 50 if available, intact pellets were selected haphazardly from the materials collected and their percent volume prey composition analysed on a per-pellet basis.

3.5 REGULATORY STATUS AND NOMENCLATURE

Throughout most of this study, three bat species potentially occurring in the survey area were candidates (Category 2) under the U.S. Endangered Species Act (ESA) and five were DFG Mammal Species of Special Concern (DFG MSSC). In November 1994, an additional five, including the species most intensively studied, *M. yumanensis*, were added to the ESA candidate 2 list. In July 1995 a memo from the director of the Fish and Wildlife Service (FWS) eliminated Category 2 status under ESA. This was formalized on February 28, 1996 with a single new candidate list which includes none of these taxa (FR 61(40):7595-7613). While FWS future role in identification of species within the former candidate pool as sensitive or at risk remains uncertain, some federal agencies (e.g., the National Park Service) may retain former candidates as sensitive. As the situation remains in some flux, Table 1 includes a summary of current (DFG Special Concern Species) and former (ESA Candidate 2) status for bat species in the survey area.

There are differences among the taxonomic names and systematic units listed in the DFG Species of Special Concern, formerly as candidates under ESA and other sources, such as the bat section of Wilson and Reeder (1993). The latter publication is widely used in North America as the standard reference for taxonomic names. To lessen confusion, these differences (noted in Table 1) are briefly discussed here. Koopman (in Wilson and Reeder 1993) does not recognize as distinct several bat species which are recognized elsewhere. The Western small-footed myotis, *Myotis ciliolabrum* and the related *M. leibii* are were listed as separate species under the ESA, but are lumped as one in Wilson and Reeder. We conclude the weight of available evidence (especially the electrophoretic study of Herd 1988) favors recognizing both species (DFG publications have used *M. ciliolabrum*). Similarly, in Wilson and Reeder, the Western red bat, *Lasiurus blossevillei*, is included within *L. borealis*. We again conclude evidence supports recognizing both species (Baker *et al.* 1988, Morales and Bickham 1995) and thus using *L. blossevillei* in DFG publications.

A nomenclatural change postdating Wilson and Reeder (1993), already adopted by some (e.g, the Nature Conservancy's Natural Diversity database program) resurrects the genus *Corynorhinus* for North American big-eared bats placed in the Eurasian genus *Plecotus* by Handley (1959). We conclude that the evidence supports this change (Tumblison and Douglas 1992, Frost and Timm 1992), so the scientific name for Townsend's big-eared bat becomes *C. townsendii*.

3.5 GENETIC ANALYSIS FOR SPECIES IDENTIFICATION

With the exception of two species pairs, bats in the spill area are reliably identified on simple external characters. There are mean size, mass and pelage differences between *M. yumanensis* and *M. lucifugus*, but it is not possible to assign all living individuals to species reliably based on external morphology (Herd and Fenton 1983). They can be separated on skull characters. A similar less completely explored problem exists in some areas (including the spill region) for separating the California myotis, *Myotis californicus* and the small-footed myotis, *M. ciliolabrum*, on external morphological characters of (van Zyll de Jong 1985).

Despite the external similarity, Herd and Fenton (1983) showed that *M. yumanensis* and *M. lucifugus* were reliably distinguishable by either protein electrophoresis or red cell agglutination. Similarly, protein electrophoresis of *M. californicus* and *M. ciliolabrum*, showed fixed allelic differences suggesting no genetic exchange (Herd 1988). In the context of possible legal action relating to the spill, it seemed prudent to objectively evaluate our assignments of banded animals to these species pairs by a nondestructive molecular method. To minimize the field handling time, trauma, and sample storage difficulties associated with blood sampling essential for the techniques used in those studies, we instead preserved hair samples from a subset of individuals in ethanol. Subsequently, aliquots of hair samples and tissue fragments of dead specimens identified on skull characters were treated to extract DNA using protocols (Walsh *et al.*

1991; Higuchi, pers. comm.) developed for human forensics. A portion of the extract provided template to amplify a defined fragment of the mitochondrial cytochrome b gene via the polymerase chain reaction (Mullis *et al.* 1986, Saiki *et al.* 1988) using versatile primers (Kocher *et al.* 1989, Irwin *et al.* 1991). As a preliminary screening test, amplified fragments from a series of individuals were cut with several restriction enzymes with four-base recognition sequences and electrophoresed in agarose to detect differences in restriction fragment patterns between the species.

3.6 QUALITY ASSURANCE

3.6.1 Participants and Training

The two primary investigators, William E. Rainey and Elizabeth D. Pierson, were involved in the study design, and helped select and train field personnel. Both hold Ph.D.s in Zoology from the University of California at Berkeley, have extensive (13-15 years each) field experience with bats, and are familiar with techniques available for population assessment.

Initial spill area surveys in 1991 to locate bat roosts and select observation stations, were conducted primarily by DFG personnel and subsequently by a Biosystems contract technician, following guidance by the primary investigators on design, bat natural history and specific field techniques. Participants were instructed by the primary investigators or qualified DFG personnel on habitat features to look for, and how to recognize the presence of bats or identify bat "sign" (guano or staining).

In subsequent phases, relevant biological background and task-specific training to new field personnel were provided by the primary investigators or DFG personnel involved over the long term. The primary investigators were present for all field work which involved handling living bats and conducted various specialized activities, such as attaching or removing radio transmitters. For mist netting, contract technicians and DFG personnel assisted in setting, monitoring, and dismantling nets. Personnel who participated in handling bats (*e.g.*, removing animals from mist nets, or assisting with application of bands or radio transmitters) had been trained by the primary investigators, had worked with them previously in the field, were rabies immunized and had what are regarded as protective titers.

For the fixed station and transect observations, technicians were trained in the office and field by one of the primary investigators or experienced DFG personnel in the operation of night vision devices, bat detectors and in execution of the sampling protocol.

The contract technician who assisted with the DNA amplification for species identification holds a Master's degree and completed a training course in DNA laboratory techniques at three campuses of the UC system. She also had prior experience assisting in studies using these methods undertaken by W.E. Rainey and other collaborators.

3.6.2 Data Collection, Validation and Security

To summarize relevant elements of the methods above, most data were manually recorded in the field in structured data formats or, to a limited extent, as narrative field notes. A subset of the maternity roost data was directly entered into portable computers in the field. For consistency, the vast majority of assessments of reproductive condition, other qualitative characters and species identifications reported here were made by the investigators. Exceptions were in the context of continuing training for other participants and some independent examination of bats in roosts by

experienced volunteers or DFG employees. Field measurements were generally verbally repeated for confirmation by the person recording data. On a time available basis, or subsequent to the field season, contents of handwritten data formats were entered into a computer. Resulting files were read back completely against the original data set and corrected. Since measurement, description, or initial data entry remained as a possible sources of error, additional validity tests were made in the exploratory phase of analysis by comparisons within the data sets (*e.g.*, review of original records, if biologically unlikely distributional outliers were detected in x-y plots of morphometric characters).

Hair and guano samples were collected from individual bats and stored in plastic vials labelled with indelible (solvent based) pen. Labels were generally redundant, including individual band number, species, date, and sometimes location. Labels were rechecked against tabular field data when samples were subsequently cataloged on computer and any apparent inconsistencies were reviewed. Hair samples were always collected by W. E. Rainey at the time an animal was processed, with the band number being simultaneously recorded on the vial and on a data sheet. The band number was systematically read aloud at the time of sample collection for verification.

All DNA extractions were also conducted by W.E. Rainey. Representative materials were retained unprocessed. Amplification experiments using both samples from the project area and known specimens collected elsewhere (as well as appropriate analytical controls) were designed by the investigator and generally executed by the laboratory technician.

When selected guano samples were transferred to a subcontractor for analysis, they were sent in their original vials, and accompanied by an itemized list. The subcontractor was instructed to retain all samples during the period prior to resolution of legal conflicts around the spill.

Duplicate copies of original data in the possession of the investigators were provided to DFG. For some observation station data collected in 1991, original data reside with DFG and the investigator has only copies. Specimens remain in the possession of the investigator in locked facilities with the exception of hair samples consumed in DNA analysis or guano samples submitted to the subcontractor.

4.0 RESULTS AND DISCUSSION

4.1 SPECIES COMPOSITION

Seventeen bat species have been identified during this study (Table 1), fifteen by capture and release (*i.e.*, mist-netting over water and hand capture at roosts), and two by tape recordings of species-specific search phase echolocation calls. One other species, the big free-tailed bat, *Nyctinomops macrotis*, (a DFG Species of Special Concern), potentially present in the area, was not detected. Only a few published records are available for this species in California (Milner *et al.* 1990) and no colonies are currently known in the state. Available evidence suggests this is primarily a warm desert species and a British Columbia record which defines the northwest corner of its range may indeed be a vagrant, though there are additional isolated winter records from the San Francisco Bay area (D. Constantine, pers. comm.)

The data collected during this project provide range extensions, as evaluated using Hall (1981) and Zeiner *et al.* (1990), for at least 4 species: *L. blossevillei*, the western pipistrelle, *Pipistrellus hesperus*, the mastiff bat, *Eumops perotis*, and the spotted bat, *Euderma maculatum*. Both *L. blossevillei* and *P. hesperus* are known from Dales, east of Red Bluff (Tehama County), with breeding records for *P. hesperus* extending up to Lake Shasta (D.G. Constantine, pers. comm.). Published breeding records for *L. blossevillei* in California are concentrated in the

southern Central Valley (Grinnell 1918). The project records from Squaw Creek and above Lake Shasta on the Sacramento River are the most northern California records for both species. Their presence in the area is not unexpected, however, since *P. hesperus* is known from eastern Oregon and southern Washington, and *L. blossevillei* from as far north as southern British Columbia (Hall 1981).

The records for *E. perotis* and *E. maculatum* (both DFG Species of Special Concern formerly ESA Category 2 candidates) indicate current state distribution maps for these species are particularly deficient. The most northern specimen locality for *E. perotis* is Oroville (Butte Co.; Eger 1977). Although this specimen was long considered a vagrant, recent acoustic surveys detected colonies of *E. perotis* associated with basalt table lands from Oroville to Chico (Pierson and Rainey 1994). Search phase echolocation calls attributable, based on present knowledge, only to *E. perotis* (unpubl. obs.) were recorded in late 1992 at Ney Springs Fishing Access on the Sacramento River above Cantara Loop. R. M. Miller subsequently recorded *E. perotis* search phase calls in the Medicine Lake Caldera, northeast of the Sacramento drainage and at Gumboot Lake to the northwest in September 1993. This species is not known to use night roosts and may forage over 40-80 km/night. The most likely sites in the spill area for day roosts are in vertical fractured rock faces, such as occur in Castle Crags State Park or Box Canyon.

Although prior specimens existed for *E. maculatum*, both northeast and southeast of the spill site (Bleich and Pauli 1988, McMahon *et al.* 1981), there were no records from the Coast Ranges north of the type locality on the northern edge of the Los Angeles basin (Pierson and Rainey 1994). The species was first detected in the study area in July 1993. R. M. Miller recorded its distinctive echolocation call (Leonard and Fenton 1984) on Aiello Rd., northeast of Box Canyon, and again in August 1993 at Castle Lake (Siskiyou County), to the west of the study area. In late July 1994, it was recorded over the field beside Ammirati's store, at the Castle Crags I-5 exit, within a few hundred m of the Sacramento River. Since elsewhere this species has been found foraging over riparian vegetation, gravel bars, rivers, and streams (Navo *et al.* 1992; unpubl. obs.) the possibility of spill effects emerged. Further investigation in 1994 and 1995 revealed that individuals of this presumably solitary species could be frequently observed foraging over meadows in the Castle Creek drainage. Results on local distribution area in draft manuscript submitted to DFG (Pierson and Rainey 1996), but no specific evidence of spill injury to this species was obtained.

4.2. RELATIVE ABUNDANCE

4.2.1. Mist Netting Surveys

Both on the Sacramento and Squaw drainages, *M. yumanensis* and *L. noctivagans*, generally recur as the first, second or third most abundant species in net captures from 1991 to 1995 across (Table 2A-B). The only exception is Squaw Creek in September 1995, when *M. yumanensis* was not among the three most common species. Other abundant species on the Sacramento drainage were *L. cinereus* in 1991, *Myotis lucifugus* in 1992-1994, and *T. brasiliensis* in 1995. On Squaw Creek *T. brasiliensis* was the most abundant species in net captures in 1991, and second most abundant in 1995. All species were captured on both the spill and control drainages, but, over 1991-1995 total captures on greater on the larger Sacramento River.

Though the spill zone covers both a latitudinal and altitudinal gradient, most of the 15 species netted likely occur throughout the area sampled on both drainages. Figure 4A shows the distribution of species by number of survey sites where they were encountered, pooling all sites sampled at least twice for all years on both the spill and control drainages. The pattern is that the most abundant species occur at almost all sites. Figure 4B plots (for the Sacramento River

and Squaw Creek separately) the number of sites at which each species was found against the \log_{10} of the number of individuals captured. This reveals exceptions to a simple linear relationship between the number of capture sites and \log_{10} of abundance. *P. hesperus* on the Sacramento fits the expectation of a rare species, two captures of single individuals at the lowest Sacramento River stations (Riverview and Dog Creek). On Squaw Creek, only at the Chirpchatter campground site, some *P. hesperus* were captured every year, for a total of 21. This small crevice dwelling species may be linked suitable roosting habitat at a smaller spatial scale than other bats. Availability of substantial rock faces near these downstream sites on both drainages is an obvious possible control on distribution. *E. fuscus* shows a contrasting pattern on the Sacramento River (Figure 4B), in that it is quite widely distributed in the drainage, but few individuals are captured at each site.

Consistent with the survey location on the margin of its known breeding range the few captures of *L. blossevillei* appearing in both drainages only in 1993 and 1994 samples suggest year-to-year shifts in movement patterns. In both years, this species was caught only at the northernmost Sacramento River stations, Prospect Ave. and above Cantara (Table 2A-B), but was more widely distributed on Squaw Creek.

In comparing captures by species across years, some seasonal patterns are evident. Figure 5 shows capture patterns 1991 to 1995 for four species. On both drainages, *M. yumanensis* and *M. lucifugus* are clearly more abundant in summer (July-August 1992-1994) than in fall samples, though *M. lucifugus* is an uncommon species on Squaw Creek at any time. In September, presumably most of the large maternity roosts on *M. yumanensis* in the survey area have disbanded, as they have elsewhere in California (unpubl. obs.). Two other species, *T. brasiliensis* and *L. cinereus*, provide a contrasting pattern. Although both occur throughout the summer in both drainages, they are also migratory, and their relatively greater numbers in the September samples (1991 and 1995) may reflect seasonal movement through the area.

While mist netting provides a sample of the bat assemblage flying low over the river, it does not sample the entire bat community equally. Those animals that are adept at avoiding nets, fly at elevations above 4 m. (the maximum height of our nets), or do not use the open water corridor may not be well represented in the net captures. For example, *T. brasiliensis*, which acoustic data suggests is common in the survey area in summer, generally forages at heights of greater than 7 m., and is typically netted low over the water late in the evening, perhaps when they attempt to drink. Several species like *E. fuscus* and the long-legged *Myotis*, *Myotis volans*, known often to forage at canopy height, may be under-represented in netting surveys, and are more effectively sampled at night roosts (see Section 4.1.2 below) (Pierson *et al.* in press). Only two *C. townsendii* (a foliage gleaning species adept at avoiding mist nets) were caught in mist nets, whereas two maternity roosts and several roosts occupied by scattered individuals were identified by roost surveys (see Section 4.1.2 below).

4.2.2 Capture Patterns as Indicators of Spill Effects

Table 3 summarizes netting captures and capture rates (n of bats*100/net hours*m² net area) for the spill and control drainages for 1991-1995. The 1991 and 1995 surveys were in September and thus would be expected to be lower than those taken in mid-summer (1992-1994), when bat activity is highest and newly volant young are most susceptible to netting. The mean of capture rates across all net nights in each sampling period are higher on the Sacramento for all years except 1991. This is consistent with the expectation of spill injury from lowered prey density and/or bat mortality, but alternative interpretations are possible.

Table 4 compares capture rates (n of bats*100/net hours*m² net area) for the two most common species, *M. yumanensis* and *L. noctivagans*, from 1991-1995, on the Sacramento River

and Squaw Creek. Consistent with the capture rate for the bat community as a whole, the 1991 *M. yumanensis* Sacramento capture rate was lower than in 1995 suggesting that *M. yumanensis* populations on the river were lower.

The capture rate for *L. noctivagans* is quite variable, and may be complicated by seasonal movement patterns. The capture rate is higher on Squaw Creek for both the July samples (1992 and 1994), and higher on the Sacramento River for the later (August and September) samples (1991, 1993, 1995). This shift may reflect the relatively early onset of both reproduction and late summer migration through the area. Comparison of the fall rates only (1991 and 1995) is, like the *M. yumanensis* rates, suggestive of reduced numbers on the Sacramento drainage in 1991, since the capture rates were approximately equal on the two drainages in 1991, and almost twice as high on the Sacramento in 1995.

The pattern of captures for *M. lucifugus* along the Sacramento River is also suggestive of spill impacts. While *M. lucifugus* was one of the species most commonly captured on the river from 1992-1995, it was notably scarce in the capture records for 1991, where it was caught at only 2 out of 6 netting stations. From 1992-1995 it was particularly abundant at the most northern netting stations (1 and 2), the two sites closest to the spill. It was most abundant in 1992 at Stations 1 and 2, and had become equally abundant at Station 3 in 1993, suggesting recruitment from above Cantara Loop, with gradual dispersal down river. Although this species appears tied to aquatic environments, feeding preferentially over open water, adults elsewhere move to cluttered environments when young begin to fly, leaving the more open habitats to the juveniles (Fenton and Barclay 1980, Barclay 1986, Adams 1990). If behavior is comparable for California populations, adults may have moved up river or into tributaries at the time of the spill, but the newly volant young may not have had that option, leaving them more vulnerable to low prey density over the river.

4.3 ROOSTING AND FORAGING PATTERNS FOR SELECTED BAT SPECIES

Roosts (either day or night) were located along the impacted stretch of the Sacramento River, between Azalea Ave. and Riverview, for nine species. These roosts were located in a variety of manmade structures (most by visual survey) and in trees (by radiotracking).

4.3.1. Day Roosts in Man-made Structures

Surveys of bridges, abandoned train tunnels, water tunnels and other structures, based in part on maps provided by Caltrans and Southern Pacific (SP), identified three accessible maternity colonies (one composed primarily of *M. yumanensis* in a building, one of *C. townsendii* in an abandoned railroad tunnel, and one of *T. brasiliensis* in a residence), and inaccessible day roosts in a railroad trestle, an abandoned bridge pylon and a residence. Three additional *M. yumanensis* colonies were located outside the study area, and were selected as controls for spill populations (see Section 4.3.2 below).

Field inspection of mines close to the river identified from public documentation had no underground workings suitable for bats, but untimbered adits in poorly consolidated deposits close to the river near the Gibson Rd. I-5 interchange (occupied by several scattered individual *C. townsendii*) were subsequently located based on local information. Also, a *C. townsendii* nursery colony was located in an unmapped adit on a tributary drainage by radiotracking. Although bats (particularly *C. townsendii*) would be expected in caves, no caves were reported or detected in the Sacramento River survey. Several blocks of karstic limestone adjoin Squaw Creek. There were

local reports of caves in that area, and DFG personnel examined several nearby limestone fissures, but no caves were located in the course of the survey close to the creek.

Another *C. townsendii* maternity colony, located in an abandoned railroad tunnel (SP tunnel 16) near the Mott Rd. exit on I-5, was estimated at approximately 200 animals by DFG personnel in August 1991, and had 46 animals (via an exit count using an NVD) on 19 September 1991. Although spill effects provided one possible explanation for the observed declines, a more likely explanation is a seasonal change in roosting patterns (*i.e.*, maternity colonies disband in the fall once young are independent). Since *C. townsendii* is extremely sensitive to roost disturbance, it is also possible some animals abandoned the roost after the initial entry or that it was subsequently disturbed. When this site was visited again on 11 July 1992, the tunnel had been destroyed, and the colony could not be located. Subsequent investigation by DFG personnel revealed that the tunnel had been previously identified as a safety hazard and was destroyed by SP during the winter.

Though moderate numbers of *T. brasiliensis* were netted on the spill and control drainage, there was scant evidence for maternity colonies or reproduction within the upper Sacramento River corridor through 1994. Identification of a bat roost in a structure in Delta close to the river as this species (based on guano characters) was confirmed by R.M. Miller by capture of emerging females in advanced pregnancy in May 1995. The presumption is that this was a maternity roost, but reconstruction of the building caused the colony to abandon the site. In summer, this species commonly forms both large day (in expansion joints) and night roosts under bridges at locations from the Central Valley floor up to moderate elevations in the Sierras. The largest known maternity colony in California seasonally occupies a lava cave at Lava Beds National Monument, northeast of the study area.

4.3.2 *M. yumanensis* Roosts

Much of the assessment of spill impacts focused on *M. yumanensis*. Because this species is known to forage extensively over open water (Herd and Fenton 1988; Brigham *et al.* 1992), it was one of the species most likely to be impacted by the spill. Also, it was one of the most abundant and accessible species. Five colonies were selected for monitoring over the five-year period, two within the spill zone along the river, and three control colonies outside the study area (see Sec. 3.3.2, Fig. 3). The two spill sites were located ca. 18 km apart, one (a maternity/day roost) in a building attic near the confluence of Soda Creek and the Sacramento River, and the second (a night roost) under an abandoned Highway 99 bridge over Shotgun Creek. The three control sites followed a latitude and altitude gradient which bracketed the spill sites-- the attic (maternity/day roost) of an abandoned house on Davis Road (Tehama Co.), a cabin attic (maternity/day and night roost) adjacent to Squaw Creek, and buildings (maternity/day and night roosts) at Meiss Ranch, a DFG wildlife refuge in Butte Valley. The Soda Creek colony, while predominantly *M. yumanensis*, had small numbers of *M. lucifugus* and *M. thysanodes*. At Meiss Ranch, most bats examined were *M. yumanensis*, but there were also large numbers of *M. lucifugus*, with small numbers of reproductive *M. evotis* and *M. thysanodes*. The Squaw Creek colony was entirely *M. yumanensis*. The Shotgun Creek night roost has seasonally harbored *A. pallidus* or *E. fuscus* (see Table 6A-B), but is largely occupied by *M. yumanensis* in late summer when we sampled.

The Shotgun Creek night roost aggregation, like the maternity day roosts in buildings, was primarily composed of adult females and recently volant young in late summer, but we do not know whether the bats aggregated there at night come from one or several maternity day roosts. For other species, such as *A. pallidus*, there are examples of both situations (Lewis, 1994; E.D. Pierson; pers. obs.) However, the survey goal was to examine reproductive maturation, individual

condition and survival for this species in the spill area. If recapture rates for banded bats emerged as comparable at day roosts and night roosts, then including this night roost among the study sites had several advantages:

1. Since both day roosts and night roosts were naturally aggregated samples of the species, apparent differences in reproduction or survival could be informative.
2. This particular site offered practical advantages of a substantial bat aggregation in a structurally simple setting with no inaccessible refuges. Building roosts typically offer many such refuges, and the number of bats accessible to capture may be a small, possibly non-random subset of the total present.
3. While *M. yumanensis* is more disturbance tolerant than most species, human entry into maternity roosts is inevitably disruptive and identifying less disruptive alternatives for mass captures is highly desirable.
4. As a massive, nonflammable, abandoned structure on public land, the bridge was likely to remain intact for the study duration, so that fluctuations in the number of bats would not result from alterations to the structure (as is common in both human-occupied and abandoned buildings).

We estimated colony size at the *M. yumanensis* day roosts by counting the exodus, typically on the night before entering the roost. Visual emergence counts from multiple exit points on complex buildings with limited personnel are inevitably approximate and time constraints have precluded within-season replication. The two spill area colonies on the Sacramento River have appeared to remain approximately stable or increased since first monitored in 1992. The Soda Creek maternity colony, which was estimated to have 170-200 animals in late May-early June of 1992 and 1993, had 383 animals on 14 July 1994. This increase over the previous year may reflect the presence of volant young in the exodus by this time (*i.e.*, an approximate doubling of the number emerging). A count of 288 animals on 28 June 1995 suggests the colony had increased since the comparable counts of 1992 and 1993, though the building was reroofed in Fall 1994 and exodus counts were subsequently more difficult to conduct. The Shotgun Creek night roost, which has been captured in August every year since 1992 yielding 300 -400 animals each time (Table 6A-B).

The control sites have presented problems in monitoring total numbers, colony persistence, and predictable access to large samples for mark and recapture. The Davis Road colony exodus contained 700-900 animals in May of 1992 and 1993, but they abandoned the site in August of 1993 (when a construction project was initiated nearby) and never reoccupied it in large numbers prior to demolition of the structure (John Siperek, pers. comm). Bat day roosts at Meiss Ranch, Butte Valley are distributed over several buildings. Before June 1994 we were not aware that many *M. yumanensis* were day roosting in an inaccessible attic in the main office building. Increasing the number of observers has gradually raised the total population estimate for this complex to over 2,000 bats, but the daytime aggregations in single buildings may be relatively stable over time. For example, the exodus count for the office was 491 on 4 June 1994 and 477 on 1 July 1995. However, bats may night roost in another building from their day roost site.

The maternity colony at Squaw Creek, the most comparable to the spill sites in latitude, had approximately 230 animals on 29 May 1993, 74 on 1 June 1994, and 209 on 5 July 1995. The marked temporary decline in the Squaw colony size in 1994 is not paralleled at the other sites, but may be related to late, locally heavy snow in April (which was reported to freeze or incapacitate birds on a nearby ranch). The rebound in the total count the following year suggests that massive

adult mortality did not occur, but the location of the bats during their presumed temporary absence is unknown.

Except at Shotgun Creek, the number of bats captured and banded was considerably less than the total counts. To hold constant investigator disturbance, we limited roost entry to one day per sampling period. Initially a team of three investigators could band and record detailed data for about 100 bats/day. Experience and digital data capture hardware increased this rate, but at Squaw Creek and Meiss Ranch the number of bats accessible to capture (*i.e.*, not concealed in the walls) from day roost and night roost areas combined typically determined the sample size. The temporary decline in colony size in 1994, and the greatly decreased number of bats accessible for examination that season has affected quantitative comparisons between this site and the Sacramento River sites.

4.3.3 Day Roosts Located by Radiotracking

To locate additional roost sites along the upper Sacramento and to evaluate the relative importance of the river and riparian areas as foraging habitat, thirteen individuals of six species known or expected to roost in colonies were radiotracked to identify roosts and foraging areas. In 1991, radio transmitters were placed on three *C. townsendii*, one *A. pallidus*, and two *M. yumanensis*. All were post-lactating females, except the *A. pallidus* (a nulliparous adult female), and one adult male *C. townsendii*. Except for two *C. townsendii*, which were taken from mine tunnel day roosts, all were captured in night roosts (old buildings or bridges within 300 m. of the river). In July 1992, transmitters were placed on four *A. pallidus*, one *E. fuscus*, two *L. noctivagans*, and one *M. volans*. All were either lactating or post-lactating females, except for one nulliparous *A. pallidus* (the same animal tracked in September 1991). All were captured either in bridge night roosts, or in mist nets set over the river or near the junction of tributaries with the river (*i.e.*, Soda Creek for the *L. noctivagans*, and Boulder Creek for the *A. pallidus*).

Table 5 summarizes information obtained by radiotracking on roost sites and foraging areas for species other than *L. noctivagans*. Except for the *C. townsendii*, which all had day roosts in abandoned mine workings, all bats were tracked to tree roosts -- either conifer snags (sugar and ponderosa pine) or oaks (black and canyon live) with hollow, broken limbs. The roosts ranged in distance from the river from 200 m to 4 km, with larger values for *L. noctivagans* (see below), indicating, from the point of view of spill impact, that the width of the habitat corridor from which bats were drawn to drink or forage over the river was several km wide.

4.3.4 *Lasionycteris noctivagans* Roosts

Prior to this study, only two maternity roosts for *L. noctivagans* had been recently reported, and no roosts were known from California. The two roost sites located by radiotracking in July 1992 were consistent with the earlier Canadian observations (Parsons *et al.* 1986) in showing that *L. noctivagans*, often described as solitary (Kunz 1982), forms colonial maternity roosts in tree cavities (Rainey *et al.* In press). Because this species was locally abundant, but its patterns of habitat use in forested landscapes were virtually unknown, two additional radiotracking studies were conducted in July 1994 and August 1995 to investigate both roosting and foraging patterns of reproductive females. A draft manuscript (Rainey *et al.* 1996) on these studies has been submitted separately to the DFG Cantara Program. Results which relate primarily to spill impact are summarized here.

Radio tracking in 1994 identified 14 additional tree roosts. Colony size varied from 1 to 69, with a mean of 29. Nine roosts contained more than 10 bats, and three had 1-2 animals. All roosts

were either in snags, or in dead parts of living trees. Of the 16 roost trees located during the two studies, 12 were dead and four were partially dead. The trees varied in DBH from 21 to 114 cm, with larger roosts more likely to be found in larger trees. All roosts were at least 5.5 m off the ground, with a mean height of 10.6 m. Roosts varied in distance from the capture site (at the confluence of the Sacramento River and Soda Creek) from 1.0 km to 17.4 km, with elevation gains exceeding 1100 m. Figure 6A is a histogram of distances from the capture site to each roost and 6B plots distance between capture site and roost against roost elevation. The most distant roosts were near the drainage divide between the Sacramento and Trinity River basins with three roosts located in the Trinity River drainage. Limited monitoring of roosts from previous years suggests low rates of re-occupation and one instance of apparent displacement of bats from a roost by an arboreal rodent.

4.3.5 Night Roosts

Field surveys of the river drainage identified a number of accessible night roosts under bridges, including one of about 400 *M. yumanensis* at the abandoned Highway 99 bridge over Shotgun Creek and one of about forty *A. pallidus* at the Highway 99 bridge near the mouth of Boulder Creek. Relatively little is known about night roosting behavior of bats (Kunz 1982), and this study has provided evidence supporting the usefulness of night roosts for sampling diversity and monitoring populations over time (Pierson *et al.* 1996).

Opportunistic sampling of night roosting sites (largely bridges, including I-5 overpasses) along the upper Sacramento River from July 1992 through October 1995 yielded 9 species (Table 6A-B). As in mist net surveys, *M. yumanensis* was the most abundant species in night roosts, but several other species (*i.e.*, *A. pallidus*, *E. fuscus*, and *M. volans*), which were not commonly netted over the river, were relatively more abundant in night roosts. Species caught in netting over water that do not appear to use bridge night roosts in this area are three small, solitary crevice dwellers (*M. californicus*, *M. ciliolabrum*, and *P. hesperus*), three known almost exclusively from tree roosts (*L. blossevillii* and *L. cinereus* roost in foliage and *L. noctivagans* in cavities and crevices), and two cliff dwelling species (*E. maculatum* and *E. perotis*). Although *T. brasiliensis* was notably scarce at monitored night roosting sites under bridges in the spill corridor, a large night roost (several thousand) was discovered in a lava tube north of the spill area (Pierson *et al.* in press).

Sampling in night roosts explicitly favored solitary bats or small aggregations to increase sample sizes for dietary and reproductive condition analysis for taxa less accessible to netting, and generally avoided large aggregations, except at two night roosts specifically targeted for population analysis (the *M. yumanensis* roost at Shotgun Creek and the *A. pallidus* roost at Boulder Creek). Thus *M. yumanensis* and *M. lucifugus* are under-represented in the night roost capture records. Not all bridges had night roosting bats, but several along the river were occupied after midnight by significant numbers of *M. yumanensis* (30 to several hundred). No similarly accessible suitable structures for night roosts were located on Squaw Creek except for the *M. yumanensis* colony which also used their nursery (day) roost site in a cabin attic as a night roost, and another apparently independent colony which night roosted in a small cabin at the Whitney Ranch.

The absence of pre-spill data makes it difficult to establish expected numbers of animals and species diversity at these roosts. Although no evidence of mass mortality was encountered at any of the sites surveyed, most bat roosts are visited or occupied by an efficient assemblage of vertebrate and invertebrate scavengers which readily consume carcasses of fallen bats, so that the likelihood of observing mortality decreases rapidly with time (see Sec 5.1 and reference therein).

The large areas of urine staining relative to the number of animals present at both the *M. yumanensis* roost at Shotgun Creek and the *A. pallidus* roost at Boulder Creek after the spill suggest declines in numbers of roosting animals. For example, at the *A. pallidus* site, the areal extent of guano deposition after the survey began was considerably smaller (less than half) than the pattern of prior accumulation encountered when the site was first examined in 1991. Measurements were made on the pattern of guano accumulation under a major portion of the Shotgun Creek night roost in summer 1991 and 1992 to monitor change. Unfortunately, the guano deposit at this site is on steep dry loose soil at the angle of repose, so that a footfall buries material for some distance down slope. Thus circumstances are considerably less than ideal for accurate monitoring and interpretation of the measurement data has not been given high priority.

At several of the I-5 overpass night roosts virtually all the small guano deposits (probably from multiple individuals or small clusters of *E. fuscus*) were covered with dust and/or spider webs when examined July-August 1992. Since recapture data for night roosts showed considerable roost philopatry (Pierson *et al.* in press), the evidence suggests mass abandonment or mortality. However, timing is unknown, other sites with similar proximity to the river are still in use and no survey of a similar series of night roosts outside the spill area (to evaluate the frequency of such events) were made.

Once a year sampling in August (1991-1995) of the *M. yumanensis* night roost at Shotgun Creek has provided the strongest evidence for roost philopatry. Of 374 band recoveries at the Shotgun Creek roost, 339 had originally been banded there, and only 35 had originally been banded at other sites. Twenty-two of these had been caught for the first time at Boulder Creek or Sims, the two netting stations on the river closest to the Shotgun Creek night roost. Only seven females from Shotgun have been located at other roosts (Soda Creek day roost or Boulder Creek night roost), so that, over years, there appears to be little exchange among sites located within the nightly foraging range of the species.

Although sample sizes are much smaller, *Antrozous pallidus* appears to show comparable philopatry to a night roost at the Gibson Road Bridge over Boulder Creek. Eighteen animals associated with the Gibson Road bridge have been recaptured at that site, or in nets set across the creek adjacent to the roost. No Gibson Road animals have been recaptured at any other locality. Additionally, an adult male *A. pallidus* banded at the Conant Avenue I-5 in August 1993 was recaptured at the same site in June 1995 (see also Section 4.4.2).

In the context of monitoring bat populations, it appears that night roosts offer relatively convenient, temporally persistent sites at which significant samples can be captured and recaptured long-term without disturbing the more sensitive day roosts. This is particularly useful during midsummer when non-volant young in maternity roosts would be vulnerable to investigative disturbance. Particularly in a landscape with extensive ongoing timber harvest, it may be that bridge night roost aggregations persist over longer intervals than day roosts.

4.3.6 Foraging Behavior

Through radiotracking, we obtained data on foraging behavior for six species: *A. pallidus*, *C. townsendii*, *E. fuscus*, *L. noctivagans*, *M. volans*, and *M. yumanensis*. Although there were intraspecific and interspecific differences, most individuals returned on sequential nights to the same foraging areas, which covered 0.5-4.5 km stretches along the river. *M. yumanensis* was most clearly associated with the river. The two radiotracked individuals foraged within a few meters of the surface over the same pools on sequential nights, covering <0.5 km. A single *E. fuscus* also appeared to feed consistently over the river, along the same 4.5 km stretch of river on sequential nights, but signal strength suggested the animal was often flying at considerable height

above the ground. Both the single *M. volans* and multiple *L. noctivagans* displayed more variable foraging patterns, flying over the river axis, along tributary creek drainages and over forested slopes. Although the *A. pallidus* and those *C. townsendii* which remained in the area consistently foraged in the river drainage, with the same individuals moving along the same 2.0-4.0 km stretches of river canyon on sequential nights, both species appeared to feed primarily in riparian or up slope woodland areas, and only *A. pallidus* was observed flying along the river course in a fashion suggestive of foraging. One *A. pallidus* female was radiotracked in both 1991 and 1992, and utilized the same stretch of the river (1-2 km upstream from the Boulder Creek night roost) for foraging both years. As noted earlier, more extensive foraging movement data on *L. noctivagans* are discussed in a separate manuscript (Rainey *et al.* 1996) submitted to the Cantara Program.

4.3.7 Implications of Roosting and Foraging Behavior for Spill Impacts

The roosting patterns as elucidated by radiotracking suggest that the bat community utilizing the Sacramento River is drawn from a large area, including all of the Sacramento River drainage and its tributaries, and reaching over the crest into the Trinity River drainage. The distance of most roosts from the river would have afforded animals protection from direct mortality, during the day at the time of the spill. The significant exception to this might be the Soda Creek nursery roost, which is located <100 m from the river, and experienced some 'fumigation' at the time of the spill (dead insects found in structure; L. Blize pers. comm.).

Radiotracking and banding data document a high degree of philopatry to both foraging areas and night roosts for a number of species, thus suggesting that variation and perhaps flexibility in foraging site selection may be more limited than might be presumed. Considering the six species which were radiotagged, the loss of foraging areas on the river was likely most significant for *M. yumanensis*, which feeds directly over the water surface, and seems to prefer areas with open expanses of slowly moving water, which would not be available on tributary streams. These behavioral traits would have left this species vulnerable to direct impacts (*i.e.*, attempting to feed over the water surface in the days following the spill), and limited their options for alternate foraging areas. Those species which appeared to feed more in the riparian vegetation (*e.g.*, *A. pallidus* and *C. townsendii*) or used tributary drainages extensively (*e.g.*, *L. noctivagans* and *M. volans*) would have been less likely to have suffered direct and indirect impacts. The philopatry of some species to night roosts near the river may, however, have put animals at risk of fumigation. This would most likely have been the case for *A. pallidus*, which appears to utilize night roosts for social as well as physiological purposes (Lewis 1995).

While the large roost to foraging site distances might suggest that most species would have alternate foraging areas along their movement routes, they also underscore the significant role the river plays in the ecology of the bat community. Although no radiotagged species appeared to be as closely tied to the river as *M. yumanensis*, all used the river corridor for part or all of their foraging activities. The energetic cost of travelling several km from roosts to the river, passing over other smaller riparian zones enroute suggests the river provided food resources which could not be obtained (as efficiently or at all) elsewhere. Beyond the spill in the long term, the condition of the river biota reasonably be expected to influence some species in the bat community throughout the drainage basin.

4.4 MOVEMENT PATTERNS

4.4.1. *Myotis yumanensis*

Recaptures of banded *M. yumanensis* allowed comparison of movement scale for this species along the Sacramento River and at Squaw Creek (Fig.7). In both drainages most recaptures

were of animals originally captured at a roost (one of the sites used for assessment of survivorship and reproductive success [see below]), and recaptured at the same site. When those recaptures are excluded, most remaining recaptures still occur less than 1 km from the site of original capture. While we have no way in net captures to distinguish foraging from commuting or other movements, this is at least consistent with very limited observations from radiotracking that foraging movements of *M. yumanensis*, once they reach river, were small.

M. yumanensis from the Squaw Creek maternity roost near Sta. 4 (see Fig.1,3), have been caught up to 4.0 km to the south (Sta. 2), and up to 6 km to the north (Sta. 7). Although it appears that most activity for this colony occurs within 4 km of the roost, since recaptures have occurred at the most frequently sampled distant stations, we cannot delimit the maximum movement scale along the Creek. Banded animals from maternity roost at Soda Creek on the Sacramento River were captured as far away as 13 km upstream at Sta.1 (above Cantara loop), and 20 km downstream at Boulder Creek (between Sta. 8 and 9) (see Fig. 1). Since no banded animals from this roost were recaptured below Boulder Creek, it appears that most activity for this colony occurred within about 20 km of the roost. Similarly, for the Shotgun Creek night roost, most of the recaptures occurred at the closest netting stations, less than 5 km from the roost, but small numbers of animals were recaptured > 16 km from the roost (at the Soda Creek nursery site).

Since the Soda Creek and Shotgun colonies were larger than the Squaw Creek colony, occupants might be predicted to disperse over greater distances along the drainage if Squaw Creek and the Sacramento River had similar levels of emergent insect production per unit length of drainage. However, the much larger area of illuminated submerged bed along the wider Sacramento should (without the spill) support higher emergent insect productivity per unit length (see sticky trap results, Section 4.8.2), so more extensive movements may be unnecessary. An alternative hypothesis would be that reduced prey availability resulting from the spill on the Sacramento River forced some individuals to travel greater distances to forage. In the absence of pre-spill movement data, a decline in recapture distances as the river insect fauna recovers appears the most feasible test of whether the spill/ control difference in recapture distances reflects injury. No such trend is apparent in the 1992-1995 recaptures. In all years 85-94% of all recaptures occurred within 5 km of the original capture site, with distant (> 5 km) recaptures ranging from 5 to 15 %, with no clear trend.

4.4.2 Other Species

Recaptures of banded bats of other species are not numerous, but offer evidence of within-season and between-season site fidelity for some individuals. Most of these recaptures have been of bats using I-5 overpasses as night roosts. For example, six *E. fuscus* have been recaptured during the course of the study, four at the site of original capture (Shotgun Creek night roost, Soda Creek I-5 overpass, and in a net at Boulder Creek), and two at sites within a few km of each other (*i.e.*, one animal netted at Sims was recaptured at the Shotgun Creek night roost, and an animal first captured at the Panorama Way I-5 overpass was recaptured at the Soda Creek I-5 overpass). One individual has been recaptured four times at the same night roost between 1992 and 1995. Two reproductive female *M. volans* were captured and recaptured together in 1992 and 1993 at the same night roost. Multiple recaptures at the *A. pallidus* site on Boulder Creek document considerable roost philopatry (Pierson *et al.* in press).

Given the relative abundance of *L. noctivagans*, it is striking that prior to 1994 there were no recaptures. Three banded individuals were recaptured on Squaw Creek in 1994, two of them only one day after banding at a site (Sta. 5) 1.2 km downstream from the original capture site (Sta. 6), and one two years later at the same site (Sta. 5). The short-term recaptures are consistent with the telemetry data and two-year return suggests some philopatry. We cannot, however, determine

the relative contributions to the low overall recapture rates from large individual foraging ranges, large total local population and low year-to-year fidelity to foraging sites.

4.5 REPRODUCTIVE PARAMETERS

4.5.1 Bat Species with Reproductive Populations in the Upper Sacramento and Squaw Drainages

Table 7 (A-B) shows the reproductive condition of mist netted bats for July and August 1992-1994. Twelve species were confirmed, through inspection of animals caught in mist nets and night roosts, to have reproductive populations along the Sacramento River or Squaw Creek. Additionally, as mentioned above, two maternity aggregations were located for *C. townsendii*, in an abandoned railroad tunnel and abandoned mine in August 1991. Although there is some variation within and among species in the timing of parturition, July falls within peak reproductive season for the bat community along the upper Sacramento River, with most species having lactating and/or post-lactating females, plus newly volant young at this time.

Two species, caught in nets over the river, may not rear young in this area. Although post-lactating *L. cinereus* females were netted at control sites, and young of the year at both control and spill sites in September 1991, only adult males and one non-reproductive female were caught on the Sacramento River during the breeding season (July-August), consistent with inferences in the literature that females move farther north to bear their young, and migrate south through northernmost California in the fall (*e.g.*, Barbour and Davis 1967). *L. blossevillii* were captured only in 1993 and 1994, and the two individuals captured on the Sacramento River were both adult males.

4.5.2 Determination of Age, Reproductive Condition, and Sexual Maturity

Our goal in examining *Myotis* colonies within the spill area and adjacent regions has been to characterize the local pattern of overwinter survival and the distribution of reproductive effort by age to evaluate whether injury from the spill may be reasonably inferred and, if so, to estimate the magnitude of that injury. The age and reproductive classes of females potentially present at these localities varied with survey date. In mid-summer, after the young of the year are volant, three classes of females, two of them common, are present:

1. young of the year (limb bone growth generally incomplete, wing tissues soft, juvenile pelage, mammary development minimal, body mass less than mature adults);
2. reproductively active females (skeletal growth complete; mammary tissue hypertrophied in lactating adults or regressing, but showing signs of use [pigmented, elongated, sometimes pendant nipple], hair loss in mammary area in post-lactating individuals);
3. nulliparous females (skeletal growth and body mass adult, minimal to slight mammary development with no signs of use).

A fourth much smaller intergrading group falls between the nulliparous and reproductively active individuals in having evidence (in the form of limited nipple development or keratinization) of either reproduction in a prior year or reproduction initiated in the current season, but truncated, perhaps by early loss of the young.

Vegetation damage and habitat fumigation by the gas plume associated with the spill presumably altered riparian insect assemblages, but the presumption of severe short term impact is best supported for obligate aquatic forms. Among the bats captured flying low over the Sacramento river or in nearby night roosts, which species eat arthropods with aquatic life stages and thus would be most detectably vulnerable to prey reduction?

2. In comparing seasonal and interannual patterns in diet composition of bat species between the Sacramento River and Squaw Creek, are there trends in the Sacramento River not paralleled on Squaw Creek which suggest a long term response reasonably attributable to the spill and subsequent recovery of the aquatic ecosystem?

Figures 8-15 provide graphical analyses of mean percent volume of arthropods in diets of bats netted over the river or caught from nearby night roosts, grouped by bat species, drainage and season. Though fragments in the diet of several insect orders (notably beetles, Coleoptera, and true bugs, Hemiptera) were typically identified to family, this is not currently possible in some other orders, particularly moths (Lepidoptera) which are common in bat diets. We have followed the normal practice of pooling the volumes of prey by order for each individual bat sample (thus temporarily obscuring family level identifications where available). For each species and sampling period, the graphs show the mean percent volume of major prey components, with trace components (less than 1%) noted in a text box.

Below the graphs the total number of bats analysed in each sampling period (e.g., Sep-91) and the mean number guano pellets analysed per bat are given. For *T. brasiliensis*, Whitaker *et al.* (In press) concluded that five pellets or more per bat were sufficient to detect all components in the diet at the family level which were found in larger numbers of pellets, but that most single pellets contained the three most common prey taxa. While this relationship may not hold precisely for other bat species, the study suggests even low volume samples offer a useful perspective on dietary breadth. For the spill diet study, mean pellet counts for analyses of the more common species are greater than five for most sampling periods, though smaller volume samples were analysed when few individuals were caught. As indicated earlier, we selected larger volume diet samples with the constraint that we wished to analyse five adults and juveniles of each sex for each major sampling period. This was possible only with the two most common species. Samples for each species are discussed by drainage and survey period without regard to sex, age, or collection site within drainages. Variation in diet with age (at least between recently volant young and older animals) within species has been demonstrated (e.g., for *L. cinereus*, Rolseth *et al.* 1994).

Figure 8 A-B shows diet composition for *M. yumanensis* on Sacramento and Squaw Creek. Data for the Sacramento include two smaller opportunistic night roost samples in Aug-92 and May-95 which are not matched on Squaw Creek. Consistent with behavioral data from radio tracking and light tagging which shows this species feeding for extended periods within 0.5 m of the water's surface, the diet is predominantly aquatic insects (almost entirely caddis flies). Other orders in the diet which include aquatic insects are Diptera and Hemiptera (water boatmen, Corixidae, were identified). Diets on both drainages show very similar trends in composition, becoming more diverse over the duration of the study. Alate ants (Hymenoptera) are abundant only in Jul-92. Termites (Isoptera) and moths are abundant in both drainages in Jul-94. The high relative abundance of Diptera and near absence of the otherwise abundant caddis flies in the single early season sample (May-95) suggests there may be large seasonal (as well as year-to-year) variation in diet taxonomic composition.

Diets for *M. lucifugus* (Figure 9 A-B) are similar to *M. yumanensis* in overall composition and variation through time on the Sacramento River. Pulses of abundant prey (e.g., alate ants [as Hymenoptera] in July 1992, termites in July 1994) appear in both species diets against a

background of gradually increasing diversity (and reduced proportion of Trichoptera). Numbers of diet samples from *M. lucifugus* on Squaw Creek are small and none were available from September 1991 or 1995, but the incomplete patterns are consistent with those on the Sacramento. Water boatmen were not detected in the diet of *M. lucifugus* on either drainage, but are known to be an important dietary component elsewhere (Adams 1993).

The dominant component of *L. noctivagans* diets is moths, but a substantial proportion of aquatic prey are present (Trichoptera, Diptera, Corixidae) during 3 of 5 sampling periods (Figure 10). Larvae of the aquatic moth *Petrophila* are an important component of stream and river benthic communities in California, but these cannot be recognized in bat diets, so the proportion of aquatic insects in the diet may be underestimated during the season when adults are flying. The July 1992 pulse of alate ants and the July 1994 pulse of termites evident in *M. yumanensis* and *M. lucifugus* diets is also present in the diet data for *L. noctivagans* on both drainages.

The pair of smaller species *M. californicus* and *M. ciliolabrum* (Fig. 11 A-C) show a diverse diet with a substantial proportion of aquatic prey in most samples on both drainages, though these species are distinctive in the consistently high proportion of Hymenoptera. Fig. 12 A-B shows that *A. pallidus* on the Sacramento eats primarily crickets and beetles with only trace amounts of aquatic insects. On Squaw Creek, perhaps because of less open habitat in the still heavily forested stream corridor, crickets are less abundant and the diet is beetle-dominated. The limited samples of *L. cinereus* show that it consumes largely moths and a few beetles, with traces of other prey including caddis flies. From Fig 13C, another large aerially foraging bat over the river, *E. fuscus*, shows greater dietary breadth in the same habitat, including some aquatic insects.

The diets (Fig. 14 A-B) of *T. brasiliensis* and *M. volans* are dominated, like *L. cinereus* by moths. Acoustic detection suggests that *T. brasiliensis* is a common forager over the river (at unknown height), but, outside the presumed fall migration it is not consistently common in net captures. While the proportion of caddis flies in its diet might be caught either low over the river or at canopy level (Jackson and Resh 1988), the both the presence of some water boatmen in the diet and visual observation suggests this species sometimes forages lower along the river. *M. evotis*, which forages both aerially and by gleaning arthropods off vegetation, has a diverse diet with a moderate component of aquatic prey in individuals captured over water.

In evaluating the impact of the spill, the question arises whether diets of bats caught directly over the Sacramento River or Squaw Creek are typical of local populations of these species. It is possible that there are major differences in the taxonomic composition of individual diets (*e.g.*, through territoriality or preference) within colonies. For some species, we can examine guano from roost accumulations to obtain an 'average' bat diet (averaged in an uncontrolled way among individuals and over some time period) at these sites. For one species, *C. townsendii*, which was rarely caught in nets over water, these offer the best available local data on diet.

Figure 16A-B show four pooled *M. yumanensis* diet samples (all are mean percent frequency from analysis of 50 individual pellets). In 16A the composition of the guano pool from a mass capture at the Shotgun Creek night roost is heavily dominated by aquatic insects and thus very similar to the small (5 individuals at other sites) nearly contemporaneous (August 92) sample showing in Figure 8. The surface of the Shotgun Creek guano accumulation (Fig. 16 B) on the same night has a more taxonomically diverse composition, but is also dominated by aquatic insects. Greater diet diversity in the roost deposit presumably reflects the integration of significant night to night variation in prey, but might also integrate variation in prey by time of night. Whitaker, *et al.* (In press) found significant differences in diet composition between evening and early morning feeding bouts for lactating *T. brasiliensis* in central Texas. Prey remains from pre-

dawn feeding would be absent from night roost sites like Shotgun Creek, since the bats are returning to their day roost around that time.

Samples from daytime captures of roosting bats or guano deposits in maternity day roosts (Fig. 16C-D) are likely to be dominated by insects consumed in predawn hours, but the amount of guano from different foraging times will vary seasonally (e.g., lactating females with dependent young may return to the roost multiple times per night). Also, locations within buildings which have day roosts may also be used as night roosts (e.g., the cabin on Squaw Creek). The Squaw Creek cabin July 92 day roost deposit (Fig. 16 D) is very similar to the contemporaneous netting sample (Fig. 8 B) and, along with the Shotgun Creek night roost analyses, support the contention that diet analyses from bats netted over the river are representative of the local population diets. The moth-dominated sample from a building maternity roost in a walnut orchard close to the Sacramento River in the northern Central Valley (Davis Rd., near Bend, Tehama Co.; see Fig. 1) differs markedly from the cooler, higher elevation forested habitat samples on the upper Sacramento and Squaw Creek, but may reflect exploitation of pest taxa in this partly agricultural landscape.

C.townsendii, a state Species of special concern, was rare in net captures over water, but several roosts were identified in the spill area. Figure 17A shows that guano from this species from a building attic night roost adjacent to Interstate 5 was almost entirely moths. Guano from a probable *C.townsendii* maternity roost close to the river in an abandoned railway tunnel (Fig. 17B) which was collected shortly after the spill (8/1/91) is slightly more diverse, including a few percent of aquatic taxa. This species appears to often forage in vegetatively cluttered areas (e.g. within tree canopies) and to take prey by gleaning from surfaces, but the substantial aquatic insect biomass on sticky traps set within forests along streams (Jackson and Resh 1989) makes it clear that aquatic insects could be a significant diet component for bat species which rarely forage for flying prey over open water. Figure 17C shows the diet composition for a night roost identified by day from the appearance and distribution of the guano as an inactive or abandoned *E. fuscus* night roost. The diverse, beetle dominated composition (lacking the large component of crickets in the upper Sacramento River pallid bat samples; Fig. 12-13) is consistent with that identification.

Several patterns emerge from these data:

1. The most common bat species, *M. yumanensis*, over the river eats largely aquatic insects (with seasonal variation in the taxa consumed). Several other species which are common to moderately abundant consume substantial amounts of aquatic prey in relatively diverse diets.
2. The bat fauna along the river also includes several species which eat almost entirely moths (e.g., *M. volans*, *L. cinereus*, *T. brasiliensis*). These are less common in net captures, but this reflects at least in part that normal foraging heights are greater than net heights. The low volume of aquatic prey does not necessarily mean that they do not commonly forage along river or stream corridors.
3. Patterns of prey composition change for three common, well-sampled species *M. yumanensis*, *M. lucifugus* and *L. noctivagans* over 1991-1995 are remarkably similar from year to year and between the spill and control drainages. Single season pulses of uncommon prey (e.g., termites in July 1994) appear simultaneously in all three species on both drainages. Presumably regional patterns of year-to-year variation (e.g., timing and magnitude of winter rains) are a primary control on the relative availability of both terrestrial and aquatic insect orders. While there is a trend toward increasing diet diversity

over the duration of the study it is present in both spill and control site samples, so that no trend in diet composition is attributable to the spill.

Composition analysis of guano samples addresses the possibility that bats might have responded to the spill by taking a different assemblage of prey perhaps in alternative foraging sites, and, that, as the aquatic community in the river reformed over time, we might detect directional change in the relative abundance of arthropod taxa in the diet. Note that it is also possible that the effect of the spill insect population reduction would force bats to hunt longer hours, perhaps in tributaries to catch the 'same' taxa (analysis resolves only to the ordinal or family level), but with less net energy retained. In this latter instance there would be no taxonomic signal of possible impact, even though the consequences, particularly for overwinter survival of juveniles, could be significant.

4.8 FIXED STATION OBSERVATIONS

4.8.1 Bat Activity

Fixed station observations in 1991-1992 (*i.e.* counts of bats and insects observed through an NVD in one minute) are shown (Fig. 18 - 19) as the mean of the three counts taken at each half hourly observation period. A single survey conducted at station 9 on the Sacramento River in 1992 is excluded from the graphs and subsequent analysis because there are no comparable data from 1991. The small number of insect counts which exceeded the ability of the observer to count them were coded for analysis as the maximum value reported (*e.g.*, 'greater than 140' = 140). Surveys in which one count (rather than three) per observation period was taken are marked by asterisks preceding the date in the graph legends. In the following analyses the data used were the square roots of the mean counts, which were approximately normally distributed and did not require adjustment to eliminate real zero values.

Inspection (Fig. 18 - 19) makes it evident that bats have not yet reached the watercourses at sunset (*i.e.*, the counts at sunset are typically zero), so that analysis was limited to observations taken 0.5 hours after sunset and subsequently. While inspection might also suggest that bat numbers are often still rising at 0.5 hours after sunset, further truncation (*e.g.*, restricting analysis to observations 1 hour after sunset) of the data set does not markedly improve resolution.

Excluding station 1 above the spill (and station 9 as noted above) on the Sacramento River, bat counts were higher overall in the fall of 1991 (22.0 ± 1.4 standard error [S.E.] per minute) than in 1992 (18.6 ± 1.6). When the effects of station to station variability, time of night and insect counts are corrected in an analysis of covariance, the difference between years is significant ($F=4.6$, 1 d.f., $p=0.03$). Data from the Squaw Creek, treated similarly, show the opposite pattern. Bat counts were lower in 1991 (7.6 ± 0.8) than in 1992 (10.6 ± 0.6). Correcting for station, time-of-night and insect count effects reveals that the year-to-year difference is statistically significant ($F=10.2$, 1 d.f., $p=0.0002$). Both drainages are physically and biologically heterogenous and there are pronounced differences in bat counts (pooled across both years) among stations within drainages. Inspection of the graphs also suggests site-to-site differences in the bat count trend between years.

Inspection of the insect count graphs (Fig. 20 and 21), as in the bat counts, suggests the common occurrence of higher early evening abundance followed by gradual decline in numbers through most observation periods. On the Sacramento River, bat counts are positively correlated with insect counts ($r=0.44$). When station, year and time-of-night effects are removed, insect

density, as indexed by the counts, still has a significant effect on bat density ($F=18.4$, $p<0.0001$). On Squaw Creek, bat and insect counts are also positively correlated ($r=0.34$), but after removing station, year, and time-of-night effects, insect density does not have a significant effect on bat density ($F=0.3$, $p=0.59$).

On the Sacramento River insect counts decreased from 1991 (10.6 ± 1.8 per minute) to 1992 (8.2 ± 1.5), but this difference is not statistically significant when station and time-of-night effects are removed ($F=1.4$, $p=0.24$). On Squaw Creek, insect counts show a proportionally similar decline from 1991 (5.2 ± 0.6) to 1992 (4.0 ± 0.5), but this difference was significant when time of night and station effects were removed ($F=16.6$, $p=0.0001$).

Air temperatures generally decline monotonically with time after sunset (Fig. 22 and 23). The collinearity between time and temperature make it difficult to separate the effects of these two variables and so, for this analysis temperature as well as possible moonlight effects were not addressed.

Testing the hypothesis that the duration of foraging was extended on the Sacramento River in response to lowered prey availability was based on two standardized indices of the time distribution of bat activity for each observation night from approximately 0.5 to 5.0 hours after sunset. These indices (the times in minutes from sunset until 50% and 75% of the total bat activity) were estimated by graphical interpolation from plots of the cumulative frequency of bat counts against time. The index values, grouped by drainage and year, are shown as box plots (Fig. 24). Some differences are clearly evident from these 'raw' data and the pattern is parallel for the 50% and 75% indices, though the 75% values may be influenced somewhat more by the boundedness of cumulative frequency values (limited to the range of 0-1). Times to 50% (or 75%) cumulative frequency on the Sacramento are higher in both years than on the Squaw. The median time to 50% declines slightly from 1991 to 1992 on the Sacramento, while on the Squaw it increases more substantially. While *a priori* prediction of more prolonged foraging activity on the Sacramento than on Squaw, particularly in late summer 1991 is supported, the larger magnitude change from year-to-year on the Squaw is not readily explained.

To test the year and drainage differences, these indices were adjusted toward normal distributions by power transformations ($[\text{time to cumulative 50\%}]^{1.25}$ and $[\text{time to cumulative 75\%}]^{2.50}$) based on evaluation of normal probability plots. Analysis of variance yielded similar values for the two indices with higher significance levels for the cumulative 75% index. For the latter there is a significant difference between drainages ($F=7.92$, $p<.01$, a nonsignificant difference between years ($F=3.09$, $p=.0854$) and significant drainage-by-year interaction ($F=6.27$, $p=.016$).

The remarkable feature of these data in the broader context of watershed ecosystem function is bat foraging intensity --- on the order of ten bats per minute for several hours pass a transverse line across the water in both drainages. From these and other data (e.g., the rapidity with which satiated bats begin to appear in night roosts) we can infer that the capture rate of insects over water (and biomass consumed per unit length of drainage) is also high and the role of bats both in local nutrient recycling (via excretion over water during foraging [see Stalinski 1994]) and transfer of aquatic productivity large distances into terrestrial habitats in movement to roosts or among foraging areas (Rainey and Pierson 1994b).

4.8.2 Sticky Trap Analyses

Sticky trap collections near the water surface in association with fixed station counts are numerically dominated by chironomids (small aquatic Diptera). For example, in pooled counts of

all 1992 samples for Sacramento and Squaw Creek stations combined 2229 of 2417 identified arthropods were chironomids. For the same pool, the second most abundant family was Hydroptilidae (Trichoptera) with 59. Most other taxonomic groups tabulated (insect families+mites and spiders) were represented by a few individuals. Pooling all samples (1991-1992) at the ordinal level across both drainages, spiders (10 individuals) were the fourth most abundant taxon, suggesting that low frequencies of spiders in the diet of *M. yumanensis* are prey taken on or near the water surface in normal aerial foraging rather than incidental captures in the roost (see section 4.7).

The graphs in Figure 25 -- which show counts for all collections based on total arthropod counts or chironomids vs other arthropods combined -- reveal several patterns. In Figure 25A for the Sacramento River, variation among trap collections (at different heights) on a single night is small relative to year-to-year differences. For most stations, total collections were lower in September 92 than in September 1991, but from 25C it is evident that the numerical difference is almost entirely more chironomids in 1991. In contrast on Squaw Creek, total counts in Figure 25B are much lower than on the Sacramento River and the pattern of relative abundance among stations from year-to-year is very constant, perhaps reflecting persistent habitat differences among sites in less a dynamic stream with more bedrock bottom reaches. From 25D it is evident that chironomids are proportionately fewer on Squaw Creek and the total counts of all other arthropods (*i.e.*, total minus chironomids) are not greatly different between drainages. Figure 25E shows that a large proportion of sticky trap samples of all sizes are predominantly chironomids. Figure 25 F shows that higher taxon diversity (counts of 'families' shown includes insect families plus the two arachnid orders) in each trap collection is only weakly related to sample size. Figure 25G shows that, with the exception of a single sampling night (three symbols in the upper right corner of the graph) on the Sacramento River in 1992 which had both a large number chironomids and a substantial sample of caddisflies, the number of other arthropods is not strongly correlated with the number of chironomids.

The non-overlapping distributions of total counts on sticky traps between September 1991 and September 92 at most Sacramento River sampling stations (Figure 25A) make it clear that there were significantly more chironomids shortly after the spill, while there is no difference between years on Squaw Creek. Though the trend was not monitored in later years, a reasonable presumption is that typically smaller, short generation time aquatic insects like chironomids might 'bloom' after the spill under both reduced predation and reduced resource competition from other larger aquatic insects.

The sticky trap counts parallel the observational insect counts treated above (See 4.8.1.) in detecting more insects in September 1991 than in September 1992 on the Sacramento River (though the difference in observational counts was not significant). However, limited testing of minimum visually detectable artificial target sizes at various ranges for the NVD suggest the tiny chironomids which dominate the sticky trap counts would not be resolved over much of the observational path length. Thus some larger insects which might not be retained by the less adhesive sticky trap medium used in this study (D. Kistner, pers. comm.) were simultaneously more numerous on the Sacramento River. The small, but statistically significant, decline from September 1991 to September 1992 in observational insect counts on Squaw Creek is not paralleled in the sticky trap counts (Figures 25B and D).

Even though these trapping results show chironomids were present and sometimes numerous in the airspace up to 1.5 m above the Sacramento river where *M. yumanensis*, *M. lucifugus*, *M. californicus* and other bat species commonly forage, nearly contemporaneous diet data from September 1991 and August 1992 net captures (Fig. 8-15), as well as roost guano composition from August 92 (Figure 16), show that dipterans are a minor dietary component at

those times. Active vs. passive prey selection and appropriate methods to measure insect prey availability are topics of ongoing debate (see Whitaker 1994 for a recent summary). In this instance, we observe that chironomids are common to abundant, but diets of bats foraging in this microhabitat are heavily dominated by caddisflies. It is possible that the smaller chironomids are less likely to be detected acoustically and are thus less available than the sticky trap data indicate, but individual bats whose diet for a night was largely chironomids (or Diptera unidentifiable to the family level) indicate they can be detected and caught. The early May 1995 *M. yumanensis* diet sample (Figure 8A) which is largely dipterans also suggests detection is not a serious constraint.

4.9 TRANSECT OBSERVATIONS

The transect study was designed to assess bat abundance at multiple sites, sampled on the same night, along the Sacramento River and Squaw Creek, for a series of nights over a five week period. While observations at fixed stations (Section 4.5) gave detailed information through the first half of the night at one site per sampling night in each drainage, the transect observations were intended to provide information on patterns of spatial variation in bat and insect activity during one night within drainages. Though it was impossible with a single observer per drainage to observe all stations simultaneously, part of the goal of the transects was to detect short-term spatial heterogeneity in activity (*e.g.*, Was bat activity low everywhere in the drainage on a given night or was it highly concentrated? How variable was the pattern from night to night?) and thus indicate whether night-to-night differences among fixed station activity measures reflected local or drainage-wide variations.

Transects were conducted simultaneously on the Sacramento and Squaw on twelve nights in August and September 1991 and 1992 (8/19-9/26), generally on the same date in each year. The transect data were treated in analysis in the same fashion as the fixed observation station data in that Station 1 on the Sacramento (above Cantara) is excluded because it was not an effective control (nor does it represent the same sort of treatment as the other spill stations).

These data offer an opportunity to examine seasonal trends in bat activity through the observation period. Graphing (Fig. 26A-B) the grand means across stations (error bar is 1 S.E.) for each transect night for each year shows on Squaw Creek (except for the aberrantly high initial 1992 survey) a close correspondence in the trends for the two years and a gradual decline through the sampling period. Values on the Sacramento are larger and more variable, without a seasonal trend. Neither shows a clear year-to-year difference, though higher counts were obtained in the early part of the 1991 survey. Graphing the standard deviation among sites (Fig. 26C-D) on each transect night demonstrates lower variability overall among the Squaw sites than the Sacramento (perhaps because they are closer together or because the habitat is more homogenous independent of the smaller geographic scale) and some tendency for 1991 values to be higher. The 1991 observations on the Sacramento are substantially more variable than 1992 on a number of nights, suggesting the possibility that this reflects disturbance by the spill.

Figures 26E and F show the mean bat count for all transect dates at each station by year (with the S.E. estimated from night to night variability). Because bat activity usually is highest shortly after dark and declines to a lower level within an hour or two, and because the stations were visited sequentially, the declining counts with increasing station numbers are presumably a consequence of sampling time. There are significant (*i.e.*, non-overlapping S.E.) differences at most stations, but roughly equal numbers of stations in each drainage have higher counts in each year sampled, indicating that analysis of variance would be unlikely to show a significant effect of sample year.

Figures 17A and B show the standard deviation in bat count means among nights for each station. The Sacramento differs from the Squaw in that variability for each station is virtually always higher in 1991. One question is how much of the pattern of standard deviation variation reflects differences in the means when the standard deviation is correlated with the mean? Figures 17C and D address this in one of several possible ways by plotting the coefficient of variation of the mean bat count among nights for each station normalized to the mean. Most Sacramento stations showed greater night to night variability in 1991 than in 1992, while the reverse is true on the Squaw. Figures 17E and F show the coefficient of variation among stations (again normalized by mean) over the sequence of transects. On the Sacramento, variability among stations over time is larger than on the Squaw, and shows a distinct, but not readily interpretable pattern.

In summary, the transect data show evidence of greater variability in bat counts in 1991 than in 1992 on the Sacramento both absolutely and relative to the Squaw. A reasonable inference is that in 1991 the prey base was less predictable. Individual stations differ significantly in their mean bat counts between years, but in these data there are no clear year-to-year trends in the overall bat activity across stations.

4.1 GENETIC ANALYSIS FOR SPECIES IDENTIFICATION

Amplification of *Myotis* mitochondrial cytochrome b from small ethanol preserved bat hair samples was generally successful when the amplification protocol included a hot start (Mullis 1991). Initial screening for species specific markers involved digesting amplified products from a small set of individuals of *M. yumanensis* and *M. lucifugus* with three restriction enzymes. This demonstrated sequence variability within and among species for this region, but the fragment length patterns obtained with these enzymes were not species specific. While the next analytic step would have been sequencing of selected fragments, partial resolution of legal aspects of the Cantara case reduced the concern regarding uncertainty in identification of a small percentage of the bats captured, so activity on this task ceased. A colleague at the University of Nevada Reno is planning a similar project for discrimination of *M. californicus* and *M. ciliolabrum* in the Great Basin, so we will transfer samples and preliminary findings to aid the startup of that study and broaden its geographical scope.

5.0 ASSESSMENT OF SPILL IMPACTS

We summarize here evidence obtained regarding hypothesized effects of the spill as well as discuss broader issues, such as the reduction in ecological services which would emerge from reductions in the bat population.

5.1 DIRECT MORTALITY

A small number of dead bats found in the upper Sacramento canyon shortly after the spill were reported or submitted by the public to DFG (or in one instance to the contractors), but no mass mortalities were reported and there were no firm links between these specimens and the spill. Scattered reports to health or wildlife authorities of isolated dead or moribund bats are not uncommon. While mortality both from fumigation of day roosts near the river and of newly volant juveniles of species highly dependent on emergent aquatic insects seem probable, no evidence was obtained. Systematic surveys of the river for bats did not begin until a few weeks after the spill. Bats are small animals that, once dead, are both difficult to detect and readily transported or consumed by scavengers. In an experimental study of carcass disappearance, Wobeser and Wobeser (1992) found that only two of 250 day old chick carcasses were relocated intact after 24 hours.

The fate of the bat specimens reported as submitted to DFG during the immediate post-spill period is unknown. The single mummified juvenile *L. noctivagans* (the first indication that this species was breeding locally) received by the contractors has been retained at room temperature with other dry Cantara specimens. As noted earlier, guano collections were obtained in August and September 1991 from both roost sites and from individual bats captured over the river or in roosts. Limited discussion with DFG personnel and pesticide researchers suggested tentatively that chemical evidence of metam sodium exposure was unlikely to persist in air dried material, so chemical assay of the samples available was not pursued.

5.2 INDIRECT MORTALITY AND REDUCED REPRODUCTION OR GROWTH

We examined several different lines of evidence, and obtained indications of spill impacts on bat populations in the form of indirect mortality (*e.g.*, reduced overwinter survival), abandonment of the river as a foraging area, or reduced reproduction. These are discussed in detail in the body of the report, but are summarized below:

1. Capture rates (number of bats captured per unit effort) was lower on the Sacramento River relative to the control drainage in September 1991 than for any other sampling period. Also, capture rates and species diversity were lower on the Sacramento River in September 1991 than in September 1995 (see Section 4.2).
2. The Soda Creek maternity roost was larger in the spring of 1995 than it was in previous years, and appeared to have increased by as much as 25 % (see Section 4.3.2).
3. Some night roosting sites close to the river appeared to be abandoned after the spill. given the long term philopatry to night roost sites documented by this study, the abandonment of previously occupied sites suggests the animals either died or were forced, by absence of food resources, to leave the area (see Section 4.3.5).
4. Radiotracking studies documented the wide geographic area served by the river, and the philopatry of bats to both night roosting sites and foraging areas close to or on the river. At the species level, much of the bat community in the Sacramento drainage appears to use the river itself or or riparian habitats for foraging at times, and some travel considerable distances to utilize this foraging area (see Section 4.3.6).
5. The proportion of non-reproductive to reproductive adult females was greater on the Sacramento River in 1992 than in any other year, and decreased with each of the sampled years after the spill (see Section 4.5.3.1).
6. The age of first reproduction appeared to be delayed by the spill. The nulliparous rate among banded first year females was higher for 1992-1994 than it was in 1995 (see Section 4.5.3.2).
7. Overwinter survival of banded juveniles was lower at the spill sites than at the controls for 1992-1994. Survivorship approaches the expected values at one spill site in 1995 (Soda Creek) but not the other (Shotgun Creek) (see Section 4.7).

5.3 REDUCTION IN SERVICES

Loss of ecological services which might emerge from reductions or radically altered activity patterns of bat populations relate to their roles as:

1. insect predators
2. landscape-scale nutrient and energy transfer organisms
3. less importantly, as prey for higher level predators

Bats are generally recognized as the primary vertebrate consumers of night flying insects. Peak numbers of flying insects for a diurnal cycle occur after sunset and overall more fly at night than in daylight (see brief review by Mayle 1990). Bats are at least locally abundant, forming aggregations of tens to millions of individuals, and ecologically diverse, exploiting a wide range of prey species. Insect consumption rates can be conservatively estimated by repeatedly weighing foraging animals (e.g., Kunz 1974 reported 25-30% of body weight per night for *M. velifer*) but because of excretion in flight, better estimates probably emerge from the combination of field metabolic rates with digestive efficiency studies (e.g., Kurta *et al.* 1989). On this basis, Barclay *et al.* 1991 conclude that *M. lucifugus* consume 50-100% of their body weight in insects per night in summer. It is important to remember, particularly for bat species favoring larger insect species as prey, that bats discard a considerable mass of the least digestible prey parts (wings, elytra, legs, heads), so that the insect biomass captured may substantially exceed that ingested (and thus represented in metabolic measurements). To a first approximation similar rates of consumption likely apply to other aerial pursuit predators, such as *M. volans* or *T. brasiliensis* (Kunz *et al.* In press). However, some metabolic scaling should presumably be applied to estimating the mass of insect consumed per unit mass of bat for larger taxa such as *E. fuscus* and *A. pallidus*.

We can assume that most bats are feeding every night (except in periods of heavy rain or high winds) for at least 5 months of the year (May-September). As outlined in Sec 1.1.2 (see also seasonal night roost occupation in table 6B) activity declines in the colder months, but several species forage on warm days even in midwinter in the lower Castle Creek drainage. Total annual consumption of insect biomass per unit weight of bat may be higher for the gleaning guild (e.g., *P. townsendii*, *M. evotis*) than for aerial pursuit predators, because adaption for detecting insects at rest on vegetation allow these species to forage effectively at lower temperatures and thus over longer intervals (both in terms of the annual season and within a night) than specialists on flying insects.

Based on the foregoing, a conservative estimate of the biomass captured annually by a hypothetical 5.5 g *M. yumanensis* adult female would be 150 days * 5.5 g body weight * 0.75 proportion of body weight per night \approx 600 g wet weight of, predominantly emergent, aquatic insects. Thus a colony of 500 adults would catch on the order of 300 kg wet weight of insects or perhaps substantially more if the consumption of a subequal number of young (which are volant for at least 60 days) is considered. With an estimate of bat populations in the Sacramento River canyon it would be possible to compute roughly the biomass of insects (ca 10³ kg wet weight per yr) which would have been consumed under 'normal conditions' by the proportion of the bat population estimated to have been driven away, killed, or not recruited.

From an utilitarian perspective, bats consume (usually adults) of a variety of economically significant silvicultural (pine beetle, spruce budworm moth, gypsy moth) and agricultural (cherry flies, cucumber beetles, June bugs, leafhoppers) pests as well as human disease vector/nuisance taxa (e.g., mosquitoes [Fascione *et al.* 1991]). Quantitative data on bat consumption of insect pests and estimates of the role of bat predation in the population dynamics of these species or groups are not numerous, but Whitaker (1993) recently pointed out that four economically important pest taxa constituted 37.8% of the diet of 184 Indiana *E. fuscus* sampled from various parts of Indiana. This and other reports (e.g., Whitaker and Clem 1992) offer the basis for compiling estimates of the

economic value of bats as pest control agents. In Europe, perception in the silvicultural community that forest insectivore habitat enhancement offers a return on investment for biological pest control, (as well as aiding biodiversity preservation) has lead to extensive trials with both bird and bat boxes in commercial timber stands (*e.g.*, Burzynski 1984, Wellenstein 1989). While it is well known that vertebrate insectivores do not effectively 'control' forest pest species during outbreaks, a number of studies suggest that insectivores can prevent outbreaks of pests by predation when their densities are low (*e.g.*, Ostfeld *et al.* 1996).

We (Rainey *et al.* 1992) reported data which demonstrate a role for bats in up slope elemental nutrient and energy transfer from riparian corridors into California forest lands. Debris traps in the interiors of a sample of fire scarred coast redwoods (*Sequoia sempervirens*) revealed some guano from night or day roosting bats in all monitored trees. In larger diameter trees used as maternity roosts several kg dry weight of excreta containing on the order of 10% nitrogen and substantial potassium were deposited in several months. Colonies shifted among trees over periods of months or among years. Conifer forests are generally nitrogen limited (Cole and Rapp 1981) and rough calculations suggest that the N in guano is comparable to annual atmospheric inputs to the area of an individual tree canopy. High rates of tree cavity occupation with much lower weights of guano were obtained in 1995 pilot study on Giant Sequoia (*Sequoiadendron giganteum*) (Heady and Pierson, unpubl. obs.) and at north coast redwood site (Gellman and Zielinski 1996)

While data on nutrient uptake and quantitation of inputs above the scale of single trees (*i.e.*, density of bat roosts per hectare) is not yet available, it is clear that aggregated roosting by bats can, over relatively short intervals, create nutrient hot spots in forest areas at up to several km (both in map distance and elevation: see Sec 4.2) from the riparian corridors which provide the base of insect production. We should also not overlook the rapid gut transit time of bats (Buchler 1975, Stalinski 1994) and thus the large volumes of excreta deposited less detectably en route overland from foraging area to roosts (deposits in the trees suggest only a relatively small proportion of the 300 kg wet weight /year/colony estimated above accumulates in the day roost). The quantitative measures of over water bat activity obtained in the fixed station and transect counts (fixed station counts $\times \approx 20$ bat passes/minute) suggest intensive harvesting of night flying aquatic insects and substantial nutrient recycling and export.

An extremely diverse array of vertebrates and invertebrates have been reported as predators on bats (see tabulation in Gillette and Kimbrough 1970). With the exception of the 'specialist' tropical bat hawks, for many of the predator species, bat predation observations are typically viewed as unusual opportunistic events. While this may be generally true, recurrent association of certain species, *e.g.*, among raptors and snakes, with the concentrations of prey provided by bat colonies suggest that, at least at an individual level, bats may be locally or seasonally significant in predator diets. Among longer lived predators with considerable behavioral flexibility and capacity for learning, some reliance on seasonal availability or local concentrations of bats as prey might be expected (*e.g.*, Wroe and Wroe 1982).

Many aspects of bat biology including nocturnality, roost selection, emergence behavior and patterns of foraging in relation to moonlight intensity are proposed at least in part to be evolutionary and behavioral responses to predation pressure. Speakman (1991) estimated that 11% of bat mortality in Britain resulted from avian predation, but bats did not exceed 1% of the diet for any predator species. As he noted, the bat fraction of, for example, barn owl diets is sometimes considerably higher in reports from other countries. However, as relatively long-lived, low fecundity predators themselves, bats clearly cannot make the same quantitative contribution to the diet of larger predators as short-generation-time herbivorous rodents.

5.4 QUANTITATION OF SPILL IMPACTS

M. yumanensis is the only species for which a semiquantitative estimate of spill impacts can be made. Colony size (number of adult females) for *M. yumanensis* at control sites varied from 230 at Squaw Creek to 936 at Davis Road. Given the generally large size of *M. yumanensis* colonies, it would be reasonable to expect about 500 adult females per colony, or 880 animals per colony once the young are born (assuming the proportion nulliparous is 24 %, as found at Squaw Creek.). Recapture data plus observations of large numbers of *M. yumanensis* feeding over the river at a number of the stations suggest that there is likely a major maternity colony of *M. yumanensis* at least every 20-25 km along the river. A conservative estimate would be that there are five maternity colonies of 500 adult females each along the affected stretch of river above Shasta Lake, plus 500 adult males (if equal sex ratios and survivorship are assumed) distributed in an unknown number of roost sites. Using the combined estimates of spill effects (*i.e.*, increased overwinter mortality for the young [both male and female], and reduced reproduction for first year females), the loss to this population in the first year would have been approximately 58 (Shotgun Creek)-106 (Soda Creek) animals per colony, or a total of 580-1,060 animals for the affected area. Spill effects may vary both with distance of the colony to the river and with distance downstream from the spill site. These numbers do not include any estimates of immediate spill-related mortality, or any mortality that occurred between July and mid-September 1991. Although the available data do not permit estimates of loss for other species, *M. yumanensis* appears to be the most abundant species along the river, and the one most clearly dependent on the river for foraging. The next most abundant species, *M. lucifugus* and *L. noctivagans* also consume a significant proportion of aquatic isneets and commonly forage low over the river.

5.5 ESTIMATION OF PRE-SPILL BASELINE AND TIME TO RECOVERY

Other than scattered museum or literature records of species presence (*e.g.*, Kellogg 1916, Grinnell, *et al.* 1930, Marcot 1984) and some detailed single species studies in the region (*e.g.*, Pearson *et al.* 1952), pre-spill baseline data on bat communities (*e.g.*, abundance, diversity, reproductive success, diet) are not available for the Sacramento River, Squaw Creek, or other potential control drainages in northern California. An estimation of pre-spill bat diversity and abundance on the Sacramento River cannot be determined based on the data collected to date, and would require sampling of other major drainages. Such a sampling regime, considered in developing the initial study design, was rejected in favor of focusing on the Sacramento and a single nearby control drainage which would provide primarily temporal control.

Such a study would be a valuable baseline for future spill events which will almost inevitably occur, given both the major north south transportation corridor and the eventual transition from a regional economy based on resource extraction. Because bat distribution is strongly affected by altitude and latitude (with diversity generally decreasing with increasing altitude and latitude), and by the quality of available roosting sites and foraging areas, it would be desirable to consider the following parameters in choosing additional rivers as study areas: 1) altitude; 2) latitude; 3) forest community structure (*i.e.*, the age structure and species diversity of the tree community will determine availability of tree roosts, which appear from radiotracking data to be primary roosting sites for bats along the Sacramento); 4) hydrographic profile and 5) seasonal variation in flow.

In the absence of baseline community information, an approach to estimating time to recovery could be made via population modelling, using data on time to reproductive maturity and other parameters derived from the current mark-recapture studies and iteratively examining different intensities of spill impact against a background of stochastic variations in reproductive success and survival. The bounds on the resulting estimates would be inevitably quite broad, but it seems probable that the effect of the spill could not be resolved against natural variation after 6-7

years. We have suggested in recommendations on restoration (Pierson and Rainey 1994a) that, as noted above, bats as a community may perform a number of important and largely unrecognized ecosystem services, particularly in nutrient dispersal and insect control on a basinwide geographical scale. The magnitude of their effect deserves careful investigation, but, in terms of management for bats, the persistence of most of the species in the large summer populations of bats along the river is tied to a continuing standing stock of defective (preferably large) trees and snags in the watershed. Thus, broadly, the long-term viability of bat populations and other secondary cavity-dwelling wildlife is tied to the basin wide pattern and intensity of timber extraction.

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Table 1. Bat species known or possibly present in the vicinity of the Sacramento River above Lake Shasta. Species in light grey have been identified in this survey by the method noted. Dark grey indicates 'sensitive' species.

		Local detection	DFG Special Concern ¹	Former ESA Candidate 2 ²
Family Molossidae				
<i>Tadarida brasiliensis</i>	Mexican free-tailed bat	Net		
<i>Nyctinomops macrotis</i>	Big free-tailed bat			
<i>Eumops perotis</i>	Western mastiff bat	Acoustic		
Family Vespertilionidae				
<i>Antrozous pallidus</i>	Pallid bat	Net		
<i>Eptesicus fuscus</i>	Big brown bat	Net		
<i>Euderma maculatum</i>	Spotted bat	Acoustic		
<i>Lasionycteris noctivagans</i>	Silver-haired bat	Net		
<i>Lasiurus blossevillei</i> (= <i>borealis</i>) ³	Western red bat	Net		
<i>Lasiurus cinereus</i>	Hoary bat	Net		
<i>Myotis californicus</i>	California myotis	Net		
<i>Myotis ciliolabrum</i> (= <i>leibii</i>) ³	Small-footed myotis	Net		
<i>Myotis evotis</i>	Long-eared myotis	Net		
<i>Myotis lucifugus</i>	Little brown myotis	Net		
<i>Myotis thysanodes</i>	Fringed myotis	Net		
<i>Myotis volans</i>	Long-legged myotis	Net		
<i>Myotis yumanensis</i>	Yuma myotis	Net		
<i>Pipistrellus hesperus</i>	Western pipistrelle	Net		
<i>Corynorhinus</i> (= <i>Plecotus</i>) ³ <i>townsendii</i>	Townsend's big-eared bat	Net		

¹ California Department of Fish and Game, Mammalian Species of Special Concern (Williams 1986)

² Formerly candidate (Category 2) for listing under U.S. Endangered Species Act (1994 FR 59(219):58984-9).

³ Names as listed by Koopman in Wilson and Reeder 1992 with amendments

Table 2A. Numbers of bat captures in 1991 and 1992 by date, locality and species from mist netting over Squaw Creek or the Sacramento River and adjacent segments of tributary creeks.

locality	<i>A. pallidus</i>	<i>C. townsendii</i>	<i>E. fuscus</i>	<i>L. blassevillii</i>	<i>L. cinereus</i>	<i>L. noctivagans</i>	<i>M. californicus</i>	<i>M. ciliolabrum</i>	<i>M. evotis</i>	<i>M. lucifugus</i>	<i>M. thysanodes</i>	<i>M. volans</i>	<i>M. yll*</i>	<i>M. yumanensis</i>	<i>P. hesperus</i>	<i>T. brasiliensis</i>	Total identified captures	nets open (hrs)	net area (m ²)	bats*10 ² / m ² *hr
Vollmers							1							1			2	2.5	151	0.53
abv Cantara					1	2								8			11	2.42	151	3.02
Prospect					3	9		1		2			3	6			24	6	95	4.22
Sac at Soda Ck			1					1								3	5	3.67	206	0.66
Pollard										1			2			1	4	3.83	279	0.37
Pollard						3							1	5			9	3.5	245	1.05
Conant					4	4		1					1	1			11	2.75	223	1.79
Sacramento R. 1991			1		8	18	1	3		3			7	21		4	66	24.67	1349	1.66
Chirpchatte cmp					1									5	4	22	32	5.5	167	3.48
no name														2			2	3	151	0.44
Hansen's Dam						4								3			7	4.66	151	1.00
Madrone cmp					2	8								1		1	12	4.58	151	1.74
Ck at Little Cbn					2		3	2						6		2	15	3.58	167	2.51
Squaw Ck. 1991					5	12	3	2						17	4	25	68	21.32	786	1.83
Riverview			3			1			2	3				32	1		42	3.08	435	3.14
abv Cantara			1		2	10	2			13		1		5		1	35	5.08	251	2.75
Prospect						17	1		1	23			3	13			58	2.83	312	6.58
Sac at Soda Ck						2	4			7	1		3	75		1	93	2.5	206	18.04
Soda Ck at Br (T)						6								38			44	2.75	59	27.34
Pollard						2				2			2	5			11	3.67	340	0.88
Conant			1		3	6	2		1	3				12			28	4.25	265	2.49
Soda Ck at Br (T)						4	1		1		1			8			15	2.08	59	12.32
Castle Ck I-5 o/c (T)						1											1	2.83	56	0.63
Soda Ck at Br (T)						4								11			17	4.5	59	6.45
Boulder Ck (T)		3	4											44			51	5.83	134	6.54
Sac at Boulder Ck														10			10	5.83	56	3.08
Hazel Ck at Sims				1						1				9			11	4.36	153	1.65
Sac at Sims Rd	1		1			10	1		2	6			2	13			36	5.16	223	3.13
Sacramento R. 1992	4	0	13	0	5	63	11	0	7	58	2	1	10	275	1	2	452	49.59	2382	7.07
Ck at Little Cbn						5	1			1				44			51	4	78	16.34
Chirpchatte cmp	4				1	7	1			1				1	1		16	3	212	2.52
Gauging sta														4			4	2	122	1.64
Hansen's Dam						8								11			19	3.25	212	2.76
Madrone cmp	2		1			21	1							5			30	3.51	248	3.45
Squaw Ck. 1992	6		1		1	41	3			2				65	1		120	15.76	872	5.34

(T) indicates netting near tributary confluence

Table 2B. Numbers of bat captures 1993-1995 by date, locality and species from mist netting over Squaw Creek or the Sacramento River and adjacent segments of tributary creeks.

locality	<i>A. pallidus</i>	<i>P. townsendii</i>	<i>E. fuscus</i>	<i>L. blassevillii</i>	<i>L. cinereus</i>	<i>L. noctivagans</i>	<i>M. californica</i>	<i>M. ciliolabrum</i>	<i>M. evotis</i>	<i>M. lucifugus</i>	<i>M. thysanodes</i>	<i>M. volans</i>	<i>M. yf/</i> *	<i>M. yumanensis</i>	<i>P. hesperus</i>	<i>T. brasiliensis</i>	Total identified captures	nets open (hrs)	net area (m ²)	bats*10 ² / m ² *hr
Prospect			1	1		22	3			18			1	7			53	2.75	223	8.64
Conant						4	1			7				13			25	3.83	245	2.66
Boulder Ck (T)	3		1			1					1			60			66	4.5	151	9.75
Sac at Boulder Ck														9			9	4.5	56	3.59
abv Cantara			1			6	2		1	7			1	6			24	4	307	1.96
Sac at Soda Ck						6	3			14				16		2	41	3.5	111	10.51
Soda Ck at Br (T)						7				3			2	35			47	3	49	31.70
Hazel Ck at Sims (T)						4		1						9		1	15	4.5	78	4.27
Sac at Sims Rd					1	15		1		6				7		3	33	4.5	223	3.29
Dog Ck (T)														6			6	4.16	78	1.85
Sac at Dog Ck		1			1	2				14			3	12	1		34	4.16	206	3.96
Sacramento R. 1993	3	1	3	1	2	67	9	2	1	69	1		7	180	1	6	353	43.4	1727	7.47
Chirpchatte cmp	1					5	4		3					10	5	2	30	4.25	265	2.67
Madrone cmp							1			1				4			6	2	223	1.35
Hansen's Dam			2			6	2			1				8			19	4.75	262	1.53
Madrone cmp						3	1		1	1				3			9	4.25	206	1.03
1.5mi abv Madrone cmp			1	1		3	3	1	3					7			19	4.83	153	2.57
Ck at Little Cbn	1		1	1		4			1			2		11			21	4	156	3.36
Squaw Ck. 1993	2	4	2			21	11	1	8	3		2		43	5	2	104	24.08	1265	2.08
Hazel Ck at Sims (T)	1		2			2	1							2			8	4	78	2.56
Sac at Sims Rd			1		1	26				23			2	23		11	87	4	223	9.75
Prospect			5		1	17	1			6			1	5			36	3.01	229	5.23
Dog Ck (T)			1											5			6	3.5	59	2.93
Sac at Dog Ck	2		2			28				7			1	15		1	56	3.75	223	6.70
abv Cantara				2	2	16				4		1	1	5			31	3.01	190	5.43
Conant						6	1			2				5			14	3.08	245	1.85
Sac at Soda Ck						18				14			11	39		8	90	3.25	151	18.40
Soda Ck at Br (T)						13			1	3			1	22			40	3.25	78	15.77
Sacramento R. 1994	3	11	2	4		126	3	1	59	0	1	17	121		20		368	30.85	1396	7.63
Chirpchatte cmp	6		1			12		2	1					3	8	1	34	4	190	4.48
Ck at Little Cbn			2			4			2					4			12	4.5	156	1.71
Hansen's Dam	2	1		1		26				2				6			38	3.66	190	5.48
1.5mi abv Madrone cmp	1					4		1	4		1			21			32	3.5	98	9.37
Madrone cmp			2			47			1	1				11			62	3.01	170	12.12
Squaw Ck. 1994	9	1	5	1		93		3	8	3	1			45	8	1	178	18.67	803	6.63
abv Cantara			1			12	1		1	8			1	8		2	34	4.83	190	3.71
Sac at Soda Ck					1	23	2			2				2		7	37	4.83	151	5.09
Soda Ck at Br (T)						6				1			1	12			20	4.75	59	7.19
Conant						9	4						1	4			18	3.67	262	1.87
Prospect					4	8	2		1	4			2	12		8	42	4.75	284	3.11
Boulder Ck	1													1			2	4.52	39	1.13
Sacramento R. 1995	1	1	5	58	9		2	15	0	5	39	17	152	27.35	984				3.69	
Madrone cmp				1	6	2										6	15	4.25	170	2.08
Hansen's Dam	1			1	8	6						1		2		5	24	4.52	114	4.65
Chirpchatte cmp			1			12	1		1	8			1	8	3	2	34	4.75	206	3.47
Squaw Ck. 1995	2			3	15	9		1			1			3	3	15	52	13.52	491	3.40
Grand Total	30	2	39	6	33	514	59	11	28	212	4	5	46	809	23	92	1913	269.2	12055	4.68

(T) indicates netting near tributary confluence

Table 3. Summary of bat captures by year, drainage and species from mist netting over Squaw Creek and the upper Sacramento River.

date	Drainage	N of net nights	<i>A. pallidus</i>	<i>C. townsendii</i>	<i>E. fuscus</i>	<i>L. blassevillii</i>	<i>L. cinereus</i>	<i>L. noctivagans</i>	<i>M. californicus</i>	<i>M. ciliolabrum</i>	<i>M. evotis</i>	<i>M. lucifugus</i>	<i>M. thysanodes</i>	<i>M. volans</i>	<i>M. y/l*</i>	<i>M. yumanensis</i>	<i>P. hesperis</i>	<i>T. brasiliensis</i>	Total identified captures	Total species	Total net area (m ²) * hr †	bats*10 ² /m ² * hr††	species /m ² *hour
Sep-91	Sacramento	7		1		8	18	1	3			3			7	21		4	66	9	4605	1.66	0.20
Sep-91	Squaw	5				5	12	3	2							17	4	25	68	7	3361	1.83	0.21
Jul-92	Sacramento	14	4		13		5	63	11		7	58	2	1	10	275	1	2	452	13	8861	7.07	0.15
Jul-92	Squaw	5	6		1		1	41	3			2				65	1		120	8	2751	5.34	0.29
Aug-93	Sacramento	11	3	1	3	1	2	67	11		1	69	1		7	180	1	6	353	14	6783	7.47	0.21
Aug-93	Squaw	6	2		4	2		21	12		8	3		2		43	5	2	104	11	5057	2.08	0.22
Jul-94	Sacramento	9	3		11	2	4	126	3		1	59		1	17	121		20	368	12	5002	7.63	0.24
Jul-94	Squaw	5	9	1	5	1		93	3		8	3	1			45	8	1	178	12	3007	6.63	0.40
Sep-95	Sacramento	6	1		1		5	58	9		2	15	2		5	39		17	152	11	4409	3.69	0.25
Sep-95	Squaw	3	2				3	15	9		1				1	3	3	15	52	9	2218	3.40	0.41
Total		71																		Mean=	4928	4.964	0.24

* *M. y/l* are either *M. yumanensis* or *M. lucifugus* †m2 net *net hr total for all net nights

††mean of net nights for identified bats*102/m2 net*net hr

Table 4. Mist netting capture rate (bat captures*100/m² net area* net hours) for *Myotis yumanensis* and *Lasionycteris noctivagans* 1991-1995.

Locality	Species	Year				
		1991	1992	1993	1994	1995
Sacramento River						
	<i>M. yumanensis</i>	0.47	2.88	2.72	2.46	0.88
	<i>L. noctivagans</i>	0.40	0.66	1.01	2.56	1.32
Squaw Creek						
	<i>M. yumanensis</i>	0.51	2.48	0.85	1.58	0.14
	<i>L. noctivagans</i>	0.36	1.56	0.42	3.27	0.68

Table 5. Roosts, foraging areas, age and reproductive condition of telemetered bats other than *L. noctivagans* along the Sacramento River.

Date	Species	Sex	Reprod. Condition	Roost site	Roost to river (km)	Roost Location	Foraging area
09/29/91	<i>A. pallidus</i>	F	Nulliparous	Black Oak	0.45	Gibson Ridge	In oak woodland in river drainage
09/29/91	<i>M. yumanensis</i>	F	Postlactating	Dead sugar pine	0.5	Shotgun Ck.	Over river at mouth of Shotgun Creek
09/29/91	<i>M. lucifugus</i>	F	Postlactating	Canyon live oak	0.9	Boulder Ck.	Low over river, near mouth of Boulder Creek
09/29/91	<i>C. townsendii</i>	F	Postlactating	Abandoned mine	2.4	Coal Pit Gulch	On slope in river drainage
10/02/91	<i>C. townsendii</i>	F	Postlactating	Abandoned mine	0.2	Gibson Interchange	2 km of river drainage in riparian and upslope
10/02/91	<i>C. townsendii</i>	M	Adult	Abandoned mine	0.2	Gibson Interchange	Upriver from female <i>C. townsendii</i> on canyon slope
07/20/92	<i>A. pallidus</i>	F	Lactating	Black Oak	0.45	Gibson Ridge	In oak woodland in river drainage
07/20/92	<i>A. pallidus</i>	F	Lactating	Black Oak	0.45	Gibson Ridge	In oak woodland in river drainage
07/20/92	<i>A. pallidus</i>	F	Nulliparous	Black Oak	0.45	Gibson Ridge	In oak woodland in river drainage
07/22/92	<i>A. pallidus</i>	F	Lactating	Unknown	<2.0	Sims	Along river between Sims and Gibson Interch.
07/22/92	<i>E. fuscus</i>	F	Postlactating	Unknown	<2.0	Bonneville Ck.	Along river between Shotgun Ck. and Gibson Interch.
07/17/92	<i>M. volans</i>	F	Postlactating	Conifer snag	4.0	Girard Ridge	On river and in Fall Creek drainage

Table 6A. Numbers of bat captures by date, locality and species in night roosts in the Sacramento River and Squaw Creek drainage basins, 1991-1994.

Date	Locality	<i>A. pallidus</i>	<i>C. townsendii</i>	<i>E. fuscus</i>	<i>M. evotis</i>	<i>M. lucifugus</i>	<i>M. thysanodes</i>	<i>M. volans</i>	<i>M. y/l*</i>	<i>M. yumanensis</i>	<i>T. brasiliensis</i>	Total
18-Sep	Shotgun Ck Hwy99 Br									7		7
27-Sep	Dog Ck Br								1	3		4
29-Sep	Gibson Rd Br	1								1		2
29-Sep	LaMoine Hse		2									2
29-Sep	LaMoine Hwy99 Br								9			9
29-Sep	Shotgun Ck Hwy99 Br									92		92
Total	Sacramento R. 1991	1	2						10	103		116
12-Jul	Castle Ck I-5 o/c							2				2
15-Jul	Conant I-5 o/c				2							2
16-Jul	Castle Ck I-5 o/c									25		25
18-Jul	Soda Ck Rd I-5 o/c			5	1		1	2		5		14
19-Jul	Panorama Wy I-5 o/c			1								1
19-Jul	Shotgun Ck Hwy99 Br									1		1
19-Jul	Sims Rd I-5 o/c									6		6
23-Jul	Castle Ck I-5 o/c			1	1			1				3
23-Jul	Shotgun Ck Hwy99 Br									3		3
23-Jul	Soda Ck Rd I-5 o/c			2				1				3
12-Aug	Shotgun Ck Hwy99 Br			1						428		429
14-Aug	Gibson Rd Br	22								8		30
12-Sep	Gibson Rd Br	7										7
Total	Sacramento R. 1992	29		10	4		1	6		476		526
10-Jun	Soda Ck Rd I-5 o/c			1								1
11-Aug	Conant I-5 o/c	1		1								2
11-Aug	Soda Ck Rd I-5 o/c			1								1
24-Aug	Gibson Rd Br	27										27
26-Aug	Shotgun Ck Hwy99 Br			2				1		422		425
Total	Sacramento R. 1993	28		5				1		422		456
16-Aug	Cbn 1.8mi abv Madrone cmp									19		19
Total	Squaw Ck. 1993									19		19
21-May	Soda Ck Rd I-5 o/c						1			2		3
23-May	Soda Ck Rd I-5 o/c							1		3		4
26-May	Soda Ck Rd I-5 o/c									2		2
30-May	Boulder Ck Br									1		1
19-Jun	Soda Ck Rd I-5 o/c									5		5
11-Jul	Sims Rd I-5 o/c									2		2
14-Jul	Flume Ck Rd. I-5 o/c									2		2
14-Jul	Sims Rd I-5 o/c							1				1
18-Aug	Shotgun Ck Hwy99 Br									309		309
20-Aug	Gibson Rd Br	12										12
22-Aug	Soda Ck Rd I-5 o/c									1		1
17-Sep	Soda Ck Rd I-5 o/c									5		5
Total	Sacramento R. 1994	12						1	2	332		347

Notes: Recaptures of same animal are included.

Night roosts in day roosts not included (e.g., at Meiss Ranch)

Table 6B. Numbers of bat captures by date, locality and species in night roosts in the upper Sacramento River and Squaw Creek drainage basins in 1995, with totals 1991-1995.

Date	Locality	<i>A. pallidus</i>	<i>C. townsendii</i>	<i>E. fuscus</i>	<i>M. evotis</i>	<i>M. lucifugus</i>	<i>M. thysanodes</i>	<i>M. volans</i>	<i>M. y/l*</i>	<i>M. yunanensis</i>	<i>T. brasiliensis</i>	Total
22-Apr	Boulder Ck Br									4		4
22-Apr	Gibson Rd Br									1		1
22-Apr	Sims Rd I-5 o/c									2		2
14-May	Boulder Ck Br									7		7
14-May	Flume Ck Rd. I-5 o/c				1							1
14-May	Sims Rd I-5 o/c	1								1		2
14-May	Soda Ck Rd I-5 o/c				1					1		2
21-May	Conant I-5 o/c			1						2		3
21-May	Flume Ck Rd. I-5 o/c			1						1		2
21-May	Shotgun Ck Hwy99 Br			16						13		29
21-May	Sims Rd I-5 o/c	5										5
12-Jun	Boulder Ck Br									7		7
12-Jun	Conant I-5 o/c	1										1
12-Jun	Shotgun Ck Hwy99 Br			3						22		25
12-Jun	Sims Rd I-5 o/c	2		1						1		4
12-Jun	Soda Ck Rd I-5 o/c									12		12
17-Jul	Soda Ck Rd I-5 o/c			1								1
30-Jul	Soda Ck Rd I-5 o/c			2	1							3
18-Aug	Boulder Ck Br									145		145
19-Aug	Shotgun Ck Hwy99 Br					7			9	310		326
23-Sep	Gibson Rd Br	23								11	4	34
28-Sep	Boulder Ck Br									6		6
28-Sep	Conant I-5 o/c								3			3
28-Sep	Flume Ck Rd. I-5 o/c	1					1	1		2		5
28-Sep	Gibson Rd Br	8										8
28-Sep	Soda Ck Rd I-5 o/c						1			12		13
13-Oct	Boulder Ck Br									1		1
13-Oct	Flume Ck Rd. I-5 o/c				1							1
13-Oct	Shotgun Ck Hwy99 Br									1		1
13-Oct	Sims Rd I-5 o/c	1										1
13-Oct	Soda Ck Rd I-5 o/c			1								1
13-Oct	Boulder Ck Br					1						1
13-Oct	Flume Ck Rd. I-5 o/c				1							1
13-Oct	Soda Ck Rd I-5 o/c				1							1
Total Sacramento R. 1995		42		26	6	8	2	1	12	562	4	659
TOTAL		112	2	41	10	8	4	10	22	1895	4	2104

Notes: Recaptures of same animal are included.

Night roosts in day roosts not included (e.g., at Meiss Ranch)

Table 7A. Reproductive condition of bats mist netted over Squaw Creek or the Sacramento River in July -August 1992-1993.

Sex	Age/ Reproductive condition	<i>A. pallidus</i>	<i>C. townsendii</i>	<i>E. fuscus</i>	<i>L. blassevillii</i>	<i>L. cinereus</i>	<i>L. noctivagans</i>	<i>M. californicus</i>	<i>M. ciliolabrum</i>	<i>M. evotis</i>	<i>M. lucifugus</i>	<i>M. thysanodes</i>	<i>M. volans</i>	<i>M. y/i</i>	<i>M. yumanensis</i>	<i>P. hesperus</i>	<i>T. brasiliensis</i>	TOTAL
6-22 July 1992																		
Female	Unknown						1											1
	Pregnant																1	1
	Lactating	2					11	10			11				79			113
	Postlactating	1		4			19			1					18	1		44
	Nulli/failure*	1		1			6			2	7	1		3	17			38
	Juvenile			1			5	1		3		1		1	76			83
	total	4	6				42	11		6	18	2		4	190	1	1	285
Male	Adult			7		5	9			1	35		1	3	30		1	92
	Juvenile						12			1	5			3	56			77
	total			7		5	21			2	40		1	6	86		1	169
	Sacramento R.	4	13		5	63	11		8	58	2	1	10	276	1	2		454
Female	Unknown														3			3
	Pregnant																	0
	Lactating						6	1			1				25	1		34
	Postlactating	1					21								6			28
	Nulli/failure														16			16
	Juvenile						7	1			1				7			16
	total	1					34	2			2				57	1		97
Male	Adult	5		1		1	3	1							6			17
	Juvenile						4								2			6
	total	5		1		1	7	1							8			23
	Squaw Creek	6		1		1	41	3			2				65	1		120
10-23 August 1993																		
Unknown					1	1												2
Female	Pregnant																	0
	Lactating	1									1				7			9
	Postlactating						26	3	2		17		1		44		2	95
	Nulli/failure	2			1		5			1	11			2	15			37
	Juvenile						12	3			7			1	52	1	2	78
	total	3			1		43	6	2	1	36			4	118	1	4	219
	Male	Adult		1	3			14	1			29			1	14		1
Juvenile							10	2			4	1		2	48		1	63
total			1	3			24	3			33	1		3	62		2	132
Sacramento R.		3	1	3		1	67	9	2	1	69	1		7	180	1	6	351
Unknown	1																1	
Female	Pregnant																	0
	Lactating			1									1			4		6
	Postlactating						3	3		2	1				6			15
	Nulli/failure			1						1	2				7			11
	Juvenile			1			12	1	1	3			1		16			35
	total		3				15	4	1	6	3		2		29	4		67
	Male	Adult	1		1			3	4		1					4	1	2
Juvenile				1	1		3	3		1					10			19
total		1		1	2		6	7		2					14	1	2	36
Squaw Creek		1		4	2		21	11	1	8	3		2		43	5	2	171

Table 7B. Reproductive condition of bats mist netted over Squaw Creek or the Sacramento River in July 1994.

Sex	Age/ Reproductive condition	<i>A. pallidus</i>	<i>C. townsendii</i>	<i>E. fuscus</i>	<i>L. blassevillii</i>	<i>L. cinereus</i>	<i>L. noctivagans</i>	<i>M. californicus</i>	<i>M. ciliolabrum</i>	<i>M. evotis</i>	<i>M. lucifugus</i>	<i>M. thysanodes</i>	<i>M. volans</i>	<i>M. y/l</i>	<i>M. yumanensis</i>	<i>P. hesperus</i>	<i>T. brasiliensis</i>	TOTAL
7-16 July 1994																		
Unknown	Juvenile						1											1
Female	Unknown						2				2				1			5
	Pregnant																	0
	Lactating						14	1		1	10				15			41
	Postlactating			1			25				5				13			44
	Nulli/failure								1		1			2	5			9
	Juvenile			1			36	1			19			6	40			103
	total			2			77	3		1	37			8	74			202
Male	Adult	3		9	2	4	19				14		1	4	14		20	90
	Juvenile						29				8			5	33			75
	total	3		9	2	4	48				22		1	9	47		20	165
	Sacramento R.	3		11	2	4	125	3		1	59		1	17	121		20	367
Unknown				1														1
Female	Unknown														1			1
	Pregnant	1					1											2
	Lactating			1			39		1	2	1				15	6		65
	Postlactating			1			7								1			9
	Nulli/failure	3		1			1			1	1				2			9
	Juvenile						19		1	1					15			36
	total	4		3			67		2	4	2				34	6		122
Male	Adult	5	1	1	1		3		1	4		1			3	2	1	23
	Juvenile						23				1				8			32
	total	5	1	1	1		26		1	4	1	1			11	2	1	55
	Squaw Creek	9	1	4	1		93		3	8	3	1			45	8	1	177

Notes: Recaptures are included (reproductive condition may change). *M. y/l* are either *M. yumanensis* or *M. lucifugus*

*Nulli/failure includes: nulliparous adult females, those which appear parous but have not given birth this season and those which may have lost young late term or perinatally

Table 8. Distribution of adult female reproductive condition for netted bats for four years following the spill.

		Jul-92		Aug-93		Jul-94		Sep-95	
		Sacto R.	Squaw	Sacto R.	Squaw	Sacto R.	Squaw	Sacto R.	Squaw
All Adult Females									
	Unknown	1	3	1	0	5	1	0	0
	Lactating	113	34	9	6	41	65	0	0
	Nulli/failure (see Table 7)	38	16	37	11	9	9	1	3
	Pregnant	1	0	0	0	0	2	0	0
	Postlactating	44	28	94	15	44	9	26	4
	Lactating+Postlactating	82	44	103	21	53	18	27	7
	(Nulli/failure) /Lactating+Postlactating	0.46	0.36	0.36	0.52	0.17	0.50	0.04	0.75
As above less									
<i>M. yumanensis</i>	Unknown	1	0	0	0	4	0	0	0
<i>M. californicus</i>	Lactating	24	8	2	6	25	49	0	0
<i>M. ciliolabrum</i>	Nulli/failure	18	0	22	4	1	7	1	3
	Pregnant	1	0	0	0	0	2	0	0
	Postlactating	26	22	47	6	31	8	17	4
	Lactating+Postlactating	50	30	49	12	56	57	18	7
	(Nulli/failure) /Lactating+Postlactating	0.36	0	0.45	0.33	0.02	0.12	0.06	0.75

Table 9. Ratio of non-reproductive (nulliparous + reproductive failure) to reproductive (lactating + post-lactating) adult females in August-September *Myotis yumanensis* roost samples.

Roost	Year	Non-Repro.	Repro.	Non-Repro. /Repro.
Spill Sites				
Soda Creek				
	1992	7	110	0.064
	1993	11	174	0.063
	1994	4	56	0.071
	1995	0	92	0.000
Shotgun Creek				
	1991	5	25	0.200
	1992	30	219	0.137
	1993	36	263	0.137
	1994	23	205	0.112
	1995	8	189	0.042
Control Sites				
Meiss Ranch				
	1992	18	60	0.300
	1993	24	78	0.308
	1994	9	53	0.153
	1995	26	45	0.578
Squaw Creek				
	1992	9	53	0.170
	1993	16	49	0.327
	1994	1	1	1.000
	1995	1	50	0.020
Davis Road				
	1992	16	108	0.148

Table 10. Variation in time to first reproduction among *Myotis* aggregation sites based on recaptures of females marked as juveniles.

Roost	Initial Capture	Nulliparous Following Year	n
Spill Sites			
Soda Creek			
	1992	39%	18
	1993	20%	15
	1994	0%	11
Shotgun Creek			
	1991	78%	9
	1992	100%	18
	1993	81%	16
	1994	43%	7
Control Sites			
Meiss Ranch			
	1992	64%	11
	1993	100%	4
	1994	100%	4
Squaw Creek			
	1991	50%	8
	1992	59%	17
	1993	ND	1
	1994	ND	0
Davis Road			
	1992	0%	9

Table 11. Survivorship of young in *M. yumanensis* populations based on recapture data. Total number of females, banded as juveniles and recaptured as first year adults, compared to total number of females that were present in sample when 1st year adults were banded and present in sample at time of recapture.

Roost	Cohort	Recapture Year	# 1st Year Banded Adults	Total # Adults	Proportion of 1st Year Adults
Spill Sites					
Soda Creek					
	1992	1993	7	37	0.189
	1993	1994	9	45	0.209
	1994	1995	6	22	0.273
Shotgun					
	1992	1993	20	119	0.168
	1993	1994	15	72	0.208
	1994	1995	5	94	0.053
Controls					
Squaw Creek					
	1992	1993	14	55	0.255
Davis Road					
	1992	1993	9	36	0.250
Meiss Ranch					
	1994	1995	4	17	0.235

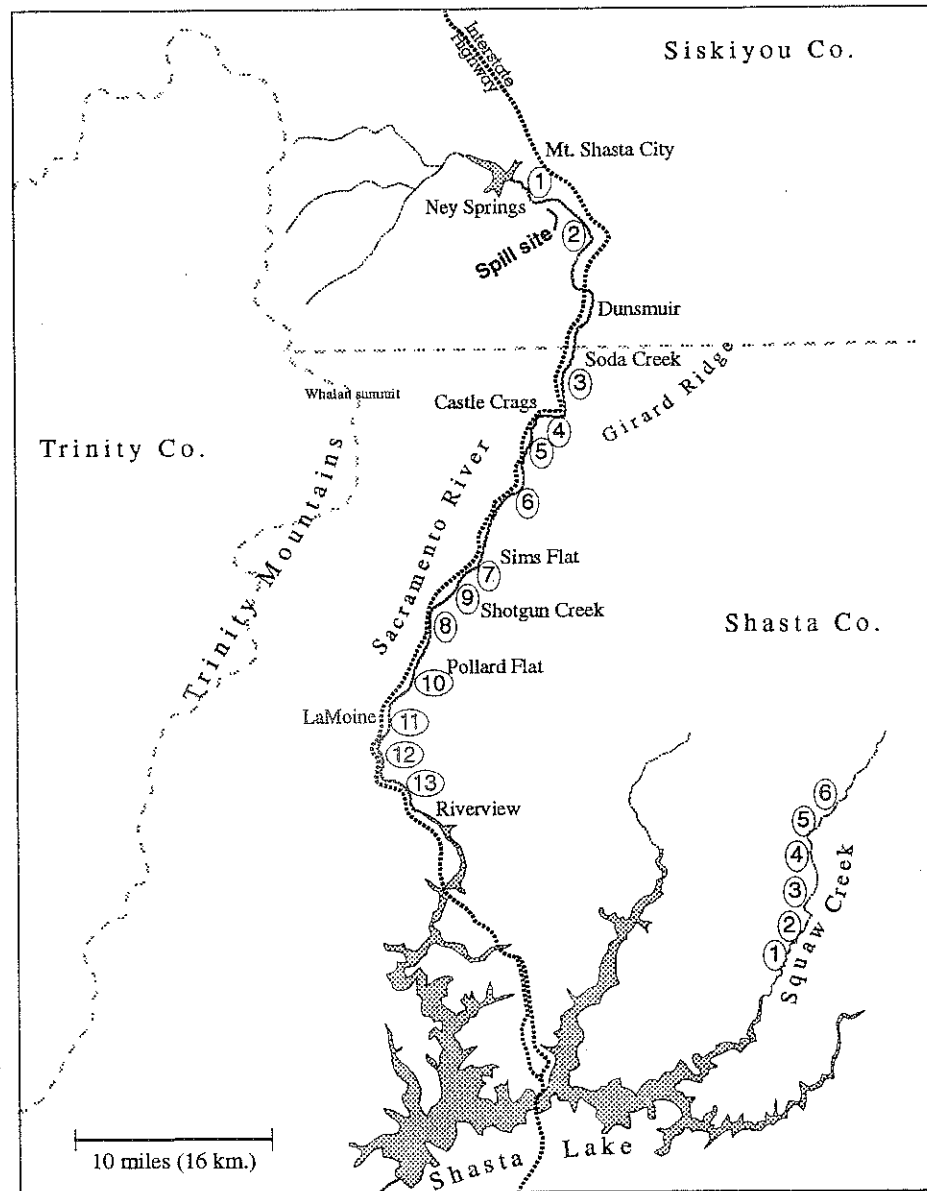


Figure 1. Map of survey region with observation and netting site localities.

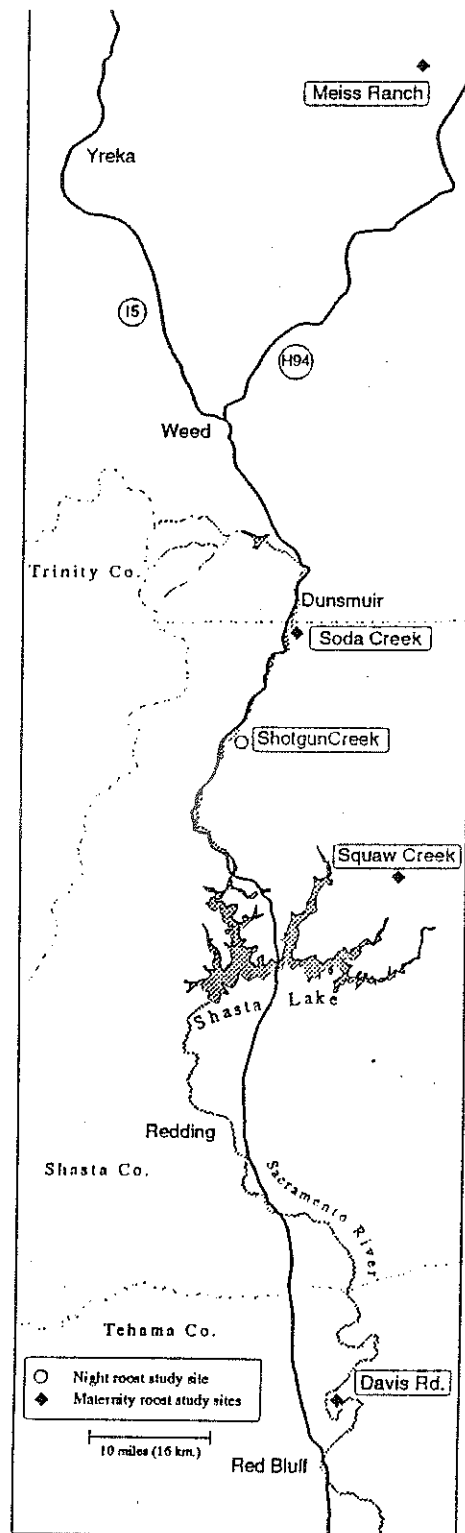


Figure 3. *Myotis* maternity and night roost study site locations

Figure 2. Seasonal flow on upper Sacramento River and Squaw Creek (prepared from U.S.G.S. Data). Note that periods of record are not identical.

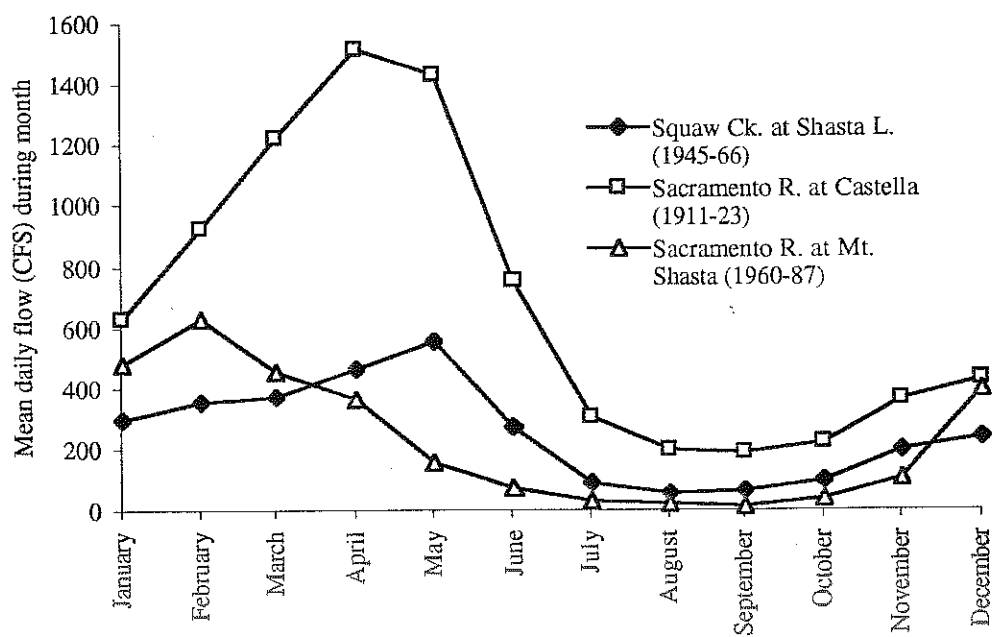


Figure 4A. Number of netting sites (limited to those sampled at least twice) at which species were detected on the upper Sacramento River or Squaw Creek.

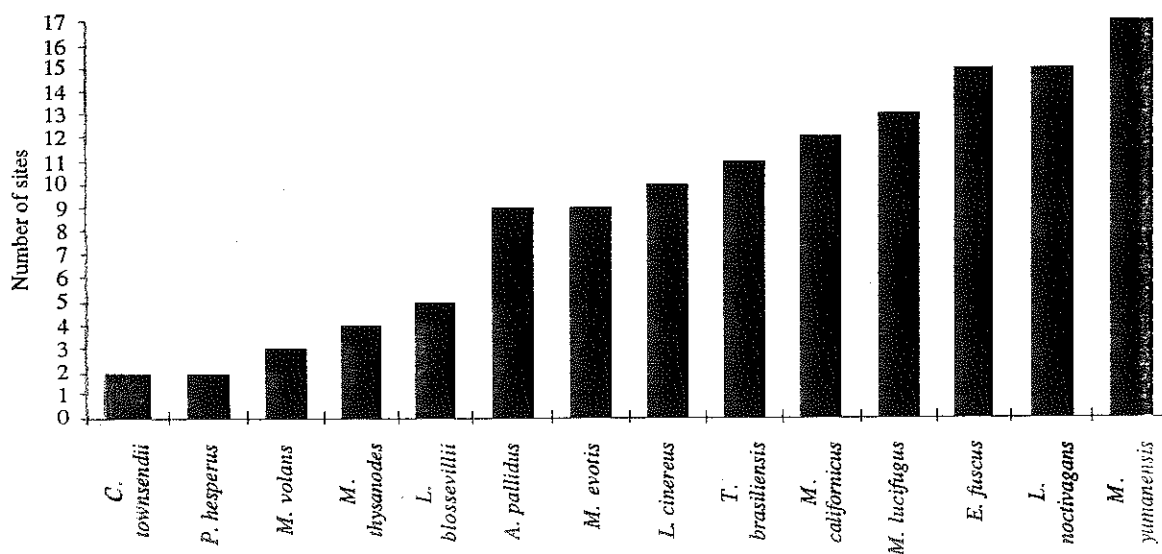


Figure 4B. Plots of total net captures by species against the number of sites at which the species was observed for both the upper Sacramento River and Squaw Creek. Sites in this analysis were sampled at least twice.

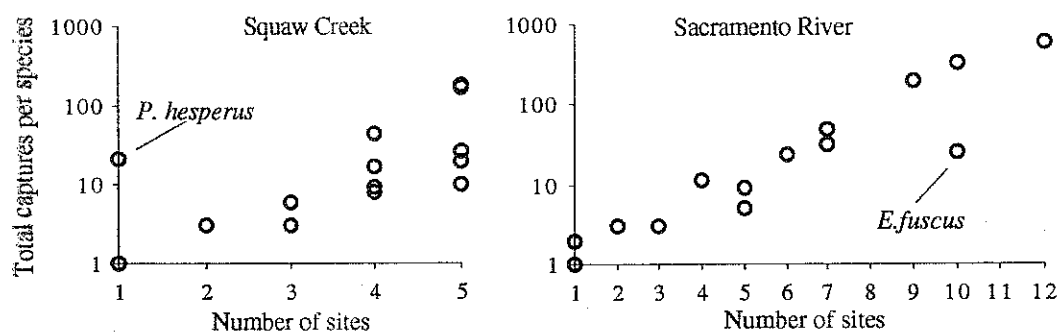


Figure 5. Seasonal abundance in net captures for four species on the upper Sacramento River and Squaw Creek.

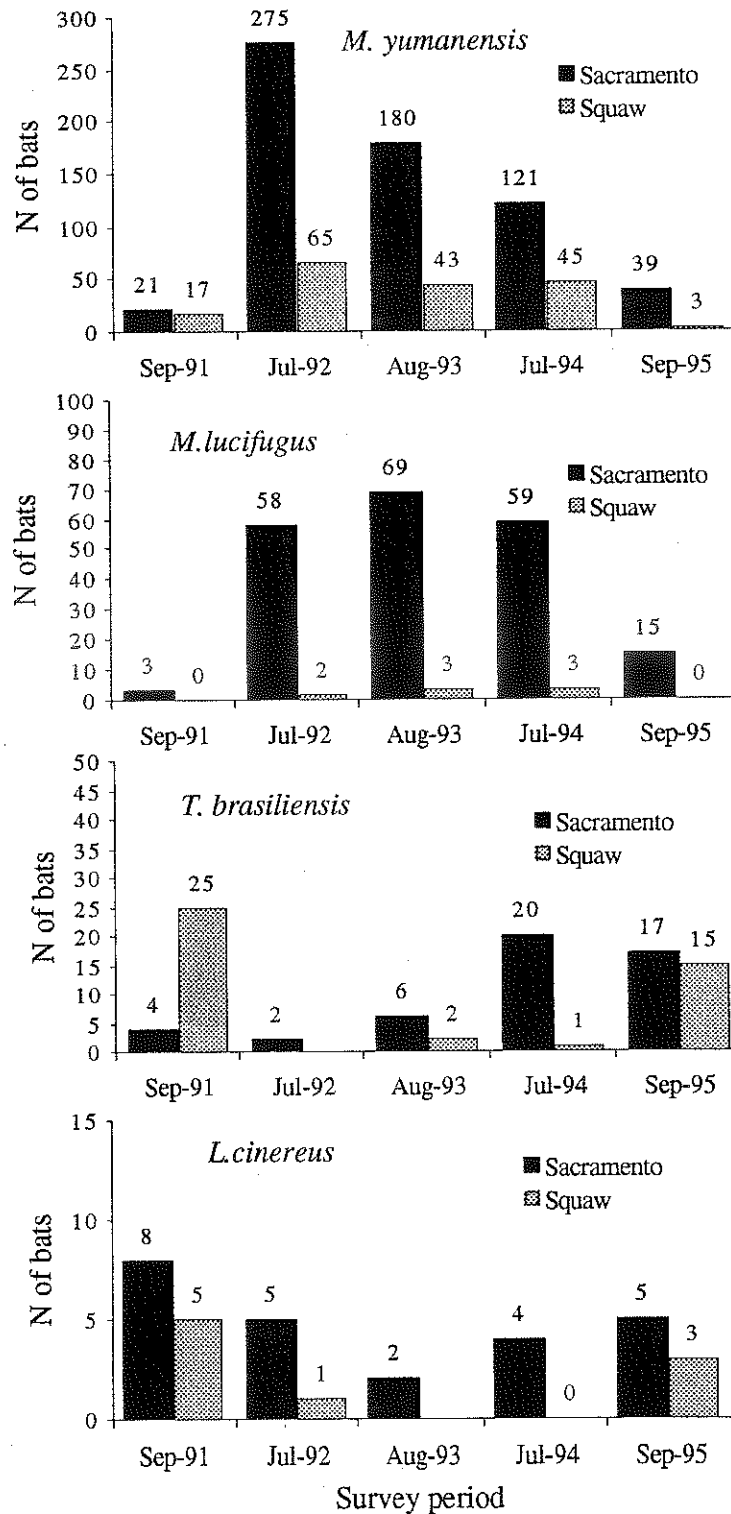


Figure 6 A. Histogram of *L. noctivagans* roost tree distances from capture site on the Sacramento River at Soda Creek. B. Elevation gain vs distance from capture site for the same roosts.

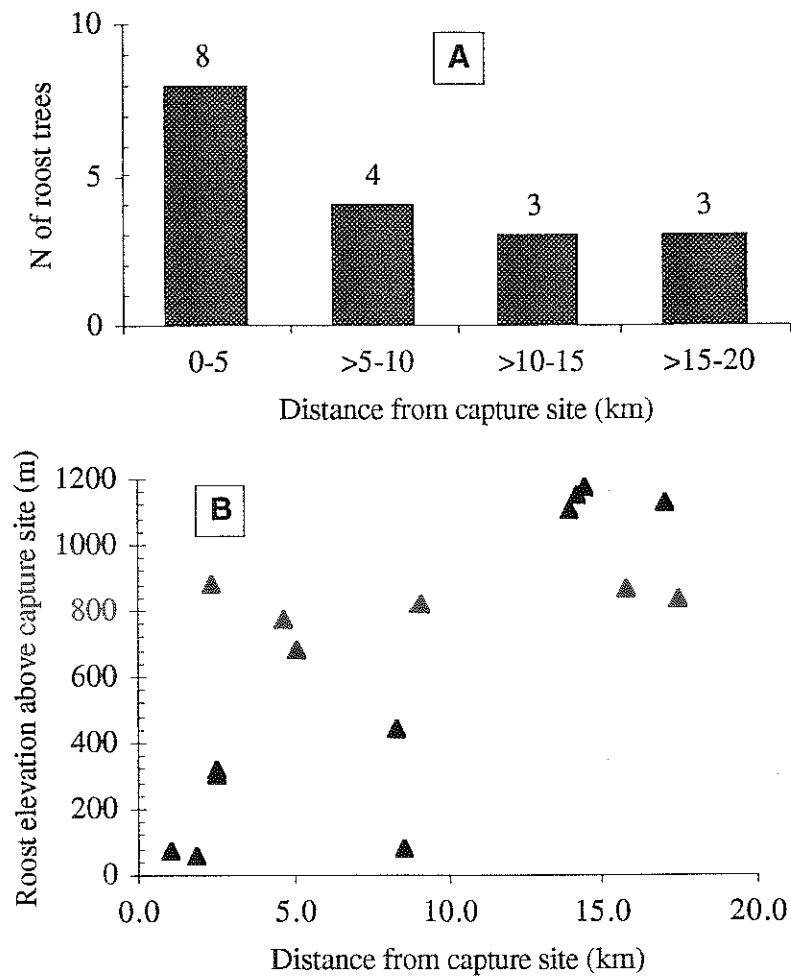


Figure 7. Distances between initial capture location and any subsequent recapture by year for the Sacramento River and Squaw Creek.

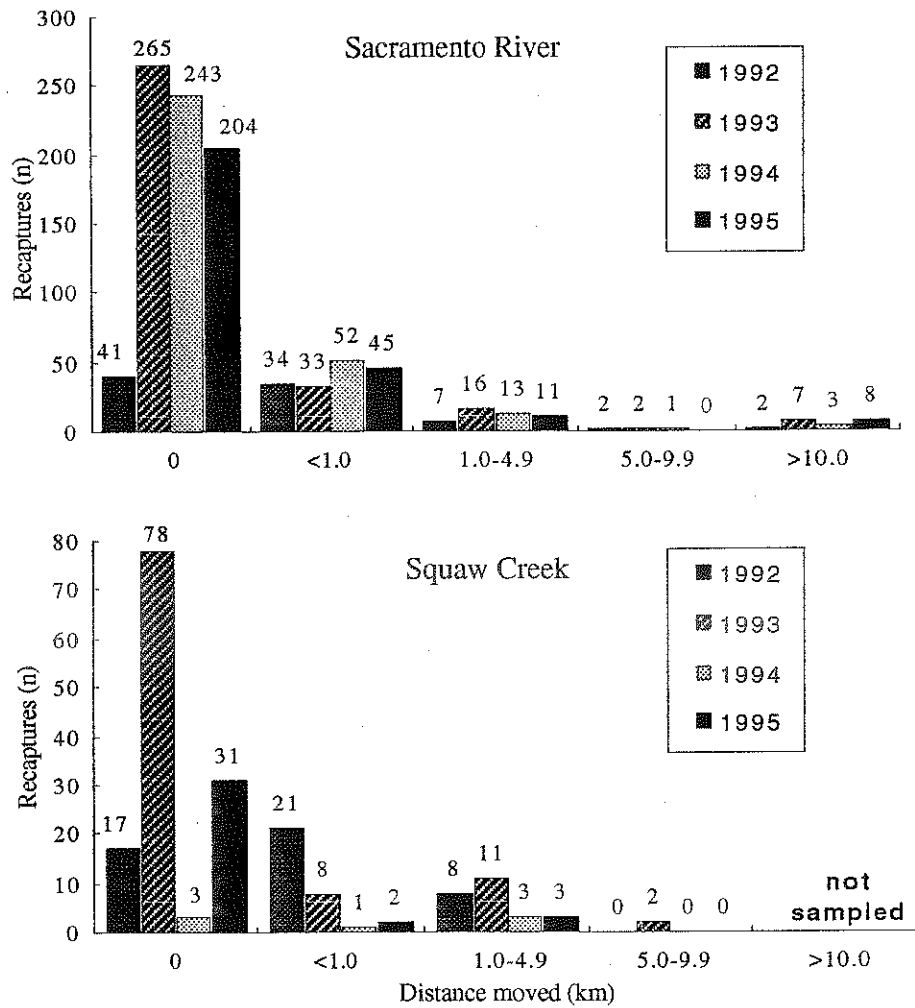


Figure 8 A-B. *Myotis yumanensis* diet (mean percent volume of prey by order) for bats netted or caught in night roosts on the Sacramento River and Squaw Creek, 1991-95. Prey orders which include identified aquatic families are labelled in bold, dark bordered boxes. Trace components labelled in text boxes are less than 1%.

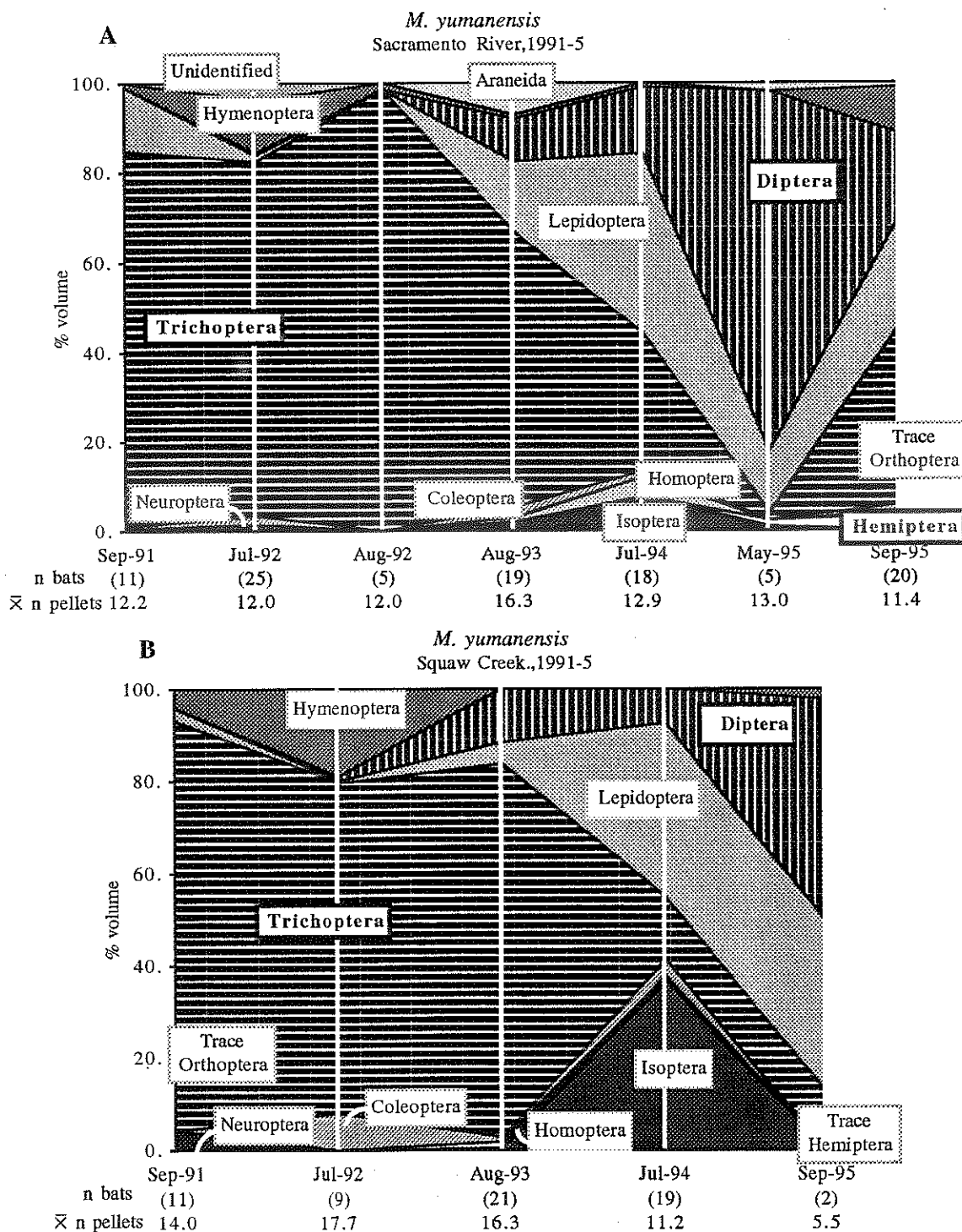


Figure 9 A-B. *Myotis lucifugus* diet (mean percent volume of prey by order) for bats netted or caught in night roosts on the Sacramento River and Squaw Creek, 1991-95. Prey orders which include identified aquatic families are labelled in bold, dark bordered boxes. Trace components labelled in text boxes are less than 1%. The number of bats in each sample interval and the mean number of fecal pellets analysed per bat are shown below the figure.

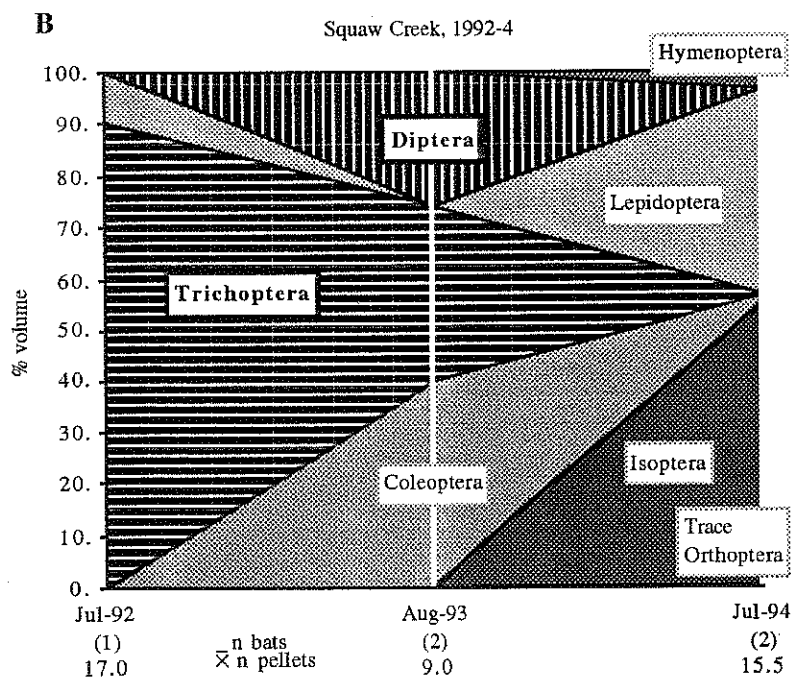
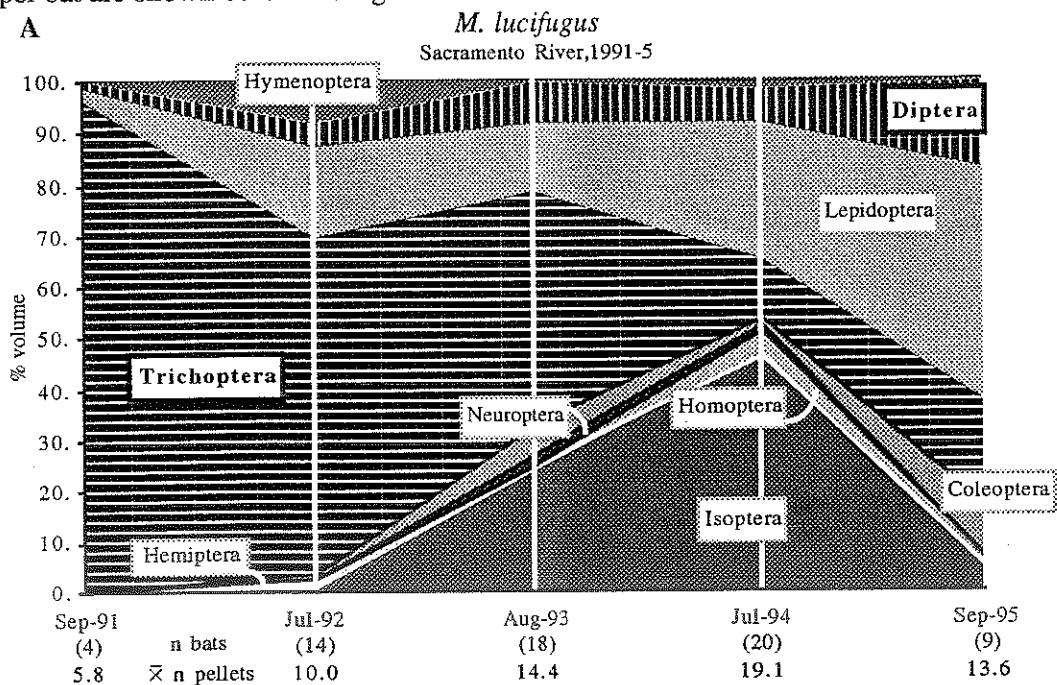


Figure 13 A-C. *Lasiurus cinereus* and *Eptesicus fuscus* diet (mean percent volume of prey by order) for bats netted or caught in night roosts on the Sacramento River and Squaw Creek, 1991-95. Prey orders which include identified aquatic families are labelled in bold, dark bordered boxes. Trace components labelled in text boxes are less than 1%.

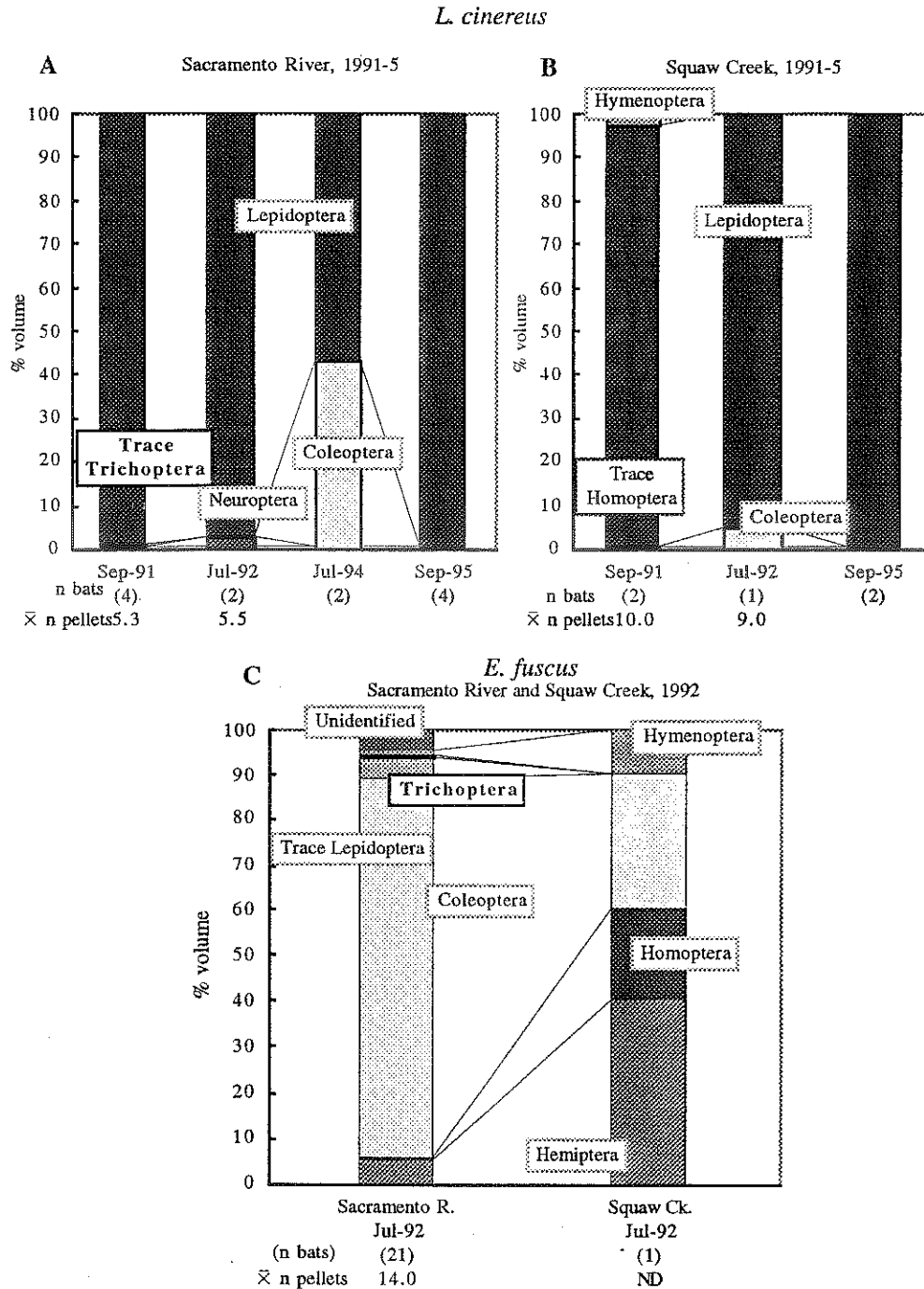


Figure 14 A-B. *Tadarida brasiliensis* and *Myotis volans* diet (mean percent volume of prey by order) for bats netted or caught in night roosts on the Sacramento River and Squaw Creek, 1991-95. Prey orders which include identified aquatic families are labelled in bold, dark bordered boxes. Trace components labelled in text boxes are less than 1%.

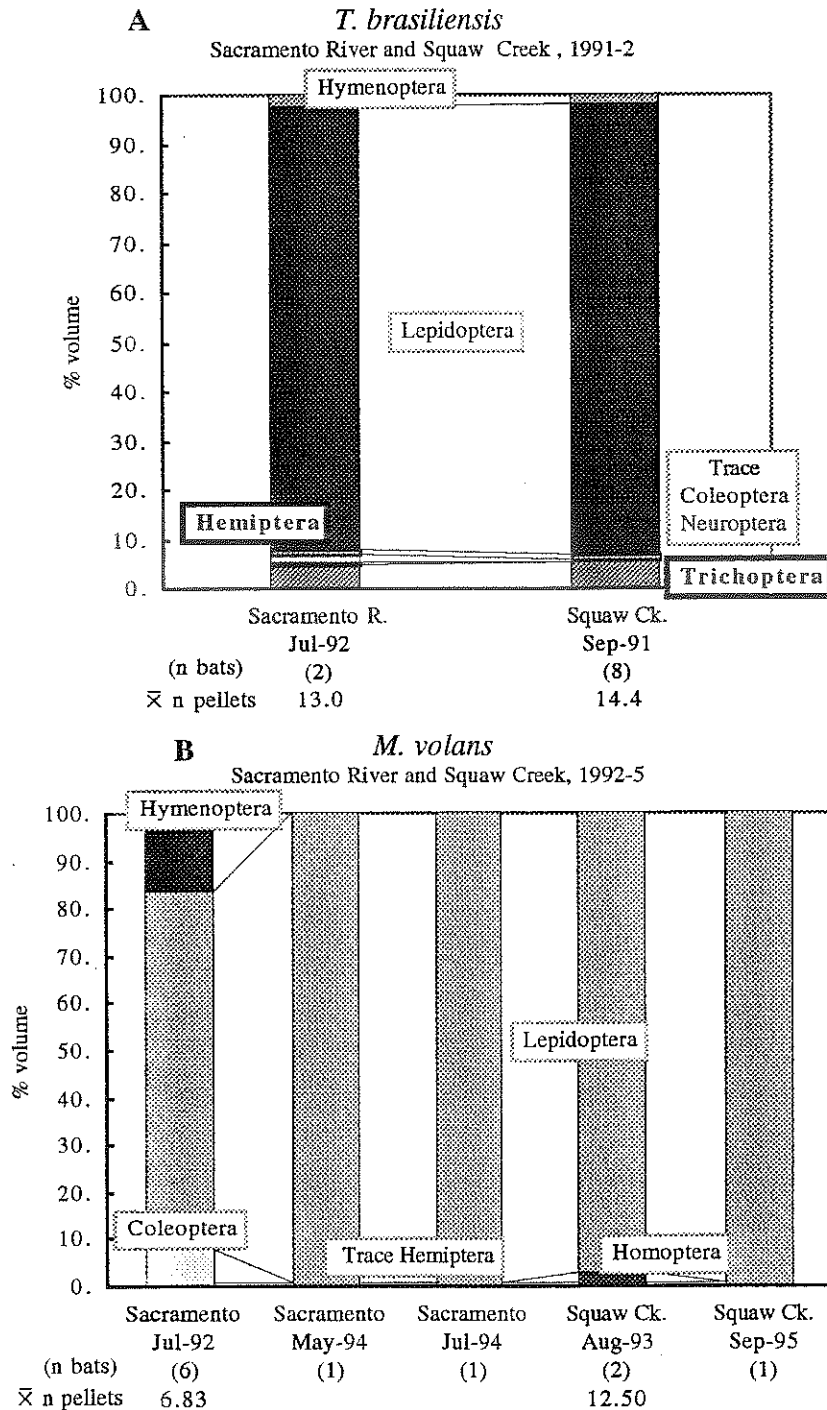


Figure 15. *Myotis evotis* diet (mean percent volume of prey by order) for bats netted or caught in night roosts on the Sacramento River and Squaw Creek, 1991-92. Prey orders which include identified aquatic families are labelled in bold, dark bordered boxes. Trace components labelled in text boxes are less than 1%.

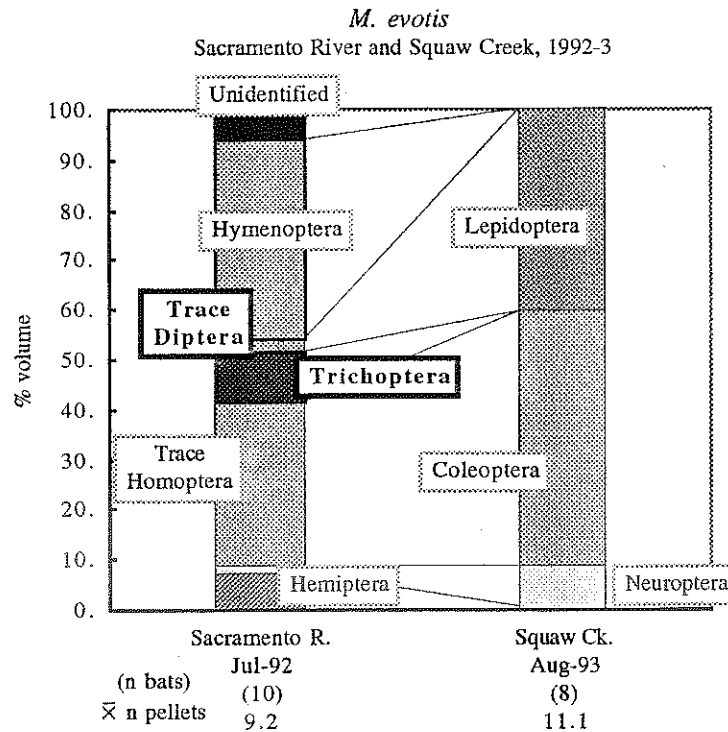


Figure 16 A-D. *Myotis yumanensis* diet (percent volume of prey by order) for pooled bats at a night roost site or guano accumulations at roosts on the Sacramento River, Squaw Creek and Davis Rd., Big Bend, Tehama Co. 1992. Prey orders which include identified aquatic families are labelled in bold, dark bordered boxes. Percentages are means from fifty fecal pellets per site.

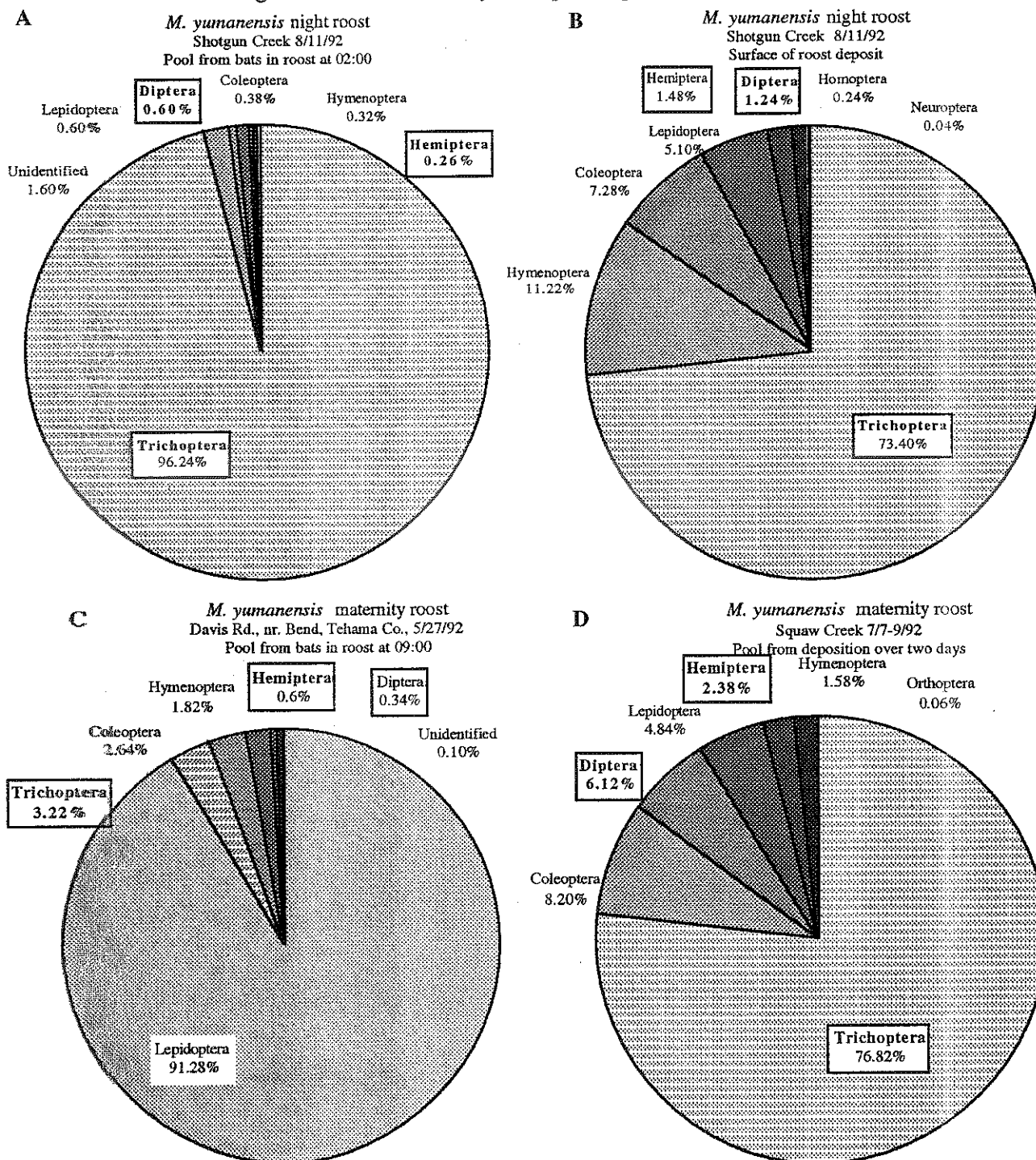


Figure 17 A-C. *Corynorhinus townsendii* and *Eptesicus fuscus* diet (percent volume of prey by order) for guano accumulations at roosts along the Sacramento River corridor 1991-2. Prey orders which include identified aquatic families are labelled in bold, dark bordered boxes. Percentages are means from fifty fecal pellets per site, unless noted.

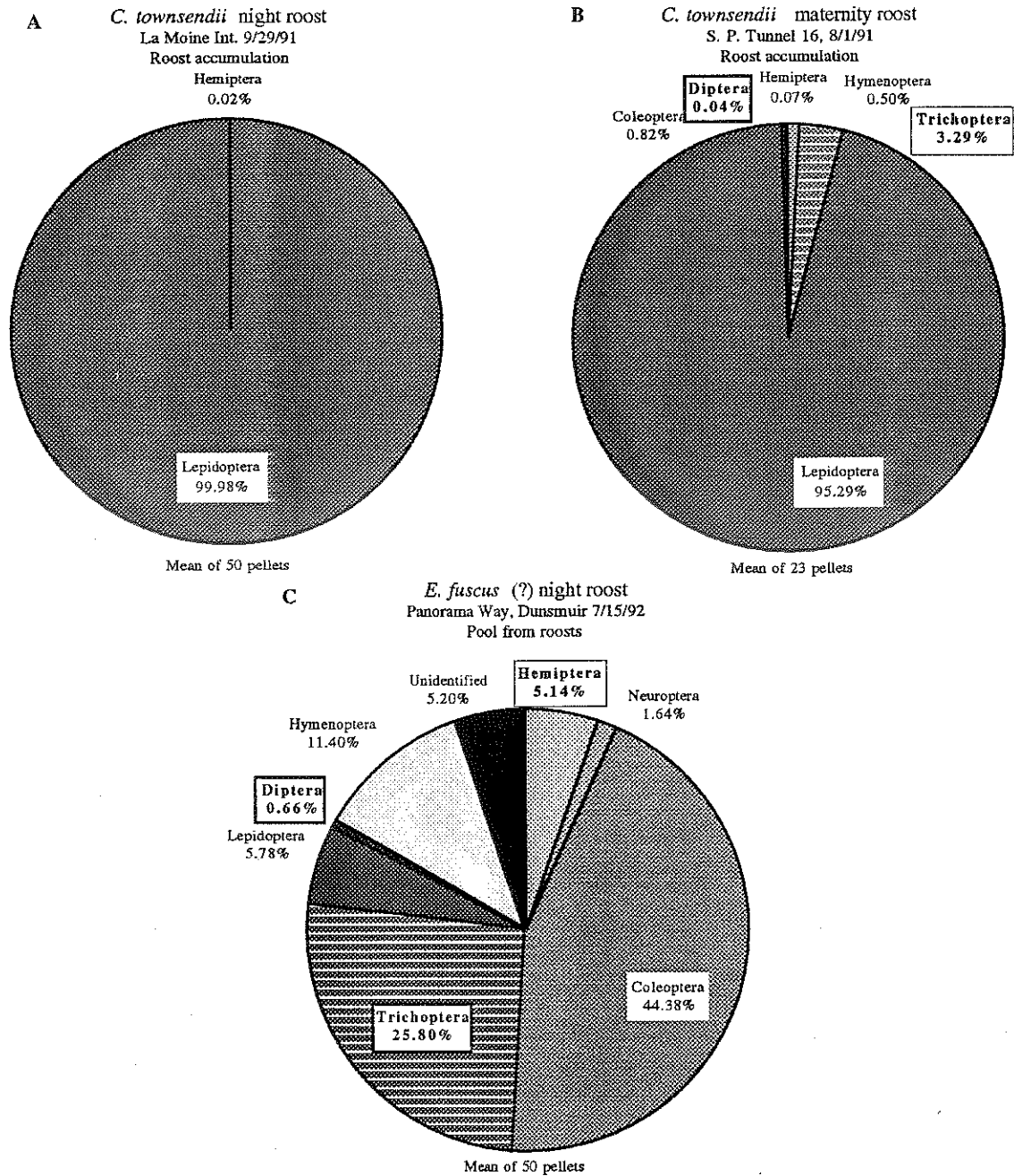


Figure 18. Bat activity at Sacramento River observation sites, Aug-Sept 1991 and 1992. Points are means of three one minute counts

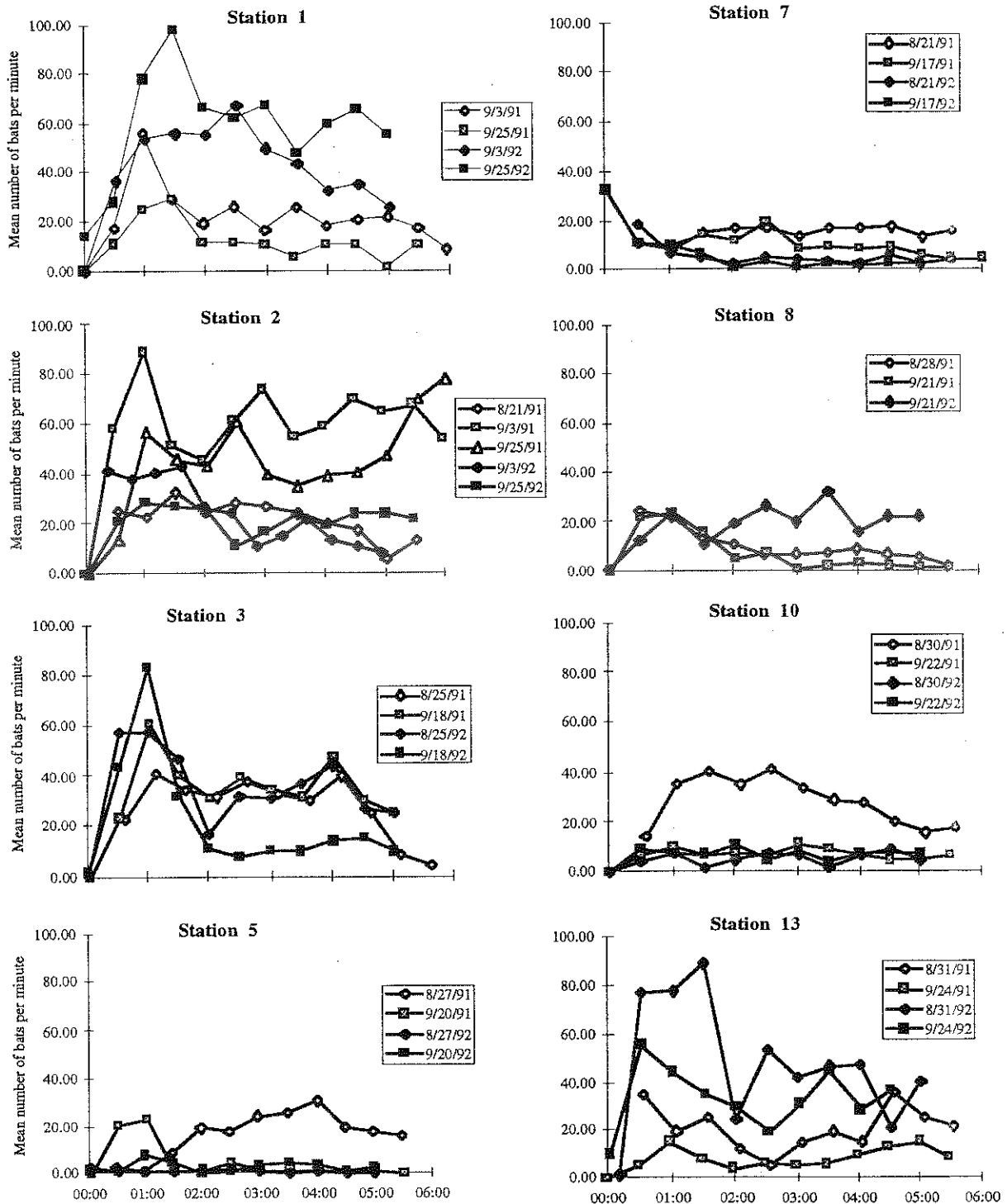


Figure 19. Bat activity counts at Squaw Creek observation sites, Aug-Sept 1991-1992. Points are means of three one minute counts.

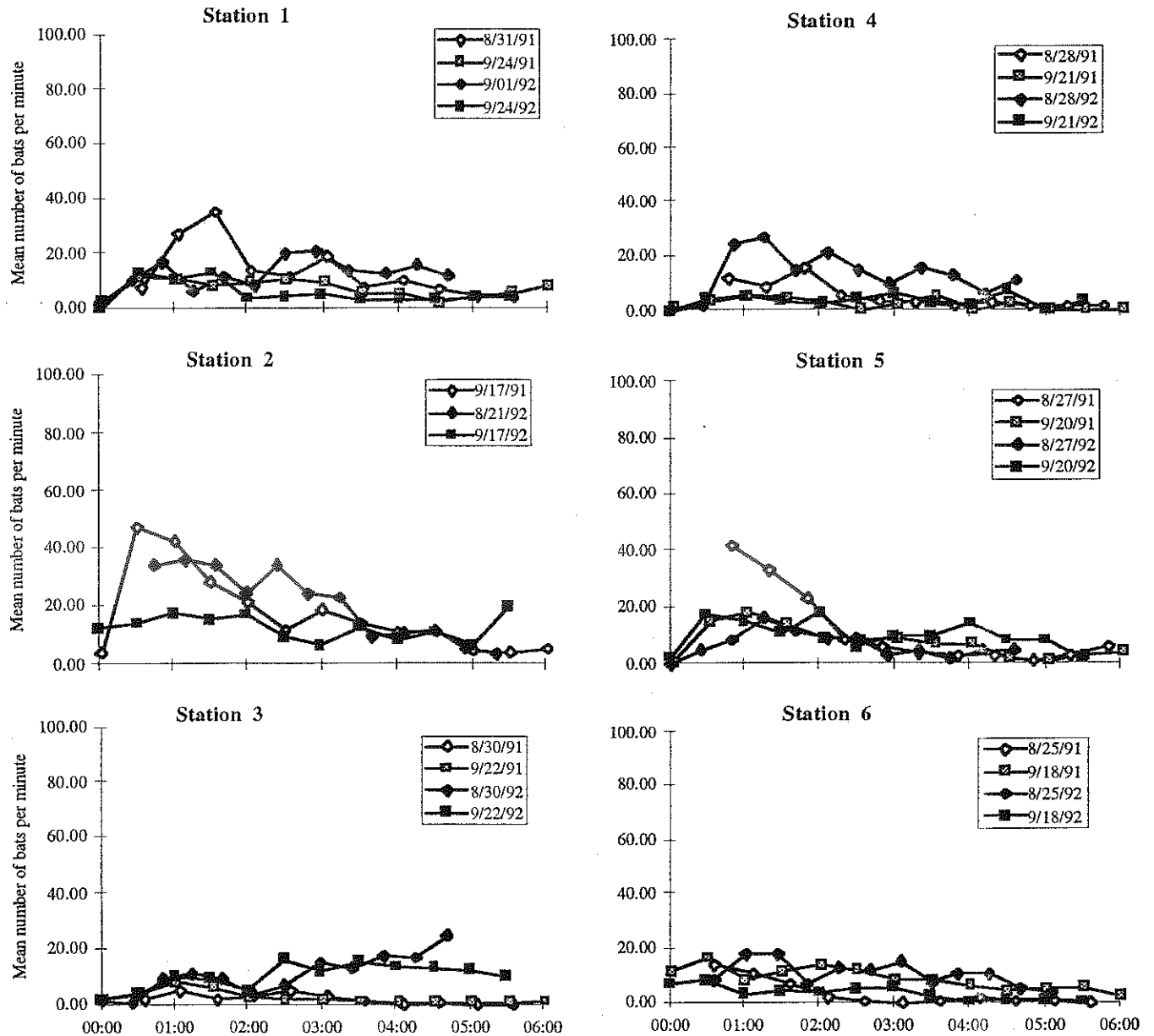


Figure 20. Insect activity counts at Sacramento River observation sites, Aug-Sept 1991-1992. Points are means of three one minute counts.

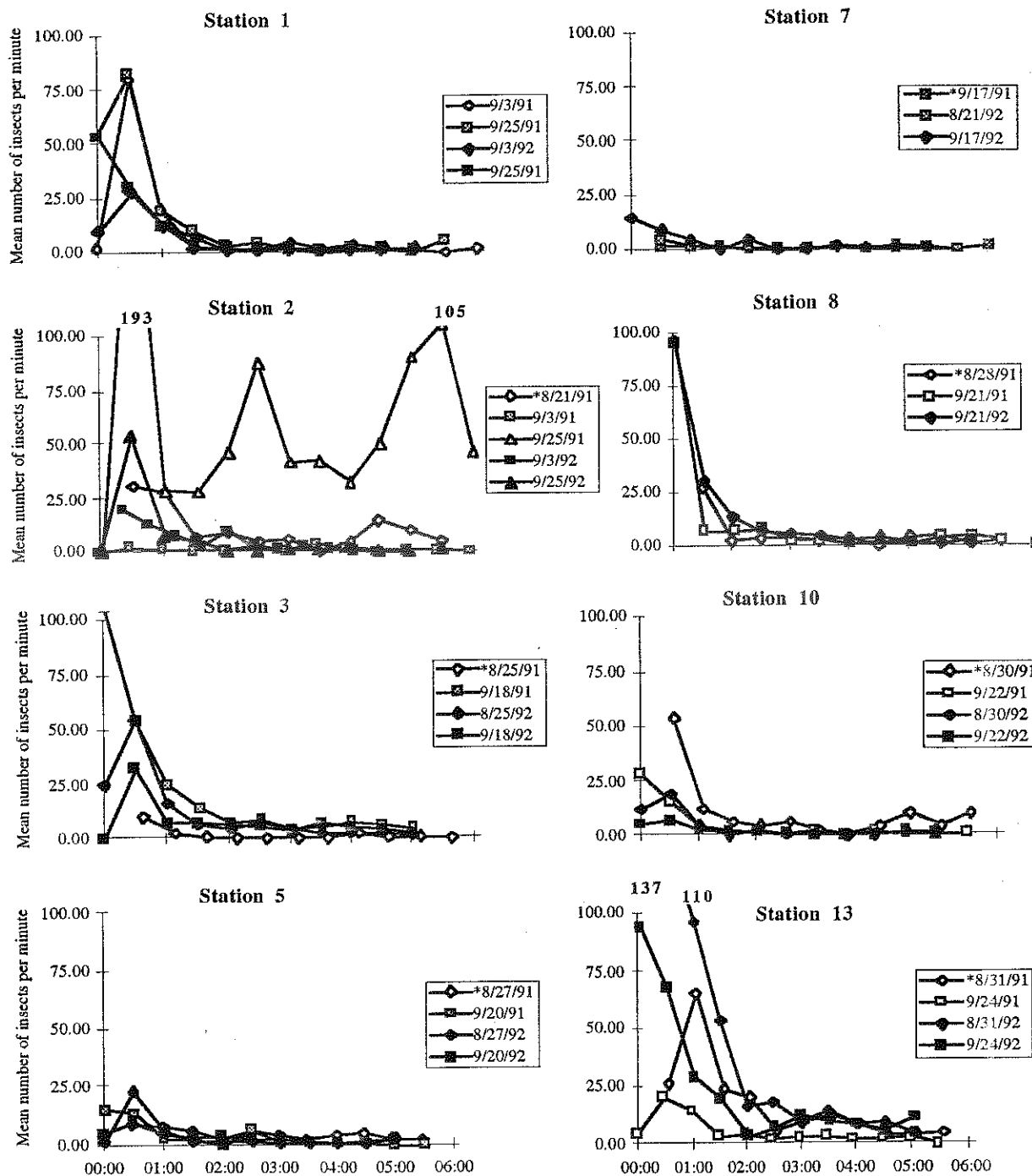


Figure 21. Insect activity counts at Squaw Creek observation sites, Aug-Sept 1991-1992. Points are means of three one minute counts.

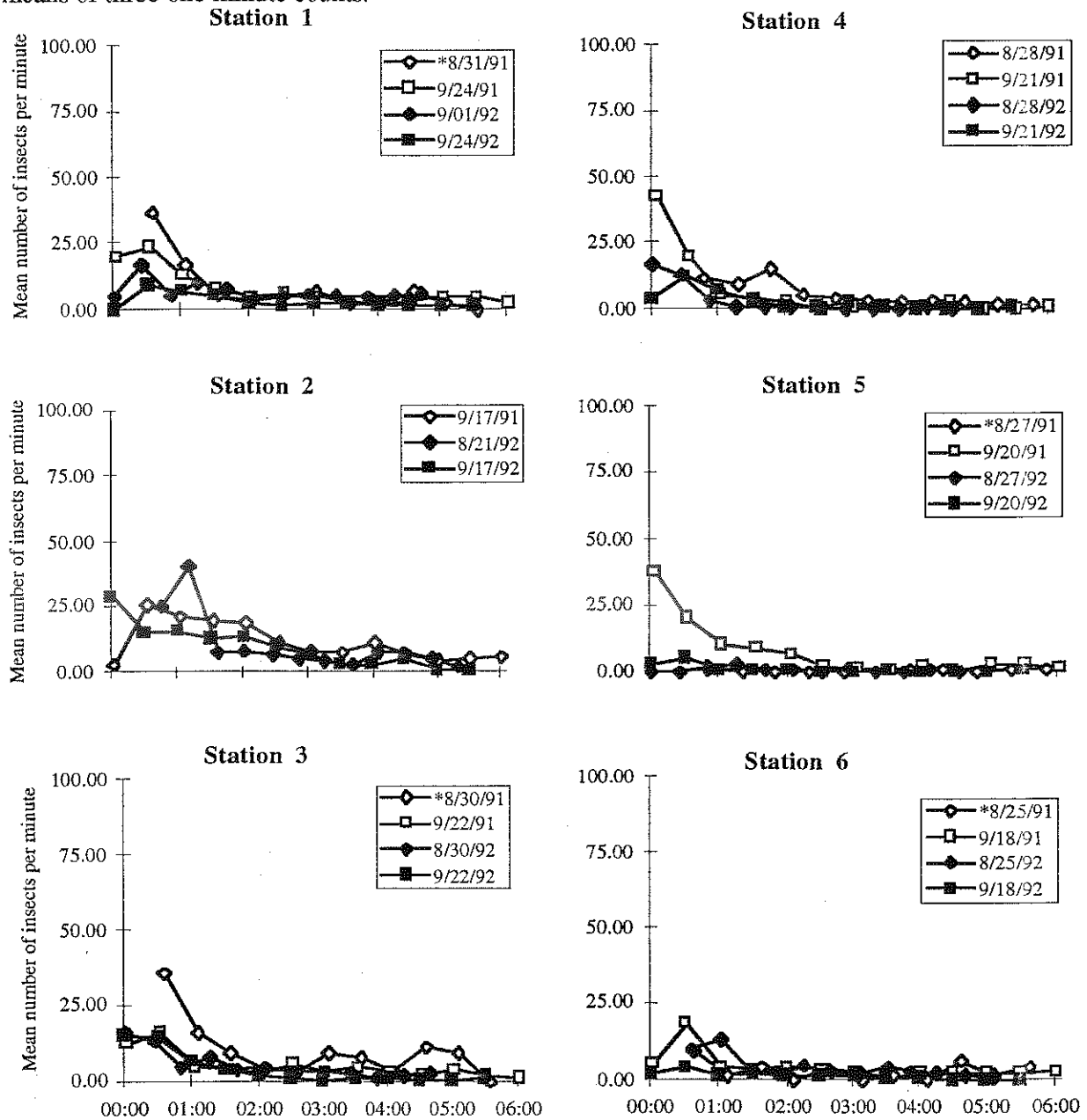


Figure 22. Air temperature at Sacramento River observation sites, Aug-Sept 1991-1992.

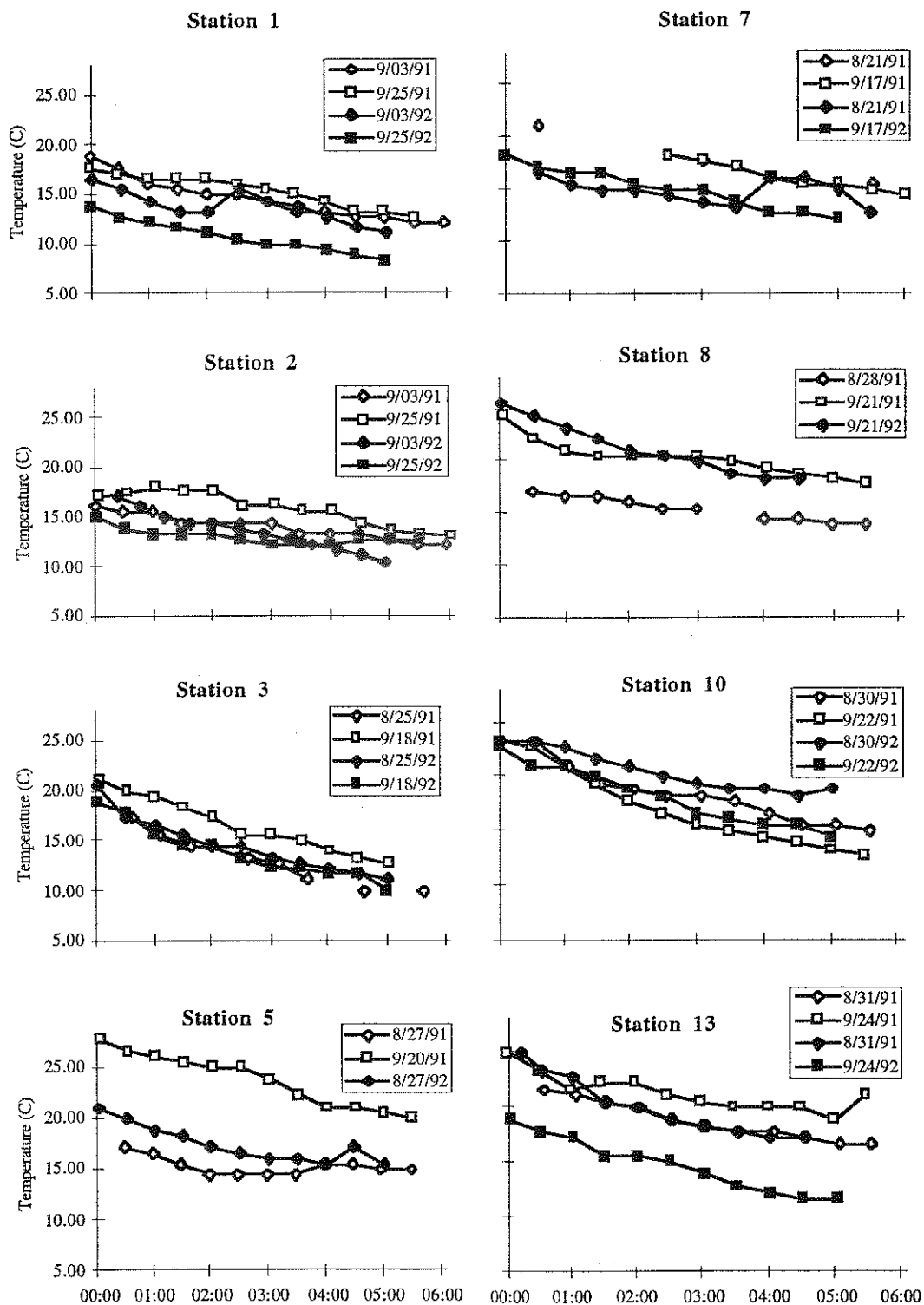


Figure 23. Air temperature at Squaw Creek observation sites, Aug-Sept 1991-1992.

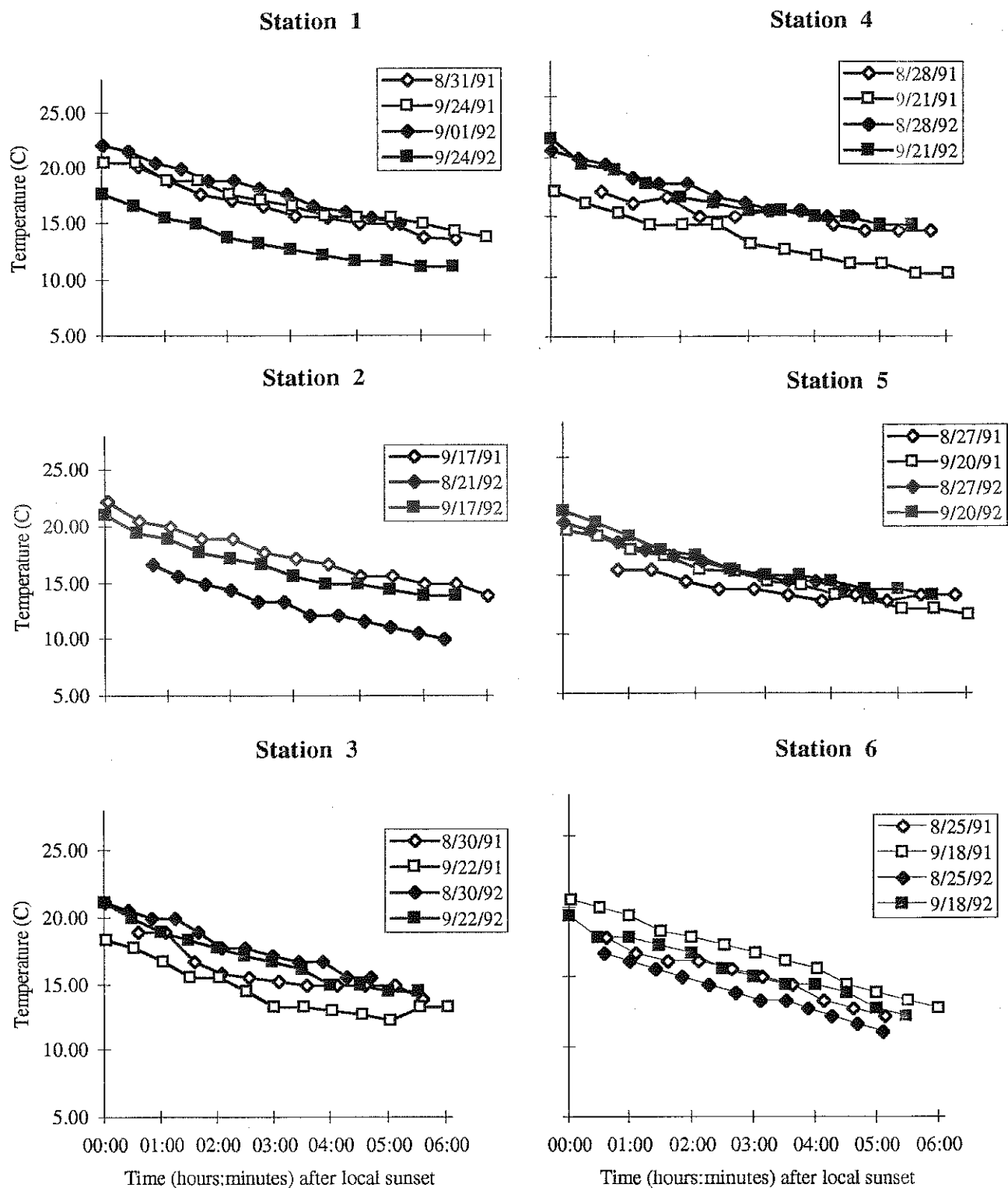


Figure 24. Box plots with median (notch shows 95% confidence interval) $\pm 25\%$ and $\pm 40\%$ of time from sunset to 50% (A) or 75% (B) of cumulative bat activity at observation stations grouped by drainage and sampling year, 1991-1992.

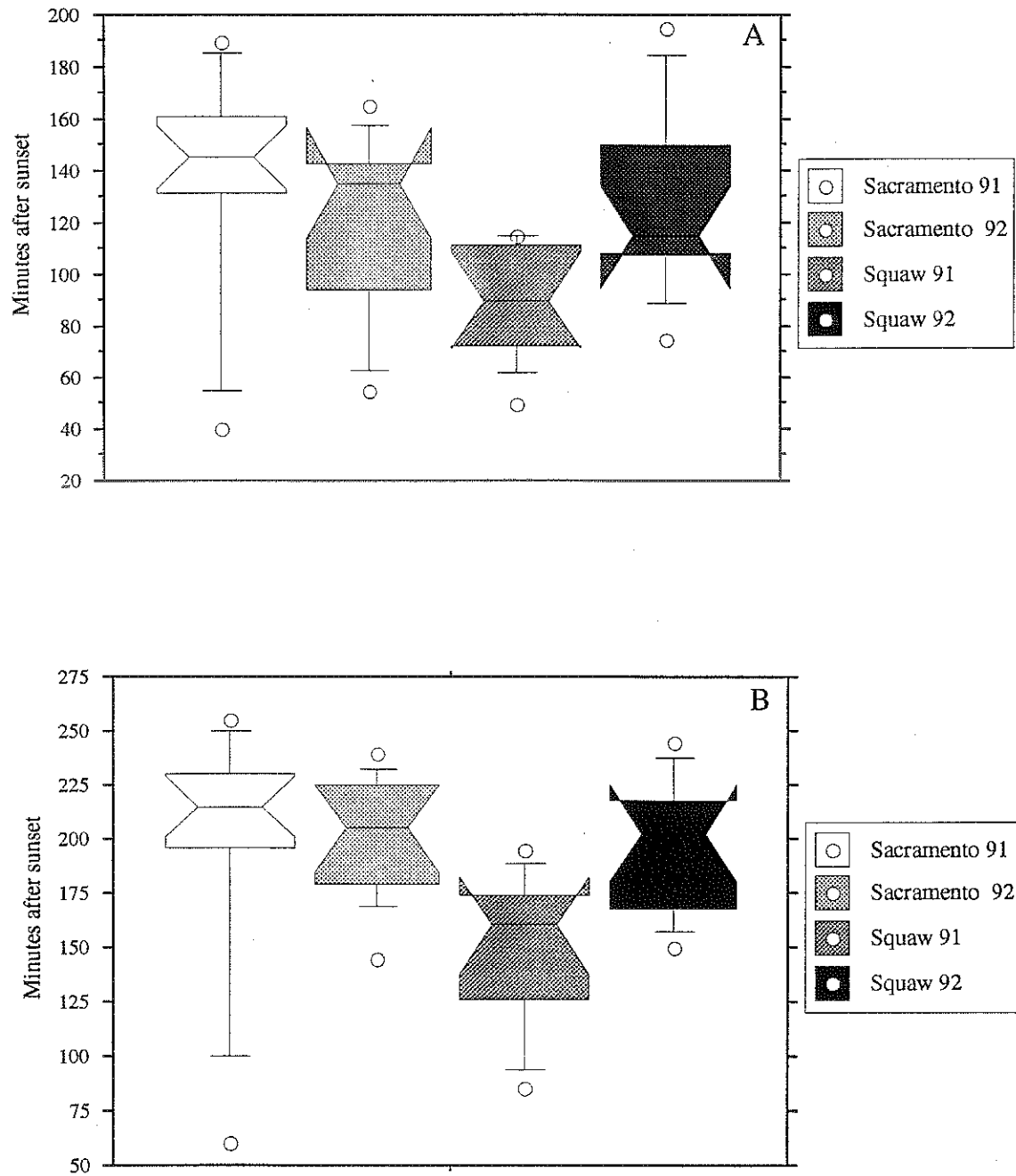


Figure 25 A-G. Number of arthropods on sticky traps by drainage, station and year, 1991-1992.

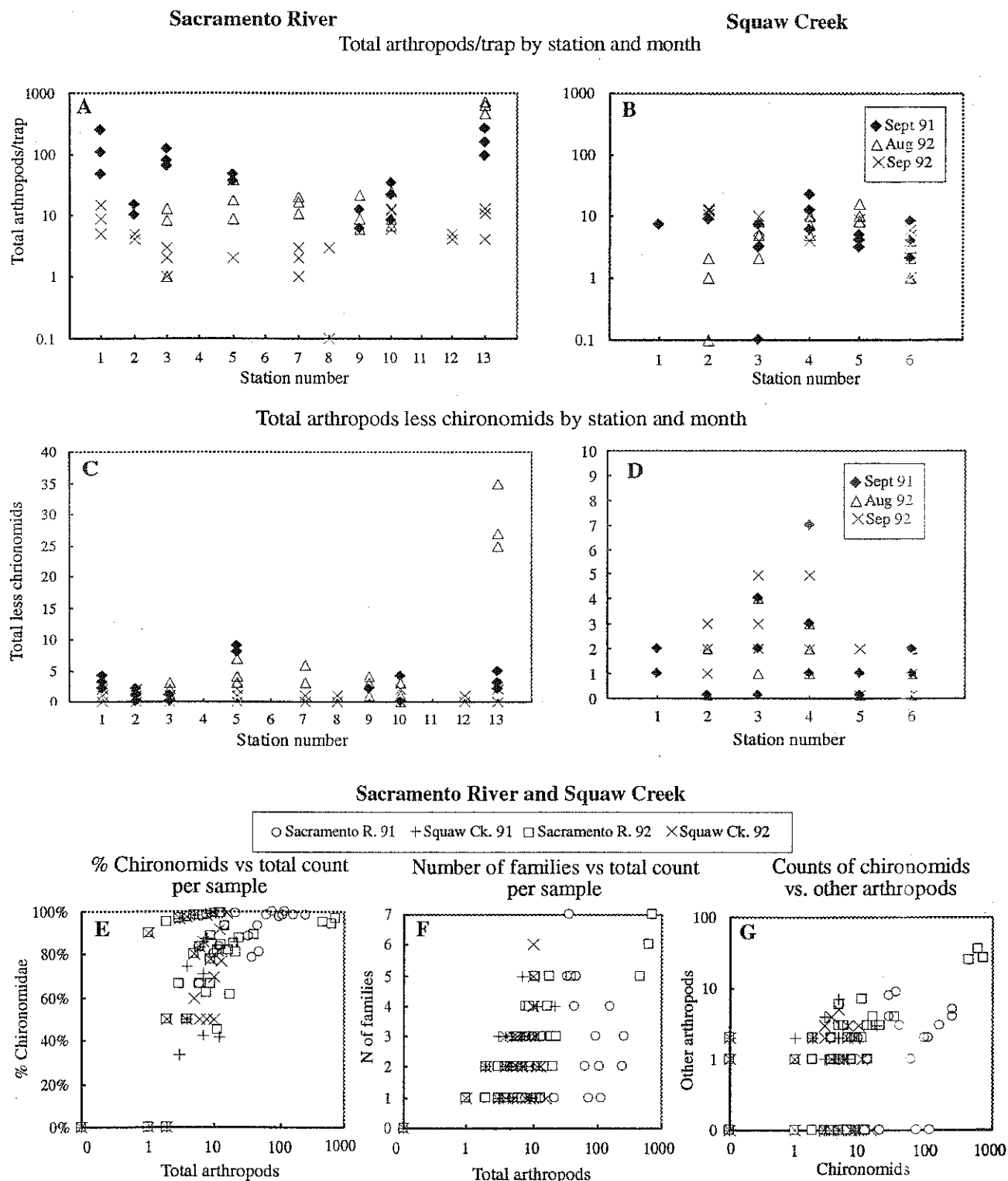


Figure 26. Summaries of transect observations on upper Sacramento River and Squaw Creek, 1991-1992 (mbat is mean of three counts. Error bars are ± 1 standard error).

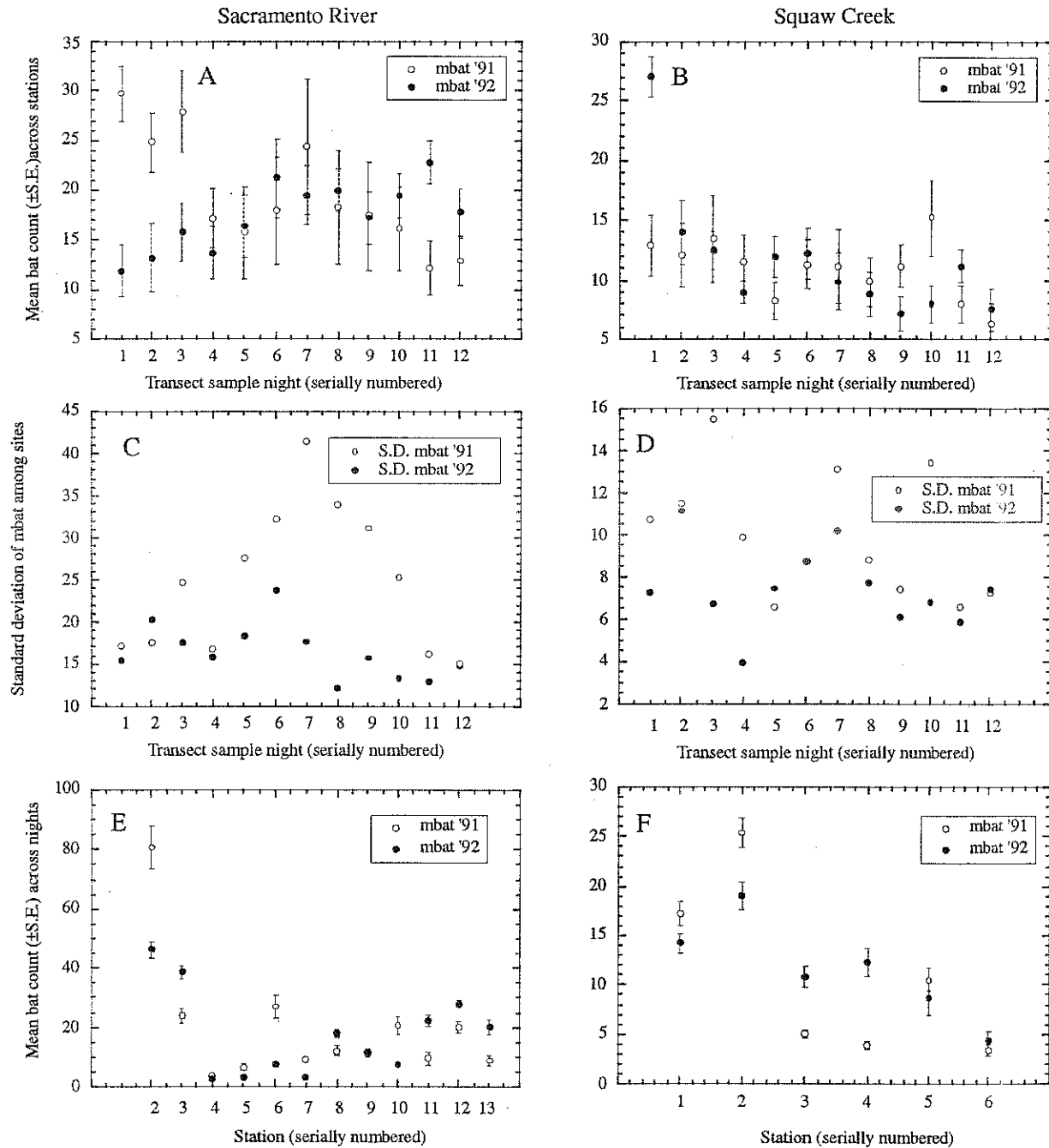
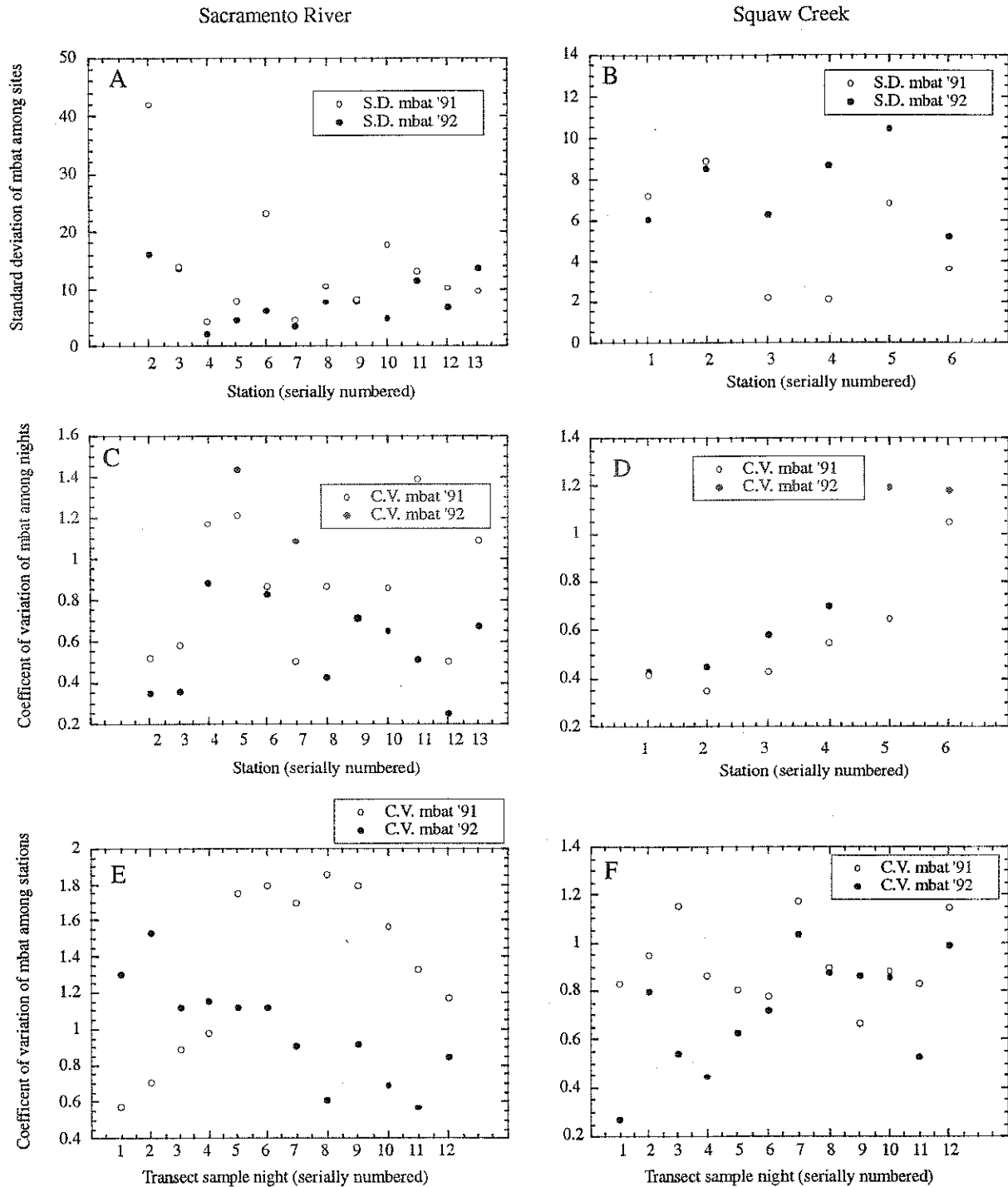


Figure 27. Summaries of transect observations on upper Sacramento River and Squaw Creek, 1991-1992 (mbat is mean of three counts. Error bars are ± 1 standard error).



road that goes behind a gravel pile and east down towards the river. At the "Y" make a strong turn north and drive 130 ft. Turn east and drop down to the railroad tracks and south along the tracks for 60 ft. The observation point is on the east side of the tracks, 62 ft. from the water's edge. The target is 84 °, 162 ft. across the river.

Station 10: Take Pollard Flat exit east. Turn north onto frontage road and drive 0.7 miles to a green welded pipe gate east side of road. Drive east on dirt road 0.55 miles down to a green bridge that crosses the river. The observation point is located just west of the bridge on the south side of the road, 46 ft. from the water's edge. The target is 206 °, 140 ft. cross river.

Station 11: Take LaMoine exit west off I-5, 0.4 miles. Turn east onto dirt road under freeway north along railroad tracks till road ends (next to rock slide detector fence). Park and hike north along east side of tracks approximately 40 ft. Observation station is located on the east side of tracks, 35 ft. from the water's edge. The target is 48 °, 172 ft. upstream.

Station 12: Take Volmers exit east off I-5 to McCardle Flat frontage road. Drive north on McCardle Flat road 1.1 miles to a dirt road that turns east towards the river and railroad tracks. Drive 0.2 miles on the dirt road to a "T" intersection and turn north for 0.65 miles to a "Y" intersection. At the "Y" intersection take the eastern most road that parallels the river for 0.2 miles. The observation point is located on the east side of the road, 42 ft. from the water's edge. The target is 100 °, 152 ft. upstream.

Station 13: Take Vollmers exit west off I-5 to Fender Ferry Road (34N17). Turn left onto Fender Ferry (dirt road) and drive east for 0.95 miles crossing over railroad tracks and wood bridge. The observation point is located on the eastern end of the wood bridge, on the downstream side of the road, by a black and yellow road marker, 196 ft. up from water's edge. The target is 189 °, 310 ft. cross river just downstream of where Dog Creek enters the Sacramento.

Squaw Creek

Compiled from R. Breshears 1991 and M.E. Colberg 1992 field notes again with some redescription from R. M. Miller.

Station 1: 2.1 miles down stream from Squaw Creek bridge. As the road and creek bend to the west, the observation point is located on the west side of the road (opposite a 10 in. fallen log) on a rock outcrop 12 in. below road surface and extending 2 ft. out from road. This point is 60 ft. above the waters edge. The target is at 42 °, 145 ft. upstream on a boulder in the middle of a pool.

Station 2: 0.85 miles down stream from Squaw Creek bridge or 1.25 miles up stream from Stationation 1. The observation point is located on the west side of road on a 12 x 18 in. rock. The target is 240 °, 205 ft. upstream on a 4 ft. wide boulder, west bank of pool.

Station 3: 0.35 miles upstream from Squaw Creek bridge or 1.20 miles upstream from Stationation 2. The observation point is located on the west side of road, on the butt end of a 4 ft. DBH fallen log. The target is located 230 °, 140 ft downstream across creek on a large flat boulder.

Station 4: 1.8 miles up stream from Squaw Creek bridge or 1.3 miles up stream from Station 3. The observation station is located on the west side of road down in a flattened pull out area, by a 4 ft. galvanized pipe cable crossing. The observation marker is under the cable crossing on a boulder. The target is 210 °, 93 ft downstream on a boulder at the base of an alder tree.

Station 5: 4.0 miles up stream from Squaw Creek bridge or 2.2 miles up stream from Station 4. Turn left onto logging road and park. Hike down the dirt road through the field on the Kelly Ranch property to

Appendix 1

Location of bat observation stations

Sacramento River

(Directions and measurements to observation and target points were taken from P. Pridmore 1991 notes with some redescription from R. Miller)

Station 1: Exit off I-5 onto Hwy. 89 southeast to Azalea Ave. On Azalea drive 1.2 miles to Cantara Rd. Turn onto Cantara Rd. and drive 1.05 miles to the second large pull-out along the river. The observation point is on a large flat rock 7 ft. from the water's edge. The target is 238 ° 162 ft across pool.

Station 2: Exit off I-5 west onto Dunsmuir/Siskiyou Ave. Drive).2 miles to Prospect Ave. Turn west onto Prospect Ave. toward the fishing access 0.4 miles. The observation point is located where the road enters the river, on the downstream side, 7 ft. from the water's edge. The target is 83 ° 341 ft. upstream.

Station 3: Exit off I-5 onto Soda Creek Rd. exit, drive east 0.3 miles down towards the river. Just before the river bridge turn south onto dirt road that parallels the river on the west bank for 0.2 miles. At that point there is a pine tree with a "No Campfire" sign posted. The observation point is at the base of this tree, 35 ft. up from the water's edge. The target is 333 ° , 249 ft upstream.

Station 4: Take the Castella exit off I-5 east toward the Castle Crag State Park picnic area to Frontage Rd. Drive north 0.2 miles on Frontage Rd. to Riverside Rd. On Riverside Rd. drive 0.25 miles north to the Castle Crag picnic area. Turn into the picnic area and drive to siteation 13 and park near the garbage cans. Walk down toward the river to a sand/concrete observation platform. The observation point is located on the downstream side of the platform 25 ft. from the water's edge. The target is 293 ° , 103 ft. downstream.

Station 5: Take the Castella exit off I-5 east toward the Castle Crag State Park picnic area to Frontage Rd. Turn south onto Frontage Rd. for 0.7 miles. Turn south again just past the railroad tracks, onto gravel road which parallels the tracks for 0.25 miles. The observation point is on the river side of the road, 30 ft up from the river's edge. The target is 75 ° , 128 ft. upstream.

Station 6: From I-5 take the Conant exit east for 0.15 miles. Drop off the pavement onto a dirt road towards the railroad tracks. Drive south 0.2 miles until you come to a small silver building. The observation point is located on the northeast corner of the building, 85 ft from the river's edge. The target is 229 ° , 196 ft. across river.

Station 7: Take Sims Rd. exit off I-5. Drive east 0.7 miles on Sims Rd. down toward the river. Cross over the railroad tracks and the river to parking area by the silver footbridge. The observation point is on the east side of the river 18 ft. downstream from the footbridge, 27 ft. from the water's edge. The target is 281 ° , 103 ft. downstream.

Station 8: If you are south bound on I-5 take the Gibson Rd. exit and cross over the freeway to the north bound lane of I-5. From where Gibson onramp intersects I-5 drive north 1.3 miles on I-5 to the end of the railing on the east side of the freeway. At the end of the railing turn east onto a dirt road leading down to the river and a train trestle. On the west side of the tracks there are two telegraph poles. The observation point is located between these two poles on a 14 in. piece of rebar, 87 ft. up from the water's edge. The target is 230 ° , 249 ft. cross river on a boulder.

Station 9: Drive north on I-5 1.9 miles from where Gibson Rd. onramp intersects I-5, or 0.6 miles north of Station 8. Turn east off freeway (before you cross Shotgun Creek) and parallel to the freeway to a dirt

Squaw Creek. The observation point is located on a concrete and rock dam on a boulder. The target is located 55 °, 183 ft. up stream on a flat boulder at the base of a willow tree.

Station 6: 4.4 miles up stream from Squaw Creek bridge, past Bill's Creek, turn left onto road 35N07. Drive 0.6 miles and turn left to Madrone Campground. At "T" intersection turn right. The observation point is located along the road on a 4 in. concrete pillar, 16 in. above ground, opposite campsite #6 and bathrooms. The target is located 294 °, 128 ft.