# Effects of Three Vegetation Management Strategies on Shore-Flies (Diptera: Ephydridae) in Newly Constructed Treatment Wetlands

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**ABSTRACT**   We tested the effects of three vegetation management strategies for constructed treatment wetlands on adult shore-fly (Diptera: Ephydridae) successional occurrence and emergence in southern California. Before flooding with effluent from a nearby wastewater treatment plant, eight 0.1-ha research cells were randomly assigned to (1) control cells which were burned to reduce the above ground plant biomass, (2) scoured cells which were burned and then scoured with a rock bucket attached to a backhoe, and (3) hummock cells which were burned and scoured before the placement of earthen mounds that provided shallow areas to concentrate vegetation growth within a small area. Emergence traps and pan traps were used simultaneously to capture adult Ephydridae from July 1998 to September 1999. Twenty-eight species of ephydrids from 23 genera were collected; the cumulative number of shore-fly taxa reached its maximum at 135 d after flooding, and exhibited a hyperbolic pattern over time. Only *Brachydeutera sturtevanti* Wirth differed significantly in its successional mean occurrence in pan traps among vegetation management treatments, being virtually absent from hummocked cells during 1998 but becoming one of the numerically dominant taxa in all treatments by August 1999. Both emergence and pan traps in the hummocked cells captured significantly fewer *B. sturtevanti* and *Notiphila* spp. in the other treatments during 1998, but there were no differences in numbers collected among the vegetation management treatments during 1999. Vegetation management significantly slowed the appearance of Ephydridae in constructed treatment wetlands, but only a short period of time (<1 yr) was needed for traps in all treatment cells to capture statistically equal numbers of individuals.

**KEY WORDS**   Ephydridae, successional occurrence, emergence, wetlands, wastewater, bulrush

SHORE-FLIES (DIPTERA: EPHYDRIDAE) constitute a diverse insect family (Mathis and Zatwarnicki 1995) and are integral components of all wetland types (Foote 1995, Keiper et al. 2002). Studies show that shore-flies can be abundant in wetlands (Todd and Foote 1987, Larson and Foote 1997), will colonize new habitats or resources quickly (Tomberlin and Adler 1998, Keiper and Walton 2000), and many taxa can make use of several microhabitats within wetlands (Keiper et al. 2002). The trophic ecology of ephydrids is diverse (Ferrar 1987, Foote 1995), and larval feeding has been shown to influence lower trophic levels (Brock et al. 1969). Secondary production of Ephydridae in Great Lakes coastal wetlands was found to exceed or was comparable to other Diptera, including Chironomidae (King and Brazner 1999).

Because wetlands have been under duress from human activities, recent efforts have examined the effectiveness of constructing wetlands to replace lost habitat, treat wastewater, and conserve precious water resources (Kadlec and Knight 1996). Vegetation-management strategies often need to address multiple uses and long-term sustainability of constructed wetlands. For example, wetland managers may need to develop vegetation-management strategies to address simultaneously the suitability of a wetland as waterfowl habitat (de Szalay and Resh 2000), significant mosquito (Diptera: Culicidae) production (Walton and Workman 1998, Walton et al. 1999a), and decline in nutrient removal efficiency caused by dense emergent vegetation die back as the wetland ages (Sartoris et al. 2000). Wetland management also can influence naturally occurring invertebrate communities. In seasonally flooded wetlands in California, burning and mowing vegetation before flooding increased invertebrate density (de Szalay and Resh 1997). In another study, mowing alone increased density, but had a lesser effect on biomass and diversity of colonizing invertebrates (de Szalay and Resh 2000). Other management options, such as flooding schedule and water depth manipulation, have been shown to influence macroinvertebrate density and diversity as well (de Szalay et al. 1999). However, relatively little work has been done to document the naturally occurring invertebrate biodiversity within human-made habitats.

We sampled the adult populations of shore-flies for 14 mo after initial flooding of a series of constructed

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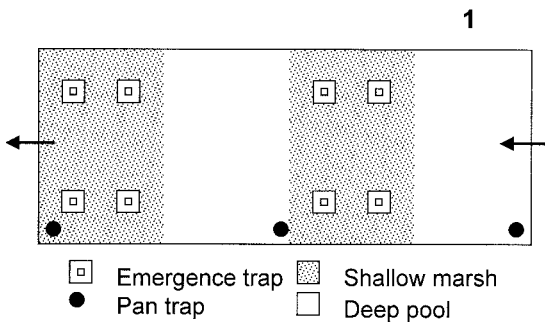[2] Department of Entomology, University of California, Riverside, CA 92521

**Fig. 1.** Diagram of one research cell and location of traps. Arrows indicate direction of water flow.

wetland research cells to determine if differential adult usage by shore-flies occurred after application of three vegetation management techniques to experimental wetland mesocosms. We tested the hypothesis that adult visitation and emergence were not influenced by the vegetation management techniques applied.

## Materials and Methods

This study was conducted at the Hemet/San Jacinto Regional Water Reclamation Facility in western Riverside County, CA (USA). Secondary-treated effluent was transferred from a wastewater treatment plant to eight research cells, each 0.1 ha (69 by 14 m) in area; cells were separated by berms three m wide. Before flooding, all cells were dried and burned to remove the above ground vegetation biomass while leaving underground rhizomes intact. Three randomly selected cells received no further manipulation and served as control cells (C). Three other cells were randomly selected, and a backhoe scoured the substrate ≈0.2 m deep with a rock bucket to reduce root and rhizome biomass (S). The remaining two cells were scoured and hummocks (earthen mounds [length by width by height: 3.7 by 1.5 by 0.4 m]) were constructed in the shallow areas (H). The hummocks were intended to supply growing vegetation a shallow area to proliferate while keeping deeper areas between the hummocks relatively free of emergent plants. Each cell was configured to contain two deep (depth = 2 m) pools and two shallow (0.7 m) marshes (Fig. 1).

Flooding began on 13 July 1998, and required about 7 d to complete; the water residence time during normal operation was ≈13–18 d. Inflow nitrogen levels were ≈9.9 mg $L^{-1}$ $NH^+_4$-N, and ≤1 mg $L^{-1}$ $NO^-_3$-N. Ammonium nitrogen concentration was reduced by 66% and 28% near the outflow during 1998 and 1999, respectively (Thullen et al. 2002). California bulrush, *Schoenoplectus californicus* (Meyer) Sojak, was the dominant plant in the wetlands, although small patches of smart weed (*Polygonum* sp.) were present.

During the second day of flooding (14 July 1998), three detergent pan traps were deployed at the western margin of all cells; one trap was placed at each end, and one was placed in the middle to provide a rep-

resentative coverage of open water, vegetation, and mud shore microhabitats (Fig. 1). Each pan was dull yellow in color and measured $23 \times 33$ cm ($\approx 0.08$ $m^2$). Pan traps were deployed during the morning and filled with ≈5 cm of water to which a few drops of liquid detergent were added (Southwood 1978, Larson and Foote 1997). Pans with insects were recovered after 24 h, and the contents sieved and placed into 95% ethanol. Traps were deployed approximately weekly for the first 12 wk of inundation, every 2–3 wk during the summer of 1999, and less frequently during winter and early spring months. Sampling was concluded on 10 September 1999.

The cumulative number of shore-fly taxa from pan traps ($y$) was plotted against time ($x$). To provide a predictive equation for species arrival, a hyperbolic function was fitted for the data by solving the equation

$$Y = a*x/(b + x),$$

where the coefficients $a$ and $b$ are the asymptote and dissociation constant of the hyperbola, respectively, and $x$ is the number of d after flooding when a sample was taken (SigmaPlot 1997).

Ten days after inundation, eight 0.25-$m^2$ pyramidal emergence traps (Walton et al. 1999b) were deployed in each cell, four in each shallow area (Fig. 1). Traps were initially supported on wooden stakes driven into the substrate. When the emergent bulrush was well developed, plants were cut with shears to 5 cm above the water surface, and traps were placed over these areas. This allowed trap placement that did not disturb the physical structure below the water surface. All traps had fine mesh skirting around the bottom to prevent flying insects from entering underneath if a trap was slightly tipped through physical disturbance. Each trap had a numbered capture jar that was collected after 1 wk. The contents were frozen, and all the emergent ephydrids enumerated. Mosquito and other macroinvertebrate population trends are discussed elsewhere (Walton et al. 1999a).

Shore-fly species collected by pan and emergence traps were quantified as to being abundant (≥20% of the total catch), common (10–20%), uncommon (≥1 but <10%), or rare (<1%). Species that represented ≥1% of the pan trap or ≥10% of the emergence trap catches were plotted to show general changes in abundance during the study. Pan trap data were compared by calculating the successional-mean occurrence for each treatment to determine if adult visitation varied over time among the three cell treatments. The successional-mean occurrence value (in days) represents the mean of the colonization curve generated by the daily mean number of adults from each taxon plotted for each treatment, and was calculated as

$$\text{SMO} = \sum_{i=1}^{n} p_i(t_i - t_{i-1})t_i \bigg/ \sum_{i=1}^{n} p_i(t_i - t_{i-1}),$$

where $p_i$ is the mean cumulative number of adults recorded for each treatment, $t_i$ is the number of d from the beginning of the experiment, and $n$ is the number of sampling days along the succession (Hanski 1980,

**Table 1. Shore-fly taxa taken in pan and emergence traps at the Hemet/San Jacinto RWRF Research Cell Complex, 1998–1999**

| Taxa[a] | Larval FFG[b] | Frequency | | Abundance | |
|---|---|---|---|---|---|
| | | Pans | Emergence | Pans | Emergence |
| *Scatella* spp. | Algivore | 0.15 | 0.04 | C | U |
|   *paludum* (Meigan) | | | | | |
|   *stagnalis* (Fallén) | | | | | |
|   sp. 1 | | | | | |
| *Brachydeutera sturtevanti* Wirth | Collector/gatherer | 0.42 | 0.35 | A | A |
| *Mosillus tibialis* Cresson | Scavenger | 0.01 | 0.03 | R | U |
| *Hydrellia* sp. | Herbivore | <0.01 | <0.01 | R | R |
| *Paracoenia bisetosa* (Coquillett) | Collector/gatherer | 0.02 | 0.11 | U | C |
| *Notiphila* spp. | Collector/gatherer | 0.28 | 0.46 | A | C |
|   *aenigma* Cresson | | | | | |
|   *macrochaeta* Loew | | | | | |
|   *olivacea* Cresson | | | | | |
|   *scalaris* Loew | | | | | |
| *Haloscatella arichaeta* Mathis | Algivore? | <0.01 | — | R | — |
| *Psilopa girschneri* von Roder | Herbivore? | <0.01 | — | R | — |
| *Allotrichoma simplex* (Loew) | Scavenger | 0.09 | <0.01 | U | R |
| *Nostima scutellaris* Cresson | Algivore | <0.01 | — | R | — |
| *Hyadina* sp. | Algivore | <0.01 | — | R | — |
| *Ephydra* sp. | Collector/gatherer | <0.01 | <0.01 | R | R |
| *Ilythea caniceps* Cresson | Algivore | <0.01 | <0.01 | R | R |
| *Paralimna multipunctata* Williston | Collector/gatherer | <0.01 | — | R | — |
| *Ochthera* sp. | Predator | <0.01 | — | R | — |
| *Parydra appendiculata* Loew | Algivore | <0.01 | — | R | — |
| *Setacera atrovirens* (Loew) | Algivore | <0.01 | <0.01 | R | R |
| *Discocerina obscurella* (Fallén) | Scavenger | <0.01 | — | R | — |
| *Typopsilopa atra* (Loew) | Secondary herbivore | <0.01 | <0.01 | R | R |
| *Philygria* sp. | Algivore | <0.01 | — | R | — |
| *Scatophila exilis* Cresson | Algivore | <0.01 | — | R | — |
| *Atissa litoralis* (Cole) | Scavenger | <0.01 | <0.01 | R | R |
| *Lytogaster excavata* (Sturtevant & Wheeler) | Algivore | <0.01 | — | R | — |

A, abundant (≥20%); C, common (10–20%); U, uncommon (≥1 but ≤10%); R, rare (<1%).
[a] Taxa arranged phylogenetically (Mathis and Zatwarnicki 1995).
[b] Functional feeding groups summarized from Ferrar (1987), Foote (1995), and Keiper et al. (2002).

Hirschberger 1998, Keiper and Walton 2000). A chi-square test was used to detect significant differences in the successional-mean occurrence.

Emergence and pan trap collection of the common ephydrids were compared among treatments with either parametric (one-way repeated measures analysis of variance (ANOVA)) or nonparametric (Friedman's one-way repeated measures ANOVA on ranks) statistics where appropriate to test the hypothesis that the numbers of shore-flies captured varied significantly among cells; tests were conducted separately for each year. A Tukey's posthoc test was used to isolate which treatments exhibited significant differences in adult abundance (SigmaPlot 1997). Emergence data for *Mosillus tibialis* Cresson and *Allotrichoma simplex* (Loew) were not analyzed statistically because of the infrequency in collections.

## Results and Discussion

Twenty eight species from 23 genera were collected in pan traps, and 16 species from 11 genera were collected in emergence traps (Table 1). Six species and five species each represented >1% of the total number of specimens from pan and emergence traps, respectively; the remaining species were rare. The 12 species absent in emergence traps are all known or suspected to have immature stages that occur in the semiaquatic margins of aquatic habitats (Ferrar 1987, Foote 1995, Keiper et al. 2002), away from emergence trap positions. Some species, such as *Hydrellia* sp. and *Typopsilopa atra* (Loew), are associated directly with plants and probably occurred in emergence traps because traps were placed over bulrush plants occupied by their immature stages.

The two most abundant taxa in both pan and emergence traps were four *Notiphila* spp. and *Brachydeutera sturtevanti* Wirth. *Notiphila* larvae exist in anoxic sediments where they pierce the roots of plants to obtain oxygen (Busacca and Foote 1978, Mathis 1979, Larson and Foote 1997). *Brachydeutera* adults rapidly colonize new aquatic habitats where their larvae exploit a variety of autotrophic and heterotrophic resources (Keiper and Walton 2000). *Paracoenia bisetosa* (Coquillett), *M. tibialis*, and three species of *Scatella* were collected repeatedly in pan traps as well; all of these species are associated with semiaquatic habitats, such as mud shores, detrital deposits, and algal mats (Zack 1983, Foote 1995; J.B.K., unpublished data). These data illustrate that the two trapping techniques used provide data sets that are somewhat different, but complimentary. Also, some of the numerically important species do not inhabit the open water and benthic regions of wetlands normally sampled by aquatic entomologists using emergence traps, dip nets, and other methods.
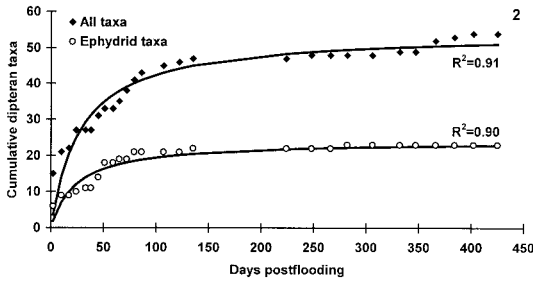
**Fig. 2.** Cumulative number of shore-fly taxa taken in pan traps, with total dipteran taxa included for comparison. Bold lines represent nonlinear regression line formed by solving for the equation for a hyperbola.

The cumulative number of ephydrid taxa reached its maximum at 135 d after flooding. The cumulative number of all dipteran taxa (56 taxa identified from the families Anthomyzidae, Chironomidae, Chloropidae, Culicidae, Muscidae, Otitidae, Sciaridae, Sciomyzidae, Sepsidae, Sphaeroceridae, Syrphidae, and Tipulidae) exhibited an excellent fit to the hyperbolic equation ($R^2 = 0.90$). Analysis of ephydrid taxa collected in pan traps also yielded a hyperbolic pattern ($R^2 = 0.91$) (Fig. 2). Comparing the number of shore-fly taxa col-

lected to all dipteran taxa identified, it becomes clear that Ephydridae are one of the first to colonize and one of the most important insect groups inhabiting constructed wetlands in terms of biodiversity. Initial habitat availability consisted only of open water, benthic, and mud-shore habitats, yet six shore-fly taxa were taken in pans 2 d after flooding. The nutrient-rich water, rapid proliferation of bulrush, and high summer temperatures probably facilitated the rapid accumulation of other Ephydridae. Shore-flies are known as a highly adaptable group able to make use of a vast number of habitats (Foote 1995), therefore the results presented here of the rapid colonization by the ephydrid community should not be applied to other insect groups.

Adult occurrence of the six most common taxa in pan traps differed among the three treatments (Fig. 3). *Brachydeutera sturtevanti*, *M. tibialis*, and *P. bisetosa* were more abundant in hummock cells, *Scatella* spp. were more abundant in control cells, and *Notiphila* spp. adults did not seem to exhibit a preference for any cell type. However, calculations of the successional mean occurrence show that only *B. sturtevanti* exhibited a significantly different pattern in its temporal use of the three treatments ($\chi^2 = 20.8$, df = 2, $P < 0.05$; Table 2). Adult *B. sturtevanti* were taken
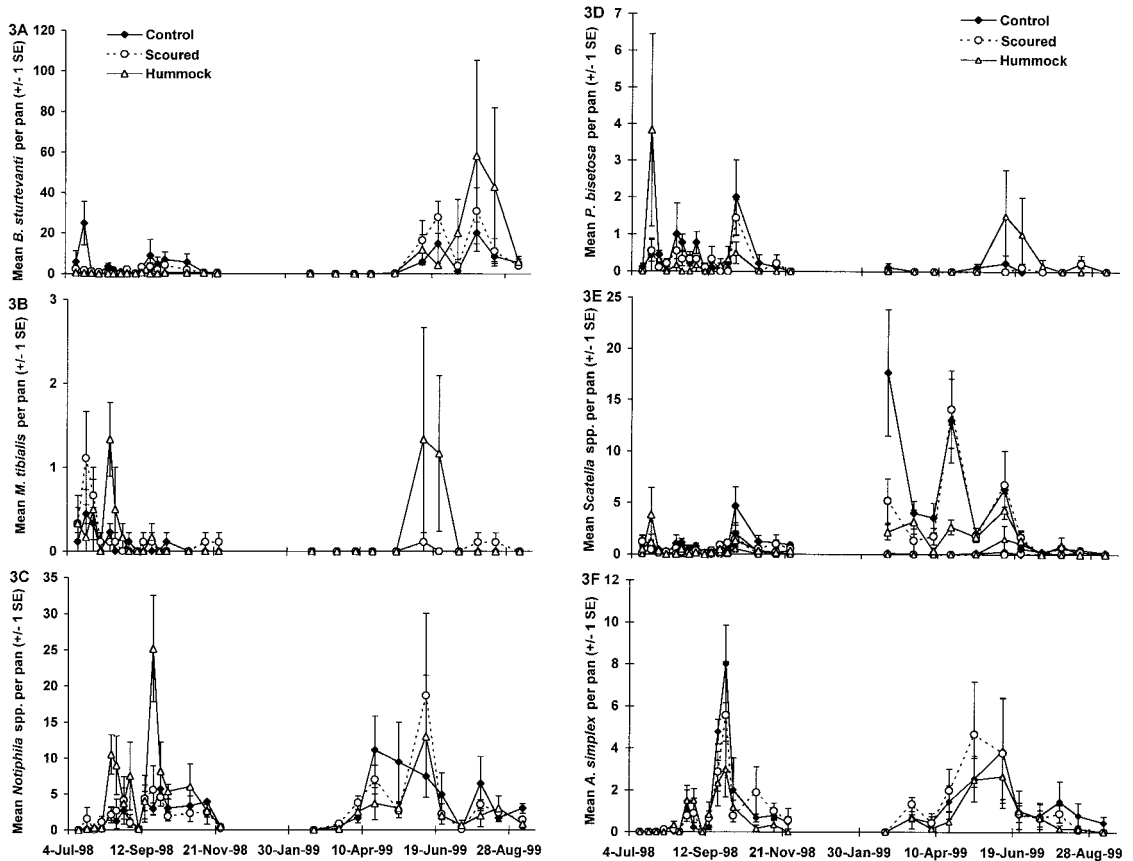


**Fig. 3A–F.** Mean ± 1 SE abundance for the six most common shore-flies taken in pan traps. Flooding began 12 July 1998, and the first sampling date was 14 July 1998.

**Table 2. Results of Successional Mean Occurrence calculations (reported in days) for the six most common ephydrid taxa taken in pan traps at control, scoured, and hummock cells, from July 1998 to September 1999**

| Taxa | Control | Scoured | Hummock | $\chi^2$ (df = 2) |
|---|---|---|---|---|
| *A. simplex* | 281.1 | 288.6 | 279.2 | 0.2 |
| *B. sturtevanti* | 261.7 | 311.0 | 375.9 | 20.8* |
| *M. tibialis* | 237.0 | 237.4 | 260.4 | 1.5 |
| *Notiphila* spp. | 299.5 | 310.0 | 299.9 | 0.2 |
| *P. bisetosa* | 252.4 | 250.9 | 249.9 | 0.1 |
| *Scatella* spp. | 293.5 | 285.9 | 265.8 | 1.5 |

*, $P < 0.05$.

in low density in H cells until August 1999, when numbers peaked at an average of nearly 60 individuals per trap (Fig. 3A). Manipulating cells using a combination of burning, scouring, and hummocks appeared to slow adult use, but only temporarily. *Brachydeutera* are excellent colonizers of newly formed aquatic habitats (Keiper and Walton 2000), and our data indicate that large populations of these omnivorous flies accumulate within 1 yr.

Pan traps placed in H cells accumulated significantly fewer *B. sturtevanti* and *Notiphila* spp. than in C and S cells during 1998; there was no significant difference in numbers of these taxa during 1999 (Table 3). In contrast, emergence traps in control cells captured significantly more adults of these two taxa than in S and H cells compared with C cells during 1998, but again no such trend was detected in 1999 (Fig. 4; Table 3). Significantly more *Scatella* spp. were taken in pan traps in control cells than S or H cells during 1998, and significantly more *A. simplex* were taken in S cells compared with H cells during 1999 (Table 3). Adult capture data indicate that the vegetation-management

strategy that most severely disturbed the cells before flooding (i.e., H cells were burned, scoured, and hummocked) was less suitable for adult emergence and activity during the first growing season. However, by the second season of flooding, all shore-fly taxa produced statistically equal numbers among vegetation treatments. Also, all taxa exhibited a trend for increasing numbers over time, or the numbers were comparably similar between years (Figs. 3 and 4).

Vegetation management techniques which create a severe substrate disturbance may initially reduce the numbers of flying insects within the wetlands, but adult numbers grow rapidly as emergent vegetation rapidly recolonizes the wetlands. Certain ephydrid taxa (e.g., *Notiphila*) are directly affected by substrate manipulations because the larval habitat is highly modified. Others (e.g., *Brachydeutera*) may find a wetland unfavorable if large clay hummocks with low organic matter content cover much of the substrate; this could in turn temporarily reduce the amount of organic food available to the neustic adults and larvae. The hummocks reduced overall vegetative growth within the cells by 40% compared with control cells (Thullen et al. 2002), and this may reduce the number of scavenging taxa using the cells (e.g., *A. simplex*) that may otherwise become abundant in areas of decaying plant matter.

Although the wetland cells were relatively simple spatially (rectangular configuration) and supported virtually monocultural vegetation, Ephydridae produced a species-rich community comparable to natural wetlands (Deonier 1965, Scheiring and Foote 1973, Todd and Foote 1987). The species richness increased quickly during the first 3 mo of inundation and reached an asymptote thereafter. If the dipteran

**Table 3. Results of parametric (one-way repeated measures ANOVA) and non-parametric (Friedman's repeated measures ANOVA on ranks) tests applied to data obtained on common shore-flies taken in pan traps and emergence traps during 1998 and 1999**

| Taxon | Year | Statistic and values | *P*-value | Differences between treatments[a] |
|---|---|---|---|---|
| | | *Pan traps* | | |
| *Brachydeutera* | 1998 | Friedman's $\chi^2$ = 22.63, df = 2 | <0.01 | C>H, S>H, C = S |
| | 1999 | Friedman's $\chi^2$ = 2.11, df = 2 | NS | — |
| *Paracoenia* | 1998 | Friedman's $\chi^2$ = 4.43, df = 2 | NS | — |
| | 1999 | RM ANOVA, $F$ = 1.96, df = 2,5 | NS | — |
| *Notiphila* | 1998 | Friedman's $\chi^2$ = 8.13, df = 2 | <0.05 | C>H, S>H, C = S |
| | 1999 | RM ANOVA, $F$ = 0.92; df = 2, 9 | NS | — |
| *Scatella* | 1998 | Friedman's $\chi^2$ = 11.65, df = 2 | <0.01 | C>H, C=S, S=H |
| | 1999 | Friedman's $\chi^2$ = 5.91, df = 2 | NS | — |
| *Allotrichoma* | 1998 | RM ANOVA, $F_{2,12}$ = 0.26; df = 2,12 | NS | — |
| | 1999 | RM ANOVA, $F$ = 4.12; df = 2,9 | <0.05 | C=S, C=S, S>H |
| *Mosillus* | 1998 | Friedman's $\chi^2$ = 3.32, df = 2 | NS | — |
| | 1999 | RM ANOVA, $F$ = 2.28; df = 2, 4 | NS | — |
| | | *Emergence traps* | | |
| *Brachydeutera* | 1998 | RM ANOVA, $F$ = 12.86; df = 2, 8 | <0.01 | C>H, C>S, S = H |
| | 1999 | RM ANOVA, $F$ = 2.19; df = 2, 5 | NS | — |
| *Paracoenia* | 1998 | Friedman's $\chi^2$ = 6.28, df = 2 | NS | — |
| | 1999 | RM ANOVA, $F$ = 0.93; df = 2, 3 | NS | — |
| *Notiphila* | 1998 | Friedman's $\chi^2$ = 15.94, df = 2 | <0.01 | C>H, C>S, S = H |
| | 1999 | RM ANOVA, $F$ = 1.30; df = 2, 6 | NS | — |
| *Scatella* | 1998 | RM ANOVA, $F$ = 1.34; df = 2, 8 | NS | — |
| | 1999 | RM ANOVA, $F$ = 0.12; df = 2, 5 | NS | — |

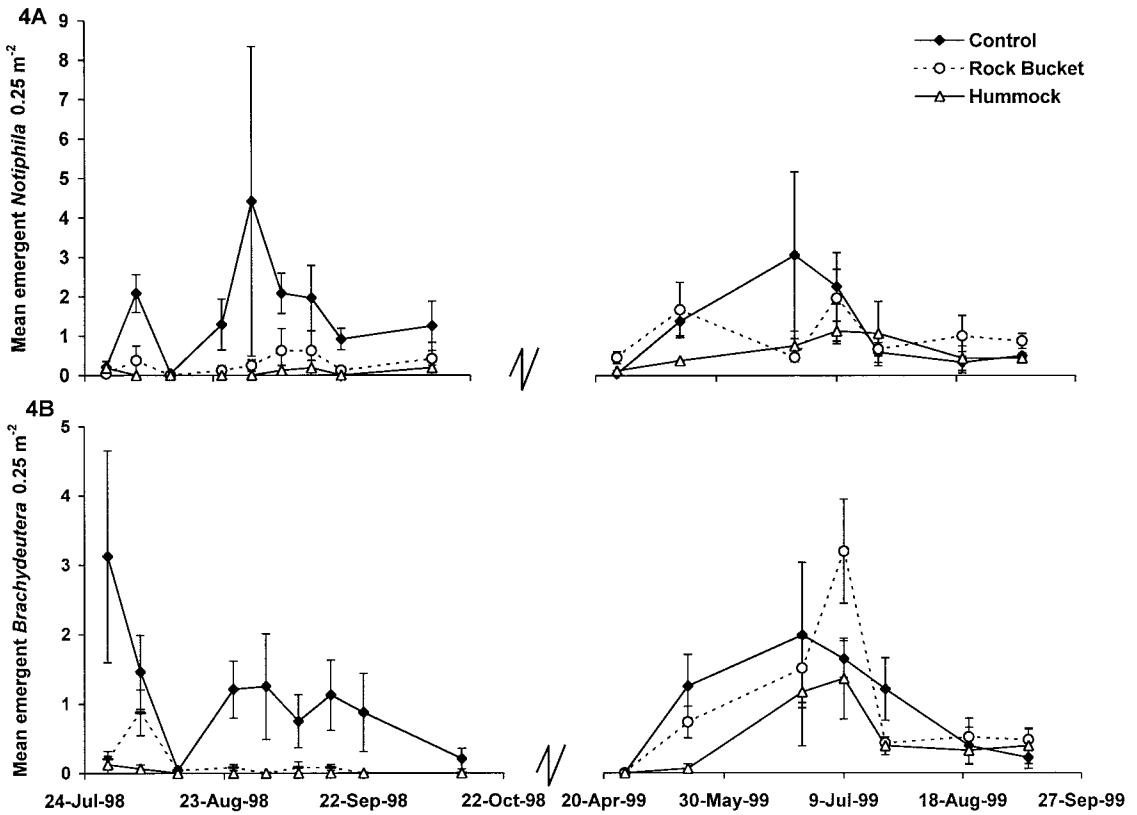C, control cells; S, scoured cells; H, hummock cells.

**Fig. 4A–B.** Mean ± 1 SE abundance for the two most common shore-flies taken in emergence traps. Flooding began 12 July 1998, and the first sampling date was 22 July 1998.

species composition of areas adjacent to a proposed site for wetlands construction is known, it is possible that the accumulation of colonizing ephydrid taxa can be predicted using a hyperbolic model. Because dipterans are an important food resource for waterfowl and other birds, wetlands and wildlife managers can use such predictions to determine when a newly constructed marsh is suitable for waterfowl breeding. Invertebrate abundance can be used to predict growth and survival of ducklings (Cox et al. 1998) which feed heavily on flying insects (Collias and Collias 1963).

## Acknowledgments

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