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EFFECTS OF LARGE OVERWATER STRUCTURES ON EPIBENTHIC JUVENILE SALMON PREY ASSEMBLAGES IN PUGET SOUND, WASHINGTON

by

Melora Elizabeth Haas
Graduate Research Assistant

Charles A. Simenstad
Senior Fisheries Biologist

Jeffery R. Cordell
Senior Research Biologist

David A. Beauchamp
Asst. Unit Leader–Fisheries

Bruce S. Miller
Professor

School of Aquatic and Fishery Sciences
University of Washington
Seattle, Washington 98195

Washington State Transportation Center (TRAC)
University of Washington, Box 354802
1107 NE 45th Street, Suite 535
Seattle, Washington 98105-4631

Washington State Department of Transportation
Technical Monitor
Tina Stotz, Environmental Program Manager
Washington State Ferries

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16. ABSTRACT

Although large over-water structures alter nearshore habitat in a number of ways, little work has been done to study how docks affect nearshore fauna. In Puget Sound, juvenile chum, pink, and ocean-type chinook salmon migrate along the shorelines and feed extensively on shallow water epibenthic invertebrates. As part of an ongoing project on the effects of ferry terminals on juvenile salmon, this study looked at the effects of large overwater structures on juvenile salmon and their prey. The epibenthic assemblage was sampled for juvenile salmon prey with four sampling regimes: monthly-stratified sampling of epibenthic invertebrates at three terminals, one-time eelgrass patch at a single terminal, one-time high-resolution cross-terminal at a single terminal, and one-time terminal structure sampling at two terminals. The response variables tested included taxa richness and densities of (1) total epibenthos, (2) total juvenile salmon prey, (3) common or abundant salmon prey taxa and (4) common or abundant non-salmon prey taxa.

Both the stratified-monthly and eelgrass sampling indicated that terminals negatively affected all summary response variables and many individual taxa. High-resolution cross-terminal sampling results were less clear, but the negative impacts of the terminal were evident for some taxa. Finally, terminal structure sampling results showed some differences in assemblages on different structure-types and elevations, and an overall smaller abundance of epibenthos on terminal structures than on intertidal sediment and benthic vegetation. In general, these results agreed with impact predictions based on vessel disturbance (propeller wash) and shading of benthic vegetation, and with assessments of these attributes completed during the sampling season. The researchers concluded that decreases or changes in the epibenthos density, diversity, and assemblage at these large overwater structures were probably caused by four interacting factors: direct disturbance or removal by vessel traffic, reduced or compromised benthic vegetation, physical habitat alterations, and biological habitat alterations.

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INTRODUCTION

With increasing human populations, coastal regions have been subjected to rising development and urbanization. For instance, approximately one third (~1230 km) of the Puget Sound shoreline has been anthropogenically modified in the 150 years since the designation of the Washington Territory (Bailey et al. 1998), and the population in this region has more than doubled in the last 50 years (Puget Sound Regional Council 2001). Anthropogenic modifications of estuarine and marine shorelines include armoring and stabilization as well as the construction of facilities ranging from private docks to marinas to large-scale port facilities. Overwater structures (OWS), including piers and docks, are among the more common nearshore[1] modifications, yet the effects of these structures on nearshore organisms have not been extensively studied.

In the Puget Sound region, this dramatic increase in human population, with accompanying development and exploitation of regional natural resources, coincides with a decline in some wild Pacific salmon populations. Many Pacific salmon stocks on the West coast of the United States are depleted or otherwise considered at risk (Nehlsen et al. 1991, Huntington et al. 1996). Two Puget Sound Evolutionarily Significant Units (ESUs) are designated as threatened under the Federal Endangered Species Act: Hood Canal summer chum (Johnson et al. 1997) and Puget Sound chinook (Department of Commerce 1999). A third ESU, Puget Sound/Georgia Strait coho, is also a candidate for federal listing (Weitkamp et al. 1995). This pervasive decline in Puget Sound salmon stocks has added to the concern for Pacific salmon and their habitat.

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[1] per Simenstad et al. 1999, nearshore is defined as beaches, intertidal, and subtidal zones between extreme high high water and –20m

All Pacific salmon utilize estuarine-nearshore habitats during their lives (e.g. Thorpe 1994), but ocean-type juvenile salmon entering estuaries and marine waters early in their first year, generally chum (*Oncorhynchus keta*), pink (*O. gorbuscha*) and ocean-type[2] chinook (*Oncorhynchus tshawytscha*) (Healey 1991), are particularly reliant on these shorelines (Healey 1980, Healey 1982, Simenstad et al. 1982). For chum and chinook, this habitat also is of great importance for foraging. While these fish are small (<45 to 55mm fork length) their diets in estuarine-nearshore areas (as opposed to tidal emergent marshes) are dominated by epibenthic crustaceans, including harpacticoid copepods, gammarid amphipods, and cumaceans (e.g., Feller and Kaczynski 1975, Healey 1979, Healey 1980, Simenstad et al. 1980). Though small pink salmon eat more planktonic organisms than do small chum and chinook, they also feed on epibenthic organisms (Kaczynski et al. 1973, Godin 1981). Even after these fish begin to eat more planktonic organisms, they continue to utilize shallow waters where vegetation, turbidity, and the shallowness of the water may provide refugia from predators (Simenstad et al. 1982, Orth et al. 1984, Gregory and Levings 1996, Gregory and Levings 1998). The term “juvenile salmon” hereafter refers only to ocean-type chinook, chum and pink salmon that are shoreline dependent.

In shallow estuarine waters, including nearshore Puget Sound, juvenile salmon depend most on those epibenthic crustaceans associated with benthic vegetation (eelgrass *Zostera marina* and its epiphytes, benthic macroalgae, diatoms), sand, and mudflats (Simenstad et al. 1991). Some taxa in the juvenile salmon prey (JSP) assemblage occur commonly among these habitat types while others may be more specific to one or two (Simenstad et al. 1979, Thom et al. 1984, Simenstad et al. 1988a). This is also the case with small epibenthic crustacean assemblages in other regions (Hicks 1986, Iwasaki 1993). Juvenile salmon appear to target specific taxa and life

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[2] The term “ocean-type” refers to salmon leaving freshwater early in their first year of life (some chinook, chum, and pink) versus those rearing extensively in freshwater (some chinook, coho, and sockeye).

history stages within the epibenthic crustacean assemblage on which they are feeding (Healey 1979, Sibert 1979, D'Amours 1987, Webb 1991a&b, Simenstad et al. 1995). Many of the taxa typically found in their diets are among those with strong habitat affinities (Thom et al. 1984, Simenstad et al. 1988a, Simenstad et al. 1995).

Intertidal habitats are susceptible to impacts of OWS (reviewed by Nightingale and Simenstad 2001). Initial construction may involve impacts such as shading from barges, and substrate disturbance from pile driving (Feist 1991), and destruction of existing eelgrass or other habitat (Thom et al. 1995). Once built, shade from the structure can reduce or completely eliminate benthic vegetation (Loflin 1995, Burdick and Short 1999, Shafer 1999). Other long-term physical alterations may include redistribution and alteration of grain size of sediments resulting from changes in current and tidal flows around pilings (Ratte 1985, Francisco 1995), analogous to scour common around bridge pilings in rivers. If the structure receives boat traffic, there can be more light attenuation both from moorage and turbidity, and physical disturbance from propeller wash, scour, and propeller or landing scarring (Loflin 1995, Sargent 1995, Thom et al. 1996, Simenstad et al. 1997a, Burdick and Short 1999, Shreffler and Gardiner 1999).

All of these effects of OWS ultimately result in biological changes. Changes in fish assemblages around OWS have been correlated with decreased habitat quality for certain fish, including juveniles that rear in estuarine-nearshore waters (Able et al. 1998). Shading has been demonstrated to reduce fish growth potential in the vicinity of OWS (Able et al. 1999, Duffy-Anderson and Able 2001), even when the crustacean prey assemblage was not significantly reduced (Duffy-Anderson and Able 1999). The reduction or elimination of benthic vegetation is presumed to result in alterations in the epibenthic faunal assemblage, since many of those organisms are closely associated with the vegetation. Such decreases have been demonstrated with the experimental removal of macroalgae in California (Everett 1994). Similarly, alterations in sediment structure and distribution may also alter the epibenthic assemblage composition. Finally, regular disturbance from strong propeller wash can be expected to remove or redistribute organisms not fixed to the substrate. While the surface of the structure itself provides a novel habitat for large and small epifauna (e.g., pilings and floats as described by Kozloff 1983) and reef-like habitat structure for fish and large invertebrates (Miller 1980, Shreffler and Gardiner 1999) these assemblages can differ markedly from those inhabiting adjacent areas (Glasby 1999a, Glasby 1999b, Connell 2000).

Research exploring OWS effects on smaller fauna, such as epibenthic invertebrates used by juvenile salmon and other fish, is limited (Duffy-Anderson and Able 2001). One expects that epiphytic fauna would be negatively impacted by shading from OWS. In addition, fauna not specifically associated with benthic vegetation may also be susceptible to the other OWS impacts described above. The goal of this study was to examine the effects of this suite of potential OWS impacts on the epibenthic crustacean assemblage on which juvenile salmon forage. Since the mid 1990s, the Washington State Department of Transportation (WSDOT) has sponsored a research program exploring the effects of its Puget Sound region ferry terminals on various estuarine-nearshore resources, including focusing on effects on juvenile salmon and their habitat. The research presented here was conducted during the spring of 2000 as a part of this program. The primary object was to test for differences in epibenthic juvenile salmon prey in the vicinity of and farther away from WSDOT ferry terminals.

REVIEW OF THE RELEVANT LITERATURE

Juvenile Pacific Salmon, Epibenthos, and the Estuarine-Nearshore

Pacific salmon exhibit a variety of life history types (Groot and Margolis 1991) with highly variable traits including length of rearing in fresh water, extent of utilization of estuarine-nearshore habitats, time spent in the open ocean, and time of return to spawning grounds. Juveniles can be divided into life-history types relating to the time spent rearing in fresh water versus salt water. "Stream-type" fish usually rear for an extended period in fresh water, up to three years, and transition to salt water at a relatively large fork length (FL), while "ocean-type" fish enter salt water at a much smaller size, shortly within days or months of emergence in late winter and early spring. In general, sockeye, coho, and some chinook populations fall into the stream-type category, while other chinook, chum, and pink are ocean-type. Stream- and ocean-type chinook often correlate with whether their parents' return to freshwater to spawn in the spring or fall, respectively. The majority of ocean-type fish in the Pacific Northwest outmigrate between March and June, with peak times varying between species and populations.

Ocean-type juvenile salmon utilize nearshore estuarine and marine habitats during outmigration, until moving offshore in the late spring and summer (e.g. Kaczynski et al. 1973, Healey 1982, Simenstad et al. 1982). In addition to the migration and predation refuge functions (Simenstad et al. 1982, Thorpe 1994, Gregory and Levings 1996), the nearshore affords foraging opportunity for these fish (e.g., Mason 1970, Macdonald et al. 1987, Levings 1994). They feed in three different zones: epibenthic, planktonic, and neustonic. Epibenthic organisms (collectively referred to as the epibenthos) that are on or close to the sediment surface or macrophytes; planktonic organisms (plankton) that are in the water column; and neustonic organisms (neuston) that are on the water surface. Juvenile salmon may feed in one or any combination of these three zones, though pink salmon often feed primarily on plankton (Kaczynski et al. 1973, Miller et al. 1977, Simenstad et al. 1982, Cordell 1986) and chinook feed heavily on neuston and plankton in certain habitats (Fresh et al. 1979, Simenstad et al. 1980, Healey 1982). Smaller chum and chinook (FL<45 to 55mm) are particularly dependent on the epibenthos in nearshore marine habitats with benthic vegetation (eelgrass *Zostera marina* and macroalgae) and intertidal flats (Simenstad et al. 1991).

Epibenthic feeding chum and pink salmon forage more on the large meiofauna component of the epibenthos while juvenile chinook feed more on smaller macrofauna. Meiofauna refers to a size class of organisms between 0.0063 (or 0.0045) and 0.5 mm, macrofauna are > 0.5 mm (International Association of Meiobenthologists 2001). Taken together, this assemblage is primarily composed of crustaceans, including harpacticoid copepods, gammarid amphipods, and cumaceans, as well as a variety of worms, molluscs, and other organisms. The majority of the epibenthic invertebrates consumed by juvenile salmon are crustaceans: generally gammarid amphipods and cumaceans in the case of chinook, and harpacticoid copepods in pink and chum (Simenstad et al. 1991). In Puget Sound, the epibenthic assemblage composition depends on a variety of interacting factors (e.g., sediment type/grain size, vegetation type, wave exposure and tidal elevation), with some taxa generally occurring in a specific habitat type while others are more ubiquitous (e.g. Simenstad et al. 1979, Thom et al. 1984, Simenstad et al. 1988a, Simenstad et al. 1988b, Thom et al. 1989).

In many cases, juvenile salmon feeding on epibenthos selectively target specific prey items. For example, Feller and Kaczynski (1975) demonstrated that chum selected harpacticoids in a size distribution significantly smaller than those available in the general epibenthos. In companion papers, Healey (1979) and Sibert (1979) showed a strong preference for the relatively rare harpacticoid *Harpacticus uniremis* by outmigrating chum in the Nanaimo River estuary, BC.

Webb (1991a,b) and D'Amours (1987) both established that chum and pink juveniles on Roberts Bank, near the Fraser River estuary BC, fed primarily on *H. uniremis*, *Tisbe* cf. *furcata*, and *Zaus aurelii*. Furthermore, while *T.* cf. *furcata* was generally the most abundant taxon of the three, the rarer taxa *H. uniremis* and *Z. aurelii* dominated fish diets. Simenstad et al. (1998a) showed that chum in Padilla Bay, Washington also extensively fed on these same harpacticoids, and that *H. uniremis* and *Zaus* sp. were available only in one of four habitat types sampled (eelgrass). Cordell (1986) also demonstrated extensive feeding on *H. uniremis* and *Tisbe* spp. by chum and pink salmon in Auke Bay, Alaska, but in contrast to much of the work in Puget Sound and the Georgia Strait, *H. uniremis* was the most abundant harpacticoid in epibenthic samples taken during fish sampling. Because there is some potential for selective feeding, it is important to identify known prey items to a relatively high taxonomic resolution when considering the juvenile salmon prey (JSP) assemblage, as opposed to simply enumerating the total epibenthos.

Impacts of Non-Ferry Terminal Overwater Structures on the Nearshore

There are a number of potential impacts of overwater structures (OWS) and resulting changes in the nearshore environment that could affect the JSP assemblage (see Nightingale and Simenstad 2001). The primary longer-term impacts appear to be associated with shading of the intertidal and shallow subtidal environment by the structure. Loflin (1995) reported reductions in seagrasses in Florida underneath small, recreational boat docks and attributed this to shading, but was unable to correlated decreased shading to any particular dock factor beyond total area. He also noted decreased epiphyte load on seagrass blades in more shaded areas. Seagrass epiphytes have been positively correlated with meiofauna abundance (Hall and Bell 1993). Burdick and Short (1999) demonstrated decreased shoot density and canopy height of eelgrass underneath and adjacent to docks in Massachusetts, as well as decreased light available for photosynthesis. They concluded that those dock-types that allowed the most light to pass (e.g. tall, narrow, north-south orientation) had the least severe impacts on the eelgrass habitat. Shafer (1999) found similar dock impacts on the seagrass *Halodule wrightii* in Alabama, including decreased available light and decreased seagrass condition that was variable according to dock-type. Fresh et al. (1995, 2001) found similar effects Puget Sound, as did Pentilla and Doty (1990 in Simenstad et al. 1999) for both eelgrass and macroalgae. The docks in these three studies were mostly small, privately owned structures used for recreational swimming and boating. Light levels under and around much larger commercial structures were also measured with a number of projects in the Hudson River estuary (Able et al. 1998, 1999, Duffy-Anderson and Able 1999, Duffy-Anderson and Able 2001). These studies consistently reported significant decreases of light levels in the vicinity of large piers. One expected result of shading would be reductions in benthic vegetation and its associated invertebrates, possibly similar to those seen with experimental removal of macroalgae (e.g., Everett 1994).

Disturbance of the inter- and subtidal environment during dock and pier construction is another potential impact of OWS. Shading impacts from floats are generally more severe that those of structures above the water surface (Burdick and Short 1999), and construction barges may have serious negative impacts associated with their presence in the nearshore. Feist (1991) found that pile driving during OWS construction altered schooling behavior and distribution of juvenile chum and pink salmon, and that hydraulic pile driving used in dock construction had the potential to significantly alter the long-term sediment grain size composition. Whether such activities impact the epibenthic faunal assemblage are unknown, but they could alter the epibenthos, at least temporarily.

Once a structure is in place, boat traffic associated with it may have additional impacts. Though understudied in marine systems, resuspended sediments from boat traffic can increase water turbidity around docks and piers (Yousef 1974, Hilton and Phillips 1982, Garrad and Hey 1988), which can further attenuate light and decrease visibility for organisms in the area. Vegetation also may be affected directly by boat traffic. Burdick and Short (1999) found that eelgrass adjacent to many docks was shorter than that away from or underneath docks, and attributed this difference in part to boat damage. They also noted that turbulence from propeller wash was severe enough to erode sediment around eelgrass rhizomes. Sargent et al. (1995) documented extensive scarring of Florida seagrasses and attributed the majority of it to direct damage from propellers, an impact also noted by Loflin (1995).

Dock structures, such as pilings and floats, provide substrate for epifauna of all sizes including encrusting organisms (e.g. barnacles, mussels, sponges), micro- and macroalgae, and mobile macrofauna (e.g. sea stars). Kozloff (1983) described many common float and piling organisms on the northern Pacific coast. Glasby (1991a) and Connell (2000) demonstrated that the assemblages present on pilings and floats in Sydney Harbor, Australia, were different from those present on nearby natural hard substrates. However, Glasby (1999b) found the assemblages on freestanding pilings more similar to those on the natural substrates, and concluded that shading from OWS was the primary cause of the assemblage difference.

Though largely undocumented, shading, structure, and other habitat alterations caused by OWS may also affect changes in macrofauna assemblages including increased densities of infauna (e.g., bivalves, Shreffler and Gardiner 1999, author pers. obs.), mobile macroinvertebrates (e.g., crustaceans and sea stars, Shreffler and Gardiner 1999, author pers. obs.), and fish (e.g., pile perch and flatfish, Miller 1980). Because effects of bioturbation on epibenthos have been demonstrated to be positive, neutral, and negative, as well as density dependent, it is unclear what role it may play a role at OWS. One might expect bioturbation by large aggregations of macrofauna, such as red rock crabs (*Cancer productus*) or flatfish, to induce changes in the epibenthic assemblage. Bioturbation by larger crustaceans on meiofauna has demonstrated in some studies, but others are inconclusive. Escaravage and Castel (1990) demonstrated a positive relationship between the presence of palaemonid shrimp and the densities of nematodes, insect larvae, and a harpacticoid copepod. Warwick et al. (1990) showed decreased species richness for nematodes in areas with high densities of soldier crabs, though total abundance of nematodes, abundance and diversity of copepods were not affected. Ólafsson and Ndaro (1997) demonstrated no effects of mangrove crab bioturbation on meiofauna (principally harpacticoids and nematodes) in experimental microcosms. Larger organisms may also be affected by bioturbation. A study on the impacts of bioturbation by a tube dwelling polychaete on larger organisms demonstrated negative effects on some taxa (e.g., the cumacean *Cumella vulgaris*), but not others (e.g., the amphipod *Corophium salmonis*) (Wilson 1981). Widdicombe and Austen (1999) demonstrated effects of bioturbation by some bivalves on macrofauna diversity to be density dependent, with a positive response at intermediate bivalve densities

Impacts of Ferry Terminals on the Nearshore Environment

Some aspects of nearshore impacts of Washington State Department of Transportation (WSDOT) ferry terminals have been relatively well studied. Simenstad et al. (1997a) evaluated potential impacts of WSDOT terminals on eelgrass. Recent documents, including an extensive literature review, have evaluated potential impacts of WSDOT terminals on juvenile salmon and their habitat (Simenstad et al. 1997a, 1999). A number of individual technical reports (e.g. Shreffler and Moursund 1999, Blanton et al. 2001) also imply potential impacts on the epibenthos in descriptions of the physical environment around ferry terminals, including shading, propeller wash, and changes in macrofaunal assemblages, sediment composition, and benthic vegetation.

The light environment and potential shading impacts around ferry terminals have been well described. Surveys have included light measurements above and in water, generally using the light spectra utilized by primary producers for photosynthesis (photosynthetically active radiation). Walking and diving transects underneath terminals consistently demonstrated reduced photosynthetically active radiation under terminals, with some light extending underneath the south margin and shade extending just beyond the north margin (Olson et al. 1997, Shreffler and Gardiner 1999, Shreffler and Moursund 1999, Blanton et al. 2001). As with other OWS studies, factors influencing the extent of shading included terminal width and height above MLLW.

Olson et al. (1997) and Visconty (1997) used light measurements to create models describing the duration and intensity of shading around a number of ferry terminals at different times during the year, as well as to predict shading impacts from proposed terminal additions. As expected, the model predicted shading to be most temporally intense in midwinter and spatially intense underneath and along the north margin of the structures. While monitoring in-water photosynthetically active radiation, they and Thom et al. (1996) found additional shading during ferry docking due to sediment resuspension and bubbles from the propeller wash. They concluded that shading from the combined sources was in part responsible for reduced eelgrass presence in the vicinity of the terminal.

Benthic vegetation, including eelgrass, also has been reduced in the vicinity of WSDOT terminals. Underwater video surveys from eelgrass around three terminals (Clinton, Edmonds, Port Townsend) were used to create a model describing eelgrass distribution at each site (Simenstad et al. 1997b). At Clinton, a continuous band of eelgrass around the structure was disrupted by complete absence of vegetation underneath and directly adjacent to the terminal decking. Similar impacts of smaller magnitude occurred at the other two terminals. While impacts were not as evident at Edmonds or Port Townsend, they specifically noted reduced shoot density under the terminal at Edmonds. On the other hand, epiphyte loads on blades did not appear to be impacted by dock proximity at any of the sites. The same authors also surveyed macrofauna under the structures and in adjacent eelgrass, and the currents generated by ferry docking. They concluded that the observed decrease in eelgrass was probably due to a combination of shading, bioturbation by macrofauna (specifically crabs and sea stars), and erosion from propeller wash scour. Blanton et al. (2001) also described reduced benthic vegetation, including macroalgae and eelgrass, underneath the Clinton, Bainbridge, and Southworth terminals, with vegetation occurring under the decking only at Southworth.

Ferry terminals differ from many other overwater structures in the frequency of large boat traffic. At some WSDOT terminals, ferries depart every half-hour for certain portions of the day, meaning that with docking and departing there are up to four propeller wash events per hour (see Olson et al. 1997). Francisco (1995) demonstrated that most resuspended sediments from ferry traffic in downtown Seattle was of a fine grain size. Over time, this can lead to a coarsening of the sediments underneath the terminal. Shreffler and Gardiner (1999) observed changes in bathymetry around pilings supporting the Clinton terminal, resulting in scour pits ringed with lighter debris. I observed similar pits at the Bainbridge terminal during field sampling. Propeller wash generated currents can be over six times the background current (Olson et al. 1997), which could result in a regular flushing of epibenthic meiofauna out of the terminal vicinity.

In most cases, presence-absence macrofauna surveys have been completed along with adjacent vegetation and light surveys at WSDOT structures. In general, macrofauna diversity underneath the terminal appears somewhat reduced, and those organisms restricted to underneath the terminal either inhabit the pilings and floats of the structure or are fish using the terminal as a reef (Thom and Schafer 1995, Simenstad et al. 1997a). Shreffler and Gardiner (1999) noted increased shell hash from sea star predation on barnacles and molluscs around pilings, and

Simenstad et al. (1997) mention that bioturbation from sea stars as well as bivalves may be a factor in the reduction of benthic vegetation near the terminal structures. I observed much higher densities of large clams, crabs, and sea stars underneath all three terminals than in the areas adjacent to them during the fieldwork for this project.

It is clear that these factors (shading, reduced benthic vegetation, propeller wash from boat traffic, and changes in macrofaunal assemblages) in combination have great potential to alter the epibenthos underneath and adjacent to WSDOT ferry terminals via habitat alteration or physical removal during propeller wash events. Though the implication had been made many times that these factors could be altering the epibenthos, specifically those taxa which ocean-type juvenile salmon use, this study is the first to sample the epibenthos directly.

STATEMENT OF RESEARCH HYPOTHESES AND OBJECTIVES

This study was organized around a major research hypothesis and corresponding objective. This hypothesis (null) was as follows:

> H_0: There are no differences in the epibenthic juvenile salmon prey (JSP) assemblage (density and composition) between areas in close vicinity to and farther away from ferry terminals.

The major hypothesis was subsequently divided into four component hypotheses testing different aspects of overwater (ferry terminal) structure effects on epibenthic JSP assemblages:

> H_{01}: There are no differences in the epibenthic assemblage (density and composition) under, near to, and away from the terminal structure during the period of the juvenile salmon outmigration.
>
> H_{02}: There are no differences in the epibenthic assemblage (density and composition) associated with eelgrass patches at increasing distances from the terminal structure.
>
> H_{03}: There are no changes in the epibenthic assemblage (density and composition) along a cross-terminal gradient.
>
> H_{04}: There are no differences in the epibenthic assemblage (density and composition) between different piling construction types (e.g., treated timber vs. concrete).

Generally, the research objective for each of these hypotheses was to describe the epibenthic JSP assemblage around ferry terminals (with specific regard to factors noted in each hypothesis) and to determine if differences could be attributed to terminal effects.

APPROACH AND SAMPLING DESIGN

Study Site Descriptions

WSDOT operates 20 ferry terminals in Puget Sound, from the Talequah terminal at Point Defiance north to the Sydney, BC terminal (Figure 1). The three terminals selected for this study were taken from a list of terminals with high research priority provided by WSDOT (Simenstad et al. 1999). The terminals selected were not intended to act as replicate sample sites, but instead to represent some of the diversity of terminal types in the WSDOT system. The Winslow terminal, at Eagle Harbor on Bainbridge Island, is an example of more modern terminal design and with both original timber and newer concrete construction materials and is one of the largest terminals in the system. The Clinton terminal, on south Whidbey Island, is the site of ongoing eelgrass transplant research, and also pairs the newest style of terminal design (2000 expansion) with the original timber construction. The Southworth terminal, south of Bremerton, is representative of the old timber style terminal construction and is a relatively small structure. These three terminals hereafter are referred to as Bainbridge, Clinton, and Southworth, respectively.

Bainbridge: The Bainbridge terminal is a concrete and timber structure 105 m long (trestle length, slip to MLLW approximately 90 m), 35 m wide (at MLLW), and 5.5 m above MLLW. It is oriented perpendicular to shore, but points roughly SE into Eagle Harbor. The original construction in 1966 used creosote-treated timber pilings, with an addition in 1984 supported by concrete pilings. There is moderate shoreline development around the terminal (Simenstad et al. 1999), mostly consisting of the terminal offices and waiting areas. It is situated on a steep bank armored under and to the north of the terminal. Shoreline hardening at Bainbridge is well above MLLW.

Due to large ferries docking on a relatively short trestle, propeller wash and bottom scour are greatest at Bainbridge, with a large halo around the terminal which is largely devoid of benthic vegetation (author pers. obs.). Because of scour and the large terminal width (and associated shading effects), I hypothesized that this terminal would have the largest effect on the epibenthos.

Clinton: The Clinton terminal is a concrete and timber structure, 195 m long (slip to MLLW approximately 104 m), 48 m wide (at MLLW), and 4.2 m above MLLW. It is oriented perpendicular to the shore and approximately NE into Possession Sound. There are two slips, North and South. In 1999-2000, construction on the south edge of the pier widened it from 31.5 m to 48 m. During field sampling, the South slip was under construction at the end of the terminal, where it was unlikely to have direct effects on the nearshore sampling sites. The support pilings in the older (north) section are creosote treated timbers installed in 1951 and 1968. The pilings in the new (south) section are steel construction coated with epoxy paint. There is a small floating public access dock at the midpoint of the terminal. The terminal is surrounded by moderate shoreline development (Simenstad et al. 1999), consisting of the ferry terminal office, several small businesses, and private residences. North of the terminal, the beach consists of a berm with driftwood and a few houses well above the waterline. South of the terminal a concrete bulkhead separates the beach from houses.

With a much longer trestle, propeller wash and scour are less severe at Clinton than at the Bainbridge terminal and there is more benthic vegetation near its edge (author pers. obs.). However, the terminal is both wider and lower, and despite grating in its middle, there is much intertidal shading. I hypothesized that impacts on the epibenthos would be moderate compared to the Bainbridge terminal, but still quite evident.

Southworth: The Southworth terminal is a timber structure, 141 m long (slip to MLLW approximately 97 m), 15.7 m wide (at MLLW), and 5.3 m above MLLW. It is perpendicular to shore, oriented NE into Puget Sound, but curves to the north just past MLLW. The support pilings are creosote-treated timber driven in 1957. There is relatively low shoreline development at Southworth (Simenstad et al. 1999), with houses set far back from the waterline to the north of the terminal and a public beach access street-end adjacent to the terminal. To the south on the upland is a large park-and-ride lot for ferry riders, with no additional development of nearshore. There is no shoreline armoring at Southworth comparable to that at Bainbridge or at Clinton.

The trestle length at Southworth is between that at Clinton and Bainbridge, and the ferries are generally smaller, so propeller wash and scour is lowest at this terminal (author pers. observation). Benthic vegetation is present up to the edge of terminal decking. The terminal is relatively narrow, less than half that of Bainbridge, and is higher than at Clinton. I hypothesized that terminal effects would be lowest at Southworth.

General Approach and Sampling Design

Research objectives were addressed through four separate tasks (Table 1). The field component was completed in spring 2000. All sampling used the epibenthic pump system commonly used to collect JSP in this region (Simenstad et al. 1988a, Simenstad et al. 1988b, Thom et al. 1988, Thom et al. 1989, Simenstad et al. 1995) and recommended by the Estuarine Habitat Assessment Protocol (Simenstad et al. 1991). Salinity and water temperature were recorded for each sampling date (Appendix 1). Sediment samples for grain size analysis were collected once at each site in early March. Battelle Marine Sciences Laboratory collected additional data on light availability, benthic vegetation cover, and sediment composition (Blanton et al. 2001).

Task 1 – Stratified-monthly sampling: Stratified-monthly sampling was used to address the research objective for H_{01} and test for terminal effects on the epibenthos. Three strata (Under, Near, and Away) were sampled (Figure 2). The Under stratum was the area directly underneath the terminal structure, where potential terminal impacts (including shading and propeller wash disturbance) were at their greatest. The Near stratum was directly adjacent to the north edge of the terminal where propeller wash was expected to be similar to the Under stratum, but shading impacts would be variable depending on the time of day, time of year, and distance from terminal and terminal orientation. The Away stratum was arbitrarily set 100 m north of the terminal margin, which was assumed to be beyond direct shading and propeller wash impacts.

Task 2 – Eelgrass sampling: Because the stratified-monthly sampling at MLLW was above the upper margin of eelgrass, the research objective for H_{02} was addressed by targeted eelgrass sampling at Clinton. Three patches of eelgrass north of the terminal edge were sampled during low tides (Figure 3). Each patch extended at least 15 m parallel to the shoreline. Paired samples were taken on eelgrass and on non-eelgrass substrate adjacent to the patch.

Task 3 – High-resolution cross-terminal transect sampling: Stratified-monthly sampling combined the entire area of shading gradient adjacent to the terminals in a single stratum. However, as distance from terminal edge increases there is a gradient of decreasing shading and propeller wash intensity. The research objective for H_{03} was addressed by sampling along a cross-terminal gradient at a relatively fine spatial resolution (Figure 4). Samples were taken at -0.6m because lower intertidal vegetation in this zone that would be more susceptible to shading effects (R. Thom, BMSL, pers. comm.). BMSL collected in-air PAR, benthic vegetation cover, and sediment composition data along the same transect within two weeks of epibenthic sampling (Blanton et al. 2001).

Task 4 – Terminal structure sampling: Terminal structures add fixed substrate for epibenthic organisms, such as pilings, decking, and floating structures. The research objective for H_{04} was addressed by sampling pilings at Bainbridge and Clinton, and a floating dock at Clinton, to compare the assemblage between different piling construction types (see site descriptions). It was also designed to compare their epibenthic fauna with those from the intertidal substrates sampled.

Data Analyses

Summary statistics (e.g., means, standard deviations) were calculated in Excel® 98 for Macintosh (Microsoft Corporation 1998) and SPSS® version 10 for Macintosh (SPSS Inc. 2000). Statistical tests consisted of single- and two-factor Analysis of Variance (ANOVA, Zar 1999) with Student-Newman-Keuls (SNK, Zar 1999) post-hoc tests where appropriate. Statistical tests were completed in SPSS® using the General Linear Model data analysis tool. Unless noted otherwise, for all tests $\alpha=0.05$ (significant results if $p \leq 0.05$). Tests always were run for three summary variables (total epibenthos density m^{-2}, total juvenile salmon prey (JSP) density m^{-2}, taxa richness sample^{-1}), certain individual JSP taxa (see criteria in each section), and common or abundant non-JSP taxa (see criteria in each section). The individual taxa and groups tested varied between sites and sample sets. All graphs were created in CA-Cricket Graph III® version 1.53 (Computer Associates International 1995).

Stratified-monthly sampling: Because the three terminals were not intended to act as replicate sites, each site was analyzed separately. The stratified-monthly sampling was designed for testing between strata differences over the entire outmigration period using two-factor ANOVA, with month and strata as the factors. High within-strata replication and equal sample sizes improved the robustness of the parametric ANOVA with respect to violations of normality assumptions (Zar 1999, L. Tear, Parametrix, pers. comm.). Where results were borderline significant ($0.01 \leq p \leq 0.05$), and data were seriously non-normal, tests were repeated using $\log_{10}$ transformed data. If significant differences occurred among strata using the two-factor ANOVA, additional single factor ANOVA tests for strata were completed for each month with SNK post-hoc analyses to determine among-strata differences and groupings. Response variables analyzed included the three summary variables, all JSP taxa present, and non-JSP taxa meeting at least one of two criteria: 1) individual taxon >1% of the total epibenthos density for half (six of 12) of the date*strata combinations (e.g., March, Away); or, 2) individual taxon was >1% of the total epibenthos density for a single strata over all four months.

Eelgrass sampling: The eelgrass sampling was also designed to be tested with a two-factor ANOVA, with distance of each eelgrass patch from terminal and on or off eelgrass as factors. SNK post-hoc analyses identified significant differences for patch distance from terminal, where interaction terms were not significant (Zar 1999). Borderline significant, non-normal data were $\log_{10}$ transformed as with the stratified-monthly sampling. Response variables were the same as for stratified-monthly sampling. Common or abundant non-JSP taxa were selected for analyses based on meeting at least one of two criteria: 1) individual taxon was >1% of the total epibenthos density for four of the six patch*on/off combinations (e.g., 95-m, off); or, 2) individual taxon was >1% of the total epibenthos density among patch (e.g., 95-m both on and off) or among on/off (e.g., 10-m on, 95-m on, 235-m on).

High-gradient cross-terminal transect sampling: Because this sampling was along a gradient, with no replication in time or space, standard statistical tests were not used. The data were evaluated graphically, relative to the terminal structure, with line graphs and stacked area graphs of densities and percent composition. Response variables were the same as for monthly stratified sampling; an individual taxon (JSP or non-JSP) was included only if its average density was >1% of the total epibenthos.

Terminal structure sampling: As with the stratified-monthly sampling, the two terminals sampled were not intended to act as replicate sites, and the results for Bainbridge and Clinton were analyzed separately. The piling data-set at each terminal was designed to be analyzed with a two-factor ANOVA (elevation, piling-type), while the floating dock samples at Clinton were described and evaluated graphically. Response variables were the same as for stratified-monthly sampling; an individual taxon (JSP or non-JSP) was only included if it was present in at least 25% of the samples, or had an average density greater than 10% of the total epibenthos average density.

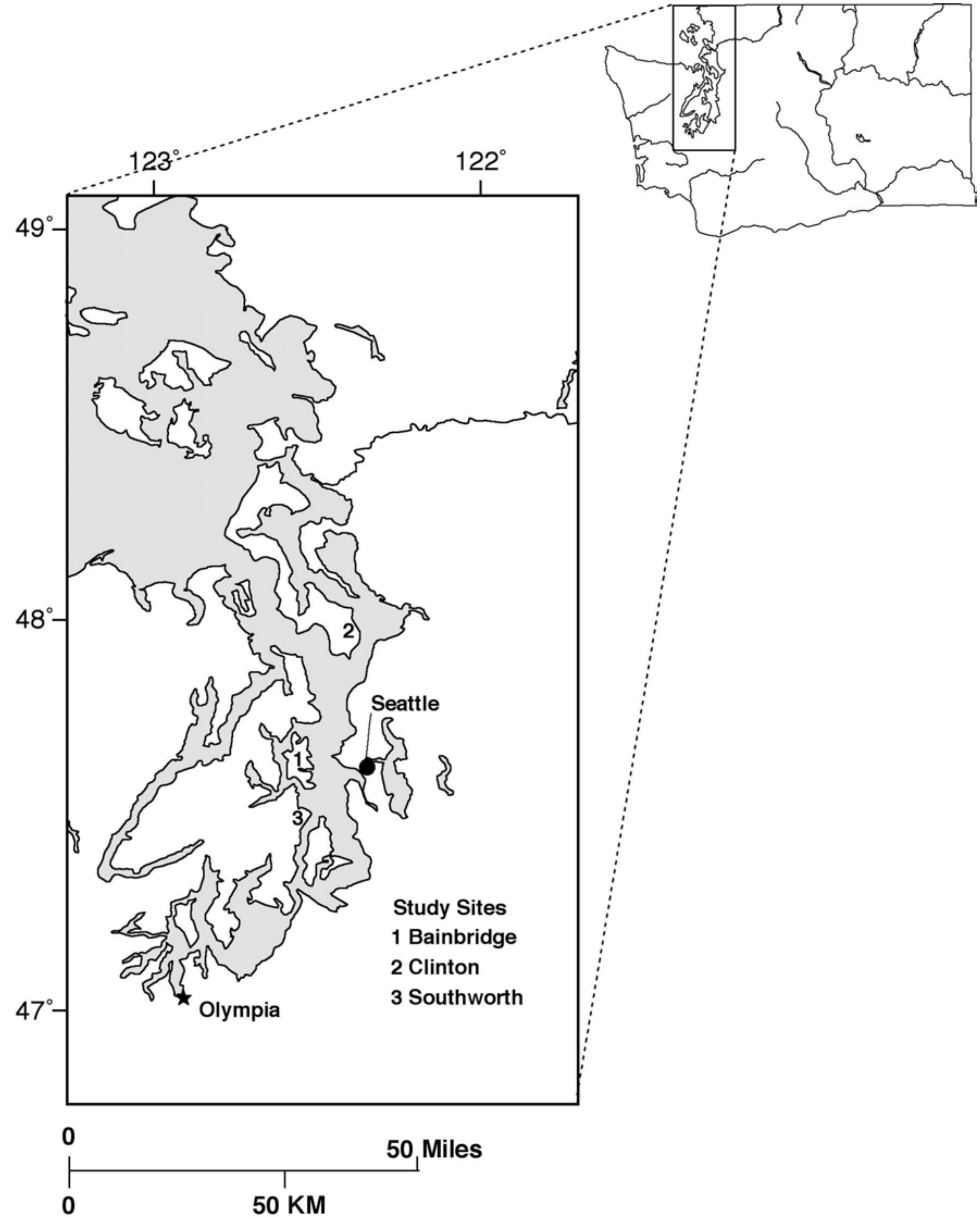

Figure 1. Central Puget Sound, Washington, Washington State Department of Transportation ferry terminals used as study sites for spring 2000 overwater structures sampling field effort.

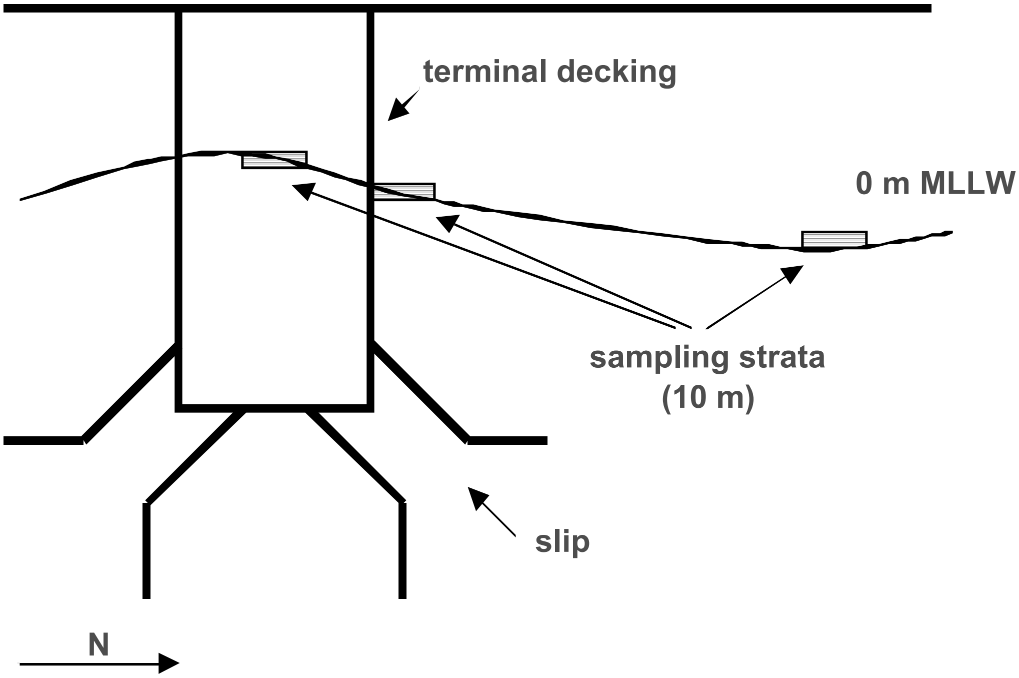

Figure 2. Generalized sampling schematic for monthly-stratified sampling (not to scale).

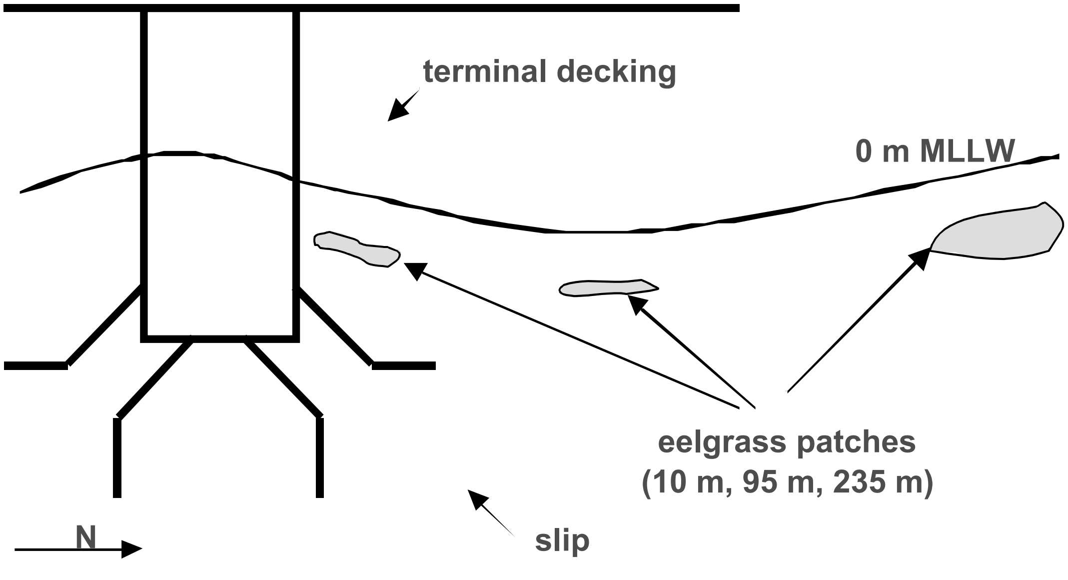

Figure 3. Generalized sampling schematic for eelgrass sampling (not to scale).

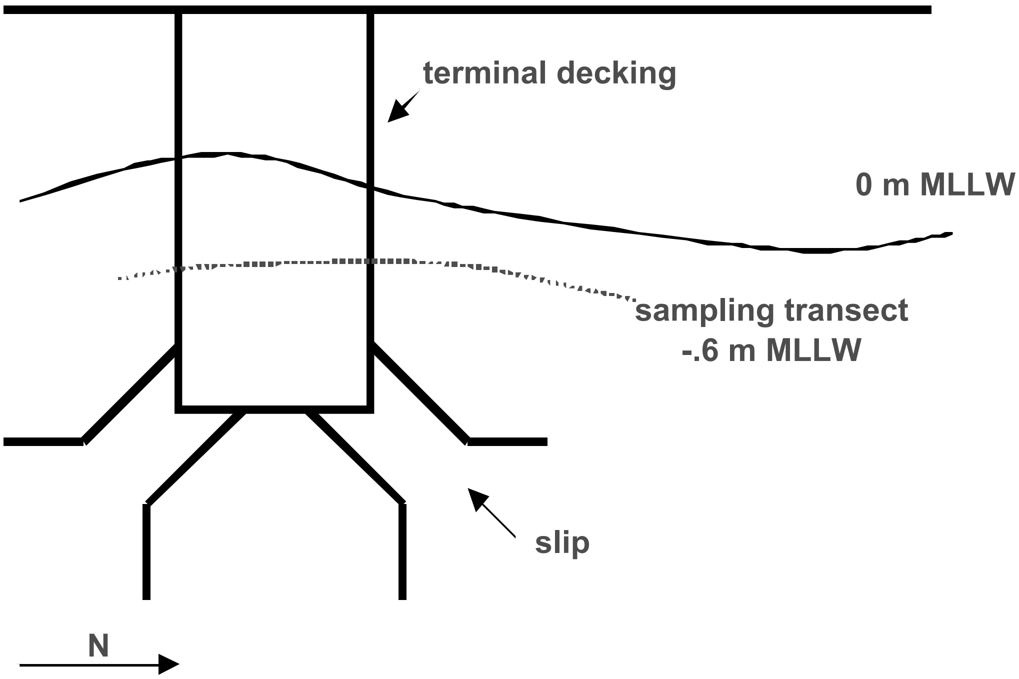

Figure 4. Generalized sampling schematic for transect sampling (not to scale)

Table 1. Field sampling design summary for all tasks for this study.

Task	Dates (2000)	Terminal	Sampling elevation (m)	Tide	Replication and sample size (per terminal)	Design notes
Stratified-monthly sampling	Monthly, early March to late May (two sets in May four weeks apart)	Bainbridge, Clinton, Southworth	MLLW	ebb	15 reps * 3 strata * 4 months; 135 total samples	random sampling within 3 strata: Under (center of structure), Near (north edge of structure), and Away (100 m north)
Eelgrass sampling	June 5	Clinton	-0.6 to -1.6	ebb	7 reps * 2 substrates * 3 patches; 42 total samples	patch distance relative to north edge of structure (10m, 95m, 235m); haphazard sampling on eelgrass on non-eelgrass substrate at patch edge
High-resolution cross-terminal gradient sampling	May 31, June 1	Clinton	-0.6	flood	111 samples (56 processed, every other sample)	cross-terminal sampling every meter along 111m transect, from 12m south to 43 m north; sampled over two days (center to north day one, center to south day two)
Terminal structure sampling	May 3, 4	Clinton, Bainbridge	-0.6, 0, 0.6, 1.2; floating dock	flood	5 reps * 2 piling-types * 4 elevations; 40 samples (plus 5 reps on floating dock)	random sampling of paired piling-types; floating dock at Clinton only; modified epibenthic pump (see description)

METHODS

Field Effort

Epibenthic natural substrate sampling: The epibenthic pump system consisted of a 2000 gallon hour^{-1} electric bilge pump housed in a 14.8 cm wide PVC sampling cylinder, open only at the base. Inflow ports on the sampling cylinder were covered with a 33 µm mesh screen. Outflow from the pump traveled though a PVC hose and is collected in a handheld sieve (106 µm). The sampling cylinder was attached to a 1.2 m handle with a switch at the top. For each sample the pump was placed through the water column slowly and carefully set into the substrate with a twist. Pump outflow with entrained epibenthos was filtered through a hand-held 106 µm sieve for twenty seconds, or until the sieve began to back up with sediment (lifting of the top layer of sediment indicated clogged inflow ports, but ensured all epibenthic organisms were also lifted and captured on the sieve). The pump was purged with surface water between samples. See Simenstad et al. (1988b) for additional information about the design and use of the epibenthic pump system.

Tide charts were generated for each site and date (Tides and Currents®, Nautical Software Inc. 1996). Tidal elevations were determined by cross-referencing the current time and tide chart, and wading out to water of the appropriate depth (using a PVC pole marked every 0.25 feet), or checking water depth at site and current time to determine elevation. All tidal elevations were converted to metric post-sampling.

Epibenthic samples were preserved in the field within two hours of collection. Upon completion of sampling, undiluted formalin, buffered with Borax, was added to each jar to reach a final concentration of 5-10% formalin. Sample jars with large quantities of sediment were stirred vigorously to allow even distribution of formalin.

Epibenthic terminal structure sampling: Terminal structure sampling was completed using a modified epibenthic pump. This sampling cylinder was identical to the standard epibenthic pump described above, except that it had no handle or switch (operated with manual battery connection). The mouth of the sample cylinder was fitted with a neoprene collar allowing it to fit flush against the curve of a piling or the flat surface of the floating dock edge. The sampling cylinder was placed against the terminal structure and a sample was taken as for the standard system.

Lab Methods

In the lab, formalin was decanted from the samples through a 73 µm mesh sieve. Epibenthic organisms were removed from sandy samples by vigorous swirling with fresh water in a round bottomed pitcher (after Webb 1989). Samples were then screened into three size fractions: 153-246 µm, 246–500 µm, >500 µm. Initial findings demonstrated no significant difference between results for juvenile salmon prey (JSP) with or without the smallest size fraction and it was not processed for the remainder of the samples.

The 246-500 µm and larger size fractions were sorted using a dissecting microscope. Sample fractions with high numbers of organisms were split to a manageable number (>200 target organisms) using a Folsom plankton splitter or Henson-Stempel pipette. Pelagic zooplankton, likely a contamination from purging the system between samples, was not counted. Nematoda were not counted from the stratified-monthly sample set because they were very abundant in some sandy samples, but are not prey. For analyses, final counts were totaled from both size fractions.

Important juvenile salmon prey items (Simenstad et al. 1991, J. Cordell, University of Washington, pers. comm.) were generally identified to the taxonomic resolution described in the

Estuarine Habitat Assessment Protocol (Simenstad et al. 1991). Harpacticoid copepod prey taxa were identified to genus or species, except for the *Harpacticus uniremis* group complex. Where juveniles precluded species identification, gammarid amphipods were identified to genus or family. Other prey items were identified as per Table 2. Non-prey organisms were not all identified to the same level. Many non-prey harpacticoids were identified to species (e.g., *Amphiascoides* sp. A, *Amonardia perturbata*), while others were only identified to family (e.g., Ectinosomatidae, Laophontidae). The same applied to non-prey gammarids and cumaceans. Other non-prey organisms were identified at most to family level, and sometimes as coarsely as phyla (Appendix 1). Taxonomic identification was completed using taxonomic keys, the assistance of Mr. Jeffery Cordell (University of Washington), and reference collections from other Puget Sound epibenthos sampling (author; B. Bachman, United States Army Corps of Engineers).

Table 2. Epibenthic juvenile salmon prey, JSP, items identified in this study (modified from Simenstad et al. 1991, J. Cordell pers. comm.).

Harpacticoid copepods
Family Harpacticidae
- *Harpacticus uniremis* group (grouped for analysis)
    - *Harpacticus septentrionalis*
    - *Harpacticus uniremis* group, other (includes *H. uniremis*, *H. compressus*, *H.* species A, *H. uniremis* group copepodids)
- *Zaus* spp.

Family Tisbidae
- *Tisbe* spp.

Family Thalestridae
- *Dactylopusia vulgaris*
- *Dactylopusia crassipes*

Gammarid amphipods (adults and juveniles)
Family Anisogammaridae (grouped for ID and analysis)
- *Anisogammarus pugettensis*
- *Eogammarus confervicolus*

Family Aoridae
- *Aoroides* spp.

Family Calliopiidae (grouped for ID and analysis)
- *Paracalliopiella pratti*
- *Calliopius* spp.

Family Corophiidae
- *Corophium* spp.

Family Hyalidae
- *Allorchestes angusta*

Family Isaeidae
- *Gammaropsis* sp.
- *Photis* spp.

Family Ischyroceridae
- *Ischyrocerus* spp.

Family Pontogeneiidae
- *Pontogeneia rostrata*
- *Pontogeneia intermedia*

Other
Cumacea, Family Nannastacidae *Cumella vulgaris*
Insecta, Diptera, Family Chironomidae (larvae

RESULTS

Stratified-Monthly Sampling

Bainbridge: Negative impacts on the epibenthos at Bainbridge were pervasive, both Under and Near compared to Away from the terminal. The two-factor ANOVA tests for differences between strata were significant for all three summary variables, 12 of 17 juvenile salmon prey (JSP) taxa, and all 10 non-JSP taxa (Table 3). For all variables and taxa but Cyclopinidae (epibenthic cyclopoid copepod) and Polychaeta the overall impact of the terminal structure was negative.

Results of the two-factor ANOVA tests for among strata differences were all highly significant for summary variables (total epibenthos, total JSP, taxa richness) (Figure 5). Within-month tests for strata differences were all significant and SNK results indicated that Near and Under values were similar and less than Away values. Taking all months together, the average total epibenthos density Away was 96,145 m^{-2} (± 1 SD 67,266) compared to 5,505 m^{-2} (± 6,880) and 7,402 m^{-2} (± 6,629) for Near and Under. The average JSP density Away was 26,079 m^{-2} (± 26,014) compared to 1,698 m^{-2} (± 2,732) and 1,962 m^{-2} (± 2,430) for Near and Under. Average taxa richness in the Away strata was 29 (± 9), more than twice those of Near (13 ± 8) and Under (12 ± 6).

All JSP taxa were found at least once at Bainbridge, and 12 of 17 of them had highly significant two-factor ANOVA tests for strata differences. All of these showed negative impacts of the terminal on densities. Where within-month strata differences were significant, SNK results were the same as for summary variables, with Near and Under similar and less than Away.

Common or abundant JSP taxa[3] were the harpacticoid copepods *Harpacticus uniremis* group, *Tisbe* spp., *Zaus* spp., the cumacean *Cumella vulgaris*, and the gammarid amphipods *Pontogeneia rostrata*, *Photis* spp., and Calliopiidae (mainly *Paracalliopiella pratti*) (Figure 6). Results were similar for the less abundant, but significant JSP taxa (the harpacticoids *Dactylopusia vulgaris* and *Dactylopusia crassipes*, and the amphipods *Aoroides* sp., *Corophium* spp., *Allorchestes angusta*, and *Gammaropsis* sp.). JSP taxa for which densities among strata were non-significantly different (the amphipods Anisogammaridae, *Pontogeneia intermedia*, *Ischyrocerus* spp., and Chironomidae fly larvae) were relatively rare in all strata.

Ten non-JSP taxa were abundant or common (the harpacticoids Ectinosomatidae, *Harpacticus spinulosus*, Laophontidae, *Robertsonia* sp., *Amphiascoides* sp. A, Thalestridae copepodids, Turbellarian flatworms, Oligochaete worms, Cyclopinid copepods, and Polychaete worms). All of these had highly significant two-factor ANOVA tests for strata differences. Eight of the ten non-JSP taxa were present in higher densities Away from the terminal, generally with corresponding within-month SNK results but with some between month variation. Cyclopinidae and Polychaeta had greater densities in the Under strata (Figure 7).

For the combined epibenthos averaged across sampling periods, densities decreased significantly in the Under and Near strata. This was also true for most individual taxa (Figure 8). However, percent composition was strongly affected by the terminal, shifting from a harpacticoid dominated to an annelid worm dominated assemblage in the Near and Under strata. One taxon of harpacticoids, *Tisbe* spp., increased in proportion in close proximity to the terminal but most other harpacticoids decreased or disappeared close to it (e.g., *Robertsonia* sp., Laophontidae).

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3 For stratified-monthly sampling these taxa fit the criteria for common or abundant non-JSP taxa, as stated in Data Analysis, or are > 1% of the total epibenthos at any strata*date combination.

Clinton: Negative impacts on the epibenthos similar to those at the Bainbridge terminal were apparent at Clinton. Most response variables were lower at the Near and Under strata, with Near values generally closer to those of Under or midway between Under and Away. Two-factor ANOVA tests were significant for strata differences for all three summary variables, nine of 15 JSP taxa present at the site, and five of seven non-JSP taxa (Table 4). For all but two taxa with significant results the overall impact of the terminal structure was negative.

All two-factor ANOVA tests of strata differences were highly significant for the summary variables, with overall negative impacts for each one (Figure 9). The average density of the total epibenthos, over all months, was 67,085 m^{-2} Away (± 65,708) compared to 18,304 m^{-2} Near (± 17,784) and 24,193 m^{-2} Under (± 21,528). The average JSP density Away was 57,107 m^{-2} (± 59,988) compared to 11,773 m^{-2} (± 12,773) and 16,794 m^{-2} (± 18,525) for Near and Under. All within-month ANOVA tests for strata differences for these two variables were highly significant with Away consistently greater than Under, except for total epibenthos during May when they were not different. The average taxa richness was 22 (± 3), 21 (± 10), and 19 (± 5) for Away, Near, and Under. The within-month ANOVA results for strata differences were also highly significant for all summary variables, but SNK groupings and pattern of taxa richness were not consistent between months.

Fifteen JSP taxa were found at Clinton, nine of which had highly significant two-factor ANOVA results indicating negative impacts in close proximity to the terminal (Figure 10). The six JSP taxa with non-significant results were relatively rare (the amphipods *Pontogeneia rostrata*, *Aoroides* sp., *Corophium* spp., *Pontogeneia intermedia*, *Photis* spp., and Chironomidae fly larvae). Two of the amphipod JSP taxa, *Gammaropsis* sp. and *Ischyrocerus* spp., were not found. The JSP taxa with significant results all were relatively common or abundant. Of these, six generally had higher densities for the Away stratum higher than for the other two (Figure 10), though there was some variability for within-month SNKs (Table 4). Three JSP taxa, *Tisbe* spp., *Cumella vulgaris*, and Calliopiidae (mainly *Calliopius* sp.) had somewhat different results, but during the months with significant strata differences the highest density stratum was generally Away or Near (Table 4).

Seven non-JSP taxa were common or abundant (Figure 11), six of which had significant results for two-factor ANOVA tests for strata differences. Results for Polychaeta were borderline significant ($p \leq 0.019$) but $\log_{10}$-transformed data for this taxon indicated no significant among strata differences ($p \leq 0.602$). Of the remaining five non-JSP taxa with significant two-factor ANOVA results, three had an overall decrease in organism densities in vicinity of the terminal (Thalestridae copepodids, Ectinosomatidae, Turbellaria) and two had increased densities (Ameiridae, Oligochaeta). Within month ANOVA and SNK results were variable between months, and did not always separate Under and Away (Table 4). Two-factor ANOVA tests for strata differences for Nemertea and Polychaeta ($\log_{10}$-transformed) were not significant.

For all months combined, total epibenthos decreased by approximately two-thirds in close proximity to the terminal. Most of the numerically dominant taxa either decreased or increased on such a small scale it could not be easily detected as a function of assemblage density (Figure 12). In percent composition two dominant taxa were strongly affected by terminal proximity, *Tisbe* spp. increased and Anisogammaridae decreased.

Southworth: As with the other two terminals, at Southworth the epibenthos was affected negatively by the terminal. Two-factor ANOVA tests for strata differences were significant for all three summary variables, six of 17 JSP taxa present at the site, and six of eight non-JSP taxa (Table 5). For all but two of these (*Amonardia perturbata*, *Harpacticus spinulosus*) the impact of the terminal structure was negative.

Strata differences in the two-factor ANOVA results for summary variables were all highly significant (Figure 13). The average density of the total epibenthos, over all months, was 84,200 m^{-2} (± 64,364) Away compared to 83,799 m^{-2} (± 61,042) Near and 43,673 m^{-2} (± 40,117) Under. The average JSP density Away was 51,231 m^{-2} (± 37,624) compared to 44,974 m^{-2} (± 33,638) and 32,737 m^{-2} (± 29,213) for Near and Under. Most within-month ANOVA results for these two variables were highly significant, with densities for Away and Near generally greater than Under and often grouped together in SNK results (Table 5). Average taxa richnesses, over all months, were 29 (± 7), 25 (± 9), and 20 (± 7) for Away, Near, and Under. Within-month ANOVA results were also all highly significant for strata differences, and SNK results were similar to those for total epibenthos and JSP. In all cases, the impact of the terminal structure on the summary variables was negative, with the lowest values generally occurring in the Under stratum and similar, higher values for Near and Away.

All seventeen JSP taxa were found at Southworth, seven had significant two-factor ANOVA results for strata differences indicating negative impacts. Two taxa (*Tisbe* spp. and *Dactylopusia vulgaris*) had borderline significant p-values. *Tisbe* spp. distributions were not seriously deviated from normal and the original result was accepted, but those for *Dactylopusia vulgaris* were and the subsequent two-factor ANOVA on the $\log_{10}$-transformed data was not significant for strata ($p \leq 0.079$). Of the six remaining taxa, one (*Corophium* spp.) was extremely rare and its ANOVA results were not reliable. The five remaining significant JSP taxa (Figure 14) all had at least one significant within-month ANOVA result and tended to have either Away or Near as the highest density strata, with SNK results supporting those trends. Most of the 11 remaining JSP taxa with non-significant results were relatively rare, but *Dactylopusia vulgaris*, Calliopiidae (mainly *Paracalliopiella pratti*) and *Pontogeneia rostrata* were more abundant

(Figure 15). Where present, impacts on JSP taxa were negative, but were variable as to whether densities Near, Away, or both were highest relative to Under.

Eight non-JSP taxa were common or abundant, one of which (*Amonardia perturbata*) increased significantly in the Near and Under strata. Of the remaining seven, five had significantly decreased densities relative to the terminal, though densities for the Near stratum sometimes were similar to those from the Under stratum. SNK results supported these trends (Table 5). *Harpacticus spinulosus* was the exception, being abundant only in the Near stratum. Polychaeta and Thalestridae copepodids both were relatively common or abundant, but were not significantly different between strata.

Density of the epibenthos for all months combined decreased by approximately half and percent composition showed a shift in many taxa relative to the terminal (Figure 17). *Tisbe* spp. was dominant both in density and numerical proportion. While its numerical abundance remained relatively constant, its proportion of the assemblage increased in the Under stratum compared to Near and Away strata. *Zaus* spp. decreased in proximity to the terminal both in terms of abundance and proportion. *Harpacticus spinulosus* was the second most numerous taxon in the Near stratum, but was scarce in the Away or Under strata.

Eelgrass Sampling

Results for the eelgrass patch sampling indicated negative impacts of the Clinton terminal on the epibenthos associated with eelgrass. ANOVA results for patch differences were significant for all three summary variables, all eight JSP taxa, and seven of nine non-JSP taxa, and though SNKs were variable, the 10-m patch was in the lowest density or taxa richness group for all significant results (Table 6).

Total epibenthos and JSP densities were not significantly different on eelgrass versus non-eelgrass substrates. Their pooled between-patch densities were significantly lower for the 10-m patch than for either 95-m or 235-m patches (Figure 18). Taxa richness was significantly higher on eelgrass versus non-eelgrass, and the non-eelgrass values were lower for the 10-m patch (average of 21 taxa) less than for the grouped 95-m (26 taxa) and 235-m (27 taxa) patches (Figure 18).

All eight JSP taxa found (Figure 19) had significant ANOVA results for patch differences indicating negative impacts of the terminal. *Tisbe* spp. and *Dactylopusia vulgaris* densities were not significantly different on eelgrass versus non-eelgrass substrates. Of the six remaining JSP taxa, Anisogammaridae (mainly *Anisogammarus pugettensis*) was the only taxon more abundant on the non-eelgrass substrate.

Of the five non-JSP harpacticoids (Figure 20), only *Harpacticus spinulosus* were significantly different on eelgrass versus non-eelgrass substrates, being lower on eelgrass. On non-eelgrass its densities increased from the 10-m patch to the 95-m and 235-m patches. The other four taxa were all significantly denser in the 95-m and 235-m patches (grouped) than the 10-m patch. Of the four remaining non-JSP taxa (Figure 21), only Nematoda and Oligochaeta densities had significant patch differences, also with 10-m densities less than those for 95-m and 235-m patches (grouped). Densities of Turbellaria and Polychaeta were not significantly different among patches.

Densities of Nematoda were numerically dominant in the assemblage, particularly in the 10-m and 235-m patches, but for greater clarity in seeing JSP trends, they were removed prior to creating assemblage composition plots (Figure 22). Densities of *Tisbe* spp. were prominent in the total assemblage, particularly at the 95-m patch. The non-eelgrass substrate assemblages at 10-m and 95-m were similar, despite large differences in overall abundance. This was also true for the eelgrass assemblages from the 10-m and 235-m patches.

High-Resolution Cross-Terminal Sampling

Despite high among-sample variability, and apparent between-day variability, some trends in the cross-terminal epibenthos gradient were apparent (Figures 23-26). From south to north, there was generally a small decrease in organism density with consistently lower values under the south half of the terminal. Densities for many taxa increased under the north half of the terminal. At the north edge of the terminal, densities generally either decreased or remained constant to a final increasing trend to the north end of the transect. Densities for total epibenthos and JSP also follow this pattern, with some of the largest single density samples occurring under the north half of the terminal (Figure 23). Taxa richness was also highly variable, initially decreasing from the south end of the transect approaching the terminal, and increasing to the north for most of the transect (Figure 23).

Of the six abundant JSP taxa, only densities for *Harpacticus uniremis* group (mostly *H. septentrionalis* and copepodids) appeared to have a clear negative response to the terminal structure (Figure 24). *Tisbe* spp. and *Zaus* spp., the numerically dominant crustacean taxa in set, and the less abundant *Cumella vulgaris* all had similar responses to those for total epibenthos. Anisogammaridae appeared to have a positive association with the terminal with consistently higher densities under the entire structure.

Two of the six abundant non-JSP taxa, *Harpacticus spinulosus* and *Acrenhydrosoma* sp. appeared to have a negative response to the structure (Figure 25). Results for the other taxa were less clear, with Ectinosomatidae, Ameiridae, and Thalestridae copepodids all following the pattern found for total epibenthos. Polychaeta, however, had consistently highest densities underneath the north half of the terminal.

Nematoda dominated within the total epibenthos (Figure 23), and was removed from the data to calculate assemblage composition (Figure 26). The assemblage was initially dominated by *Harpacticus spinulosus* in abundance and composition, but changed to dominance by Anisogammaridae under the south portion of the dock. While Anisogammaridae was still a relatively large proportion of the under dock assemblage in the north half, the dominance again shifted to *Tisbe* spp. and, to a lesser extent, *Zaus* spp.. There was a more evenly distributed assemblage away from and to the north of the dock.

Terminal Structure Sampling

The encrusting organisms on pilings at Bainbridge were similar on the older wood and newer concrete pilings. Small barnacles were the dominant organisms at all elevations, with compound ascidians present at lower elevations and mussels present higher. Macroalgae was not abundant. The highest elevation (1.2 m) for both piling-types was different from the other elevations with large (3-5 cm diameter) barnacles as well as relatively large mussels. Total densities and taxa richness of epibenthos on pilings at Bainbridge were all extremely low (Figure 27). Differences in piling-type were not significant for any summary variable or individual taxon, but there were significant elevation differences for all variables but Polychaeta, with densities and taxa richness decreasing with increasing elevation (Table 7).

At Clinton, encrusting organisms both on older wood and new epoxy-steel pilings were mainly barnacles and mussels. Mussels and barnacles were generally larger, and mussels were denser, on the wood pilings, but at the sampling elevations the epoxy-steel pilings also were completely encrusted. Both piling-types had thicker encrustations and greater mussel densities at higher elevations. Macroalgae was minimal on all pilings. Total epibenthos densities and taxa richness were relatively higher at Clinton than at a Bainbridge, and more taxa fit the criteria for ANOVA testing (Table 7). The three summary variables were significantly different based on both piling-type and elevation, with new pilings having higher densities and taxa richness than old pilings, and low elevations having higher densities and taxa richness than higher elevations (Figure 28). Differences in density of three JSP taxa were significant by piling-type. The test results for *Tisbe* spp. were borderline significant and were not significant at all when $\log_{10}$-transformed. Densities of *Dactylopusia vulgaris* were significantly different by both elevation and piling-type. Densities of Calliopiidae were only significant for piling-type. Densities of three non-JSP taxa were significant for piling-type and elevation (Figure 29), Thalestridae copepodids, Ectinosomatidae, and Ameiridae. For all taxa with significant results new pilings had higher densities than old pilings. *Amphiascoides* sp. A was significant for elevation, but not piling-type. For all individual taxa with significant results for elevation, densities were higher at lower elevations.

There was much attached macroalgae on the float at Clinton, as well as mussels, barnacles, tube worms, and anemones. The epibenthos had relatively low taxa richness, average 5.8 (± 2.17), with a total of 10 taxa (Figure 30) five of which were JSP taxa (Calliopiidae, *H. uniremis* group copepodids, *Zaus* spp., *Pontogeneia rostrata*, and *Ischyrocerus* spp.). Non-JSP taxa included Caridea, *Robertsonia* sp., *Lamprops quadriplicata*, and *Munna ubiquita*. Calliopiidae (mainly *Calliopius* spp.) was the numerically dominant taxon, approximately half of the total epibenthos. *Harpacticus uniremis* group copepodids, *Mesochra pygmaea*, and Caridea (shrimp larvae) were also abundant.

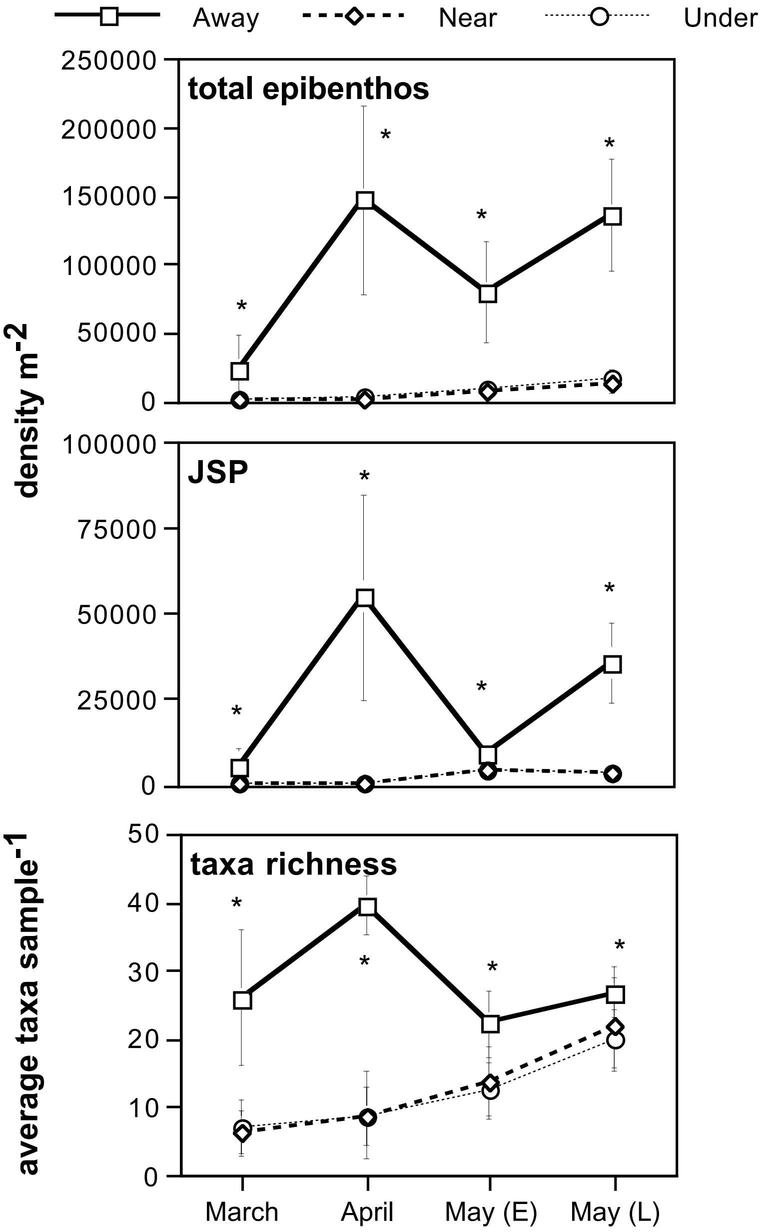

Figure 5. Mean response of summary variables for Bainbridge stratified-monthly sampling. Asterisks denote significant strata differences within month. Error bars are ± 1 standard deviation.

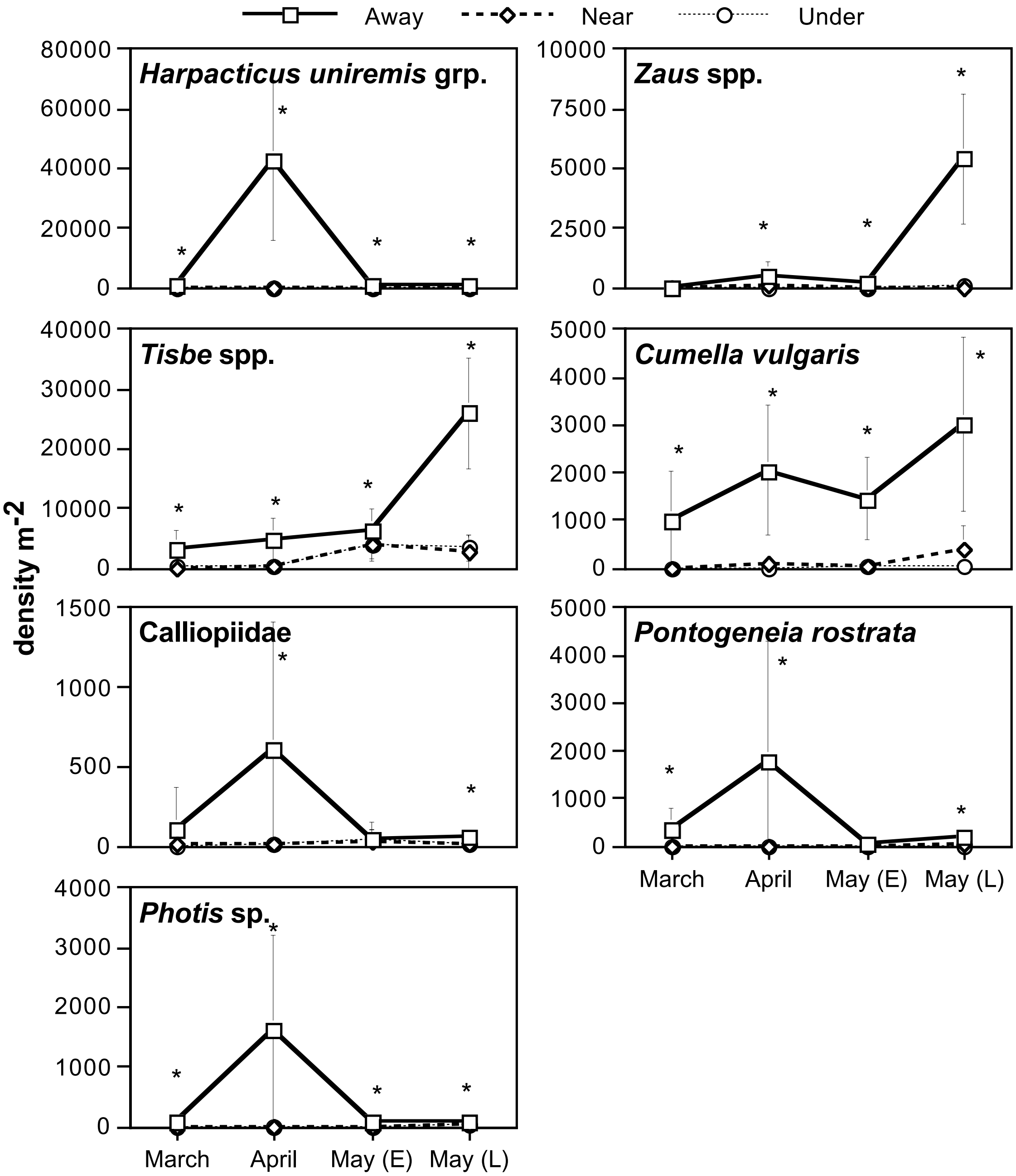

Figure 6. Mean response of JSP taxa from Bainbridge stratified-monthly sampling with significant two-factor ANOVA results for strata. Asterisks denote significant within month strata differences. Error bars are ± 1 standard deviation.

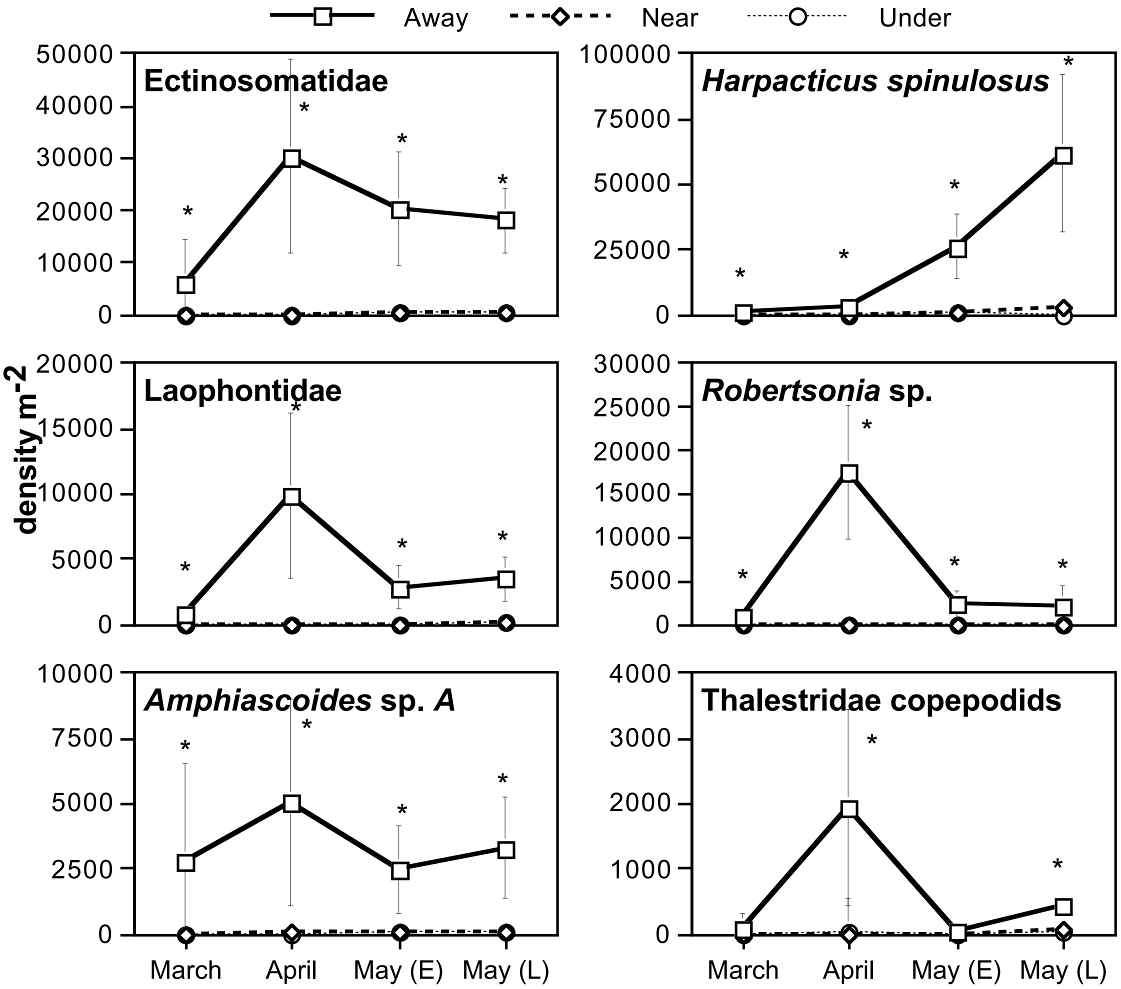

Figure 7. Mean response of common non-JSP taxa from Bainbridge stratified-monthly sampling. All taxa have significant two-factor ANOVA results for strata. Asterisks denote significant within month strata differences. Error bars are ± 1 standard deviation.

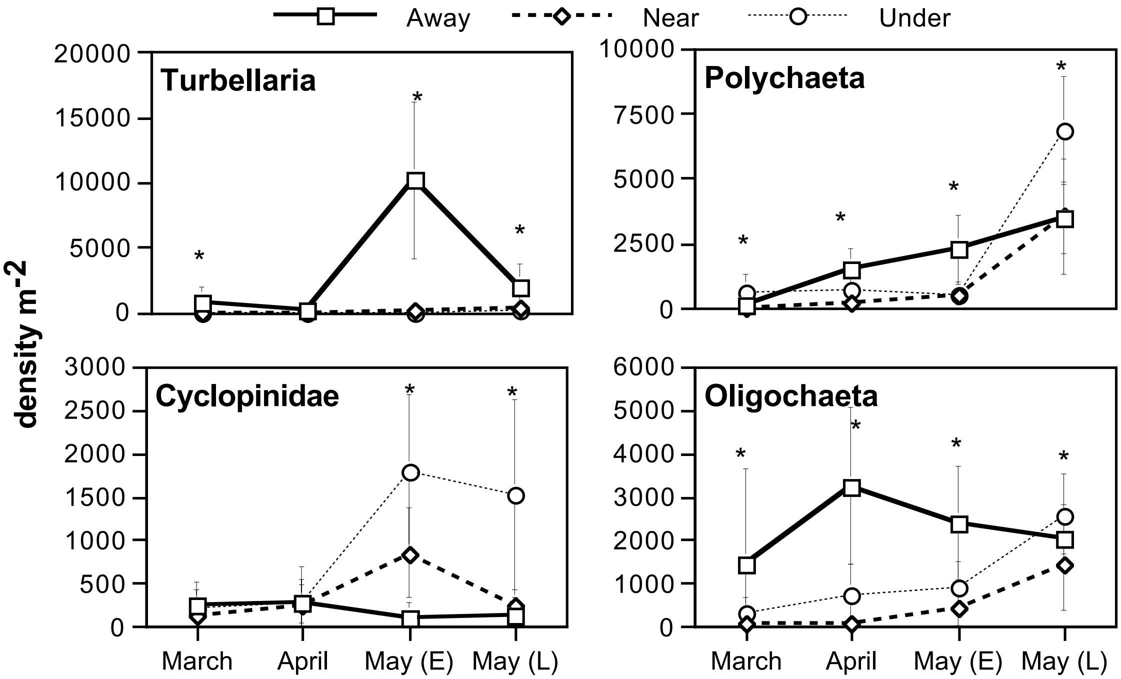

Figure 7 (continued). Mean response of common non-JSP taxa from Bainbridge stratified-monthly sampling. All taxa have significant two-factor ANOVA results for strata. Asterisks denote significant within month strata differences. Error bars are ± 1 standard deviation.

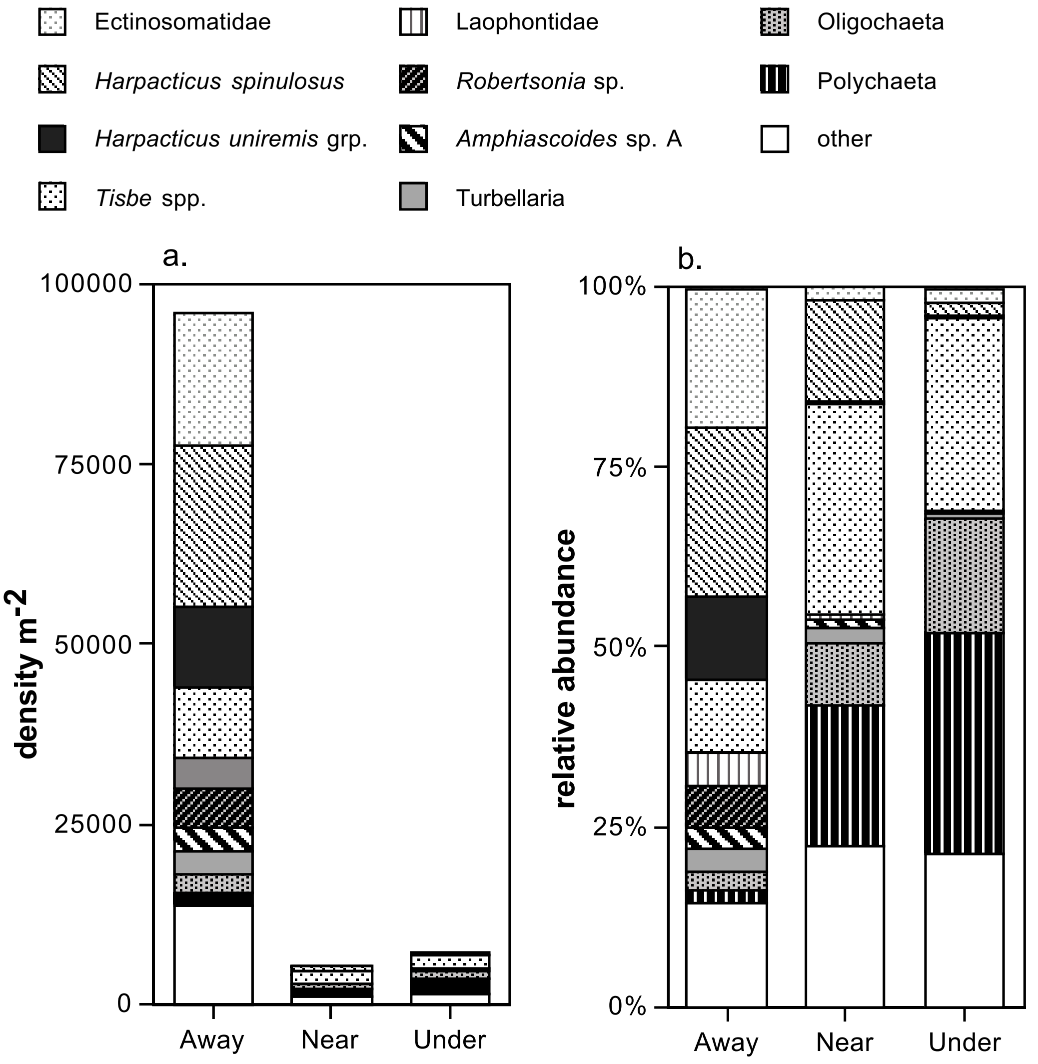

Figure 8. Assemblage composition at Bainbridge (total density and relative density); stratified-monthly sampling averaged across all months.

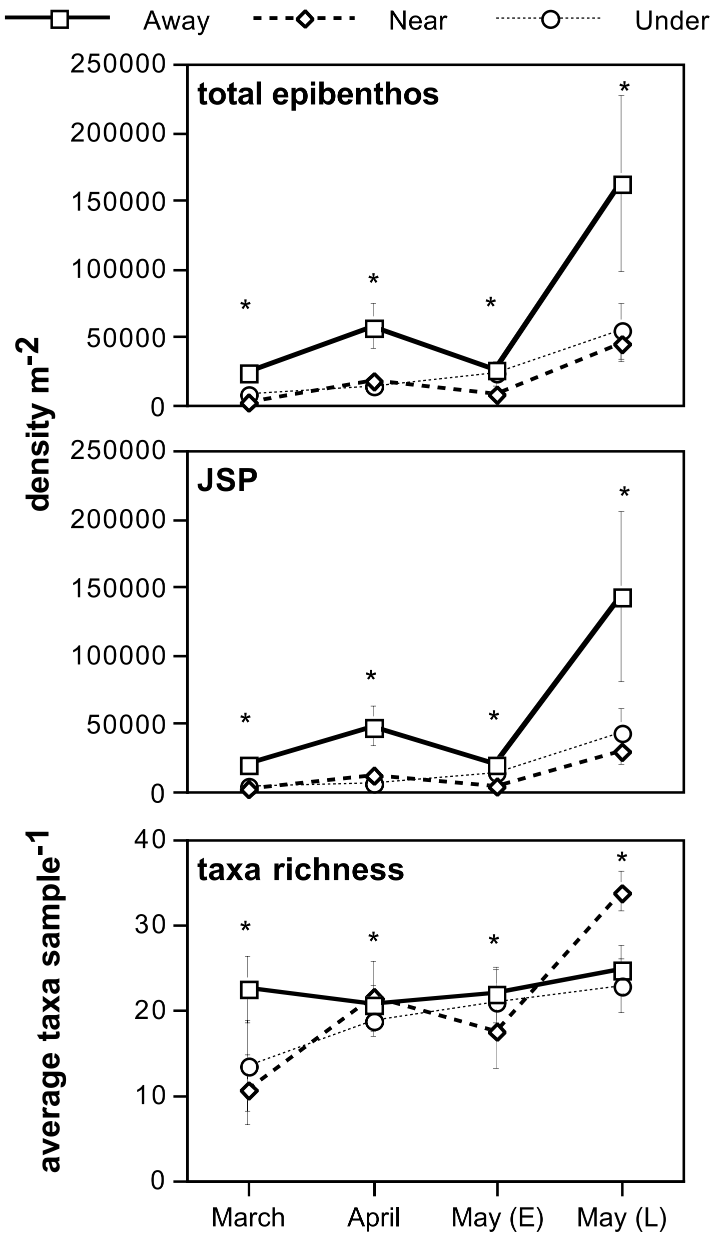

Figure 9. Mean response of summary variables for Clinton stratified-monthly sampling. Asterisks denote significant strata differences within month. Error bars are ± 1 standard deviation.

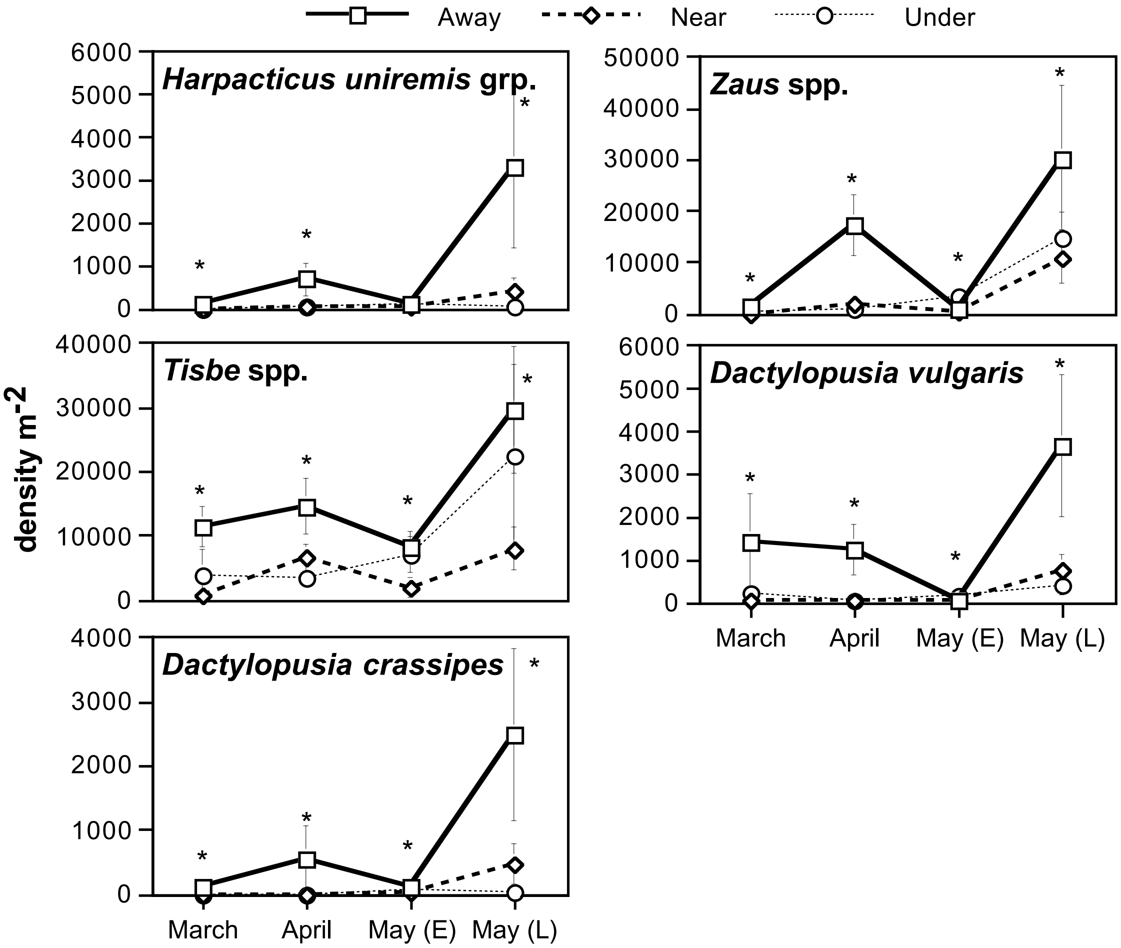

Figure 10. Mean response of JSP taxa from Clinton stratified-monthly sampling with significant two-factor ANOVA results for strata. Asterisks denote significant within month strata differences. Error bars are ± 1 standard deviation.

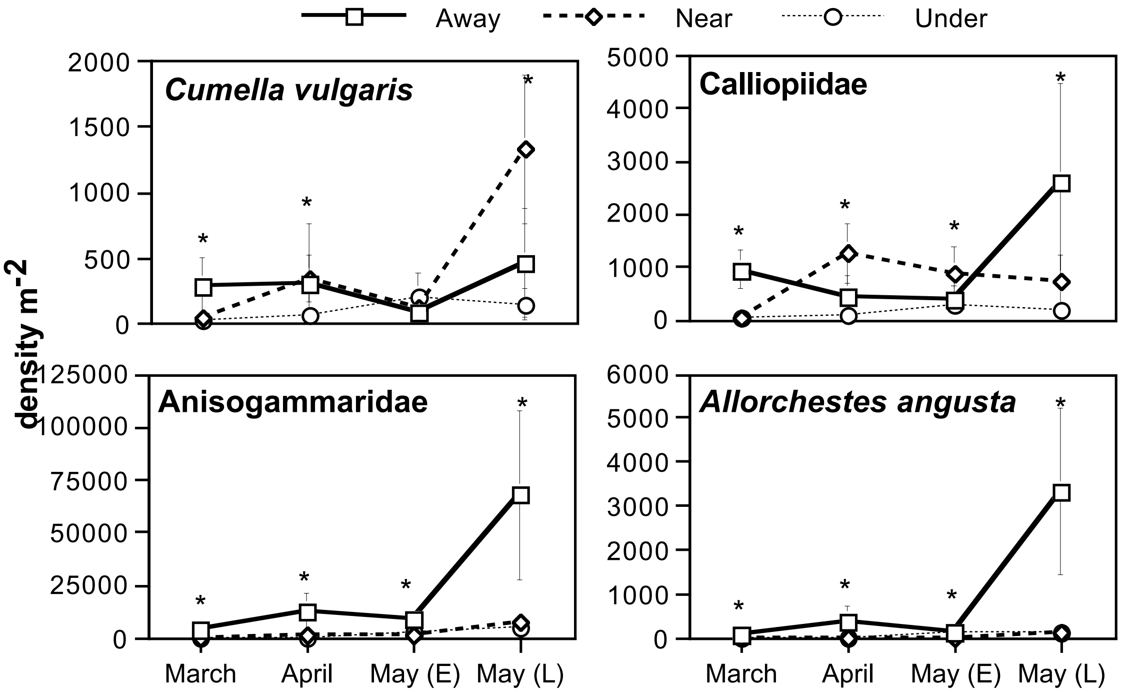

Figure 10 (continued). Mean response of JSP taxa from Clinton stratified-monthly sampling with significant two-factor ANOVA results for strata. Asterisks denote significant within month strata differences. Error bars are ± 1 standard deviation.

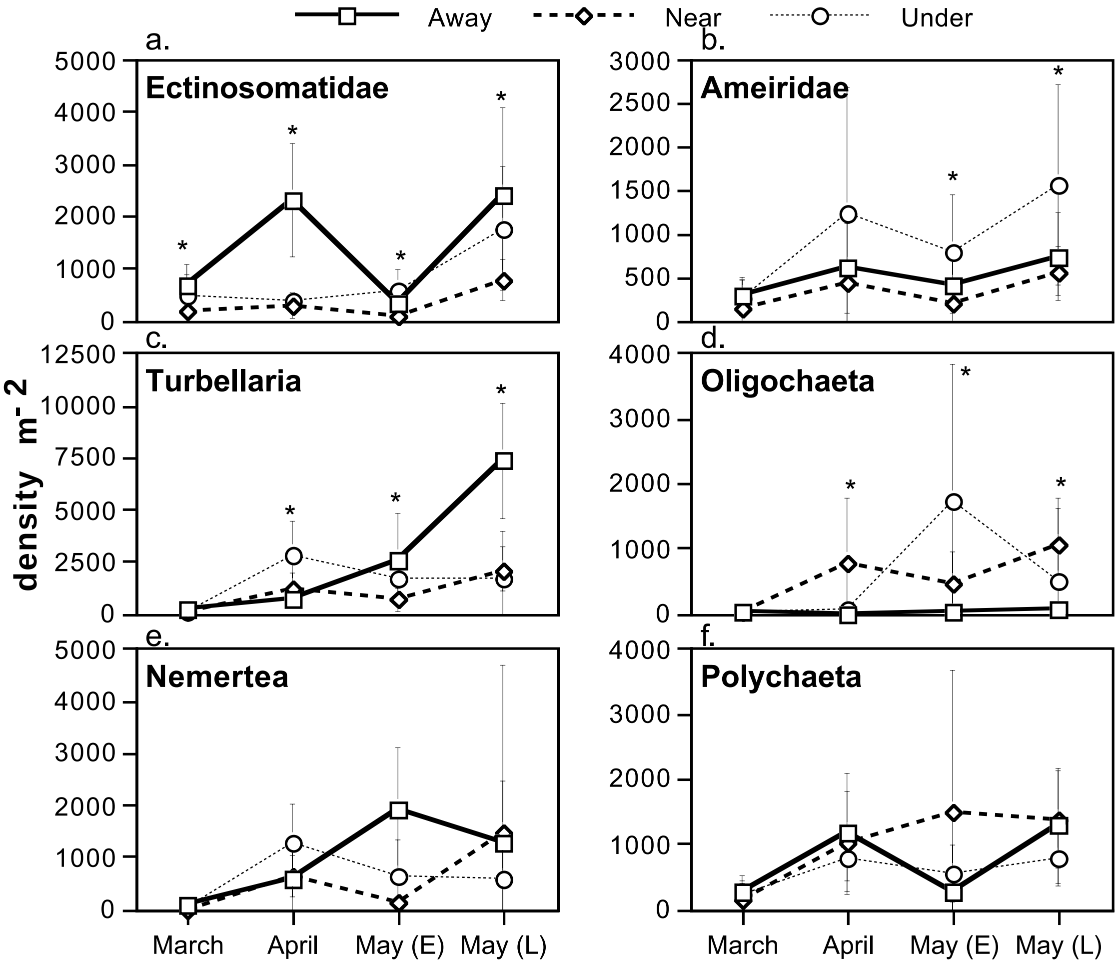

Figure 11. Mean response of common non-JSP taxa from Clinton stratified monthly-sampling, a – d with significant two-factor ANOVA results for strata. Asterisks (a – d) denote significant within month strata differences. Error bars are ± 1 standard deviation.

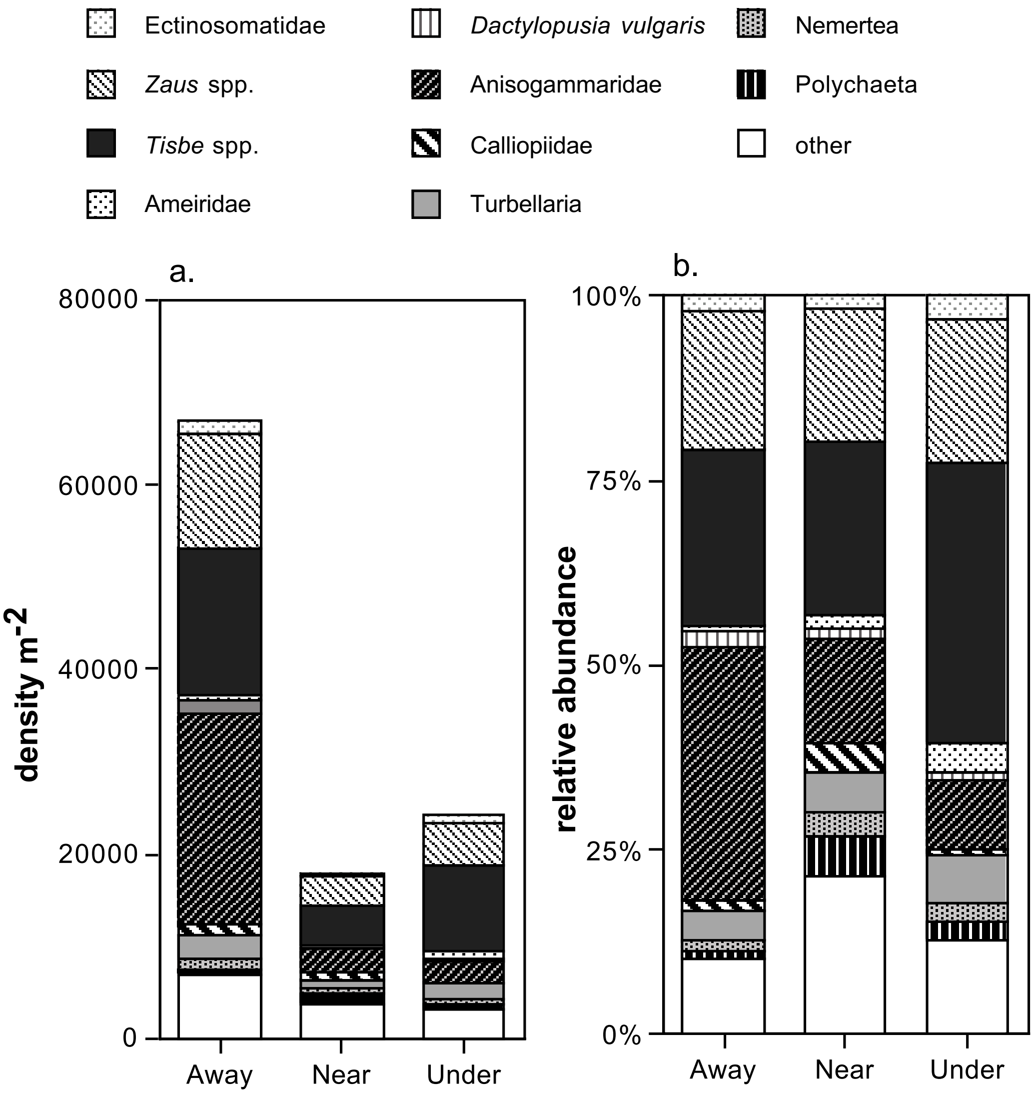

Figure 12. Assemblage composition at Clinton (total density and relative density); stratified-monthly sampling averaged across all months.

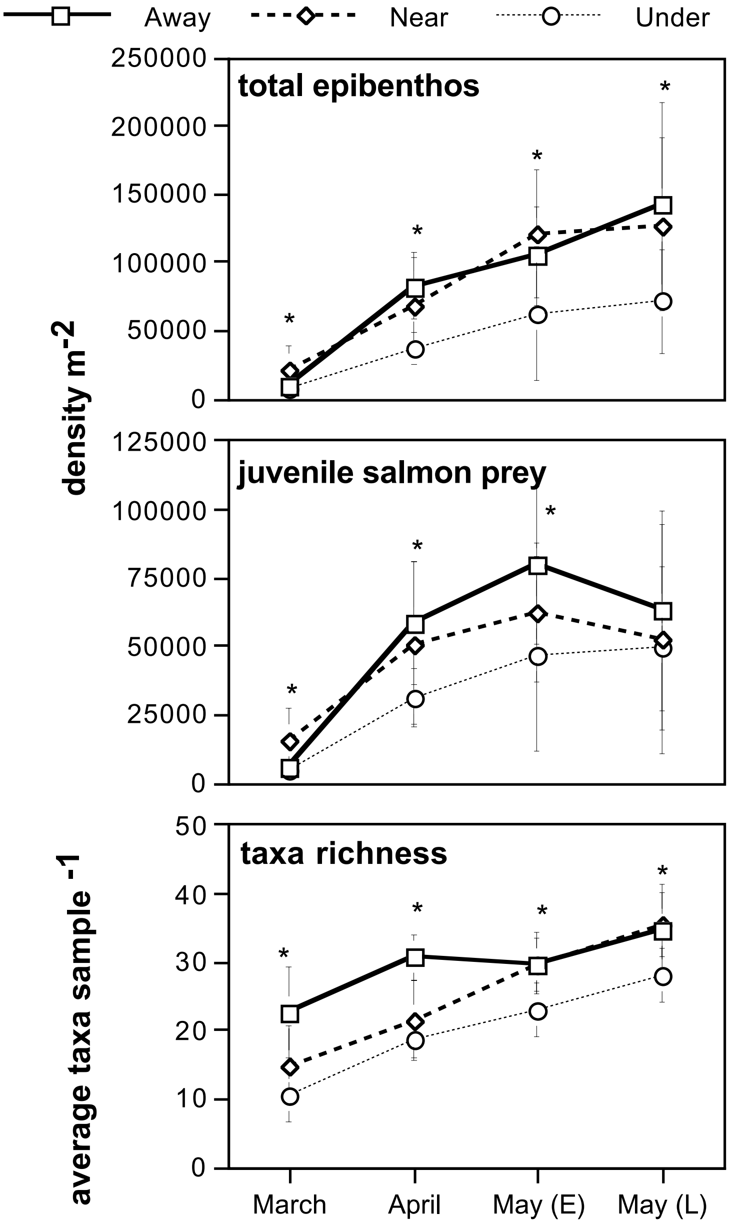

Figure 13. Mean response of summary variables for Southworth stratified-monthly sampling. Asterisks denote significant strata differences within month. Error bars are ± 1 standard deviation.

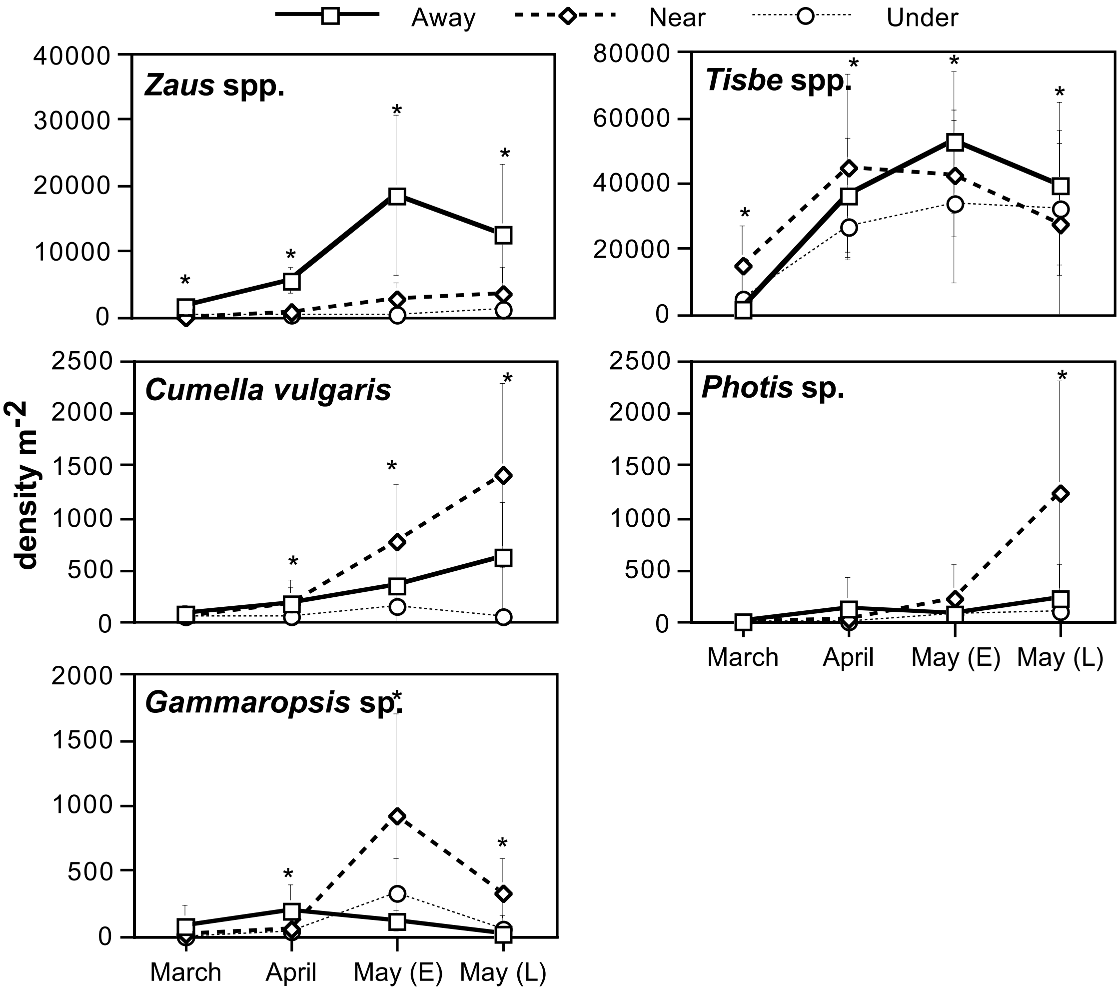

Figure 14. Mean response of abundant JSP taxa from Southworth stratified-monthly sampling with significant two-factor ANOVA results for strata. Asterisks denote significant within month strata differences. Error bars are ± 1 standard deviation.

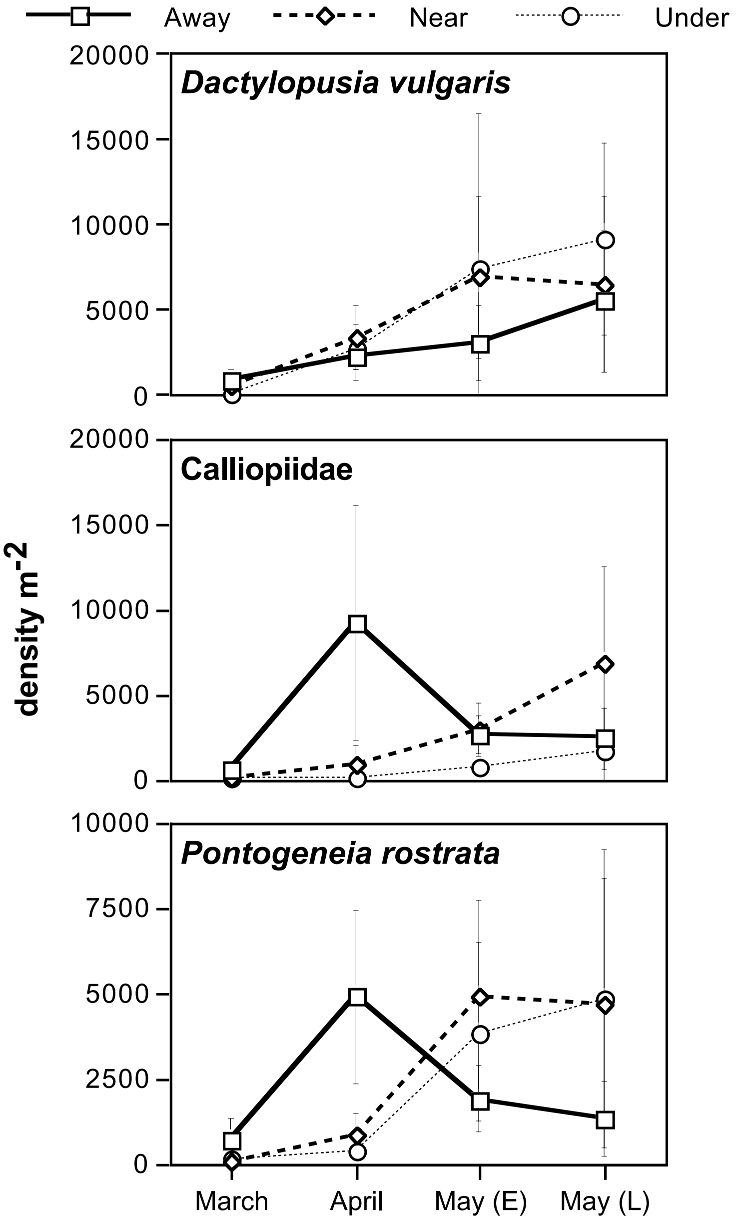

Figure 15. Mean response of abundant JSP taxa from Southworth stratified-monthly sampling with non-significant two-factor ANOVA results for strata. Error bars are ± 1 standard deviation.

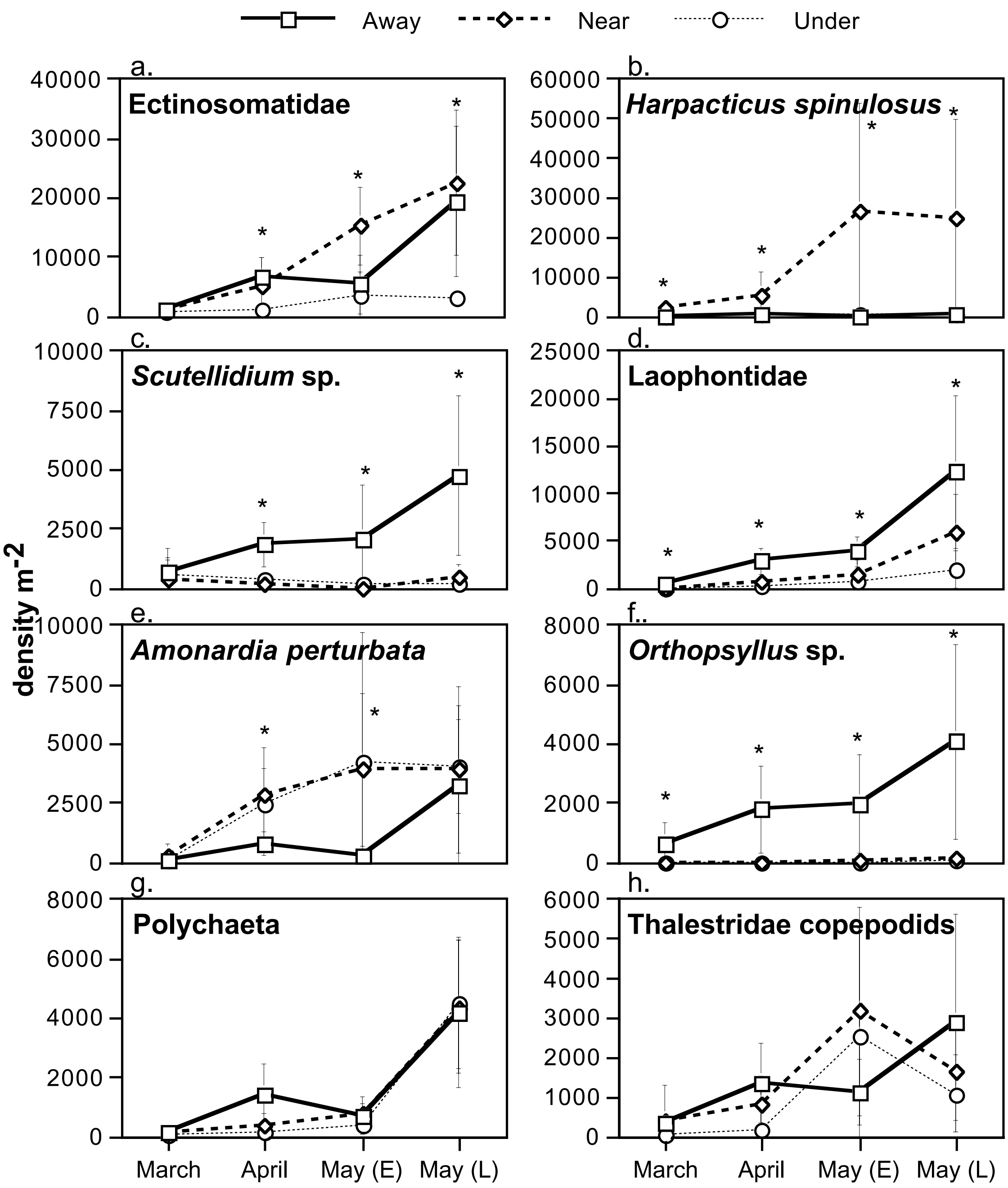

Figure 16. Mean response of common by non-JSP taxa from Southworth stratified-monthly sampling, a – f with significant two-factor ANOVA results for strata. Asterisks (a – f) denote significant within month strata differences. Error bars are ± 1 standard deviation.

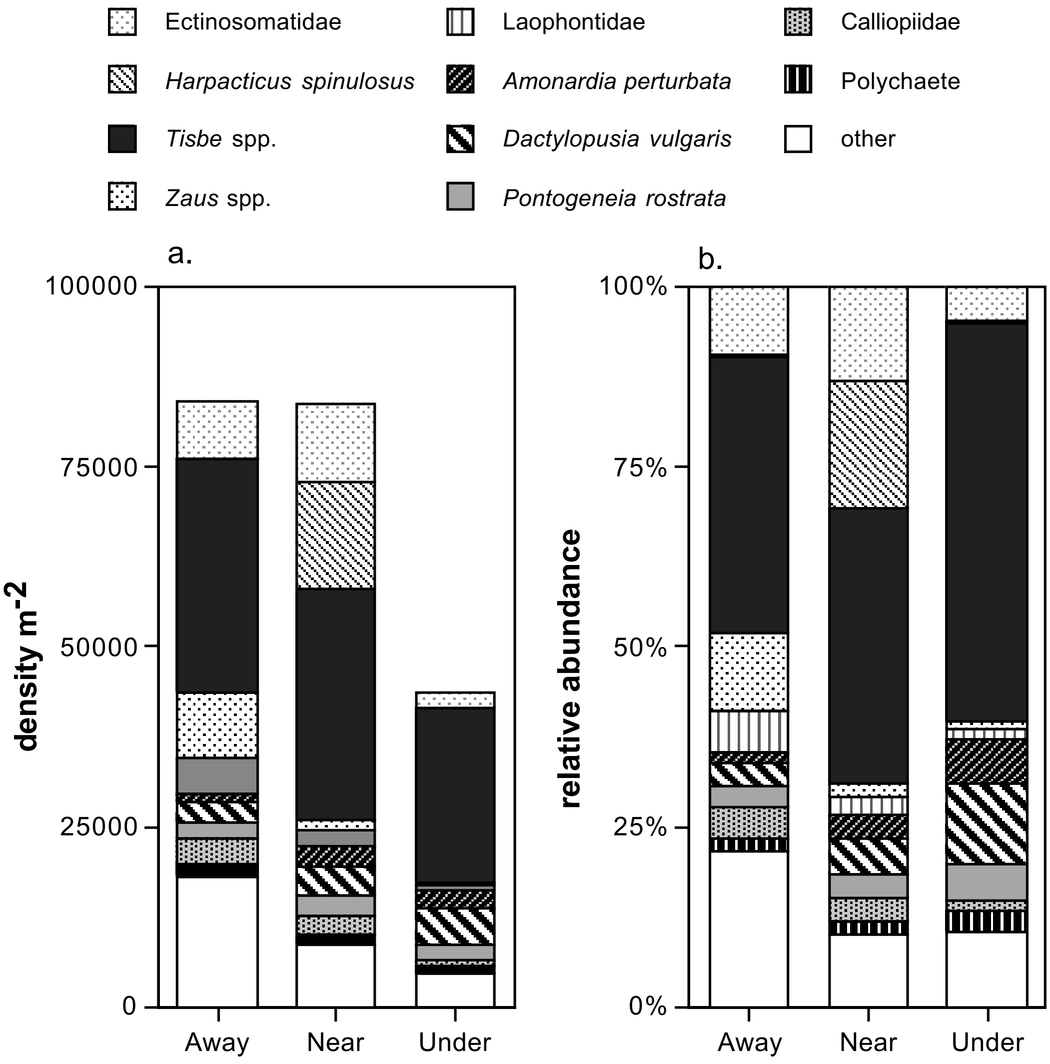

Figure 17. Assemblage composition at Southworth (total density and relative density); stratified-monthly sampling averaged across all months.

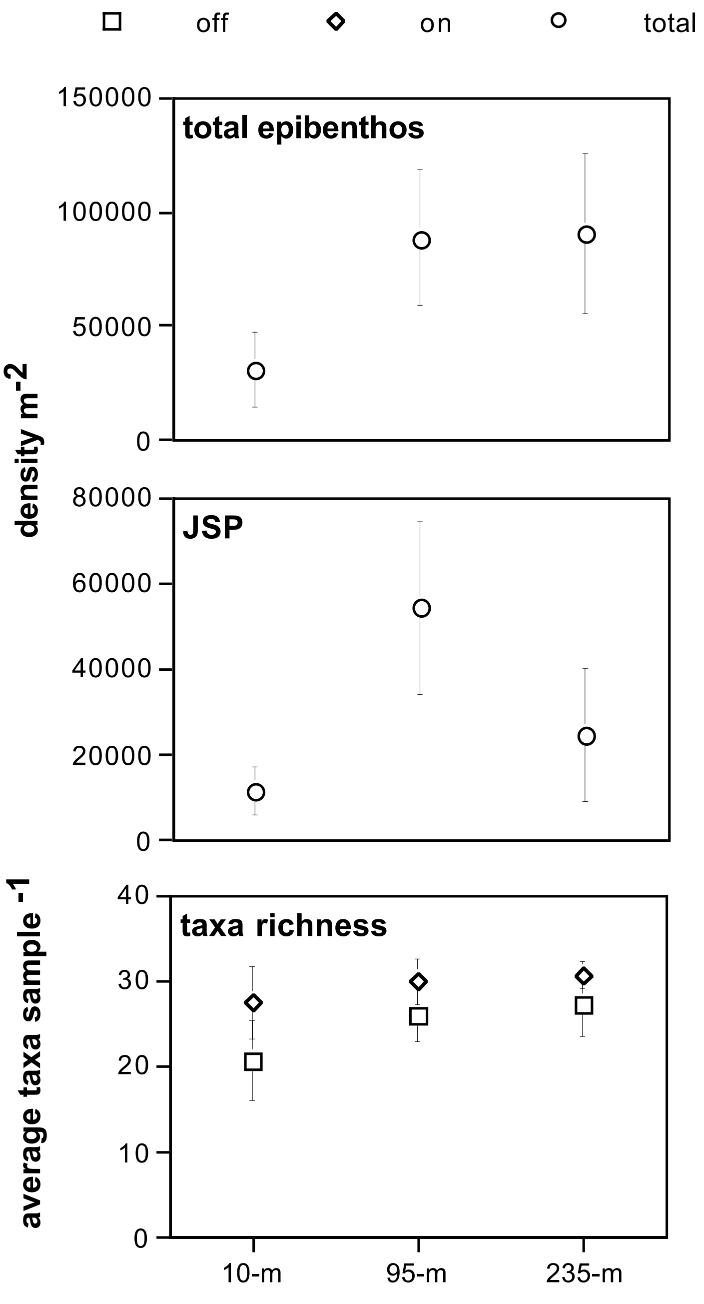

Figure 18. Mean response of summary variables for eelgrass sampling at the Clinton terminal. Total is the pooled eelgrass and non-eelgrass substrate averages where there was no significant difference between the two. Error bars are ± 1 standard deviation.

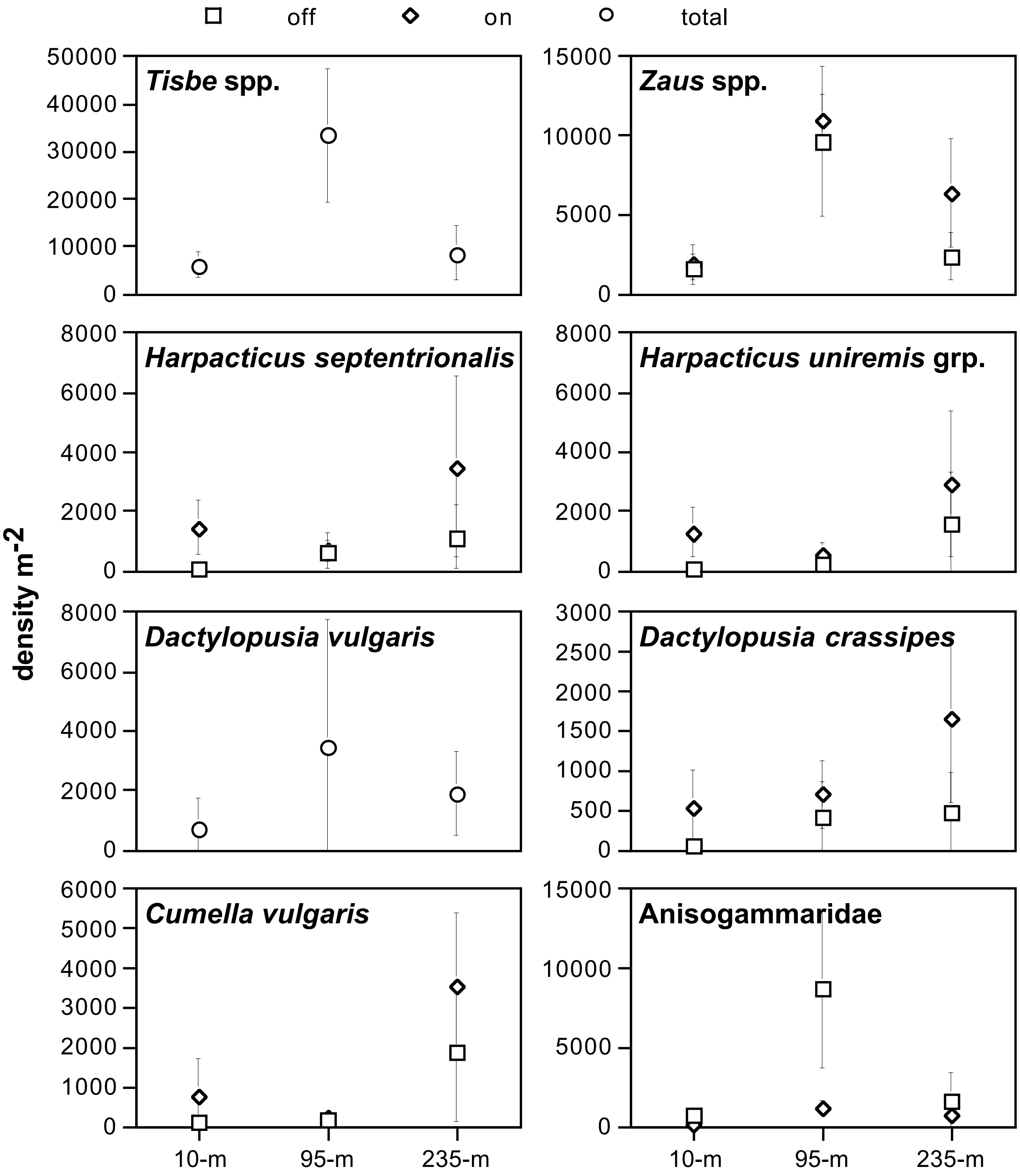

Figure 19. Mean response of JSP taxa for eelgrass sampling at the Clinton terminal. Total is the average of off and on eelgrass where there was no significant difference between the two. Error bars are ± 1 standard deviation.

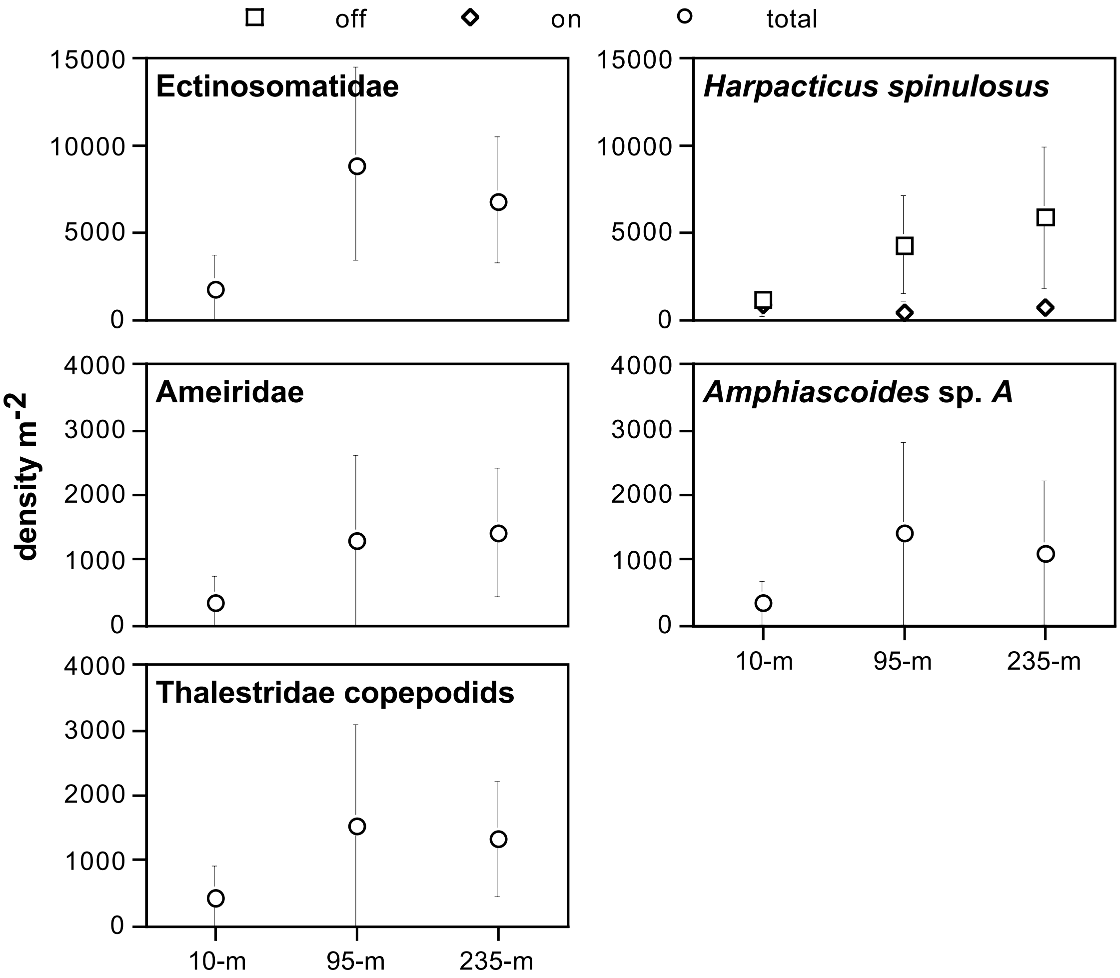

Figure 20. Mean response of harpacticoid non-JSP taxa for eelgrass sampling at the Clinton terminal. Total is the average of off and on eelgrass where there was no significant difference between the two. Error bars are ± 1 standard deviation.

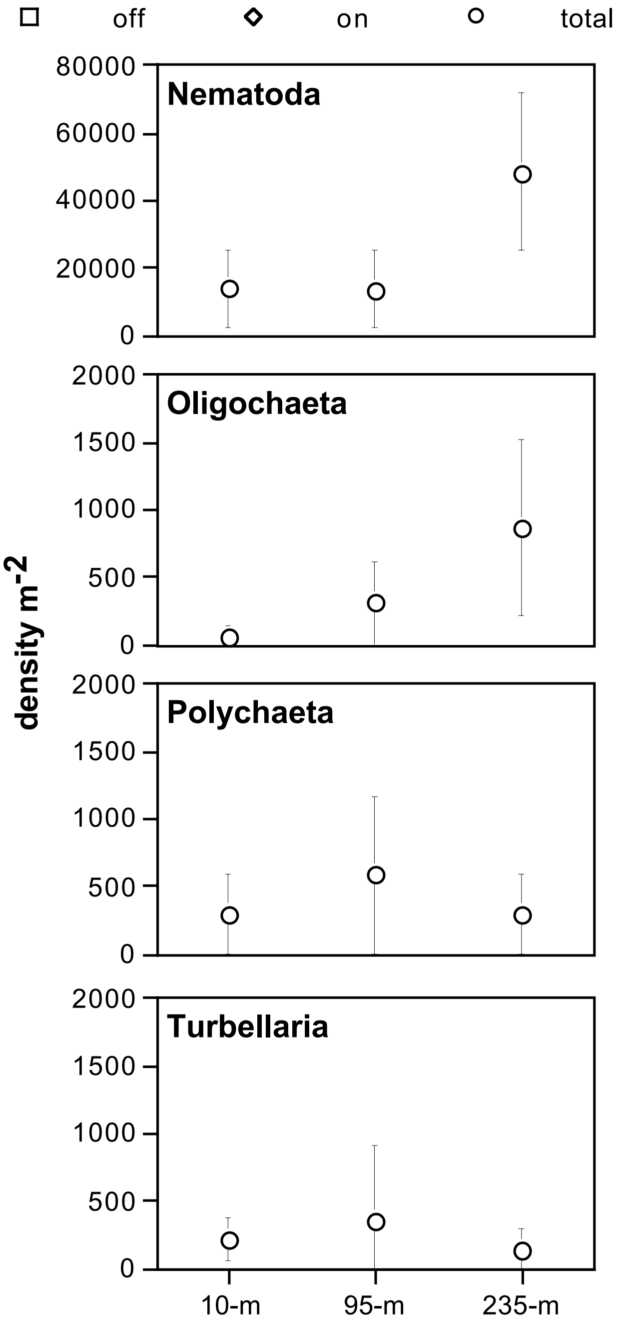

Figure 21. Mean response of additional non-JSP taxa for eelgrass sampling at the Clinton terminal. Polychaeta and Turbellaria are not significantly different among patch distances from terminal. Total is the average of off and on eelgrass where there was no significant difference between the two. Error bars are ± 1 standard deviation.

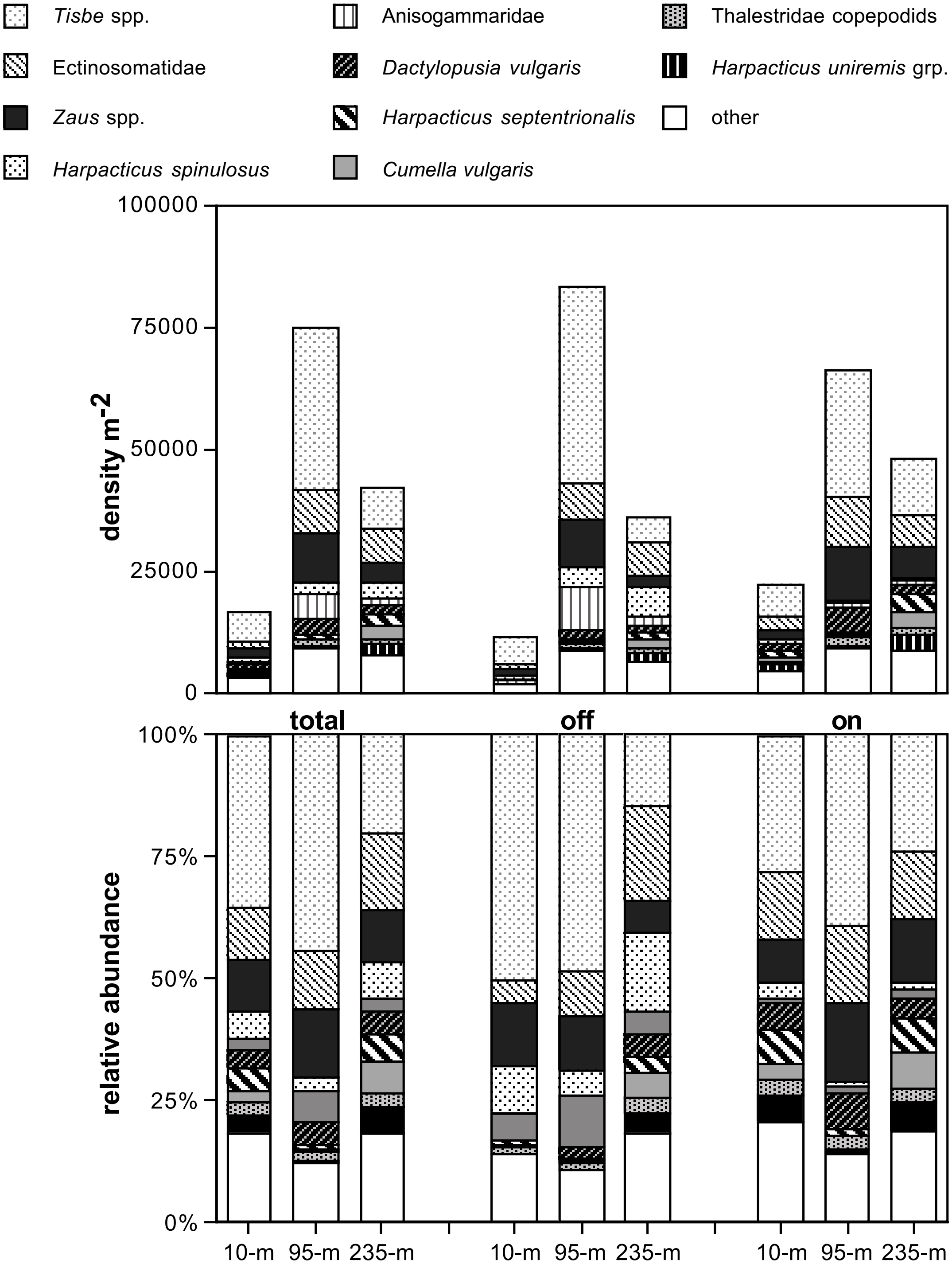

Figure 22. Assemblage composition for the 10 most abundant taxa present (after nematodes) in eelgrass patch sampling at the Clinton terminal. Total is the pooled the average of eelgrass (on) and non-eelgrass (off) substrate values.

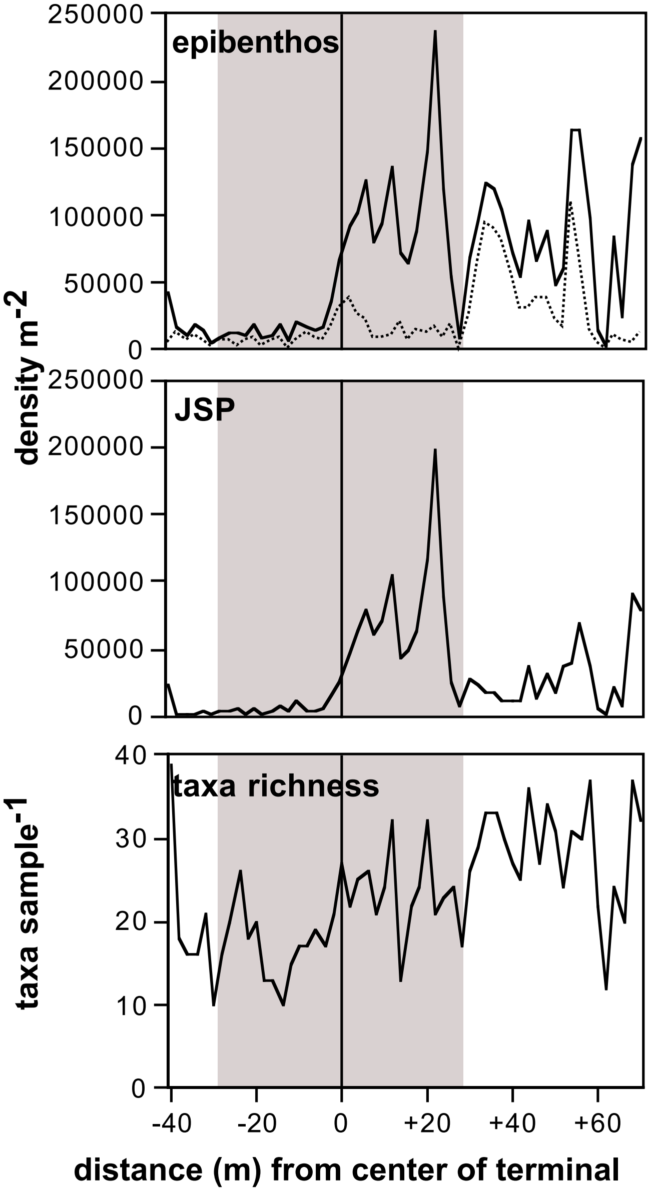

Figure 23. Response of summary variables for transect sampling. Dotted line in epibenthos graph shows nematode density, which was removed from subsequent assemblage composition graphs. Gray shading indicates cover by terminal decking, center line separates day two (south) and day one (north) sampling.

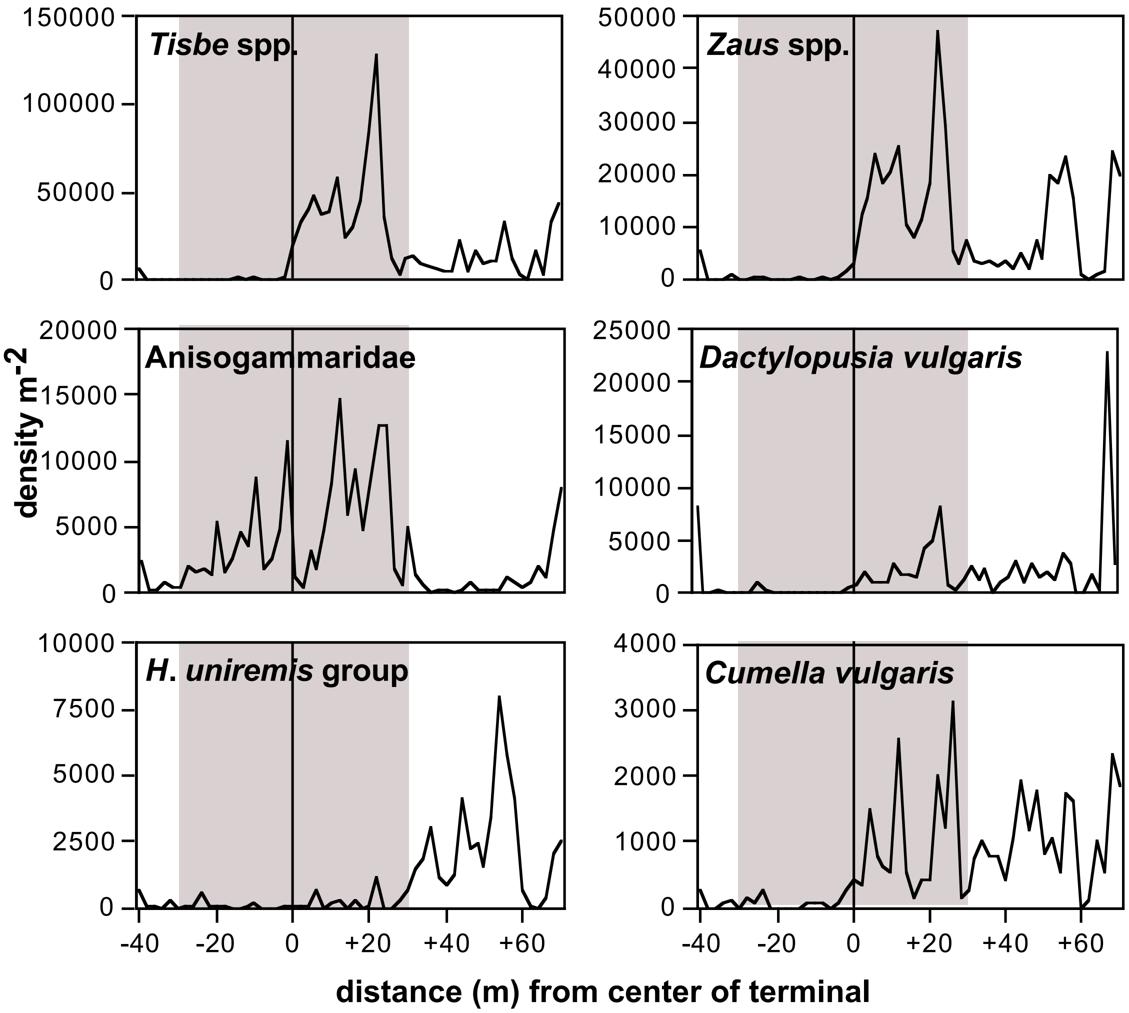

Figure 24. Response of abundant JSP taxa for transect sampling. Gray shading indicates cover by terminal decking, center line separates day two (south) and day one (north) sampling.

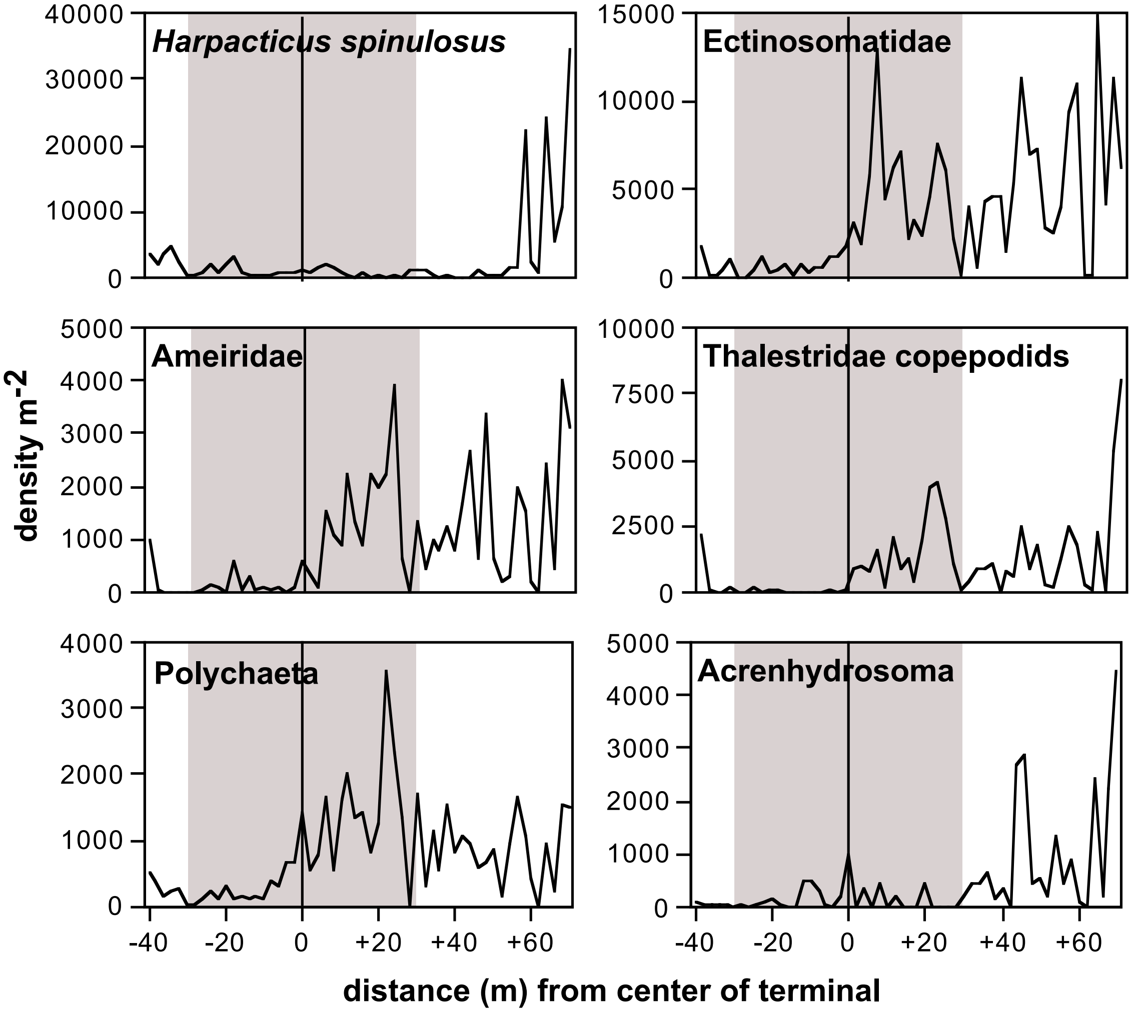

Figure 25. Response of abundant non-JSP taxa for transect sampling. Gray shading indicates cover by terminal decking, center line separates day two (south) and day one (north) sampling.

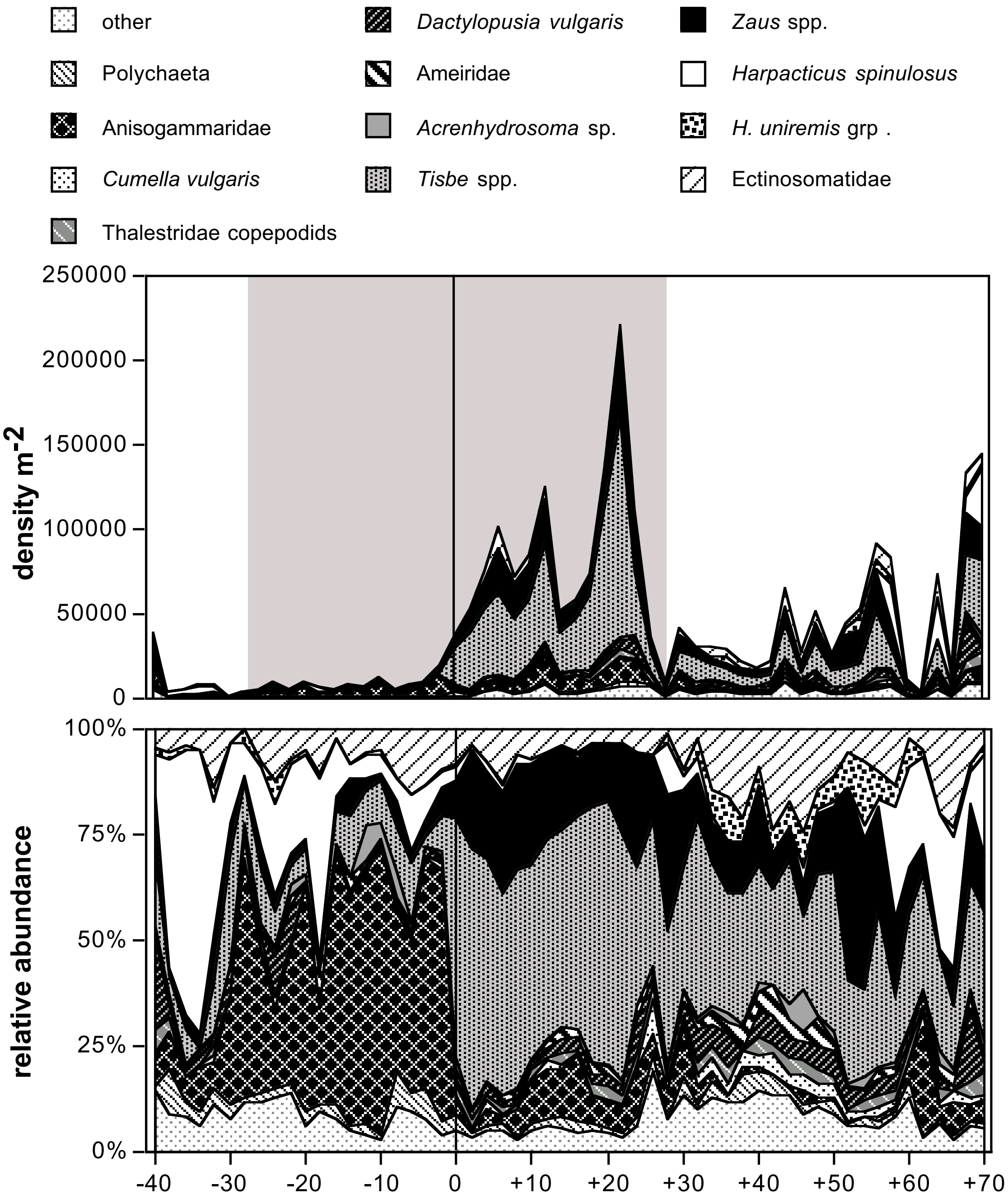

Figure 26. Assemblage composition for transect sampling. Taxa included are > 1% of the total epibenthos without nematodes. Gray shading indicates cover by terminal decking, center line separates day two (south) and day one (north) sampling.

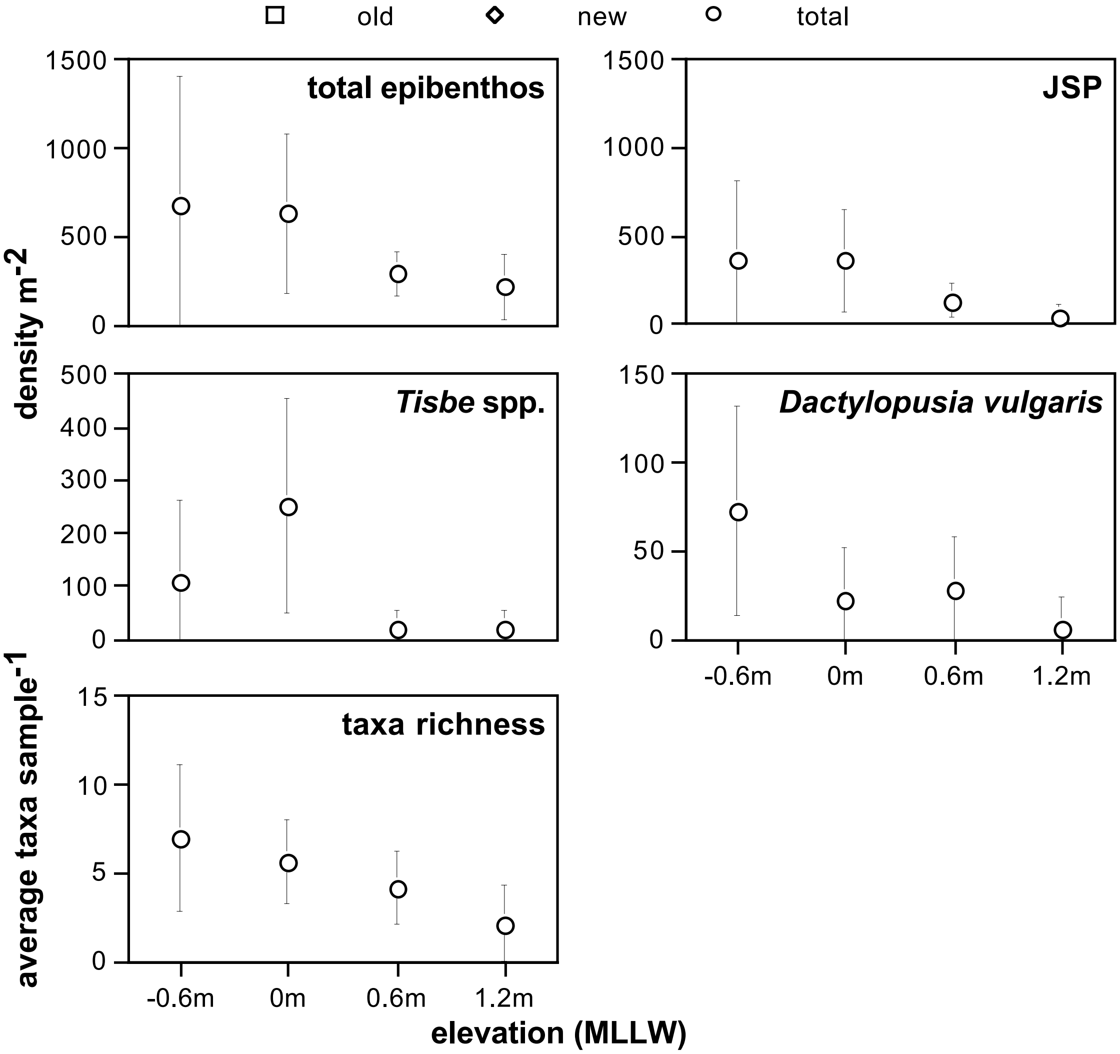

Figure 27. Mean response of summary variables and abundant taxa with significant two-factor ANOVA results for elevation from Bainbridge piling sampling. Results for piling-type type are not significant. Error bars are ± 1 standard deviation.

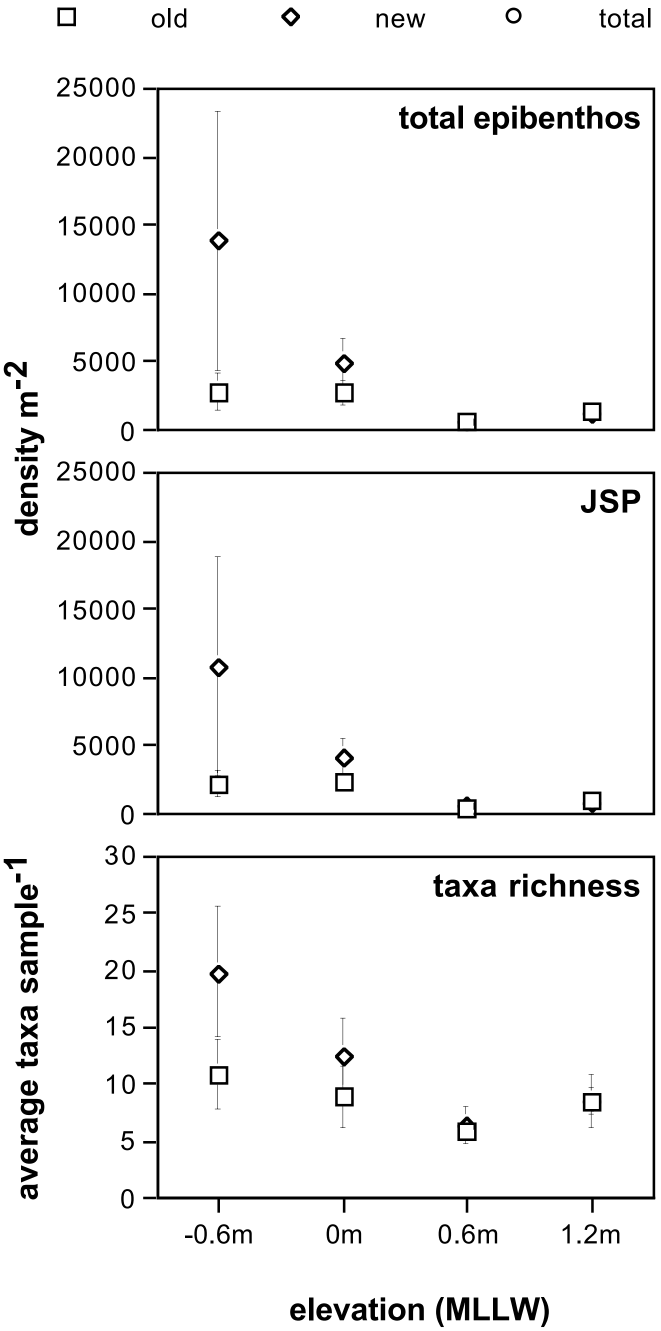

Figure 28. Mean response of summary variables from Clinton piling sampling. Piling-type and elevation factors are significant for all. Error bars are ± 1 standard deviation.

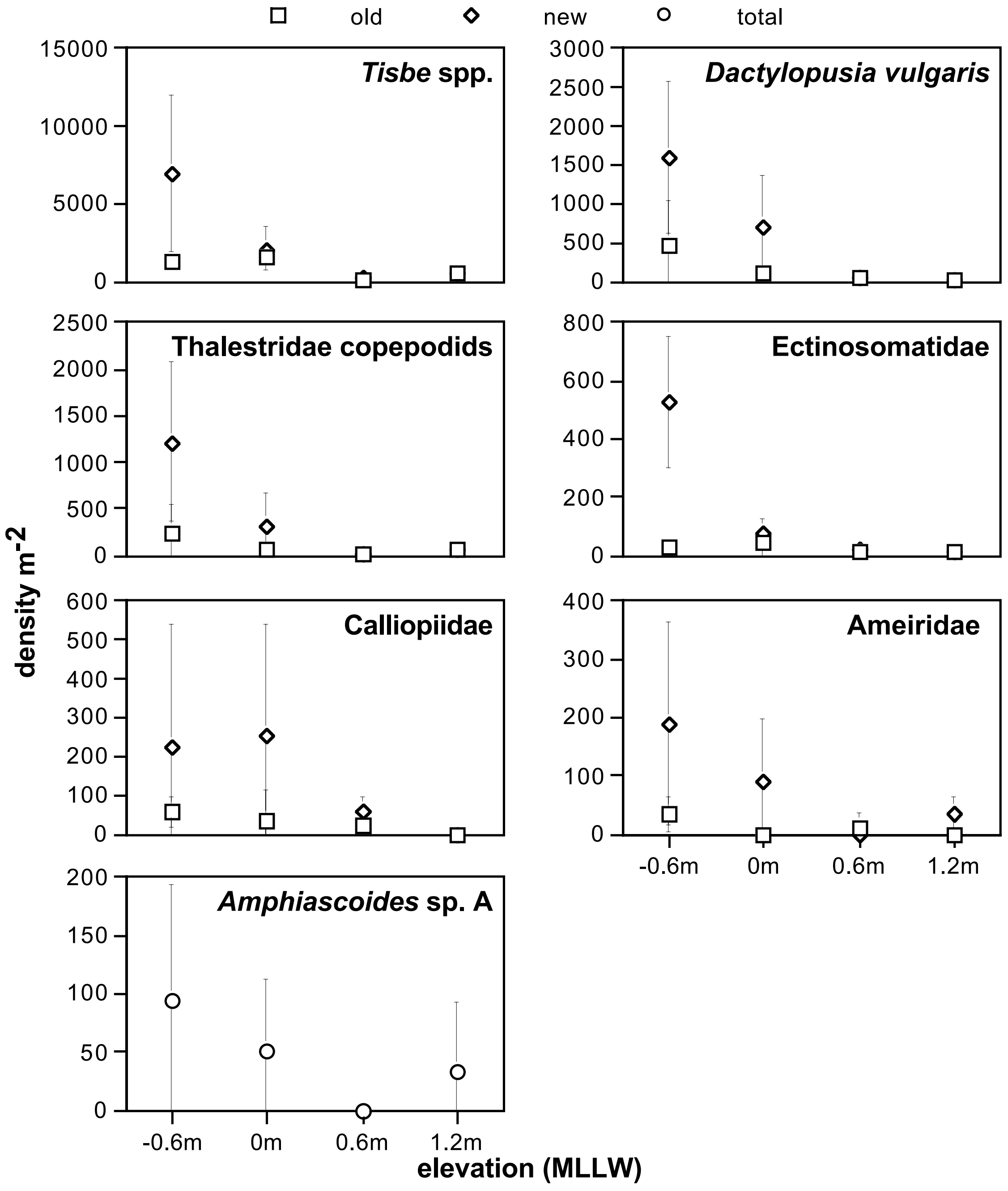

Figure 29. Mean response of abundant taxa from Clinton piling sampling. Total is the average for old and new piles where piling-type type is not significant. Elevation not significant for Calliopiidae. Error bars are ± 1 standard deviation.

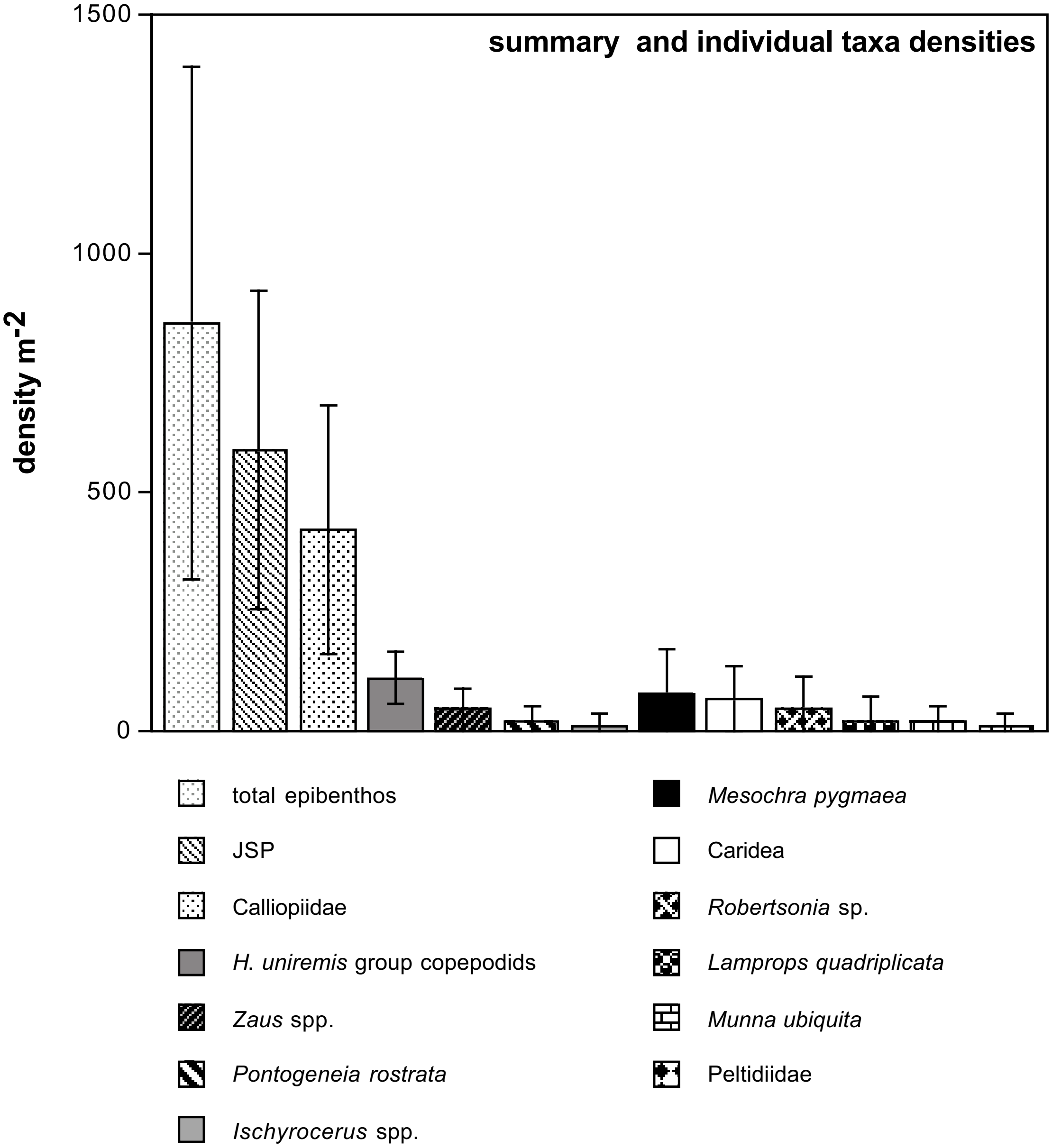

Figure 30. Average densities of total epibenthos, JSP, and all taxa present on floating public access dock at Clinton. Error bars are ± 1 standard deviation.

Table 3. Summary of statistical results (two-factor ANOVA, within month ANOVA, SNK post-hoc analyses) for Bainbridge stratified-monthly sampling for all summary variables, all present JSP taxa, and common and abundant non-JSP taxa (significant variables in shaded cells).

Taxa or Variable (JSP in bold)	2-factor ANOVA *p*-value (strata)	month	p-value	SNK (increasing)
total epibenthos	0.000	March	0.000	NU A
		April	0.000	NU A
		May, early	0.000	NU A
		May, late	0.000	NU A
JSP	0.000	March	0.000	NU A
		April	0.000	UN A
		May, early	0.000	NU A
		May, late	0.000	NU A
taxa richness	0.000	March	0.000	NU A
		April	0.000	UN A
		May, early	0.000	UN A
		May, late	0.003	UN A
***Harpacticus uniremis* grp.**	0.000	March	0.000	UN A
		April	0.000	NU A
		May, early	0.000	UN A
		May, late	0.000	UN A
***Zaus* spp.**	0.000	March	0.472	
		April	0.002	UN A
		May, early	0.025	NU A
		May, late	0.000	NU A
***Tisbe* spp.**	0.000	March	0.000	NU A
		April	0.000	NU A
		May, early	0.048	NU A
		May, late	0.000	NU A
Dactylopusia vulgaris	0.000	March	0.004	NU A
		April	0.000	NU A
		May, early	0.360	
		May, late	0.622	
Dactylopusia crassipes	0.012	March	NO BUGS	
		April	0.015	UN A
		May, early	0.129	
		May, late	0.139	
Cumella vulgaris	0.000	March	0.000	UN A
		April	0.000	UN A
		May, early	0.000	UN A
		May, late	0.000	UN A
Calliopiidae	*0.123*			

Table 3 (continued). Summary of statistical results (two-factor ANOVA, within month ANOVA, SNK post-hoc analyses) for Bainbridge stratified-monthly sampling for all summary variables, all present JSP taxa, and common and abundant non-JSP taxa (significant variables in shaded cells).

Taxa or Variable (JSP in bold)	2-factor ANOVA *p*-value (strata)	month	p-value	SNK (increasing)
Pontogeneia rostrata	0.000	March	0.003	UN A
		April	0.002	UN A
		May, early	0.024	UN A
		May, late	0.000	UN A
Anisogammaridae	*0.370*			
***Aoroides* spp.**	0.000	March	0.079	
		April	0.000	NU A
		May, early	0.376	
		May, late	0.186	
***Corophium* spp.**	0.001	March	0.376	
		April	0.004	NU A
		May, early	0.036	U(N A)
		May, late	0.134	
Pontogeneia intermedia	*0.370*			
Allorchestes angusta	0.000	March	NO BUGS	
		April	NO BUGS	
		May, early	0.129	
		May, late	0.000	NU A
***Photis* spp.**	0.000	March	0.022	NU A
		April	0.000	NU A
		May, early	0.024	NU A
		May, late	0.400	
***Gammaropsis* sp.**	0.000	March	NO BUGS	
		April	0.000	UN A
		May, early	0.610	
		May, late	NO BUGS	
***Ischyrocerus* spp.**	*0.139*			
Chironomidae	*0.607*			
Ectinosomatidae	0.000	March	0.004	NU A
		April	0.000	UN A
		May, early	0.000	NU A
		May, late	0.000	NU A
Harpacticus spinulosus	0.000	March	0.000	UN A
		April	0.000	UN A
		May, early	0.000	UN A
		May, late	0.000	UN A
Laophontidae	0.000	March	0.000	NU A
		April	0.000	UN A
		May, early	0.000	NU A
		May, late	0.000	UN A

Table 3 (continued). Summary of statistical results (two-factor ANOVA, within month ANOVA, SNK post-hoc analyses) for Bainbridge stratified-monthly sampling for all summary variables, all present JSP taxa, and common and abundant non-JSP taxa (significant variables in shaded cells).

Taxa or Variable (JSP in bold)	2-factor ANOVA *p*-value (strata)	month	p-value	SNK (increasing)
Amphiascoides sp. *A*	0.000	March	0.001	NU A
		April	0.000	UN A
		May, early	0.000	NU A
		May, late	0.000	UN A
Robertsonia sp.	0.000	March	0.001	NU A
		April	0.000	NU A
		May, early	0.000	NU A
		May, late	0.000	NU A
Thalestridae copepodids	0.000	March	0.150	
		April	0.000	NU A
		May, early	0.498	
		May, late	0.001	UN A
Cyclopinidae	0.000	March	0.403	
		April	0.905	
		May, early	0.000	A N U
		May, late	0.000	AN U
Turbellaria	0.000	March	0.013	UN A
		April	0.634	
		May, early	0.000	UN A
		May, late	0.000	UN A
Polychaeta	0.000	March	0.003	NA U
		April	0.000	N U A
		May, early	0.000	NU A
		May, late	0.000	AN U
Oligochaeta	0.000	March	0.013	NU A
		April	0.000	NU A
		May, early	0.000	NU A
		May, late	0.006	N(A U)

Table 4. Summary of statistical results (two-factor ANOVA, within month ANOVA, SNK post-hoc analyses) for Clinton stratified-monthly sampling for all summary variables, all present JSP taxa, and common and abundant non-JSP taxa (significant variables in shaded cells).

Taxa or Variable (JSP in bold)	2-factor ANOVA *p*-value (strata)	month	*p*-value	SNK (increasing)
total epibenthos	0.000	March	0.000	N U A
		April	0.000	UN A
		May, early	0.000	N UA
		May, late	0.000	NU A
JSP	0.000	March	0.000	N U A
		April	0.000	UN A
		May, early	0.000	NU A
		May, late	0.000	N U A
taxa richness	0.000	March	0.000	NU A
		April	0.003	U(A N)
		May, early	0.000	N UA
		May, late	0.000	UN A
***Harpacticus uniremis* grp.**	0.000	March	0.000	NU A
		April	0.000	UN A
		May, early	0.079	
		May, late	0.000	UN A
***Zaus* spp.**	0.000	March	0.000	NU A
		April	0.000	UN A
		May, early	0.000	NA U
		May, late	0.000	N U A
***Tisbe* spp.**	0.000	March	0.000	N U A
		April	0.000	U N A
		May, early	0.000	N UA
		May, late	0.000	N UA
Dactylopusia vulgaris	0.000	March	0.000	NU A
		April	0.000	NU A
		May, early	0.003	NA U
		May, late	0.000	UN A
Dactylopusia crassipes	0.000	March	0.000	UN A
		April	0.000	UN A
		May, early	0.004	NU A
		May, late	0.000	UN A
Cumella vulgaris	0.000	March	0.000	UN A
		April	0.023	U AN
		May, early	0.068	
		May, late	0.000	UA N
Calliopiidae	0.000	March	0.000	UN A
		April	0.000	U A N
		May, early	0.000	UA N
		May, late	0.000	UN A

Table 4 (continued). Summary of statistical results (two-factor ANOVA, within month ANOVA, SNK post-hoc analyses) for Clinton stratified-monthly sampling for all summary variables, all present JSP taxa, and common and abundant non-JSP taxa (significant variables in shaded cells).

Taxa or Variable (JSP in bold)	2-factor ANOVA *p*-value (strata)	month	*p*-value	SNK (increasing)
Pontogeneia rostrata	0.292			
Anisogammaridae	0.000	March	0.000	NU A
		April	0.000	UN A
		May, early	0.000	N U A
		May, late	0.000	UN A
***Aoroides* spp.**	0.835			
***Corophium* spp.**	0.633			
Pontogeneia intermedia	0.370			
Allorchestes angusta	0.000	March	0.000	NU A
		April	0.000	NU A
		May, early	0.010	N UA
		May, late	0.000	NU A
***Photis* spp.**	0.291			
Chironomidae	0.443			
Ectinosomatidae	0.000	March	0.000	N UA
		April	0.000	NU A
		May, early	0.000	N A U
		May, late	0.002	N UA
Ameiridae	0.000	March	0.280	
		April	0.080	
		May, early	0.003	NA U
		May, late	0.001	NA U
Thalestridae copepodids	0.000	March	0.000	NU A
		April	0.000	UN A
		May, early	0.605	
		May, late	0.024	U(N A)
Polychaeta	0.019	very non-normal, NSD (p ≤ 0.602) log10		
Oligochaeta	0.000	March	0.591	
		April	0.001	AU N
		May, early	0.001	AN U
		May, late	0.004	A(U N)
Turbellaria	0.000	March	0.625	
		April	0.000	AN U
		May, early	0.002	N UA
		May, late	0.000	UN A
Nemertea	0.136			

Table 5. Summary of statistical results (two-factor ANOVA, within month ANOVA, SNK post-hoc analyses) for Southworth stratified-monthly sampling for all summary variables, all present JSP taxa, and common and abundant non-JSP taxa (significant variables in shaded cells).

Taxa or Variable (JSP in bold)	2-factor ANOVA *p*-value (strata)	month	*p*-value	SNK (increasing)
total epibenthos	0.000	March	0.002	UA N
		April	0.000	U NA
		May, early	0.003	U AN
		May, late	0.006	U NA
JSP	0.001	March	0.000	UA N
		April	0.004	U NA
		May, early	0.018	N(U A)
		May, late	0.572	
taxa richness	0.000	March	0.000	U N A
		April	0.000	UN A
		May, early	0.000	U AN
		May, late	0.001	U AN
***Harpacticus uniremis* grp.**	0.055			
Zaus spp.	0.000	March	0.000	NU A
		April	0.000	UN A
		May, early	0.000	UN A
		May, late	0.000	UN A
***Tisbe* spp.**	0.039	March	0.000	AU N
		April	0.065	
		May, early	0.085	
		May, late	0.392	
Dactylopusia vulgaris	.029	non-normal		
Dactylopusia crassipes	0.137			
Cumella vulgaris	0.000	March	0.365	
		April	0.025	U AN
		May, early	0.000	UA N
		May, late	0.000	U A N
Calliopiidae	0.076			
Pontogeneia rostrata	0.524			
Anisogammaridae	0.504			
***Aoroides* spp.**	0.222			
***Corophium* spp.**	0.005	March	NO BUGS	
		April	NO BUGS	
		May, early	0.610	
		May, late	0.007	AU N
Pontogeneia intermedia	0.081			
Allorchestes angusta	0.114			

Table 5 (continued). Summary of statistical results (two-factor ANOVA, within month ANOVA, SNK post-hoc analyses) for Southworth stratified-monthly sampling for all summary variables, all present JSP taxa, and common and abundant non-JSP taxa (significant variables in shaded cells).

Taxa or Variable (JSP in bold)	2-factor ANOVA *p*-value (strata)	month	*p*-value	SNK (increasing)
***Photis* spp.**	0.000	March	0.773	
		April	0.193	
		May, early	0.073	
		May, late	0.000	UA N
***Gammaropsis* sp.**	0.000	March	0.078	
		April	0.001	UN A
		May, early	0.000	UA N
		May, late	0.000	UA N
***Ischyrocerus* spp.**	0.498			
Chironomidae	0.37			
Ectinosomatidae	0.000	March	0.341	
		April	0.000	U NA
		May, early	0.000	UA N
		May, late	0.000	U AN
Harpacticus spinulosus	0.000	March	0.006	UA N
		April	0.000	UA N
		May, early	0.000	AU N
		May, late	0.000	UA N
Scutellidium sp.	0.000	March	0.051	
		April	0.000	NU A
		May, early	0.000	NU A
		May, late	0.000	NU A
Laophontidae	0.000	March	0.000	UN A
		April	0.000	UN A
		May, early	0.000	UN A
		May, late	0.000	U N A
Amonardia perturbata	0.000	March	0.081	
		April	0.001	A UN
		May, early	0.008	A NU
		May, late	0.758	
Orthopsyllus sp.	0.000	March	0.000	NU A
		April	0.000	NU A
		May, early	0.000	UN A
		May, late	0.000	UN A
Thalestridae copepodids	0.098			
Polychaeta	0.285			

Table 6. Summary of statistical tests for eelgrass patch sampling (two-factor ANOVA, SNK where appropriate). Shaded cells indicate statistically significant results for the Patch (10-m, 95-m, 235-m) factor.

Taxa or Variable (JSP in bold)	Patch *p*-value	Eelgrass/ non-Eelgrass *p*-value	interaction *p*-value	Type SNK	Off/On direction
total epibenthos	0.000	0.267	0.170	10 (95 253)	
JSP	0.000	0.765	0.010	10 235 95	
taxa richness	0.002	0.000	0.392	**off** 10 (95 235)	off < on
				on not significant	
Harpacticus septentrionalis	0.005	0.006	0.100	**off** (10 **95**) **235**	off < on
				on (95 **10**) **235**	
***Harpacticus uniremis* grp. other**	0.000	0.020	0.550	**off** (10 **95**) **235**	off < on
				on (95 **10**) **235**	
***Zaus* spp.**	0.000	0.024	0.118	**off** (10 235) 95	off < on
				on 10 235 95	
***Tisbe* spp.**	0.000	0.292	0.005	(10 235) 95	
Dactylopusia vulgaris	0.029	0.076	0.377	(10 **235**) **95**	
Dactylopusia crassipes	0.005	0.001	0.111	**off** not significant	off < on
				on (10 95) 235	
Cumella vulgaris	0.000	0.028	0.168	**off** (10 **95**) **235**	off < on
				on (95 **10**) **235**	
Anisogammaridae	0.000	0.000	0.000	*	on < off
Ectinosomatidae	0.000	0.175	0.537	10 (235 95)	
Harpacticus spinulosus	0.019	0.000	0.011	*	off < on
Ameiridae	0.013	0.252	0.552	10 (95 235)	
Amphiascoides sp. A	0.008	0.815	0.195	10 (235 95)	
Thalestridae copepodids	0.021	0.138	0.797	10 (235 95)	
Turbellaria	0.191	0.140	0.055		
Nematoda	0.000	0.125	0.604	(95 10) 253	
Polychaeta	0.114	0.035	0.912		on < off
Oligochaeta	0.000	0.650	0.711	(10 95) 235	

* SNK not appropriate due to significant interaction factor

Table 7. Summary of statistical results for piling sampling (two-factor ANOVA for Pile and Elevation). Shaded cells indicate significant results for either factor.

Site	Taxa or Variable (JSP in bold)	Pile *p*-value	Elevation *p*-value	Interaction *p*-value
Bainbridge	total epibenthos	0.782	0.050	0.308
	JSP	0.271	0.023	0.219
	taxa richness	0.479	0.005	0.504
	Polychaeta	0.327	0.607	0.893
	Tisbe spp.	0.171	0.000	0.000
	Dactylopusia vulgaris	0.496	0.004	0.801
Clinton	total epibenthos	0.005	0.000	0.002
	JSP	0.008	0.000	0.008
	taxa richness	0.002	0.000	0.008
	Harpacticus uniremis grp. other	0.308	0.131	0.070
	Harpacticus septentrionalis	0.260	0.540	0.785
	Zaus spp.	0.170	0.137	0.368
	Tisbe spp.	0.013	0.000	0.004
	Tisbe spp. (logged)	0.258	0.000	0.264
	Dactylopusia vulgaris	0.006	0.000	0.031
	Dactylopusia crassipes	0.420	0.801	0.515
	Anisogammaridae	0.166	0.231	0.302
	Calliopiidae	0.037	0.103	0.327
	Calliopiidae (logged)	0.023	0.001	0.254
	Ectinosomatidae	0.000	0.000	0.000
	Harpacticus spinulosus	0.754	0.124	0.731
	Laophontidae	0.256	0.095	0.053
	Ameiridae	0.008	0.015	0.903
	Ameiridae (logged)	0.003	0.009	0.050
	Amphiascoides sp. A	0.772	0.012	0.032
	Amphiascoides sp. A (logged)	0.412	0.005	0.123
	Thalestridae copepodid	0.008	0.000	0.010
	Cyclopinidae	0.082	0.105	0.191

DISCUSSION

The main purpose of this project was to describe the intertidal and shallow subtidal epibenthos (large meiofauna and small macrofauna), particularly juvenile salmon prey, around ferry terminals in order to determine if they impacted that assemblage. Although variable, the differences indicated negative impacts of the terminals. The major null hypothesis was "there are no differences in the epibenthic JSP assemblage (density and composition) between areas in close vicinity to and farther away from ferry terminals". My results demonstrated many clear, significant differences both in density and composition of the epibenthos at three ferry terminal structures, both over time (stratified-monthly sampling) and at several tidal elevations and habitat types (stratified-monthly sampling, eelgrass sampling, and cross-terminal sampling). Therefore, the major null hypothesis was rejected: significant differences in epibenthic assemblages do exist around the ferry terminals.

While this project was not designed to determine causal factors, there are several that may be responsible. Blanton et al. (2001) described the light environment, benthic vegetation cover, and general substrate composition (visual assessment) at -0.6 m (-2') at each of the three terminals. The magnitude of under-terminal shading impacts, in terms of distance of intense shading, was greatest at Clinton, where the decking is nearly 20 meters wider than at Bainbridge and 35 meters wider than at Southworth. However, the north side of the Bainbridge main terminal structure has two overhead walkways, which produced variable but less intense intertidal shading than under the terminal. The area of intense shading at Southworth was not as wide as at the other two terminals. In addition, adjusted in-water photosynthetically active radiation (corrected from in-air readings) was generally close to zero under the structure at Bainbridge and Clinton, whereas at Southworth it was reduced but detectable. Coverage of attached vegetation followed similar patterns to those for light. Bainbridge and Clinton had no vegetation under or within five meters of the terminal. Bainbridge had relatively lower vegetation cover (*Enteromorpha* sp., *Ulva* sp., and *Porphyra* sp.) than Clinton (eelgrass, *Ulva* sp., *Laminaria* sp., and *Enteromorpha* sp.). Southworth had the highest coverage of benthic vegetation (primarily *Enteromorpha* sp. and *Ulva* sp., also eelgrass), extending underneath the terminal decking by five meters on both sides. Substrate compositions for all three terminals were noticeably different around the structure, with higher gravel, shell, and cobble proportions as compared to sand, the dominant component of all substrates.

The findings of Blanton et al. (2001) provide evidence for shading and propeller wash impacts, as well as possible biotic sources of changes in sediment composition (increased shell hash from sea star foraging). The documented lack of vegetation beyond the edge of the terminal at Clinton and Bainbridge was likely an indicator of propeller wash as well as shading impacts on the intertidal area. The apparent substrate coarsening was a predicted response to propeller wash, as was increased shell or shell hash in the sediments. I completed additional sediment grain size analysis from within each stratified-monthly sampling stratum that confirmed sediment coarsening close to the terminal at Bainbridge, some at Southworth (Figure 31), and increased proportions of shell hash in sediments closer to all three terminals (Figure 32). This was most likely due to a combination of sea star foraging on pilings and in substrate, and the decomposition of shells from the large numbers of bivalves in the sediments under and near to the terminals. Clearly, the structures and ferries altered the biological and physical environments around these structures.

At all three terminals, there were consistent, clear, highly statistically significant differences in both the density and composition of the epibenthos among the Under, Near, and Away strata. Given this, H_{01} was rejected: significant differences do exist for the epibenthic JSP assemblage among these three strata relative to ferry terminals during the period of salmon outmigration. With few exceptions (only non-prey taxa), significant differences suggested negative impacts of these ferry terminals on the epibenthos. The differences in the epibenthos corresponded with the predictions made based on the differences in magnitude of disturbances from propeller wash, shading (i.e., benthic vegetation reduction), and substrate composition changes. Therefore, it is likely that the combination of these factors related to terminal size and boat traffic caused differences seen in the epibenthos.

As hypothesized, the most seriously impacted epibenthos occurred at Bainbridge, with the greatest difference between the Away and Under strata for most variables. Because the Under and Near strata were similar, the causes of impact at Bainbridge extended beyond shading, which affected the Near stratum but was less strong as the completely shaded Under stratum (Olson et al. 1997, Visconty 1997, Blanton 2001). I observed docking events at Bainbridge to subject both the Under and Near strata to extreme propeller wash: water levels rose by over 0.3 m, and currents were strong enough to move barnacle encrusted bivalve shells as well as sediment and organic debris in both the Under and Near strata. Without benthic vegetation on which to attach, it was likely that such strong and regular disturbance resuspended and redistributed much of the epibenthic meiofauna and small macrofauna close to the terminal. This may explain the assemblage shift at Bainbridge, from ~75% harpacticoids, distributed among many groups, Away from the terminal to one in which *Tisbe* spp. was the only abundant harpacticoid (~25% of the total) and where over 40% of the organisms were annelids (Polychaeta, Oligochaeta). *Tisbe* spp. has been demonstrated to be more ubiquitous among habitat-types within close proximity to one another (Simenstad et al. 1988a), and may spend a relatively large amount of time higher in the water column (Marcotte 1983), in this case making it susceptible to transport by propeller wash. In contrast, the larger annelids may have been partially burrowed in the sediment, allowing them withstand the wash disturbance. Neither Clinton nor Southworth had such strong differences in the density or assemblage of the epibenthos relative to the terminal structure, but negative impacts on the epibenthos were clear. The overall abundance of most individual taxa, taxa richness, and total epibenthos declined. The decline in taxa richness may have been due to the decreased probability of finding rarer organisms in lower total abundance samples (especially at Bainbridge). However, these results agree with those from the Hudson River estuary, where invertebrate density decreased under piers even though total abundance increased (J. Duffy-Anderson, NMFS, pers. comm.). In this way, OWS may be similar to other disturbed habitats, which often have high densities of a few organisms that can withstand the disturbance. Compared to Bainbridge, the total assemblage close to Clinton and Southworth terminals remained relatively well distributed among those taxa found away from them, with the few exceptions covered in the Results section. These smaller differences in the epibenthos matched the relatively smaller differences observed the physical and biotic environment.

Because clear, highly statistically significant differences in both the density and composition of the epibenthos were found among the eelgrass patches at Clinton, H_{02} was rejected. Moreover, most significant differences indicated negative impacts of these OWS on the epibenthos. There were a few cases in which patch effects unrelated to terminal proximity were significant. The substrate in the middle patch was coarse, gravel and cobble with eelgrass, compared to the sand and fine sand close to and farthest away from the terminal. The middle patch was also at a slightly higher tidal elevation. These physical differences may explain the cases when certain taxa within the epibenthos from the patches closest and farthest from the terminal were grouped and less dense than the middle patch.

The eelgrass results suggest that it is important to assess habitat function, not just presence, absence, or condition (e.g., blade density, canopy height, and patch size). A visual assessment of the area around the Clinton terminal would indicate potential juvenile salmon habitat, such as the 10-m eelgrass patch, within just meters of the terminal margin. This eelgrass withstands the magnitude of the OWS impacts present, including shading and propeller wash. However, the data showed that the epibenthos sampled both directly on and just adjacent to this near-terminal eelgrass were significantly reduced, and that in terms its role as a source of JSP, its function was probably compromised.

High-resolution cross-terminal sampling at Clinton demonstrated some differences in both the density and composition of the epibenthos along the sampling transect, though the differences were not always those predicted prior to the study. H_{03} was tentatively rejected: significant differences do exist the in epibenthic JSP assemblage along a cross-terminal gradient. Whether or not those differences indicate negative impacts of OWS on the epibenthos was less clear. Some less abundant taxa, including *Harpacticus uniremis* group, *Harpacticus spinulosis*, and *Acrenhydrosoma* indicated a negative impact on the epibenthos correlating well with the light and benthic vegetation surveys completed by Blanton et al. (2001). Eight of the 12 taxa considered, including the highly abundant *Tisbe* spp, *Zaus* spp, and *Ectinosomatidae*, had anomalous large densities under the north half of the terminal, but not the south. Because the sampling took place in essentially the same habitat, during the same time in the tide cycle, over two days, there are several possible explanations for these results. The first is changes in the sediment composition along the sampling transect. Blanton et al. (2001) described an abrupt change in substrate at the mid-terminal line from sand dominated to the south to gravel or shell dominated substrate to the north, extending up the terminal edge prior to returning to sandy substrate. This corresponds very well with to the cross-terminal epibenthos results under the terminal decking, though the to the north of the decking it is vegetation rather than sediment that appears to correspond with the epibenthos. A second possible explanation is between-day variability. Sampling on day one went from the center of the terminal to the north, and on day two went to the south. The water was rougher and more turbid on day two, with winds in the area were stronger. However, one would expect to see more of the easily transported organisms (i.e., *Tisbe* spp.) under these conditions, opposite of what the data showed. Finally, the large numbers of organisms found under the terminal may have resulted from organism transport during docking events. These occurred during sampling, but were not recorded and cannot be compared to the peaks of organisms observed.

The limited results from terminal structure sampling indicated that, whether old or new construction, pilings or floats, terminal structures may not be great sources of JSP, or total epibenthos, in any way comparable to those from in non-impacted or impacted intertidal habitats. While there were differences between piling-type and elevation comparisons, and between structure types (floats and pilings) in terms of JSP availability the more interesting comparison was between the terminal and intertidal substrates. For instance, at Clinton, the total JSP on the pilings at the lowest elevation was less than half of that from the intertidal substrate (MLLW) in the Under stratum, and less than a third of that from the Away stratum. The float had JSP densities of about 2% compared the Away stratum. Low densities of epibenthic organisms on the terminal structures made statistical evaluation of these data difficult, particularly at Bainbridge. However, when differences were detected, individual taxa or summary variables were less dense or diverse on older timber pilings than on newer concrete or epoxy-steel pilings. For this reason, H_{04} was rejected: differences appear to exist in the epibenthic assemblage among piling construction types. The consistent finding was overall greater densities and diversity of organisms at lower elevations on the pilings. During sampling, the tide was never below -0.6 m (the lowest elevation sampled), and the epibenthos were not exposed. The pilings at Clinton and Bainbridge both had extensive evidence of sea star feeding, with the lower piling elevations kept relatively clear of everything except small barnacles and small mussels up to about +0.6 m (author pers. obs.). This left little available habitat for epibenthic organisms during tidal exposure. Above +0.6 m, the tidal exposure may be too extreme for many of them.

The float epibenthic assemblage at Clinton was very different from that on either piling-type. While *Tisbe* spp. and *Dactylopusia vulgaris* were dominant on the pilings, they were completely absent from assemblage on the float. Calliopiidae was the dominant taxon on the float and was almost twice as dense there than at –0.6 m and 0 (the two highest densities) on the epoxy-steel pilings. The dominance of Calliopiidae may be in part explained by the large amount of attached macroalgae on the float. *Calliopius pacificus*, the most common *Calliopius* spp. in the region, is strongly associated with submerged plants and algae (Bousefield and Hendrycks 1997). Low epibenthos densities from the float also may have been due to flattening of the macroalgae by the pump system, trapping some organisms between algae rather than sampling them.

Stratified-monthly sampling generated the most robust data-set, particularly in terms of generating similar results at multiple sites and over a period of time. Distributions of many epibenthic organisms, including harpacticoid copepods, are highly variable on a very small scale depending on differences in substrate, elevation, vegetation, and micro-habitat features such as wave ripples (as reviewed by Hicks and Coull 1983, Coull 1988). Stratified-monthly sampling was designed with high replication in order to account for this variability. The other three sample sets had no replication in time and low replication in space. Therefore, they were much more susceptible to variability on a variety of scales, demonstrated by strong differences in individual taxon densities and assemblage features between day one and two of cross-terminal sampling. These results provide a good starting point for additional investigations, particularly in terms of eelgrass or other habitat function near to and farther from the terminal. However, where one-time sampling appears to contradict results from stratified-monthly sampling (e.g., high-resolution cross-terminal results for total epibenthos, JSP, *Tisbe* spp., and *Zaus* spp.), the latter should be considered the more reliable result. Ideally, both the eelgrass and high-gradient cross-terminal sampling could be improved upon (e.g., sampling eelgrass blades as well as epibenthic pumps) and repeated multiple times during the spring.

Ultimately this research implicates large OWS (ferry terminals) induce decreases or changes in epibenthos density, diversity, and assemblage composition probably caused by the following four interacting factors:

1) direct disturbance and/or removal by regular vessel disturbance
2) reduced benthic vegetation or compromised benthic vegetation function due to shading and physical disturbance
3) physical habitat alterations (e.g., altered grain-size distribution from propeller wash or piling effects), and
4) biological habitat alterations (e.g., increased shell hash from sea star foraging and reduced eelgrass density due to benthic macrofauna disturbance).

These factors in interaction provide a good explanation for the observed differences in the epibenthos around ferry terminals. It is clear that at some sites a single factor can completely overwhelm others. At Southworth, where shading was the likely primary impact, there was a reduction in some organisms (e.g., *Harpacticus uniremis* group,) strongly affiliated with benthic macrovegetation, particularly eelgrass. Other organisms that are more strongly associated with shell-gravel (*Amonardia* per Hicks and Coull 1983), and sand (*Harpacticus spinulosis*, J. Cordell, University of Washington, pers. comm.) were present in greatest densities near to or under the structure. A similar positive response to physical conditions may also account for increased densities of Ameiridae under the structure at Clinton. Alternatively, at Bainbridge the intensity of vessel disturbance apparently was so great that few harpacticoids or gammarids could persist.

Perhaps the strongest demonstration of OWS effects is that those epibenthic organisms most closely affiliated with benthic vegetation showed consistently negative large OWS impacts, even when other organisms were less affected. When in an environment where *Harpacticus uniremis* group, *Zaus* spp., and *Tisbe* spp. are all present, juvenile chum salmon have been demonstrated to feed preferentially on the first two, especially *H. uniremis* group, though they are less available than the latter (Sibert 1979, Simenstad et al. 1980, D'amours 1987, Simenstad et al. 1988a, Webb 1991 a,b). As discussed previously, *H. uniremis* and *Zaus* spp. have much stronger affinities to benthic macrovegetation than does *Tisbe* spp.. This is one reason why conserving benthic vegetation (by reducing shading impacts) may be equally important to reducing vessel disturbance for the protection of JSP resources around ferry terminals.

WSDOT ferry terminals make good models for relatively high-decked, fixed large OWS with very high levels of vessel disturbance. Most of the major suspected modes of impact from OWS are present at ferry terminals, and my results confirm impacts of these large OWS on JSP and epibenthos. However, it is difficult to use these results to predict the magnitude of impact from other types of OWS. Compared to many other types of OWS, ferry terminals are wide and have extensive shading potential. But they also have fixed-height decking that allows greater light penetration underneath the terminal footprint than do floating docks. Impacts from relatively high frequency and intense disturbance from ferry docking events is greater than propeller wash or scour associated with residential boat use, though these smaller boats disturb the benthos directly with propeller scarring or boat landings over wider areas. The four listed factors causing impacts on the epibenthos may be particularly damaging in cases such as these where the undisturbed state of the estuarine-nearshore includes some benthic vegetation. The extent and type of impact on the estuarine-nearshore from other types of OWS will likely vary with intensity of those factors. This study demonstrated significant OWS impacts associated with large ferry terminals set in otherwise relatively undisturbed intertidal areas. Additional research to determine the thresholds at which epibenthos becomes affected could include sampling at variety of dock sizes and degrees of vessel disturbance. Information about the mechanisms of OWS impacts would be gained by sampling around pilings without structures, OWS over non-vegetated substrates or in areas of chronic impacts (industrial waterfronts), and before-after-control-impact designs at proposed OWS construction sites.

Thom et al. (1995) recommended a number of measures for the expansion of the Clinton terminal in order to mitigate for eelgrass impacts from construction, the new structure, and continued vessel use. These included (1) a longer, narrower terminal deck, which would decrease intertidal shading and reduce propeller wash by keeping the ferries in deeper water; (2) the use of light passing structures (glass blocks and grating) in the decking to increase photosynthetically active radiation underneath the terminal; (3) newer construction that used fewer, more widely spaced pilings in order to reduce sea star and crab bioturbation. Because factors impacting eelgrass also impact the epibenthos associated with it, these types of mitigation measures also apply for conserving epibenthos at various OWS types. Since the completion of this study, all ferries at Clinton have used a new south slip, incorporating these mitigation recommendations, while the north slip has been undergoing retrofitting. This older north slip, in use during the 2000 field season, was closer to the shoreline. Because construction was already underway at the time of 2000 sampling, re-sampling would not constitute a true before-after control-impact design, but a comparison of my results with a true post-construction sampling design could give some information about the success of the mitigation efforts.

Large overwater structures have serious impacts on the intertidal and shallow subtidal estuarine nearshore, including reduced benthic vegetation and decreased densities of epibenthic juvenile salmon prey organisms. There are only twenty WSDOT ferry terminals, but given the potential for impacts by other types of OWS, the cumulative effects in such densely populated regions such as Puget Sound may be large. To what extent this reduced prey availability may be limiting to juvenile salmon is unknown. Much more information on the carrying capacity of Puget Sound for juvenile salmon, including thresholds at which they may become food-limited, is needed. Additionally, knowledge of minimum patch size or connectivity of eelgrass required for it to function as a prey source is required in order to quantify these impacts. Given the hundreds or thousands of OWS encountered during a fish's outmigration, the potential for cumulative impacts may be great. Extensive impacts such as those occurring at the Bainbridge ferry terminal also illustrate the potential for habitat fragmentation of the estuarine-nearshore juvenile migratory corridor. Effects of this fragmentation on fish condition and survival (reduced refugia and prey, barriers to outmigration) have been considered in several reviews but are not well understood (e.g., Simenstad et al. 1999, Nightingale and Simenstad 2001, Williams and Thom 2001). My results provide strong evidence of the negative effects of ferry terminals on nearshore habitat function, and suggest that further research should be conducted to determine if other types of OWS have similar impacts.

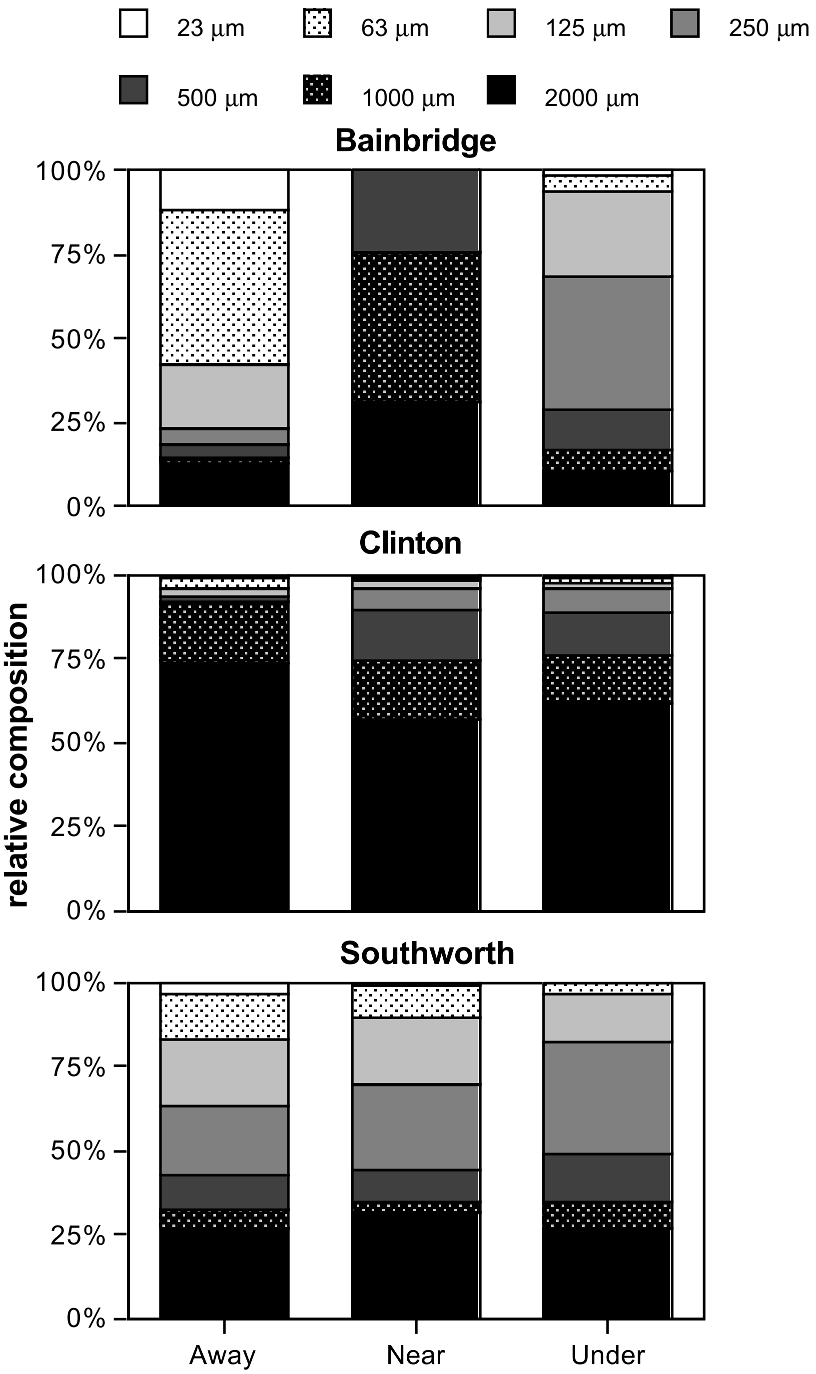

Figure 31. Sediment grain size analysis for the stratified-monthly sampling strata by minimum screen size.

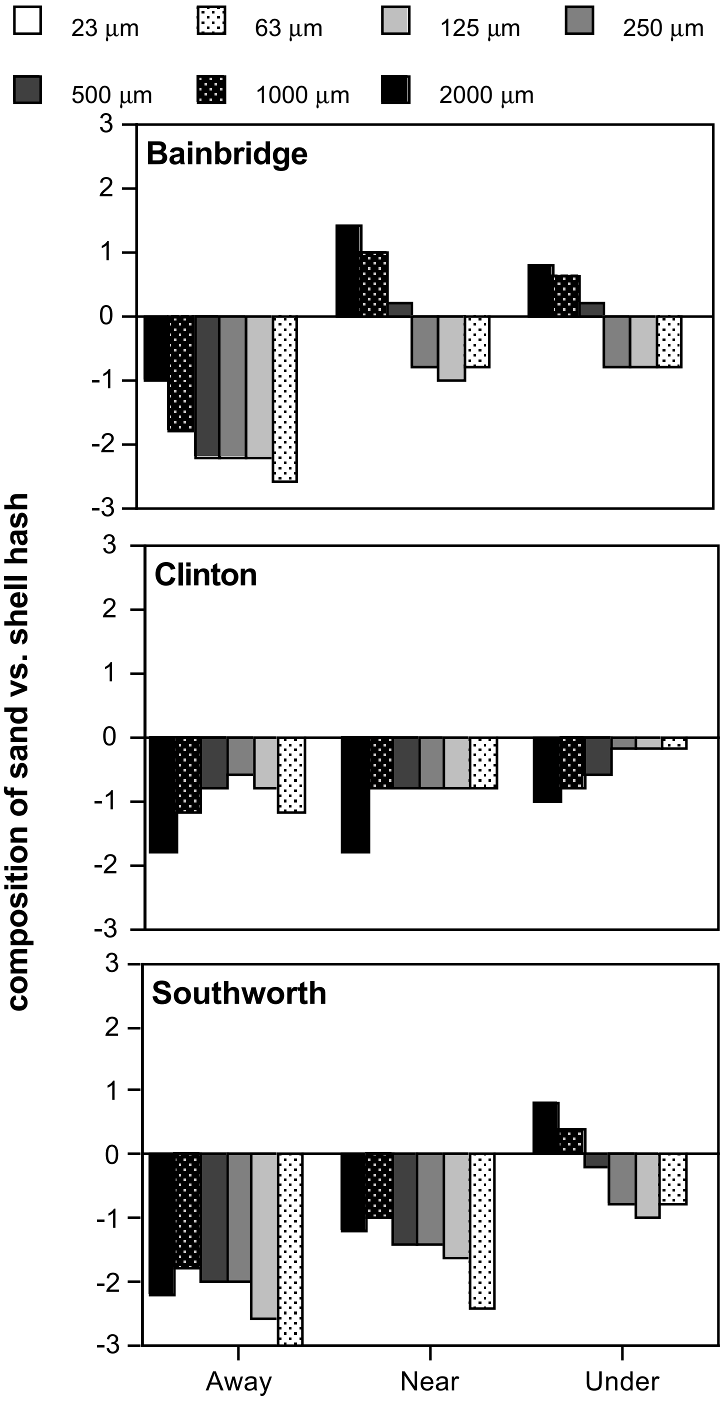

Figure 32. Relative proportion of shell hash in sediment grain size fractions (by minimum screen size) for stratified-monthly sampling strata. Sand dominated values are negative, shell hash dominated values are positive, the zero line represents a 50/50 mix of sand and shell hash

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APPENDIX A. Environmental Conditions

Water temperature and salinity readings for all sampling dates. YSI readings were taken at the beginning of each sampling trip after wading into approximately .5 m deep water 30m north of the terminal edge.

Date	Sampling	Terminal	Time Begin	Time End	Water Temp (C)	Salinity (ppt)
3/10/00	Stratified	Southworth	12:00	14:00	8.7	24.9
3/11/00	Stratified	Clinton	12:20	14:20	8.8	24.9
3/12/00	Stratified	Bainbridge	13:45	16:15	8.5	24.9
4/5/00	Stratified	Bainbridge	10:10		9.6	24.0
4/6/00	Stratified	Southworth	10:20	12:00	8.7	24.9
4/7/00	Stratified	Clinton	10:30		9.5	18.5
5/1/00	Stratified	Southworth	8:10	10:15	9.3	25.2
5/2/00	Stratified	Bainbridge	8:20		10.3	23.2
5/3/00	Stratified, Terminal structure	Clinton	8:45	14:20	9.9	21.0
5/4/00	Terminal structure	Bainbridge	12:00		10.6	23.1
5/29/00	Stratified	Southworth	6:55	9:20	10.6	24.5
5/30/00	Stratified	Bainbridge	7:30		11.7	19.4
5/31/00	Stratified, Cross-terminal (N)	Clinton	7:15		12.4	15.0
6/1/00	Cross-terminal (S)	Clinton	11:30	13:05	13.0	16.4
6/5/00	Eelgrass	Clinton	11:30	13:00		

APPENDIX B. List of Taxa in Study

The following is a list of all taxa recorded during spring 2000 WSDOT epibenthic sampling.

Phylum	Order or Class	Family (Harpacticoids and Gammarid Amphipods only)	Organism Identification	Data Set *
Platyhelminthes			Turbellaria	SM, EG, CT, TS
unknown			unk. worm	SM, EG, CT
Nemertea			Nemertea	SM, EG, CT, TS
Nematoda			Nematoda	EG, CT
Annelida			Polychaeta	SM, EG, CT, TS
			Archiannelida	SM, EG, CT, TS
			Oligochaeta	SM, EG, CT, TS
Mollusca			Gastropoda	SM, EG, CT, TS
			Nudibranchia	SM, EG, CT
Arthropoda	O. Acarina		Halacaridae	SM, EG, CT, TS
	C. Pycnogonida		Pycnogonidae	SM, CT
	O. Harpacticoida		Harpacticoida copepodids	SM, EG, CT
			Harpacticoida misc.	SM, CT
		Tegastidae	Tegastidae	SM
		Porcellidiidae	*Porcellidium* sp.	SM, EG, CT
		Longipediidae	*Longipedia* sp.	SM, EG, CT
		Ectinosomatidae	Ectinosomatidae	SM, EG, CT, TS
		Harpacticidae	*Harpacticus uniremis*	SM, EG, TS
			Harpacticus spinulosus	SM, EG, CT, TS
			Harpacticus septentrionalis	SM, EG, CT, TS
			Harpacticus obscurus	SM, EG, CT, TS
			Harpacticus uniremis grp.	SM, EG, CT, TS
			Harpacticus uniremis grp. copepodids	SM, EG, CT, TS
			Zaus spp.	SM, EG, CT, TS
		Peltidiidae	Peltidiidae	SM, EG, CT, TS
		Tisbidae	*Tisbe* spp.	SM, EG, CT, TS
			Scutellidium sp.	SM, EG, CT, TS
		Tachidiidae	*Microarthridion* spp.	SM, CT
			Tachidius triangularis	SM
			Danielssenia sp.	SM, EG, CT, TS
		Laophontidae	Laophontidae	SM, EG, CT, TS
		Ameiridae	Ameiridae	SM, EG, CT, TS
		Ancorabolidae	Ancorabolidae	SM
		Cletodidae	Cletodidae	SM
			Enhydrosoma sp.	SM
			Huntemannia jadensis	SM, EG, CT
			Acrenhydrosoma sp.	SM, EG, CT, TS
		Diosaccidae	Diosaccidae	SM, EG, CT, TS
			Amonardia perturbata	SM, EG, CT, TS
			Amonardia normani	SM, CT
			Diosaccus spinatus	SM, EG, CT, TS
			Amphiascopsis cinctus	SM, EG, CT, TS
			Amphiascus undosus	EG, CT
			Amphiascus spp.	SM, EG, CT, TS
			Amphiascus sp. A	SM
			Stenhelia spp.	SM, EG, CT

Phylum	Order or Class	Family (Harpacticoids and Gammarid Amphipods only)	Organism Identification	Data Set *
			Tymphlamphiascus sp.	SM, EG, TS
			Amphiascoides sp.	SM
			Amphiascoides sp. A	SM, EG, CT, TS
			Bulbamphiascus sp.	SM
			Robertsonia sp.	SM, EG, CT, TS
			Paramphiascella sp.	SM
		Canthocamptidae	*Orthopsyllus* sp.	SM, CT, TS
			Leimia vaga	SM
			Mesochra pygmaea	SM, EG, CT, TS
		Thalestridae	Thalestridae copepodids	SM, EG, CT, TS
			Dactlyopusia spp.	SM, EG
			Dactylopusia vulgaris	SM, EG, CT, TS
			Dactylopusia crassipes	SM, EG, CT, TS
			Paradactylopodia spp.	SM, EG, CT, TS
			Parathalestris californica	SM, EG, CT, TS
			Parathalestris sp. A	SM
			Diarthrodes spp.	SM, EG, CT, TS
			Thalestris sp.	SM
			Rhyncothalestris helgolandica	SM
			Idomene purpurocincta	SM
		Parastenhelidae	*Parastenhelia spinosa*	TS
	O. Cyclopoidea		Cyclopinidae	SM, CT, TS
	O. Leptostraca		*Nebalia* sp.	SM, EG
	O. Mysidacea		Mysidacea	SM
			Archaeomysis grebnitzkii	SM
	O. Cumacea		*Lamprops quadriplicata*	SM, EG, CT, TS
			Diastylopsis sp.	SM
			Diastylis santamariensis	SM, CT
			Cumella vulgaris	SM, EG, CT, TS
	O. Tanaidacea		*Leptochelia dubia*	SM, EG, CT
	O. Isopoda		*Gnorimosphaeroma oregonense*	SM, TS
			Exosphaeroma sp.	SM
			Idotea sp.	EG, CT
			Synidotea sp.	SM
			Ianiropsis tridens	SM
			Ianiropsis kincaidi	SM
			Munna ubiquita	SM, EG, CT, TS
			Exocirolana vancouverensis	SM
			Epicaridea	SM, EG, CT, TS
	O. Amphipoda			
	Sub. O. Gammaridea		Gammaridea	SM, EG, CT, TS
		Ampeliscidae	*Ampelisca* sp.	SM
		Amphithodae	*Ampithoe* sp.	SM
		Aoroidae	*Aoroides* spp.	SM, EG, CT
		Calliopiidae	Calliopiidae	SM, EG, CT, TS
			Paracalliopiella pratti	SM, EG, CT, TS

Phylum	Order or Class	Family (Harpacticoids and Gammarid Amphipods only)	Organism Identification	Data Set *
			Calliopius sp.	SM, EG, CT, TS
		Corophiidae	*Corophium* spp.	SM, EG, CT, TS
		Dexaminidae	*Guernea reduncans*	SM
		Pontogeneidae	*Pontogeneia intermedia*	SM
			Pontogeneia rostrata	SM, EG, CT, TS
		Anisogammaridae	Anisogammaridae	SM, EG, CT, TS
			Anisogammarus pugettensis	SM, EG, CT, TS
			Eogammarus confervicolus	SM
		Melitidae	Melitadae	SM
			Desdimelita sp.	SM
		Hyalidae	Hyalidae	SM
			Allorchestes angusta grp.	SM, EG, CT, TS
		Isaeidae	*Photis* sp.	SM, EG, CT, TS
			Protomedeia sp.	SM
			Gammaropsis sp.	SM
		Ischyroceridae	*Ischyrocerus* spp.	SM, EG, CT, TS
			Microjassa sp.	TS
			Jassa sp.	TS
		Lysianassidae	Lysianassidae	SM
		Oedicerotidae	*Westwoodilla caecula*	SM, CT
			Americhelidium sp.	SM, CT
		Phoxocephalidae	Phoxocephalidae	SM, EG, CT
		Pleustidae	Pleustidae	SM, EG, CT, TS
		Podoceridae	Podoceridae	SM
		Stenothoidae	Stenothoidae	SM
	Sub. O. Caprellidea		Caprella	SM, EG, CT, TS
	O. Decapoda		Caridea	SM, EG, CT, TS
			Anomura	SM, EG, CT
			Brachyura juvenile	SM, CT
			Brachyura megalopae	SM
	C. Insecta		Collembola	SM, EG, CT
			Coleoptera larvae	SM
			Diptera larvae	SM
			Chironomidae	SM, EG, CT, TS
Echinodermata			Asteroidea	SM
			Ophiuroidea	SM
			Echinoidea	SM, EG

* SM, stratified-monthly; EG, eelgrass patch; CT, high-gradient cross-terminal; TS,terminal structure

APPENDIX C. Summary Statistics for Stratified-Monthly Sampling

Summary statistics for all summary variable,s, JSP (bold), and abundant or common non-JSP taxa; n = 15 for all. Strata designations: A, Away; N, Near; U, Under.

			Bainbridge		Clinton		Southworth	
Organism	Month	strata	Average	St. Dev.	Average	St. Dev.	Average	St. Dev.
Total epibenthos	March	A	22196	25154	22719	5667	9156	5190
		N	663	831	2130	2236	20622	17904
		U	1622	1483	7189	6904	6359	4820
	April	A	146785	69769	57011	16358	81493	24087
		N	1319	1578	17289	4587	68163	35047
		U	2289	1371	13044	4075	35863	12282
	May (Early)	A	79956	37007	26367	5489	103785	35597
		N	7056	3918	8722	5725	120063	47122
		U	8215	3636	22819	8666	61963	49377
	May (Late)	A	135644	40214	162244	64574	142367	74207
		N	12981	8637	43996	13687	126348	63613
		U	16041	4898	53722	20846	70515	38505
Taxa Richness	March	A	26	10	22	4	23	7
		N	6	3	11	4	15	6
		U	7	4	13	5	10	4
	April	A	39	4	21	2	31	3
		N	9	6	22	4	21	6
		U	9	4	19	2	18	3
	May (Early)	A	22	5	22	3	29	4
		N	14	5	17	4	30	4
		U	12	4	21	4	23	4
	May (Late)	A	27	4	25	3	35	7
		N	22	7	34	2	35	5
		U	20	4	23	3	28	4
JSP	March	A	5307	5410	19507	4898	4967	2962
		N	74	75	1167	895	15189	12085
		U	137	216	4559	4448	4633	3259
	April	A	54900	29929	47370	14589	58252	22423
		N	244	267	11141	3010	50585	29641
		U	230	169	5078	1356	30426	10824
	May (Early)	A	8689	4406	18989	4672	79159	28374
		N	4063	2791	4589	2734	61952	25007
		U	4067	2319	14304	5878	46867	35233
	May (Late)	A	35422	11733	142563	62525	62548	36469
		N	3159	3221	30193	11422	52170	42072
		U	3589	2255	43237	18079	49033	29612
Harpacticus uniremis **grp.**	March	A	604	545	122	90	0	0
		N	15	33	0	0	11	31
		U	0	0	0	0	0	0
	April	A	42270	27012	689	388	30	41
		N	11	23	26	41	15	25
		U	15	25	19	34	30	59
	May (Early)	A	600	481	104	103	304	284
		N	26	46	22	28	196	335
		U	15	44	93	142	119	157
	May (Late)	A	752	608	3285	1873	419	559
		N	37	40	415	254	159	162
		U	26	41	22	62	285	221

			Bainbridge		Clinton		Southworth	
Organism	Month	strata	Average	St. Dev.	Average	St. Dev.	Average	St. Dev.
***Zaus* spp.**	March	A	15	57	1567	787	1311	1570
		N	4	14	70	102	19	40
		U	0	0	189	297	63	75
	April	A	430	585	17341	5895	5248	1985
		N	26	59	1641	769	500	657
		U	4	14	837	340	263	261
	May (Early)	A	204	374	1000	461	18381	12097
		N	4	14	359	197	2430	2563
		U	15	25	3211	1781	241	297
	May (Late)	A	5359	2684	30004	14033	12400	10719
		N	7	20	10752	5149	3426	3990
		U	26	46	14533	4828	963	1480
Dactlyopusia vulgaris	March	A	341	529	1396	1118	896	648
		N	0	0	70	77	481	521
		U	0	0	222	157	74	78
	April	A	696	501	1207	586	2267	1350
		N	11	31	30	41	3304	1854
		U	11	23	63	46	2774	1329
	May (Early)	A	11	43	59	90	3022	2209
		N	33	59	30	41	6944	4765
		U	48	98	181	184	7359	9077
	May (Late)	A	89	202	3656	1652	5507	4152
		N	104	96	748	387	6481	5209
		U	141	139	407	258	9137	5611
Dactylopusia crassipes	March	A	0	0	104	100	0	0
		N	0	0	0	0	0	0
		U	0	0	0	0	0	0
	April	A	152	261	541	498	22	72
		N	11	31	4	14	4	14
		U	0	0	0	0	19	40
	May (Early)	A	7	20	119	119	11	31
		N	0	0	11	23	4	14
		U	0	0	52	83	0	0
	May (Late)	A	0	0	2489	1337	111	295
		N	15	33	459	306	4	14
		U	4	14	22	62	37	88
Cumella vulgaris	March	A	956	1070	293	207	74	62
		N	7	20	52	65	41	102
		U	4	14	30	51	41	44
	April	A	2019	1364	311	446	181	142
		N	63	78	352	179	181	219
		U	7	20	78	75	44	43
	May (Early)	A	1437	868	96	57	341	346
		N	59	61	133	111	759	545
		U	19	27	204	177	148	171
	May (Late)	A	3000	1831	456	417	611	525
		N	363	514	1322	569	1396	869
		U	52	77	156	113	41	65

			Bainbridge		Clinton		Southworth	
Organism	Month	strata	Average	St. Dev.	Average	St. Dev.	Average	St. Dev.
Calliopiidae	March	A	104	260	926	371	644	501
		N	11	23	19	27	148	151
		U	0	0	15	33	59	74
	April	A	604	794	437	397	9170	6918
		N	7	20	1233	578	930	1023
		U	4	14	59	61	44	85
	May (Early)	A	41	65	356	245	2670	1094
		N	26	75	870	466	2967	1585
		U	41	102	270	142	704	411
	May (Late)	A	59	44	2593	1883	2430	1775
		N	11	43	722	509	6852	5632
		U	4	14	152	104	1730	2503
Pontogeneia rostrata	March	A	315	470	4	14	652	646
		N	4	14	11	31	78	148
		U	0	0	0	0	100	136
	April	A	1737	2513	0	0	4878	2531
		N	4	14	4	14	826	646
		U	0	0	7	29	352	285
	May (Early)	A	52	85	0	0	1878	976
		N	11	31	4	14	4867	2823
		U	0	0	11	43	3833	2636
	May (Late)	A	178	133	0	0	1319	1069
		N	56	79	7	20	4678	3638
		U	4	14	0	0	4830	4355
Anisogammaridae	March	A	0	0	3644	968	0	0
		N	0	0	89	69	0	0
		U	0	0	237	560	0	0
	April	A	0	0	12074	8936	0	0
		N	0	0	1359	561	4	14
		U	0	0	607	274	0	0
	May (Early)	A	4	14	8748	2870	0	0
		N	0	0	1159	706	0	0
		U	0	0	3044	1542	0	0
	May (Late)	A	0	0	67133	40434	30	115
		N	0	0	7663	3342	11	31
		U	0	0	5363	3258	0	0
***Aoroides* spp.**	March	A	30	69	7	20	89	228
		N	0	0	4	14	4	14
		U	0	0	0	0	0	0
	April	A	559	682	15	57	130	396
		N	0	0	4	14	0	0
		U	0	0	0	0	4	14
	May (Early)	A	0	0	0	0	189	373
		N	7	29	0	0	130	217
		U	0	0	4	14	96	149
	May (Late)	A	11	23	30	115	115	156
		N	11	23	26	46	411	614
		U	0	0	33	66	141	177

			Bainbridge		Clinton		Southworth	
Organism	Month	strata	Average	St. Dev.	Average	St. Dev.	Average	St. Dev.
***Corophium* spp.**	March	A	11	43	0	0	0	0
		N	0	0	0	0	0	0
		U	0	0	7	29	0	0
	April	A	59	90	0	0	0	0
		N	0	0	0	0	0	0
		U	0	0	0	0	0	0
	May (Early)	A	30	51	0	0	0	0
		N	7	20	11	23	4	14
		U	0	0	19	34	4	14
	May (Late)	A	44	67	37	143	0	0
		N	63	86	59	68	33	55
		U	15	25	41	71	0	0
Pontogeneia intermedia	March	A	0	0	0	0	4	14
		N	0	0	0	0	0	0
		U	0	0	0	0	0	0
	April	A	0	0	0	0	0	0
		N	0	0	0	0	0	0
		U	0	0	0	0	0	0
	May (Early)	A	0	0	0	0	0	0
		N	4	14	0	0	4	14
		U	0	0	0	0	0	0
	May (Late)	A	0	0	15	57	7	29
		N	0	0	0	0	7	20
		U	0	0	0	0	52	90
Allorchestes angusta	March	A	0	0	37	34	0	0
		N	0	0	0	0	0	0
		U	0	0	0	0	0	0
	April	A	0	0	363	337	0	0
		N	0	0	11	23	0	0
		U	0	0	11	31	0	0
	May (Early)	A	7	20	130	124	4	14
		N	0	0	22	28	0	0
		U	0	0	100	105	0	0
	May (Late)	A	96	116	3300	1896	0	0
		N	0	0	100	79	11	23
		U	0	0	100	224	0	0
***Photis* spp.**	March	A	56	105	0	0	7	20
		N	0	0	0	0	4	14
		U	0	0	0	0	4	14
	April	A	1604	1570	30	115	122	311
		N	0	0	4	14	30	100
		U	4	14	0	0	0	0
	May (Early)	A	70	135	11	31	70	114
		N	0	0	0	0	230	314
		U	0	0	0	0	81	127
	May (Late)	A	56	141	74	161	222	325
		N	22	46	48	51	1241	1046
		U	15	25	52	71	100	128

			Bainbridge		Clinton		Southworth	
Organism	Month	strata	Average	St. Dev.	Average	St. Dev.	Average	St. Dev.
***Gammaropsis* sp.**	March	A	0	0	0	0	74	159
		N	0	0	0	0	7	20
		U	0	0	0	0	4	14
	April	A	226	264	0	0	189	192
		N	4	14	0	0	52	74
		U	0	0	0	0	26	36
	May (Early)	A	0	0	0	0	111	81
		N	4	14	0	0	915	774
		U	4	14	0	0	322	272
	May (Late)	A	0	0	0	0	22	41
		N	0	0	0	0	333	248
		U	0	0	0	0	52	102
***Ischyrocerus* spp.**	March	A	4	14	0	0	0	0
		N	0	0	0	0	4	14
		U	0	0	0	0	0	0
	April	A	4	14	0	0	11	31
		N	0	0	0	0	7	20
		U	0	0	0	0	0	0
	May (Early)	A	0	0	0	0	0	0
		N	0	0	0	0	0	0
		U	0	0	0	0	4	14
	May (Late)	A	0	0	0	0	15	39
		N	0	0	0	0	0	0
		U	0	0	0	0	11	23
Chironomidae	March	A	0	0	0	0	0	0
		N	0	0	0	0	0	0
		U	0	0	4	14	0	0
	April	A	0	0	0	0	0	0
		N	0	0	0	0	0	0
		U	4	14	4	14	0	0
	May (Early)	A	0	0	4	14	0	0
		N	0	0	4	14	0	0
		U	0	0	7	29	4	14
	May (Late)	A	0	0	15	57	0	0
		N	4	14	15	25	0	0
		U	0	0	26	59	0	0
Ectinosomatidae	March	A	5722	8638	689	380	915	568
		N	78	124	148	235	967	1077
		U	93	114	467	397	522	963
	April	A	30011	18461	2289	1074	6770	2834
		N	115	219	256	242	4848	4815
		U	30	46	348	181	1044	891
	May (Early)	A	20041	10652	333	206	5233	4990
		N	122	123	78	69	15233	6521
		U	144	137	552	419	3544	3752
	May (Late)	A	18052	6154	2393	1654	19056	12610
		N	167	101	763	384	22263	12207
		U	189	127	1752	1195	2885	1568

			Bainbridge		Clinton		Southworth	
Organism	Month	strata	Average	St. Dev.	Average	St. Dev.	Average	St. Dev.
Harpacticus spinulosis	March	A	522	416	163	350	70	155
		N	22	35	44	52	2256	3504
		U	4	14	11	23	48	78
	April	A	2707	2687	200	273	322	491
		N	41	53	52	61	5411	6496
		U	26	41	30	46	156	192
	May (Early)	A	25493	12330	107	123	96	294
		N	559	360	30	29	26741	26643
		U	356	233	11	31	207	380
	May (Late)	A	61152	30130	333	614	207	398
		N	2422	3336	1359	660	24752	23098
		U	174	131	267	375	307	908
Scutellidium sp.	March	A	81	134	33	59	700	919
		N	37	50	0	0	370	847
		U	7	20	4	14	611	548
	April	A	48	89	0	0	1800	970
		N	0	0	0	0	181	232
		U	7	20	7	20	337	273
	May (Early)	A	0	0	0	0	2033	2300
		N	0	0	0	0	11	31
		U	4	14	0	0	130	274
	May (Late)	A	0	0	0	0	4670	3358
		N	0	0	0	0	426	553
		U	0	0	26	86	130	200
Laophontidae	March	A	815	707	48	63	348	294
		N	7	20	26	46	44	76
		U	7	29	56	76	37	58
	April	A	9822	6381	193	250	2763	1462
		N	11	23	293	407	663	894
		U	7	20	59	61	126	116
	May (Early)	A	2800	1763	81	75	3815	1629
		N	26	41	44	52	1519	1398
		U	37	58	267	186	696	621
	May (Late)	A	3400	1597	1137	810	12211	8030
		N	89	145	559	302	5881	3874
		U	63	66	552	386	1978	1927
Ameiridae	March	A	344	903	267	220	52	90
		N	4	14	130	337	59	127
		U	100	203	259	203	56	200
	April	A	1030	1099	593	529	211	482
		N	11	23	430	792	393	612
		U	22	41	1230	1445	237	230
	May (Early)	A	56	115	411	336	407	391
		N	22	46	200	236	1000	1192
		U	22	35	785	644	544	472
	May (Late)	A	0	0	722	491	959	787
		N	19	34	556	275	1607	2348
		U	37	65	1552	1148	441	553

			Bainbridge		Clinton		Southworth	
Organism	Month	strata	Average	St. Dev.	Average	St. Dev.	Average	St. Dev.
Amphiascoides sp.	March	A	2741	3701	74	72	30	59
		N	4	14	15	25	156	223
		U	15	25	107	120	11	31
	April	A	4956	3942	1674	1095	81	120
		N	26	51	93	78	270	317
		U	4	14	326	266	96	93
	May (Early)	A	2433	1705	137	122	59	155
		N	52	71	11	23	326	453
		U	63	81	241	262	48	124
	May (Late)	A	3263	1944	833	645	152	311
		N	85	94	215	191	315	444
		U	41	25	444	289	133	206
Amonardia perturbata	March	A	115	165	11	31	67	97
		N	4	14	0	0	278	502
		U	0	0	0	0	52	88
	April	A	1841	1200	0	0	763	519
		N	0	0	0	0	2874	1922
		U	0	0	0	0	2393	1477
	May (Early)	A	63	154	0	0	248	271
		N	52	49	0	0	3874	3169
		U	26	41	0	0	4193	5449
	May (Late)	A	219	283	44	92	3252	3302
		N	144	131	26	51	3870	3463
		U	30	55	26	69	4019	1936
Robertsonia sp.	March	A	770	1002	7	20	7	20
		N	0	0	4	14	7	29
		U	0	0	0	0	7	20
	April	A	17363	7752	0	0	170	259
		N	0	0	0	0	56	131
		U	0	0	0	0	0	0
	May (Early)	A	2237	1617	7	20	0	0
		N	0	0	0	0	119	237
		U	0	0	15	57	37	143
	May (Late)	A	1967	2255	37	143	78	206
		N	30	55	63	100	511	588
		U	26	41	15	57	74	287
Orthopsyllus sp.	March	A	41	80	4	14	615	738
		N	0	0	0	0	0	0
		U	0	0	0	0	0	0
	April	A	211	350	0	0	1763	1458
		N	0	0	67	128	0	0
		U	0	0	0	0	0	0
	May (Early)	A	26	72	4	14	1933	1646
		N	0	0	0	0	89	192
		U	0	0	7	29	0	0
	May (Late)	A	78	195	37	143	4063	3271
		N	7	20	52	61	133	267
		U	11	23	59	178	26	63

			Bainbridge		Clinton		Southworth	
Organism	Month	strata	Average	St. Dev.	Average	St. Dev.	Average	St. Dev.
Thalestridae copepodids	March	A	89	228	270	236	341	223
		N	7	20	11	23	393	878
		U	4	14	44	67	37	72
	April	A	1919	1483	830	493	1359	1010
		N	4	14	33	28	837	679
		U	11	23	15	25	152	152
	May (Early)	A	37	143	56	66	1111	812
		N	7	20	30	59	3148	2645
		U	4	14	48	89	2530	2687
	May (Late)	A	426	524	1070	997	2856	2766
		N	56	79	674	457	1630	1225
		U	37	50	363	435	1067	982
Cyclopinidae	March	A	233	291	126	95	15	25
		N	126	118	85	103	52	71
		U	200	219	278	298	137	455
	April	A	274	403	0	0	0	0
		N	237	246	0	0	4	14
		U	285	248	0	0	7	29
	May (Early)	A	100	168	15	39	19	72
		N	844	519	7	29	119	309
		U	1785	889	111	151	96	132
	May (Late)	A	115	229	830	657	1070	1104
		N	233	199	167	164	81	216
		U	1511	1103	411	614	63	124
Polychaeta	March	A	159	203	256	185	174	182
		N	56	87	159	209	119	183
		U	589	695	237	276	67	113
	April	A	1526	716	1185	911	1422	986
		N	219	232	1019	789	393	347
		U	726	601	763	322	122	180
	May (Early)	A	2256	1362	256	278	689	415
		N	474	361	1481	2179	733	573
		U	541	418	537	420	393	316
	May (Late)	A	3452	1354	1274	877	4167	2521
		N	3526	2200	1374	737	4344	2269
		U	6815	2058	793	446	4459	2165
Oligochaeta	March	A	1419	2196	30	46	4	14
		N	44	119	30	75	15	57
		U	281	405	11	43	0	0
	April	A	3230	1823	7	29	641	703
		N	48	107	767	977	52	123
		U	719	733	67	70	4	14
	May (Early)	A	2359	1302	41	71	256	293
		N	411	403	463	481	107	140
		U	889	597	1741	2087	78	109
	May (Late)	A	2030	777	74	155	1374	2128
		N	1437	1039	1067	693	200	225
		U	2581	929	507	1112	63	81

			Bainbridge		Clinton		Southworth	
Organism	Month	strata	Average	St. Dev.	Average	St. Dev.	Average	St. Dev.
Turbellaria	March	A	730	1241	152	424	7	29
		N	37	143	59	104	33	66
		U	11	31	119	134	7	20
	April	A	48	172	667	394	4	14
		N	30	55	1185	743	0	0
		U	11	31	2837	1528	37	58
	May (Early)	A	10115	6036	2611	2118	0	0
		N	67	52	652	579	111	230
		U	30	46	1722	1085	126	221
	May (Late)	A	1985	1778	7348	2780	96	200
		N	307	218	2085	1070	281	356
		U	85	94	1715	2168	126	216
Nemertea	March	A	0	0	70	145	7	20
		N	0	0	0	0	0	0
		U	4	14	41	106	11	23
	April	A	4	14	578	692	544	782
		N	181	461	619	406	11	43
		U	41	80	1248	752	122	178
	May (Early)	A	44	143	1896	1199	37	58
		N	156	438	126	161	4	14
		U	26	46	644	691	4	14
	May (Late)	A	33	69	1285	3386	352	420
		N	504	291	1489	953	230	398
		U	256	195	556	896	511	554