Distribution of Adult Aquatic Insects in the Cosumnes River Floodplain

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Abstract Emerged aquatic insects can play a major role in terrestrial food webs. Often the location of these insects affects the foraging behavior of terrestrial insectivores such as birds and bats. Not only the location of emergence, but also the patterns of insect dispersal are relevant in interpreting energy flows from aquatic insects to terrestrial insectivores. One calendar year of emergence trapping at the Cosumnes River floodplain—a Nature Conservancy restoration site in California's Central Valley—has yielded a set of insect emergence data. However, little is known about the distribution of these insects by wind or flight. This study addresses the aerial distribution of emerged aquatic insects at the Cosumnes floodplain using "sticky" traps and compares this distribution to the emergence levels of various sites on the floodplain. Results showed that sampling date, trap height, site, and distance from water all had significant effects on insect abundance, but only date and height significantly affected insect biomass. Sampling date had the most significant effect on abundance and biomass. Moreover, many interactions between the variables had significant effects on abundance and biomass. This suggests that further study is needed in order to understand the true impact of each variable on insect distribution, especially in the face of temporal variability. Understanding the factors that affect the distribution of insects in the Cosumnes floodplain may aid scientists in interpreting insectivore foraging behavior and help the Nature Conservancy to make management decisions that will help insectivore species targeted in reserve restoration efforts to thrive.

Introduction

The distribution of adult aquatic insects has been shown to affect the distribution and foraging behavior of insectivores, including bats and birds (Maurer and Whitmore 1981, Gray 1993, Power and Rainey 2000, Iwata *et al*. 2003). As such, the distribution of these insects can play a major role in the trophic interactions of the ecosystem as a whole (Power and Rainey 2000). Many factors are known to affect the distribution of emerged aquatic insects. Insects may arrive in a different spot from which they emerge by flying or crawling—so-called active distribution (Flecker and Allan 1988, Jackson and Resh 1989). Insects may also move to a new location through passive distribution, such as being blown by the wind (Pasek 1988, Pedgley 1990). Because of distribution, emergence trap data on insect community composition may not accurately reflect the flying aquatic insect community in the surrounding airspace.

Studies have often investigated the lateral flux of aquatic insects in lower-order, mountain streams (Jackson and Resh 1989, Power and Rainey 2000). These low-order mountain streams frequently have steep banks and dense vegetation, which tend to decrease average wind speed (Jackson and Resh 1989). Thus many of these studies considered wind a negligible factor in insect distribution (Jackson and Resh 1989, Power and Rainey 2000).

Few studies have attempted to look at aquatic insect dispersal in high-order stream floodplains. In terms of active distribution, flat terrain can influence the distance of flight away from the stream (Jackson and Resh 1989, Power and Rainey 2000). In terms of passive distribution, the flat terrain and generally sparse vegetation of many floodplains can make wind a major factor in insect distribution (Pasek 1988, Pedgley 1990, Power and Rainey 2000, Whitaker *et al.* 2000). Some studies have investigated the effect of wind speed and vegetation height on insect distribution, usually in locations other than floodplains (Pasek 1988, Pedgley 1990, Whitaker *et al.* 2000, Harrison and Harris 2002). There is often a net movement of insects from areas with shorter vegetation and higher wind speeds to areas with taller vegetation and lower wind speeds (Pasek 1988, Whitaker *et al.* 2000, Harrison and Harris 2002).

The floodplain of California's Cosumnes River consists mostly of flat land and contains much low-lying vegetation (Florsheim and Mount 2002, Clinton 2003, pers. comm.). With a relatively level topography, the floodplain has the potential to exhibit a significant amount of passive insect dispersal (Power and Rainey 2000). The Cosumnes River is the only river on the western slope of California's Sierra Nevada mountain range without a large dam on its main stem (Florsheim and Mount, 2002). As such, many environmental groups are interested in the ecology of the site. In particular, the Nature Conservancy is currently conducting restoration work on the Cosumnes floodplain, which previously consisted of farmland, in order to create a more natural floodplain ecosystem (The Nature Conservancy 1992).

The vegetation in the Cosumnes floodplain consists of patches of two types of forest—cottonwood-willow and valley oak—surrounded by large amounts of open meadow (Florsheim and Mount 2002). Wind speed tends to be higher in the open meadow areas than in the areas with dense vegetation (Clinton 2003, pers. comm.). As a result, there is reason to suspect that wind might affect insect distribution on the Cosumnes floodplain.

Emergence trapping has been conducted on the Cosumnes River since late 2002. The data from this trapping indicate that the open meadow areas of the floodplain tend to produce the most aquatic adults (Power 2003, pers. comm.). However, data from bat detectors at the site show the most bat foraging activity in forested rather than open areas (Rainey 2003, pers. comm.). If all other factors are equal, one would expect the most foraging activity to take place where most insects are located. Since this is not the case at the Cosumnes, it may imply that dispersal after emergence affects the aerial distribution of insects at the site. The distribution of aquatic insects after emergence has not yet been investigated at the Cosumnes River floodplain. A thorough understanding of patterns of adult aquatic insect distribution could aid in interpreting the foraging behavior of local insectivores (Gray 1993, Power and Rainey 2000, Iwata *et al*. 2003).

In addition, the Nature Conservancy is attempting to restore the Cosumnes River site to a natural floodplain ecosystem, replete with birds and bats (The Nature Conservancy 1992). Consequently, understanding how vegetative structure affects the distribution of insects—a major source of food for many birds and bats—will aid in determining which vegetative structures provide an optimal distribution of insects for restoration and management purposes (Maurer and Whitmore 1981, Iwata *et al*. 2003).

Over the course of several months, I investigated the distribution of adult aquatic insects in the Cosumnes River floodplain. I compared the composition of samples from emergence traps to the composition of samples taken simultaneously from nearby transects of Tanglefoot™, sticky traps (Harris and McCafferty 1977). My hypothesis was that the insect abundance and biomass on the sticky traps in the windier meadow areas would be lower than that on the sticky traps in forested areas. I also anticipated that the emergence trap biomass and abundance and the sticky trap biomass and abundance at each site would not depend strongly on each other.

Methods

The study was conducted at the Nature Conservancy's Cosumnes River Preserve, which is located approximately 20 miles south of Sacramento, California. The preserve consists mainly of former farmland that was converted to a floodplain when the Nature Conservancy intentionally breached several levees in the mid 1990s (The Nature Conservancy 1992). Due to the levee breaches, all parts of the floodplain may be intermittently covered with standing water, depending on the extent of flooding.

The floodplain has three major vegetation types—open meadow, cottonwood-willow forest, and valley oak (*Quercus lobata*) forest (Florsheim and Mount 2002). To represent the different vegetation types, four sites within the preserve were sampled (see Fig. 1). The Triangular Pond (TP) is in an open meadow area. The Accidental Forest (AF) site is part of the cottonwood-willow forest, and Wood Duck Slough (WD) is within the valley oak forest. The Channel by Wendell's (WC) site includes the Cosumnes River itself and has mixed vegetation types.

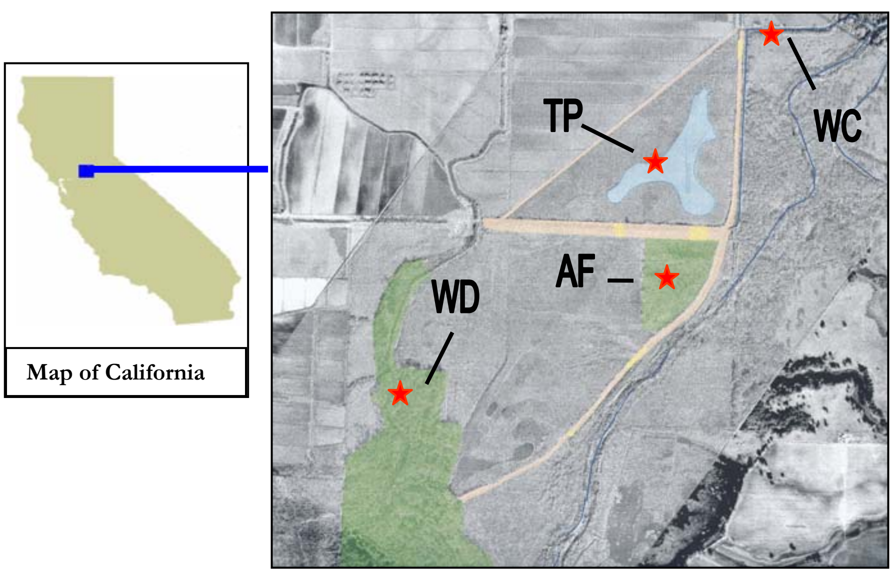

Figure 1. Cosumnes River Preserve, including its location within California. Sample sites are the Triangular Pond (TP), the Accidental Forest (AF), Wood Duck Slough (WD), and the Channel by Wendell's (WC).

Traps using Tanglefoot™ mixture, also known as "sticky traps" (Harris and McCafferty 1977, Flecker and Allan 1988, Jackson and Resh 1989), were placed at each of the four sites. These sticky traps were constructed by spreading a thin layer of Tanglefoot™ onto an 8.5-inch by 11-inch sheet of clear acetate. These acetate sheets were then taped, sticky-side out, in a cylinder around a 1.5-liter plastic water bottle for structure. Holes were drilled in the bottom of these bottles. The bottle traps were then placed axially around pieces of electrical conduit by feeding the conduit pipe through the hole in the bottom of the bottle and then through the bottle's mouth. Two traps were placed on each pole, one at the surface of either the water or ground and the second at a height of 0.9 above the first trap. The electrical conduit was then placed on top of a piece of rebar that had been pounded into the ground for support. Once set up, the traps were retrieved after 24 hours, covered in cellophane for preservation, and taken back to the laboratory for identification.

On each sampling date, one sampling transect was set up at each of the four sites. Each transect consisted of a set of three poles, each with its own set of two traps. On each sampling date at each site, one poles was placed in the water near shore, one was placed approximately five meters inland, and the last pole was placed approximately 30 meters inland, within the surrounding vegetation

The sticky traps were deployed simultaneously with emergence traps. These emergence traps consisted of mesh screening in a dome shape floating on top of the water, covering a surface area of 0.20 m^2. The emergence traps were arranged in two transects of three traps at each of the sites. Each transect consisted of one emergence trap at the shore, one trap at the deepest point reachable in chest-waders, and one trap at half the depth of the deepest point. After 24 hours, the insects in the emergence traps were collected with aspirators, preserved in 70% ethanol, and returned to the lab for identification.

Sampling was conducted twice in early 2004—on the weekends of February 7-8 and March 6-7. After each run, the insects from both the sticky and emergence traps were identified to order in the laboratory. Insects of the order Diptera were also identified to suborder. Each specimen from both types of traps was also measured from its head to the tip of its abdomen for use in biomass calculations. An algorithm was used to approximate biomass based on insect order and length (Sabo *et al.* 2002).

The insect abundance and biomass data were log transformed using base *e* in order to normalize them. ANOVA tests were run on these transformed data in the statistical program JMP IN® (SAS Institute, Inc. 2001) in order to determine whether site or distance from the water had a significant effect on insect biomass or abundance on the sticky traps. In addition, the sticky trap pole over the water at each of the sites was paired with the nearest emergence trap, and an analysis of correlation was conducted to determine the strength of the relationships between emergence and ambient insect abundance and biomass at a site.

Results

Sampling date had a significant effect on the log normalized biomass per trap (ANOVA multi-factor test, $F=129.8612$, $n=48$, $p<0.0001$), as well as the log normalized abundance per trap (ANOVA multi-factor test, $F=354.8214$, $n=48$, $p<0.0001$). Fig. 2 shows that, on average, log normalized biomass and abundance per trap were higher in March than in February.

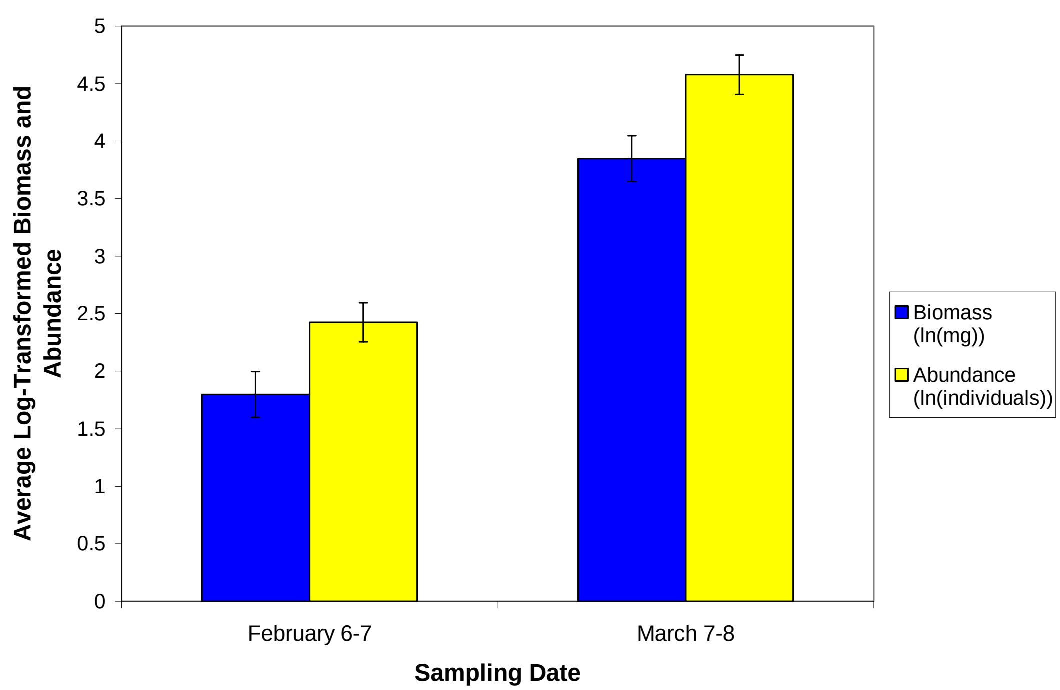

Figure 2. Average log-normalized biomass and abundance per trap by sampling date. Date did significantly influence biomass (ANOVA multi-factor test, F=129.8612, n=48, p<0.0001) and abundance (ANOVA multi-factor test, F=354.8214, n=48, p<0.0001). Bars represent one standard error in each direction.

Height above the surface of the ground or water also had a significant effect on the log normalized biomass per trap (ANOVA multi-factor test, F=14.8646, n=48, p=0.0008). Height also significantly affected the log transformed abundance per trap (ANOVA multi-factor test, F=22.2043, n=48, p<0.0001). As one can see in Fig. 3, the traps closer to the ground or water, on average, had higher abundance and biomass than the traps 0.9 meters above them.

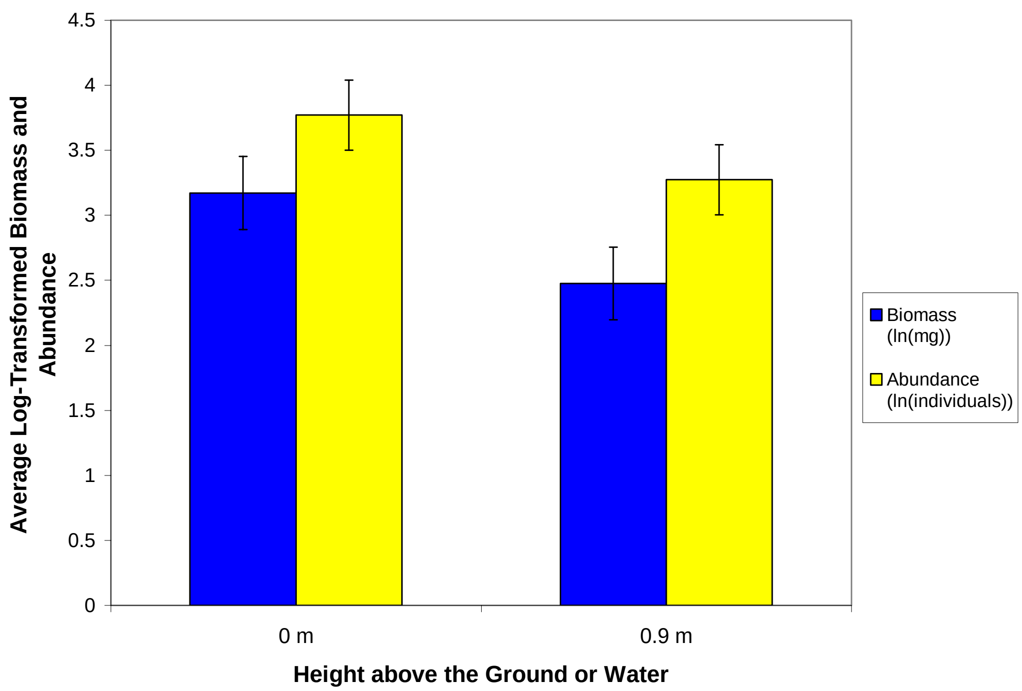

Figure 3. Average log-normalized biomass and abundance per trap versus height above the surface of the ground or water. Height did significantly influence biomass (ANOVA multi-factor test, F=14.8646, n=48, p=0.0008) and abundance (ANOVA multi-factor test, F=22.2043, n=48, p<0.0001). Bars represent one standard error in each direction.

Distance from the water had a significant effect on the log normalized abundance (ANOVA multi-factor test, F=5.3060, n=48, p=0.0127) but not on the log normalized biomass per trap (ANOVA multi-factor test, F=1.2652, n=48, p=0.3011). As evident in Fig. 4, insect abundance was, on average, highest directly over the water, followed by the site farthest from the water, in the vegetation. Biomass tended to taper off moving away from the water.

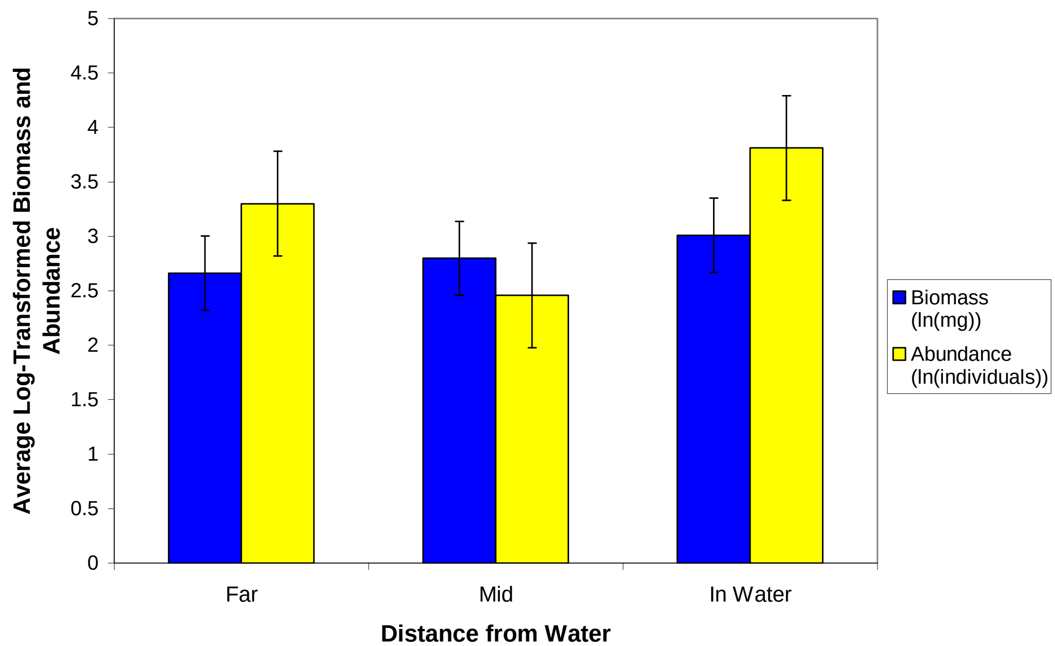

Figure 4. Average log-normalized biomass and abundance per trap versus distance from the water. Distance did significantly influence abundance (ANOVA multi-factor test, F=5.3060, n=48, p=0.0127) but not biomass (ANOVA multi-factor test, F=1.2652, n=48, p=0.3011). Bars represent one standard error in each direction.

Likewise, site did not have a significant effect on biomass (ANOVA multi-factor test, F=0.5613, n=48, p=0.6459). However, site did have a significant effect on log normalized abundance per trap (ANOVA multi-factor test, F=8.2947, n=48, p=0.0006). Fig. 5 shows the relationship between average biomass and abundance per trap and site. Though the results for biomass were not statistically significant and the results for abundance were, both show the same pattern, with the insect load increasing among the sites in the order WD, WC, TP, and AF.

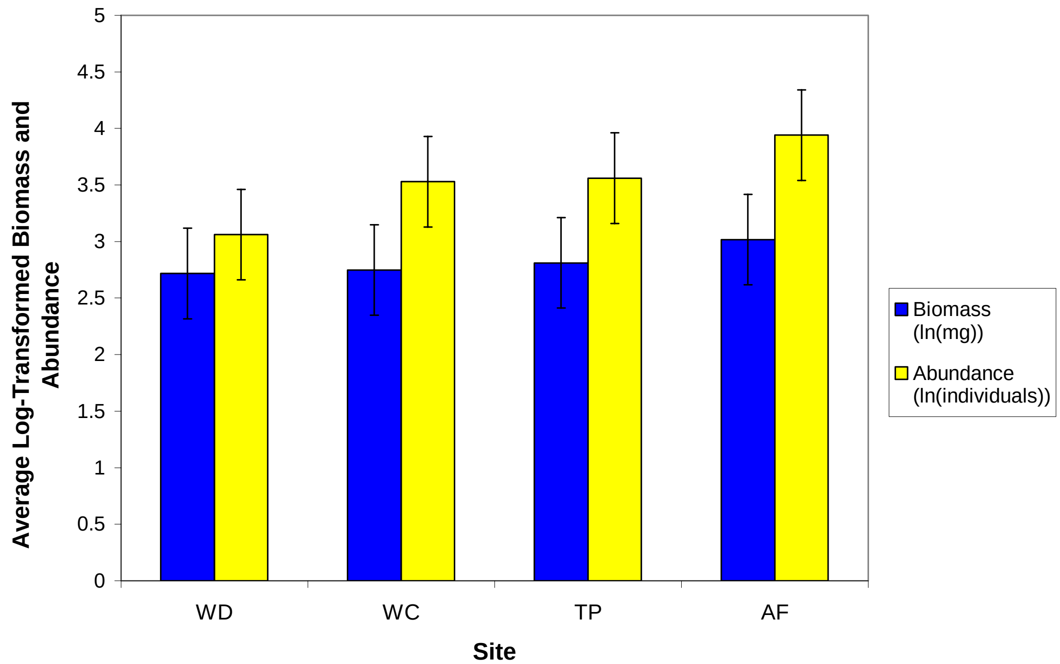

Figure 5. Average log-normalized biomass and abundance per trap by site. Site did significantly influence abundance (ANOVA multi-factor test, F=8.2947, n=48, p=0.0006) but not biomass (ANOVA multi-factor test, F=0.5613, n=48, p=0.6459). Bars represent one standard error in each direction.

A number of interactions between variables also had significant effects on the log normalized biomass and abundance per trap. For biomass, the interactions between distance and site (ANOVA multi-factor test, F=2.9325, n=48, p=0.0283), site and date (ANOVA multi-factor test, F=3.5188, n=48, p=0.0311), and distance, site, and date (ANOVA multi-factor test, F=6.4716, n=48, p=0.0004) all had significant effects. Similarly, the interactions between distance and site (ANOVA multi-factor test, F=2.7729, n=48, p=0.0354), site and date (ANOVA multi-factor test, F=12.1925, n=48, p<0.0001), and distance, site, and date (ANOVA multi-factor test, F=6.7858, n=48, p=0.0003) significantly affected abundance.

Fig. 6 shows the relationship between the abundances on the paired emergence and sticky traps at each site. A linear correlation analysis finds that variation in one of the variables explained 39% of the variation in the other variable. However, the relationship between the emergence and sticky trap abundance at each site was not statistically significant (Linear correlation test, n=8, r=0.39179, p=0.3268).

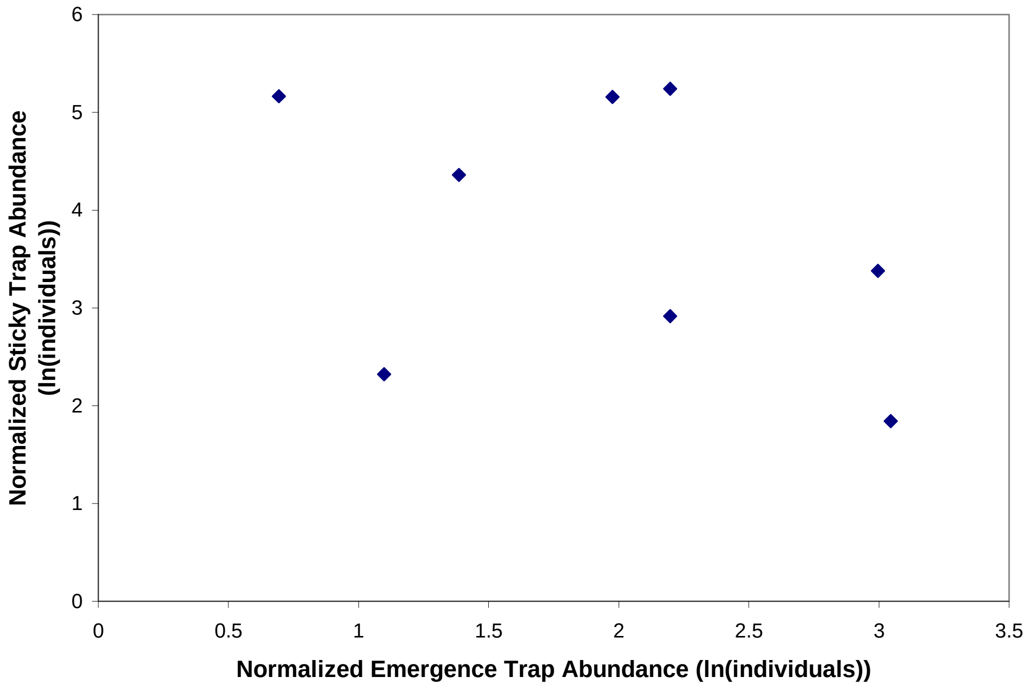

Figure 6. Average log-normalized insect abundance for the sticky trap pole over the water at each site versus the log-transformed insect abundance in the nearest emergence trap. The relationship between emergence trap and sticky trap abundance was not statistically significant (Linear correlation test, n=8, r=0.39179, p=0.3268).

The relationship between the biomasses on the paired emergence and sticky traps at each site was stronger but still was not statistically significant (Linear correlation test, n=8, r=0.60415, p=0.0569). In this case, variation in one of the variables accounted for 60% of the variation in the other variable. Fig. 7 illustrates the relationship between biomass on the paired emergence and sticky traps at each site.

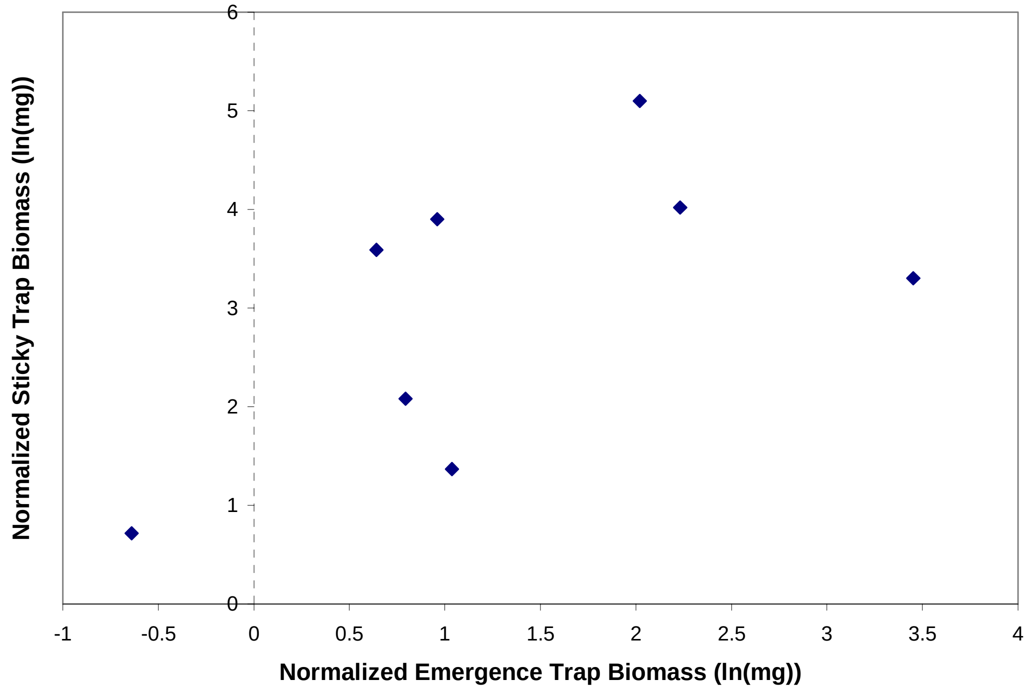

Figure 7. Average log-normalized insect biomass for the sticky trap pole over the water at each site versus the log-transformed insect biomass in the nearest emergence trap. The relationship between emergence trap and sticky trap biomass was stronger than the relationship between emergence and sticky trap abundance but was still not statistically significant (Linear correlation test, n=8, r=0.60415, p=0.0569).

Discussion

The data did not support my hypothesis that the most heavily forested sites would have a higher average biomass per trap. Though there was a significant association between site and insect abundance, the most densely forested site, WD, had the fewest insects, while the most sparsely forested site, TP, had more insects than either WD or WC.

The data did show a significant difference between the two sampling dates for both abundance and biomass, indicating that variation over time is a major factor in determining insect abundance at the Cosumnes floodplain. In fact, date had a stronger effect on abundance and biomass than any of the other variables. It is possible that my hypothesis about more insects in denser vegetation could be true on some days but not on others—due to higher winds, for example. Future study should attempt to take seasonality into account more thoroughly, by sampling over the course of an entire year and over multiple years, as well.

Height also significantly affected insect abundance and biomass, with both of these variables decreasing with increasing altitude. In order to accomplish the goal of understanding how insect distribution affects insectivore foraging activity at the Cosumnes floodplain, it would be useful to obtain data at additional heights above the ground, since insectivores do not necessarily forage precisely at ground level or at 0.9 meters above the ground.

The comparison between distance from the water and insect abundance and biomass is somewhat more complex. Abundance was highest over the water, followed by the far, forested site. Yet, biomass tended to taper off with increasing distance from the water. The effect of distance on abundance was statistically significant and the effect on biomass was not, which means that these findings are not necessarily at odds with one another. However, if this disparity between the biomass and abundance results is not due to mere chance, it could be due in part to a disparity in dispersal between insects of different body size. Perhaps small insects are less able to control their flight in high winds. This could result in high numbers of insects with small biomass in the forested areas farther from the water.

The findings that insects taper off with height above the water and, to some degree, with distance away from the water seem to suggest that emergence trap data at a given site could be a strong determiner of the sticky trap data at that site. However, the correlation results suggest otherwise. For neither biomass nor abundance was there a significant association between the emergence data and paired sticky trap data. This suggests that the emergence data alone cannot explain the sticky trap data. The results for biomass did come close to significance, however. Perhaps with additional data points in the future, this relationship may be deemed significant.

Several weaknesses existed in this study, which could perhaps be remedied with further work. First of all, because of a lack of time and the difficulty of manipulating specimens that were adhered to the sticky traps, the insects were only identified to a taxonomic level of order or suborder, rather than the more specific family or genera classifications. Since the members of many orders can be both terrestrial and aquatic, this presents a problem for a terrestrially conducted study. The issue is especially vexing for the Diptera, the most common insects in the samples, for which one must identify a specimen to family or even genus to determine if it is aquatic or terrestrial. For this study, I ignored the aquatic/ terrestrial distinctions. This could have affected my assumptions about distribution, since terrestrial insects would not be dispersing from the same locations as aquatic ones. Ideally, one would process the samples further in order to distinguish terrestrial insects from aquatic ones, making the results more meaningful.

Another weakness is the seasonality of emergence. Emergence can vary greatly over the course of a year. The significant difference in biomass and abundance per trap from February to March supports this idea. Moreover, emergence often varies widely between different years. Since sampling occurred over the course of only two months, this study cannot be considered representative of the Cosumnes River floodplain system in every year, or even over the course of one year. Further work is necessary over the course of the next few years to gain a strong picture of the behavior of the system.

It would also be helpful to consider the direct effects of wind speed and direction on insect distribution in the floodplain. Perhaps anemometers could be set up near the sticky traps to determine whether vegetation does indeed act as a windbreak, and whether wind speed actually affects insect distribution.

One of the most useful areas of future study would be to compare the sticky trap data, as well as the emergence data, to insectivore foraging activity by site. In this way, one could see whether the quantity of emerging insects or the quantity of ambient insects has a larger effect on insectivore foraging activity. Any observed trends could impact future management decisions for the Cosumnes River Preserve, especially for insectivore species targeted in the restoration efforts, such as certain birds and bats. If it was found that emergence had a large effect on insectivore feeding, the Nature Conservancy could consider engineering the landscape to make it more conducive to insect productivity. If it was found that ambient insects have a large effect on insectivore feeding activities, the Nature Conservancy could plant more trees and conduct other activities to create habitat for insects and food repositories for their predators. Future research in the area will determine whether such actions might be warranted.

Overall, the main determination that can be made about the Cosumnes floodplain system is that it is complex and highly variable over time. The numerous significant interactions between independent variables suggest that no one factor alone can predict insect distribution patterns on the floodplain. In order to truly understand the system, it will be necessary to conduct much more sampling, covering each variable in more depth and over more time periods. Perhaps, a multivariate analysis could then determine the true effect of each variable.

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