

**INSECT – HABITAT ASSOCIATIONS  
IN SALT MARSHES OF NORTHERN PUGET SOUND:  
IMPLICATIONS OF TIDAL RESTRICTION  
AND PREDICTED RESPONSE TO RESTORATION**

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**ABSTRACT**

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To promote Pacific salmon (*Oncorhynchus* spp.) recovery, intensive efforts are underway to preserve natural coastal wetlands and to restore degraded ecosystems. However, the scientific and restoration communities have largely overlooked barrier salt marshes, found throughout the island archipelago of northern Puget Sound. Little is known about the animal communities utilizing these marshes, and even less is understood about barrier salt marsh response to hydrologic modification and restoration.

This thesis documents existing conditions and predicts post-restoration changes in a tidally muted salt marsh in Crescent Harbor, located on the northeastern shore of Whidbey Island, Island County, Washington. I evaluated the existing habitat value of Crescent Harbor marsh (CH) for juvenile salmon by comparing fish, insect, and vegetation assemblages between CH and five Island County salt marshes having natural tidal regimes. I also assessed physicochemical properties of the marshes (e.g., tidal flooding duration, porewater depth and salinity, soil organic matter) to help explain insect assemblage patterns. Results of post-restoration hydrologic modeling were

synthesized with biological findings to predict the ecological response to restoration of CH. Restoration is scheduled for August 2005.

Compared to one reference marsh, CH contained >95% fewer tidal channel fishes, none of which were juvenile Pacific salmon. Similar insect taxa inhabited all marshes, but assemblages differed among vegetation types. Flies (esp. ceratopogonids, chironomids, dolichopodids, ephydriids), parasitoid wasps, Saldidae, homoptera (esp. delphacids and coccoids), Collembola, and Acari were particularly common. Overall, CH supported more freshwater and brackish vegetation than all reference marshes (56% vs. 0–4% frequency) and less euhaline vegetation (19% vs. 44–76% frequency). However, within euhaline vegetation, CH experienced abiotic conditions similar to reference marshes. Indirect gradient analysis revealed that tidal flooding and vegetation richness explained a large portion of insect assemblage variation.

The preferred restoration design allows full tidal inundation throughout the eastern portion of CH and improves tidal exchange within the western portions of the marsh. The open inlet will allow estuarine and marine fishes, including juvenile Pacific salmon, full access to the restoring CH habitat. Given current elevations, I predicted that euhaline vegetation will more than triple in areal coverage. Freshwater and brackish vegetation will remain, particularly in the tidally muted western portions of the marsh. Insects within euhaline vegetation may experience a 100% increase in total density as well as major shifts in composition. Insect densities will also shift in relation to their associated vegetation types. Post-restoration monitoring will test predictions and further enhance our understanding of these barrier salt marsh systems.

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## INTRODUCTION

Insects are prominent components of coastal wetland systems (Adam 1990) and an important food source for many animals, including small mammals, birds, and fishes. Pacific salmon (*Oncorhynchus* spp.) are of particular concern in the Pacific Northwest, with 16 evolutionary significant units (ESUs) in Idaho, Oregon, and Washington currently listed as endangered or threatened under the federal Endangered Species Act. Insects represent a large portion of juvenile Chinook salmon (*O. tshawytscha*) diets during their migration through and rearing in coastal wetlands (Simenstad et al. 1982). Quantifying insect abundance and composition aids assessment of a particular habitat's capacity to support juvenile salmon foraging, growth, and growth efficiency (Simenstad and Cordell 2000). Insect assemblages have been studied in fresh and brackish marshes (e.g., Higley and Holton 1981, Hansen and Castelle 1999, Gray et al. 2002), but ecological research in euhaline marshes is generally lacking. This project describes relationships between insect assemblages and their habitat in barrier salt marshes of northern Puget Sound and predicts post-restoration changes in one tidally restricted marsh system.

## BACKGROUND

Coastal salt marshes are vegetated by herbs, grasses, or low shrubs and are periodically flooded by an adjacent, saline water body (Adam 1990). They represent one of the world's most productive natural systems, yielding up to  $8 \text{ kg m}^{-2} \text{ yr}^{-1}$  of aboveground vegetation (Mitsch and Gosselink 1993). This high productivity derives

from flooding waters, which constantly deposit nutrients and minerals, aerate sediments, and remove metabolic toxins from the root zone (Portnoy 1999).

Estuarine and elevation gradients strongly influence the vegetation structure and geomorphology of Pacific Northwest salt marshes (Simenstad et al. 2000). The composition of vegetation depends on multiple environmental factors, including salinity, elevation, and tidal flooding regime (Jefferson 1975, Burg et al. 1976, Disraeli and Fonda 1979) as well as soil aeration, texture, temperature, and organic content (Ewing 1983). Marshes that receive minimal freshwater inputs experience higher salinity (>25‰) and typically contain *Salicornia virginica* (American glasswort), *Distichlis spicata* (seashore saltgrass), *Jaumea carnosa* (fleshy Jaumea), and *Grindelia integrifolia* (entire-leaved gumweed) (Jefferson 1975).

Fishes and crustaceans gain access to coastal wetlands through tidal channels during series of tidal pulsing (Rozas 1995). The extent to which Pacific Northwest estuaries function as nursery habitats for marine fauna is not fully understood (Seliskar and Gallagher 1983, Simenstad et al. 2000). Eighteen fish species readily occur in tidal marshes as larvae or juveniles, and several fishes inhabit wetlands for extended periods, including Chinook, chum (*O. keta*), and coho (*O. kisutch*) salmon as well as redbelt shiner (*Richardsonius balteatus*), shiner perch (*Cymatogaster aggregate*), and starry flounder (*Platichthys stellatus*) (Simenstad et al. 2000). Tidal marshes are also utilized by motile macroinvertebrates, such as juvenile Dungeness crab (*Cancer magister*) and shore crabs (*Hemigrapsus* spp.) (Seliskar and Gallagher 1983).

For most juvenile Pacific salmon, estuaries offer a zone for physiological transition, avoidance of predators, and optimal foraging (Simenstad et al. 1982). Ocean-type Chinook salmon enter estuaries as fry (<40 mm, 0.5 g) and rear for several weeks to months within coastal wetland systems (Healey 1982, Simenstad et al. 1982). This salmon life-history type is, therefore, particularly dependent upon estuaries and coastal wetlands as juvenile rearing habitat (Thorpe 1994). While most of the literature relates to Chinook salmon rearing in estuaries of their natal rivers, researchers are beginning to recognize the utilization of non-natal wetlands by ocean-type Chinook. For example, sub-yearling Chinook have been observed using non-natal pocket estuaries as rearing habitat in Skagit Bay (E. Beamer 2003, Skagit System Cooperative, LaConner, WA, personal communication).

### ***Salt Marsh Modifications***

In Puget Sound, 73% of historic tidal marshes have been lost to agriculture and development during the past 150 years (Bortelson et al. 1980, Hutchinson 1988b). Diking and draining for agricultural crops or grazing caused substantial wetland loss in rural areas, such as the Skagit and Stillaguamish River deltas, whereas marsh dredging and filling for port development occurred in urbanized river deltas, such as the Snohomish and Duwamish (Thom and Hallum 1990). Other marshes experience altered hydrologic regimes (e.g., muted tides) due to dikes, roads, or active water management (WSCC 2000).

Restricted tidal exchange induces significant changes in salt marsh soil properties, primary production, and ecological functions. Reduced tidal flooding decreases porewater salinity, lowers the water table, allows more aerobic decomposition, and likely contributes to greater soil density and lower surface elevation (Zedler et al. 1980, Roman et al. 1984, Portnoy and Giblin 1997, Kuhn et al. 1999). Adapted to high salinity levels and frequent anaerobic conditions, salt marsh plants lose their competitive advantage over terrestrial and freshwater plants, leading to vegetation change (Roman et al. 1984). How these changes affect salt marsh invertebrates is relatively undocumented, but typical infaunal species are likely absent from most areas of tidally restricted marshes (Fell et al. 2000). Changes in benthic invertebrate composition or export rates could negatively affect populations of marine fishes that depend upon marsh-derived prey resources (Seliskar and Gallagher 1983). Water management structures further constrain the opportunity for marine fauna to access and benefit from wetland habitats by directly interfering with fish and crustacean passage (Rogers et al. 1994), resulting in dramatic reductions in nekton abundance and diversity (Roman et al. 2002). These cumulative effects are thought to limit the role of tidally restricted marshes within the larger coastal ecosystem (Roman et al. 1984, Montague et al. 1987).

### ***Salt Marsh Restoration***

The extensive loss of coastal wetlands in Puget Sound has likely contributed to the decline of Pacific salmon in this region (Simenstad and Cordell 2000). Indeed in 1999, Puget Sound Chinook and summer chum salmon were listed as threatened under

the federal Endangered Species Act. To promote Pacific salmon recovery, intensive efforts are underway to preserve remaining coastal wetlands, rehabilitate damaged ecosystems, and restore altered wetlands in order to expand the quantity and quality of juvenile salmon habitat (Simenstad and Cordell 2000).

To evaluate the success of restoring coastal wetlands for juvenile salmon habitat, fish growth and survival rates would be the most direct indicators. However, evaluating these rates in terms of a particular habitat is extremely difficult (Simenstad and Cordell 2000). A more practical option is the assessment of ecological and structural attributes of the habitat that promote salmon growth and survival. Simenstad and Cordell (2000) describe three categories of habitat assessment metrics: (1) *capacity* metrics quantify habitat features that support juvenile salmon production, through conditions that promote foraging, growth, growth efficiency, and decreased mortality; (2) *opportunity* metrics assess the extent to which structural attributes allow juvenile salmon to access and benefit from the habitat's capacity; and (3) *realized function* metrics focus on physiological or behavioral responses that promote fitness and survival, and thus relate fish performance to habitat occupation. These metrics allow quantitative comparison of restoring wetlands both within and among estuarine systems.

Juvenile salmon have utilized recently restored wetlands as rearing habitat (Healey 1982, Simenstad et al. 1982, Thorpe 1994, Gray et al. 2002). Restored wetlands offer a variety of prey items, including Diptera larvae, pupae, and adults, gammarid amphipods, terrestrial insects, and benthic crustaceans and annelid worms (Shreffler et al. 1992, Cordell et al. 1999, Gray et al. 2002). Juvenile Chinook reside in restoring

wetlands for extended periods of time and show increases in body length and weight after several weeks (Shreffler et al. 1990).

### ***Salt Marsh Insects***

Existing literature (e.g., Healey 1982, Simenstad et al. 1982, Miller and Simenstad 1997, Gray et al. 2002) suggests that terrestrial and aquatic insects are an important prey resource for juvenile Chinook in estuaries. For example, in several Vancouver Island, British Columbia, estuaries (i.e., Nanaimo, Nitinat, Cowichan, and Courtenay), adult insects were the primary food source, with decapod larvae and gammarid amphipods of secondary importance (Healey 1982).

In addition to their utility as indicators of juvenile salmon habitat capacity in estuaries, insects are frequently used in metrics of ecological integrity, particularly in aquatic and terrestrial environments. Because of their diverse ecological requirements and life history strategies, insects are sensitive to a variety of ecosystem structuring factors (Garono et al. 2001). Some applications include assessing streams exposed to placer gold mining effluent (Bailey et al. 1998), evaluating floodplain habitats in regulated rivers (Greenwood et al. 1991), identifying dry and intensively farmed wetlands (Euliss et al. 2001), and investigating ecological effects of grassland management practices (Eyre et al. 1989). In addition, their high diversity and abundance makes insects appropriate indicators even in small habitats (Desender and Maelfait 1999). Applied to restoration projects, ecological indicators measure progress and allow for assessments of functional equivalency with natural reference sites (Keddy 1999).

Wetland insects may reflect subtle aspects of vegetation structure, such as predominant vegetation growth forms (e.g., vines, herbs, shrubs, and trees) (Garono and Kooser 2001) and emergent vegetation density (King and Brazner 1999). In coastal salt marshes, vegetation zones sometimes support different insect assemblages. For example, Davis and Gray (1966) described how insect composition and abundance differed among *Spartina alterniflora*, mixed *S. alterniflora*–*Salicornia perennis*–*Limonium carolinianum*, *Juncus roemerianus*, *Spartina patens*, and *D. spicata* vegetation zones in North Carolina salt marshes. Similarly, Dobel et al. (1990) found different spider assemblages between *S. alterniflora* and *S. patens*. However, Cameron (1972) observed insect assemblages to be very similar between *Salicornia pacifica* and *Spartina foliosa* zones in California salt marshes. Tides appear to have no direct effect on insect abundance, diversity, or trophic structure in natural systems (Davis and Gray 1966, Cameron 1972, 1976). Rather, insect assemblages respond primarily to biological fluctuations, particularly of their food resources (Davis and Gray 1966, Cameron 1972, Balling and Resh 1991). However, tides indirectly affect insects through their influence on food quality, availability, and vegetation patterns (Balling and Resh 1991).

## **APPROACH**

This study describes relationships between insect assemblages and their habitat in barrier salt marshes of northern Puget Sound and predicts post-restoration changes in one tidally restricted marsh. Barrier (pocket) marshes receive significantly less freshwater discharge than deltaic marshes and are relatively unstudied in the Pacific

Northwest. I characterize the structure of insect assemblages in six barrier salt marshes and quantify biotic and abiotic features of their habitat. Then, I utilize multivariate statistical approaches to elucidate relationships between insect assemblages and their habitat. Finally, I apply these findings to predict post-restoration changes in the tidally restricted marsh. I also evaluate ancillary data on estuarine and marine fish occurrence in the main channel of the tidally restricted marsh, to document potential pre-restoration access. I test the following null hypotheses:

***H<sub>01</sub>:** No difference in insect assemblages among marshes or vegetation types;*

***H<sub>02</sub>:** No difference in habitat features (e.g., vegetation composition, salinity, and tidal inundation) among marshes;*

***H<sub>03</sub>:** No relationship between insect assemblages and habitat features; and*

***H<sub>04</sub>:** No difference in fish composition and abundance between tidally restricted and natural marshes.*

## **SITE DESCRIPTIONS**

Crescent Harbor marsh (CH), owned by the Naval Air Station Whidbey Island (NASWI), is situated on the northeastern shore of Whidbey Island in northern Puget Sound (Figure 1). Crescent Creek supplies seasonal freshwater flow to this 100-ha wetland system. In the early 1900s, the marsh was diked and drained for agriculture and grazing (WSCC 2000). A tide gate was installed in the main channel to allow freshwater escape during low tides and to block saltwater intrusion during high tides. An attempt was made in 1994 to restore tidal inundation by opening the tide gate that separates the

marsh from Crescent Harbor (WSCC 2000). While saltwater can now enter the marsh, tidal exchange remains severely muted, and salt marsh vegetation has colonized only a small area proximal to the main tidal channel. Prevalent plant species include *S. virginica*, *D. spicata*, *Atriplex patula*, *J. balticus*, *Potentilla pacifica*, *Scirpus lacustris*, *Typha latifolia*, *Rosa nutkana*, and terrestrial grasses and herbs. Restoration of full tidal inundation to CH is planned for August 2005, when the tide gate will be replaced with an open channel, interior culverts enlarged, and low-order channels excavated.

Reference sites were chosen to represent natural salt marshes comparable to CH. A natural reference marsh was not available in the close vicinity of CH. Thus, I selected marshes on Whidbey and Camano Island that currently experience natural tidal exchange, minimal freshwater inputs, and minimal surrounding development. Lake Hancock (LH) and Cultus Bay (CB) were selected for initial sampling because they include the features of relatively large size ( $\geq 10$  ha), easy travel access, and few property owners. Expanded sampling occurred at Elger Bay (EB), Maylor Point (MP), and Race Lagoon (RL), to allow assessment of the variability in natural salt marshes of the region.

Located along Admiralty Inlet on the western shore of Whidbey Island, LH is owned by NASWI and The Nature Conservancy of Washington. Historically a saltwater lagoon with surface runoff the only source of freshwater, LH was converted to a freshwater system and used for cranberry farming in the early 1900s (WSCC 2000). Storms breached the sandbar in 1913 and again in 1934, when cranberry farming was finally abandoned (WSCC 2000). LH includes 46 ha of salt marsh and 16 ha of coastal lagoon (WSCC 2000). A mixed assemblage of *S. virginica*, *J. carnosus*, *Triglochin*

*maritimum*, *D. spicata*, and *Plantago maritima* dominates the salt marsh. Patches of *J. balticus* and *T. latifolia* occur along the southern upland border.

CB is located on the southeastern tip of Whidbey Island. Cultus Creek drains into the 93-ha estuary system (WSCC 2000). A dike and tide gate were installed in the 1920s, separating the western 81 ha from Cultus Bay (WSCC 2000). The diked portion continues to be used for agriculture and grazing, and the undiked portion contains salt marsh vegetation and a wide tidal channel. The vegetation assemblage is similar to that found at LH, with the addition of *G. integrifolia*.

EB is a 27 ha salt marsh located on the west coast of central Camano Island. Upland development surrounds the marsh on all sides, including the barrier sand spit. A typical salt marsh assemblage exists throughout most of the marsh, with *T. latifolia* and *S. lacustris* present along the northern upland border. Driftwood covers nearly 30% of the marsh surface, and little vegetation grows in that area.

MP is located on the western shore of Oak Harbor in northeastern Whidbey Island. Historically a tidal mudflat, MP was diked and filled with dredge material in 1942, during construction of the NASWI Seaplane Base (John Phillips 2004, NASWI Environmental Division, Oak Harbor, WA, personal communication). In the 1960s, juvenile salmon were reared in a pond that was excavated on the property. The dike eventually breached in the early 1970s, promoting the development of salt marsh vegetation and channel systems. The 34-ha salt marsh is currently dominated by *D. spicata*, but includes many other salt marsh species at lower frequencies.

RL is a small saltwater lagoon positioned on the eastern shore of central Whidbey Island. Approximately 17 ha of salt marsh vegetation occur behind a barrier sand spit. The channel opening continues to migrate northward, and as a result, the lagoon is nearly cut off from Saratoga Passage (WSCC 2000).

## **2002 PILOT STUDY**

To evaluate the feasibility and effectiveness of three sampling methods, I conducted a pilot study to assess the abundance, composition, and variability of insect assemblages at CH, LH, and CB.

### ***Sampling Design***

Because mixed *S. virginica* assemblages dominate reference marshes, I concentrated CH sampling in a 3-ha patch of mixed *S. virginica*, *D. spicata*, and *A. patula* adjacent to the primary marsh channel. I expect this patch to experience rapid change upon restoration of tidal inundation, due to its location near the breach site and channel systems that are not enclosed by high berms. Sampling at LH and CB occurred in similarly sized and positioned areas of the *S. virginica* vegetation assemblage.

Insect sampling areas were delineated over digital orthophoto quarter quadrangles (DOQQs, USGS 1996) using ArcView 3.2 (ESRI, Redlands, CA) and verified in the field. I randomly located eight stations within sampling areas using the ArcView extension Random Point Generator 1.1 (Jenness Enterprises, Flagstaff, AZ). I navigated to the sampling stations using a handheld global positioning system (GPS) unit having <3 m horizontal error (Magellan Meridian Marine, Thales Navigation, Santa

Clara, CA). Each sampling station consisted of a sediment core, fallout trap, and pitfall trap. Sampling occurred during the week of 1 July 2002.

### ***Techniques***

*Sediment cores:* Immature insects and other soil-dwelling invertebrates were collected using sediment cores. These samples tend to capture Coleoptera and Diptera larvae (Sutherland 1996) as well as nematode and annelid worms. I extracted 385 cm<sup>3</sup> of soil using a standard corer. The soil plug was emptied into a jar, and the contents were fixed in the field with 5% buffered formalin. Samples were returned to the laboratory, and then washed and separated under flowing water. Insects and other invertebrates retained in a 500- $\mu$ m sieve were preserved in 70% isopropyl alcohol and stained with Rose Bengal.

*Fallout traps:* Aerial input from vegetated marshes to the aquatic system was quantified using fallout traps. These traps tend to capture flying insects, primarily adult Hymenoptera and Diptera (Sutherland 1996), and have been used in other studies of emergent marshes (e.g., Cordell et al. 1994, Gray et al. 2002). I used clear plastic 15 x 43 x 58-cm bins, each resting on a level 40 x 55-cm platform and surrounded by four 1.5-m stakes. One end of the bin was tethered to a stake, such that the bin could rise with tidal flooding of the marsh surface, remain in place, and come back to rest on the level platform upon the ebb tide. The traps were filled with 3 L of water mixed with 5 mL of unscented biodegradable dish soap. Traps were set for 48 h. Insects were collected by

pouring trap contents through a 106- $\mu$ m sieve and washing the retained portion into a labeled jar. Insects were preserved in the field with 70% isopropyl alcohol.

*Pitfall traps:* Insects susceptible to falling or being washed from the marsh surface to the aquatic system were collected using pitfall traps. These traps capture active, surface-living insects, including Diptera, Hemiptera, Coleoptera, Blattodea, Dermaptera, Isoptera, and Hymenoptera (Sutherland 1996). I used clear plastic 7-cm-diameter jars, sunk level with the marsh surface. The traps were filled with 50 mL soapy water. Tidal flooding at LH and CB prohibited overnight sampling, and travel constraints reduced available trapping time to 8 hours. Insects were collected by removing the jar from the marsh and screwing on the cap. Insects were preserved in the field with 70% isopropyl alcohol.

*Sample Processing:* Contents of all samples were sorted, counted, and identified to the finest taxonomic resolution possible under an illuminated dissecting microscope. I compared invertebrate composition and total density among marshes and sampling methods. Data and processing times were then evaluated to guide future sampling efforts. I used the invertebrate data from each marsh and sampling method to determine the number of samples necessary to detect a 50% change in density with 80% power ( $1 - \beta$ ) and 10% Type I error rate ( $\alpha$ ) (Zar 1999). I also examined the average processing time required for each type of sample, after learning a majority of taxa and establishing standard techniques.

## ***Results***

The following invertebrates were collected most frequently: Acari, Araneae, Diptera, Hemiptera, Homoptera, Hymenoptera, talitrid amphipods, harpacticoid copepods, annelid and nematode worms, and bryozoan polyps. Fallout traps sampled on average 70% of taxa richness for each site, sediment cores 35%, and pitfall traps 19%. At a given marsh, fallout and pitfall traps tended to capture similar taxonomic orders, while sediment cores contained a much different group of organisms (Figure 2). Diptera dominated fallout trap samples at all marshes, as well as pitfall traps at CH. Diptera also represented a large proportion of the sediment core taxa at CH, versus a dominance of annelid and nematode worms at CB and LH.

Fallout and pitfall traps captured similar densities of invertebrates at all marshes. However, fewer invertebrates occurred in sediment cores at CH than at CB and LH (ANOVA with Bonferroni adjustment,  $F = 19.7$ ,  $n = 3$ ,  $P < 0.001$ ). Annelid and nematode worms accounted for the greatest difference between CH and reference marsh densities. However, CH also demonstrated lower densities than reference marshes for all other invertebrate orders, except Diptera.

Fallout traps proved to be the most powerful sampling method for common invertebrate taxa (median = 8 samples) and pitfall traps the least (median = 35 samples) (Table 1). Pitfall and fallout traps were the most efficient to process, requiring 0.5 and 0.75 h per sample, respectively. Sediment cores were the least efficient to process, requiring 6 h per sample.

## ***Conclusions***

Based on these results, I proposed that a majority of field and laboratory effort be focused on fallout trap samples. Setting eight fallout traps at each site for each sampling event should allow statistically powerful detection of differences in combined salmon prey (i.e., Araneae, Coleoptera, Diptera, Hemiptera, Homoptera, and Hymenoptera) as well as total Diptera and chironomid flies. Although sediment cores capture invertebrate taxa very different from fallout traps, they require substantial processing time per sample, and many samples are necessary to detect significant differences in invertebrate densities. Pitfall traps are efficient to process; however, there was considerable taxa overlap with fallout traps, and many samples need to be collected.

## **2003 INTENSIVE STUDY**

Sampling in 2003 focused on characterizing insect abundance and composition using fallout traps in distinct vegetation types at CH and the five reference marshes. I also documented vegetation composition and physicochemical factors, to help explain insect assemblage patterns. The methods and results of these insect–habitat investigations are presented as scientific manuscripts in the next two chapters. Information on tidal channel fishes is presented below.

## ***Methods***

I monitored estuarine and marine fish occurrence in the main channel of CH to document pre-restoration conditions. Opportunity for fish to access the marsh is currently minimal due to the tidal elevation and small diameter of the intake/outlet pipe

in Crescent Harbor. On a spring tide in March, May, and June, I used a modified fyke net to capture any fish entering the marsh on an incoming tide. Such nets have been used to trap fishes utilizing marsh channels in other systems (Levy and Northcote 1982, Shreffler et al. 1992, Miller and Simenstad 1997, Gray et al. 2002). In the same tidal series, I also sampled fish at one reference marsh, setting the net at high tide and counting fishes captured in the net during ebb flow from the marsh. MP represented the reference marsh in March, and EB in May and June.

For all fish captured, I recorded species and abundance. Up to 20 individuals of each salmon species were anesthetized with MS-222 for measurement of fork lengths. Up to five individuals of each salmon species were taken for diet analysis. These individuals were preserved in the field with 5% buffered formalin. In the laboratory, dissected stomachs were ranked for fullness, and then contents were sorted, enumerated, and identified to the finest taxonomic resolution possible under an illuminated dissecting microscope. I ranked the amount of digestion based on the percentage of contents identified. I then recorded the damped wet weight of all organisms combined and of each taxonomic group. For each taxonomic group, I calculated the frequency of occurrence, percent numeric and gravimetric contribution, and percent total IRI<sup>1</sup> (Pinkas et al. 1971).

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<sup>1</sup> Index of Relative Importance, equivalent to (frequency of occurrence) x [(% numeric composition) + (% gravimetric composition)].

## **Results**

I found six fish species in CH and reference tidal channels during the sampling season: Chinook salmon, chum salmon, shiner perch, snake pricklyback (*Lumpenus sagitta*), Pacific staghorn sculpin (*Leptocottus armatus*), and threespine stickleback (*Gasterosteus aculeatus*). Threespine stickleback dominated the numerical composition at CH (88%), whereas shiner perch represented 96% of the assemblage at reference marshes (Figure 3). Juvenile salmon were present at reference marshes but absent from CH, and total fish densities at CH represented only 5% of reference marsh densities.

Of six juvenile Chinook salmon (41–90 mm) collected from reference marshes for diet analysis, the stomachs of two individuals were empty, three were moderately full, and one was totally full. Adult chironomid flies comprised 53.9% of the IRI, and gammarid amphipods 24.0% (Table 2). Chironomids were the most representative prey item, having the greatest frequency of occurrence and comprising 55.4% of the numeric composition; however, gammarid amphipods contributed the greatest biomass (47.7%) to the sample overall. Chironomids (Miller and Simenstad 1997) and gammarid amphipods (Gray et al. 2002) were important prey items for juvenile Chinook in other Pacific Northwest estuaries.

**Table 1.** Results of sample size power analysis for three invertebrate sampling methods.

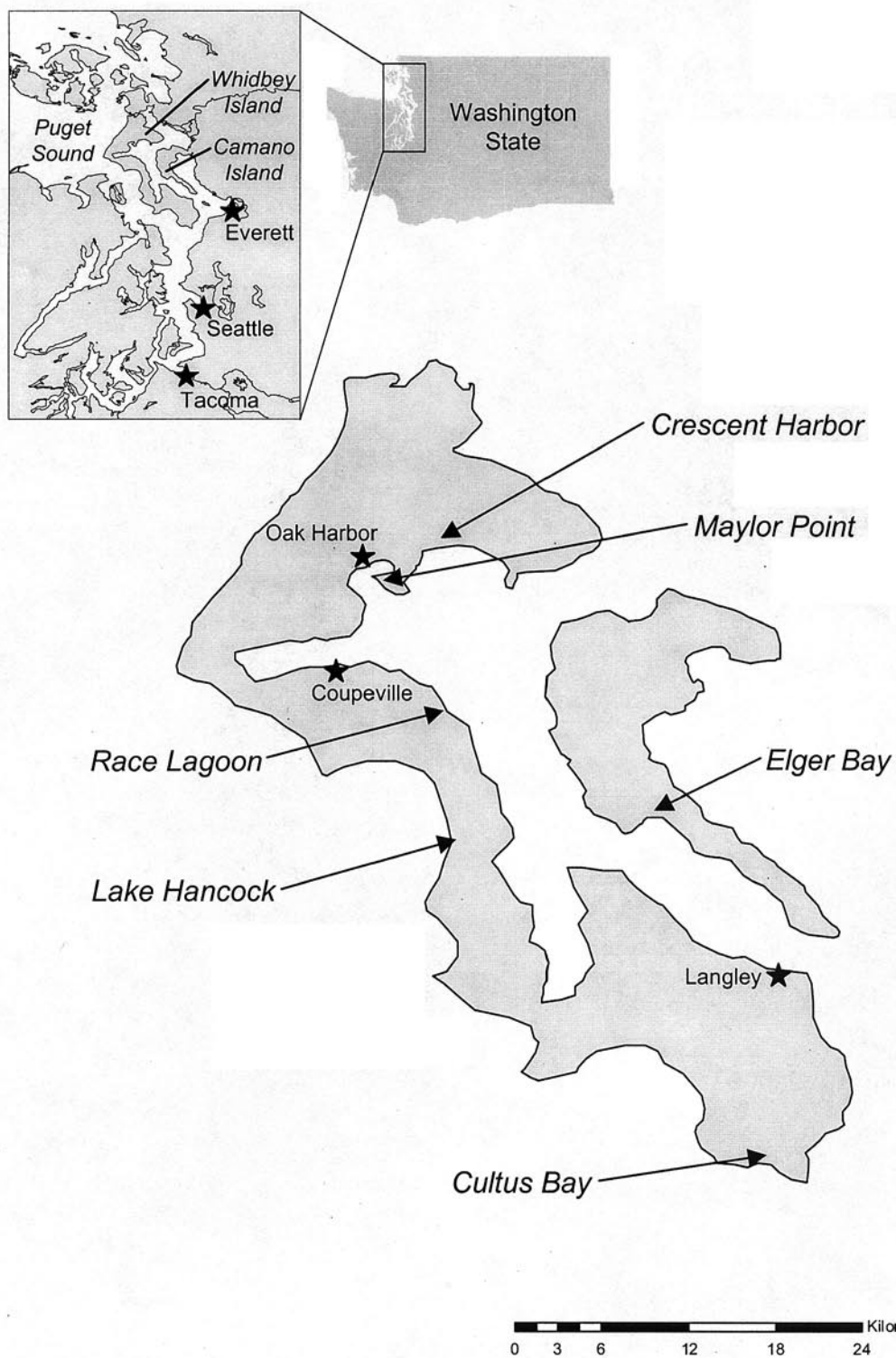
| Sampling Method | Taxa            | Number of Samples |     |    |
|-----------------|-----------------|-------------------|-----|----|
|                 |                 | CH                | CB  | LH |
| Sediment Cores  | Salmon Prey     | 14                | 8   | 47 |
|                 | Acari           | 26                | 46  | 27 |
|                 | Annelida        | 79                | 6   | 8  |
|                 | Bryozoa         | -                 | 177 | 69 |
|                 | Diptera         | 16                | 8   | 53 |
|                 | Harpacticoida   | 200               | 30  | 34 |
|                 | Nematoda        | 16                | 8   | 29 |
| Fallout Traps   | Salmon Prey     | 7                 | 2   | 6  |
|                 | Acari           | 64                | 21  | 17 |
|                 | Diptera         | 10                | 2   | 8  |
|                 | Ceratopogonidae | 23                | 13  | 2  |
|                 | Chironomidae    | 2                 | 7   | 7  |
|                 | Hemiptera       | 16                | 9   | 7  |
|                 | Hymenoptera     | 13                | 8   | 17 |
| Pitfall Traps   | Salmon Prey     | 23                | 16  | 20 |
|                 | Acari           | 55                | 28  | 16 |
|                 | Amphipoda       | -                 | 23  | 87 |
|                 | Araneae         | 16                | 43  | 59 |
|                 | Diptera         | 45                | 45  | 33 |
|                 | Hemiptera       | 62                | 36  | 32 |
|                 | Hymenoptera     | 55                | 10  | 43 |

*Notes:* Number of samples needed to detect a 50% change in invertebrate density with 80% power ( $1-\beta$ ) and 10% Type I error rate ( $\alpha$ ) (Zar 1999). Salmon prey includes Araneae, Coleoptera, Diptera, Hemiptera/Homoptera, and Hymenoptera combined. CH – Crescent Harbor, CB – Cultus Bay, LH – Lake Hancock

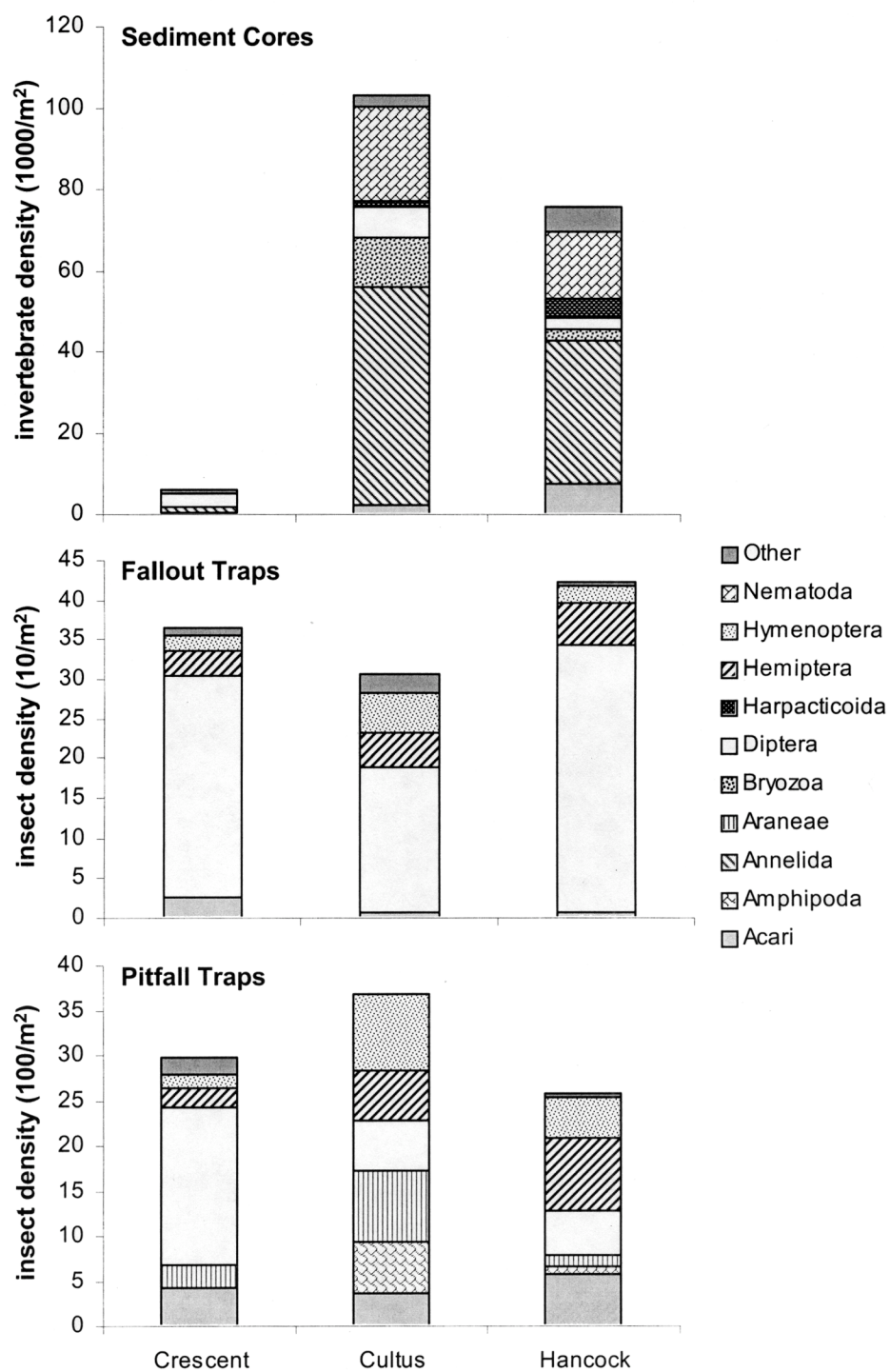
**Table 2.** Summary of juvenile salmon stomach contents from reference marsh tidal channels.

| Prey Taxa          | Frequency<br>of Occurrence | Numeric<br>Composition (%) | Gravimetric<br>Composition (%) | IRI (%) |
|--------------------|----------------------------|----------------------------|--------------------------------|---------|
| Chironomidae adult | 3                          | 55.4                       | 20.4                           | 53.9    |
| Gammaridea         | 2                          | 3.0                        | 47.7                           | 24.0    |
| Aphididae          | 2                          | 3.0                        | 4.3                            | 3.4     |
| Chironomidae pupa  | 1                          | 9.9                        | 3.9                            | 3.3     |
| Insect parts       | 1                          | 11.9                       | 1.4                            | 3.2     |
| Polychaeta         | 1                          | 1.0                        | 10.4                           | 2.7     |
| Collembola         | 2                          | 4.0                        | 1.4                            | 2.6     |
| Plant parts        | 1                          | 5.9                        | 2.9                            | 2.1     |
| Cumacea adult      | 2                          | 2.0                        | 2.2                            | 2.0     |
| Chironomidae larva | 2                          | 2.0                        | 1.1                            | 1.4     |
| Diptera adult      | 1                          | 1.0                        | 3.9                            | 1.2     |
| Harpactacoidea     | 1                          | 1.0                        | 0.4                            | 0.3     |

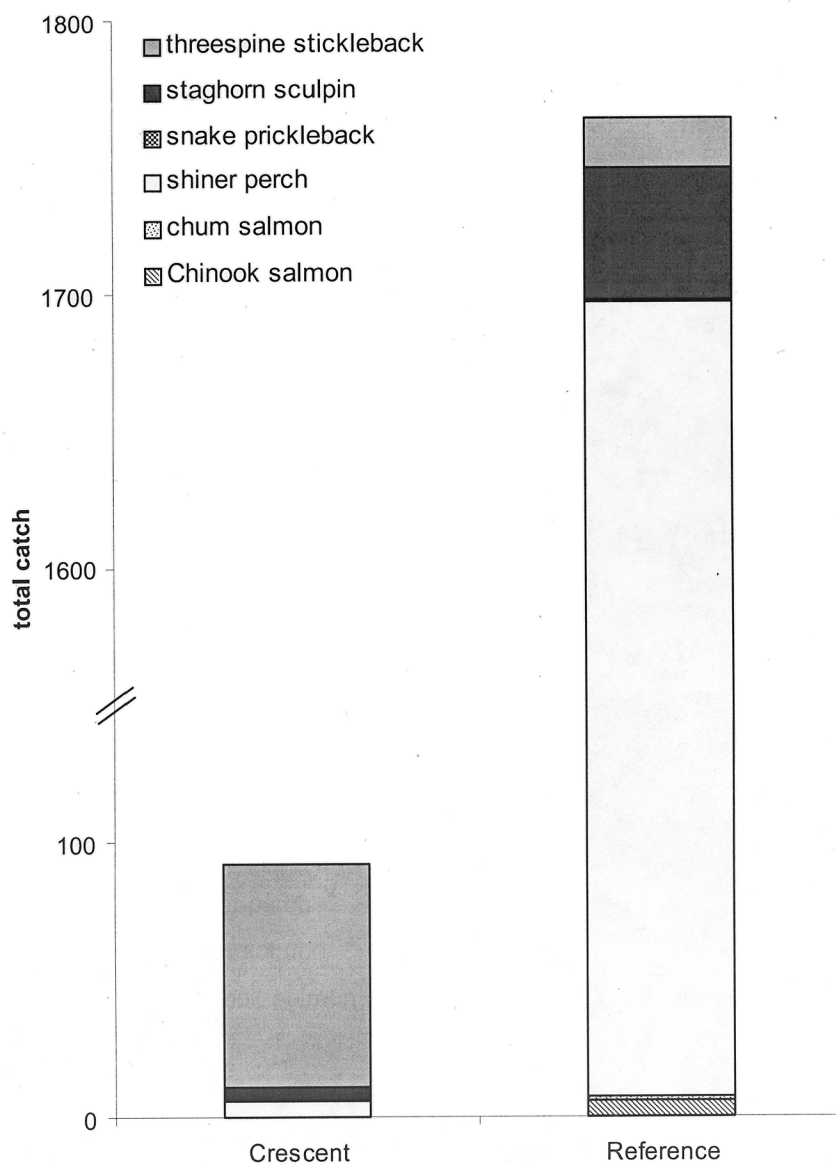
*Notes:* IRI – Index of Relative Importance, equivalent to (frequency of occurrence) x [(% numeric composition) + (% gravimetric composition)] (Pinkas et al. 1971)



**Figure 1.** Map of Whidbey and Camano Islands, showing locations of Crescent Harbor marsh and the five reference marshes.



**Figure 2.** Average densities of invertebrates from three sampling methods at Crescent Harbor, Cultus Bay, and Lake Hancock.



**Figure 3.** Total catch of tidal channel fishes at Crescent Harbor marsh and reference marshes. Note break in y-axis scale.

## **INFLUENCE OF HABITAT ON INSECT ASSEMBLAGES IN TIDALLY RESTRICTED AND NATURAL PUGET SOUND SALT MARSHES**

### **ABSTRACT**

Although biogeochemical and vegetation changes associated with tidal restrictions are well documented, indirect effects on salt marsh insect assemblages have rarely been studied. This project investigated insect assemblages in one tidally restricted and five natural salt marshes in Island County, Washington. Using fallout traps, I characterized insect diversity, density, and composition in three vegetation types: *Salicornia virginica*, *Juncus balticus*, and *Typha latifolia*. Associated vegetation assemblages and physicochemical factors were documented at multiple space and time scales, to help explain insect assemblage patterns. Similar insect taxa inhabited all marshes: chironomid and dolichopodid flies, Coccoidea, Saldidae, Acari, and lathridiid beetles were particularly common. Within a given marsh, assemblages differed between *S. virginica* and *T. latifolia*. However, the insect assemblages inhabiting *S. virginica* varied among marshes. Differences were related primarily to tidal flooding and porewater depth as well as local and marsh-scale vegetation patterns. These results suggest that insect assemblages in *S. virginica* and *T. latifolia* at the tidally restricted marsh were within the range of natural variation. However, if we consider the areal extent of these vegetation types within the tidally restricted marsh, it is likely that the overall insect community is more characteristic of freshwater, rather than euhaline, marshes.

## INTRODUCTION

During the past century, more than 50% of tidal wetlands in the U.S. have been lost or hydrologically modified for development, agriculture, or insect control (Roman et al. 1995). Biogeochemical and vegetation changes associated with tidal restrictions are well documented (Zedler et al. 1980, Roman et al. 1984, Portnoy and Giblin 1997, Kuhn et al. 1999). Reduced tidal flooding decreases porewater salinity, lowers the water table, allows more aerobic decomposition, and likely contributes to greater soil density and lower surface elevation. Salt marsh plants adapted to high salinity levels and frequent anaerobic conditions lose their competitive advantage over terrestrial and freshwater plants, leading to vegetation change.

Water management structures directly interfere with nekton passage (Rogers et al. 1994) and can dramatically reduce nekton abundance and diversity (Roman et al. 2002). Indirect effects of tidal restrictions on non-target invertebrates and wildlife are rarely studied. Yet, understanding their response is of basic and applied importance. For example, salinity and flooding are strong environmental filters for vegetation. Evaluating whether these filters act as strongly on animal communities is informative for assembly rule theory. Also, knowing whether animal communities inhabiting degraded marshes are within the limits of natural variation is relevant to predicting functional trajectories for restoring ecosystems.

With their diverse ecological requirements and life history strategies, insects are sensitive to many factors that influence ecosystem structure (Garono et al. 2001). This characteristic allows insects to be useful indicators of ecological integrity (Garono et al.

2001). In addition, their high diversity and abundance make insects appropriate indicators even in small habitats (Desender and Maelfait 1999). A number of studies have related insect assemblage patterns to vegetation zones and abiotic factors in natural coastal wetlands. In general, insect assemblages respond primarily to biological fluctuations, particularly of their food resources (Davis and Gray 1966, Cameron 1972, Balling and Resh 1991). This trophically-driven response is sometimes revealed as insect assemblage differences by vegetation zone (Davis and Gray 1966, Cameron 1972). Tides appear to have no direct effect on insect abundance, diversity, or trophic structure (Davis and Gray 1966, Cameron 1972, 1976). However, tides exhibit indirect effects on insect assemblages through their influence on food quality, availability, and vegetation patterns (Balling and Resh 1991).

This project investigates insect assemblage patterns and potential controlling factors in barrier salt marshes of northern Puget Sound. I compare insect assemblages in distinct vegetation types at one tidally restricted and five natural marshes. In addition, I evaluate biotic and abiotic environmental factors as underlying causes of variation in insect assemblages. It is expected that insect assemblages differ among vegetation types and that tidal flooding duration is a major, although indirect, controlling factor.

## **METHODS**

### ***Site Descriptions***

Crescent Harbor marsh (CH) is located on the northeastern shore of Whidbey Island, Island County, Washington (48° 17' 58"N, 122° 36' 28"W). Once the largest

barrier salt marsh on Whidbey Island (120 ha), CH was diked and drained in the early 1900s for agricultural use, and the natural channel was replaced with a gated culvert. In 1993, the tide gate was permanently opened; however, the undersized culvert severely limits tidal heights during the summer (0.6 m vs. 3.7 m in the bay) and impedes freshwater discharge during the winter (Orr et al. 2003). Restoration of full tidal exchange to CH is planned for August 2005, when the gated culvert will be replaced with an enlarged, open channel.

I selected five Island County salt marshes with natural tidal regimes as references for CH: Cultus Bay (CB), Elger Bay (EB), Lake Hancock (LH), Maylor Point (MP), and Race Lagoon (RL). The marshes range in location, size, elevation, vegetative composition, and disturbance history (Table 3) and are the best representatives of natural salt marsh conditions in Island County.

### ***Sampling Design***

I collected insect and environmental data in three vegetation types defined by the following plant species: *Salicornia virginica* (American glasswort), *Juncus balticus* (Baltic rush), and *Typha latifolia* (cattail). All marshes contained *S. virginica*; however, only CH and LH contained *J. balticus* and *T. latifolia* in adequate quantity for study. Sampling effort was split over two neap tide series in April, June, and August 2003. I sampled *S. virginica* at all marshes during the first tidal series, and the three vegetation types at CH and LH during the second. Access and ownership limited the locations and general areas available for sampling within each marsh. Suitable areas were outlined

onsite with a handheld global positioning system unit (Magellan Meridian Marine, Thales Navigation, Santa Clara, CA) and imported to ArcView 3.2 (ESRI, Redlands, CA). I randomly located eight stations within each area for each sampling event using the ArcView extension Random Point Generator 1.1 (Jenness Enterprises, Flagstaff, AZ).

### ***Techniques***

I sampled salt marsh insect assemblages using one fallout trap at each station. I used clear plastic containers (43W x 58L x 15H cm), each resting on a 40 x 55-cm PVC platform and surrounded by four 1.5-m stakes. One end of the bin was tethered to a stake, such that the bin could rise with tidal flooding of the marsh surface, remain in place, and come back to rest on the level platform upon the ebb tide. The traps were filled with 3 L of water mixed with 5 mL of unscented biodegradable dish soap and set for 48 h. Insects were collected by pouring trap contents through a 106- $\mu$ m sieve and washing the retained portion into a labeled jar. I preserved insects onsite with 70% isopropyl alcohol. Samples were brought to the laboratory and were sorted, identified, and enumerated under a dissecting microscope. I generally identified insects to family and crustaceans, millipedes, and arachnids to order. However, Apterygota, Thysanoptera, and newly hatched or rare insects were identified to order, and Hymenoptera and some Homoptera (e.g., Coccoidea) were identified to superfamily.

I characterized the local environment at each fallout trap concurrently with insect sampling. Porewater salinity and depth were measured within 3 m of each trap. Using a

hand auger, I dug to 10 cm below the porewater, to the extent of the auger (1.2 m), or to impervious substrate. I allowed approximately 20 min for the porewater level to stabilize before determining its depth. Salinity was gauged using a digital salinity-conductivity-temperature instrument (YSI-30, YSI, Inc., Yellow Springs, OH). To document the vegetation assemblage, I laid around each trap a 2.5 x 2.5-m grid of 25 cells, using marked rope. I randomly selected five cells, and within each, recorded plant species presence and maximum standing height. Such frequency methods are considered less prone to observer differences than percent cover estimates (Tear 1995). Flooding duration was calculated at each station for 15 d preceding each sampling event. In ArcView, I used station coordinates to query LIDAR digital elevation models (DEMs) (Martinez 2003) for reference marshes. Elevations at CH were estimated from a DEM based on digitized topographic survey data (Aelyteck and Amsatek 1994). Hourly tidal heights for reference marshes were acquired from the NOAA National Water Level Observation Network's (NWLON) Seattle station; tidal heights within the main channel of CH were recorded using a continuous water level logger (WL15, Global Water Instrumentation, Inc., Gold River, CA). I entered tidal height and elevation data into Tide Miner 3.0 (Numbers to Knowledge, Williamstown, MA) to compute flooding duration.

I monitored additional environmental data for comparison among vegetation types and sites. Sediment samples were collected once at five stations in each sampling area for analysis of soil organic matter (SOM). I used a standard corer to extract a 385 cm<sup>3</sup> of sediment. Samples were frozen, then dried at 105 °C for 30 h and burned at 550

°C for 2 h (Portnoy and Giblin 1997). I considered the mass lost upon burning to be the total organic matter. Throughout the sampling season, hourly air/water temperature near the marsh surface was recorded in each sampling area using temperature loggers (StowAway TidbiT, Onset Computer Corporation, Bourne, MA). Daily precipitation levels were acquired from Washington State University/Island County Precipitation Network locations near each site. Marsh-scale features, including size, plant species richness, and frequency of vegetation types, were documented in a vegetation mapping study that is described in the following chapter.

### ***Statistical Analysis***

For vegetation type comparisons, insect diversity and abundance were analyzed using Nested ANOVA, followed by Tukey's multiple comparison test (Zar 1999). I used species richness as the diversity metric. Richness was square root-transformed, and densities were log-transformed, prior to analysis. Fixed factors included sampling month, marsh, and vegetation type nested within marsh. In addition, I analyzed insect assemblages using multivariate statistical procedures in PC-ORD 4.25 (McCune and Mefford 1999). I evaluated differences among assemblages, defined by month, marsh, and vegetation type, using a multi-response permutation procedure (MRPP) based on Sorensen distance. MRPP is a non-parametric method that tests for differences among pre-defined groups (Zimmerman et al. 1985). Significance of the null hypothesis was assessed by Monte Carlo randomization procedure with 1000 permutations. In MRPP, the chance-corrected within-group agreement (A) describes the effect size, independent

of the sample size. I considered  $A > 0.2$  to be ecologically significant. I split my dataset various ways to achieve pairwise comparisons, using Bonferroni's adjustment to the p-value. Assemblage patterns were also evaluated using nonmetric multidimensional scaling (NMDS). Based on ranked distances, this ordination method is well suited for nonnormal or discontinuous data (McCune and Grace 2002). I used Sorensen's distance measure on log-transformed abundance data. Rare taxa (occurring in  $<5\%$  of the samples) and outlying stations (average distance  $>2$  sd) were excluded from ordination analysis. Using Dufrene and Legendre's (1997) method, I calculated insect indicator values (INDVAL) to compare taxa performance across vegetation types. INDVALs express the extent to which a taxon occurs in particular habitat without error (McCune and Grace 2002). The perfect indicator (value = 100) is faithful and exclusive to a particular habitat (McCune and Grace 2002). Significance of the indicator value for each taxon was tested by a Monte Carlo randomization procedure with 1000 permutations (McCune and Grace 2002). Finally, environmental characteristics for each vegetation type were transformed as needed and analyzed using ANOVA, followed by Tukey's multiple comparison test.

I conducted similar analyses for comparing insects across marshes. I tested for month and marsh effects on diversity, density, and environment using ANOVA, followed by Tukey's multiple comparison test. MRPP and NMDS were again used to evaluate assemblage patterns, and indicator values were calculated for each marsh. To investigate underlying causes of insect patterns, I performed principal components analysis (PCA) on environmental variables, and then regressed average insect ordination

scores on the primary axes. PCA is an ordination method useful for data having approximately linear relationships among normally distributed variables (McCune and Grace 2002). When applied to environmental data, PCA reduces a large number of intercorrelated variables to a few uncorrelated macrovariables (McCune and Grace 2002). I used a correlation-based cross-products matrix for the analysis. Environmental variables included abiotic conditions as well as marsh-scale features and local vegetation characteristics. Data were transformed to achieve  $|\text{skew}| < 1$ .

## RESULTS

### *Vegetation Type Comparisons*

92 taxa of insects in 20 orders and 3 classes were collected in the three vegetation types at CH and LH. Insect richness and density were affected by sampling month, marsh, and vegetation type within marsh, as well as interactions between factors (Figure 4, Table 4). In total, samples collected in June and August had twice the insect richness and 75% and 21% greater density, respectively, than those collected in April (Tukey test:  $D_{r,ApJ} = -1.51$ ,  $D_{r,ApAu} = -1.43$ ,  $P_r < 0.001$ ;  $D_{d,ApJ} = -0.25$ ,  $D_{d,ApAu} = -0.18$ ,  $P_d < 0.004$ ). To investigate vegetation type effects more clearly, the data were analyzed separately by month. June and August offered similarly large insect assemblage differences among vegetation types. To eliminate interacting effects, all further vegetation type comparisons were conducted on June data exclusively. As such, insect assemblages were compared during their peak complexity and density.

In June, with all vegetation types combined, CH supported greater insect richness than LH (25.9 vs. 21.1 taxa) and 92% higher density (Table 4). However, assemblages varied widely within marshes (MRPP:  $A = 0.07$ ,  $P < 0.001$ ). At CH, *T. latifolia* demonstrated greater insect richness than *S. virginica* (Tukey test:  $D = 0.44$ ,  $P = 0.02$ ) and 3X greater density than *S. virginica* and *J. balticus* (Tukey test:  $D_{TS} = 0.65$ ,  $D_{TJ} = 0.55$ ,  $P < 0.001$ ) (Figure 4). Furthermore, the *T. latifolia* assemblage differed from *S. virginica* and *J. balticus* assemblages (MRPP:  $A_{TS} = 0.27$  and  $A_{TJ} = 0.29$ ,  $P < 0.001$ ). Similarly at LH, richness was greatest in *T. latifolia* and least in *S. virginica* (Tukey test:  $D_{TJ} = 0.44$ ,  $D_{JS} = 0.74$ ,  $P < 0.03$ ), and density was 67% higher in *T. latifolia* than in *S. virginica* and *J. balticus* (Tukey test:  $D_{TS} = 0.20$ ,  $D_{TJ} = 0.27$ ,  $P \leq 0.05$ ). However, the *S. virginica* assemblage was different than assemblages in *T. latifolia* and *J. balticus* (MRPP:  $A_{ST} = 0.36$ ,  $A_{SJ} = 0.33$ ,  $P < 0.001$ ).

NMDS supported the assemblage patterns identified by MRPP, with CH *T. latifolia* stations separate from other CH stations and LH *S. virginica* stations distant from all other stations (Figure 5). In addition, NMDS revealed that assemblages in *T. latifolia* were fairly similar at CH and LH, although some separation occurs on axis 2.

Eight taxa comprised 26–76% of the total density within vegetation types: chironomid, dolichopodid, and ephydrid flies; Collembola; Acari; Coccoidea (scale insects); lathridiid beetles; and Saldidae (shore bugs) (Figure 6). INDVAL revealed differences in insect composition among vegetation types (Monte Carlo permutation test:  $P \leq 0.005$ ). Indicator taxa were identified for all vegetation types except LH *J. balticus* and *T. latifolia* (Table 5).

CH and LH differed in all measured environmental variables (Table 4). Specifically, CH was characterized by reduced flooding duration, porewater salinity and depth, and SOM. Within each marsh, environmental variables typically differed among vegetation types (Table 6). Even though all vegetation types at CH received minimal tidal flooding, *S. virginica* experienced higher porewater salinity than the other vegetation types (Tukey test:  $D_{ST} = 3.6$ ,  $D_{SJ} = 3.0$ ,  $P < 0.001$ ), and *J. balticus* had deeper porewater (Tukey test:  $D_{JT} = -0.49$ ,  $D_{JS} = -0.41$ ,  $P < 0.002$ ). SOM was least in *J. balticus* and greatest in *T. latifolia* (Tukey test:  $D_{JS} = -0.29$ ,  $D_{ST} = -0.13$ ,  $P < 0.05$ ). At LH, tidal flooding duration and porewater salinity were greatest in *S. virginica* and least in *T. latifolia* (Tukey test:  $D_{fd,SJ} = 0.11$ ,  $D_{fd,JT} = 0.19$ ,  $P_{fd} < 0.001$ ;  $D_{ps,SJ} = 3.5$ ,  $D_{ps,JT} = 2.0$ ,  $P_{ps} < 0.001$ ); porewater depth was similar among vegetation types. Finally, SOM was lower in *S. virginica* than in *T. latifolia* and *J. balticus* (Tukey test:  $D_{ST} = -0.34$ ,  $D_{SJ} = -0.33$ ,  $P < 0.001$ ).

### ***Marsh Comparisons***

In total, 86 insect taxa in 14 orders and 3 classes were collected from the *S. virginica* vegetation type in the 6 marshes. Again, insect richness and density varied by sampling month (Figure 7, Table 7). On average, June samples had the greatest insect richness (24.1 taxa) and April samples the least (10.4 taxa, Tukey test:  $D_{JAu} = 0.32$ ,  $D_{AuAp} = 1.4$ ,  $P < 0.001$ ). Also, June and August had 54% and 35% greater density, respectively, than April (Tukey test:  $D_{JAp} = 0.25$ ,  $D_{AuAp} = 0.17$ ,  $P < 0.001$ ). When

analyzed separately by month, June samples best distinguished assemblages among marshes, and I conducted further analyses on June data only.

CH had greater insect richness than LH (28.4 vs. 21.4 taxa, Tukey test:  $D_{CHLH} = 0.71$ ,  $P = 0.002$ ), with other marshes intermediate (Figure 7). Insects at LH were 82–200% more dense than at CB, CH, RL, and EB (Tukey test:  $0.24 < D < 0.45$ ,  $P < 0.02$ ); in addition, MP had 154% greater insect density than EB (Tukey test:  $D = 0.27$ ,  $P = 0.008$ ). Again, assemblages varied widely within marshes (MRPP:  $A = 0.08$ ,  $P < 0.001$ ). However, comparisons between individual marshes revealed a pattern similar to insect abundance: LH differed from CB, EB, RL, and CH (MRPP:  $0.21 < A < 0.34$ ,  $P < 0.001$ ), and MP also differed from CH (MRPP:  $A = 0.25$ ,  $P < 0.001$ ).

These findings were supported by NMDS (Figure 8). LH and MP stations were positioned separately from other marshes, particularly RL on axis 1 and CH on axes 2 and 3. CB and EB were not readily distinguishable.

Nine taxa comprised 41–74% of total density within marshes: chalcidoid wasps; ceratopogonid, chironomid, and dolichopodid flies; Acari; Saldidae; Coccoidea; Cicadellidae (leafhoppers); and lathridiid beetles (Figure 9). INDVAL determined significant (Monte Carlo permutation test:  $P \leq 0.01$ ) indicator taxa for CH, CB, LH, and RL (Table 8).

All environmental variables differed among marshes (Table 6). LH experienced more tidal flooding than all other marshes (Tukey test:  $0.28 \leq D \leq 0.36$ ,  $P < 0.001$ ). LH also had porewater higher in salinity and closer to the marsh surface than all other marshes (t-test:  $D_{ps,LHMP} = 13.5$ ,  $D_{ps,LHCH} = 13.0$ ,  $P_{ps} < 0.001$ , CB/EB/RL  $n < 3$ ; Tukey

test:  $0.26 < D_{pd} < 0.57$ ,  $P_{pd} < 0.07$ ). Finally, MP contained less SOM than all other marshes ( $-0.24 < D \leq -0.18$ ,  $P \leq 0.06$ ).

PCA extracted 10 components from the environmental matrix. The first 4 components represented 98.2% of the variance in the matrix of environmental correlations (Table 9). Loadings describe component correlation with environmental variables, where larger absolute values suggest a stronger correlation. Regression analysis of average NMDS axis scores on the principle components showed that axes 2 and 3 were related to components 2 and 1, respectively (ANOVA:  $F_{22} = 13.4$ ,  $F_{31} = 21.0$ ,  $n = 6$ ,  $P < 0.03$ ; Linear Regression:  $R^2_{22} = 0.71$ ,  $R^2_{31} = 0.80$ ). Thus, NMDS axis 2 correlates primarily with hydrologic features, including rainfall, *Jaumea carnosa* (fleshy *Jaumea*) frequency in the insect sampling area, porewater depth, and tidal flooding duration. NMDS axis 3 correlates most strongly with vegetation features at the marsh scale, specifically plant richness and the frequency of upland herbs and shrubs. NMDS axis 1 was not correlated with any of the measured environmental features.

## DISCUSSION

In this study of insects in barrier salt marshes, I found that *S. virginica* and *T. latifolia* supported different assemblages; however, the *S. virginica* assemblages were not consistent among marshes. Plant composition differences within the *S. virginica* vegetation type explained only a portion of the insect variation. Porewater depth and tidal flooding duration as well as vegetation composition at the marsh scale represented additional underlying causes of insect variation.

Whether differences in insect assemblages are discernable among different vegetation types may depend upon the habitats being compared. Davis and Gray (1966) compared insects in *Spartina alterniflora*, mixed *S. alterniflora*–*Salicornia perennis*–*Limonium carolinianum*, *Juncus roemerianus*, *Spartina patens*, and *Distichlis spicata* and found differences in insect abundance and composition. Similarly, Dobel et al. (1990) saw different spider assemblages between *S. alterniflora* and *S. patens*. However, Cameron (1972) observed insect assemblages to be very similar between *Salicornia pacifica* and *Spartina foliosa*. In this study, the vegetation types demonstrating consistent assemblage differences represented opposing ends of salinity and tidal inundation gradients, factors possibly related to NMDS axes 1 and 3, respectively. In addition, *S. virginica* and *T. latifolia* differed greatly in vertical structure. The intermediate *J. balticus* assemblage was not readily distinguishable; assemblage differences reflected spatial distance rather than habitat preference.

This study was not designed to decipher between the influences of vegetation versus abiotic factors in different vegetation types. However, the observed pattern of taxa richness (low in *S. virginica* / high in *T. latifolia* and low at LH / high at CH) could have been related to tidal flooding and salinity. This type of relationship was demonstrated with spider and ground beetle assemblages in salt marshes of the North and Baltic Seas (Irmeler et al. 2002). Also, Desender and Maelfait (1999) observed lower insect species richness in true salt marshes than in brackish and freshwater marshes. Cameron (1976), however, found that tidal inundation had no direct effect on adult insect diversity, composition, or trophic structure. At least for herbivorous and

detritivorous insects, the observed pattern of increased insect density in *T. latifolia* might have been related to the habitat's great quantity (Vince et al. 1981) of high quality (Balling and Resh 1991) food resources.

Factors distinguishing insect assemblages among marshes included biotic and abiotic factors at both local (sampling area) and marsh scales. NMDS axis 3 best separated CH from the reference marshes, perhaps due to CH's high insect diversity. This axis was related to herb frequency, shrub frequency, and plant richness at the marsh scale. Although plant species richness was low within the *S. virginica* sampling area, CH as a whole supported high plant species richness and a variety of vegetative cover types. The different cover types were arranged in a mosaic pattern at CH, leading to a higher edge:interior ratio than was found at the more stratified reference sites. Edges between salt marsh vegetation types may contribute to higher insect diversity (Webb 1976). NMDS axis 2 separated LH from all marshes except MP and appeared to illustrate LH's high insect density. This axis correlated with rainfall, local *J. carnosus* frequency, porewater depth, and tidal flooding duration. LH experienced more tidal flooding than all other marshes studied, likely contributing to elevated porewater levels and a unique local plant assemblage. In freshwater wetlands, hydrology is considered a major structuring factor of invertebrate assemblages (Wissinger 1999), and wetlands with intermediate hydroperiods have demonstrated a higher abundance of emergent insects than drier or wetter wetlands (Whiles and Goldowitz 2001). It may be possible that tidal flooding at LH represented an intermediate disturbance for its resident insect assemblage, even though it was not intermediate in the marshes investigated here.

Within *S. virginica*, CH was not consistently different from the reference marshes in measured environmental characteristics. This result might have been expected, given that vegetation is somewhat indicative of specific chemical and hydrologic conditions (Ewing 1983, Hackney et al. 1996). LH likely represents the best reference marsh for CH, based on similar elevation, size, and agricultural history. When compared to LH across the three vegetation types, CH demonstrated several primary symptoms of tidal restriction: limited tidal flooding, lower porewater salinity and depth, and reduced SOM. The effect of tidal restriction was further revealed in the prevalence of freshwater marsh vegetation at CH. Insect assemblages in *S. virginica* and *T. latifolia* at CH appeared to be within the range of natural variation. However, considering the areal extent of these vegetation types within CH, it is likely that the overall insect community is more characteristic of freshwater, rather than euhaline, marshes.

**Table 3.** Characteristics of Island County salt marshes included in study.

| Variable             | Marsh                                                       |                                       |                                              |                                                         |                             |                             |
|----------------------|-------------------------------------------------------------|---------------------------------------|----------------------------------------------|---------------------------------------------------------|-----------------------------|-----------------------------|
|                      | Crescent Harbor                                             | Cultus Bay                            | Elger Bay                                    | Lake Hancock                                            | Maylor Point                | Race Lagoon                 |
| Location             | northeastern<br>Whidbey Is.                                 | southern<br>Whidbey Is.               | southern<br>Camano Is.                       | west central<br>Whidbey Is.                             | northeastern<br>Whidbey Is. | east central<br>Whidbey Is. |
| Latitude             | 48° 17' 58"N                                                | 47° 55' 29"N                          | 48° 07' 51"N                                 | 48° 06' 47"N                                            | 48° 16' 44"N                | 48° 11' 33"N                |
| Longitude            | 122° 36' 28"W                                               | 122° 23' 23"W                         | 122° 28' 30"W                                | 122° 35' 46"W                                           | 122° 38' 33"W               | 122° 35' 57"W               |
| Size (ha)            | 96                                                          | 18                                    | 27                                           | 77                                                      | 34                          | 17                          |
| Elevation (m MLLW)   | 2.6                                                         | 3.0                                   | 3.5                                          | 2.8                                                     | 3.4                         | 3.8                         |
| Rainfall (cm)        | 5.0 (0.08)                                                  | 5.0 (0.26)                            | 5.7 (0.23)                                   | 4.4 (0.00)                                              | 3.5 (0.00)                  | 3.9 (0.06)                  |
| Total plant richness | 66                                                          | 28                                    | 34                                           | 28                                                      | 40                          | 18                          |
| Cover type frequency |                                                             |                                       |                                              |                                                         |                             |                             |
| salt marsh           | 19%                                                         | 44%                                   | 45%                                          | 60%                                                     | 76%                         | 50%                         |
| brackish marsh       | 17%                                                         | 0%                                    | 2%                                           | 4%                                                      | 0%                          | 0%                          |
| freshwater marsh     | 39%                                                         | 0%                                    | 4%                                           | 0%                                                      | 0%                          | 0%                          |
| upland shrub         | 12%                                                         | 0%                                    | 4%                                           | 1%                                                      | 2%                          | 0%                          |
| mud / wood           | 2%                                                          | 47%                                   | 40%                                          | 26%                                                     | 4%                          | 6%                          |
| Impacts              | muted tide, sewage<br>treatment plant,<br>berms and ditches | upland<br>development,<br>81 ha diked | upland<br>development,<br>collection of logs | historic target range,<br>historic cranberry<br>farming | created on<br>dredge spoils | upland<br>development       |

*Notes:* Approximate marsh sizes and elevations were calculated in ArcView 3.2 using orthorectified aerial photographs and elevation data for vegetated areas from LIDAR and a topographic survey. Rainfall represents the sum of daily precipitation for 2 weeks prior to April, June, and August sampling (and June sampling alone). Plant and cover type data were collected in July 2003, using a stratified random sampling protocol described in the following chapter.

**Table 4.** Results of statistical tests for insects collected in three vegetation types at Crescent Harbor and Lake Hancock during April, June, and August 2003.

| Factor                             | Levels            | Test  | Dependent Variable  | Month | Statistic | n   | P value |
|------------------------------------|-------------------|-------|---------------------|-------|-----------|-----|---------|
| Month                              | Apr, Jun, Aug     | ANOVA | insect richness     |       | 379.6     | 143 | 0.000   |
|                                    |                   |       | insect density      |       | 28.3      | 143 | 0.000   |
| Marsh                              | CH, LH            |       | insect richness     |       | 48.7      | 143 | 0.000   |
|                                    |                   |       | insect density      |       | 57.4      | 143 | 0.000   |
| Month*Marsh                        |                   |       | insect richness     |       | 7.4       | 143 | 0.001   |
|                                    |                   |       | insect density      |       | 3.9       | 143 | 0.023   |
| Vegetation<br>(within Marsh)       | <i>Sv, Jb, Tl</i> |       | insect richness     |       | 38.6      | 143 | 0.000   |
|                                    |                   |       | insect density      |       | 25.6      | 143 | 0.000   |
| Month*Vegetation<br>(within Marsh) |                   |       | insect richness     |       | 10.9      | 143 | 0.000   |
|                                    |                   |       | insect density      |       | 6.8       | 143 | 0.000   |
| Marsh                              | CH, LH            | ANOVA | insect richness     | Apr   | 23.4      | 47  | 0.000   |
|                                    |                   |       |                     | Jun   | 35.0      | 48  | 0.000   |
|                                    |                   |       |                     | Aug   | 1.0       | 48  | 0.313   |
|                                    |                   | ANOVA | insect density      | Apr   | 28.3      | 47  | 0.000   |
|                                    |                   |       |                     | Jun   | 14.3      | 48  | 0.000   |
|                                    |                   |       |                     | Aug   | 15.7      | 48  | 0.000   |
| Vegetation<br>(within Marsh)       | <i>Sv, Jb, Tl</i> | ANOVA | insect richness     | Apr   | 3.2       | 47  | 0.024   |
|                                    |                   |       |                     | Jun   | 17.7      | 48  | 0.000   |
|                                    |                   |       |                     | Aug   | 45.5      | 48  | 0.000   |
|                                    |                   | ANOVA | insect density      | Apr   | 8.9       | 47  | 0.000   |
|                                    |                   |       |                     | Jun   | 19.2      | 48  | 0.000   |
|                                    |                   |       |                     | Aug   | 11.8      | 48  | 0.000   |
|                                    |                   | MRPP  | insect assemblage   | Apr   | 0.25      | 47  | 0.000   |
|                                    |                   |       |                     | Jun   | 0.36      | 48  | 0.000   |
|                                    |                   |       |                     | Aug   | 0.36      | 48  | 0.000   |
| Marsh                              | CH, LH            | ANOVA | flooding duration   | Jun   | 91.8      | 48  | 0.000   |
|                                    |                   |       | porewater salinity  | Jun   | 59.1      | 43  | 0.000   |
|                                    |                   |       | porewater depth     | Jun   | 18.6      | 48  | 0.000   |
|                                    |                   |       | soil organic matter | Jun   | 110.2     | 28  | 0.000   |
| Vegetation<br>(within Marsh)       | <i>Sv, Jb, Tl</i> | ANOVA | flooding duration   | Jun   | 33.4      | 48  | 0.000   |
|                                    |                   |       | porewater salinity  | Jun   | 167.0     | 43  | 0.000   |
|                                    |                   |       | porewater depth     | Jun   | 6.5       | 48  | 0.000   |
|                                    |                   |       | soil organic matter | Jun   | 53.1      | 28  | 0.000   |

Notes: CH – Crescent Harbor, LH – Lake Hancock, *Sv* – *Salicornia virginica*, *Jb* – *Juncus balticus*, *Tl* – *Typha latifolia*

**Table 5.** Results of indicator species analysis (INDVAL) in three vegetation types at Crescent Harbor and Lake Hancock.

| Indicator Taxon | Crescent Harbor |           |           | Lake Hancock |           |           |
|-----------------|-----------------|-----------|-----------|--------------|-----------|-----------|
|                 | <i>Sv</i>       | <i>Jb</i> | <i>Tl</i> | <i>Sv</i>    | <i>Jb</i> | <i>Tl</i> |
| Saldidae        | 0               | 0         | 1         | <b>95</b>    | 0         | 0         |
| Delphacidae     | <b>84</b>       | 2         | 0         | 2            | 0         | 0         |
| Drosophilidae   | 0               | 0         | <b>84</b> | 0            | 0         | 10        |
| Collembola      | 0               | 0         | <b>74</b> | 0            | 5         | 21        |
| Miridae         | <b>73</b>       | 4         | 5         | 0            | 0         | 1         |
| Sphaeroceridae  | 11              | 3         | <b>73</b> | 0            | 0         | 6         |
| Aphidoidea      | 8               | 5         | <b>71</b> | 1            | 2         | 10        |
| Ptiliidae       | 0               | 0         | <b>70</b> | 0            | 0         | 1         |
| Tipuloidea      | 0               | 2         | 15        | <b>70</b>    | 0         | 1         |
| Chironomidae    | 10              | 3         | <b>66</b> | 3            | 3         | 15        |
| Amphipoda       | 0               | 0         | 0         | <b>63</b>    | 0         | 0         |
| Coccoidea       | <b>59</b>       | 24        | 0         | 0            | 7         | 0         |
| Acrididae       | 0               | <b>58</b> | 1         | 0            | 0         | 0         |
| Ephydriidae     | 12              | 0         | <b>57</b> | 22           | 2         | 5         |
| Psychodidae     | 8               | 6         | <b>56</b> | 0            | 0         | 22        |

*Notes:* Shown are 15 taxa having the highest indicator values for vegetation types within marshes. The highest indicator value for each taxon is provided in bold characters. *Sv* – *Salicornia virginica*, *Jb* – *Juncus balticus*, *Tl* – *Typha latifolia*

**Table 6.** Mean environmental characteristics of three vegetation types at Crescent Harbor and Lake Hancock, and of the *Salicornia virginica* vegetation type at the six marshes.

| Marsh /<br>Vegetation Type | Variable                 |                         |                             |                         |
|----------------------------|--------------------------|-------------------------|-----------------------------|-------------------------|
|                            | flooding<br>duration (%) | salinity (‰)            | depth below<br>surface (cm) | SOM (%)                 |
| Crescent Harbor            |                          |                         |                             |                         |
| <i>Sv</i>                  | 5.0 (2.6)                | 25.1 (1.7) <sup>a</sup> | -18.3 (3.2)                 | 52.0 (5.0) <sup>b</sup> |
| <i>Jb</i>                  | 0                        | 4.2 (0.9)               | -45.1 (3.5) <sup>a</sup>    | 22.9 (2.0) <sup>c</sup> |
| <i>Tl</i>                  | 0                        | 2.1 (0.5)               | -16.4 (4.5)                 | 64.6 (1.6) <sup>a</sup> |
| Lake Hancock               |                          |                         |                             |                         |
| <i>Sv</i>                  | 23.8 (0.9) <sup>a</sup>  | 29.7 (1.2) <sup>a</sup> | -9.7 (2.0)                  | 48.5 (2.6) <sup>a</sup> |
| <i>Jb</i>                  | 10.7 (0.4) <sup>b</sup>  | 15.6 (0.6) <sup>b</sup> | -16.6 (2.1)                 | 82.0 (0.9)              |
| <i>Tl</i>                  | 0.9 (0.9) <sup>c</sup>   | 4.1 (0.6) <sup>c</sup>  | -10.3 (1.1)                 | 83.0 (2.5)              |
| Crescent Harbor            | 4.5 (2.3)                | 19.1 (1.0)              | -29.4 (6.4)                 | 38.6 (3.4)              |
| Cultus Bay                 | 2.8 (0.7)                | 24.4 <sup>d</sup>       | -37.8 (5.3)                 | 40.9 (5.6)              |
| Elger Bay                  | 2.6 (0.7)                | <sup>e</sup>            | -48.2 (3.5)                 | 44.3 (6.4)              |
| Lake Hancock               | 19.1 (1.8) <sup>a</sup>  | 32.1 (1.2) <sup>a</sup> | -14.2 (1.4) <sup>a</sup>    | 42.6 (2.9)              |
| Maylor Point               | 3.5 (1.0)                | 18.6 (1.5)              | -28.7 (4.7)                 | 20.7 (2.9) <sup>a</sup> |
| Race Lagoon                | 1.7 (0.9)                | 21.5 <sup>d</sup>       | -57.1 (6.7)                 | 38.9 (2.3)              |

Notes: *Sv* – *Salicornia virginica*, *Jb* – *Juncus balticus*, *Tl* – *Typha latifolia*; a,b,c – significant difference ( $P < 0.07$ ), as revealed by Tukey multiple comparison tests; d – n = 2; e – no salinity measurements taken due to inaccessible porewater

**Table 7.** Results of statistical tests for insects collected in *Salicornia virginica* at the six marshes during April, June, and August 2003.

| Factor      | Levels                    | Test  | Dependent Variable  | Month | Statistic | n   | P value |
|-------------|---------------------------|-------|---------------------|-------|-----------|-----|---------|
| Month       | Apr, Jun, Aug             | ANOVA | insect richness     |       | 303.1     | 142 | 0.000   |
|             |                           |       | insect density      |       | 22.1      | 142 | 0.000   |
| Marsh       | CH, CB, EB,<br>LH, MP, RL |       | insect richness     |       | 7.9       | 142 | 0.000   |
|             |                           |       | insect density      |       | 16.4      | 142 | 0.000   |
| Month*Marsh |                           |       | insect richness     |       | 2.5       | 142 | 0.009   |
|             |                           |       | insect density      |       | 4.1       | 142 | 0.000   |
| Marsh       | CH, CB, EB,<br>LH, MP, RL | ANOVA | insect richness     | Apr   | 5.9       | 47  | 0.000   |
|             |                           |       |                     | Jun   | 3.6       | 47  | 0.008   |
|             |                           |       |                     | Aug   | 2.7       | 48  | 0.036   |
|             |                           | ANOVA | insect density      | Apr   | 6.9       | 47  | 0.000   |
|             |                           |       |                     | Jun   | 8.0       | 47  | 0.000   |
|             |                           |       |                     | Aug   | 11.6      | 48  | 0.000   |
|             |                           | MRPP  | insect assemblage   | Apr   | 0.24      | 47  | 0.000   |
|             |                           |       |                     | Jun   | 0.26      | 47  | 0.000   |
|             |                           |       |                     | Aug   | 0.24      | 48  | 0.000   |
| Marsh       | CH, CB, EB,<br>LH, MP, RL | ANOVA | flooding duration   | Jun   | 14.4      | 47  | 0.000   |
|             |                           |       | porewater salinity  | Jun   | 19.3      | 25  | 0.000   |
|             |                           |       | porewater depth     | Jun   | 10.1      | 47  | 0.000   |
|             |                           |       | soil organic matter | Jun   | 4.2       | 30  | 0.007   |

Notes: CH – Crescent Harbor, CB – Cultus Bay, EB – Elger Bay, LH – Lake Hancock, MP – Maylor Point, RL – Race Lagoon

**Table 8.** Results of indicator species analysis (INDVAL) in *Salicornia virginica* at all six marshes.

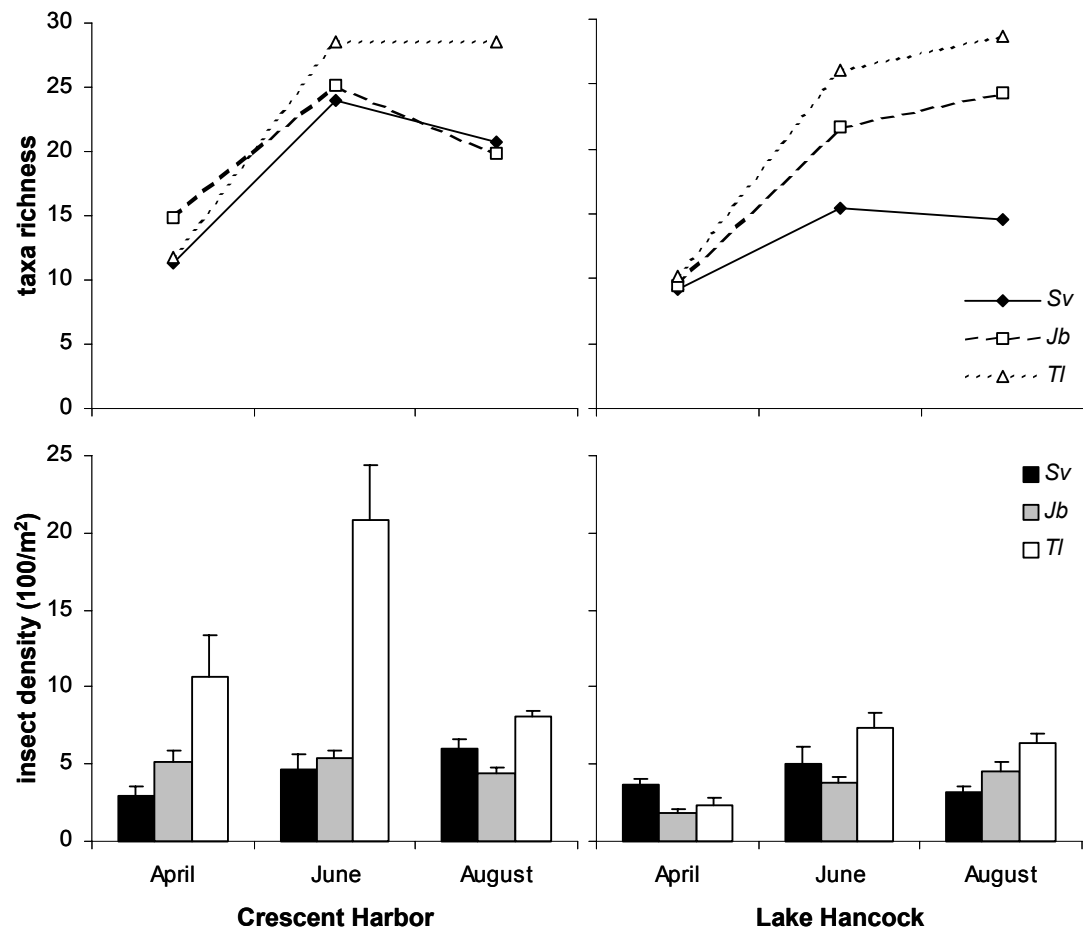
| Indicator Taxon | <i>Salicornia virginica</i> |           |    |           |    |           |
|-----------------|-----------------------------|-----------|----|-----------|----|-----------|
|                 | CH                          | CB        | EB | LH        | MP | RL        |
| Cryptophagidae  | <b>100</b>                  | 0         | 0  | 0         | 0  | 0         |
| Lathridiidae    | <b>90</b>                   | 0         | 1  | 4         | 0  | 0         |
| Saldidae        | 2                           | 1         | 0  | <b>84</b> | 11 | 0         |
| Coccoidea       | 4                           | 2         | 5  | 1         | 8  | <b>74</b> |
| Muscoidea       | 0                           | 1         | 2  | <b>72</b> | 13 | 0         |
| Staphylinidae   | <b>71</b>                   | 3         | 0  | 0         | 1  | 0         |
| Psyllidae       | <b>67</b>                   | 0         | 0  | 0         | 1  | 1         |
| Delphacidae     | <b>54</b>                   | 7         | 6  | 1         | 10 | 1         |
| Psocoptera      | 9                           | <b>53</b> | 3  | 1         | 0  | 1         |
| Curculionidae   | 0                           | 1         | 2  | <b>52</b> | 20 | 11        |
| Cecidomyiidae   | 17                          | 5         | 23 | 0         | 0  | <b>50</b> |
| Tipuloidea      | 0                           | 8         | 15 | <b>49</b> | 26 | 1         |
| Dolichopodidae  | 4                           | 18        | 10 | <b>48</b> | 7  | 4         |
| Cicadellidae    | 9                           | <b>47</b> | 4  | 22        | 12 | 0         |
| Scatopsidae     | 1                           | 0         | 8  | 0         | 28 | <b>47</b> |

*Notes:* Shown are 15 taxa having the highest indicator values for the *Salicornia virginica* vegetation type among marshes. The highest indicator value for each taxon is provided in bold characters. CH – Crescent Harbor, CB – Cultus Bay, EB – Elger Bay, LH – Lake Hancock, MP – Maylor Point, RL – Race Lagoon

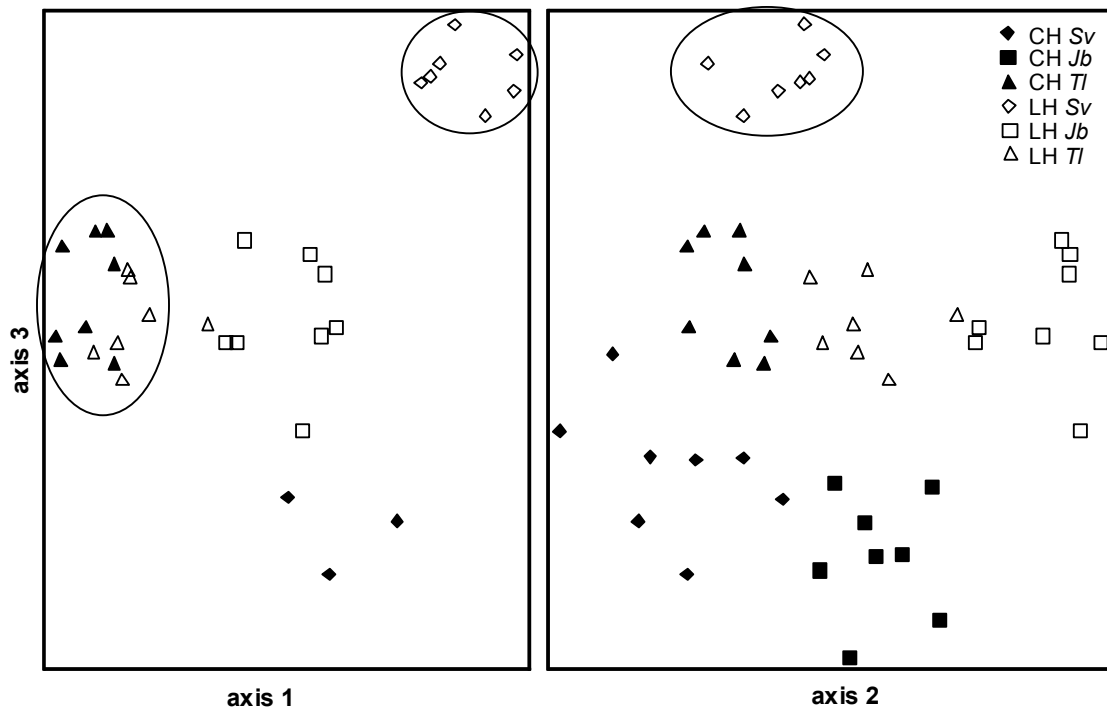
**Table 9.** First four eigenvectors from principal components analysis of marsh characteristics.

| Variable                  | Eigenvector    |                |                |                |
|---------------------------|----------------|----------------|----------------|----------------|
|                           | 1              | 2              | 3              | 4              |
| local plant richness      | 0.2652         | -0.1759        | -0.1229        | 0.2505         |
| local <i>Sv</i> frequency | 0.2799         | -0.1142        | -0.0790        | -0.2444        |
| local <i>Ds</i> frequency | -0.1651        | -0.2799        | -0.0390        | <b>0.4491</b>  |
| local <i>Jc</i> frequency | 0.1876         | <b>-0.3803</b> | -0.0379        | 0.0062         |
| local <i>Tm</i> frequency | 0.2194         | 0.1267         | -0.2001        | <b>0.4147</b>  |
| local plant height        | -0.2824        | -0.0850        | 0.1343         | 0.2440         |
| porewater salinity        | 0.1805         | 0.1862         | <b>-0.3767</b> | -0.0967        |
| porewater depth           | 0.0983         | <b>-0.3449</b> | 0.2413         | <b>-0.3016</b> |
| flooding duration         | 0.1108         | -0.2936        | <b>0.3338</b>  | -0.2055        |
| SOM                       | 0.0946         | -0.1455        | <b>-0.4142</b> | <b>-0.3129</b> |
| daytime temperature       | -0.2649        | -0.2599        | -0.0085        | 0.0695         |
| total 2 wk rainfall       | 0.0689         | <b>-0.4129</b> | -0.2067        | 0.1248         |
| marsh plant richness      | <b>-0.3003</b> | -0.0243        | -0.1463        | 0.1208         |
| mud/wood frequency        | 0.2021         | -0.1915        | <b>-0.3332</b> | 0.1295         |
| salt marsh frequency      | 0.2025         | 0.1575         | <b>0.3327</b>  | 0.0039         |
| brackish marsh frequency  | -0.2457        | 0.0631         | -0.2679        | -0.2611        |
| cattail frequency         | -0.2359        | -0.2284        | -0.1620        | -0.2497        |
| shrub frequency           | <b>-0.3024</b> | -0.1340        | -0.0223        | -0.0693        |
| herb frequency            | <b>-0.3031</b> | -0.1148        | 0.0305         | 0.0056         |
| marsh size                | -0.2262        | 0.2478         | -0.2220        | -0.1290        |

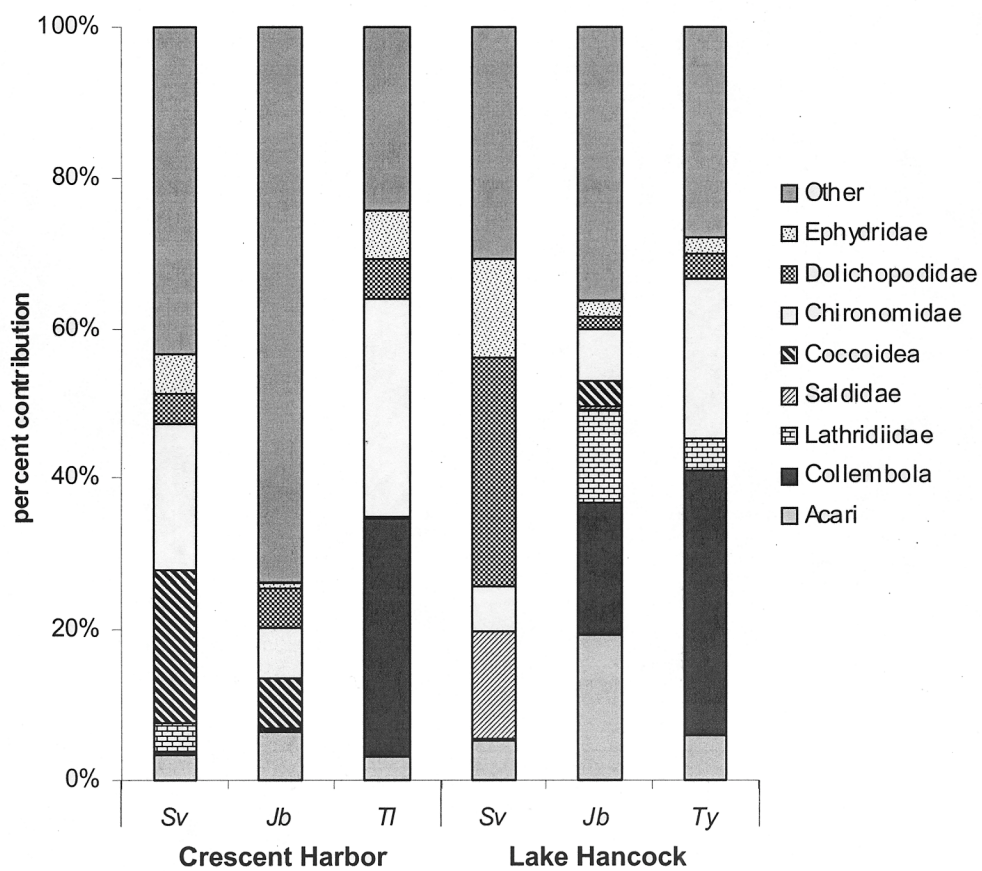
*Notes:* These first four eigenvectors represent 98.2% of the total variance: 49.1% in component 1, 22.2% in component 2, 17.9% in component 3, and 9.1% in component 4. Loadings greater than 0.3 are shown in bold. *Sv* – *Salicornia virginica*, *Ds* – *Distichlis spicata*, *Jc* – *Jaumea carnosa*, *Tm* – *Triglochin maritimum*



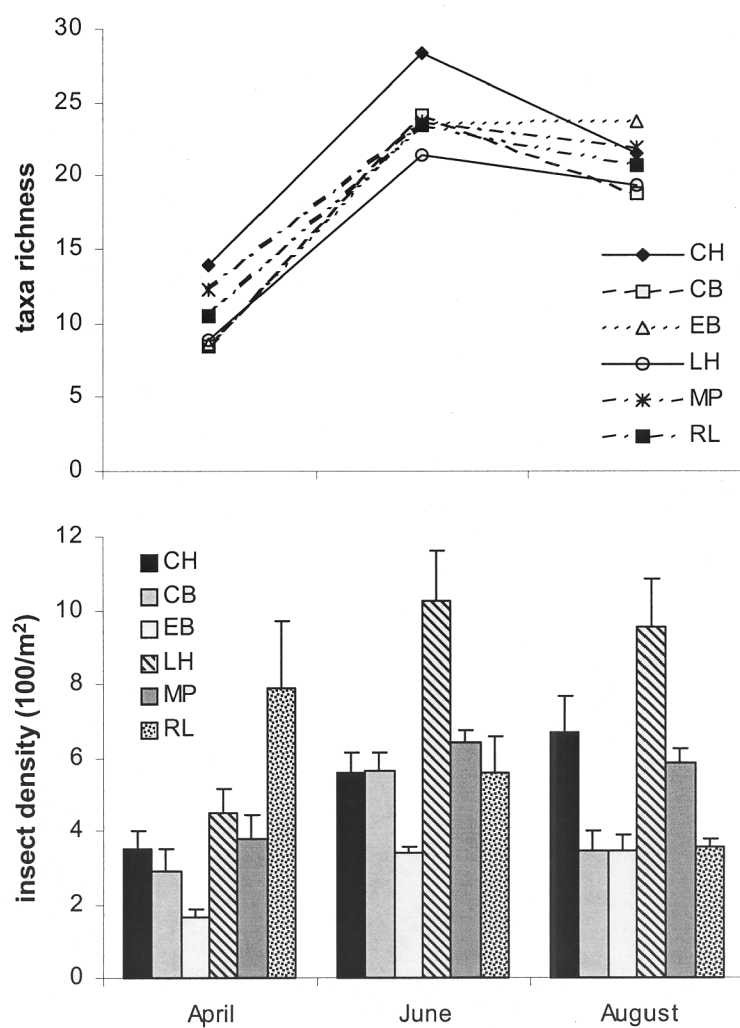
**Figure 4.** Effect of sampling month on mean insect richness and density in three vegetation types at Crescent Harbor and Lake Hancock marshes. Error bars represent standard error of the mean. *Sv* – *Salicornia virginica*, *Jb* – *Juncus balticus*, *Tl* – *Typha latifolia*



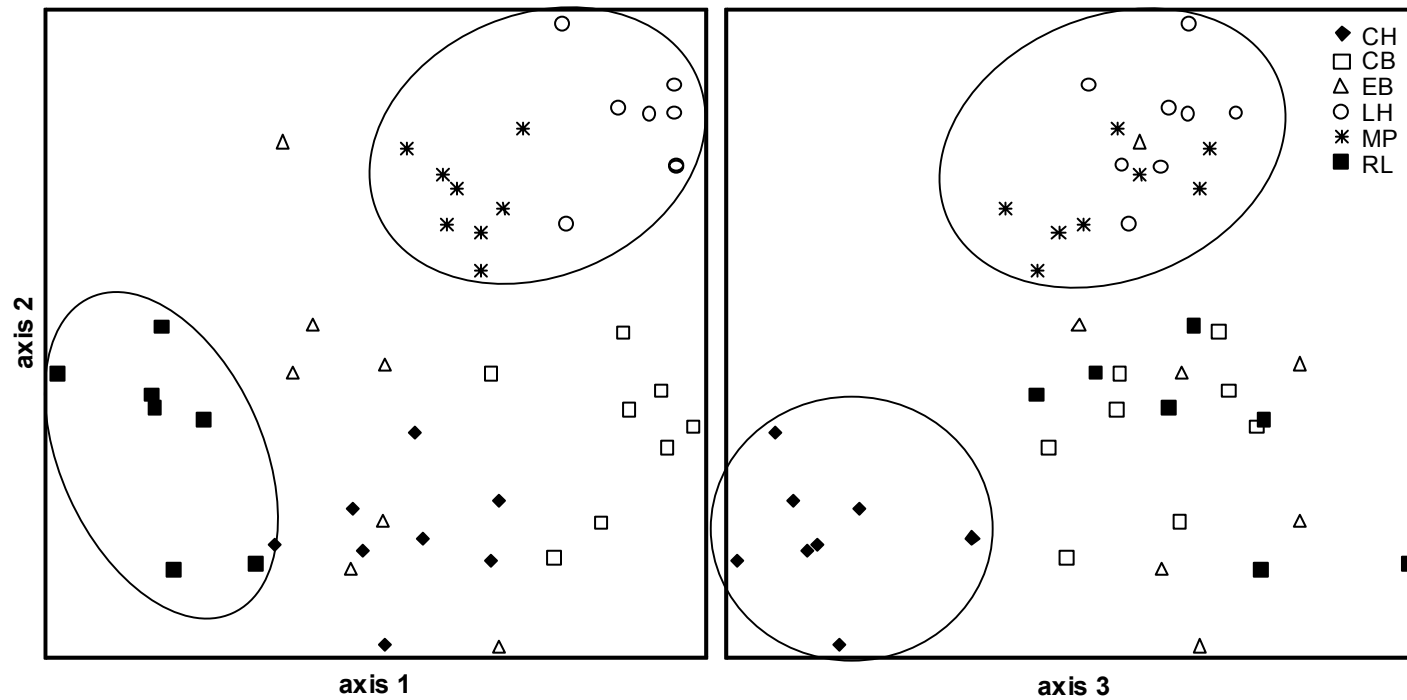
**Figure 5.** NMDS of sampling stations in insect taxa space, for June vegetation type comparisons. This 3-dimensional solution represents 86.7% of the total variance: 44.5% in axis 3, 26.9% in axis 1, and 15.2% in axis 2. 65 iterations were required to achieve the final solution, with 12.5 final instability (Monte Carlo permutation test:  $P < 0.001$ ). CH – Crescent Harbor, LH – Lake Hancock, Sv – *Salicornia virginica*, Jb – *Juncus balticus*, Tl – *Typha latifolia*



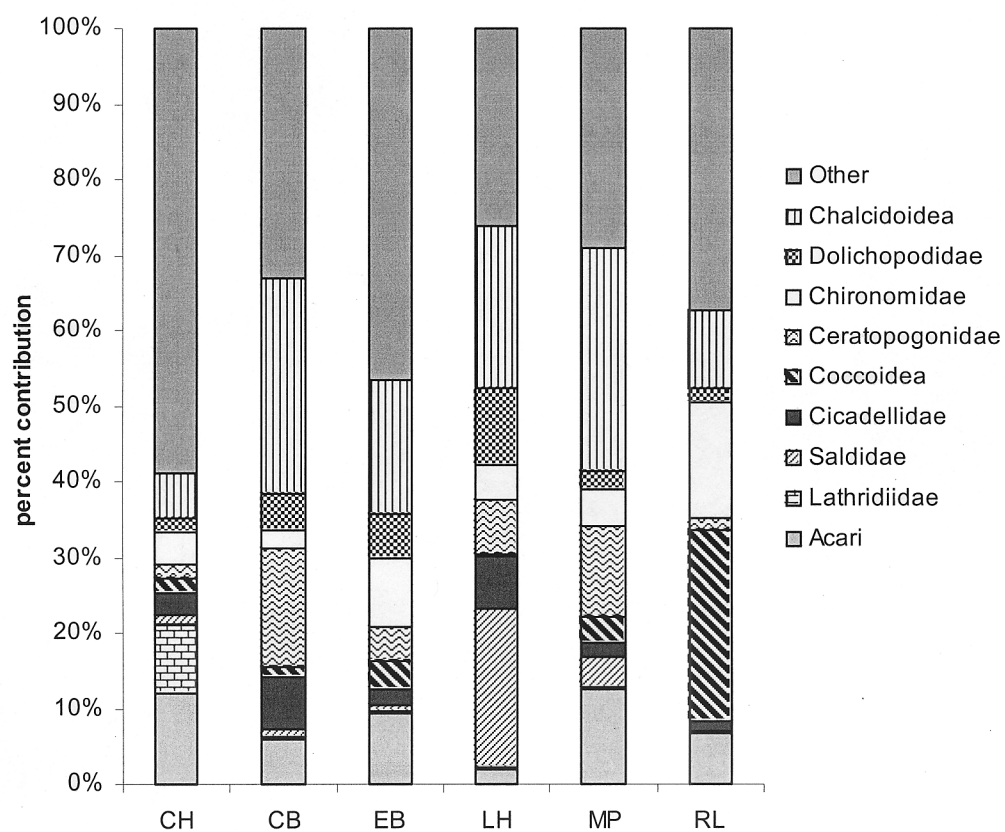
**Figure 6.** Percent contribution of insect taxa to assemblages in three vegetation types at Crescent Harbor and Lake Hancock marshes during June sampling. Sv – *Salicornia virginica*, Jb – *Juncus balticus*, Tl – *Typha latifolia*



**Figure 7.** Effect of sampling month on mean insect richness and density in *Salicornia virginica* habitats at the six marshes. Error bars represent standard error of the mean.



**Figure 8.** NMDS of sampling stations in insect taxa space, for marsh comparisons in June. This 3-dimensional solution represents 84.8% of the total variance: 32.8% in axis 2, 26.2% in axis 1, and 25.8% in axis 3. 64 iterations were required to achieve the final solution, with 13.5 final instability (Monte Carlo permutation test:  $P < 0.001$ ). CH – Crescent Harbor, CB – Cultus Bay, EB – Elger Bay, LH – Lake Hancock, MP – Maylor Point, RL – Race Lagoon



**Figure 9.** Percent contribution of insect taxa to assemblages in *Salicornia virginica* at six marshes during June sampling.

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## PREDICTING VEGETATION AND INSECT RESPONSE TO RESTORATION OF A TIDALLY RESTRICTED SALT MARSH

### ABSTRACT

Forecasting ecological response to restoration activities is a central objective of restoration ecology; however for coastal wetlands, specific predictions are often unreliable. To improve our understanding of restoration processes and develop more accurate predictions in the future, we must quantify anticipated results and test these hypotheses after restoration. In this paper, I develop models to predict changes in vegetation and insect assemblages following reintroduction of full tidal exchange to a tidally muted salt marsh in Island County, Washington. I used five natural marshes as references. My approach included (1) characterizing relationships between tidal flooding, salt marsh vegetation, and insect assemblages; (2) modeling post-restoration tidal flooding; and (3) predicting responses of vegetation and insect assemblages. Restoration is planned for September 2005.

Marsh vegetation was sampled at elevations ranging from 1.96 to 4.36 m MLLW. At reference marshes, *Salicornia virginica*, *Distichlis spicata*, *Triglochin maritimum*, and *Atriplex patula* occurred most frequently. The tidal flooding experienced by these and 13 other species comprised the vegetation model. As described in the previous chapter, I collected insects in mixed *S. virginica* and characterized features of their environment. Indirect gradient analysis revealed that tidal flooding and vegetation richness explained a large portion of insect assemblage variation.

Upon restoration, tidal elevations within the marsh will resemble bay elevations. Given current elevations, I predicted that salt marsh vegetation will more than triple in areal coverage. The insect models forecasted a 100% increase in total density and major shifts in composition. While my predictions carry considerable error, they represent quantitative and spatially explicit hypotheses to be tested after restoration. Their acceptance or rejection will inform future restoration predictions and support adaptive restoration management.

## **INTRODUCTION**

Coastal wetland restoration is generally lacking in spatially explicit and quantitative predictions, particularly for plant and animal communities. While forecasting ecological response to restoration activities is a central objective of restoration ecology (Zedler 2000), specific predictions of development rates, patterns, and functions are typically unreliable (Thom et al. 2002). Indeed, restoring systems often develop unexpectedly (e.g., Frenkel and Morlan 1991, Simenstad and Thom 1996). However, both restoration science (Keddy 1999) and management (Thom 2000) stand to benefit from making predictions and testing them against observed community response. A prediction framework is already in place, but applications to coastal wetland restoration are just beginning.

Hydrology is the major factor controlling coastal wetland structure and functioning (Zedler 2000). Hydrologic processes are fairly well understood, and models can accurately simulate water levels even in highly modified wetlands (e.g., Coats et al.

1989, Roman et al. 1995, Boumans et al. 2002). Such models are useful for evaluating sites prior to restoration, identifying potential socioeconomic consequences, and deciding among restoration alternatives (Coats et al. 1989). When combined with ecological models, hydrologic models represent powerful tools for generating hypothesis and identifying major forcing factors (Coats et al. 1989).

Coastal wetland vegetation assemblages respond to a combination of environmental factors, including salinity and elevation (Jefferson 1975, Burg et al. 1976, Disraeli and Fonda 1979) as well as soil aeration, texture, temperature, and organic content (Ewing 1983). At a given salt marsh, salinity often corresponds with tidal inundation, making elevation a particularly important predictor of vegetation composition (Keddy 1999). Boumans et al. (2002) applied this concept to predict vegetation assemblages in three tidally restricted, New England salt marshes. They determined tidal elevation ranges for major plant species at reference marshes, and then projected these findings onto predicted flooding regimes for the restoring marshes. Five years after restoring one salt marsh, the observed vegetation coincided with predictions.

Salt marsh insects also respond to a variety of environmental factors, especially vegetation structure and fluctuations in food resources (Davis and Gray 1966, Cameron 1972, Balling and Resh 1991). Biodiversity conservation efforts have recently produced quantitative models that translate environmental features into insect richness or abundance. For example, Lobo and Martin-Piera (2002) developed a general linearized model to predict dung beetle richness from 24 environmental variables, which captured geographic, topographic, geologic, climatic, and habitat diversity information. Similarly,

Sawchik et al. (2003) used canonical ordination and stepwise regression to predict butterfly abundances from vegetation data. These methods appear to be applicable to coastal wetlands and are particularly relevant in the Pacific Northwest, where insects represent important dietary items for juvenile salmonids (*Oncorhynchus* spp.), the expected beneficiaries of many restoration efforts (Simenstad and Cordell 2000).

This project focuses on a tidally restricted, barrier salt marsh located on Whidbey Island in northern Puget Sound, WA. In this paper, I develop models to predict changes in vegetation and insect assemblages following reintroduction of full tidal exchange to the marsh. My approach includes (1) characterizing relationships between tidal flooding, salt marsh vegetation, and insect assemblages; (2) modeling post-restoration tidal flooding; and (3) predicting responses of vegetation and insect assemblages.

## **METHODS**

### ***Site Descriptions***

Like many coastal wetlands in the Puget Sound region, Crescent Harbor marsh (CH) has experienced a long history of hydrologic modifications. In the early 1900s, CH was diked and drained for agricultural use, and the natural channel was replaced with a gated culvert (Figure 10). In the 1960s, the City of Oak Harbor constructed a 3-ha wastewater treatment plant in the center of the marsh, which was later quadrupled in area. Levees protecting the wastewater intake and outlet pipes divide the marsh into three cells, which are connected only through small culverts. In 1994, the tide gate separating the marsh from the bay was permanently opened. However, the undersized

culvert severely limits tidal heights during the summer and impedes freshwater discharge during the winter. Restoration of CH is planned for August 2005, when the gated culvert will be replaced with an open channel, interior culverts enlarged, and first-order channels excavated.

I selected five Island County salt marshes with natural tidal regimes as references for CH: Cultus Bay (CB), Elger Bay (EB), Lake Hancock (LH), Maylor Point (MP), and Race Lagoon (RL) (Figure 1). Marsh characteristics were summarized in Table 3.

### ***Hydrologic Model***

Tidal heights throughout CH were examined by Orr et al. (2003), using the hydrologic model MPOND. This model simulates water elevations in connected ponding areas as functions of tidal and freshwater flow through hydraulic structures (Coats et al. 1989). Model inputs included marsh topography, culvert dimensions, time series of Crescent Harbor tidal heights and Crescent Creek flows, and initial water elevations in the three marsh cells (Orr et al. 2003). The model was calibrated using recorded tidal heights from the main channel (WL15, Global Water Instrumentation, Inc., Gold River, CA).

### ***Vegetation Model***

Using field sampling and geospatial analyses, I documented the range of tidal flooding experienced by different plant species at CH and the reference marshes. I utilized ERDAS IMAGINE 8.6 (Leica Geosystems GIS & Mapping, Atlanta, GA) to develop a stratified random vegetation sampling design. I acquired 2001 color aerial

photographs of the study marshes from the Washington Department of Natural Resources. These images were digitized, and then orthorectified using digital orthophoto quarter quadrangles (DOQQs, USGS 1996) and 10-m digital elevation models (DEMs, Greenberg 1999) as references in IMAGINE. The resultant orthophotos were filtered and stacked with LIDAR DEMs (Martinez 2003). I ran unsupervised classifications, with five to seven classes for each photo, and then utilized the accuracy assessment tool to generate 417 stratified random sampling points throughout the six marshes (M. Logsdon 2003, University of Washington, Seattle, WA, personal communication).

Vegetation sampling was conducted on 22–31 July 2003, using a global positioning system (GPS Pathfinder Pro XR, Trimble, Sunnyvale, CA) to locate sampling points. At each point, I laid out a 2.5 x 2.5-m grid of 25 cells using marked rope. I randomly selected five of the 25 cells and recorded the plant species present within each.

I calculated the duration of tidal flooding from May through August at each sampling point. For the reference marshes, I used sampling point coordinates to query LIDAR DEMs in ArcView 3.2 (ESRI, Redlands, CA). Hourly tidal heights were downloaded from the NOAA National Water Level Observation Network's (NWLON) Seattle station. For CH, sampling point elevations were estimated from a DEM based on digitized topographic survey data (Aelyteck and Amsatek 1994). This model was preferred because LIDAR was flown during winter, and elevations for CH appeared to reflect impounded water rather than bare ground. To generate the DEM, I isolated point elevations for the marsh surface, and then utilized non-directional, universal Kriging

(Geostatistical Analyst Extension for ArcMap, ESRI, Redlands, CA) for interpolation (R. Timm 2004, University of Washington, Seattle, WA, personal communication).

Tidal heights within CH were obtained from the water level logger located in the main channel. I entered all tidal height and elevation data into Tide Miner 3.0 (Numbers to Knowledge, Williamstown, MA) to compute flooding duration.

Finally, I determined the range of tidal flooding experienced by different plant species at the six marshes. For each sampling point, I linked the calculated duration of tidal flooding to the observed plant species. The resultant vegetation model included the minimum and maximum flooding experienced by common species at reference marshes.

### ***Insect Model***

In the previous chapter, I characterized insect assemblages in *Salicornia virginica* (American glasswort) and *Typha latifolia* (cattail) vegetation types and described relationships between *S. virginica* insect assemblages and environmental factors. For the latter, I evaluated environmental factors with principal components analysis (PCA), and then regressed insect ordination axes against the resultant components. This approach worked well for identifying potential underlying causes of insect variation (McCune and Grace 2002). However, PCA does not provide information sufficient for making quantitative predictions of insect response. For this task, I employed stepwise multiple regression, a technique useful for choosing a minimum set of predictors to describe the observed variation (McCune and Grace 2002).

I used stepwise regression to evaluate insect taxa richness, total density, and ordination axis scores in relation to seven environmental variables: local plant species richness, porewater salinity, porewater depth, flooding duration, marsh species richness, “salt marsh” frequency, and “mud/wood” frequency. I measured additional environmental variables, but excluded them from analysis because they were not readily predictable at CH after restoration. In order to avoid unanticipated effects of freshwater flooding (Zedler 1983) due to size limitations for culverts connecting the western cells, I focused my analyses and predictions on the eastern cell. Site-wide measurements at CH were recalculated to represent only the focal area (31 ha). Environmental variables were transformed as necessary to reduce kurtosis, and then standardized by mean and standard deviation. Linear, quadratic, and logarithmic expressions of ordination axis scores were included in the regression analysis. Entry and exit values for stepwise procedures were set at  $P = 0.05$  and  $P = 0.10$ , respectively.

The model for ordination axis scores predicts marsh locations in insect space based on environmental variables, but offers no information about taxa densities within the marshes. Insect taxa of particular interest include indicators of particular marshes and important juvenile salmon prey (Table 10). To predict densities of these taxa, I followed the approach developed by Sawchik et al. (2003) and used stepwise multiple regression to model taxa densities as functions of ordination axis scores. I log-transformed average taxa densities to meet regression assumptions, and I included both linear and quadratic expressions of ordination axis scores. Again, entry and exit values for stepwise procedures were set at  $P = 0.05$  and  $P = 0.10$ , respectively.

### ***Predictions of Change***

Orr et al. (2003) used the model MPOND to estimate post-restoration tidal elevations throughout CH, based on the preferred design of full tidal inundation, culvert expansion, and channel excavation. I entered into Tide Miner the predicted summer tidal elevations for the eastern cell and calculated incremental (10-cm) flooding durations for current marsh elevations.

I compared the predicted flooding durations at CH to vegetation flooding tolerances that were observed in the reference marshes. In ArcView, I reclassified the CH DEM to reflect the maximum flooding tolerance of each plant species, thus generating a vegetation map for the entire eastern cell. From this map, I estimated the areal coverage of each vegetation zone and the richness of plant species throughout the cell. I evaluated the predicted percent change from pre-restoration conditions.

CH tidal and vegetation predictions were then applied to the insect regression models. I assumed that insects would be recollected at the June 2003 sampling stations and estimated local environmental conditions for those positions. I calculated the predicted percent change in insect taxa richness, total density, and the densities of individual taxa.

## **RESULTS**

### ***Hydrology***

Analysis of existing conditions revealed that tidal exchange and freshwater drainage are severely impeded by the hydraulic structures within CH (Orr et al. 2003).

Under typical summer conditions, the inlet culvert reduces tidal range in the eastern cell by nearly 60%. During 10-year storm events, impounded freshwater elevations approach 4 m MLLW, overtopping adjacent roadways. This volume of water drains slowly from the marsh, over a period of several days (M. Orr 2003, Philip Williams and Associates, San Francisco, CA, public communication).

### ***Vegetation***

Vegetation sampling throughout the six marshes characterized a wide spectrum of topography, from channel mouth to upland shrub. Points ranged in elevation from 1.96 to 4.36 m MLLW and in tidal flooding duration from 58.3% to 0%.

I documented or visually estimated vegetation frequency at 393 of 417 sampling points, encountering more than 80 plant species plus 20 generic cover types (e.g., mud, driftwood, pasture, shrubs). *S. virginica* occurred most frequently (163 points), followed by *Distichlis spicata* (seashore saltgrass, 141 points), mud (110 points), and *Atriplex patula* (sparscale, 107 points). *Triglochin maritimum* (sea arrow-grass), *Jaumea carnosa* (fleshy jaumea), driftwood, *Cuscuta* spp. (dodders), *Puccinellia* spp. (alkali grass), *Plantago maritima* (sea plantain), and *Grindelia integrifolia* (entire-leaved gumweed) were common (>20 points) at reference marshes but absent from CH.

Plant species occurring at >1 reference marsh and >10 sampling points were included in the vegetation model (Figure 11). For the summer tides investigated here, flooding duration appears to limit only the lower end of species elevation ranges, and the salt marsh becomes increasingly diverse with elevation gain.

### ***Insects***

Stepwise regression provided linear models for total insect density and NMDS axes 2 and 3 (Table 11). Linear relationships were also identified between NMDS axes and the densities of Araneae, four Coleoptera families, seven Diptera families, Hemiptera: Saldidae, and four Homoptera families. However, no correlations were identified for several insect taxa that are commonly consumed by juvenile salmon (e.g., Chironomidae, Dolichopodidae, and Aphidoidea).

### ***Predictions***

Upon restoration, the tidal regime in the eastern cell of CH is expected to reflect tidal elevations in Crescent Harbor (Orr et al. 2003). The predicted tidal range will expand to 3.35 m, 79% of the bay's range. Freshwater inputs will drain quickly from the marsh surface and are anticipated to have minimal impacts on vegetation composition.

Given current elevations, I predict that salt marsh vegetation will initially expand throughout the eastern cell, more than tripling the present areal coverage. Maximum flooding duration (50%) is expected to occur along the natural channel near the wastewater treatment plant (Figure 12), and tides will periodically inundate the entire marsh surface. Approximately 93% of the eastern cell is within elevations readily colonized by salt marsh plant species. Higher marsh species (e.g., *Potentilla pacifica*, silverweed, and *Juncus balticus*, Baltic rush) will likely colonize elevation bands along the forest border and East Pioneer Way. Freshwater species (e.g., *T. latifolia* and *Scirpus*

*lacustris*, tule) may persist in seepage zones along the upland forest edge. LH provides a good reference for these vegetation patterns.

I expect the insect assemblage to roughly double in mean density and experience major shifts in composition (Table 12). Densities of Saldidae, muscoid and tipuloid flies, and curculionid beetles are anticipated to increase by orders of magnitude. However, densities of cryptophagid, lathridiid, and staphylinid beetles as well as Psyllidae and cecidomyid flies should decrease to very low levels ( $\leq 1/m^2$ ). Coccoidea, Cicadellidae, and ceratopogonid, ephydrid, and scatopsid flies may maintain densities similar to pre-restoration levels. These taxa regressed with NMDS axis 1, which correlated to none of the measured environmental variables.

## DISCUSSION

My findings suggest that restoration of full tidal exchange to CH will induce significant changes in water elevations, vegetation composition, and insect assemblages. In developing my prediction models, I documented salt marsh vegetation at a variety of sites and elevations. Maximum tidal inundation tolerances were used to predict vegetation patterns after restoration. Finally, I applied flooding and vegetation predictions to models of insect density. The validity of these predictions should be tested several years after restoration.

Documenting vegetation composition at various elevations in natural marshes was essential for predicting post-restoration vegetation change at CH. Deltaic systems dominate the literature for Pacific Northwest estuarine vegetation (e.g., Burg et al. 1976,

Ewing 1983, Hutchinson 1988a). Considering the apparent differences in salinity, sediment loads, and seasonal flooding, vegetation patterns from deltaic salt marshes may be inappropriate for the barrier marshes investigated here. For example, Hutchinson (1988a) observed that *J. carnosus* appeared to be latitudinally limited to southern Puget Sound; however, I documented the plant in all five reference marshes. Comparable euhaline salt marshes do exist in Padilla Bay, located approximately 20 km northeast of CH. Granger and Burg (1990) characterized vegetation patterns at Padilla Bay that are somewhat consistent with my findings. *S. virginica* dominated low marsh elevations and areas near salt pans. With increasing elevation, *S. virginica* eventually converged with *D. spicata*, and then occurred sporadically within a zone dominated by *D. spicata*. *T. maritimum* and *G. integrifolia* were limited to areas near marsh channels and sloughs. Direct comparison of these results to my study is difficult, however, because plant species were not tied to specific elevation levels.

My vegetation model utilized simple assembly rules for predicting vegetation patterns. I filtered plant species according to observed tidal inundation (i.e., salinity) tolerances at reference marshes. Salinity tolerances of New Zealand salt marsh plant species have been tested experimentally (Partridge and Wilson 1987), and resulted in similar patterns of increasing diversity with decreasing salinity. Evidence suggests that assembly rules do play a role in natural salt marsh vegetation patterns (Wilson and Whittaker 1995). An interesting question is whether assembly rules also affect salt marsh insect assemblages.

Eleven insect taxa appear to be influenced by measured environmental variables. Associations with tidal flooding likely represent insect responses to changes in habitat or food resources, rather than direct responses to tidal inundation (Cameron 1976, Balling and Resh 1991). Decreases in taxa densities with increasing tidal inundation may result from insect retreat to higher elevations, as was predicted for several species of carabid beetles inhabiting salt marshes bordering the North and Baltic Seas (Irmiler et al. 2002). Conversely, density increases likely reflect expansion of preferred environmental conditions. This may be the case for tipuloid flies, which tend to inhabit moist environments with abundant vegetation (Borrer et al. 1981).

Restoration of CH should benefit juvenile salmonids, particularly ocean-type Chinook salmon (*O. tshawytscha*). Individuals expressing this life history type enter estuaries as fry (<40 mm, 0.5 g) and rear for several weeks to months within coastal wetland systems (Healey 1982, Simenstad et al. 1982). The open marsh channel will provide fish and crustacean access to more than 30 ha of wetland habitat. Total insect densities are expected to increase with tidal flooding. While regression analysis did not generate many predictions for specific juvenile salmon prey taxa (e.g., chironomid, ceratopogonid, dolichopodid, and ephydrid flies), these taxa were found in high densities at all reference marshes. Restoring wetlands generally offer a variety of juvenile salmon prey, including fly larvae, pupae, and adults (Shreffler et al. 1992, Cordell et al. 1999), gammarid amphipods (Cordell et al. 1999), terrestrial insects, benthic crustaceans, and neritic plankton (Cordell et al. 2001).

Post-restoration monitoring is needed to evaluate the accuracy of my predictions. Indeed, many factors could cause deviation from expected results. For example, my vegetation model does not incorporate soil quality, seedling establishment, biological interactions (i.e., facilitation, competition, and herbivory), or sediment accretion. However, these factors can exhibit significant impacts on vegetation structure and composition (Gough and Grace 1998, Levine et al. 1998, Hacker and Bertness 1999, Noe and Zedler 2000). Similarly, my insect models do not account for seasonal or annual variation in insect assemblages. I observed in the previous chapter that sampling month significantly affected insect richness and density (see also Davis and Gray 1966, Balling and Resh 1991). Finally, my low sample size ( $n = 6$ ) and method of model development (sequential stepwise regression) gave rise to substantial error in the predicted insect densities. Even with these uncertainties, my predictions still represent quantitative and spatially explicit hypotheses for restoration development, and they should inform restoration science and management with either acceptance or rejection.

**Table 10.** Insect taxa of particular interest for post-restoration density predictions: salt marsh indicators and common juvenile salmon prey.

| Insect Taxon    | Marsh Indicated | Prey Frequency |
|-----------------|-----------------|----------------|
| Araneae         | -               | 2              |
| Coleoptera      |                 |                |
| Cryptophagidae  | CH              | -              |
| Curculionidae   | LH              | -              |
| Lathridiidae    | CH              | -              |
| Staphylinidae   | CH              | 2              |
| Collembola      | -               | 3              |
| Diptera         |                 |                |
| Cecidomyiidae   | RL              | 2              |
| Ceratopogonidae | -               | 2              |
| Chironomidae    | -               | 3              |
| Dolichopodidae  | LH              | 2              |
| Ephydriidae     | -               | 2              |
| Muscoidea       | LH              | 1              |
| Scatopsidae     | RL              | -              |
| Sciaridae       | -               | 2              |
| Tipuloidea      | LH              | 2              |
| Hemiptera       |                 |                |
| Saldidae        | LH              | 1              |
| Homoptera       |                 |                |
| Aphidoidea      | -               | 2              |
| Cicadellidae    | CB              | 2              |
| Delphacidae     | CH              | 1              |
| Coccoidea       | RL              | -              |
| Psyllidae       | CH              | 2              |
| Hymenoptera     |                 |                |
| Formicidae      | -               | 2              |
| Psocoptera      | CB              | 2              |

*Notes:* Typical frequencies of consumption by juvenile salmonids: 3 - prominent, 2 - common, 1 - rare. From Wetland Ecosystem Team, School of Aquatic and Fishery Sciences, University of Washington unpublished.

**Table 11.** Regression models for total and taxa-specific insect densities.

| Variable (y)    | Equation                                                                                                                    | Adjusted $R^2$ | F statistic | P value |
|-----------------|-----------------------------------------------------------------------------------------------------------------------------|----------------|-------------|---------|
| Total density   | $\log y = 2.78 + 0.0995 \times \{Z [\log (\text{flood})]\}$                                                                 | 0.86           | 26.2        | 0.01    |
| NMDS 2          | $y^2 = 0.282 + 0.198 \times \{Z [\log (\text{flood})]\} - 0.076 \times [Z (\text{local richness})]$                         | 0.99           | 227.3       | 0.004   |
| NMDS 3          | $\log (y + 1) = -0.00639 + 0.152 \times [Z (\text{marsh richness})^{1/3}]$                                                  | 0.75           | 13.1        | 0.04    |
| Araneae         | $\log (y + 0.5) = 1.02 + 0.562 \times (\text{NMDS } 3)^2$                                                                   | 0.7            | 12.6        | 0.02    |
| Coleoptera      |                                                                                                                             |                |             |         |
| Cryptophagidae  | $\log (y + 0.5) = -0.297 + 1.58 \times (\text{NMDS } 3)^2 + 0.463 \times (\text{NMDS } 3) + 0.0410 \times (\text{NMDS } 1)$ | 1.00           | 28945.2     | < 0.001 |
| Curculionidae   | $\log (y + 0.5) = 0.683 + 0.695 \times (\text{NMDS } 2)$                                                                    | 0.74           | 15.4        | 0.02    |
| Lathridiidae    | $\log (y + 0.5) = 0.407 + 1.27 \times (\text{NMDS } 3)$                                                                     | 0.78           | 19.1        | 0.01    |
| Staphylinidae   | $\log (y + 0.5) = 0.0447 + 0.900 \times (\text{NMDS } 3)$                                                                   | 0.87           | 34.6        | 0.004   |
| Diptera         |                                                                                                                             |                |             |         |
| Cecidomyiidae   | $\log (y + 0.5) = 0.690 - 1.10 \times (\text{NMDS } 2)$                                                                     | 0.72           | 13.9        | 0.02    |
| Ceratopogonidae | $\log (y + 0.5) = 1.51 + 0.635 \times (\text{NMDS } 1)$                                                                     | 0.66           | 10.8        | 0.03    |
| Ephydriidae     | $\log (y + 0.5) = 1.31 + 0.547 \times (\text{NMDS } 1)$                                                                     | 0.62           | 9.1         | 0.04    |
| Muscoidea       | $\log (y + 0.5) = 0.564 + 0.900 \times (\text{NMDS } 2)$                                                                    | 0.9            | 47.2        | 0.002   |
| Scatopsidae     | $\log (y + 0.5) = 0.444 - 0.968 \times (\text{NMDS } 1)$                                                                    | 0.71           | 13.2        | 0.02    |
| Sciaridae       | $\log (y + 0.5) = 0.627 - 0.409 \times (\text{NMDS } 2)$                                                                    | 0.67           | 11.2        | 0.03    |
| Tipuloidea      | $\log (y + 0.5) = 1.30 - 1.72 \times (\text{NMDS } 3)^2$                                                                    | 0.66           | 10.9        | 0.03    |
| Hemiptera       |                                                                                                                             |                |             |         |
| Saldidae        | $\log (y + 0.5) = 0.267 + 2.87 \times (\text{NMDS } 2)^2$                                                                   | 0.74           | 15.5        | 0.02    |
| Homoptera       |                                                                                                                             |                |             |         |
| Cicadellidae    | $\log (y + 0.5) = 1.16 + 0.713 \times (\text{NMDS } 1)$                                                                     | 0.83           | 26.0        | 0.007   |
| Delphacidae     | $\log (y + 0.5) = 0.978 + 0.705 \times (\text{NMDS } 3)$                                                                    | 0.72           | 13.7        | 0.02    |
| Coccoidea       | $\log (y + 0.5) = 1.17 - 0.791 \times (\text{NMDS } 1)$                                                                     | 0.75           | 16.4        | 0.02    |
| Psyllidae       | $\log (y + 0.5) = -0.232 + 1.28 \times (\text{NMDS } 3)^2$                                                                  | 0.85           | 28.5        | 0.006   |

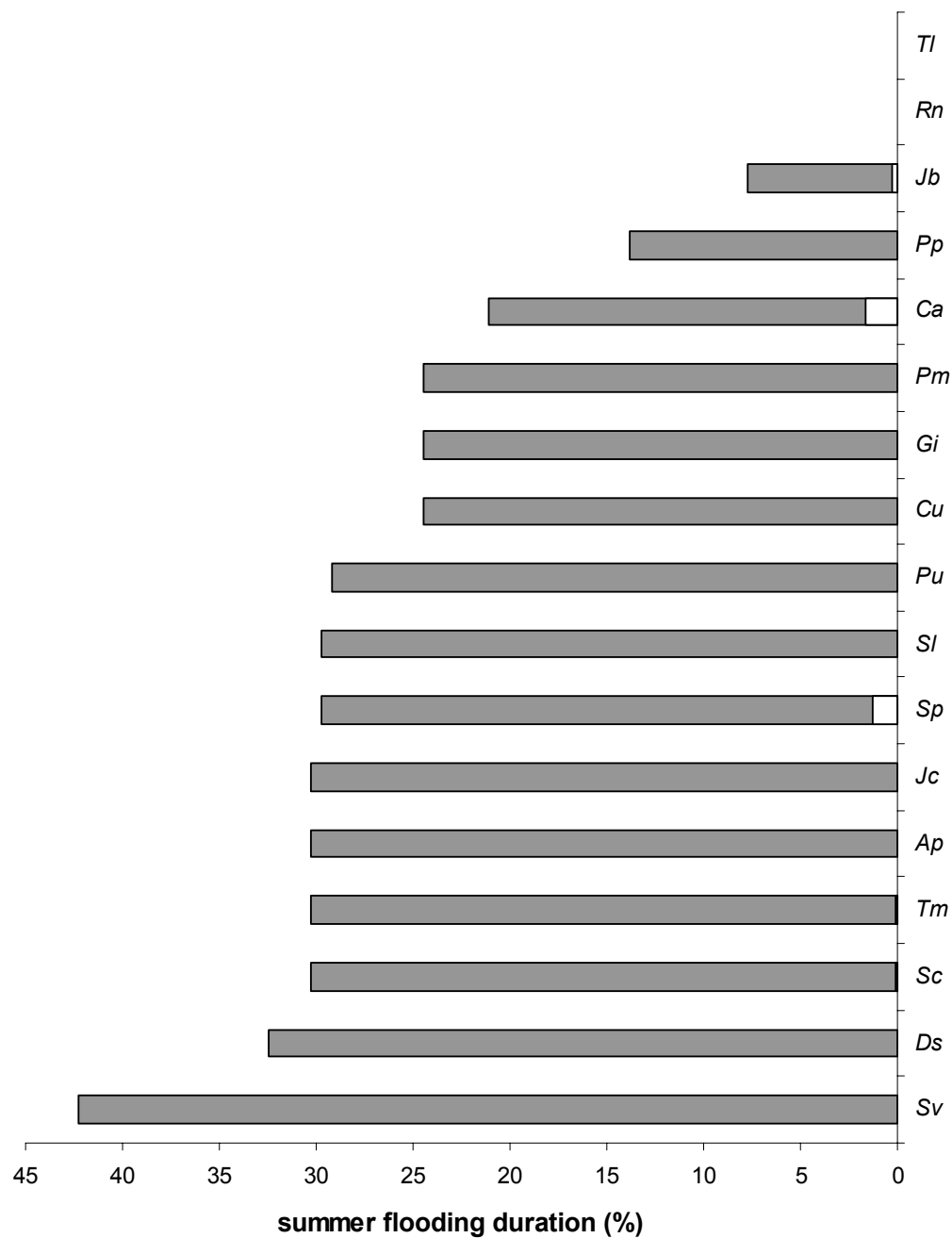
Notes: Environmental predictor variables were standardized to Z-values, with mean 0 and standard deviation 1. Average marsh values range from -0.999 to 0.664 on NMDS 1, -0.639 to 0.813 on NMDS 2, and -0.354 to 0.981 on NMDS 3.

**Table 12.** Estimated mean densities of total insects and individual taxa.

| Insect Taxon   | Density (individuals per square meter) |                            |                  |
|----------------|----------------------------------------|----------------------------|------------------|
|                | Pre-restoration                        | Predicted Post-restoration | Factor of Change |
| Total          | 561                                    | 1146                       | 2                |
| Araneae        | 37                                     | 10                         | 0.28             |
| Coleoptera     |                                        |                            |                  |
| Cryptophagidae | 46                                     | 0                          | 0.01             |
| Curculionidae  | 1                                      | 23                         | 28               |
| Lathridiidae   | 50                                     | 1                          | 0.02             |
| Staphylinidae  | 8                                      | 0                          | 0.04             |
| Diptera        |                                        |                            |                  |
| Cecidomyiidae  | 13                                     | 0                          | 0.01             |
| Muscoidea      | 1                                      | 28                         | 33               |
| Sciaridae      | 8                                      | 1                          | 0.14             |
| Tipuloidea     | 1                                      | 18                         | 18               |
| Hemiptera      |                                        |                            |                  |
| Saldidae       | 8                                      | 1096                       | 135              |
| Homoptera      |                                        |                            |                  |
| Delphacidae    | 41                                     | 7                          | 0.17             |
| Psyllidae      | 10                                     | 0                          | 0.01             |



**Figure 10.** Map of Crescent Harbor marsh.



**Figure 11.** Maximum and minimum flooding duration observed for plant species at reference marshes. *Sv* - *S. virginica*, *Ds* - *D. spicata*, *Sc* - *Spergularia canadensis*, *Tm* - *T. maritimum*, *Ap* - *A. patula*, *Jc* - *J. carnosa*, *Sp* - *Spartina* spp., *Sl* - *S. lacustris*, *Pu* - *Puccinellia* spp., *Cu* - *Cuscuta* spp., *Gi* - *G. integrifolia*, *Pm* - *P. maritima*, *Ca* - *Calamagrostis* spp., *Pp* - *P. pacifica*, *Jb* - *J. balticus*, *Rn* - *Rosa nutkana*, *Tl* - *T. latifolia*



**Figure 12.** Map of predicted salt marsh vegetation for the eastern cell of Crescent Harbor marsh.

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## SUMMARY & CONCLUSIONS

This thesis describes relationships between insect assemblages and their habitat in barrier salt marshes of northern Puget Sound and predicts post-restoration changes in one tidally restricted marsh. In addition, tidal channel fishes were compared between tidally restricted and reference marshes. Presented below are the key findings for each null hypothesis.

***H<sub>01</sub>:*** *No difference in insect assemblages among marshes or vegetation types.*

*Rejected:* Insect assemblages differed by marsh and vegetation type. *T. latifolia* supported greater total richness and density than *S. virginica*, resulting in distinct insect assemblages. High densities of Collembola and chironomid flies typified the *T. latifolia* vegetation type at both CH and LH. The insect assemblage found in *S. virginica* differed significantly among marshes, with CH having greater total richness and LH and MP supporting greater total density. LH promoted high densities of salticids, cicadellids, dolichopodids, and chalcidoid wasps, whereas MP contributed high Acari densities.

***H<sub>02</sub>:*** *No difference in habitat features (e.g., vegetation composition, salinity, and tidal inundation) among marshes.*

*Generally rejected, but dependent upon spatial scale of test:* Documentation of habitat features concurrently with insect sampling revealed that the marshes differed in tidal flooding duration, porewater salinity and depth, and soil organic matter (SOM). LH experienced the most marine influence, with the greatest tidal flooding, highest porewater salinity, and most saturated soils. Within the *S. virginica* vegetation type, CH resembled reference marshes in all environmental parameters. As expected, the different

vegetation types reflected different abiotic environments. However, my study design prohibited distinction between biotic versus abiotic influences on insect assemblages in the different vegetation types.

Stratified random vegetation sampling demonstrated that upland, freshwater marsh, and brackish marsh plant species occurred more frequently at CH than at reference marshes. Conversely, salt marsh plant species, driftwood, and mud were more frequent at reference marshes.

***H<sub>03</sub>:*** *No relationship between insect assemblages and habitat features.*

*Rejected:* Stepwise regression showed that habitat features explained variation in total insect density as well as the densities of Araneae and 11 insect families. Tidal flooding and habitat diversity represented the characteristics most strongly related to density patterns.

***H<sub>04</sub>:*** *No difference in fish composition and abundance between tidally restricted and natural marshes.*

*Rejected:* Reference marshes had higher fish species richness and abundance than CH. Juvenile salmon were absent from CH but present at reference marshes.

## **CRESCENT HARBOR MARSH**

My research findings were generally consistent with research conducted in tidally restricted salt marshes elsewhere. The restriction of tidal inundation at CH presumably generated changes in vegetation composition throughout the marsh, from typical salt marsh species to more upland, freshwater marsh, and brackish marsh species.

The insect community appears to have responded to these, and perhaps other unmeasured, environmental changes. In addition, the tide gate limits utilization of CH by estuarine and marine fishes.

Significant ecological changes should occur upon restoration of full tidal inundation to CH. Increased tidal elevations and expanded tidal range and prism will likely diversify the existing tidal channel systems through sediment erosion and large woody debris deposition. Increased tidal flooding should also stunt or kill salt-intolerant vegetation, such as *T. latifolia*. As more saline habitat becomes available, typical salt marsh plants will colonize most of the eastern cell, and likely expand their range in the northwestern cell, as well. Insects associated with *T. latifolia* at CH, such as drosophilid and sphaerocerid flies, Collembola, and aphids, should decrease in density. Taxa typical of infrequent inundation, including Araneae and several Coleoptera and Homoptera families, may also experience decreased densities within the marsh. However, insects requiring wet, marine conditions, particularly Saldidae and tipuloid flies, are expected to increase in density by an order of magnitude. Furthermore, breaching the dike to create an open channel between CH and Crescent Harbor will allow full utilization of the marsh by estuarine and marine fauna. The low elevation of CH may be particularly beneficial for ocean-type Chinook fry (Seliskar and Gallagher 1983).

To take full advantage of my findings and predictions, post-restoration monitoring at CH should include techniques and sampling designs that are directly comparable to those described in this study. A combination of environmental, plant, invertebrate, and fish sampling would be ideal. Environmental parameters might include

channel salinity, temperature, tidal elevation, and extent—metrics that quantify marsh attributes important to juvenile salmon survival and growth (Simenstad and Cordell 2000). Vegetation composition tends to reveal information about specific environmental conditions (Hackney et al. 1996) and appears to influence resident insect assemblages. Because pre-restoration conditions were documented throughout CH at the stratified random sampling points, at least a portion of these same points should be monitored after restoration. This strategy will allow spatially explicit and quantitative documentation of vegetation change through time. LH represents the best reference marsh for vegetation monitoring because it most resembles CH in tidal elevation and in predicted vegetation types.

Invertebrate monitoring will be more informative if it occurs simultaneously with tidal channel fish sampling, as this approach allows evaluation of the similarity between marsh invertebrates and fish diet and begins to assess marsh functions. Because the primary goal of restoring CH is to provide increased and higher quality habitat for juvenile salmon, sampling should take place during peak salmon migration—March through June. The addition of benthic core samples, to characterize invertebrates inhabiting tidal channels, will provide a more complete representation of prey resources available to juvenile salmon. Benthic prey resources for fish may be especially important in early spring, when adult insects occur at low densities. In this study, EB was more effective than MP for fish sampling. However, another marsh may be more appropriate.

## **BROADER RELEVANCE**

There is a growing need to apply more effective management to coastal wetland restoration projects. Few projects currently undergo formal scientific evaluation (Michener 1997), and many projects lack components that are necessary for assessing and documenting the progress of restoration (e.g., clear goals and criteria for performance, a natural reference marsh, and long-term data collection) (Zedler and Callaway 2000). As a result, wetland restoration might be considered a haphazard collection of individual projects (Keddy 1999) rather than a focused discipline with repeatable methods.

One approach to overcoming this problem is to acquire long-term data under pre-restoration, restoring, and reference marsh conditions, such that objective evaluation of restoration progress can occur (Roman et al. 2002). Quantitative assessments should also incorporate the making and testing of ecological predictions, which is a critical component of adaptive management (Thom 2000). This combined approach will improve our understanding of restoration processes, strengthen restoration predictions, and assist in future restoration design.

This study was the first step in quantitatively evaluating the restoration of CH. It provides hypotheses, sampling designs, protocols, and quantitative predictions for tracking post-restoration performance. In addition, it contributes to a broader ecological understanding of barrier salt marshes, which occur throughout the island archipelago of northern Puget Sound but are frequently overlooked by wetland and restoration scientists. More studies are needed to evaluate the ecological role of barrier marshes in

the nearshore ecosystem, particularly the benefits they provide to Pacific salmon populations.

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## APPENDIX A — AVERAGE DENSITIES OF INSECT TAXA

| Taxa           | April     |           |           |           |           |           | June      |           |           |           |           |           | August    |           |           |           |           |           |
|----------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|                | Crescent  |           |           | Hancock   |           |           | Crescent  |           |           | Hancock   |           |           | Crescent  |           |           | Hancock   |           |           |
|                | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> |
| Arachnida      |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Acari          | 38.4      | 213.1     | 29.5      | 150.5     | 48.0      | 33.0      | 16.5      | 34.8      | 65.9      | 26.5      | 73.0      | 42.5      | 40.8      | 84.5      | 53.5      | 16.3      | 64.5      | 78.0      |
| Araneae        | 18.6      | 12.5      | 8.5       | 1.5       | 7.5       | 11.5      | 18.5      | 23.2      | 17.3      | 7.5       | 8.5       | 14.5      | 5.9       | 6.5       | 11.5      | 6.4       | 13.0      | 15.0      |
| Opiliones      |           |           |           |           |           |           |           | 2.4       | 0.8       |           | 0.5       | 0.5       | 0.8       | 2.0       |           |           | 1.5       |           |
| Crustacea      |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Amphipoda      | 0.9       |           |           | 0.5       | 0.5       |           |           |           |           | 5.0       |           |           |           |           |           | 7.3       | 0.5       |           |
| Isopoda        |           |           |           |           |           |           |           |           |           |           |           | 1.5       |           |           |           |           | 1.5       | 1.5       |
| Diplopoda      |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Polyxenida     |           |           |           | 1.0       |           | 2.0       |           |           |           |           |           |           |           |           |           |           |           |           |
| Insecta        |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Coleoptera     | 0.9       |           |           |           |           | 1.5       |           | 0.8       | 0.8       | 0.5       |           |           |           | 1.5       | 3.5       | 0.8       | 2.0       | 1.5       |
| Adephaga       |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Carabidae      |           | 0.8       | 2.0       |           |           |           |           |           | 1.9       |           |           | 1.5       |           |           |           |           |           |           |
| Dytiscidae     |           |           |           |           |           |           |           |           |           |           |           | 0.5       |           |           |           |           |           |           |
| Polyphaga      |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Buprestidae    |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           | 0.8       | 1.0       |           |
| Byrrhidae      |           |           | 0.5       |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Cantharidae    |           | 0.8       |           |           |           | 0.5       |           |           | 0.8       |           | 0.5       | 0.5       |           |           |           |           |           |           |
| Chrysomelidae  |           | 0.8       |           |           |           |           |           |           |           |           |           |           | 1.9       |           |           |           |           |           |
| Coccinellidae  |           | 0.8       |           |           |           |           |           |           |           |           |           |           | 0.8       | 0.5       |           |           |           |           |
| Corylophidae   |           |           |           |           |           |           | 0.5       |           | 0.8       |           |           |           |           |           |           |           |           |           |
| Cryptophagidae |           |           |           |           |           | 0.5       | 1.0       | 0.8       |           |           |           |           | 3.2       |           |           |           |           |           |
| Curculionidae  |           |           | 1.0       |           |           | 0.5       |           |           | 0.8       |           |           | 1.0       |           | 0.5       | 1.0       |           |           | 0.5       |
| Elateridae     |           | 2.7       |           |           |           |           |           |           |           |           |           | 0.5       |           |           |           |           |           | 0.5       |
| Lathridiidae   |           |           | 0.5       |           | 1.0       |           | 18.0      | 1.6       | 2.7       |           | 46.5      | 30.0      | 1.6       | 1.0       | 1.0       |           | 17.0      | 16.0      |

| Taxa            | April     |           |           |           |           |           | June      |           |           |           |           |           | August    |           |           |           |           |           |
|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|                 | Crescent  |           |           | Hancock   |           |           | Crescent  |           |           | Hancock   |           |           | Crescent  |           |           | Hancock   |           |           |
|                 | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> |
| Leiodidae       |           |           |           |           |           |           |           |           |           |           |           |           |           |           | 0.5       |           |           |           |
| Pselaphidae     |           |           |           |           |           |           |           |           | 0.8       |           |           | 0.5       |           |           |           |           |           |           |
| Ptiliidae       |           |           | 0.5       |           |           |           |           |           | 7.8       |           |           | 0.5       |           |           | 9.0       |           |           | 0.5       |
| Scarabaeidae    |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           | 2.0       |
| Staphylinidae   |           |           | 1.0       |           | 0.5       | 0.5       | 1.5       |           | 6.4       |           |           | 2.0       |           | 0.5       | 6.0       |           |           | 3.0       |
| Collembola      | 71.6      | 61.3      | 756.5     | 3.5       | 6.5       | 96.0      | 1.5       | 1.9       | 655.3     | 1.5       | 67.5      | 260.5     |           |           | 82.5      |           | 23.5      | 78.5      |
| Diptera         |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Brachycera      |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Dolichopodidae  |           |           |           | 5.0       |           | 0.5       | 18.5      | 26.6      | 107.0     | 151.5     | 6.0       | 23.5      | 34.2      | 16.0      | 93.5      | 15.5      | 9.0       | 18.5      |
| Empididae       | 6.8       | 5.4       | 0.5       |           |           |           | 1.0       |           | 4.4       | 0.5       | 1.5       | 2.5       |           | 0.5       | 0.5       |           |           | 0.5       |
| Rhagionidae     |           |           |           |           |           |           |           |           | 0.8       |           | 0.5       |           |           |           |           |           |           |           |
| Tabanidae       |           |           |           |           |           |           |           |           |           | 0.5       |           |           |           |           |           |           |           | 2.0       |
| Cyclorrhapha    |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Agromyzidae     | 3.1       | 1.6       |           | 0.5       | 0.5       | 0.5       |           |           |           |           |           |           |           |           |           |           | 0.5       |           |
| Chamaemyiidae   |           |           |           |           |           |           |           | 2.5       |           |           |           |           |           | 0.5       |           |           |           |           |
| Chloropidae     | 0.9       |           | 0.5       |           |           |           | 1.5       | 4.4       | 1.6       |           | 1.0       | 0.5       | 1.6       |           |           |           | 1.0       | 1.5       |
| Drosophilidae   |           |           |           |           |           |           |           |           | 28.6      |           |           | 5.0       |           |           | 3.5       |           |           | 9.5       |
| Dryomyzidae     |           |           |           |           |           |           |           |           |           |           |           | 0.5       |           |           |           |           |           |           |
| Ephydriidae     | 3.4       | 0.8       | 1.0       | 16.0      | 0.5       | 1.5       | 25.0      | 4.3       | 136.7     | 65.5      | 8.0       | 16.5      | 59.7      | 13.0      | 8.5       | 36.4      | 36.5      | 20.0      |
| Heleomyzidae    |           | 1.6       |           |           |           |           | 0.5       |           |           |           |           |           |           |           |           |           |           |           |
| Lonchopteridae  |           |           |           |           |           |           |           |           | 0.8       |           |           | 0.5       |           |           |           |           |           |           |
| s.f. Muscoidea  |           | 0.8       | 0.5       | 5.5       | 1.0       |           | 2.0       | 4.0       | 3.5       | 4.0       | 3.0       | 6.0       | 2.5       | 0.5       | 13.5      | 3.5       | 1.5       | 9.0       |
| s.f. Oestroidea | 1.9       | 0.8       |           |           |           |           |           | 2.7       | 0.8       |           | 0.5       | 1.0       | 3.2       |           | 17.0      |           | 0.5       | 26.0      |
| Opomyzidae      | 0.9       |           |           |           |           |           |           | 0.8       |           |           |           |           |           |           | 0.5       |           |           |           |
| Otitidae        |           |           |           |           |           |           |           |           | 0.8       |           |           | 0.5       |           |           | 37.5      |           |           | 6.0       |

| Taxa            | April     |           |           |           |           |           | June      |           |           |           |           |           | August    |           |           |           |           |           |
|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|                 | Crescent  |           |           | Hancock   |           |           | Crescent  |           |           | Hancock   |           |           | Crescent  |           |           | Hancock   |           |           |
|                 | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> |
| Phoridae        | 1.9       | 6.7       |           |           | 0.5       |           | 15.0      | 36.3      | 13.4      | 0.5       | 0.5       | 5.5       | 20.8      | 32.5      | 96.5      | 5.6       | 10.0      | 13.5      |
| Pipunculidae    |           |           |           |           |           |           |           |           |           |           |           |           | 0.8       |           |           |           |           | 1.5       |
| Sphaeroceridae  | 20.4      | 44.7      | 2.0       | 1.0       | 2.0       | 2.5       | 8.0       | 4.9       | 48.2      | 0.5       | 0.5       | 5.5       | 4.3       |           | 5.5       | 4.9       | 3.0       | 11.5      |
| Syrphidae       |           |           |           |           |           |           |           |           | 1.6       |           |           | 1.0       |           |           | 19.0      |           |           | 6.5       |
| Tethinidae      |           |           |           |           |           |           | 0.5       | 3.2       | 4.8       | 2.5       | 0.5       | 1.0       |           |           | 3.0       | 3.3       | 3.0       |           |
| Nematocera      |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Anisopodidae    |           |           |           |           |           | 0.5       |           |           |           |           |           |           |           |           |           |           |           |           |
| Cecidomyiidae   | 1.9       | 3.2       | 0.5       | 1.0       | 1.5       |           | 4.0       | 23.2      | 11.8      |           | 13.0      | 12.0      | 3.3       | 19.5      | 44.5      | 0.8       | 8.5       | 8.0       |
| Ceratopogonidae | 2.8       | 0.8       | 6.5       | 2.5       | 9.0       | 2.5       | 4.0       | 24.9      | 13.4      | 38.5      | 22.5      | 17.5      | 9.9       | 14.5      | 5.5       | 31.7      | 22.0      | 19.5      |
| Chironomidae    | 93.3      | 71.3      | 212.0     | 167.5     | 89.5      | 44.5      | 92.0      | 36.7      | 603.7     | 30.0      | 26.5      | 154.0     | 28.5      | 33.0      | 18.5      | 54.0      | 79.0      | 28.0      |
| Culicidae       |           |           |           |           |           | 0.5       |           |           | 0.8       |           |           | 2.0       | 0.8       |           | 0.5       | 0.8       | 21.0      | 20.5      |
| Dixidae         |           |           | 1.5       | 1.5       | 0.5       | 0.5       |           |           | 4.1       |           |           |           |           |           | 1.0       |           |           |           |
| Mycetophilidae  |           | 0.8       | 1.0       |           | 0.5       | 0.5       |           | 2.4       | 3.0       |           |           |           |           |           | 1.5       |           | 0.5       | 3.5       |
| Psychodidae     | 1.9       | 1.6       | 7.5       | 0.5       | 2.0       | 2.0       | 4.0       | 4.9       | 16.8      |           | 0.5       | 8.0       | 0.8       |           | 0.5       |           |           | 1.0       |
| Scatopsidae     |           |           |           |           |           |           | 2.5       | 17.9      | 1.9       |           | 9.5       | 5.0       |           |           |           | 3.5       |           |           |
| Sciaridae       | 4.9       | 24.3      | 4.5       |           | 1.5       | 3.0       | 10.0      | 42.6      | 22.7      | 0.5       | 6.0       | 23.5      | 2.5       | 2.0       | 15.0      |           | 1.0       | 5.0       |
| Tanyderidae     |           |           |           |           | 1.5       |           |           |           |           |           |           |           |           |           |           |           |           |           |
| s.f. Tipuloidea |           |           | 2.5       |           | 1.5       | 1.5       |           | 2.5       | 7.0       | 20.0      | 0.5       | 1.0       |           | 1.0       |           | 1.6       | 1.0       |           |
| Hemiptera       |           |           |           |           | 0.5       |           |           |           | 0.8       |           | 1.5       | 1.0       |           |           |           |           |           |           |
| Amphibicorizae  |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Saldidae        | 4.6       |           |           | 7.5       |           |           | 0.5       |           | 2.5       | 70.0      | 2.0       | 1.0       | 3.5       | 0.5       | 0.5       | 21.1      | 2.0       |           |
| Geocorizae      |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Miridae         |           |           |           | 0.5       |           |           | 20.0      | 3.3       | 4.3       |           | 0.5       | 1.5       | 6.2       | 0.5       |           | 0.8       | 0.5       | 0.5       |
| Nabidae         |           |           | 1.0       | 0.5       |           |           |           |           |           |           |           |           |           | 1.0       | 3.0       |           | 0.5       | 4.0       |
| Scutelleridae   |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           | 0.5       |           |

| Taxa                  | April     |           |           |           |           |           | June      |           |           |           |           |           | August    |           |           |           |           |           |
|-----------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|                       | Crescent  |           |           | Hancock   |           |           | Crescent  |           |           | Hancock   |           |           | Crescent  |           |           | Hancock   |           |           |
|                       | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> |
| Tingidae              |           |           |           |           |           |           |           |           |           |           |           |           |           |           | 0.5       |           |           |           |
| Homoptera             | 1.9       | 4.6       |           |           | 2.5       | 0.5       | 13.0      | 5.1       |           | 1.0       | 3.0       | 2.0       | 100.5     | 1.0       | 0.5       | 0.8       | 5.0       | 1.0       |
| Auchenorrhyncha       |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Cercopidae            |           | 0.8       |           |           |           |           |           | 2.7       | 0.8       |           | 6.0       | 6.5       | 1.6       | 2.5       | 0.5       |           | 3.0       | 2.0       |
| Cicadellidae          | 0.9       | 11.8      | 18.0      | 2.0       | 1.0       | 12.5      | 7.5       | 36.2      | 4.8       | 12.0      | 4.0       | 7.5       | 40.5      | 42.0      | 29.0      | 1.1       | 9.0       | 9.0       |
| Delphacidae           |           |           |           |           | 0.5       |           | 24.0      | 2.5       |           | 2.5       | 0.5       |           | 7.7       |           | 4.0       | 4.6       |           |           |
| Sternorrhyncha        |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Aleyrodidae           |           |           |           |           |           |           |           | 0.8       |           |           |           |           |           |           |           |           |           |           |
| s.f. Aphidoidea       | 0.9       | 0.8       |           |           |           | 0.5       | 12.5      | 10.5      | 93.1      | 2.5       | 3.0       | 16.5      | 1.1       | 3.0       | 49.0      | 2.1       | 1.5       | 89.0      |
| s.f. Coccoidea        |           | 0.8       |           | 0.5       | 1.0       | 0.5       | 95.0      | 35.7      | 0.8       | 0.5       | 11.5      |           | 26.4      | 15.5      |           | 0.8       | 22.5      | 2.0       |
| Psyllidae             |           |           |           |           |           |           |           |           | 1.6       |           |           | 2.0       | 0.8       |           |           |           |           |           |
| Hymenoptera           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Apocrita              |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Formicidae            |           |           |           |           |           |           |           |           |           |           |           |           |           |           | 0.5       |           | 1.5       | 1.5       |
| Pompilidae            |           |           |           |           |           |           | 3.5       | 4.4       |           |           |           |           | 3.2       | 4.0       |           | 2.7       |           |           |
| s.f. Apoidea          |           |           |           |           |           |           |           | 0.8       |           |           |           |           |           |           |           | 0.8       |           | 0.5       |
| s.f. Bethyloidea      |           |           |           |           |           |           | 1.5       | 3.7       |           |           | 0.5       |           |           |           |           |           |           |           |
| s.f. Chalcidoidea     | 1.9       | 8.0       | 0.5       | 1.5       | 0.5       | 1.5       | 9.5       | 22.7      | 83.3      | 42.5      | 11.0      | 11.0      | 74.9      | 33.5      | 40.0      | 79.1      | 22.0      | 15.0      |
| s.f. Cynipoidea       | 1.9       | 4.6       |           |           |           |           | 4.0       | 1.1       | 2.7       | 1.0       | 4.0       | 3.0       | 3.0       | 1.5       | 2.0       |           | 0.5       | 3.0       |
| s.f. Ichneumonoidea   | 4.0       | 14.1      | 0.5       |           | 1.0       | 0.5       | 8.5       | 19.2      | 34.1      | 7.5       | 3.5       | 2.0       | 1.9       | 2.5       | 8.5       | 3.8       | 13.0      | 2.0       |
| s.f. Proctotrupeoidea | 1.9       | 3.5       | 4.5       |           |           | 0.5       | 10.0      | 34.6      | 28.8      | 1.0       | 12.5      | 5.0       | 4.1       | 6.5       | 21.0      |           | 2.5       | 5.0       |
| s.f. Sphecoidea       |           |           |           |           |           |           |           | 0.8       | 0.8       |           |           | 1.5       |           |           | 1.0       |           |           | 2.0       |
| s.f. Vespoidea        |           |           |           |           |           |           |           | 0.8       |           |           |           |           |           | 0.5       | 0.5       |           |           | 4.5       |
| Symphyta              |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Tenthredinidae        |           |           |           |           |           |           |           |           |           |           | 0.5       |           |           |           |           |           |           |           |

| Taxa          | April     |           |           |           |           |           | June      |           |           |           |           |           | August    |           |           |           |           |           |
|---------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|               | Crescent  |           |           | Hancock   |           |           | Crescent  |           |           | Hancock   |           |           | Crescent  |           |           | Hancock   |           |           |
|               | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> | <i>Sv</i> | <i>Jb</i> | <i>Tl</i> |
| Lepidoptera   | 2.2       |           | 0.5       | 0.5       | 0.5       | 1.5       | 5.0       | 9.6       | 1.6       | 0.5       | 8.0       |           | 1.6       | 2.5       | 5.0       |           | 1.5       | 4.0       |
| Neuroptera    |           |           |           |           |           |           |           |           | 1.6       |           |           |           |           | 0.5       |           |           |           |           |
| Odonata       |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Zygoptera     |           |           |           |           |           |           | 0.5       |           |           |           |           |           | 0.8       |           |           |           |           |           |
| Orthoptera    |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Acrididae     |           |           |           |           |           |           |           | 7.5       | 0.8       |           |           |           | 46.9      | 3.0       |           |           |           |           |
| Tettigoniidae |           |           |           |           |           |           | 0.5       |           |           |           |           |           |           |           |           |           |           |           |
| Psocoptera    | 0.9       |           |           | 0.5       | 0.5       | 3.0       | 3.5       | 1.9       | 0.8       |           | 2.0       | 8.0       | 5.9       | 7.0       | 15.0      | 9.1       | 7.5       | 14.0      |
| Thysanoptera  | 0.9       | 6.2       | 5.0       | 2.0       | 1.0       | 0.5       | 6.0       | 28.7      | 14.4      | 2.0       | 8.5       | 16.0      | 43.2      | 85.5      | 64.5      | 1.6       | 40.5      | 64.0      |
| Thysanura     |           |           |           |           | 0.5       |           |           |           |           |           |           |           |           |           |           |           |           |           |
| Trichoptera   |           | 0.8       |           |           |           |           |           |           | 1.6       |           |           |           |           |           | 4.5       |           |           |           |

| Taxa        | April |     |      |      |      |      | June |      |      |      |      |      | August |      |      |      |       |      |
|-------------|-------|-----|------|------|------|------|------|------|------|------|------|------|--------|------|------|------|-------|------|
|             | CH    | CB  | EB   | LH   | MP   | RL   | CH   | CB   | EB   | LH   | MP   | RL   | CH     | CB   | EB   | LH   | MP    | RL   |
| Arachnida   |       |     |      |      |      |      |      |      |      |      |      |      |        |      |      |      |       |      |
| Acari       | 7.5   | 9.3 | 18.5 | 12.3 | 87.4 | 44.0 | 68.0 | 32.0 | 31.4 | 20.5 | 80.5 | 38.0 | 79.4   | 51.5 | 36.5 | 48.5 | 140.9 | 14.0 |
| Araneae     | 13.0  | 2.7 | 1.5  | 3.8  | 2.3  | 0.5  | 36.7 | 16.0 | 8.6  | 13.0 | 7.5  | 11.0 | 9.9    | 6.5  | 5.0  | 35.5 | 13.4  | 2.5  |
| Opiliones   |       |     |      |      |      |      | 0.8  |      |      |      |      |      |        |      |      |      |       |      |
| Crustacea   |       |     |      |      |      |      |      |      |      |      |      |      |        |      |      |      |       |      |
| Amphipoda   |       | 2.7 | 2.0  | 1.6  | 2.3  |      |      | 1.5  | 1.1  | 11.0 | 4.5  | 0.8  |        | 19.0 | 26.5 | 29.5 | 29.4  | 3.5  |
| Insecta     |       |     |      |      |      |      |      |      |      |      |      |      |        |      |      |      |       |      |
| Coleoptera  | 1.0   |     |      |      |      |      |      |      |      | 0.5  |      | 0.8  |        | 1.5  | 0.5  |      |       | 0.5  |
| Adephaga    |       |     |      |      |      |      |      |      |      |      |      |      |        |      |      |      |       |      |
| Carabidae   | 0.5   |     |      |      |      |      |      |      |      |      |      | 1.6  |        |      |      |      |       |      |
| Polyphaga   |       |     |      |      |      |      |      |      |      |      |      |      |        |      |      |      |       |      |
| Alleculidae |       |     |      |      |      |      |      |      |      |      |      | 2.1  |        |      |      |      |       |      |

| Taxa           | April |     |     |      |     |     | June |      |      |       |      |     | August |      |      |       |      |      |
|----------------|-------|-----|-----|------|-----|-----|------|------|------|-------|------|-----|--------|------|------|-------|------|------|
|                | CH    | CB  | EB  | LH   | MP  | RL  | CH   | CB   | EB   | LH    | MP   | RL  | CH     | CB   | EB   | LH    | MP   | RL   |
| Anobiidae      |       |     |     |      |     |     |      |      | 0.6  |       | 1.5  | 1.1 |        |      |      |       |      |      |
| Buprestidae    |       |     |     |      |     |     |      |      |      |       |      |     |        |      |      |       |      | 0.5  |
| Byrrhidae      |       |     |     |      |     |     | 0.8  |      |      |       |      |     |        |      |      |       |      |      |
| Cantharidae    |       |     |     |      |     | 2.0 |      |      |      |       |      |     |        |      |      |       |      |      |
| Chrysomelidae  |       |     |     |      |     |     | 1.1  |      |      |       |      |     |        |      |      |       |      |      |
| Cleridae       |       |     |     |      |     |     | 0.8  |      |      |       |      | 1.6 |        |      |      |       |      |      |
| Coccinellidae  |       |     |     |      |     |     | 1.6  |      | 0.6  | 0.5   | 0.5  | 0.8 | 0.8    |      | 1.0  | 0.5   |      |      |
| Corylophidae   |       |     |     |      |     |     | 3.5  | 0.5  | 0.6  |       |      |     |        |      |      |       |      |      |
| Cryptophagidae |       |     |     |      |     |     | 46.2 |      |      |       |      |     |        |      |      |       |      |      |
| Curculionidae  |       |     |     |      |     |     | 0.8  | 1.5  | 2.9  | 19.5  | 8.5  | 6.5 |        |      |      |       |      |      |
| Elateridae     |       |     |     |      |     |     |      |      | 1.1  |       |      |     |        |      |      |       |      |      |
| Heteroceridae  |       |     |     |      |     |     |      |      |      | 0.5   |      |     |        |      |      |       | 0.8  |      |
| Hydrophilidae  |       |     | 0.5 |      |     |     | 0.8  |      |      |       |      |     |        |      |      |       |      |      |
| Lathridiidae   | 0.5   |     |     |      |     |     | 49.6 | 1.0  | 1.1  | 3.0   | 0.5  |     | 3.3    |      | 14.0 | 0.5   |      | 1.0  |
| Mordellidae    |       |     |     |      |     |     |      |      |      |       |      | 1.1 |        |      |      |       |      |      |
| Nitidulidae    |       |     |     |      |     |     | 1.6  |      |      | 0.5   |      |     |        |      |      |       |      |      |
| Pselaphidae    |       |     |     |      |     |     |      |      |      |       |      |     |        |      |      |       |      |      |
| Ptiliidae      |       |     |     |      |     |     | 1.6  | 1.5  | 0.6  |       |      |     |        |      | 1.0  |       |      |      |
| Scarabaeidae   |       |     |     |      |     |     |      | 0.5  |      |       |      |     |        |      |      |       |      |      |
| Staphylinidae  | 10.0  | 1.6 | 2.5 |      |     |     | 7.8  | 1.0  |      |       | 0.5  |     | 1.6    |      |      |       |      |      |
| Collembola     | 5.0   |     | 2.0 | 2.7  | 1.7 |     | 0.8  | 6.5  | 13.1 | 9.5   | 0.5  | 7.2 | 2.7    | 0.5  | 3.0  | 14.0  | 4.8  | 1.0  |
| Diptera        |       |     |     |      |     |     |      |      |      |       |      |     |        |      |      |       |      |      |
| Brachycera     |       |     |     |      |     |     |      |      |      |       |      |     |        |      |      |       |      |      |
| Dolichopodidae |       | 7.0 | 1.5 | 26.1 | 7.4 | 1.0 | 9.9  | 26.5 | 19.4 | 108.0 | 15.5 | 9.9 | 58.3   | 41.0 | 21.5 | 187.0 | 11.2 | 19.0 |
| Empididae      | 1.5   |     |     | 0.8  |     | 0.5 | 1.6  | 0.5  |      |       |      |     |        |      | 1.5  |       |      |      |

| Taxa            | April |       |       |       |       |       | June |      |      |      |      |      | August |      |      |       |      |      |
|-----------------|-------|-------|-------|-------|-------|-------|------|------|------|------|------|------|--------|------|------|-------|------|------|
|                 | CH    | CB    | EB    | LH    | MP    | RL    | CH   | CB   | EB   | LH   | MP   | RL   | CH     | CB   | EB   | LH    | MP   | RL   |
| Cyclorrhapha    |       |       |       |       |       |       |      |      |      |      |      |      |        |      |      |       |      |      |
| Agromyzidae     | 0.5   |       | 1.0   |       | 5.7   | 1.0   | 0.8  |      |      |      |      | 1.6  |        |      |      |       |      | 1.0  |
| Chamaemyiidae   |       |       |       |       |       |       |      |      |      |      |      |      | 0.8    |      |      |       |      |      |
| Chloropidae     | 0.5   |       |       |       | 0.6   | 0.5   | 4.9  | 3.5  | 2.9  | 1.5  | 7.5  | 8.9  | 2.5    | 10.5 | 2.5  |       | 3.3  | 5.0  |
| Chyromyidae     |       |       |       |       |       |       | 0.8  |      |      |      | 1.0  |      |        |      |      |       |      |      |
| Drosophilidae   |       |       |       | 0.8   |       |       |      |      |      |      |      |      |        |      |      |       |      | 0.5  |
| Ephydriidae     | 36.5  | 16.3  | 3.0   | 91.0  | 25.1  | 0.5   | 29.0 | 36.5 | 6.9  | 74.5 | 12.5 | 7.2  | 55.1   | 35.5 | 40.0 | 380.0 | 27.0 | 96.5 |
| Heleomyzidae    |       |       |       |       |       |       |      |      |      |      |      |      |        |      |      | 0.5   |      |      |
| s.f. Muscoidea  | 0.5   | 1.9   |       | 3.5   |       | 1.5   | 0.8  | 1.0  | 1.7  | 30.0 | 7.0  | 1.6  | 4.1    | 5.5  | 3.5  | 1.5   | 1.9  | 2.5  |
| s.f. Oestroidea | 0.5   |       |       |       |       |       |      |      |      |      |      |      | 1.9    |      | 0.5  |       |      |      |
| Opomyzidae      |       |       |       |       |       | 0.5   |      |      |      |      |      |      |        |      |      |       |      |      |
| Phoridae        | 5.0   |       | 0.5   | 0.8   | 0.6   | 6.0   | 9.2  | 3.0  | 21.1 | 1.5  | 2.5  | 9.1  | 29.8   | 3.5  | 15.5 | 2.5   | 23.4 | 45.5 |
| Pipunculidae    |       |       |       |       |       |       |      |      |      |      |      |      | 0.8    |      |      |       |      |      |
| Sciomyzidae     |       |       |       |       |       |       |      |      |      |      |      |      |        | 0.5  |      |       |      |      |
| Sphaeroceridae  | 46.0  | 10.5  | 7.0   | 4.1   | 3.4   | 1.0   | 1.6  | 0.5  | 0.6  | 4.5  | 0.5  | 3.5  | 1.6    | 6.5  | 0.5  | 42.5  | 2.7  | 2.5  |
| Tethinidae      |       |       |       | 0.8   |       |       | 0.8  | 0.5  | 1.1  | 1.0  | 0.5  | 0.8  | 0.8    | 3.0  | 4.5  | 1.0   | 1.6  | 3.0  |
| Nematocera      |       |       |       |       |       |       |      |      |      |      |      |      |        |      |      |       |      |      |
| Bibionidae      |       |       |       | 0.8   |       |       |      |      |      |      |      |      |        |      |      |       |      |      |
| Cecidomyiidae   | 1.5   | 1.9   | 1.0   | 1.6   | 1.7   | 1.0   | 13.1 | 6.0  | 10.9 | 0.5  |      | 32.0 | 0.8    | 1.0  | 3.0  | 0.5   | 0.8  | 14.0 |
| Ceratopogonidae | 3.5   | 4.6   | 0.5   | 0.8   | 13.1  | 0.5   | 10.2 | 85.0 | 15.4 | 79.5 | 77.5 | 9.6  | 5.9    | 29.5 | 7.5  | 35.5  | 16.0 | 5.0  |
| Chironomidae    | 163.5 | 214.9 | 110.5 | 278.7 | 200.6 | 684.0 | 24.0 | 12.5 | 30.9 | 49.5 | 30.0 | 85.4 | 63.1   | 7.5  | 11.5 | 18.0  | 9.3  | 13.5 |
| Culicidae       |       |       |       |       |       |       |      |      |      |      |      |      |        |      | 1.0  |       |      |      |
| Dixidae         |       |       |       |       | 0.6   |       |      |      |      |      |      |      |        |      |      |       |      |      |
| Mycetophilidae  |       |       |       |       |       | 1.0   | 2.4  |      |      |      | 1.0  |      |        |      |      |       |      |      |
| Psychodidae     | 1.5   | 2.5   |       | 0.8   | 0.6   | 1.5   |      | 1.5  | 2.9  | 1.0  |      | 3.5  |        |      |      |       |      |      |

| Taxa            | April |     |     |     |     |     | June |      |      |       |      |       | August |      |      |      |      |     |
|-----------------|-------|-----|-----|-----|-----|-----|------|------|------|-------|------|-------|--------|------|------|------|------|-----|
|                 | CH    | CB  | EB  | LH  | MP  | RL  | CH   | CB   | EB   | LH    | MP   | RL    | CH     | CB   | EB   | LH   | MP   | RL  |
| Scatopsidae     |       |     |     |     |     |     | 1.6  |      | 5.1  |       | 10.0 | 21.1  |        | 0.5  | 1.5  | 2.0  |      | 4.5 |
| Sciaridae       | 8.0   | 2.5 | 1.5 | 1.9 | 4.6 | 2.5 | 8.3  | 4.5  | 2.9  | 2.0   | 1.5  | 7.8   | 1.6    | 0.5  | 1.0  |      |      | 1.0 |
| Tanyderidae     |       |     |     |     |     |     |      |      |      |       |      |       |        |      |      |      |      |     |
| s.f. Tipuloidea | 1.5   |     |     |     |     | 0.5 |      | 9.5  | 17.1 | 55.5  | 29.0 | 2.5   |        | 13.5 | 2.5  | 3.0  | 9.2  | 3.0 |
| Hemiptera       |       |     |     |     |     |     |      |      |      |       | 0.5  |       |        |      |      | 0.5  |      |     |
| Amphibicorizae  |       |     |     |     |     |     |      |      |      |       |      |       |        |      |      |      |      |     |
| Saldidae        | 6.5   | 1.9 | 1.5 | 5.2 | 5.1 |     | 8.1  | 6.0  | 2.9  | 225.0 | 25.5 | 0.8   | 6.1    | 17.5 | 0.5  | 22.0 | 13.8 |     |
| Geocorizae      |       |     |     |     |     |     |      |      |      |       |      |       |        |      |      |      |      |     |
| Anthocoridae    |       |     |     |     |     |     |      |      |      |       |      |       |        |      |      | 1.0  |      |     |
| Lygaeidae       |       |     |     |     |     |     |      | 0.5  |      |       |      | 0.8   | 0.8    |      | 0.5  |      |      |     |
| Miridae         |       |     |     |     | 0.6 |     | 12.5 | 7.0  | 8.0  | 1.0   | 11.5 |       | 3.2    |      | 1.0  | 2.0  | 12.9 |     |
| Homoptera       |       |     | 0.5 |     | 1.1 | 3.5 | 21.3 | 16.5 | 1.7  | 10.0  | 4.5  | 7.5   | 33.8   | 9.0  | 11.0 | 14.5 | 4.9  | 3.5 |
| Auchenorrhyncha |       |     |     |     |     |     |      |      |      |       |      |       |        |      |      |      |      |     |
| Cercopidae      |       |     |     |     |     |     |      |      | 1.7  |       |      |       |        | 0.5  | 1.0  |      | 0.8  |     |
| Cicadellidae    |       | 0.8 | 1.0 | 1.9 | 0.6 | 1.5 | 16.6 | 60.5 | 7.4  | 23.5  | 15.0 | 1.9   | 56.2   | 9.5  | 9.5  | 24.0 | 24.5 | 6.0 |
| Delphacidae     |       |     |     |     | 0.6 |     | 41.2 | 8.0  | 7.4  | 3.5   | 16.0 | 3.0   | 13.8   | 6.5  | 10.5 | 7.0  | 57.1 | 3.5 |
| Sternorrhyncha  |       |     |     |     |     |     |      |      |      |       |      |       |        |      |      |      |      |     |
| Aleyrodidae     |       |     | 0.5 |     |     |     |      | 0.5  |      |       |      |       | 0.8    |      | 0.5  | 1.5  |      |     |
| s.f. Aphidoidea |       |     | 0.5 |     | 1.1 | 1.5 | 11.2 | 5.0  | 6.3  | 22.0  | 11.5 | 13.7  | 4.4    | 2.0  | 3.0  | 3.5  | 5.9  | 4.5 |
| s.f. Coccoidea  | 1.0   |     | 0.5 |     | 0.6 | 0.5 | 10.7 | 7.5  | 13.1 | 3.0   | 22.0 | 144.1 | 76.0   | 1.5  | 13.5 | 1.0  | 12.0 | 3.5 |
| Psyllidae       | 0.5   |     |     |     | 0.6 |     | 9.6  |      |      |       | 0.5  | 0.8   |        |      |      |      |      |     |
| Hymenoptera     |       |     |     |     |     |     |      |      |      |       |      |       |        |      |      |      |      |     |
| Apocrita        |       |     |     |     |     |     |      |      |      |       |      |       |        |      |      |      |      |     |
| Formicidae      |       | 0.8 | 0.5 |     |     |     |      | 2.0  | 0.6  | 0.5   |      | 1.6   |        |      | 4.0  |      |      |     |
| Pompilidae      |       |     |     |     |     |     | 1.9  | 4.0  | 1.1  |       | 0.5  | 2.4   | 3.0    | 1.5  | 2.0  |      | 4.1  | 2.5 |

| Taxa                 | April |     |     |     |     |      | June |       |      |       |       |      | August |      |      |      |      |      |
|----------------------|-------|-----|-----|-----|-----|------|------|-------|------|-------|-------|------|--------|------|------|------|------|------|
|                      | CH    | CB  | EB  | LH  | MP  | RL   | CH   | CB    | EB   | LH    | MP    | RL   | CH     | CB   | EB   | LH   | MP   | RL   |
| s.f. Apoidea         |       | 0.8 | 0.5 |     |     |      | 1.6  |       | 1.1  |       | 4.0   | 0.8  | 1.6    | 1.0  | 2.5  |      |      |      |
| s.f. Bethyloidea     |       |     |     |     |     |      | 6.1  |       | 2.3  |       |       | 0.8  | 1.6    |      |      |      |      |      |
| s.f. Chalcidoidea    | 4.5   | 4.6 | 1.5 | 6.5 | 5.1 | 5.0  | 32.5 | 153.5 | 60.0 | 232.0 | 188.0 | 59.9 | 29.7   | 42.0 | 21.5 | 53.0 | 68.9 | 25.5 |
| s.f. Cynipoidea      | 9.5   | 0.8 |     |     | 0.6 | 1.5  | 8.0  | 4.5   |      |       | 2.5   | 5.1  | 8.6    | 1.0  | 2.0  |      | 2.7  | 18.0 |
| s.f. Ichneumonoidea  | 9.0   | 0.8 | 1.5 |     | 1.1 | 1.0  | 7.8  | 1.0   | 2.9  | 14.0  | 12.5  | 4.9  | 4.6    |      |      | 9.5  | 7.0  | 2.0  |
| s.f. Proctotrupoidea | 1.5   |     | 2.0 |     | 0.6 | 0.5  | 11.3 | 5.5   | 10.9 | 1.5   | 17.0  | 12.0 | 3.3    | 0.5  | 4.5  | 2.5  | 17.3 | 2.0  |
| s.f. Sphecoidea      |       |     |     |     |     |      | 0.8  |       | 1.7  |       |       | 1.6  |        | 0.5  | 0.5  |      | 0.8  | 0.5  |
| s.f. Vespoidea       |       |     |     |     |     |      |      | 1.0   |      |       |       |      |        |      | 1.0  |      |      |      |
| Symphyta             |       |     |     |     |     |      |      |       |      |       |       |      |        |      |      |      |      |      |
| Orussidae            |       |     |     |     |     |      |      |       |      |       |       | 1.6  |        |      |      |      |      |      |
| Tenthredinidae       |       |     |     |     |     | 0.5  |      |       |      |       |       |      |        |      |      |      |      |      |
| Lepidoptera          | 8.0   |     |     |     |     |      | 4.0  | 2.0   |      |       | 0.5   | 4.6  | 4.3    |      | 2.0  | 1.0  | 0.8  | 2.0  |
| Orthoptera           |       |     |     |     |     |      |      |       |      |       |       |      |        |      | 2.0  |      |      |      |
| Acrididae            |       |     |     |     |     |      |      |       |      |       | 0.5   | 4.3  | 9.6    | 4.0  | 6.0  |      | 2.7  | 5.5  |
| Tettigoniidae        |       |     |     |     |     |      |      | 3.5   | 1.7  |       |       |      |        | 2.0  | 1.5  |      |      |      |
| Psocoptera           | 0.5   |     |     |     |     | 0.5  | 4.1  | 10.5  | 1.7  | 1.0   | 0.5   | 1.6  | 10.9   | 4.5  | 10.0 | 4.0  | 1.6  | 4.5  |
| Thysanoptera         |       |     | 1.5 |     | 1.7 | 21.0 | 9.2  | 11.0  | 7.4  | 1.0   | 7.0   | 9.1  | 73.1   | 4.0  | 29.0 | 2.5  | 50.3 | 33.0 |

Notes: Taxa organized by class, order, suborder, and family, except when preceded by "s.f." for superfamily. Density values represent individuals per square meter, and designate the lowest taxonomic level identified. *Sv* - *S. virginica*, *Jb* - *J. balticus*, *Tl* - *T. latifolia*; CH - Crescent Harbor, CB - Cultus Bay, EB - Elger Bay, LH - Lake Hancock, MP - Maylor Point, RL - Race Lagoon

# APPENDIX B — FREQUENCY OF PLANT SPECIES

| Scientific Name                               | Common Name              | Frequency of Occurrence |    |    |    |    |    |
|-----------------------------------------------|--------------------------|-------------------------|----|----|----|----|----|
|                                               |                          | CH                      | CB | EB | LH | MP | RL |
| <i>Achillea millefolium</i>                   | yarrow                   | 5                       |    | 2  |    | 2  | 2  |
| <i>Agropyron repens</i>                       | quackgrass               | 7                       |    |    |    |    |    |
| <i>Agropyron</i> spp.                         | wheatgrass               |                         |    |    |    | 1  |    |
| <i>Agrostis</i> spp.                          | bentgrass                | 3                       |    |    |    |    |    |
| <i>Alnus rubra</i>                            | red alder                | 1                       |    |    |    |    |    |
| <i>Alopecurus</i> spp.                        | foxtail                  | 1                       |    |    |    |    |    |
| <i>Ambrosia chamissonis</i>                   | silver burweed           |                         |    | 1  |    | 2  |    |
| <i>Atriplex patula</i>                        | orache                   | 22                      | 3  | 19 | 43 | 11 | 9  |
| <i>Aveneae</i>                                | oat tribe                | 1                       |    |    |    | 1  |    |
| <i>Brassica campestris</i>                    | field mustard            | 5                       |    |    |    |    |    |
| <i>Brassicaceae</i>                           | mustard family           | 2                       |    |    |    |    |    |
| <i>Calamagrostis nutkaensis</i>               | Nootka reedgrass         |                         | 1  |    |    |    |    |
| <i>Calamagrostis</i> spp.                     | reedgrass                | 15                      |    |    | 5  | 1  |    |
| <i>Cardamine oligosperma</i>                  | few-seeded bitter-cress  | *                       |    |    |    | 1  |    |
| <i>Carex lyngbyei</i>                         | Lyngby's sedge           | 1                       |    |    |    |    |    |
| <i>Chenopodium</i> spp.                       | goosefoot                | 1                       |    |    |    |    |    |
| <i>Cirsium arvense</i>                        | Canada thistle           | 10                      |    |    |    |    |    |
| <i>Cirsium vulgare</i>                        | bull thistle             | 5                       |    |    |    |    |    |
| <i>Cornus</i> spp.                            | dogwood                  | 1                       |    |    |    |    |    |
| <i>Cotula coronopifolia</i>                   | brass buttons            | 2                       |    |    |    |    |    |
| <i>Cuscuta</i> spp.                           | dodder                   | *                       | 2  | 7  | 19 | 1  | 4  |
| <i>Daucus carota</i>                          | wild carrot              | 7                       |    |    |    | 1  |    |
| <i>Distichlis spicata</i> var. <i>spicata</i> | seashore saltgrass       | 32                      | 8  | 21 | 40 | 38 | 2  |
| <i>Elymus mollis</i>                          | dunegrass                |                         | 1  |    | 1  | 1  |    |
| <i>Epilobium ciliatum</i>                     | purple-leaved willowherb | 19                      |    | 2  | *  |    |    |
| <i>Equisetum arvense</i>                      | common horsetail         | 2                       |    |    |    |    |    |
| <i>Festuca occidentalis</i>                   | western fescue           |                         | 1  |    |    |    |    |
| <i>Festuceae</i>                              | fescue tribe             |                         | 1  |    |    |    |    |
| <i>Galium aparine</i>                         | cleavers                 | *                       |    |    | 1  |    |    |
| <i>Galium trifidum</i>                        | small bedstraw           | 6                       |    | 1  | *  |    | *  |
| <i>Glaux maritima</i>                         | sea milk-wort            |                         | 2  | 2  |    |    | *  |
| <i>Grindelia integrifolia</i>                 | entire-leaved gumweed    |                         | 2  | 10 |    | 3  | 6  |

| Scientific Name                                 | Common Name           | Frequency of Occurrence |    |    |    |    |    |
|-------------------------------------------------|-----------------------|-------------------------|----|----|----|----|----|
|                                                 |                       | CH                      | CB | EB | LH | MP | RL |
| <i>Holcus lanatus</i>                           | common velvet-grass   | 12                      |    |    |    | 1  |    |
| <i>Hordeum brachyantherum</i>                   | meadow barley         |                         | 1  |    | 1  |    |    |
| <i>Hypochaeris radicata</i>                     | hairy cat's-ear       | 5                       |    |    |    |    |    |
| <i>Jaumea carnosa</i>                           | fleshy jaumea         |                         | 11 | 20 | 25 | 1  | 3  |
| <i>Juncus balticus</i>                          | Baltic rush           | 14                      |    | 1  | 3  | 1  |    |
| <i>Juncus effusus</i>                           | common rush           | 1                       |    |    |    |    |    |
| <i>Leucanthemum vulgare</i>                     | oxeye daisy           | 4                       |    |    |    |    |    |
| <i>Lonicera involucrata</i>                     | black twinberry       | 3                       |    | 4  |    |    |    |
| <i>Mahonia</i> spp.                             | Oregon-grape          | 1                       |    |    |    | 1  |    |
| <i>Malus fusca</i>                              | Pacific crab apple    | 2                       |    |    |    | 1  |    |
| <i>Mentha arvensis</i>                          | field mint            |                         |    | 1  | *  |    |    |
| <i>Myrica gale</i>                              | sweet gale            |                         |    |    | 1  |    |    |
| <i>Oenanthe sarmentosa</i>                      | Pacific water-parsley | 1                       |    |    | *  |    |    |
| <i>Plantago lanceolata</i>                      | ribwort               | 2                       |    |    |    |    |    |
| <i>Plantago major</i>                           | common plantain       | 1                       |    |    |    |    |    |
| <i>Plantago maritima</i>                        | sea plantain          |                         | 4  | 3  | 9  | 4  | 3  |
| <i>Poa pratensis</i>                            | Kentucky bluegrass    | 4                       | 1  |    |    |    |    |
| <i>Potentilla anserina</i> ssp. <i>pacifica</i> | silverweed            | 28                      |    | 2  | 5  |    |    |
| <i>Puccinellia</i> spp.                         | alkali grass          |                         | 1  | 1  | 23 | 3  |    |
| <i>Ranunculus occidentalis</i>                  | western buttercup     | 1                       |    |    |    |    |    |
| <i>Rosa nutkana</i>                             | Nootka rose           | 11                      |    | 3  |    | 1  |    |
| <i>Rubus discolor</i>                           | Himalayan blackberry  | 11                      | 1  |    |    |    |    |
| <i>Rubus spectabilis</i>                        | salmonberry           |                         |    |    | 1  |    |    |
| <i>Rumex acetosella</i>                         | sheep sorrel          | 5                       |    |    |    |    |    |
| <i>Rumex crispus</i>                            | curled dock           | 1                       |    |    |    |    |    |
| <i>Rumex maritimus</i>                          | golden dock           | 3                       |    |    |    |    |    |
| <i>Rumex occidentalis</i>                       | western dock          | 3                       |    | 2  | *  |    | 1  |
| <i>Sagina</i> spp.                              | pearlwort             | 1                       |    |    |    | 2  |    |
| <i>Salicornia virginica</i>                     | American glasswort    | 10                      | 14 | 23 | 76 | 32 | 8  |
| <i>Salix exigua</i> ssp. <i>melanopsis</i>      | sandbar willow        |                         |    | 1  |    |    |    |
| <i>Salix</i> spp.                               | willow                | 3                       |    |    |    |    |    |
| <i>Scirpus lacustris</i>                        | tule                  | 17                      | 1  | 2  | *  |    |    |
| <i>Scirpus maritimus</i>                        | seacoast bulrush      | 9                       |    |    |    |    |    |

| Scientific Name                                  | Common Name          | Frequency of Occurrence |    |    |     |    |    |
|--------------------------------------------------|----------------------|-------------------------|----|----|-----|----|----|
|                                                  |                      | CH                      | CB | EB | LH  | MP | RL |
| <i>Solanum dulcamara</i>                         | European bittersweet | 26                      |    |    | *   |    |    |
| <i>Sonchus asper</i>                             | prickly sow-thistle  | 7                       |    |    | *   |    |    |
| <i>Sonchus</i> spp.                              | sow-thistle          | 1                       |    |    |     |    |    |
| <i>Spartina anglica</i>                          | common cordgrass     |                         | 6  | 2  | 6   | 3  |    |
| <i>Spergularia canadensis</i>                    | Canadian sand-spurry | 3                       | 10 | 1  | 31  | 13 |    |
| <i>Symphoricarpos albus</i>                      | common snowberry     | 1                       |    |    |     |    |    |
| <i>Taraxacum officinale</i>                      | common dandelion     | 2                       |    |    |     |    |    |
| <i>Trientalis arctica</i>                        | northern starflower  | *                       |    |    | 1   |    |    |
| <i>Triglochin maritimum</i>                      | sea arrow-grass      |                         | 9  | 11 | 59  | 11 | 1  |
| <i>Typha latifolia</i>                           | cattail              | 51                      |    | 2  | *   |    |    |
| <i>Veronica beccabunga</i> ssp. <i>americana</i> | American brooklime   | 1                       |    |    |     |    |    |
| <i>Vicia americana</i>                           | American vetch       | 4                       |    |    |     |    |    |
| <i>Vicia sativa</i>                              | common vetch         | 6                       |    |    |     |    |    |
| <i>Vulpia bromoides</i>                          | barren fescue        |                         | 1  | 1  |     |    |    |
| <i>Vulpia</i> spp.                               | annual fescue        |                         | 1  | 2  |     | 4  | 1  |
|                                                  | evergreens           | 1                       |    |    |     |    |    |
|                                                  | shrubs               | 2                       |    |    |     |    |    |
|                                                  | mown roadside        | 2                       |    |    |     |    |    |
|                                                  | unknown dead         | 3                       |    |    |     | 3  |    |
|                                                  | unknown grass        | 6                       | *  | 1  | *   | 2  |    |
|                                                  | unknown herb         | 1                       |    |    |     |    |    |
|                                                  | wood                 |                         | 1  | 31 | 15  | 2  | 8  |
| <i>Total Number of Points</i>                    |                      | 145                     | 31 | 47 | 109 | 50 | 11 |

*Notes:* Frequency of occurrence from stratified random vegetation sampling 22-31 July 2003. \* indicates that a species was observed during characterization of vegetation surrounding insect fallout traps.

## APPENDIX C — PLANT SPECIES OBSERVATIONS AND PREDICTIONS FOR CRESCENT HARBOR MARSH

| Cell | Point | Easting  | Northing  | Elevation | Existing Vegetation                                              | Predicted Vegetation |
|------|-------|----------|-----------|-----------|------------------------------------------------------------------|----------------------|
| east | 133   | 528863.7 | 5349608.2 | 2.29      | <i>D. spicata</i> , water                                        | mud                  |
| east | 117   | 529085.2 | 5349696.2 | 2.29      | <i>D. spicata</i> , <i>A. patula</i>                             | mud                  |
| east | 114   | 529097.7 | 5349684.7 | 2.34      | <i>D. spicata</i> , <i>A. patula</i> , <i>S. lacustris</i>       | <i>S. virginica</i>  |
| east | 20    | 528974.2 | 5349692.2 | 2.36      | <i>D. spicata</i>                                                | <i>S. virginica</i>  |
| east | 94    | 528846.2 | 5349691.2 | 2.41      | <i>D. spicata</i> , <i>A. patula</i>                             | <i>S. virginica</i>  |
| east | 119   | 528956.7 | 5349647.7 | 2.42      | <i>D. spicata</i> , <i>A. patula</i>                             | <i>S. virginica</i>  |
| east | 4     | 529073.2 | 5349802.7 | 2.44      | mud                                                              | <i>S. virginica</i>  |
| east | 40    | 529142.2 | 5349759.7 | 2.44      | <i>D. spicata</i> , <i>P. pacifica</i> , <i>S. maritimus</i>     | <i>S. virginica</i>  |
| east | 78    | 529142.2 | 5349740.7 | 2.45      | <i>Calamagrostis</i> spp., <i>P. pacifica</i>                    | <i>S. virginica</i>  |
| east | 109   | 529072.2 | 5349782.2 | 2.46      | <i>D. spicata</i>                                                | <i>S. virginica</i>  |
| east | 36    | 529157.2 | 5349672.2 | 2.47      | <i>D. spicata</i> , <i>A. patula</i> , <i>R. maritimus</i>       | <i>S. virginica</i>  |
| east | 24    | 529126.7 | 5349839.2 | 2.47      | mud                                                              | <i>S. virginica</i>  |
| east | 70    | 529247.2 | 5349756.2 | 2.51      | <i>T. latifolia</i>                                              | <i>S. virginica</i>  |
| east | 111   | 529179.2 | 5349638.7 | 2.52      | <i>J. balticus</i> , <i>A. patula</i> , <i>E. ciliatum</i>       | <i>S. virginica</i>  |
| east | 13    | 529178.7 | 5349914.7 | 2.52      | <i>A. rubra</i> , <i>Cornus</i> spp.                             |                      |
| east | 103   | 528936.7 | 5349545.7 | 2.52      | <i>D. spicata</i> , <i>Calamagrostis</i> spp.                    | <i>S. virginica</i>  |
| east | 90    | 528985.7 | 5349840.2 | 2.53      | <i>D. spicata</i>                                                | <i>S. virginica</i>  |
| east | 140   | 529363.2 | 5349725.2 | 2.55      | <i>T. latifolia</i> , <i>O. sarmentosa</i>                       | <i>S. virginica</i>  |
| east | 122   | 529010.2 | 5349562.2 | 2.55      | <i>D. spicata</i>                                                | <i>S. virginica</i>  |
| east | 115   | 529105.7 | 5349553.2 | 2.56      | <i>A. repens</i> , <i>P. pacifica</i> , <i>C. vulgare</i>        | <i>S. virginica</i>  |
| east | 162   | 529337.2 | 5349685.2 | 2.56      | <i>D. spicata</i> , <i>A. patula</i> , <i>E. ciliatum</i>        | <i>S. virginica</i>  |
| east | 152   | 528983.2 | 5349526.7 | 2.56      | <i>A. repens</i>                                                 | <i>S. virginica</i>  |
| east | 160   | 529160.7 | 5349582.7 | 2.56      | asst. upland herbs                                               | <i>S. virginica</i>  |
| east | 151   | 528976.7 | 5349819.7 | 2.56      | <i>S. lacustris</i> , mud                                        | <i>S. virginica</i>  |
| east | 89    | 528994.7 | 5349808.2 | 2.57      | water                                                            | <i>S. virginica</i>  |
| east | 143   | 528940.2 | 5349902.7 | 2.57      | <i>Salix</i> spp.                                                |                      |
| east | 46    | 528975.2 | 5349517.7 | 2.57      | <i>D. spicata</i>                                                | <i>S. virginica</i>  |
| east | 59    | 529047.7 | 5349563.7 | 2.57      | <i>D. spicata</i>                                                | <i>S. virginica</i>  |
| east | 118   | 528963.7 | 5349888.2 | 2.58      | upland shrubs                                                    |                      |
| east | 116   | 528935.2 | 5349793.2 | 2.59      | <i>D. spicata</i> , <i>S. virginica</i>                          | <i>S. virginica</i>  |
| east | 124   | 529398.2 | 5349678.2 | 2.62      | <i>D. spicata</i> , <i>A. patula</i>                             | <i>D. spicata</i>    |
| east | 146   | 528936.7 | 5349859.2 | 2.64      | <i>T. latifolia</i> , <i>S. lacustris</i> , <i>P. potentilla</i> | <i>D. spicata</i>    |
| east | 93    | 529599.7 | 5349655.2 | 2.64      | <i>Calamagrostis</i> spp., <i>P. pacifica</i>                    | low salty mix        |
| east | 167   | 529433.7 | 5349727.2 | 2.64      | <i>Calamagrostis</i> spp., <i>P. pacifica</i>                    | low salty mix        |
| east | 80    | 528924.2 | 5349861.7 | 2.65      | <i>S. lacustris</i>                                              | <i>D. spicata</i>    |
| east | 7     | 529420.7 | 5349756.2 | 2.65      | <i>T. latifolia</i>                                              | <i>D. spicata</i>    |

| Cell      | Point | Easting  | Northing  | Elevation | Existing Vegetation                                           | Predicted Vegetation |
|-----------|-------|----------|-----------|-----------|---------------------------------------------------------------|----------------------|
| east      | 2     | 529378.7 | 5349776.7 | 2.65      | <i>T. latifolia</i>                                           | <i>D. spicata</i>    |
| east      | 84    | 529248.7 | 5349701.7 | 2.67      | <i>T. latifolia</i>                                           | low salty mix        |
| east      | 25    | 529199.2 | 5349471.2 | 2.68      | roadside                                                      |                      |
| east      | 38    | 529069.2 | 5349477.2 | 2.69      | asst. upland herbs, <i>J. balticus</i>                        | low salty mix        |
| east      | 163   | 529601.7 | 5349630.2 | 2.70      | <i>R. nutkana</i> , <i>R. discolor</i> , <i>C. arvense</i>    | low salty mix        |
| east      | 91    | 529578.2 | 5349720.2 | 2.72      | <i>S. lacustris</i> , <i>P. pacifica</i>                      | low salty mix        |
| east      | 96    | 529595.2 | 5349704.7 | 2.73      | <i>T. latifolia</i> , <i>P. pacifica</i>                      | low salty mix        |
| east      | 83    | 529692.2 | 5349718.2 | 2.73      | <i>T. latifolia</i> , <i>S. dulcamara</i>                     | low salty mix        |
| east      | 121   | 529491.7 | 5349777.7 | 2.74      | <i>T. latifolia</i>                                           | low salty mix        |
| east      | 76    | 529570.7 | 5349629.7 | 2.74      | <i>R. nutkana</i> , <i>E. ciliatum</i>                        | low salty mix        |
| east      | 33    | 529538.7 | 5349640.2 | 2.76      | <i>Calamagrostis</i> spp., <i>P. pacifica</i>                 | low salty mix        |
| east      | 120   | 529457.7 | 5349712.7 | 2.76      | <i>Calamagrostis</i> spp., <i>P. pacifica</i>                 | low salty mix        |
| east      | 144   | 529725.2 | 5349678.2 | 2.76      | <i>T. latifolia</i>                                           | low salty mix        |
| east      | 141   | 529453.7 | 5349701.7 | 2.76      | <i>J. balticus</i> , <i>P. pacifica</i>                       | low salty mix        |
| east      | 5     | 529485.2 | 5349741.2 | 2.76      | <i>T. latifolia</i> , <i>G. trifidum</i>                      | low salty mix        |
| east      | 129   | 529570.2 | 5349615.7 | 2.77      | <i>R. nutkana</i> , <i>R. discolor</i> , <i>S. dulcamara</i>  | low salty mix        |
| east      | 64    | 529833.2 | 5349628.2 | 2.78      | asst. upland herbs                                            | low salty mix        |
| east      | 92    | 529490.2 | 5349691.7 | 2.78      | <i>Calamagrostis</i> spp., <i>P. pacifica</i>                 | low salty mix        |
| east      | 79    | 529838.7 | 5349680.7 | 2.78      | <i>Salix</i> spp.                                             | low salty mix        |
| east      | 159   | 529261.7 | 5349513.2 | 2.80      | asst. upland herbs                                            | low salty mix        |
| east      | 148   | 529369.2 | 5349598.2 | 2.82      | <i>Calamagrostis</i> spp., <i>P. pacifica</i>                 | low salty mix        |
| east      | 32    | 529307.7 | 5349525.7 | 2.82      | asst. upland herbs                                            | high salty mix       |
| east      | 17    | 529541.2 | 5349606.2 | 2.83      | <i>J. balticus</i> , <i>Sonchus</i> spp.                      | high salty mix       |
| east      | 72    | 529441.2 | 5349554.7 | 2.86      | asst. upland herbs                                            | high salty mix       |
| east      | 51    | 529487.7 | 5349576.2 | 2.87      | asst. upland herbs                                            | high salty mix       |
| northwest | 104   | 528545.2 | 5349980.7 | 2.37      | water                                                         |                      |
| northwest | 28    | 528607.7 | 5350002.2 | 2.39      | <i>D. spicata</i> , <i>S. virginica</i> , <i>S. maritimus</i> |                      |
| northwest | 165   | 528564.2 | 5350044.7 | 2.44      | <i>D. spicata</i> , <i>A. patula</i>                          |                      |
| northwest | 155   | 528643.2 | 5349881.7 | 2.47      | <i>D. spicata</i> , <i>S. virginica</i> , <i>A. patula</i>    |                      |
| northwest | 112   | 528613.7 | 5350287.2 | 2.49      | <i>J. balticus</i> , <i>C. arvense</i>                        |                      |
| northwest | 137   | 528508.2 | 5350082.2 | 2.53      | <i>T. latifolia</i> , <i>S. dulcamara</i>                     |                      |
| northwest | 6     | 528501.7 | 5350153.2 | 2.54      | <i>T. latifolia</i> , <i>S. dulcamara</i>                     |                      |
| northwest | 14    | 528439.7 | 5350068.2 | 2.55      | <i>T. latifolia</i> , <i>S. dulcamara</i>                     |                      |
| northwest | 123   | 528417.7 | 5350100.7 | 2.55      | <i>T. latifolia</i> , <i>S. dulcamara</i>                     |                      |
| northwest | 12    | 528459.7 | 5349936.7 | 2.55      | <i>D. spicata</i> , mud                                       |                      |
| northwest | 57    | 528387.7 | 5349954.7 | 2.55      | <i>T. latifolia</i> , <i>S. dulcamara</i>                     |                      |
| northwest | 166   | 528678.7 | 5349927.2 | 2.56      | mud                                                           |                      |
| northwest | 45    | 528456.7 | 5350146.7 | 2.57      | <i>T. latifolia</i>                                           |                      |
| northwest | 153   | 528445.2 | 5350140.7 | 2.57      | <i>T. latifolia</i>                                           |                      |
| northwest | 142   | 528692.7 | 5349840.2 | 2.57      | <i>S. virginica</i> , <i>S. canadensis</i>                    |                      |

| Cell      | Point | Easting  | Northing  | Elevation | Existing Vegetation                                           | Predicted Vegetation |
|-----------|-------|----------|-----------|-----------|---------------------------------------------------------------|----------------------|
| northwest | 73    | 528710.7 | 5349919.7 | 2.57      | <i>D. spicata</i> , <i>A. patula</i>                          |                      |
| northwest | 125   | 528665.2 | 5349804.2 | 2.58      | <i>D. spicata</i> , <i>A. patula</i>                          |                      |
| northwest | 88    | 528371.7 | 5349898.2 | 2.59      | <i>T. latifolia</i> , <i>S. dulcamara</i>                     |                      |
| northwest | 3     | 528500.2 | 5350262.7 | 2.60      | asst. upland herbs                                            |                      |
| northwest | 158   | 528705.7 | 5349996.2 | 2.61      | <i>D. spicata</i> , <i>P. pacifica</i> , <i>S. lacustris</i>  |                      |
| northwest | 43    | 528735.7 | 5350097.2 | 2.61      | upland shrubs                                                 |                      |
| northwest | 30    | 528686.2 | 5349812.7 | 2.62      | <i>S. maritimus</i>                                           |                      |
| northwest | 39    | 528572.7 | 5349840.2 | 2.62      | <i>D. spicata</i> , <i>A. patula</i>                          |                      |
| northwest | 105   | 528416.7 | 5350267.2 | 2.62      | <i>J. effusus</i> , <i>C. arvense</i>                         |                      |
| northwest | 164   | 528703.7 | 5349975.2 | 2.64      | <i>S. lacustris</i>                                           |                      |
| northwest | 127   | 528698.2 | 5349831.7 | 2.64      | <i>S. virginica</i>                                           |                      |
| northwest | 139   | 528381.2 | 5350236.7 | 2.66      | <i>R. nutkana</i> , <i>R. discolor</i>                        |                      |
| northwest | 149   | 528044.7 | 5349640.2 | 2.66      | <i>R. discolor</i>                                            |                      |
| northwest | 126   | 528408.7 | 5349834.2 | 2.66      | <i>T. latifolia</i> , <i>S. dulcamara</i>                     |                      |
| northwest | 74    | 528388.7 | 5350072.2 | 2.66      | <i>S. lacustris</i> , <i>S. dulcamara</i>                     |                      |
| northwest | 95    | 528419.2 | 5349840.7 | 2.67      | <i>T. latifolia</i> , <i>S. dulcamara</i>                     |                      |
| northwest | 52    | 528246.7 | 5349732.7 | 2.67      | <i>T. latifolia</i>                                           |                      |
| northwest | 71    | 528843.2 | 5349884.7 | 2.67      | <i>T. latifolia</i>                                           |                      |
| northwest | 60    | 528325.2 | 5349891.2 | 2.67      | <i>T. latifolia</i>                                           |                      |
| northwest | 99    | 528858.7 | 5349827.7 | 2.68      | <i>R. discolor</i> , <i>S. albus</i>                          |                      |
| northwest | 75    | 528398.7 | 5349818.2 | 2.68      | <i>T. latifolia</i> , <i>S. dulcamara</i>                     |                      |
| northwest | 18    | 528272.2 | 5349701.2 | 2.69      | <i>T. latifolia</i>                                           |                      |
| northwest | 47    | 528285.7 | 5349696.2 | 2.69      | <i>T. latifolia</i>                                           |                      |
| northwest | 154   | 528291.7 | 5349677.7 | 2.69      | <i>T. latifolia</i>                                           |                      |
| northwest | 34    | 528247.2 | 5349667.2 | 2.69      | <i>T. latifolia</i>                                           |                      |
| northwest | 65    | 528811.2 | 5349812.2 | 2.70      | upland shrubs                                                 |                      |
| northwest | 68    | 528799.7 | 5349818.2 | 2.70      | water                                                         |                      |
| northwest | 100   | 528353.2 | 5349760.2 | 2.70      | <i>T. latifolia</i> , <i>S. dulcamara</i>                     |                      |
| northwest | 61    | 528344.7 | 5349663.2 | 2.70      | <i>T. latifolia</i> , <i>S. dulcamara</i>                     |                      |
| northwest | 66    | 528367.2 | 5349776.7 | 2.71      | water                                                         |                      |
| northwest | 44    | 528356.7 | 5349791.7 | 2.71      | <i>T. latifolia</i> , <i>S. dulcamara</i>                     |                      |
| northwest | 55    | 528819.2 | 5350027.7 | 2.72      | <i>S. lacustris</i>                                           |                      |
| northwest | 108   | 528889.2 | 5349927.7 | 2.72      | <i>T. latifolia</i>                                           |                      |
| northwest | 156   | 528248.7 | 5349814.2 | 2.74      | <i>T. latifolia</i>                                           |                      |
| northwest | 77    | 528344.7 | 5349723.2 | 2.75      | <i>T. latifolia</i> , <i>S. dulcamara</i>                     |                      |
| northwest | 11    | 528361.7 | 5349828.2 | 2.75      | <i>T. latifolia</i> , <i>S. dulcamara</i>                     |                      |
| northwest | 42    | 528295.2 | 5349936.2 | 2.76      | <i>T. latifolia</i>                                           |                      |
| northwest | 130   | 528283.2 | 5349839.7 | 2.77      | <i>T. latifolia</i>                                           |                      |
| northwest | 102   | 528440.2 | 5349820.7 | 2.79      | <i>T. latifolia</i> , <i>P. pacifica</i> , <i>G. trifidum</i> |                      |
| northwest | 69    | 528250.7 | 5349863.7 | 2.84      | <i>T. latifolia</i>                                           |                      |

| Cell      | Point | Easting  | Northing  | Elevation | Existing Vegetation                                            | Predicted Vegetation |
|-----------|-------|----------|-----------|-----------|----------------------------------------------------------------|----------------------|
| northwest | 1     | 528454.7 | 5349833.7 | 2.92      | <i>T. latifolia</i> , <i>S. dulcamara</i> , <i>P. pacifica</i> |                      |
| southwest | 97    | 528615.7 | 5349490.7 | 2.31      | <i>Calamagrostis</i> spp., <i>S. maritimus</i>                 |                      |
| southwest | 22    | 528534.2 | 5349462.7 | 2.40      | <i>L. involucrata</i> , <i>R. nutkana</i>                      |                      |
| southwest | 110   | 528560.2 | 5349427.7 | 2.45      | <i>J. balticus</i> , <i>P. pacifica</i> , <i>R. nutkana</i>    |                      |
| southwest | 161   | 528634.2 | 5349481.2 | 2.45      | <i>S. lacustris</i> , <i>P. pacifica</i> , <i>A. patula</i>    |                      |
| southwest | 107   | 528146.2 | 5349493.2 | 2.49      | <i>S. lacustris</i>                                            |                      |
| southwest | 168   | 528566.2 | 5349373.7 | 2.49      | <i>J. balticus</i> , <i>L. vulgare</i>                         |                      |
| southwest | 31    | 528426.2 | 5349375.7 | 2.50      | <i>T. latifolia</i> , <i>P. pacifica</i>                       |                      |
| southwest | 15    | 528587.2 | 5349361.7 | 2.53      | <i>J. balticus</i> , <i>P. pacifica</i>                        |                      |
| southwest | 147   | 528602.2 | 5349392.2 | 2.53      | <i>R. nutkana</i> , <i>A. millefolium</i>                      |                      |
| southwest | 23    | 528476.2 | 5349504.2 | 2.54      | <i>Calamagrostis</i> spp., <i>P. pacifica</i>                  |                      |
| southwest | 27    | 528473.2 | 5349506.7 | 2.54      | <i>J. balticus</i> , <i>P. pacifica</i>                        |                      |
| southwest | 26    | 528807.7 | 5349442.2 | 2.55      | asst. upland herbs                                             |                      |
| southwest | 63    | 528608.2 | 5349353.7 | 2.56      | <i>R. nutkana</i> , <i>J. balticus</i> , <i>P. pacifica</i>    |                      |
| southwest | 41    | 528215.7 | 5349534.2 | 2.58      | <i>T. latifolia</i> , <i>S. lacustris</i>                      |                      |
| southwest | 132   | 528311.2 | 5349495.2 | 2.58      | <i>T. latifolia</i>                                            |                      |
| southwest | 67    | 528614.7 | 5349419.7 | 2.62      | <i>M. fusca</i> , <i>R. nutkana</i>                            |                      |
| southwest | 10    | 528332.7 | 5349510.7 | 2.62      | <i>T. latifolia</i>                                            |                      |
| southwest | 29    | 528616.2 | 5349422.7 | 2.62      | <i>M. fusca</i> , <i>P. pacifica</i>                           |                      |
| southwest | 131   | 528633.2 | 5349419.7 | 2.65      | <i>R. discolor</i>                                             |                      |
| southwest | 136   | 528399.2 | 5349462.7 | 2.65      | <i>S. lacustris</i> , <i>S. dulcamara</i>                      |                      |
| southwest | 98    | 528120.2 | 5349323.7 | 2.66      | <i>R. nutkana</i>                                              |                      |
| southwest | 157   | 528095.2 | 5349601.2 | 2.68      | <i>T. latifolia</i>                                            |                      |
| southwest | 49    | 528195.7 | 5349547.2 | 2.75      | <i>T. latifolia</i> , <i>S. lacustris</i>                      |                      |
| southwest | 128   | 528326.2 | 5349550.2 | 2.75      | <i>T. latifolia</i>                                            |                      |
| southwest | 135   | 528278.2 | 5349616.7 | 2.77      | <i>T. latifolia</i>                                            |                      |
| southwest | 21    | 528779.2 | 5349373.7 | 2.83      | roadside                                                       |                      |
| southwest | 85    | 528143.2 | 5349559.2 | 2.86      | <i>T. latifolia</i> , <i>S. dulcamara</i>                      |                      |

Notes: Easting and Northing are x,y coordinates for UTM Zone 10, NAD 83 projection. Elevation is meters above MLLW. "Low salty mix" includes *S. virginica*, *D. spicata*, *A. patula*, *J. carnosa*, *Puccinellia* spp., *S. lacustris*, *Spartina* spp., *S. canadensis*, and *T. maritimum*. "High salty mix" includes the previous species plus *Calamagrostis* spp., *C. salina*, *G. integrifolia*, and *P. maritima*.