

An Assessment of Potential Impacts Of Mussel Raft Culture to Surrounding Waters and Associated Biota of Totten Inlet

October 2004



Prepared for:

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Shelton, Washington 98584**

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Executive Summary

Taylor Resources, Inc. is considering the placement of a floating mussel raft facility on the northeastern portion Totten Inlet, approximately 1,000 m north of Gallagher Cove. This facility would feature mussels attached to grow-out lines that are suspended from approximately 50 to 58 rafts placed in water depths of -15 to -70 ft. MLLW. As part of the permitting process, Thurston County has asked Taylor Resources to conduct an environmental assessment to determine the nature of any affects the rafts may have on the surrounding environment. Because mussels feed on seston in the water column and release waste products back into the water column, they may alter ambient nutrients and plankton populations. However, the nature and extent of these changes and potential impacts on Totten Inlet resources has not been fully addressed. The goal of this technical report is to define possible effects of the proposed mussel raft on water-column organisms in Totten Inlet, within the requirements of an environmental impact statement.

Evaluation of the mussel raft effects from Totten Inlet was divided into three regions of potential impact: near-field, mid-field, and far-field. Near-field includes those areas where the physical processes of water passage through and around the mussel raft array occur, including the mixing and entrainment of water underneath and to either side of the array. The mid-field is defined by extent of tidal excursion and the resulting horizontal transport from the rafts. The far-field represents the overall effects occurring throughout Totten Inlet as a result of the removal of carbon and nitrogen by the mussel raft complex.

In the near-field, the bounds of turbulent mixing were based on models and field experiments at mussel rafts in Totten Inlet. The near-field area was considered to be 46 m down current from the end of the rafts and 5.5 to 7.1 m to either side of the rafts. Sampling at the Deepwater Point-Totten Inlet raft system showed significant removal of phytoplankton, carbon, and nitrogen from the water column, with average reductions at the raft center of 29%, 68% and 59% of background, respectively. Samples collected 10 ft. downcurrent from the terminal face of the mussel rafts showed less of an effect than anticipated, with phytoplankton abundance, carbon and nitrogen content of 71%, 87%, and 83% of reference. This was primarily due to turbulent mixing and entrainment of water from beside and below the rafts. With typical current speeds of ~27 cm/sec, transport across the near-field area occurs within the first 5 minutes of exposure to the raft environment. There may be some limited additional mixing that occurs within the near-field zone; however, for the purposes of this exercise we have made the assumption that the concentrations of phytoplankton, carbon and nitrogen observed at 10 ft. from the terminal face will be retained throughout the near-field environment.

The mid-field area is based on the additional transport that occurs during a tidal cycle, using spring incoming tides. This distance has been estimated to be approximately 1.59 nm for the travel distance of the major portion of the water mass movement and approximately 3.4 nm for the travel distance of the leading edge of the water that encountered the mussel raft. Processes occurring within the mid-field area include cell divisions of entrained phytoplankton, responses to the regenerating nutrients released by the mussel/fouling community complex, fixation of carbon and nitrogen through photosynthesis, settlement of the more rapidly settling particles (generally pseudofeces from mussels and detrital materials from the fouling community), and regeneration of nutrients from these settled particles. Field samples collected at Deepwater Point showed that there was no significant difference in phytoplankton abundance, chlorophyll a, or nitrogen content between water samples collected 230 ft. down current for the raft terminal face and background concentrations. It is believed that this recovery to background levels is primarily due to advection and entrainment of adjacent water masses that have not passed through the mussel rafts. Further predictions using models based on cell division rates and residence time indicate that phytoplankton populations will return to within 90% of background within the mid-field area. However, the ability to predict changes in highly mixed areas and impacts to associated resources are limited by the available data.

The far-field area is defined as Totten Inlet. Determination of the influence of mussel rafts in the far-field area was based on removal of carbon and nitrogen during harvest. The proposed expansion of mussel culturing in North Totten Inlet will produce approximately 38,600 kg dry body weight (DBW) of mussel tissue on an annual basis (or 52,800 kg DBW at harvest). Conversion rates for the carbon (35 to 45% of DBW) and nitrogen content (7 to 10% of DBW) of mussel mass provide an estimate of 15,440 kg C and 3,281 kg N removed from North Totten Inlet per year. Harvesting of fouling organisms removes an additional 5,096 kg C/yr and 1,083 kg N/yr.

The net removal of carbon and nitrogen is assumed to occur over the average surface area of Totten Inlet, approximately $21 \times 10^6 \text{ m}^2$. The effect of this removal is then estimated based on the assumption that it will be equally lost to all aspects of the Totten Inlet food webs through a reduction of carbon and nitrogen flowing through food webs. Based on an average primary productivity estimate for Totten Inlet of 4.3 g C/m²/d and a surface area of $21 \times 10^6 \text{ m}^2$, the carbon removed by mussel tissues and associated fouling organisms is equivalent to approximately 0.06% of the Totten Inlet water column carbon used in phytoplankton production annually. This does not address the additional transfer of approximately 0.11% of carbon from the water-column to the sediment, some of which would be regenerated. The total loss of potential carbon for primary productivity as a result of the proposed mussel rafts would range from 0.06 to 0.17% for Totten Inlet.

The percentage reduction in standing stock were estimated for key receptor species using a trophic transfer model that incorporates both feeding preferences and transfer efficiencies of 10% to 20% depending upon receptor species. Based on this trophic transfer model, it is clear that the taxa feeding lower on the food chain are most affected by the reduced phytoplankton abundance. The predicted reductions in bivalve standing stock ranged from 0.005% to 0.018%. This would likely be experienced as a reduction of total biomass across an area, rather than a reduction in the number of individuals. Zooplankton standing stock was projected to decrease by 0.016%. Effects of phytoplankton reductions to forage fish, juvenile salmonids, and adult salmonids are substantially less, primarily due to the dilution effect with additional trophic transfer steps. Juvenile salmonids and forage fish are predicted to have standing stock reductions of 0.0016% and 0.0021%, respectively. Fish on the fourth trophic level would be relatively unaffected, with 0.0006 to 0.0008% reductions in standing stock. This model assumes that the system is food limited and that changes in phytoplankton abundance would be directly transferred through the food web. Based on previous predictions of carrying capacity for zooplankton and bivalves, Totten Inlet is at 10% of carrying capacity for bivalves and zooplankton.

Estimates of mussel raft effects to receptors in the vicinity of the North Totten Inlet site were limited due to a lack of site specific data regarding bivalve populations, local currents, and zooplankton populations in Totten Inlet. In addition, all data regarding raft interactions in Totten Inlet were recorded from Deepwater Point site and are assumed to be similar to what might occur at the North Totten Inlet site.

1. Introduction

1.1. Background

Taylor Resources, Inc. currently operates two mussel raft operations in Totten Inlet, located at Deepwater Point and Gallagher Cove, and believes that the bay is well suited for an additional mussel raft operation located in North Totten Inlet. Therefore, Taylor Resources, Inc. is considering the placement of a floating mussel raft facility on the eastern side of North Totten Inlet, approximately 1,000 m north of Gallagher Cove (Figure 1). This facility would feature mussels attached to grow-out lines that are suspended from approximately 50 to 58 rafts that would be placed in water depths of -15 to -70 ft. MLLW. As part of the permitting process, Thurston County has asked Taylor Resources to conduct an environmental assessment to determine the nature of any affects the rafts may have on the surrounding environment. Because mussels feed on seston in the water column and release waste products back into the water column, they may alter ambient nutrients and plankton populations. However, the nature and extent of these changes and potential impacts on Totten Inlet resources has not been fully addressed. The goal of this technical report is to define possible effects of the proposed mussel raft on water-column organisms in Totten Inlet, within the requirements of an environmental impact statement. Existing data sets from literature sources and several unpublished studies were used to evaluate potential impact of the new mussel facility on the physical and chemical characteristics of the surrounding waters, phytoplankton resources, and key fish and invertebrate species of Totten Inlet.

Totten Inlet is one of five embayments in the southern portion of South Puget Sound. It serves as a drainage basin for the Kennedy-Goldsborough watershed, an area dominated by agricultural and residential land use. The inlet is a tidally-influenced, marine embayment classified by the Washington State Department of Ecology as Class AA waters (WDOE 2003a), indicating that it is a water body that “markedly and uniformly exceeds the requirements for all or substantially all uses” (WAC Chapter 173-201A). Totten Inlet, and its inner bays, Inner Totten Inlet and Little Skookum Inlet, are rich in invertebrate and fish resources, with native intertidal and subtidal clams and oysters, Dungeness crab, and four species of salmon. In addition, this area is a highly productive shellfish growing area. It is estimated that Totten-Little Skookum and the neighboring Eld inlets produce approximately 10% of Washington State shellfish (WDFW 2003a) and a large portion of the State’s manila clams.

Totten Inlet

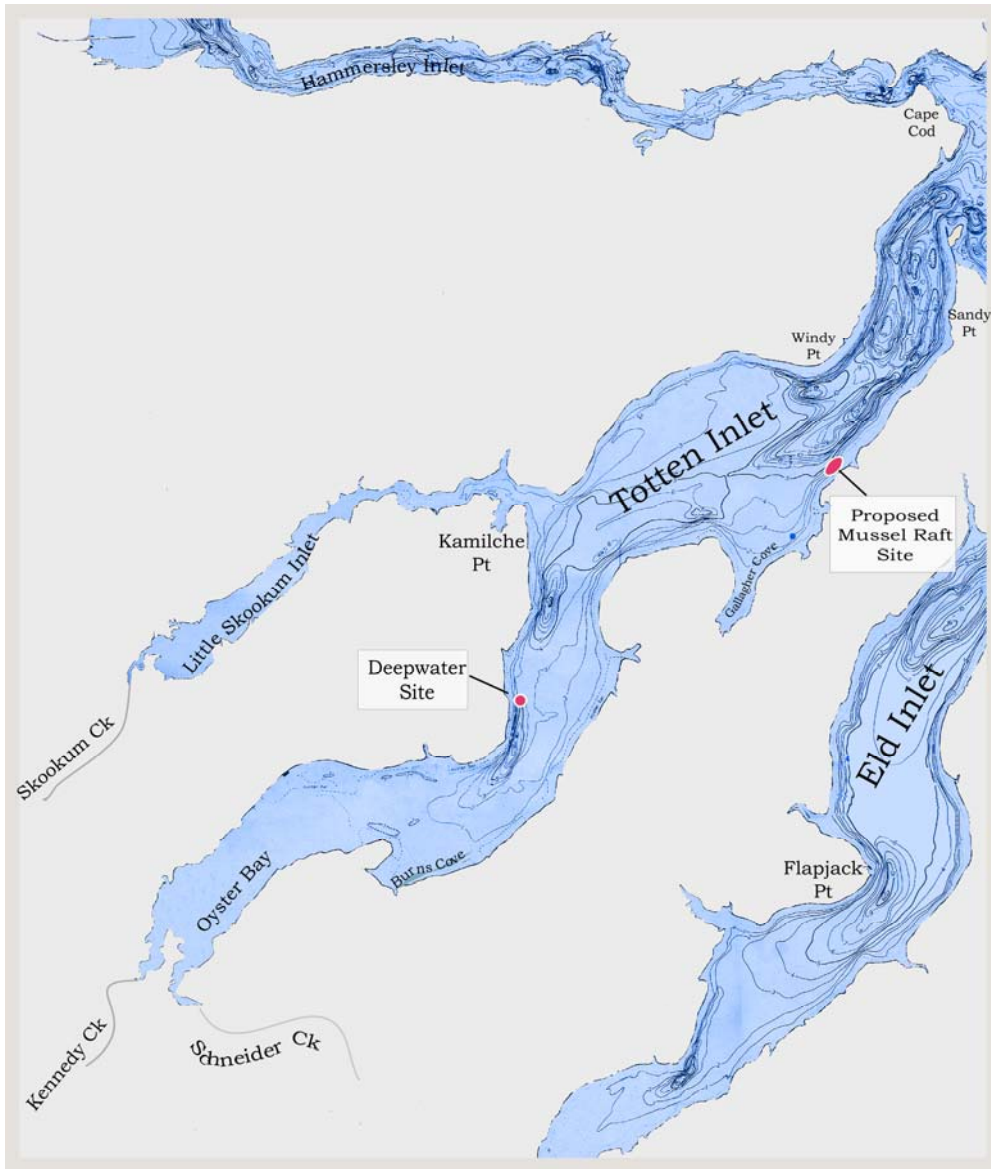


Figure 1. Location of Proposed Mussel Raft Facility in Totten Inlet, Washington.

The objectives of this investigation were to 1) identify key resource species of concern, 2) identify key predator-prey linkages in the biological community for the neritic and shallow sublittoral food webs leading to these key resources, 3) characterize the nature of potential alterations to the water column by mussel rafts, 4) identify those key predator-prey linkages that are likely to be altered by mussel rafts, and 5) determine the nature and extent of these alterations. This report assimilates data currently available in the literature, previous reviews, and unpublished data sets available from the Washington Department of Ecology (WDOE) and Pacific Shellfish Institute (PSI) that assess water-

Objectives

column impacts of existing mussel rafts. Members of Thurston County and the Independent Technical Review Committee have identified salmonids and bivalve shellfish as the key receptors for our current evaluation and thus, these species are the focus of our investigation. However, because a food-web approach was used, many critical biological components of the water column are considered as well.

The following sections of the report describe the physical and chemical setting of Totten Inlet; characterize the target receptors and the key food-web linkages supporting those receptors; and review mussel raft potential impacts to the water column. This information is then used to overlay those impacts on key food-web linkages based on carbon budgets to determine the ultimate impact to our target receptors. The final section presents our conclusions and discusses potential data gaps that remain.

2. Physical Setting and Chemical Characteristics

2.1. Totten Inlet: General Characteristics

Totten Inlet is one of five long, narrow inlets that make up southern South Puget Sound. The embayment is broken into four subbasins, the deeper northern Totten Inlet, a shallower central portion of Totten Inlet, Inner Totten Inlet extending to Oyster Bay, and the very shallow Little Skookum Inlet. The Totten Inlet complex covers a total surface area of 4,184 acres at MLLW, with an intertidal area of approximately 1,965 acres (Brooks 2000). Relative to the deeper bays in Puget Sound, Totten Inlet is a shallow basin, with a mean depth of 8.5 m (28 ft.) and a maximum depth of 35 m (144 ft.). The average depth is skewed by the long shallow inlets in the south. Depths in the main basin, North Totten Inlet, typically range from 9-24 m (30-80 ft.). Totten Inlet is hydraulically connected to Pickering and Squaxin Passages and South Puget Sound at its northern terminus (Figure 2). The inlet entrance is approximately 600 m (1968 ft.) wide and has a sill depth of 14.6 m (48 ft.). The depths in Pickering and Squaxin Passages are also quite shallow, so the sill likely does not dramatically separate these water bodies and vertical mixing is probably limited. The sill at the entrance of Squaxin Passage from Dana Pass is likely to act more like a classic sill impeding some water flow and causing vertical mixing (LOTT 1998).

Totten Inlet is primarily situated in a southwest to northeast direction and is basically divided into a main basin and two distinct inlets, Inner Totten Inlet and Little Skookum Inlet in the south. The main basin is further divided between the deeper northern portion between the mouth and Windy Point (averaging about 18 m deep with a linear distance of approximately 2.2 and width of 0.6 nautical miles) and a shallower southern portion extending from Windy Point south towards the entrances of Skookum Inlet and Inner Totten Inlet (averaging 8 m deep with a linear distance of approximately 1.7 miles and an average width of 1.2 nautical miles). Little Skookum Inlet and Inner Totten Inlet are generally very shallow (<3 m of water depth) and are approximately 3.5 miles in length.

Totten Inlet is part of the Kennedy Creek/Goldborough basin and receives its primary direct freshwater input from the Kennedy Creek, Skookum Creek, and Schneider Creek watersheds (WSCC 2003). The area receives 50 to 70 inches of rainfall annually (WDOE 2002), with much of this input occurring between October and March. Winter

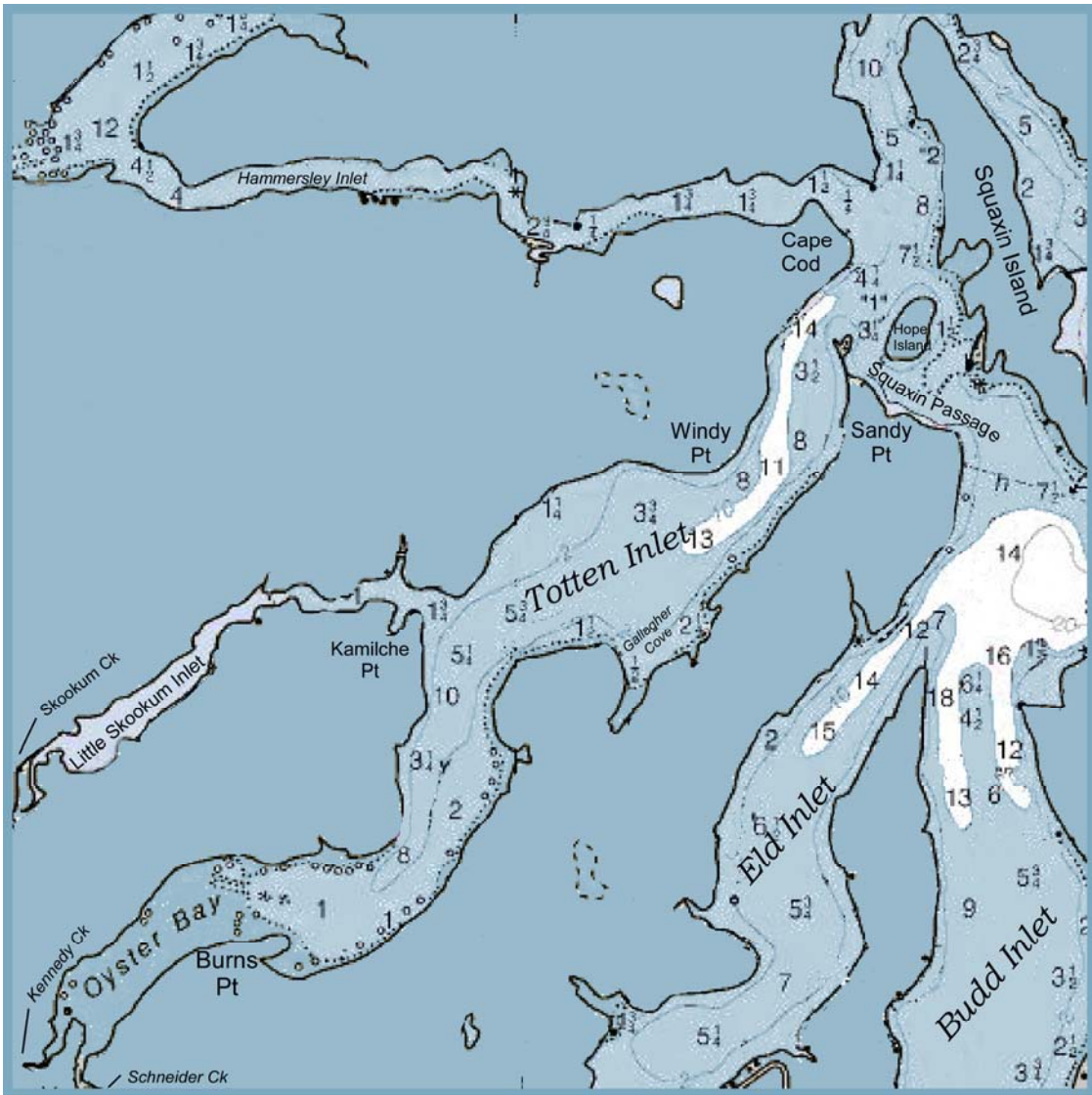


Figure 2. Totten Inlet: Hydraulic Linkages.

flows range from 406 cfs to and are directly associated to seasonal rainfall. Summer low flows at maximum are 18.7 cfs and are maintained primarily by spring-fed lowland streams (Brooks 2002; WSCC 2003). Although episodic winter flows from the three watersheds can exceed 400 cfs, freshwater input from Totten Inlet watersheds does not appear to greatly affect salinity in the main basin.

2.2. Currents and Flushing Rates

Average current speeds at the mouth of Totten Inlet were measured at 90 cm/sec during the flood tide and 50 cm/sec on the ebb (Brooks 2000). Drogue measurements at a depth of 6 m collected from mid-channel between Windy Point and Sandy Point during five days in April 1975 indicate mean current speeds in the central portion of Totten Inlet range between 20 and 36 cm/sec (EDAW 1998). PSI measured current speeds near Deepwater Point for a period of 5.7 days in November 2002 (Cheney et al. unpublished data). The average current speed was 16 cm/sec, with a range of 0 to 42 cm/sec. Current speeds nearshore, at the proposed North Totten site, were collected by current meters at a depth of 12 m above the bottom on September 15, 1997 between a strong flood tide and a strong ebb tide. The time-integrated, mean current speed over the 5.25-hour time period was 18.7 cm/sec and maximum current speed was 32.5 cm/sec. However, this dataset did not include peak flows and likely underestimated current speeds. Therefore, this value was not used for currents at the proposed site.

Based on the limited data collected from North Totten Inlet, an average current was calculated for the proposed mussel raft site. This was estimated using the average maximum current velocity measured at the mouth of Totten Inlet (1.8 knots), the ratio of the maximum current to average speed during the tidal cycle (50%), and the ratio of cross-sectional area at the mouth of Totten Inlet and at the proposed site (59.4%). The average maximum for the mouth of Totten Inlet was calculated from the 20-year maximum (3.0 knots on December 4, 1990; NOAA 2003 Current Tables), the typical Spring maximum (2.6 knots; NOAA 2003 Current Tables), and the minimal neap tidal current (1.0 knots).

$$\text{Mean } V_{\text{site}} = \text{Mean } V_{\text{max}} \times (V_{\text{mean}}/V_{\text{max}}) \times (A_{\text{site}}/A_{\text{mouth}}) \quad \text{Eq 1}$$

Using this formula, the average current speed at the site was calculated at 0.53 knots or 27 cm/sec. This falls between the average and maximum speed observed at the proposed site by EDAW (1998).

Water mass residence time refers to the amount of time it takes for a volume of water within a basin to be replaced with water from outside the system. Residence times or turnover rates are important because they represent the rates at which new food and nutrient resources can be brought into the system and the amount of time to remove dissolved wastes. Residence times in South Puget Sound are complicated by the intricate morphology and bathymetry that results in water recycling, or refluxing. This refluxing

results in longer residence times for a given parcel of water. Residence times have been calculated for Totten Inlet using several measures. EDAW (1998) applied a basic tidal prism model using flushing rates calculated by two different methods (current meter measurements and fresh-saltwater budgets). Brooks (2000) calculated residence time based on a complex tidal prism model that incorporated refluxing. Finally, WDOE (2002) calculated residence times for South Puget Sound based on the South Puget Sound Area Synthesis Model (SPASM), which incorporates mean-flow, rather than tidal prism. Each approach is discussed below.

The simple tidal prism model is based on the tidal volume of a water body (total volume at mean high tide minus volume at MLLW) and the net volume transport into and out of that water body. EDAW used this simple tidal prism model to calculate a residence time of 10 days in Totten Inlet. This was based on a tidal volume of 213,000,000 m³ and a net volume transport of 245 m³/sec. Net volume transport or flushing rate was calculated both by direct current measurement at the entrance of Totten inlet and by water property budgets. The water property budget uses measurements of salinity and river runoff to calculate mass and salt budgets for Totten Inlet. Flushing rates calculated using both methods were quite similar. Brooks (2000) used a more complex tidal prism model based on the PSEP model which was designed for use in Puget Sound and incorporates reflux, that volume of water that leaves the inlet, but that returns on the next flood tide. Using a refluxing rate of 78%, Brooks determined that the time to achieve water renewal was 11 days (Brooks 2000).

The South Puget Sound Area Synthesis Model (SPASM) was developed by WDOE in response to concerns regarding water quality in South Puget Sound. The model is based on the Environmental Fluid Dynamics Code (EFDC; WDOE 2002) and takes into account three-dimensional motion, tidal reflux, and seasonal differences in variable density fluids. Albertson et al. (2001) note that this method has marked advantages over tidal prism models that ignore cancellation effects of following tides, and salt and mass-balance models that rely on direct measurements and therefore have seasonal limitations. In contrast, mean flow calculates the mean difference between MHW and MLLW, thereby incorporating seasonal changes in refluxing due to vertical differences in salinity and temperature. Using a simple tidal prism model, Albertson et al. (2001) calculated residence time in Totten Inlet at 1.2 days. Mean flow residence time was calculated at 4.0 days with a mean flow of 620 m³/sec. This relatively short residence time, compared to other South Puget Sound inlets was likely due to weak stratification present in Totten Inlet. There were no seasonal values given for Totten Inlet. It can be concluded from these approaches, that residence time in Totten inlet may range from 4 to 11 days.

2.3. Temperature, Salinity and Dissolved Oxygen in Totten Inlet

WDOE has been monitoring water quality in Totten Inlet since 1977 as a part of its Marine Water Quality Monitoring Program (WDOE 2003c). Observations of temperature, salinity, density, and dissolved oxygen are available for Windy Point for various months in 1989, 1990, 1992-93, 1996, and 1999. During these years, the temperature ranged between 5.1°C and 19.6°C. Temperature observations in 1999 (Figure 3) exhibited a typical seasonal pattern at Windy Point, where temperatures were the lowest during the winter months and the highest during late summer. There appeared to be little stratification in the water column at Windy Point, with similar temperatures occurring at 0.5 m and 10 m depth. This is perhaps best illustrated in the monthly temperature profiles (Figure 4), indicating that temperatures remained relatively consistent throughout the water column. The three exceptions occurred in June, July and August, however, the difference along the gradient did not exceed 2°C.

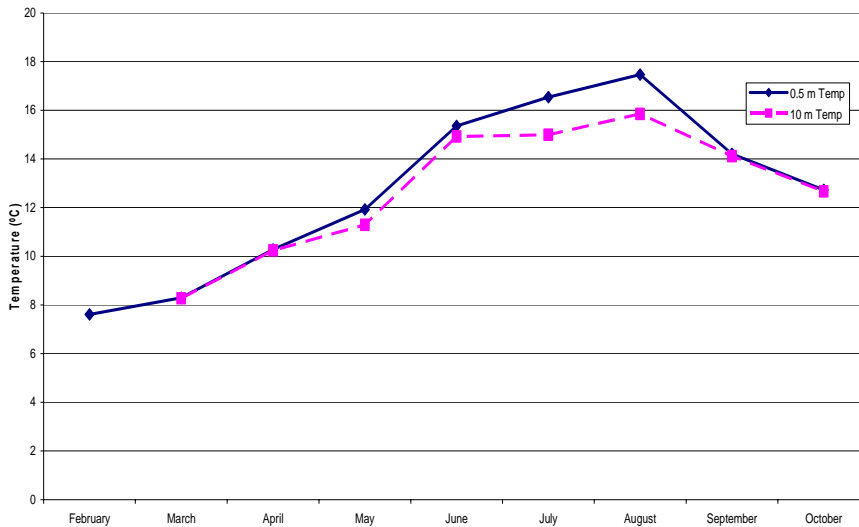


Figure 3. Temperature in
Totten Inlet, 1999.

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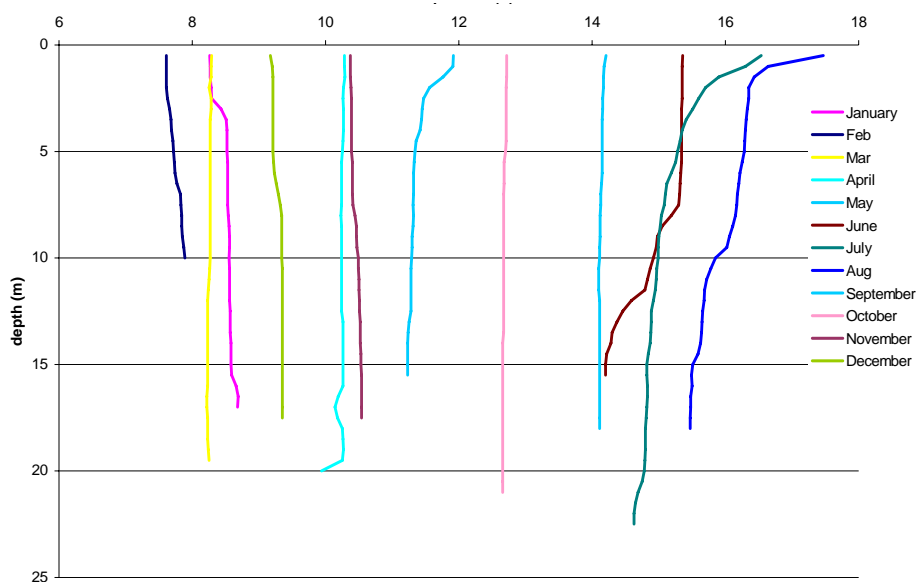


Figure 4. Temperature Profiles from Windy Point, 1999.

Seasonal patterns for salinity in Totten Inlet tended to vary more from year to year than temperature. This is most likely due to changes in freshwater runoff into the Inlet from surrounding watersheds. Salinities between 1989 and 1999 ranged from 22.3 ppt to 29.9 ppt, with the lowest salinities occurring during spring rain events. The general pattern observed in 1999 was fairly typical of salinity ranges at Windy Point (Figure 5), with low salinities during the winter and early spring and increased throughout late spring, summer and early fall (WDOE 2003c). The lowest salinity was measured in the March surface (22.4 ppt), while the highest salinity was measured in October (29.0 ppt).

Surface salinities were generally within 1 ppt of subsurface salinities; however, differences of 2 ppt were observed during extreme wet events, generally in the winter and spring. Trends in water density were similar to those of salinity, with differences between surface and subsurface densities occurring during heavy rain events and generally short in duration. Similarities between the surface and subsurface waters for temperature, salinity, and density support the observations that, unlike many of the inlets in South Puget Sound, Totten Inlet does not tend to stratify due to the inlet's shallow depths, wind and tidal mixing (WDOE 2002; Gordon King, personal communication).

This lack of stratification is reflected in the dissolved oxygen concentrations, which were very similar between the surface and subsurface. Dissolved oxygen (calculated as percentage saturation to correct for temperature) in at Windy Point ranged between from 65% to 155%, with the lowest concentrations occurring in winter and the highest dissolved oxygen concentrations occurring in the surface samples in August. Surface and subsurface measurements were similar throughout most of the year, with the exception of August where there was a difference of 5 mg/L (Figure 6).

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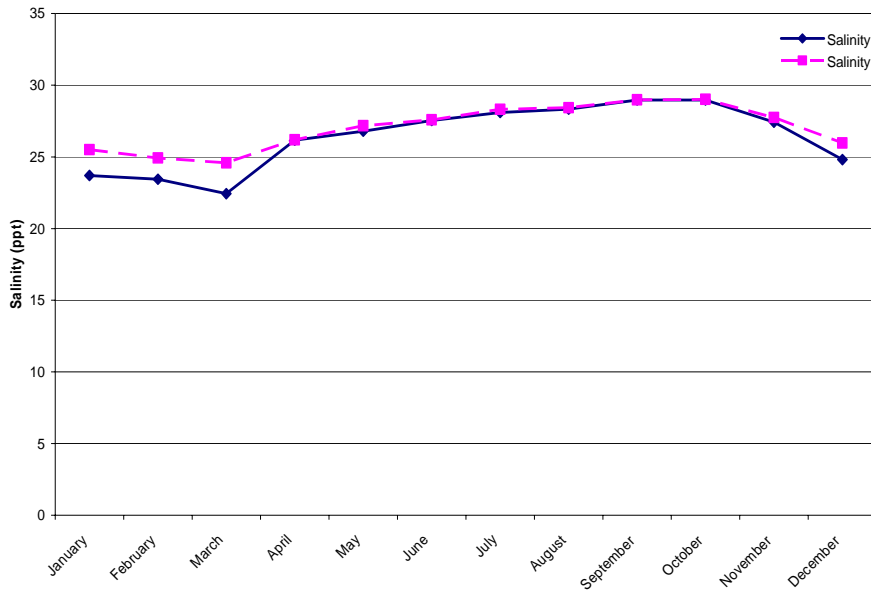


Figure 5. Salinity in Totten Inlet, 1999.

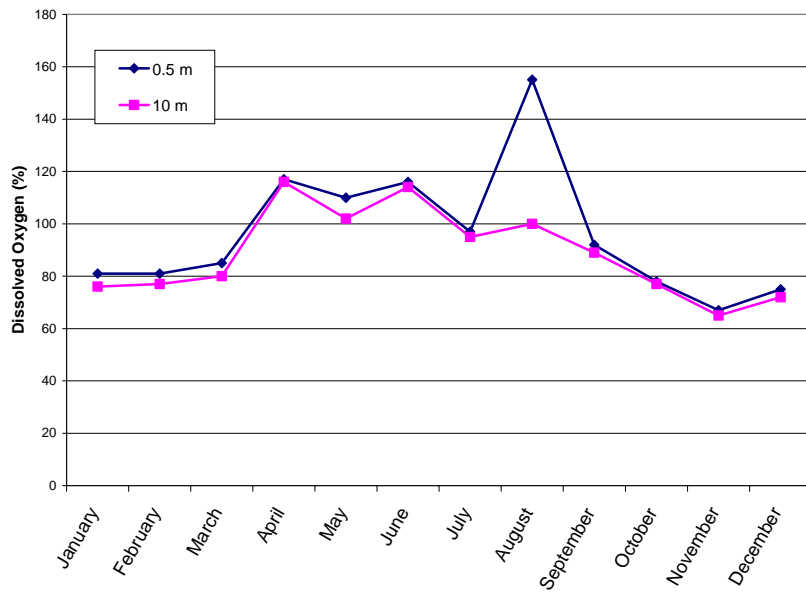


Figure 6. Dissolved Oxygen in Totten Inlet, 1999.

2.4. Nutrients in Totten Inlet

WDOE has been monitoring nutrients in Totten Inlet at Windy Point as a part of its Marine Water Quality Monitoring Program. To describe the current water quality conditions of northern Totten Inlet, data from the 1999 Windy point monitoring station (TOT001) is presented. This dataset was selected because it represents a typical seasonal pattern of nutrients observed in Totten Inlet over the monitoring period and it represents the most complete and quality data set in Totten Inlet (Brooks 2000, WDOE 2003c). The samples were taken at 0.5 m and 10 m once a month between February and October.

Nitrogen enters marine water primarily through biological sources such as excreta from organisms living in the environment; however other sources of nitrogen include rivers and streams, anthropogenic, and atmospheric contributions. In the marine environment, nitrogen is an essential nutrient for phytoplankton to synthesize proteins. Bacteria use N as a food source and release excess nitrogen back into the environment as inorganic N.

There are three common forms of inorganic nitrogen, ammonia (ammonium ion NH_4^+ and NH_3 ammonia), nitrite (NO_2) and nitrate (NO_3). The seasonal patterns that are typical in Puget Sound for these nutrients often begin with relatively high levels of nitrates and ammonia in late winter, which rapidly decrease during the spring as sunlight becomes available for phytoplankton production. Throughout the summer, low levels of nitrogen are typically maintained as zooplankton and fish excrete urine or feces, which are then quickly used by phytoplankton. As sunlight decreases in fall through winter, phytoplankton populations are reduced. Vertical mixing in the fall can redistribute inorganic nitrogen converted by bacteria in the sediment into the water column. In general, nitrite levels remain relatively low throughout the year.

Nitrogen concentrations in Totten Inlet generally follow this typical seasonal cycle, with the highest values measured in late fall and through winter, followed by lower concentrations starting in spring and continuing throughout the summer (Brooks 2000). Because Totten Inlet is only weakly stratified, the fall vertical mixing event is less important. In 1999, ammonium concentrations at the surface (0.5 m) were between 1.6 and 2.6 μM ($\mu\text{M} = \mu\text{moles/L}$) in October and February through March, with similar values recorded in the samples taken 10 m below the surface (Figure 7). During April through September, the ammonium levels at the surface are generally below 0.5 μM , with the exception of July. The ammonium concentrations measured at 10 m below the surface during the late spring and summer months appear to be more variable, with episodic increases to fall winter levels (0.09 and 1.7 μM ammonium). This may be due in part to fish, zooplankton, and phytoplankton population dynamics

Nitrite concentrations in 1999 followed a similar seasonal pattern to that described for ammonium (Figure 8). Fall and early spring concentrations

Nitrogen

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were the highest, ranging from 0.28 to 0.49 μM NO_2 . Late spring and summer concentrations were generally lower at the surface. Subsurface samples were characterized by generally low nitrate concentrations, with episodic increases in May and July.

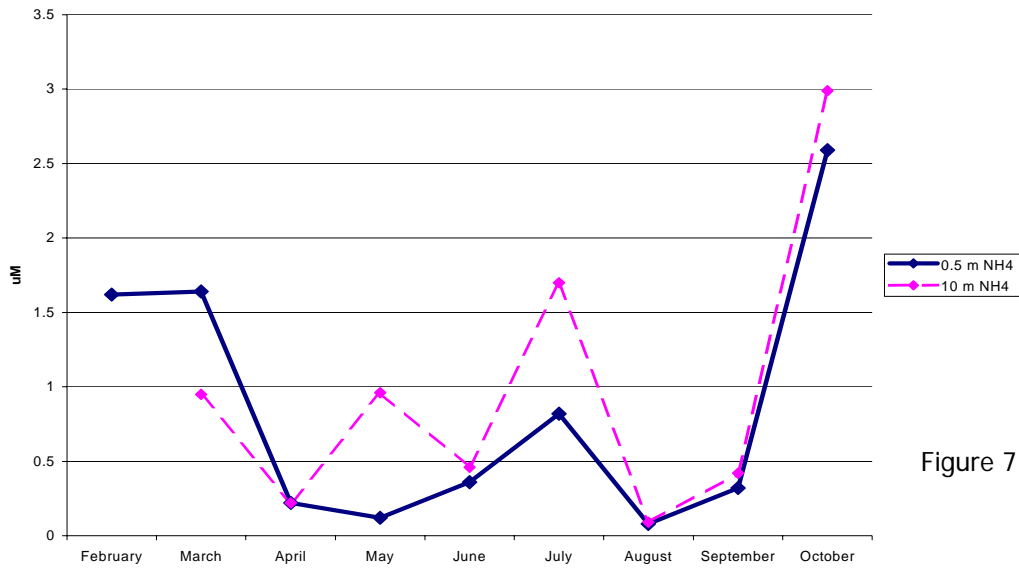


Figure 7. Ammonium Values Collected at Windy Point, 1999.

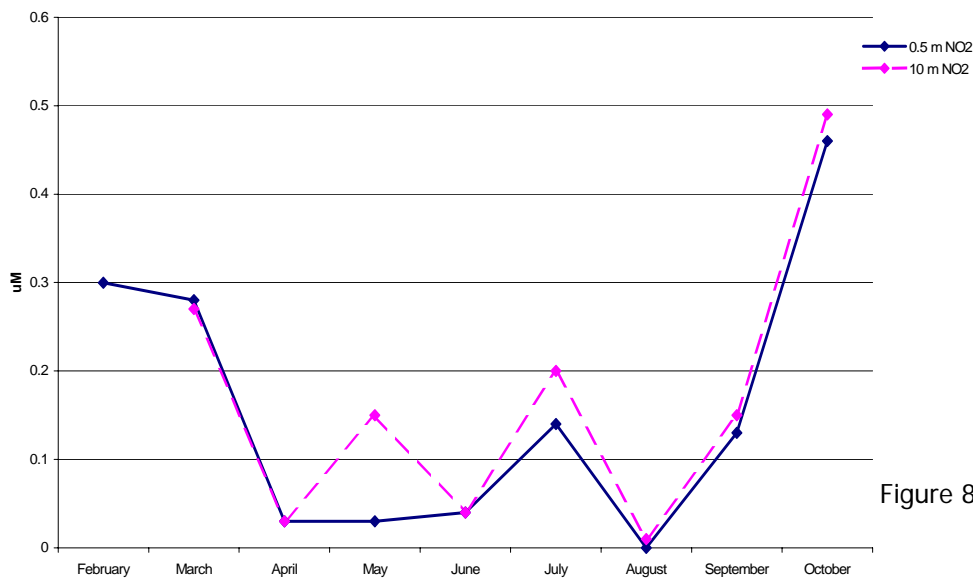


Figure 8. Nitrite Values Collected in Totten Inlet, 1999.

While the general pattern was similar for nitrate, the difference between winter-early spring and summer concentrations was considerably greater (Figure 9). In 1999, nitrate concentrations at 0.5 m and 10 m were high in February and March (28 and 25 μM respectively), followed by a sharp decline in the spring and summer to concentration ranging between 0 and 3.4 μM NO_3 . In general, nitrates were found in considerably higher concentrations than ammonium and nitrite. This is characteristic of Puget Sound, which has significant amount of nitrate input from the Pacific Ocean, as well as terrestrial sources (WDOE 2002).

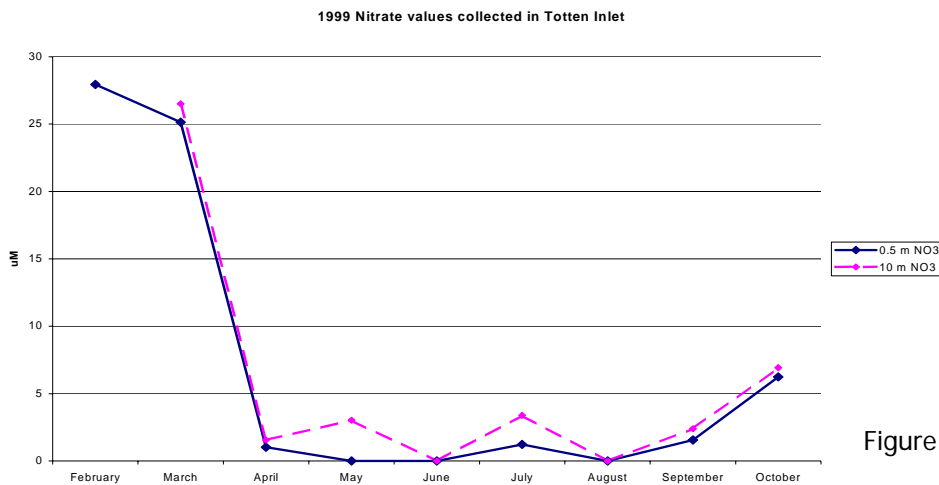


Figure 9. Nitrate Values Collected in Totten Inlet, 1999.

2.5. Habitat in Totten Inlet

Intertidal sand and mud flats, extensive estuarine deltas in the inlet headwaters, and the productive waters of Totten Inlet provide a rich habitat for marine and estuarine species, including salmonids and shellfish. There are a number of distinct habitats represented in Totten Inlet, including the sublittoral zone of the main basin, the littoral zone throughout the Inlet, and the emergent marsh occurring in the Little Skookum Inlet and Oyster Bay.

The sublittoral region of the main basin (North Totten Inlet) is represented by relatively homogeneous substrate, dominated by silt and clay (67.5%) with some sand (31.5%), and very little structure (PSAMP 2000; Puget Sound Environmental Atlas 1992). Sediment in the southern arms of Totten Inlet (Inner Totten Inlet and Skookum Inlet) is comprised of 87% silt/clay and 12% sand. The sediments in Totten Inlet are rated as having high sediment quality, based on the Sediment Quality Triad (PSEP 2001). The SQT examines sediment chemistry, benthic infaunal community, and sediment toxicity. The benthic community is dominated by polychaetes, serpent stars (*Amphiodia*), amphipods, and bivalve mollusks (PSAMP 2000).

The intertidal zone along much of the main basin is low angle beach featuring fine-grained sand or mud/fines overlying the glacially compacted clay layer that is found throughout much of Puget Sound (WSCC 2003; WDNR 2003). Sand flats and sand beaches with a pebble veneer and mud flats are the dominant habitats throughout all of Totten Inlet. *Ulva* is the dominant intertidal algae and the intertidal community is dominated by clams, oysters, *Callinassa (Neotrypaea) californiensis* ghost shrimp, and sand dollars (*Dendraster excentricus*) in the northern inlet. There are some small patches of kelp that occur in the nearshore zone, predominantly on the western shore (WDNR 2003).

Extensive emergent marsh and tidally influenced channels are the dominant habitat in Little Skookum Inlet and Oyster Bay. Substrates are organically enriched muds and fine-grained sand. Dominant vegetation includes sedges and salt-tolerant high marsh plants (*Salicornia*, *Triglochin*, *Deschampsia*, and *Distichlyus*). Dominant invertebrates include ghost shrimp, oysters, and clams.

3. Food Webs and Species of Concern

3.1. Totten Inlet Carbon-Based Food Web

The nearshore/neritic food web found in Totten Inlet is similar to those occurring throughout Puget Sound. The conceptual food web model presented here is somewhat truncated, focusing on the key pathways and linkages that support the identified species of concern, i.e., salmonids and bivalves. This food web was developed with a top-down approach, identifying major taxa involved in carbon dynamics by evaluating stomach contents and Index of Relative Importance data (IRI), feeding habits, species presence/absence, and seasonal trends in abundance. Where possible, Totten Inlet or South Puget Sound data were used to construct this model. However, some of these data sets are sporadic; consequently, region-wide information was used to fill in gaps where possible.

The food web that supports salmonids is comprised of four trophic levels: primary producers, herbivores, and primary consumers (often heterotrophs) and secondary consumers (Figure 10). Bivalves are supported by a relatively simple food web, feeding directly on phytoplankton and bacterioplankton, and to a certain extent feeding on microzooplankton. It is important to recognize that some energy requirements of organisms at the second trophic level are met by direct uptake from the water. Some organisms, such as bivalves, are omnivores and as such occupy two trophic levels as primary and secondary consumers. These organisms may be affected both directly and indirectly by changes in phytoplankton standing stock, potentially affecting model predictions of impacts to upper trophic levels. However, this effect can be minimized by integrating the approximate relative importance of different food sources with trophic transfer calculations.

Based on the review presented below, adult salmonids, including Chum and Coho salmon, Steelhead, and cutthroat trout, are present in Totten Inlet throughout much of the year. Returning Chum and Coho salmon are present in the system primarily in fall and early winter with an estimated standing stock of 1.3 g C/m². This estimate only includes returning Chum, since returning Coho are not actively feeding (WDOEb; WSCC 2003). Returning Chum feed primarily on forage fish (~75%), with a small proportion of the diet from large zooplankton, such as euphausiids or mysid shrimp (~25%).

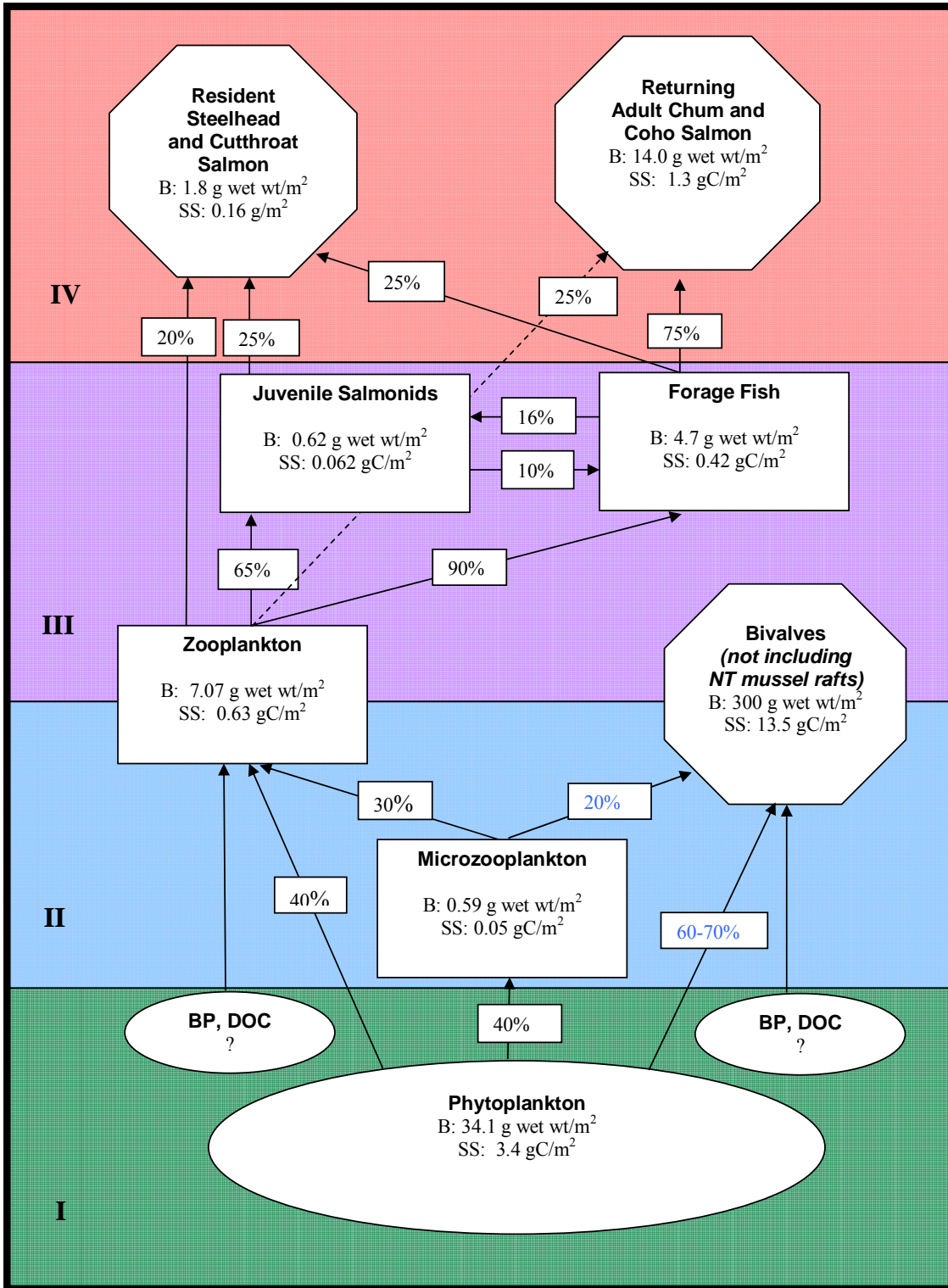


Figure 10. Carbon-Based Food Web with Bivalves and Salmonids Identified as Key Species. (Arrows indicate the direction of carbon flow; percentages represent portions of diet from that trophic level) B = Biomass, SS = Standing Stock

Winter steelhead and coastal cutthroat are present in the spring through late summer. Resident adult standing stock is estimated at 0.16 g C/m^2 . The steelhead diet is dominated by fish and gammarid amphipods, whereas coastal cutthroat are feeding primarily on fish, euphausiids, and decapod larvae.

Juvenile Chum and Coho salmon are present in Totten Inlet from early spring to summer. The Kennedy Creek Chum run is one of the largest in Puget Sound. Chum smolt standing stock (0.041 g C/m^2) remains more or less constant prior to emigration, with mortality rates matching growth. Coho smolt standing stock increases from 0.014 g C/m^2 to 0.028 g C/m^2 over the course of the outmigration. Salmonid smolts feed primarily on zooplankton (~65%) and other fish (16%), as well as amphipods, and insects.

Forage fish are presumed to be present in varying abundance throughout the year, with an estimated average standing stock of 0.42 g C/m^2 . Although spawning events may represent episodic increases in production (Hay and Fulton 1983), it is not included here since the extent of spawning events in Totten Inlet varies considerably by year. Based on stomach contents analysis, forage fish feed primarily on zooplankton (~90%); however, juvenile salmonids are a significant component during the early spring (10% of annual consumption).

Zooplankton are a critical component in the transfer of energy between phytoplankton and higher trophic levels. While copepods are the most numerically important zooplankton taxa, larval crab and barnacles become a dominant food source for forage fish and salmon smolts during the summer months. Based on Budd Inlet surveys, zooplankton standing stock is estimated at 0.63 g C/m^2 . Most zooplankton species are heterotrophs feeding on phytoplankton (40%) and microzooplankton (30%), with additional nutrients acquired from bacterioplankton and direct absorption.

Bivalves are at a relatively low trophic level, being linked directly to phytoplankton. With extensive sand flats, the Totten Inlet is well suited to clams, mussels, and oysters, as well as geoduck and subtidal clams. The standing stock for shellfish is estimated to be 13.5 g C/m^2 . In general, bivalves rely on phytoplankton (~65%) for most nutritive requirements, although microzooplankton (~20%), benthic diatoms, and dissolved organic material are also important components of bivalve diets.

Microzooplankton, particularly Tintinnids, are an important class of herbivores that comprise a significant portion of the zooplankton and bivalve diet. Although relatively abundant in Totten Inlet, the standing stock of microzooplankton was estimated at 0.05 g C/m^2 . Microzooplankton feed on phytoplankton (40%), bacterioplankton, and dissolved organic carbon.

Phytoplankton are the foundation for both the salmonid and bivalve food webs. Diatoms and dinoflagellates are seasonally dominant, with a dramatic spring bloom of *Chaetoceros* sp. which then fuels subsequent increases in zooplankton and fish abundance. Centric and pennate diatoms and dinoflagellates increase in abundance following the spring bloom. A second, smaller bloom occurs in late summer/early fall dominated by dinoflagellates. The standing stock of phytoplankton in Totten Inlet is estimated at 3.4 g C/m².

The following section details life histories for key taxa supporting the salmonid and bivalve food web.

3.2. Life Histories of Key Taxa

The low gradient streams that feed Totten Inlet support runs of fall Chum and Coho salmon and winter steelhead trout. Though not well documented, it is also likely that there are coastal cutthroat trout in the Totten Inlet watersheds. While there is some historic evidence of fall Chinook in Little Skookum Inlet, they are considered strays from the Elson Creek hatchery and not naturally supported by the small streams and low flows in this watershed. The occurrence and life histories of each of these runs is discussed below.

Totten Inlet supports three genetically and/or geographically distinct fall Chum stocks, the Totten Inlet stock, the Upper Skookum Creek stock, and the Skookum Inlet stock. The Chum population in Totten Inlet is classified as “healthy” and is characterized as a mixed stock with both native (Totten Inlet and Upper Skookum Creek) and hatchery reared (Skookum Inlet) fish.

Adult Chum salmon enter South Puget Sound during early October and spawn in late October through January, depending on the stock. The Totten Inlet stock spawns in Kennedy Creek in from late October to early December, peaking in mid-November. Kennedy Creek is one of the most productive Chum-rearing streams in Puget Sound, with a mean escapement of 41,000 fish between 1992 and 2001 (WDFW 2002). Skookum Inlet Chum are primarily fish from the Elson Creek Hatchery, with contributions from native stocks in lower Skookum Creek and its tributaries. Mean escapement from this stock was 7,000 fish between 1993 and 2000 (WSSC 2002). The Upper Skookum Creek Chum are primarily wild fish, with mean escapement of 11,900 fish during this same time period. Spawning in the Skookum Inlet and Skookum Creek stocks occurs in December and January (WSSC 2002). The ratio of males to females for the entire run is considered to be 1:1, with males more dominant early in the run and females more dominant later in the run (Salo 1991).

On average, females lay approximately 3,000 eggs (WDFW 2002). Chum fry emerge from the gravel from March to May and migrate

Salmonids

Fall Chum (*Oncorhynchus keta*)

immediately downstream to the estuary. Chum salmon are highly dependent upon the estuary during fry development, moving from the upper to lower estuary depending upon productivity (Salo 1991). Chum fry remain in the estuary for several months, with the timing of smoltification dependent upon the warming of marine waters and spring plankton blooms (WDFW 2002). Duffy (2003) found juvenile Chum abundance in South Puget Sound estuaries/deltas peaked in early April to early May. Abundance in the nearshore marine waters peaked in mid-May and decreased in mid-June. Bax (1983) found that Chum fry entering the nearshore areas of Hood Canal in February and March migrated more rapidly (7-14 km/d) than fry that enter the nearshore area later in Spring (May and June) as epibenthic and neritic food resources increase, suggesting that residence time in the nearshore area is related to food availability. Simenstad et al. (1982) suggest that the summer out-migration of juveniles northward along Washington and British Columbia coastlines is related to declining food in Hood Canal and diet changes towards more nektonic and pelagic organisms. This agrees with observations by Duffy (2003) that juvenile Chum abundance at neritic sites peaks in mid-June.

Chum fry enter the nearshore areas at size classes <40 mm fork length (FL), or 0.8 g (Salo 1991; Duffy 2003). Growth rates in the nearshore are exponential, averaging 3.4% body weight per day, based on a natural food diet (Salo 1991). Juvenile Chum are typically leaving the nearshore and moving offshore when they reach lengths that allow them to feed on larger neritic prey (55 to 90 mm length or 1.2 g to approximately 3 g/ind.). Fresh et al. (1981) found Chum in the sublittoral zone at 47 to 101 mm FL (mean = 69 mm FL); whereas in the neritic zone, juvenile Chum ranged from 80 mm to 128 mm (mean = 100 mm FL).

Survival rate of eggs is dependent upon a number of complex interactions between environmental, biological, and human factors. Based on a review of survival rates of egg to fry and fry to adult in Washington, British Columbia, Alaska, USSR, and Japanese waters, mean survival rates to fry were 10.1% (1.5% to 27.6%; Salo 1991). Survival of fry to adult was considerably lower, at 1.8% (range: 0.8% to 2.8%; Salo 1991). An estimate of the number of fry entering Totten Inlet can be calculated using mean survival of fry to adult, mean escapement data for each of the Chum runs, and the overall sex ratio of 1:1.

$$\text{No. Smolts} = (\text{Mean Escapement}/2) \times (\text{Eggs}/\text{Female}) \times \text{Survival Rate}_{(\text{egg-fry})} \quad \text{Eq 2}$$

Based on the average Kennedy Creek escapement of 41,000 adults and an overall male to female ratio of 1:1, an estimated 6.2 million fry would enter the Kennedy Creek estuary in February to April. Based on the mean escapement of 18,900 fish for the Skookum Inlet and Upper Skookum Creek runs combined, 2.8 million fry would enter via Skookum Inlet. It is important to note that Chum mortality within the nearshore areas of Totten Inlet is fairly high, perhaps as high as 95% during the first five months (Salo 1991). Smolt mortality in marine

waters is largely due to predation from birds and other fish species, such as Coho and cutthroat trout. Based on bioenergetics and population models (Preikshot and Beattie 2001), the emigrating population would be approximately 43,804 smolts. Biomass increases at a rate similar to mortality, such that total biomass ranges from 0.43 g wet wt./m² at immigration to 0.39 g wet wt./m² at smolt outmigration.

During their residence in the estuary, the dominant prey items for juvenile Chum are chironomids, harpacticoid copepods, larvaceans, insect larvae and benthic invertebrates (Gardiner 2003; WDFW 2003; Duffy 2003). Once in the nearshore zone, juvenile Chum feed primarily over submerged tidal flats, feeding in the water column during the daylight hours and feeding on epibenthic prey at night (Feller 1974). Stomach contents analysis of fish captured in May in South Puget Sound confirm this trend, with epibenthic organisms comprising >75% of prey during the dusk and dark hours (Duffy 2003). During daylight hours, planktonic and insect prey comprised >60% of the diet. However, Chum preferentially feed during the daylight and crepuscular hours, indicating that planktonic and insect prey are more important overall.

Juvenile Chum appear to have distinct nearshore and offshore stages, for both feeding and residence. Duffy (2003) noted a shift from epibenthic feeding in the deltas during April and May to more planktonic and neustonic feeding in the nearshore in June and July. Gut contents analysis of juvenile Chum in the nearshore area of South Puget Sound indicate that their diet is dominated by euphausiids, calanoid copepods, gammarid amphipods, ostracods, larvaceans, as well as harpacticoid copepods (Duffy 2003). This is consistent with gut content analyses conducted on fish from Hood Canal, which indicated that gammarid amphipods and calanoid copepods were the dominant prey from nearshore and neritic sampling sites (Simenstad 1976, Fresh et al. 1981). In the neritic sites sampled by Duffy (2003), copepods, larvaceans, and crab larvae were the dominant prey items. Chum salmon tend to be both size and taxa selective in the neritic environment (Healey et al. 1982; Simenstad et al 1982). Selectivity is based on visual perception, active selection based on gape, and optimal bioenergetics of foraging (Salo 1991).

Duffy (2003) further evaluated consumption by juvenile salmonids in South Puget Sound (SPS) using the Wisconsin bioenergetics model. This model uses an energy-balance approach in which total energy consumption equals the sum of growth, metabolic costs, and waste losses. Proportional prey consumption was then calculated based on stomach contents analysis and prey energy densities, expressed as Joules per gram. In simulations of SPS sites, average weekly individual consumption increased from 0.7 g in late April to 1.1 g prey in early June to satisfy their estimated growth rates. Proportion consumption for different prey categories were: copepods (38% to 68%), crab larvae (2% to 25%), insects (4% to 28%), and other prey, including larval forms,

amphipods, and fish (14% to 20%). As was noted above, the diet shifted towards more pelagic and neustonic prey items with season.

It is important to note that juvenile Chum are also opportunistic and are able to adapt their diet to available food (Gardiner 2003; von Saunders 2004), provided available prey is within their size selection range. Gardiner (2003) showed that the stomach contents of juvenile Chum from estuarine channels were dominated by marine ostracods that were transported by wind driven currents/tides into the estuary. Juvenile salmonids in highly stressed urban estuaries may shift their diet to available prey items in selected size classes (von Saunders 2004).

Both Kennedy and Skookum Creek support significant Coho salmon runs. Adult Coho enter the freshwater to spawn in mid-September to mid-November. Adults typically make short migrations into the streams, and then return to salt water prior to up-migration. Up-migration will then occur during a high flow event. Escapement from Totten, Hammersley and Eld inlets have shown a decreasing trend with mean escapement of 3,500 fish between 1993 and 2002 (SSHIAP 1999; WSCC 2003). The sex ratio of Coho salmon smolts is 1:1; however, up-migrating stocks include early migrating “jacks”. Jacks are males that only stay in marine water for 4 to 6 months. Thus, the sex ratio of the adult return can be variable with males comprising greater than 50% of smolts.

Coho
(Oncorhynchus kisutch)

Female Coho salmon lay approximately 2,500 eggs. Fry emerge in late spring, and remain in freshwater, rearing in the streams for just over one year. Downstream migration begins in the spring. Duffy (2003) observed juvenile Coho arriving in the deltas in April to early June, with abundance peaking in mid-May. There was little difference between peak abundance in the delta and nearshore sites, suggesting a relatively short residence time in the estuaries prior to entering the nearshore zone. Coho residence time in nearshore areas is tied to environmental conditions and food availability. Juvenile Coho spend several months in the nearshore zone prior to migrating to the Pacific Ocean (Sandercock 1991). Duffy (2003) found that Coho residence time in South Puget Sound was approximately 18 weeks; however, juveniles appeared to move throughout the region, with local residence times of 1 to 3 weeks.

A variety of estimates have been made for fry to smolt and smolt to adult survival. Fry to smolt survival estimates range from 0.7% to 9.65% in the Pacific Northwest; however, 1% to 2% appear to be the average range (for the purposes of this study, 2% will be used). Smolt to adult survival rates for northwest Coho runs range 3.2% to 10.8%, with an average survival of 7.1% (Sandercock 1991). Because the sex ratio is variable due to the presence of jacks, it is difficult to know the extent of this imbalance. For the sake of estimating abundance of juvenile salmon in Totten Inlet, a ratio of 1:1 will be used. Based on an escapement of 3,500 adults, it is estimated that approximately 87,500 smolts enter

Totten Inlet. While in the estuary, Coho smolts are exposed to predation from both birds and fish, such as cutthroat trout. In the neritic waters, Coho are also exposed to predation from dogfish and marine mammals. Based on survival rates for the first six months, the population of Coho smolts in Totten Inlet is estimated as high as 87,500 in the estuaries to 6,125 emigrating fish after six months. Based on bioenergetics and population modeling in South Puget Sound, Preikshot and Beattie (2001) estimate that 25% of entering smolts emigrate in July and that biomass increases during that period by approximately 8-fold. Smolt biomass at entry is estimated at 0.14 g wet wt./m² and 0.28 g wet wt./m² at emigration.

While in the nearshore zone, Coho smolts feed on various planktonic crustaceans, pink and Chum salmon fry, herring, sand lance, and other fishes. Juvenile fish from sublittoral habitats had stomach contents consisting mainly of decapod crustacean larvae, plus fishes (mostly herring), amphipods and polychaetes (MACSIS, Marine and Coastal Species Information System). Duffy (2003) found gut contents in south Puget Sound Coho shifted as the fish moved from the river delta to the nearshore to the neritic waters. In the delta, juvenile Coho diet was comprised of polychaetes, gammarid amphipods, insects, isopods, and crab larvae. In the nearshore zone, juvenile Coho consumed gammarid amphipods, mysid shrimp, euphausiids, and fish. Once in the neritic zone, gut contents was almost exclusively crab larvae and fish (Pacific sand lance and herring). Young Coho from the offshore pelagic zone consumed euphausiids, fishes (mostly herring), gammarids, and decapod larvae (Salo 1991). Fishes formed the highest biomass in stomach contents, but occurred in only 30% of the Coho salmon stomachs analyzed. Juvenile Coho can consume fish up to 50% of their body length. Coho size analysis indicated that mean nearshore size 84 mm and neritic sites (110-130 mm).

Based on bioenergetics model analysis, Duffy (2003) calculated apparent growth rates for juvenile Coho at 1.3 to 2.0% body weight per day. Based on this growth rate, consumption rates were calculated at 3.4 g to 8.4 g of prey per week. Using prey energy density and stomach contents analysis, juvenile Coho consumed 0.00 - 0.33 g of amphipods, 0.08 - 0.18 g of euphausiids, 0.28 - 2.41 g crab larvae, and 0.93 - 2.76 g of other invertebrate prey in order to satisfy estimated growth. Similar prey items were important in the nearshore fish in 2002. In the neritic sample, crab larvae comprised 82% of the diet; however, this was only one sample.

The food of marine adults is more pelagic and more varied than that of many Pacific salmon. Fishes made up 70% to 80% of the Coho diet and 20% to 30% were invertebrates. The following species were common prey items: pilchard, herring, anchovy, Coho salmon, capelin, lanternfish, Pacific saury, hake, whiting, rockfishes, black cod, sculpins, sand lance, squid, barnacles, isopods, amphipods, euphausiids, crab larvae, and jelly fish (ADFG 1986). Herring and sand lance made up 75% of the

biomass. Cloud (2001 in WSCC 2003) indicated that returning Coho are not feeding prior to entering their natal streams.

Coastal cutthroat trout are the most widely distributed salmonid in the Totten Inlet watersheds (WSCC 2003), with the anadromous populations occurring in most South Puget Sound tributaries. However, quantitative distribution and abundance data are currently unavailable.

Coastal Cutthroat Trout
(Oncorhynchus clarki clarki)

Adult, sea-run cutthroat trout return to their natal stream to spawn. Migration begins in November, peaking in January/February. Spawning occurs in late winter and spring. Spawned sea-run cutthroat can return to marine waters, and generally migrate downstream in late March to early April. Mean fecundity is 1,400 eggs per female. The age and time that fry migrate to marine waters is highly variable; however, in Washington smolts migrate downstream from late April to June, with peaks in mid-May (Trotter 1997, Percy 1997). Anadromy is not well developed in sea-run cutthroat. They spend little time in saltwater and often spend considerable time in tidal rivers and low gradient estuarine sloughs. In the nearshore areas, sea-run cutthroat remain near the mouth of their natal river (within 50 km). Schools of cutthroat feed and migrate along the shoreline, mostly in water less than 3 m deep. Although residence time in marine waters varies, cutthroat return to freshwater in the same year they migrated out. Based on estimates in Oregon, smolt survival is 20% to 40%. Predation by Pacific hake, spiny dogfish, harbor seals and adult salmon accounts for smolt mortality (Trotter 1997). Cutthroat trout are generally larger than the juvenile salmonids in Puget Sound. Fresh et al. 1981 found cutthroat trout were 356 ± 82 mm FL in central and south Puget Sound.

In the marine environment, cutthroat trout feed on gammarid amphipods, isopods, callinassid shrimp, immature crabs, and various fish, including Chum salmon, pink salmon, and sand lance. Herring and sculpins have also been observed in cutthroat trout stomachs (Jaquet 2002). Cutthroat trout from central and south Puget Sound were mostly piscivorous, with fish comprising 74% of the stomach contents (Fresh et al. 1981). Sand lance made up 60% of the fish prey biomass. The major invertebrate prey was gammarid amphipods, making up 16% of the prey biomass.

Totten Inlet steelhead spawn in Kennedy, Skookum, and Schneider Creeks. Low flows and limited spawning habitat limit production. The status of these stocks is unknown because escapement is not monitored. Winter steelhead typically enter freshwater December through mid-March and spawn in early February to early April. Outmigration to marine waters is determined primarily by size and environmental factors. In this region, juvenile steelhead typically enter marine waters at two years of age (WSCC 2003). Steelhead in central and south Puget Sound were $259 \text{ mm} \pm 125 \text{ mm}$ FL (Fresh et al. 1981).

Winter Steelhead
(Oncorhynchus mykiss)

In the marine environment steelhead have a diet similar that of Coho, with smaller fish feeding on benthic and nearshore invertebrates and

larger fish feeding on small fish (Costello 1977). The prey found in stomachs of adult steelhead captured in central and south Puget Sound were numerically dominated by euphausiids, gammarids, insects, and decapod larvae (Fresh et al 1981). Herring were also present and dominated the prey biomass in those fish.

The term forage fish refers to a number of fish species that are common prey items for large juvenile and adult salmonids. In Puget Sound, this includes herring, Pacific sand lance, eulachon, surf smelt, and longfin smelt. In Totten Inlet there are known populations of herring, sand lance, and surf smelt.

Herring spawn in distinct locations throughout Puget Sound, each with very specific grounds and timing. The peak of spawning seldom varies by more than seven days from year to year. The Squaxin Pass stock is the only South Puget Sound herring stock and is considered moderately healthy. The average run size between 1977 and 1996 was 439 tons of herring (WDFW 1998). Herring biomass can be estimated at 1.1 g wet wt./m² or 0.1 g C/m² (Preikshot and Beattie 2001; Hay and Fulton 1983).

Squaxin Pass herring spawn in January to April. Spawning grounds include Squaxin Pass, portions of the eastern shore of North Totten Inlet north of Gallagher cove, a small portion of Little Skookum Inlet, and the mouth of Hamersley Inlet (WDFW 1998). Herring spawn by depositing eggs on vegetation or other shallow water substrate, including man-made structures. Egg deposition generally occurs from 0 to -40 ft. MLLW, with most eggs deposited between 0 and -10 ft. MLLW. The eggs hatch after 10-14 days, at which point the larvae drift at the surface with local currents. Food availability is critical during this stage and strongly linked to year class strength (Sinclair and Tremblay 1984).

Following metamorphosis at 3 months of age, young herring spend a year in Puget Sound, although not necessarily close to natal waters. Some herring remain in Puget Sound, while others summer in coastal areas of Washington and southern British Columbia (Trumble 1983). Fresh et al. (1981) found herring throughout the year in south Puget Sound. At age two to four years, herring migrate back to their spawning grounds. Ripening adults will remain near the mouth of the creek before for 3 to 4 weeks before spawning.

Herring mortality in Puget Sound is quite high, with 25% to 30% survival. Natural mortality is the predominant cause of mortality (60% to 70%), with fishery-related mortalities of approximately 5 to 10% (WDFW 1998, on-line data 2004). Natural mortality is due in large part to predation of floating eggs, as well as juvenile and adult forms, from Pacific cod, whiting, lingcod, halibut, Coho and Chinook salmon, seabirds, and marine mammals (Barnhart 1988; ADFG 1986; Grosse and Hay 1988). Disease can also be a significant contributor to herring

Forage Fish

Pacific Herring *(Clupea harengus pallasii)*

survival, effectively cropping the older, more reproductively successful herring from the population (Hershburger, P, unpublished data).

As soon as the yolk is exhausted, herring larvae begin exogenous feeding. This is a critical period because the margin between sufficient nutrition and starvation is exceedingly narrow. The first food consists mainly of invertebrate eggs, copepod nauplii, and diatoms. Juvenile herring consume mostly crustaceans such as copepods, amphipods, cladocerans, decapods, barnacle larvae, and euphausiids (Barnhart 1988).

Adult herring feed primarily on planktonic crustaceans throughout their life cycle (ADFG 1986). Stomach contents analysis of herring in central and south Puget Sound indicated that juvenile herring in sublittoral habitats feed on calanoid copepods (45%), decapod larvae (23%), and chaetognaths (10%; Fresh et al. 1981). However, they are opportunistic feeders as well, and will consume juvenile salmonids and other forage fish. In neritic habitats, prey items are dominated by calanoid and harpacticoid copepods and euphausiids.

While sand lance are widely distributed throughout Puget Sound, there is surprisingly little information on abundance or distribution. Forage fish surveys have not found spawning grounds inside Totten Inlet. There are, however, spawning areas in Squaxin Pass and Pickering Passage (Pentilla 1997; WDFW 1998) and it is likely that larval and adult sand lance are present in Totten Inlet. Sand lance spawn between November 1 and February 15, and deposit eggs on a fine sand to gravel beaches from +5 ft. to 0 ft. MLLW. Eggs hatch in approximately four weeks and move into the water column. Larvae reside in the nearshore, migrating passively with currents and tides. Once larvae reach adult size, they travel in schools feeding in the open water during the daylight hours. At night, sand lance move to the bottom and burrow into the substrate. Little is known about the movement of adults in Puget Sound, however, based on some plankton surveys conducted by WDFW (referred to in WDFW 1998), they appear to be common and quite numerous throughout the Sound. Fresh et al. (1981) found sand lance in Central Puget Sound from May to August in surveys that included hook and line, purse-seine, mid-water trawls, and beach seine sampling of nearshore and neritic waters. No sand lance were found in South Puget Sound stations from September to April.

Larval and adult sand lance feed on primarily on zooplankton. Sand lance stomach contents from central Puget Sound (Fresh et al. 1981) were dominated by calanoid copepods (71%), with some harpacticoid and cyclopoid copepods. Sand lance are an important trophic link between zooplankton and larger predators. Sand lance comprise 35 percent of salmon diets in Puget Sound and are also important components of Pacific cod, Pacific hake, and dogfish diets (WDFW 1998).

Sand Lance *(Ammodytes hexapterus)*

Surf Smelt
(Hypomesus pretiosus)

Surf smelt are common, year-round residents of nearshore Puget Sound waters. As with sand lance, there is little data to estimate abundance. However, based on estimates of surf smelt spawner biomass from an egg production model which was based on spawner beach surveys (Pentilla 1997; WDFW 1998), the South Puget Sound biomass is approximately 4.2 million kilograms wet weight.

In south Puget Sound, spawning occurs in the fall and winter months. Spawning grounds in south Puget Sound include Totten Inlet, Hammersley Inlet, Pickering and Squaxin Passages, Eld Inlet, and Budd Inlet (WDFW 1998; Pentilla 1997). Adults spawn on at the water's edge during high tide. Eggs hatch after 27 to 56 days. Hatching larva move passively in the currents and tides in the nearshore waters until they mature after approximately three months. The movement of juvenile and adult smelt is virtually unknown. Stocks of mixed juvenile and recovering-spent surf smelt in the general vicinity of spawning grounds suggest long-term residency. Based on research trawls, there does not appear to be a migration out of Puget Sound, nor are surf smelt found in the mid-water. Thus it appears that Puget Sound surf smelt are resident in Puget Sound, if not regionally within Puget Sound and they reside either in the shallower nearshore zones or close to the bottom.

As with other forage fish, surf smelt feed primarily on planktonic organisms and are an important component of seabird, marine mammal, and fish diets. Fresh et al. (1981) found that surf smelt ate primarily pelagic prey including calanoid copepods (24%), urochordates (25%), carideans (10%) and euphausiids (10%). However, the presence of small numbers of harpacticoid copepods in a large proportion of the stomachs observed indicate that surf smelt are also epibenthic feeders.

Both surf smelt and sand lance populations are considered present in variable abundance throughout the year. Based on Priekshot and Beattie (2001), the estimated biomass for forage fish (excluding herring) is 3.3 g wet wt./m².

The bivalve community in Totten Inlet is comprised of a natural community and existing cultivated stocks. The natural community includes intertidal and subtidal clams, geoducks, oysters, and a number of small bivalves that are part of the benthic infaunal community. Cultivated shellfish stocks include oysters, intertidal clams, and mussel rafts.

Geoduck are present in the lower intertidal and subtidal sediments. WDFW has conducted geoduck surveys for subtidal populations of geoduck, estimated geoduck abundance in Totten Inlet at 217,000 individuals, with an average density of 0.026 ind./ft² or 0.28 ind./m² (WDFW 2003). Surveys conducted in the area of the proposed mussel raft and in Inner Totten Inlet indicate that geoduck populations in these muddy areas are very low (Goodwin 1997; Gordon King personal communication). There is likely to be some error in this estimate since

**Bivalves of Totten
Inlet**

WDFW only surveys to -70 ft. MLLW and, although geoduck density in Inner Totten Inlet and Inner Skookum Inlet, it is unclear whether there is a complete absence of geoduck. Based on the wet weight per individual estimated by WDFW of 1,394 g/ind., the average wet weight biomass of geoduck in Totten Inlet is estimated to be 390 g/m² and the estimated total wet weight biomass of 3.0 x 10⁵ kg.

Geoduck population densities are fairly static, with life spans of greater than 100 years (Goodwin and Pease 1989). Natural mortality is approximately 2% and growth rates are less than 1% in a mature stock (Bradbury et al. 2001). Growth rates for geoduck less than 5 yrs old are quite high, nearly doubling biomass annually. After five years, this rate slows considerably and after 10 to 15 years, growth rates slow to less than 1%. Based on low mortality, low settlement rates, and slow growth at maturity, annual production of a mature stock is likely to be quite low [estimate for Totten Inlet = 0.13 g C/m²/yr based on 2% replacement annually and 3.4% carbon for mussels (Brooks 2000)]. Harvesting can alter this production estimate. Geoduck harvesting has occurred in north Totten Inlet, with 8.6 x 10⁵ geoduck harvested in the 1980s. However, the community in Totten Inlet is now considered to be a mature community. For this reason, trophic transfer to growth is considered to be lower for geoduck, than other bivalves.

Geoduck are filter feeders, clearing 49.2 L/h/ind. There is little data on geoduck feeding behavior. They appear to feed exclusively on phytoplankton (WDFW, unpublished data); however, what proportion of this diet that is derived from detritus at the sediment-water interface and what is derived from the water column is unclear.

The clam community is dominated by the intertidal clams, *Tapes japonica*, *Prototheca staminea*, *Clinocardium nutallii*, and *Saxidomas nutallii* and the subtidal clam, *Tresus* sp. The total estimated abundance of clams in Totten Inlet is 9.0 x 10⁷ (EDAW 1998) or 10.5 ind./m². WDFW (2001) determined that the average biomass of intertidal clams in Totten Inlet was 19.9 g/ind. wet wt. Average wet wt. biomass of clams in Totten Inlet is then estimated at 209 g/m² (9 g C/m²), with a total biomass of 1.8 x 10⁶ kg (3.5 x 10⁵ kg dry wt.). Intertidal clams feed on phytoplankton, bacterioplankton, microzooplankton, benthic diatoms, and detrital organic material (Sorokin and Giovanardi 1995; Word 1990).

Two species of oyster are present in Totten Inlet, the native Olympia oyster (*Ostrea conchaphila*) and the Japanese oyster, *Crassostrea gigas*. *Crassostrea gigas* are size-selective, filter-feeding bivalves that consume phytoplankton, bacterioplankton, and benthic-diatoms in size classes of 3 to 40 µm in diameter (Ward et al. 2003; Cognie et al 2001). *Ostrea conchaphila* feed larger particles, primarily phytoplankton. The estimated average wet wt biomass of oysters in Totten Inlet is approximately 235 g/m², or 11.0 g C/m² (EDAW 1998).

Zooplankton

Zooplankton are a remarkably diverse assemblage of small water-column organisms. They include not only animals that are planktonic throughout their entire life (holoplankton), but also animals that are planktonic only in their larval form (meroplankton). Zooplankton provide a crucial link between the photosynthetic phytoplankton and the fish and shellfish resources in Puget Sound. Although there is a substantial amount of information on zooplankton population structure and abundance in Puget Sound, there is considerably less data on zooplankton in Totten Inlet. The following section will discuss zooplankton abundance and species distributions in Totten Inlet and South Puget Sound, as well as a description of life histories of those families of zooplankton that are the dominant prey items that have been identified in the previous sections. Because many consumers are, to a certain extent, opportunistic feeders, zooplankton that have not been observed in fish or shellfish diets but occur in Totten Inlet will be discussed as well.

Zooplankton populations cycle throughout the year, both in abundance and in species composition. PSI examined zooplankton in water samples collected during their extensive phytoplankton sampling effort in Totten Inlet in 2002 and 2003 (Cheney, et al. unpublished data). Once monthly, five gallon water samples from discrete water depths were examined for phytoplankton (identified to species) and zooplankton (macroplankton and microplankton identified to family). Peak zooplankton abundance was observed in June and July, with sporadic presence in May and from August to November. No zooplankton were observed in February or March. Because this effort sampled limited volumes from discrete depths (generally near surface) and zooplankton have diel vertical migration patterns, it is likely underestimated. This is reflected in the low densities of copepods, which are typically numerically dominant in Puget Sound. This sampling effort did, however, provide a good characterization of the micro-zooplankton community. *Heleocostamella* and other tintinnids were the most common micro-zooplankton, occurring most frequently and comprising 60% to >90% of the zooplankton observed in samples. Other dominant groups were copepods, barnacle and crab nauplii, and *Tiarina*. In August/September, unidentified species (“other”) were numerically dominant. Based on Giles and Cordell (1998), these may be larvaceans or cladocerans.

Giles and Cordell (1998) conducted a zooplankton study in Budd Inlet examining abundance, biomass, and species distribution of macroplankton zooplankton (>200 μm) throughout the inlet. Vertical zooplankton tows were conducted in six locations in Budd Inlet on 21 sampling events from October 1996 to September 1997 using a 220- μm mesh net. At the northern portion of the inlet, zooplankton abundance was lowest during the fall and winter months and was generally less than 1000 ind./ m^3 from November to February. Abundance increased in spring and early summer from 5,000 to 30,000 ind./ m^3 between mid-March to mid-July. This was presumably a response to increasing phytoplankton abundance with increasing light. Abundance declines throughout the summer as various species of fish and crustacean larvae

successively develop. This predatory pressure can allow a second phytoplankton bloom in the late summer. Zooplankton abundance in late July to September was approximately 5,000 ind./m³. Abundance in the mid-bay stations were generally similar; however, peak abundance in early June reached 65,000 ind./m³. Abundance in the South Bay stations was generally higher during the peak season May through July, but was similar to other stations during the winter and late summer/early fall months. The higher spring/early summer abundance may be due to greater amounts of stratification and higher plankton densities in the southern inlet.

Average zooplankton biomass from October 1996 to September 1997 in the North Bay and Central Bay stations was 0.094 g dry wt./m³. Seasonal average for the upper and central bay stations were approximately 0.18 g dry weight/m³ in March – May, 0.22 g dry wt. in June – early August, and 0.03 g DW/m³ in late August to February. Using a dry to wet wt. conversion of 1:9.17 (Preikshot and Beattie 2001), wet weight biomass was 0.86 g/m³.

Giles and Cordell (1998) found that temporal variation in species composition was greater than spatial variation, with similar species composition throughout Budd Inlet. Crustaceans dominated the zooplankton composition throughout the year, comprising 60% to >90% of the total zooplankton population between December and September. Dominant crustaceans were copepods and crab and barnacle larvae. Larvaceans were the dominant taxon in October through November. Other dominant groups were cnidarians, and polychaete larvae.

The observations of the Giles and Cordell (1998) and the PSI surveys combined with previous characterizations of the neritic food web in Puget Sound (Simenstad 1983; Strickland 1981; Dumbauld 1985) indicate that crustaceans (dominated by copepods and larval barnacles and crab) dominate the zooplankton community during the spring and summer blooms, with larvaceans and micro-zooplankton becoming more dominant during non-bloom periods in late summer and early fall. Unlike northern Puget Sound, the sheltered waters of south Puget Sound allow for year-round populations of larger zooplankton (Strickland 1985) such as copepods; however, they are likely to remain in the deeper waters of the central inlet during the winter months.

Calanoid copepods are a family of crustaceans that dominates the zooplankton of Puget Sound and are a critical component of salmonid and forage fish diets. Calanoid copepods have preferences for phytoplankton or zooplankton food sources, and their sizes and feeding structures differ accordingly. While the copepod community in Totten Inlet is not well understood, Giles and Cordell (1998) provide a detailed analysis of the species distribution of South Puget Sound copepods. For outer and central Budd Inlet, *Acartia* (*Acartiura*) spp. were the numerically dominant neritic copepod from March through mid-June. In early July through September, *Paracalanus* spp. was numerically

Copepods

dominant, comprising 90% of the calanoid copepods observed in both the outer and central inlet. In October to March, *Paracalanus* and *Pseudocalanus* were dominant in the outer inlet; whereas *Acartia* was more dominant in the central inlet. *Pseudocalanus* was also numerically important between December and late May. Although not numerically important, the larger *Calanus* sp. copepod and the carnivorous copepod, *Tortanus* spp., were also present in the spring and summer months.

Acartia, *Pseudocalanus*, and *Paracalanus* are smaller copepods (approximately 0.01 mg/ind.) that are widely distributed in Puget Sound. Using modified mouth parts that essentially rake the water preferentially, they size-select high quality food particles (Sell, unpublished data). Bollins and Penry (2003) showed that *Acartia* spp. in South Bay and San Pablo Bay, California feed selectively on prey items >10 μm in size, despite phytoplankton communities dominated by high numbers of smaller phytoplankton (nanoplankton). During periods of high food abundance, smaller copepods have been shown to preferentially select ciliates and dinoflagellates. However, during blooms, feeding rates on diatoms increase to 188% of body carbon per day (Bollins and Penry 2003; Suzuki et al. 1999). As predicted by optimal foraging theory, copepods will feed on a diverse diet of available food; however, when food abundance is high, the diet becomes less diverse as a result of selective feeding on ciliates and flagellates.

Although not the most abundant copepod, the larger copepod, *Calanus* spp. (170 μg dry wt./ind.), comprises a large fraction of the copepod biomass in Puget Sound. It is a grazer that as an adult consumes diatoms, although will also eat some protozoans or larvae (Strickland 1983). However, in mesocosm experiments with simulated diatom blooms and a subsequent ciliate population increase, *Calanus* preferred ciliates >30 μm in size, comprising 74% of the carbon ingestion during ciliate blooms (Nejstgaard et al. 1997). Diatoms and smaller ciliates comprised the remaining diet. During non-bloom periods, ciliates consumption was significantly lower. The primary impact of *Calanus* on the phytoplankton community was indirect, through the consumption of ciliates.

Copepods rely exclusively on sexual reproduction. Although copepods reproduce continuously throughout the year, maximum egg production is typically linked to bloom events. Soon after laying, copepod eggs hatch into free-swimming larvae called nauplii. Nauplii feed on the tiniest phytoplankton and molt eleven times before reaching adult size. The entire life-cycle takes approximately one month in summer or several months in winter. Most zooplankters continue feeding and laying eggs throughout the summer while the food supply lasts. During winter, copepods restrict their activities, conserving energy while living off of stored food.

Although numerically not dominant, euphausiids and mysids are an important link between zooplankton and fish. Euphausiids and mysids are shrimp-like crustaceans that consume both zooplankton and phytoplankton. Because of their larger size, they are a preferred component of juvenile salmonids diets and are second only to copepods in herring diets.

Much larger than copepods, euphausiids get to be 20 mm in length. Generally, euphausiids cluster in schools, migrating to deeper waters in the daytime and feeding at the surface during the nighttime. Euphausiids feed on both phytoplankton and zooplankton, including copepod adults and nauplii. There is little quantitative data on the abundance or biomass of euphausiids in South Puget Sound.

Larval forms of benthic invertebrates and fish are a critical seasonal component of the zooplankton community. Based on Giles and Cordell (1998), barnacle and crab larvae comprise 30% to 40% of the zooplankton abundance in Budd Inlet during migrations. Duffy (2003) found that in neritic waters, juvenile Chum stomach contents were dominated by crab larvae. A number of phyla have swimming larval forms, including echinoderms, annelids, crustaceans, molluscs, and fish.

Just as there are a variety of larval forms, there are a variety of feeding strategies, including omnivores, carnivores, and larvae that do not feed or use lipid stores during their swimming phase. For the purposes of this evaluation, larval forms will be included with zooplankton.

Microzooplankton are emerging as a critical link between phytoplankton and zooplankton and bivalves. Many zooplankton previously thought to be herbivores feed almost as heavily on ciliate and flagellate protozoans as on phytoplankton (Bollins and Penry 2003; Strom et al. 2001; Uye et al. 1996). During periods of low primary productivity, microzooplankton support the food chain. They are often the more numerically important class of zooplankton since their abundance appears to be less affected by algal boom-bust cycles. In Totten Inlet, tintinnids are the dominant microzooplankton species (Figure 11), with abundance ranging from 3.0×10^6 ind./m³ in winter to 7.7×10^6 ind./m³ in late summer (Cheney et al., unpublished data). Microzooplankton biomass in Totten Inlet was estimated at 10 g wet wt./m².

Tintinnids are ciliates, unicellular organisms featuring cilia as food-catching and locomotor organs. They are mostly solitary, free-swimming organisms that range in size from 50 to 150 µm in size. Tintinnids are distinguished by protective vase-like cases that are that the protozoan secretes and adorns with particles of sand. *Heleocostamella* is the most common tintinnid encountered in Totten Inlet. The armored ciliate, *Tiarina* was also relatively common, particularly in summer and fall. *Tiarina* feeds on dinoflagellates and was likely associated with the Fall bloom.

Other Zooplankton

Larval forms

Microzooplankton

Microzooplankton feed primarily on smaller size classes of phytoplankton, nanoplankton and picoplankton, including diatoms and dinoflagellates. Bacterioplankton and dissolved organic matter are also an important energy source. Approximately 25% to 50% of the diet of *Oikopleura* is comprised of bacterioplankton of <1 µm in size (Valiela 1984). Uye et al. (1995) found that approximately 26% of primary production was consumed by microzooplankton; whereas microzooplankton accounted for 17% of net zooplankton carbon requirements.

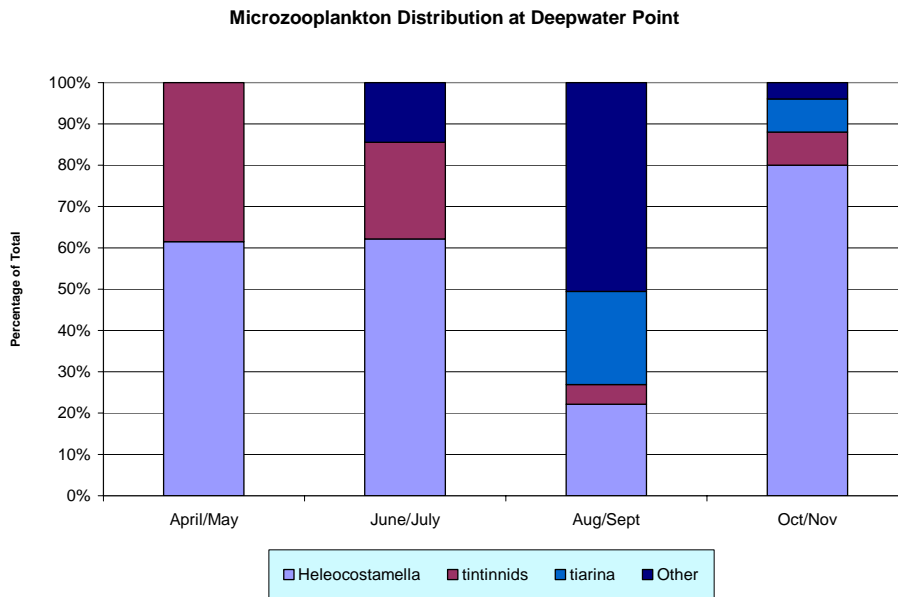


Figure 11. Microzooplankton Distribution at Deepwater Pt.

Phytoplankton forms the foundation of the marine water-column food web. Abundance and species composition is a complex function of productivity, intensity of predation and rates of settlement. These processes contribute significantly to the transfer of energy to pelagic and benthic ecosystems and result in a cyclical pattern of abundance and distribution of the invertebrate predators and the food chain that they support.

Phytoplankton abundance, biomass, and species distribution in Totten Inlet can be determined using two data sets. PSI (Cheney et al., unpublished data) has sampled phytoplankton near Deepwater Point and Kamilche Point as part of a study of mussel rafts in 2002 and 2003. Samples were collected, typically from 2.5 m depth, throughout the year. Phytoplankton were identified to species and abundance for each species was determined.

Phytoplankton

Total phytoplankton abundance in both 2002 and 2003 was characterized by relatively low abundance in late fall and winter, with total abundance of <100,000 cells/L (Figures 12 and 13). The highest abundance was observed in early spring in late April and early May. This population increase was due solely to a bloom of centric diatoms, primarily *Chaetoceros* spp. (2002 and 2003) and *Cerataulina pelagica* in 2003. Total phytoplankton abundance during this spring bloom was 3,156,000 to 4,123,000 cells/L. The spring bloom was followed by much lower cell densities in late May through July, presumably due to decreased nutrient levels and increased populations of herbivorous zooplankton. In mid-July to early August, a second bloom was observed. This second bloom was less pronounced than the spring bloom, with total abundances of 220,000 (2003) to nearly 1 million cells/L (2002). The fall bloom was more prolonged than the spring bloom, and was due first to an increase in centric diatoms that was followed by an increase in dinoflagellate bloom. The fall bloom in 2003 was much less pronounced than that of 2002, but exhibited this same pattern.

Two phytoplankton samples were collected from North Totten Inlet on 11/2/02 and on 4/28/03. The North Totten Inlet site showed similar total abundance and species distribution to the Deepwater Point site during these two events, with 119,000 cells/L in November and 3,563,000 cells/L in April.

The patterns in abundance and species composition observed in Totten Inlet was very similar to that observed in Budd Inlet in 1997 (LOTT 1998). Low abundance in fall and winter (100,000 to 200,000 cells/L) were followed by a diatom bloom of approximately 3 million cells/L. The spring bloom occurred near May 1 and passed quickly. The smaller, more prolonged fall bloom occurred in August through early September.

The species composition observed in Totten Inlet was dominated by centric diatoms and dinoflagellates. During the fall and winter months, the centric diatoms *Thalassiosira* sp., *Skeletonema costatum*, and *Chaetoceros* sp. were the dominant phytoplankton species. *Chaetoceros* sp. increased in abundance prior to the spring bloom event, comprising from 10% of the assemblage in March to 90% of the assemblage in May. Following the spring bloom, *Chaetoceros* became less abundant and the assemblage became more diverse including centric (*Thalassiosira* sp.) and pinnate diatoms (*Thalassionema* sp, and *Eucampia zodiacus*) and dinoflagellates (*Ceratium* sp., *Gyrodinium* sp. and UI dinoflagellates). The fall bloom started with *E. zodiacus* (2002) and *Chaetoceros* sp. (2003) and was followed by a dinoflagellate bloom of *Gymnodinium* spp., *Ceratium* spp. *Heterocapsa triquetra*, and UI dinoflagellates.

Plankton biomass in Totten Inlet was estimated using WDOEs measurements of chlorophyll a. WDOE measured chlorophyll a at 0.5 and 10 m at Windy Point and in Inner Totten Inlet sporadically from 1989 to 1999 (Figure 14). Average chlorophyll a concentrations were calculated for each month and each depth strata. Because there was little difference between the surface and subsurface samples, all monthly data was used to

An Assessment of Potential Impacts of Mussel Raft Culture To Surrounding Waters and Associated Biota of Totten Inlet

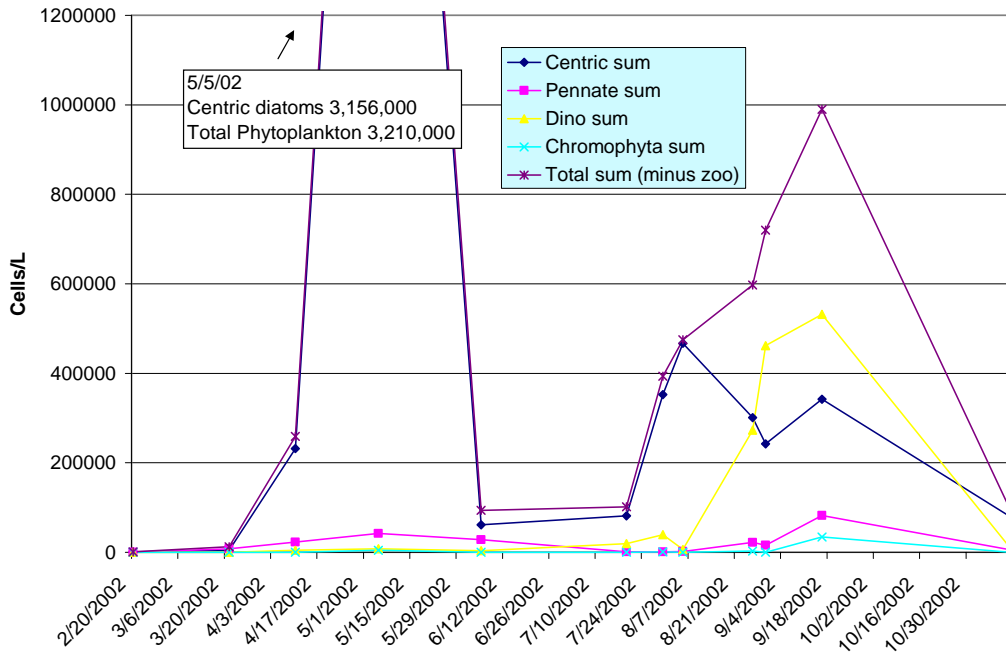


Figure 12. Phytoplankton Abundance at Reference Station, Totten Inlet, 2002.

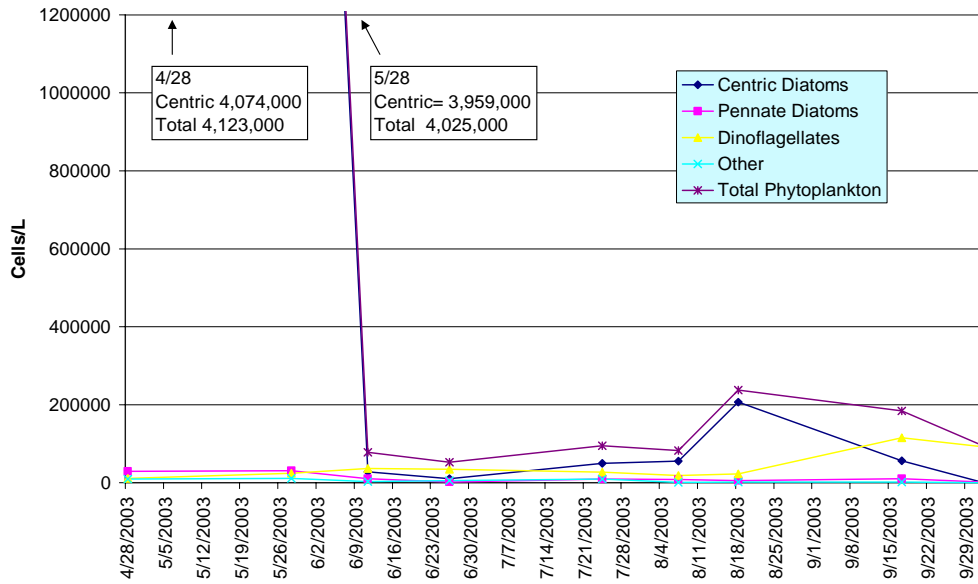


Figure 13. Phytoplankton Abundance at Reference Station, Totten Inlet, 2003.

calculate an average monthly and annual value for chlorophyll a which was then used to determine biomass in North Totten Inlet. Chlorophyll a measurements were collected from Inner Totten Inlet in 1999 only. Because 1999 year had unusually high chlorophyll a concentrations and the Inner Totten Inlet data was only collected at this time, this data was not included in the analysis. North Totten Inlet average chlorophyll density was converted to wet weight of phytoplankton biomass and grams of carbon based on two conversion factors (Redman and Newton 1998): 60:1 carbon to chlorophyll; and 10:1 wet weight to carbon. The annual average wet weight biomass was 4.0 g/m^3 or 34.1 g/m^2 , based on a mean depth of 8.5 m. Monthly values ranged from 27.4 g/m^2 in January to 81.5 g/m^2 in August. Mean standing stock was 3.4 gC/m^2 (0.26 g C/m^2 to 8.2 g C/m^2). It is important to note that the carbon content in chlorophyll can vary by a factor of 10 or more, between species (WDOE 2002) as well as within species (Prins and Smaal 1989) and would greatly affect standing stock estimates.

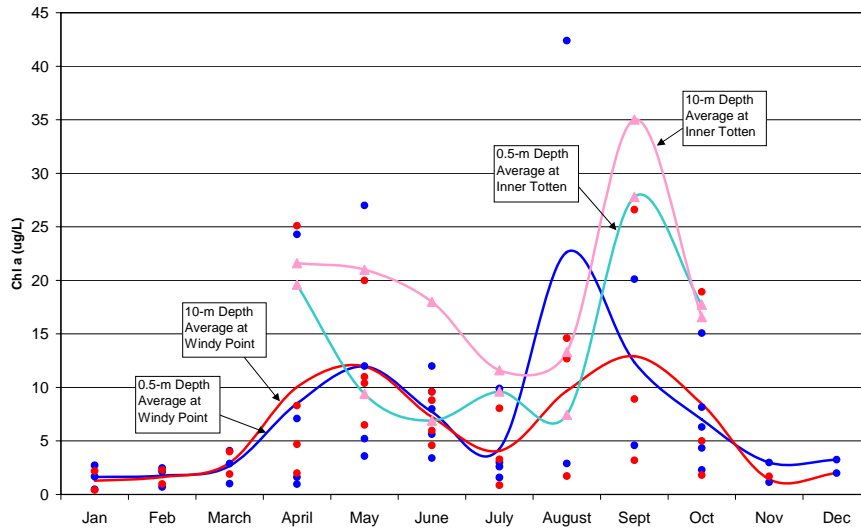


Figure 14. Chlorophyll -a Concentrations in Totten Inlet.

4. Mussel Raft Culture

The site of the proposed mussel raft arrays in Totten Inlet is located approximately 0.9 km northeast of Gallagher Cover in water depths of -15 to -70 ft. MLLW. At this site, Taylor Resources, Inc. proposes to install 50 to 58 rafts measuring 30 ft. x 34 ft. Suspended from each unit will be 720 lines (5 m long) that are seeded with approximately 1,000 mussels (Cheney et al., unpublished data). After seeding, the average time for mussels to reach harvestable size is between 14 and 18 months, when the typical mussel will weigh approximately 1.5 g dry wt. (EDAW 1998). Growth rates measured at Deepwater Point ranged between 0.08 and 0.18 g wet weight per day (PSI report in progress). The projected total yield for the North Totten Inlet site is 51,467 kg dry wt., with an estimated annual yield of 38,600 kg dry wt. (EDAW 1998).

4.1. Mussel Raft Interactions with the Surrounding Environment

Suspended longline mussel culture can influence the nutrient cycle in the water column through a several pathways. These pathways include removal of organic and inorganic nutrients in the water column through filtration and tissue storage, transformation and regeneration of nutrients through excretion of urea and biodeposits, and the transfer of water-column energy flow to benthic systems. Settlement and decomposition of biodeposits in the sediment then contribute to benthic biomass production or are regenerated back into the water column as dissolved and particulate organic matter. This is an important part of the nutrient cycle and will be covered in depth in a separate report (Brooks, *in preparation*). The regeneration of biodeposits back into the water column will be discussed here. It is important to note that the influences from mussel culture on the water column are not only caused by the cultured mussels, but also by the fouling community that also grows on the lines.

The blue mussel (*Mytilus edulis galloprovincialis*) feeds by filtering seston from the water column. Mussels effectively filter detritus and phytoplankton larger than 2-4 μ m. Captured seston is either ingested or discarded as pseudofeces, and in this way mussels are able to selectively feed on phytoplankton. Selective feeding (Prins and Smaal 1989) and increased gut retention time (Bayne et al 1987) are two methods in which mussels extract required nutrients from seston. In order to induce active filtration, mussels require a minimum of concentration of 2 to 6 x 10³ cells/ml (Newell et al 2001). Decreased filtration rates occur above 700 to 900 x 10³ cells/ml (Foster-Smith 1975). In general, filtration rates increase as temperature increases from 5 to 20°C (Widdows and Bayne

1971) and decrease over 20°C (Bayne 1976). Oxygen tension and salinity, as well as differing mussel species, can affect filtration rates (Bayne 1976). These factors probably account for the wide range of reported filtration rates in the literature (0.85 to 6.9 l/h/g; Jorgensen 1960, Bayne 1971, Bayne et al 1987, Prins and Smaal 1989, and Newell 2001). For Totten Inlet, mussel feeding rates measured between 0.85 to 3.5 mg/h/g (Davis et al, *manuscript in preparation*). However, these rates were calculated from mussels located in the center of the Deepwater Point mussel raft where phytoplankton concentrations were assumed to be the most depleted and may not represent mussel feeding rates along the perimeter of the raft. It is worth noting that although phytoplankton are the primary source of nutrition for mussels (Foster-Smith 1975, Bayne et al. 1987, Prins and Smaal 1989); detritus, bacteria and silt can be important, especially when phytoplankton is sparse during the winter (Gosling 1992, Langdon and Newell 1990, Winter 1978).

Several studies have examined the influence of mussel filtration on seston concentration and/or phytoplankton populations. One way to quantify this is to measure the flux of the phytoplankton, often measured as chlorophyll a, across the mussel bed or raft. Dame et al. (1991) measured flux across two mussel beds in Holland and found a significant decrease of chlorophyll a from the outflow of a flume placed over both mussel beds (4.13 mg/m²/h and 20.82 mg/m²/h). In Killary Harbour, Ireland, Rodhouse et al. (1985) measured a 30 – 60% reduction of chlorophyll a between the three hours before and three hours after slack tide. In another flux study in the Western Wadden Sea, the authors reported a 37% decrease of phytoplankton after passing through a mussel bed (Amus and Amus 1991). However, Amus and Amus (1991) also found a positive relationship between the uptake of phytoplankton and phytoplankton concentration. They hypothesized this relationship may be due to the nutrient release by the mussel bed, and calculated that the nitrogen produced by the mussels was sufficient to promote an eventual increase in phytoplankton biomass beyond by the incoming density.

The biological and physical processes affected by the presence of a mussel raft on the surrounding environment are summarized below:

Active Filtration by the Mussels

- a. Mussels filter detritus and phytoplankton larger than 2-4 µm, retaining a fraction of that filtered material for mussel growth processes and discard undigested seston and captured suspended sediment as pseudofeces. Various studies indicate that approximately 70% of the encountered suspended materials are captured by the mussel array, with 7.8% of that material being used for mussel growth and the remainder being discarded and regenerated within the surrounding water.
- b. A portion of this discarded fraction is also captured by fouling organisms associated with the array creating a mass of fouling and scavenger organisms with a biomass

approximately 33% of mussel biomass and carbon and nitrogen content that is approximately equal that of cultivated mussels.

Physical Structure Imposed by the Mussel Raft

- a. The raft array will also act as a vertical structure and reef that will attract small fish and invertebrates that orient to the structure (e.g., perch, crab, shrimp, etc.).
- b. The rafts will act to slow down the water entering the line array while water from the surrounding water mass will be entrained from the sides of the arrays and produce turbulent eddies down current.

Production of Turbulent Mixing

- a. This mixing process induced by the mussel raft structure will mix the surrounding unaffected water, nutrients and phytoplankton from the sides of the raft array with water that has passed through the mussel array. Modeling indicates that this is relatively rapid and will result in approximately 70% of the original concentrations of nutrients and phytoplankton within a very short distance from the raft (~10 ft.) and approximately 85% within the near-field mixing area where turbulent mixing is complete which is estimated to extend approximately 70-150 ft. down-current.

Waste Regeneration, Nutrient Cycling, and Particle Settlement

- a. Approximately 20% of the discarded materials (equivalent 11.0% of the filtered seston) settle at rates of <0.5 to <0.8 cm/sec and this material may accumulate in the sediments surrounding the array.
- b. The remaining fractions of nutrients (carbon, phosphorus, ammonia, nitrates, and nitrites) are released back into the water column and are apparently directly useable by phytoplankton.
- c. Once the momentum of the mixing process is dissipated, the particles that can settle will begin to fall and the most rapidly settling particles are estimated to come in contact with the bottom.
- d. The nutrients released into the water column after passage through the raft are in different forms than they were prior to this passage. The predominance of ammonia in the release during phytoplankton growing seasons may permit different phytoplankton species to increase in abundance. The responding phytoplankton are food for various species of zooplankton which in turn provide nourishment to higher trophic levels, including larger zooplankton, shrimp, other small water column invertebrates, small fish, larger fish (including juvenile and adult salmonids) that reside in Totten Inlet permanently or for only short periods of time.

Key attributes of raft dynamics in Totten Inlet that will be used throughout this report are presented in Table 1. Cultivated mussel tissue is comprised of 35 to 45% dry wt. carbon and 7 to 10% dry wt. nitrogen, depending upon the time of year (Rodhouse et al. 1984). According to Prins and Smaal (1989), the nitrogen concentration in mussel tissue is more consistent than carbon content due to carbon storage and loss with pseudofeces and gamete production. Tissue storage represents an important overall negative flux of carbon and nitrogen when mussels are harvested from the environment. Rodhouse et al. (1985) estimated that 8.13 kg C/m² and 1.65 kg N/m² over the raft area would be removed from an estuary in Ireland during harvest. For North Totten Inlet, Brooks estimated that the harvest of mussels over 16 months would result in the removal of approximately 11,000 kg of carbon, or 2.12 kg C /m² raft area (Brooks 2000). The carbon and nitrogen percentages used for this estimate were lower than those derived by Rodhouse et al. (1984).

For this analysis, we use the estimated carbon and nitrogen content reported by Rodhouse (1985). Based on the harvested biomass of 51,467 kg dry wt. (EDAW 1998), or 20,587 kg C and 4,375 kg N. This would represent an annual harvest of 38,600 kg dry wt., or 15,440 kg C and 3,281 kg N. It is important to consider the mass of tissue, carbon, and nitrogen that is placed into Totten Inlet at the beginning of the grow-out. The stocking biomass, based on 200 seed/g, would be 686 kg wet wt. (68.6 kg dry wt.) or 27.5 kg C and 5.8 kg N. The project net gain of biomass in North Totten Inlet is then projected at 51,399 kg dry wt. Annual net harvest would be 38,549 kg dry wt., or 15,412 kg C and 3,275 kg N. These values are the basis of analyses of impacts to species of concern, presented in Section 4.3

In addition to nutrient uptake by mussels, the mussel rafts provide habitat and substrate for fouling organisms. This community is quite diverse and includes species that feed on seston in the water column, as well as on the mussel feces and pseudofeces. Brooks (2003) evaluated the fouling community associated with the Deepwater Point rafts shortly after seeding, in the middle of the grow out period, and prior to harvest. Dominant species observed in the fouling community included bivalves (*O. conchophila*, *Modiolus* sp. and *Mytilus* sp.), *Nereis* sp., *Corophium* sp., and anemones. Seasonally important species included *Caprella* sp. and *Chthamalus dalli*. Based on harvest data collected by Taylor Resources, Inc from Deepwater Point, fouling organisms represent approximately 33% of the total wet weight removed from Totten Inlet at harvest. Based on a projected harvest wet weight biomass of 514,670 kg (Table 1), the projected fouling community biomass would be 169,841 kg or 16,984 kg dry wt. As the fouling community includes a diverse community and biomass data are not available by taxa, wet weight conversion factors and carbon/nitrogen content are difficult to determine. For dry wt., a general conversion of 10% is used.

An Assessment of Potential Impacts of Mussel Raft Culture To Surrounding Waters and Associated Biota of Totten Inlet

Table 1. Key Attributes of Raft Dynamics in Totten Inlet.

Attribute	Measurement	Citation	Value Used in Discussion
Length of Line	10m	Rodhouse et al., 1985	5m
	5m	Cheney et al. unpublished data	
Number of Lines per Unit	720	Cheney et al. unpublished data	720
Meters of Line per Unit	54 rafts*720 lines*5m = 194,400 m	Cheney et al. unpublished data	194,400 m
Density of Lines	4-5/m ²	Rodhouse et al., 1985	7.2 m ²
	5,160 m ² /720 lines = 7.2/m ²	Cheney et al. unpublished data	
Entrainment Dimensions	5.5 and 7.3 m to the side of each raft (estimated from figures)	Alden Research Laboratory, 2003	5.5 and 7.3 m to side of each raft
Initial mixing	(7.3m+5.5m+9.1m) = 21.9 m	This report from Alden Research Laboratory data	21.9
Phytoplankton Standing Stock	80.7 g/m ² (live wt.)	Redmond and Newton, 2001	100 g/m ²
	120 g/m ² (live wt.)	This report, based on	
	96.4 to 291 g/m ² (live wt.)	Cheney et al. unpublished data	
Phytoplankton Production	400 to 5700 mg C/m ² /day	WDOE, 2002	2.5 g C/m ² /day
Harvest Time	<18 months	Rodhouse et al., 1985	16 months
	14-18 months	Cheney et al. unpublished data	
% Dry Wt/ Live Wt Mussels	10%	Cheney et al. unpublished data	10%
Carbon content of mussel	3.4%	Sutterlin et al., 1981	40%
	35% to 45% (average 40%)	Rodhouse et al. 1985	
Chlorophyll/Carbon ratio of phytoplankton	1/50 or 0.02%	Brooks, 2000	0.02%
Harvest Biomass (Total Weights)	51,467 kg dry wt. 514,670 kg live wt.	EDAW 1998 – total estimate DBW*/0.1	51,467 kg dry wt. 514,670 kg live wt.
	<5 kg/m (live wt.) <250 kg/m ² (live wt.)	Rodhouse et al., 1985	
	10.2 kg/m ² (dry wt.) or ~102 kg/m ² (live wt.)	52,800 kg/5,160 m ² for Totten Inlet (≈40.8% of Rodhouse)	10.2 kg/m ² (dry wt.) or ~102 kg/m ² (live wt.);
	0.27 kg/m (dry wt.) or ~2.72 kg/m (live wt.)	EDAW, 1998	0.27 kg/m (dry wt.) or ~ 2.7 kg/m (live wt.)
	5 g/individual (live wt.)	Rodhouse et al., 1985	1.5 g/individual (dry wt.) or 15 g (live wt.)
	1.5 g/individual (dry wt.) or 15 g (live wt.)	EDAW, 1998	
Initial Stocking Biomass	3.77 kg C/m ²	Rodhouse et al., 1985	689 kg wet wt.; 68.9 kg DBW 27.5 kg C; 5.8 kg N
	0.78 kg N/m ²		
	4.83 C/N		
	689 kg wet wt.; 68.9 kg dry wt.	This report; Johnson, personal comm.	
	27.5 kg C; 5.8 kg N 4.74 C:N		
Harvest Biomass (Carbon and Nitrogen Weights)	8.13 kg C/m ² – Net 4.36 kg C/m ²	Rodhouse et al., 1985	8.10 kg C/m ² *0.408=3.30 kg C/m ² 1.64 kg N/m ² *0.408=0.67 kg N/m ²
	1.65 kg N/m ² – Net 0.87 kg N/m ²		
	4.93 C/N – Net 5.01 C/N		
	8.13 kg C/m ² – Net 8.10 kg C/m ²	This report; Johnson, personal comm.	
	1.65 kg N/m ² – Net 1.64 kg N/m ² 4.93 C:N		
Consumption Prior to Harvest	55.5 kg C/m ²	Rodhouse et al. 1985	55.5 kg C/m ² *0.408=22.7 kg C/m ² 6.69 kg N/m ² =2.73 kg C/m ² 8.30 C/N
	6.69 kg N/m ²		
	8.30 C/N		
Respiration	34.2 kg C/m ²	Rodhouse et al. 1985	34.2 kg C/m ² *0.408=13.93 kg C/m ² 3.16 kg N/m ² *0.408=1.29 kg C/m ² 10.81 C/N
Excretion	3.16 kg N/m ²		
Respiration/Excretion	10.8 C/N		
Feces Production	11.1 kg C/m ²	Rodhouse et al. 1985	11.1 kg C/m ² *0.408=4.53 kg C/m ² 1.29 kg N/m ² *0.408=0.53 kg C/m ² 8.61 C/N
	1.29 kg N/m ²		
	8.61 C/N		
Gametes	1.59 kg C/m ²	Rodhouse et al. 1985	1.59 kg C/m ² *0.408=0.65 kg C/m ² 0.49 kg N/m ² *0.408=0.20 kg C/m ² 3.25 C/N
	0.49 kg N/m ²		
	3.25 C/N		

Table 1. Key Attributes of Raft Dynamics in Totten Inlet. (Continued)

Attribute	Measurement	Citation	Value Used in Discussion
Benthic Scavenger/ Decomposers	4.32 kg C/m ²	Rodhouse et al. 1985	4.32 kg C/m ² *0.408=1.76 kg C/m ²
	0.88 kg N/m ²		0.88 kg N/m ² *0.408=0.36 kg C/m ²
	4.91 C/N		4.91 C/N
Filtration Rates	30-60% Chlorophyll a removal	Rodhouse et al., 1985	30-60% Chlorophyll a removal
	37% phytoplankton decrease	Amus and Amus 1991	69% phytoplankton decreased
Biodeposition	20% of filtered but not converted to tissue C or Nitrogen in mussels or fouling	Estimation	3.82 kg C/m ² 0.403 kg N/m ²
Returned Nutrients	42% of filtered N	Rodhouse et al. 1985	67% of filtered N
	58 % of filtered C	Rodhouse et al. 1985	68 % of filtered but unused C
% Consumed Phytoplankton Producing Mussel Biomass (Trophic Transfer)	7.85% of C	Percentages determined from data in Rodhouse, et al., 1985.	7.85% of C
	13% of N		13% of N

Rodhouse et al. (1985) report carbon and nitrogen removed during content in scavengers/decomposers that is approximately equal to that of harvested mussels. However, they also comment that starfish consuming feces and pseudofeces that drop from rafted mussels onto the seabed comprise the majority of this biomass. Based on Brooks' survey, the Totten Inlet fouling community biomass is likely dominated by the heavier anemones, bivalves, and gastropods. Although numerically dominant (approximately 40% of total abundance), amphipods, crustaceans, and annelids combined probably represent a relatively small portion of the harvested biomass. Anemones contribute significantly to wet weight biomass, but probably do not contribute significantly to overall harvested carbon or nitrogen. Since mollusks are numerically dominant and likely to contribute significantly to overall biomass, the carbon and nitrogen content estimated for mussels will be used for the fouling community (40% dry wt. for carbon and 8.5% dry wt. for nitrogen). Thus, the estimated amount of carbon and nitrogen associated with harvest of the fouling community is estimated at 6,794 kg C and 1,444 kg N, or 1.32 kg C/m² and 0.28 kg N/m². Annual harvest is estimated at 5,096 kg C and 1,083 kg N.

The transfer efficiency for rafted mussels was calculated based on the model presented by Rodhouse et al. (1985) and is based on consumption rates and harvest biomass. In order to reach the projected growth at harvest, the mussels would have removed approximately 22.7 kgC/m² from Totten Inlet (Table 1), resulting in an increased net growth of 3.3 kg C/m². The conversion of carbon to mussel biomass therefore represents an efficiency of approximately 14.5% of the filtered carbon.

Mussels excrete nitrogen into the water as ammonium, urea, and/or amino-N. Of the total nitrogen excreted by mussels, Bayne (1973) found that during the winter months 41% of the nitrogen excreted was ammonium, 4% as urea and 55% as amino-N. These rates changed slightly during the summer, where 67% was ammonium, 5% as urea and 28% as amino-N. Bayne and Scullard (1977) developed several equations

Excretion

to predict ammonium excretion based on mussel biomass (dry wt.):

$$V = aW^b$$

Eq 3

Where: V is the rate of excretion, W is the mussel dry weight, a and b are fitted parameters for the variables. Nitrogen excretion was observed to be highest in the summer months and lowest in the winter months. In addition to the generic equation, Bayne and Scullard (1977) also developed equations to calculate ammonium production for five months to account for seasonal differences in excretion rates: January $V_{\text{NH}_4}=7.1*W^{1.160}$; May $V_{\text{NH}_4}=31.9*W^{1.480}$; July $V_{\text{NH}_4}=34.6*W^{0.615}$; September $V_{\text{NH}_4}=18.5*W^{0.720}$; and November $V_{\text{NH}_4}=4.9*W^{0.482}$ (*M. edulis*). These equations showed that ammonium excretion for mussels weighing between 0.2 and 2.0 grams were highest during the spring and summer months (Bayne and Scullard 1977). Brooks (2000) used the generic equation for *M. galloprovincialis*; where NH_4 (μg) = $6.27 W^{0.287}$, to estimate the average total ammonium load from the proposed mussel raft to equal 179.6 grams per hour. Based on Rodhouse et al. (1985), the amount of nitrogen released by the rafted mussels through excretion and fecal production is estimated at 1.29 kg N/m² and 0.53 kg N/m², respectively and an additional 0.54 kg N/m² by the fouling community.

An increase in ammonium downstream of mussel beds has been reported for several mussel beds and mussel culture sites (Rodhouse 1985, Amus and Amus 1991, Dame et al. 1991). This trend also occurred at the Deepwater Point mussel raft in Totten Inlet. During the Deepwater Point study by PSI, measurements of ammonium (NH_4), nitrate (NO_3^-), and nitrite (NO_2^-) were taken on selected dates through June and October of 2002. Samples were collected 2.5 m below the surface during flood and ebb tides (Cheney et al., report *in preparation*). This data suggests that ammonium, nitrate, and nitrite concentrations increase as water moves through the mussel raft during a tidal cycle, with peaks typically occurring either at the raft center or immediately downstream of the tide, at the boom. In the center of the raft, the concentration of ammonium ranged from 0.87 to 6.11 μM . However, in all samples except one, ammonium concentrations at the downstream buoy (230 ft. from raft end) were similar to the background concentrations taken at upstream buoy station. This suggests dilution or settling of the nitrogen occurs within the water column between the boom and buoy (230 ft). Modeling of water flow around the rafts also suggests that lateral mixing may account for the apparent removal of inorganic nitrogen in the water column (Alden Research Laboratory 2003).

Contributions to the organic nitrogen by mussels and epifouling organisms occur through fecal and pseudofecal production. In fact, in a review on the feedback mechanisms from mussel culture, Prins et al. (1998) state that it appears the primary source of nitrogen released back into the environment is from the re-mineralization of organic nitrogen found in mussel biodeposits. Several studies have found that the

degradation of biodeposits from suspended mussel culture resulted in a significant increase of ammonium in the water column above the sediment (Amus et al. 1990, Hatcher et al. 1994, Christensen et al. 2003). Similar results were reported for the Deepwater Point mussel raft, where significantly elevated concentrations of total nitrogen and ammonium were detected in the water column 2 and 20 cm above the sediments, but not at 50 cm above the sediment (Brooks 2003b). This suggests that the source for total nitrogen and ammonium originated from the benthos.

Kautsky and Evans (1987) estimated a yearly biodeposition rate of 11.7 g/m² per gram of dry wt. for *M. edulis*. These biodeposits contained a C:N ratio of 7.9. The mean annual deposition rate of biodeposits from *M. chilensis* was 234 g of sediment/m²/d (250 – 300 ind./m²) with a C:N sediment ratio 21.4 (Jaramillo et al 1992). Miller et al. (2002) found settling rates of 1.1 and 1.7 cm/sec for horse mussels (*Atrina zelandica*) fed cultured phytoplankton diet, and 2.0 and 3.0 cm/sec mussels fed a phytoplankton diet with silt. Chamberlain et al (2001) reported settling rates for *M. edulis* were slower than those observed with horse mussels, being less than 0.5 cm/sec for feces and less than 0.8 cm/sec for pseudofeces.

Biodeposits and their breakdown materials can become re-suspended as the current passes under the mussel raft. Cromey et al. (2002) calculated an average re-suspension rate of 1.8 g/m²/hr for biodeposits, with a mean current velocity of 4.9 cm/sec. At Deepwater Point, currents at 2.5 m below the surface within the Deepwater Point mussel raft ranged between 2.9 and 3.4 cm/sec, while outside the raft the average currents ranged from 14.2 to 16.5 cm/sec. However, the effect near the bottom is unclear, as currents have been shown to accelerate beneath the rafts, increasing the near bottom erosional forces (Richardson and Newell 2002).

EDAW (1998) calculated that currents at the proposed North Totten Inlet site exceeded the erosional threshold of 10 cm/sec approximately 75% of the time and suggested that pseudofeces that were not incorporated into the bottom by biogenic processes would be resuspended and transported away from the site. However, observations by Brooks (in preparation) indicate that a portion of the biodeposits remain and form a stable benthic community. This is probably related to the benthic infauna methods for capturing suspended material from the water column and using them for food or building materials for tubes and burrows. However, the proportion of biodeposits that remain in the vicinity of the site will be discussed in a subsequent report (Brooks, in preparation).

Dissolved oxygen concentrations are subject to increase oxygen demand in area of organic enrichment or increased demand. Dissolved oxygen concentrations were measured during incoming tides in the Deepwater Point mussel rafts by PSI during the 2002 and 2003 surveys. There was a decrease in dissolved oxygen in the raft center from each sampling event; however, dissolved oxygen at the down-current edge of the raft returned

Biodeposits and Resuspension

Dissolved Oxygen

to background concentrations. Figure 15 shows two representative dissolved oxygen profiles at the Deepwater Point site. The August profile was typical of those observed in August and September and the July profile was more typical of fall, spring and early summer. For August, 100% saturation was 7.78 mg/L and the low value in the raft center was 4.4 mg/L.

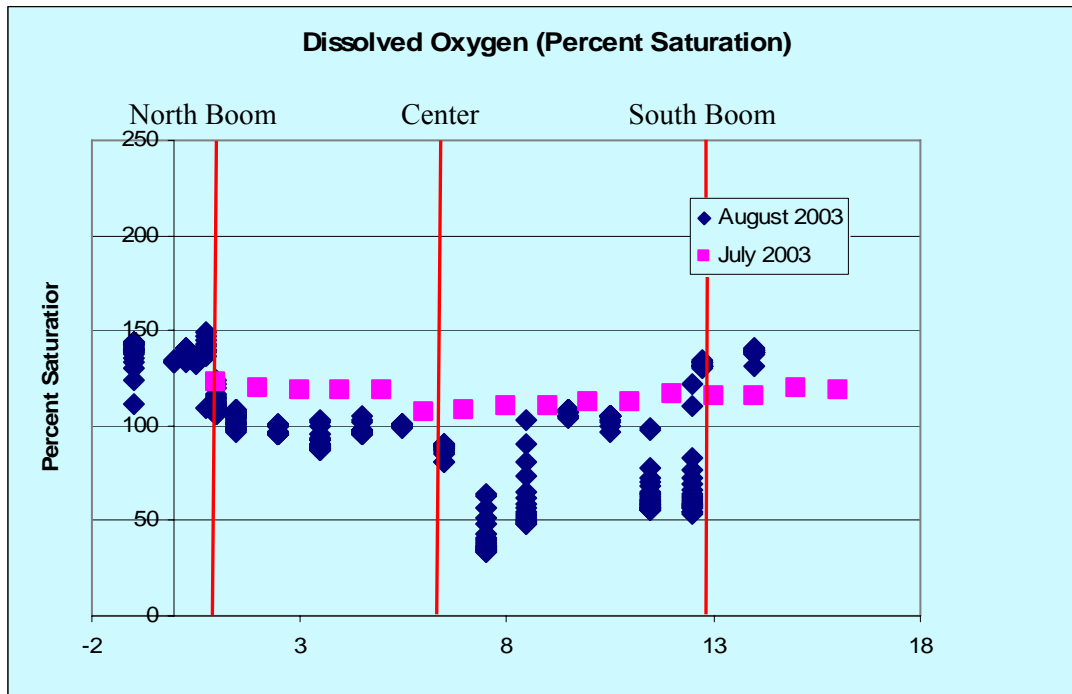


Figure 15. Dissolved Oxygen Profile at Deepwater Point in July and August 2003.

4.2. Mussel Raft Effects on the Surrounding Environment

Definitions of near-field, mid-field and far-field provide spatial boundaries for assessment of the effects of the mussel raft cultures on existing conditions. A variety of definitions could be developed that range from legal descriptions of allowable ‘footprints’ of the rafts, to turbulence patterns associated with the rafts, settlement characteristics of particles and their influence on benthic communities, the extent of water movement under various tidal regimes (ranging from minimum to maximum tidal extent), and areas or volumes of water containing elevated or decreased concentrations of various nutrients or biological materials (e.g., ammonium, urea or phytoplankton populations numbers or chlorophyll content), or arbitrary boundaries based on many potential attributes (e.g., personal ownership, city or county boundaries; historical uses, etc.).

Definition of Near Field, Mid Field, and Far Field

We intend to use the physical movement of water (slow down, eddy production, dissipated eddy patterns, and tidal extent of the potential transport of raft related impacts) combined with the influence of tidal ranges to designate spatial boundaries for the evaluation of near-, mid- and far-field biological effects. Our examination of potential changes to biological attributes within Totten Inlet is based on assessments within each of these generalized fields.

For the purposes of this review we examined the physical effects associated with a mussel raft located at Deepwater Point within Totten Inlet (Alden Research Laboratory 2003). When water is swept towards the raft/mussel-line complex, the water velocity moving through the array is reduced. As the water passes through the mussel raft complex turbulence is created by the more rapidly moving water surrounding the raft moving into the slower moving waters adjacent to and downstream of the raft. The turbulence created by these physical factors is transported in the direction of the tides where eddies are observed until the momentum produced by the rafts is dissipated.

The near-field locations are closely associated with the mussel rafts and are within the area of maximum expected environmental change that occurs as a result of mussel raft culture. This near-field area can be described as the physical structure of the raft producing a ‘shadow’ of itself within the water column through production of reduced current speeds. For single rafts arranged with the long axis parallel to tidal currents the reduction of speed from outside of the raft to within the raft is approximately 3.5 to 4-fold throughout the water column (Alden Research Laboratory 2003). This disruption in current speed continues to influence the water column through the production of turbulence patterns turning

Near-Field

inward from both sides of the array until they eventually degrade and form larger “composite” eddies (rather than eddies produced by single rafts). Based on physical measurements made during field experiments and subsequent current modeling of the Deepwater Point rafts (Alden Research Laboratory 2003), the area of turbulent mixing extends to 25 to 46 m in the direction of the current at a current speed of 15 cm/sec (Figure 16). The apparent width of the mixing zone was 5.5 m to 7.1 m to the sides of the raft during current speeds of ~15 cm/sec. A similar pattern of entrainment likely occurs at the bottom of the array, creating turbulence near the bottom that provides upward mixing, as well as intermixing with the lateral eddies. This process would not only mix the dissolved and particulate matter entrained from the raft, but would possibly suspend or resuspend settling particles. For the purposes of this analysis we assume that the dimensions at the proposed site are similar to those observed at Deepwater Point. It is important to note that differences in current speeds could effectively lengthen or shorten the initial turbulent mixing zone.

A summary of biological processes that have been observed at other suspended culture farms and may be expected at the proposed North Totten Inlet mussel rafts are summarized below:

Removal of Plankton

- a. The removal of plankton and seston from the water swept through the mussel array (ranges from 30-60% of chlorophyll a and ~37% decrease in phytoplankton – Rodhouse et al., 1985 and Amus and Amus 1991). Additional measurements include the removal of plankton over a partial tidal cycle of approximately 47% of the chlorophyll content and 62% of the carotenoid materials contained in the incoming water, seston and plankton (Rodhouse et al. 1985). This removal is concentrated on particles that are larger than 2 to 3 and as much as several hundred microns in diameter (Wright et al. 1982; Bayne 1976).
- b. It appears that the mussels are able to retain this rate of removal over a wide range of plankton densities (<50,000 to more than 800,000 cells per mL; Foster Smith 1975). Concentrations of phytoplankton lower or higher than these ranges result in changes in filtration efficiency.

Removal of Carbon and Nitrogen

- a. The estimated quantity of C and N that was consumed by the mussels in Killary Harbour prior to harvest was 55.3 and 6.69 kg/m². Projected use by mussels in Totten Inlet is lower than observed in Killary Harbour by a factor of 2.37 (net harvest biomass increases). The amount of carbon and nitrogen used by mussels to create this mass is projected to be 23.33 and 2.82 kg/m², respectively.

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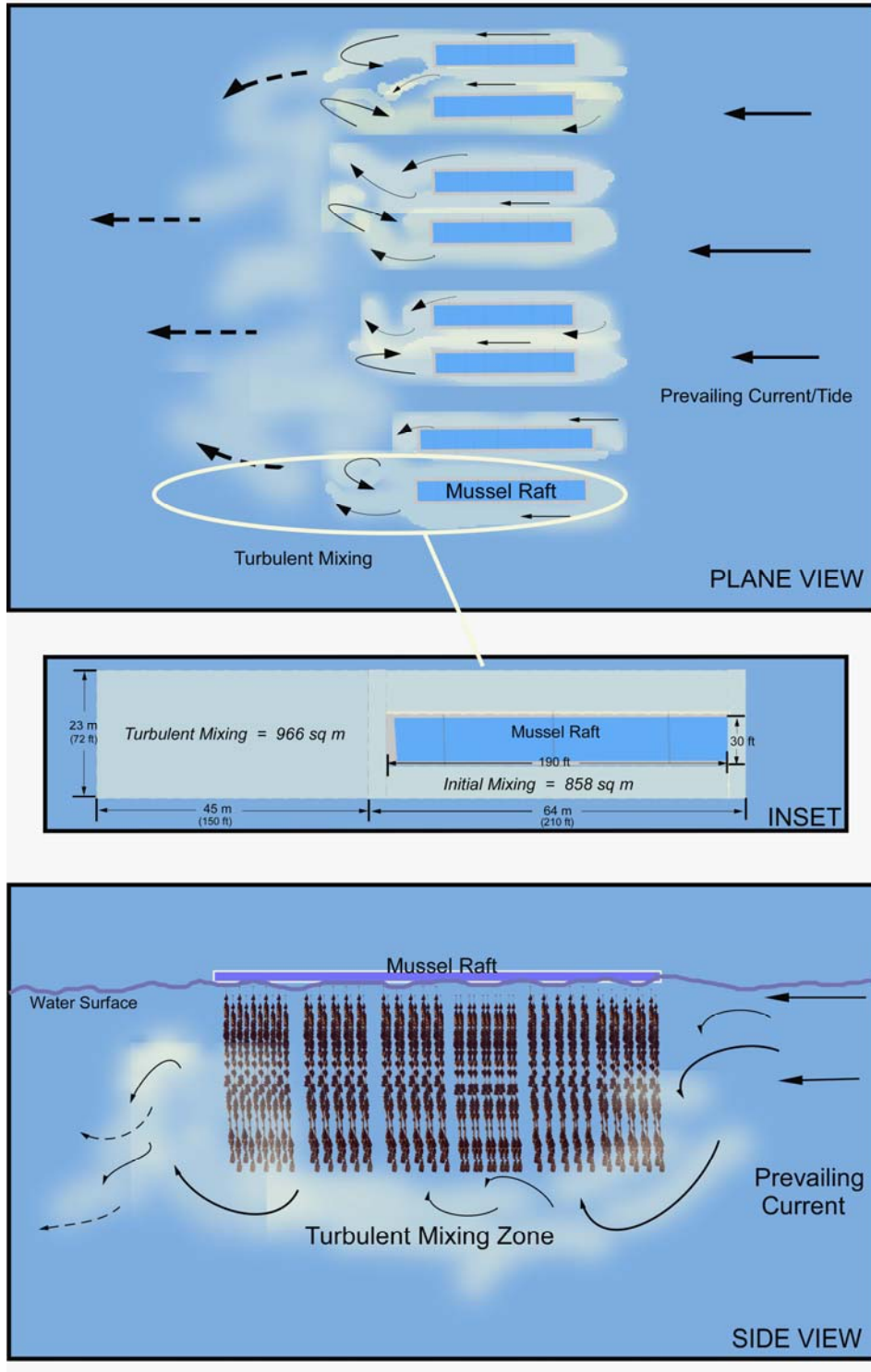


Figure 16. Illustration of Turbulent Mixing Patterns in the Vicinity of Mussel Rafts

Increase in Mussel Biomass

- a. The addition of the initial mussel mass that was deployed from the rafts in Killary Harbour was 3.77 kg C, 0.78 kg N, and 111 kg total biomass/m² (Rodhouse et al. 1985). Total biomass was determined by dividing C values by the conversion value of 3.4% (Sutterlin et al. 1981 and Haamer 1996).
- b. Some of the consumed material was converted into mussel biomass (~7.85% of the consumed carbon and 13% of nitrogen) while the remainder was voided as pseudofeces, gametes or waste materials for use by other organisms. Approximately the same amount of C and N are converted into fouling or scavenging organisms living associated with the raft and are converted into mussel biomass. On average the percentage of consumed food sources that are converted to mussel biomass is approximately 10%. These percentage values were obtained from the net carbon or nitrogen contained in harvested mussels divided by the total carbon or nitrogen consumed by the mussels in Killary Harbour (Rodhouse et al. 1985).
- c. The removal of mussels during harvesting at Killary Harbour resulted in 8.13 kg C, 1.65 kg N, and 239 kg total biomass/m². The net increase in mussel biomass that is then removed during harvesting was 4.36 kg C, 0.87 kg N and 129.12 kg of biomass/m² (Rodhouse et al. 1985). This represents an average of 2.15-fold the stocking biomass. It is also interesting to note that a comparable amount of carbon and nitrogen (4.2 kg of C and 0.88 kg of N) are also converted into scavenger or decomposer biomass associated with the rafts.
- d. The projections by EDAW (1998) indicate a live weight harvest biomass of 102 kg/m². Using the same relationship of stocking biomass to harvest biomass obtained from data provided in Rodhouse et al. (1985) indicates the increased growth would be equivalent to 54.6 kg/m².

Excretion and Regeneration of Nutrients

- a. The materials that are not converted to mussel biomass are released into the water column and include particulate wastes and pseudofeces that may contain living or dead phytoplankton cells and gametes as well as regenerating nutrients including ammonium, ammonia, nitrates, nitrites, dissolved organic carbon, organic phosphorus among others (Dame et al. 1991).
- b. Bayne (1973) found that urea releases ranged from 4 to 5% while ammonium release of nitrogen containing

compounds representing 41 and 67%, and amino-N compounds representing 55 and 28% of the release during winter and summer, respectively. Estimates of the total ammonium excreted from the proposed mussel raft in Totten Inlet represented 179.6 g/h. Kasper et al. (1985) demonstrated that the ammonium released by the mussel rafts is immediately available for phytoplankton production in surface waters.

- c. Measurements of ammonium concentrations in the center of mussel rafts at the Deepwater site in Totten Inlet indicate a concentration of <0.11 mg/L, indicating that the amount of water that this quantity of ammonia is released into, over an hour must be at least 1,000,000 L. This could be through dilution but is more likely due to movement and resupply of water mass as ammonium is released.

The mid-field area begins at the end of the turbulent mixing zone and extends to the maximum extent of tidal excursion during spring tidal events. mid-field is therefore defined as the spatial increase that occurs between the locations of principal turbulent eddy production (25 to 46 m down-current and 7.1 m to the side of the rafts) to the distance that maximum tides will carry a body of water away from the raft. Based on available data, this distance is estimated at 2500 ft. (see discussion below). Because of the relatively rapid speed of these tidal currents, it is anticipated that the main influence of the rafts will continue down-current with a width equivalent to that of the near-field. It is important to note that areas with dramatic shift in bathymetry will introduce additional lateral and vertical forcing which would expand the mid-field laterally and further dilute any affects due to the rafts. Another consideration is tidal reflux, the partial return of water to the rafts during the reverse tide. Given the complex nature of water movement in north Totten Inlet, this influence is expected to be relatively small. Although not included in our calculations, refluxing could affect estimates of water-column changes from the mussel rafts.

Mid-Field

The physical processes that occur in the mid-field area include horizontal transport away from the rafts and settlement of particles released from the rafts or resuspended from the bottom in the near-field zone. These materials may become incorporated in the mid-field sediments or they may be captured by suspension feeding organisms living in the bottom. If integrated into the sediments or benthos, the particulate may influence benthic conditions by providing additional detrital food resources or by releasing nutrients during the regeneration of the organic materials. Both sulfides and ammonium may be released from the sediments. A summary of components of the mid-field are presented in Table 2.

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Table 2. Physical and Biological Characteristics Used to Define the Mid Field Environment.

Attribute	Measurement	Citation or Method	Value Used in Discussion
Average bottom depth at proposed site	19 m	Brooks 2000; EDAW1998	19 m
Settling rates of feces and pseudofeces	<0.5 cm/sec (f)	Chamberlin et al. 2001	<0.5 cm/sec (f)
	<0.8 cm/sec (pf)		<0.8 cm/sec (pf)
Particle fall height range	9 -19 m	Range of min to max fall heights	9 – 19 m
Incoming Tidal Current Velocities			
Maximum Tidal Current Speed at Mouth of Totten Inlet	3 kts	NOAA, Tidal Current Tables, 20 year Maximum – December 4, 1990	1.8 kts
More typical maximum spring tidal current at mouth of Totten Inlet	2.6 kts	Estimated from Tidal Current Tables – Example Jan 30, 1998	
Minimal neap tidal current at mouth of Totten Inlet	1.0 kts	Estimated from Tidal Current Tables – Example – January 22, 1998	
Average of maximum current speed at mouth of Totten Inlet	1.8 kts	Estimated average from typical spring and neap maximum tidal currents at mouth of Totten Inlet	
Ratio of maximum tidal current to average speed during tidal cycle	50%	EHI estimate = maximum velocity to 0 velocity integrated over time	50%
Average current velocity at mouth of Totten Inlet	0.9 kts	1.8 kts*0.5 = 0.9 kts	0.9 kts
Ratio of tidal velocity at Totten Inlet site compared to opening of Totten Inlet	1,070m 1,800m = 59.4%	(ratio of cross sectional areas at mouth of Totten Inlet and at proposed mussel site) – depths across channel ave ~ 10 fm	59.4%
Average velocity of incoming current at North Totten Inlet Mussel Raft Site	0.53 kts	0.9 knots*0.594 = 0.53 kts	0.53 kts
Tidal Current Speed Cross Checks With Alternative Methods of Measurement			
Maximum current velocity measured at site	32.5 cm/sec = 0.63 kts	32.5 cm/sec /51.4 cm/sec/kt (EDAW1998)	0.63 kts
Average current velocity measured at site	18.7 cm/sec = 0.36 kts	18.7 cm/sec / 51.4 cm/sec/kt – EDAW, 1998.	0.36 kts
Average drogue speed	16-36 cm/sec = 0.31-0.70 knots; averaging 0.51 kts	EDAW, 1998	0.51 kts
Distance of Tidal Excursion Using Various Tidal Velocities			
Typical length of time for incoming tide	6 hours	NOAA Tide Table, 1998	6 h
Excursion distance of leading edge of plume	19,334 ft.	0.53 knots *6hour*6,080ft/knot	3.18 nautical mi
Excursion distance of center of plume event	9,667 ft.	0.5 typical length of the incoming tide	1.59 nautical mi
Times to settlement for fastest settling particles (pseudofeces)	1,125 secs	(9 m*100cm/m)/0.8 cm/sec	1800 secs
	2,375 secs	(19 m*100cm/m)/0.8 cm/sec	3800 secs
Distance traveled over fall times for fastest settling particles (pseudofeces)	1,007 ft.	0.53 kts*(1,125 secs/3,600 secs/h)	1,007 ft.
	2,125 ft.	0.53 kts*(2,375 secs/3,600 secs/h)	2,125 ft.
Times to settlement for fastest settling particles (feces)	1,800 secs	(9 m*100cm/m)/0.5 cm/sec	1800 secs
	3,800 secs	(19 m*100cm/m)/0.5 cm/sec	3800 secs
Times to settlement for fastest settling particles (feces)	1,611 ft.	0.53 kts*(1,800 secs/3,600 secs/h)	1,611 ft.
Distance traveled over fall times for fastest settling particles (feces)	3,401 ft.	0.53 kts*(3,800 secs/3,600 secs/h)	3,401 ft.
Annual biodeposits for North Totten Site	26,400 kg dry wt.*11.7 kg/ yr-kg dry wt. = 308,880 kg 308,880 kg/(600m*30m) = 17.16 kg/m ²		
Deposition rates of feces and pseudofeces	11.7 g dry wt./yr.	Katusky and Evans, 1987	11.7 g dry wt./yr.
Organic content of excretory products	18% Volatile Solids 7% C 1% N		18% TVS 7% C 1% N

Biological processes that are expected to occur in the mid-field area include changes to the benthic community, additional cycling of nutrients, and phytoplankton growth. A fraction of the waste material (~20%) settles to the sea floor where it may become incorporated into benthic community biomass. This increased deposition of organic materials may manifest itself as increased abundance and species richness of deposit feeding invertebrates or increased biomass of suspension feeders. Changes to the benthic community will be evaluated in a separate report. Nutrients released by raft organisms or those that pass through the array are rapidly converted into forms that are then used for phytoplankton growth. Based on C/N ratios, calculations of the potential value of the waste products to increased production by localized phytoplankton stocks were estimated to be equivalent to the production that had occurred prior to passing through the mussel raft.

The far-field area is that area beyond the maximum range of the spring tidal excursion. The outer boundaries of the far-field area are more difficult to define, as turbulent mixing and interactions with incoming water masses at the mouth of Totten Inlet increase and effectively erase any signature the rafts may have. For the purposes of this analysis, the outer boundary of the far-field area will be the perimeter of Totten Inlet. The dominant physical process in the far-field area is extensive mixing at the sills south of Gallagher Cove where depths decrease from >18 fathoms to 2-3 m, and at the mouth of Totten Inlet.

Far-Field

In an effort to understand the effects of mussel rafts on the phytoplankton community, PSI conducted a series of sampling surveys at the Deepwater Point mussel rafts. During 2002 and 2003, phytoplankton samples were collected from discrete depths at locations up-current of the rafts, within the raft array, and down-current from the rafts. Samples were collected intensively in 2002 with 33 sampling events for phytoplankton and five sampling events for chlorophyll a. Sampling was less intensive in 2003, with 10 sampling events for phytoplankton and five sampling events for chlorophyll a. Samples were generally collected with a Niskin bottle, fixed in the field, then concentrated and sorted to species in the laboratory. Phytoplankton were identified to Lowest Taxonomic Level and reported as cells/L. As water moved through the rafts on an incoming tide, current moved from the North Buoy (NBY) station (-230 ft.), to the North Boom (NBM) (-10 ft.), through the center (CENTER) of the raft (0 ft.) and on to the South Boom (SBM) (+10 ft.) and the South Buoy (SBY) (+230 ft.). For this analysis, the north buoy is considered the reference station.

PSI Field Experiments

In 2002, there was a statistically significant difference between phytoplankton abundance at the center station, relative to the NBY reference, with a 72.4% reduction in abundance (Figure 17 and 18). There was no statistically significant difference between the average phytoplankton abundance observed at NBY and that of NBM, SBM, and SBY, which had average percentage reductions in phytoplankton abundance of 8.4%, 27.1%, and 0%, respectively. The lack of statistical significance at SBM may be due in part to the variability about the means. In two sampling events, there was a 50% to 60% reduction in abundance at NBM and there is clearly decreased abundance at SBM, with percentage reductions of 7.8% to 71.3%.

In 2003, there was a statistically significant reduction in plankton abundance, relative to NBY, at all stations, with the exception of SBY (Figure 19). Relative to NBY, mean phytoplankton abundance was reduced by 23.0% (NBM), 65.4% (center), and 36.3% (SBM). Phytoplankton abundance at SBY was not statistically significantly different than NBY, with only a mean reduction of 4.8%.

Chlorophyll a measurements were collected at transects from the North Buoy to the South Buoy (Table 3). As with the plankton abundance, chlorophyll a concentrations decreased significantly in the center of the raft and returned to near background at the South Buoy. There was a decrease at the NBM, up current of the leading edge of the raft. This pattern was further demonstrated by a series of depth profiles collected by PSI and Alden Research Laboratory at Deepwater Point (2003). Instantaneous measures of chlorophyll a were collected at 2 m depth intervals at the North Buoy, North Boom within the raft system and at the South Boom and South Buoy. Chlorophyll a concentrations show a decrease at the North Boom, then a rapid decrease, to $< 2 \mu\text{g/L}$, at approximately 60 feet from the leading edge of the raft. Chlorophyll a concentrations increased at the final rafts and were near background 50 m from the trailing edge of the raft. Chlorophyll a concentrations at depth within the raft and at the down-current stations varied considerably. This was credited to an upwelling effect caused by the acceleration of flows beneath the raft and lateral mixing, or advection, induced by the raft wake (Alden Research Laboratory 2003).

A similar effect was observed in oyster raft experiments in Gorges Harbour, British Columbia (Richardson and Newell 2002). Phytoplankton abundance in the center of the raft was reduced by approximately 60%; however, phytoplankton populations and chlorophyll a concentrations in the wake of the raft were increased due to upwelling and advection (Figure 19). There was also a high degree of variability with depth, with the samples from under the raft having the highest chlorophyll concentrations. This was also credited to upwelling resulting from current acceleration under the raft. Continuous measurements through the tidal cycle indicate that the lowest concentrations at the raft center occurred at low tide. There was little difference between the center and the raft edge during the mid-ebb or mid-flood.

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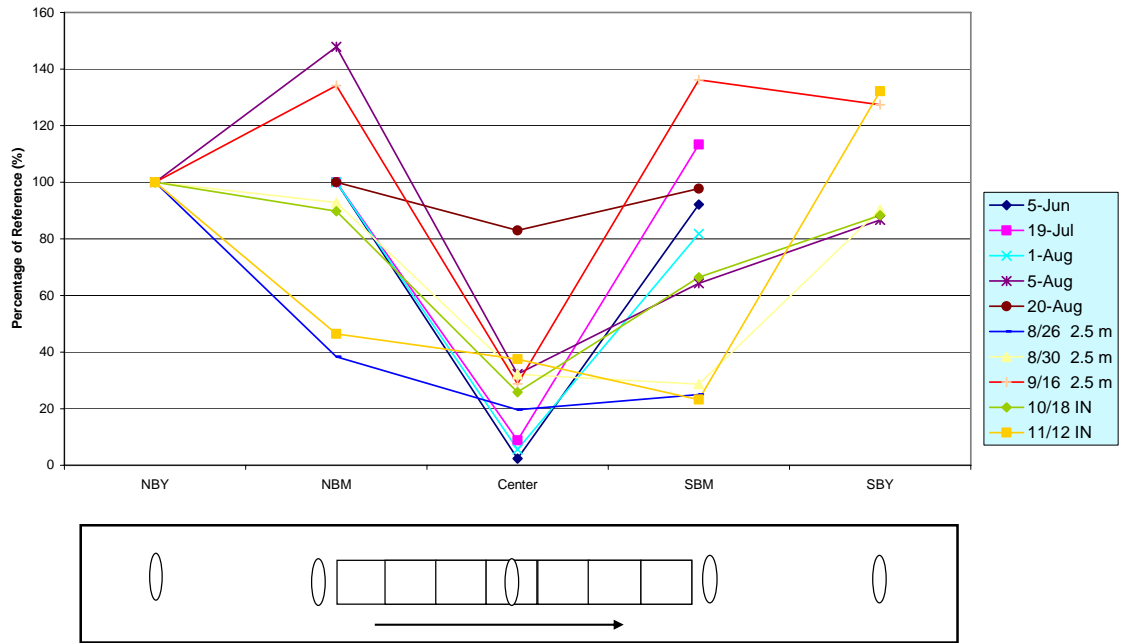


Figure 17. Percentage Change in Phytoplankton Density at Deepwater Point 2002

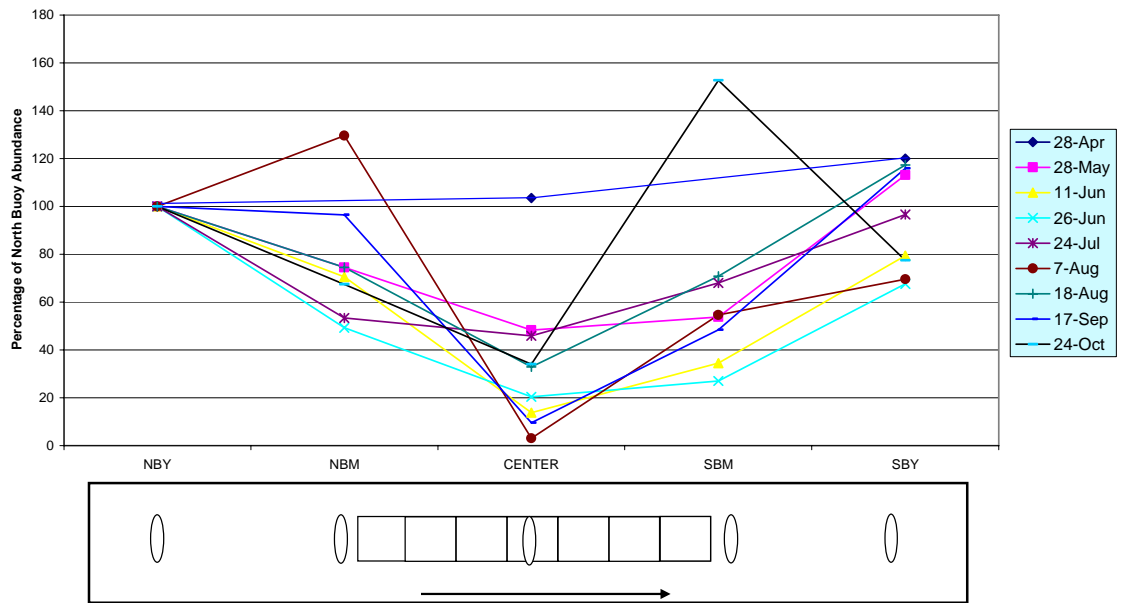


Figure 18. Percentage Change in Phytoplankton Density at Deepwater Point 2003.

Table 3. Predicted Changes in Phytoplankton Biomass at Deepwater Point Rafts.

Sampling Event/Data Source	NBY	NBM	Center	SBM	SBY
Deepwater Raft - June Average (PSI)	4.4	3.6	1.5	3.9	4.0
Deepwater Raft - August Average (PSI)	13.0	7.4	1.2	8.9	15.5
Deepwater Raft – Sept. Average (PSI)	13.5	18.0	2.0	16.0	17.5
Average (chl a $\mu\text{g/L}$)	10.3	9.7	1.6	9.6	12.3
Percent of Reference	100.0	93.6	15.2	93.0	119.7
Predicted Biomass:					
Average Biomass (WDOE) (g C/m ²)	34.1	31.9	5.18	31.7	40.8
Average Biomass (ECOPATH) (g C/m ²)	72.6	68.0	11.0	67.5	86.9
Dec Primary Productivity	400 mg C/m ² /d				
July Primary Productivity	5300 mg C/m ² /d				

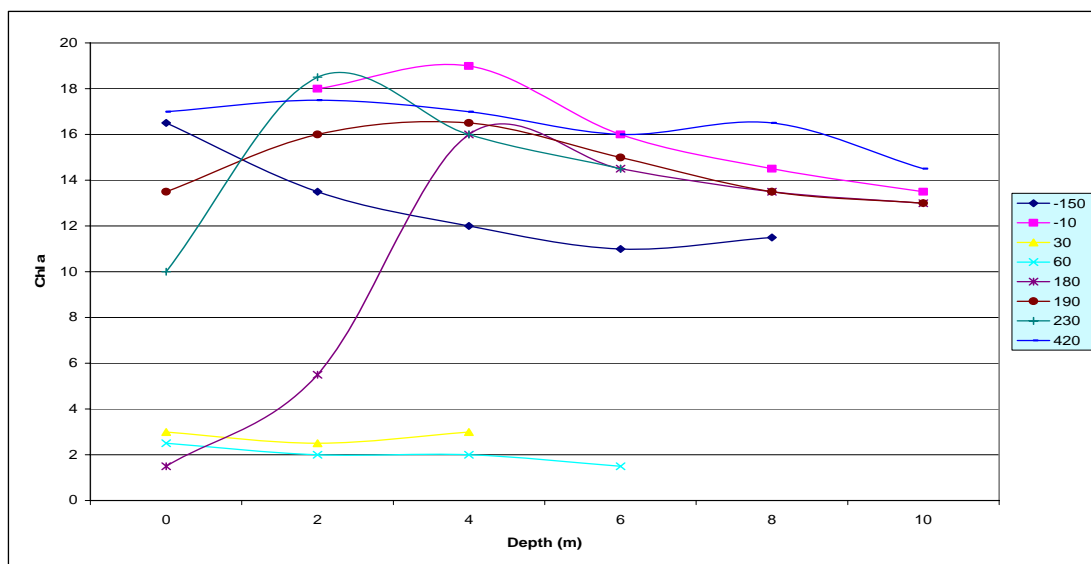


Figure 19. Chlorophyll a Depth Profiles at Different Distances (ft.) from the Leading Edge of the Raft at Deepwater Pt.

Phytoplankton species composition shifted as water passed through the rafts. During periods for which there was one dominant species there was little difference in composition inside the raft versus outside the raft. This is true of the February sampling dominated by the pennate diatom, *Thalassiosira* sp. and the April/May spring bloom, dominated by *Chaetoceros* sp. (>90% of the total in all stations). As the phytoplankton assemblage became more diverse, a preferential decrease in centric diatoms occurred in the center and south boom stations. When dinoflagellates were present in dominant numbers, there was little difference between sampling stations. These trends were consistent across tidal stages. As with abundance and chlorophyll a concentrations, the phytoplankton assemblage returned to background at the SBY.

Changes in the phytoplankton assemblage were also observed in Gorges Harbour, with a selective removal of smaller flagellates and a community shift to diatoms and dinoflagellates (Richardson and Newell 2002). In mesocosm experiments, Prins et al. (1995) showed that mussel grazing induced a species shift, not necessarily through top-down control, but from preferential bottom-up selection for faster reproducing phytoplankton.

The importance of advection has been previously observed both in mussel beds and mussel rafts (Prins et al. 1995; Richardson and Newell 2002). In each case, phytoplankton abundance and chlorophyll a show little, if any, decrease after passing through the rafts. Turbulent mixing and entrainment of waters adjacent to the rafts are most likely the cause of such immediate response and appear to overwhelm any measurable signal from the rafts.

To determine whether these observations are consistent with mixing of unfiltered water entrained from the sides of the raft a simple mixing model can be used. The physical processes and dimensions of the mixing zone are based on those presented in the previous discussion of the near-field area. Separate calculations were made based on phytoplankton abundance, carbon concentrations and nitrogen concentrations measured outside and within the rafts by PSI. It is assumed that, as water passes through the rafts, phytoplankton are removed and not replaced immediately; whereas, carbon and nitrogen are both removed and released by the mussels and fouling community, although carbon release is considered to be relatively insignificant (Rodhouse et al. 1985).

Based on observations at Deepwater Point, phytoplankton abundance downstream of the raft could be calculated using the following initial mixing calculation:

$$[(5.5\text{m} \times 100\%) + (9.1\text{m} \times 29\%) + (7.3 \text{ m} \times 100\%)] \div 21.9 \text{ m} = 70.5\%$$

Eq. 3

Thus, the percentage reduction in phytoplankton abundance relative to the reference attributable to turbulent mixing alone would be 29.5% (Figures 20 and 21). This estimate agrees with the field measurements taken at the SBM, 10 feet from the raft end, which indicated reductions of 27.1% in 2002 and 36.3% in 2003 with an average of 31.7% reduction. The percentage reduction for carbon and nitrogen after initial mixing would be 13% and 17%, respectively.

**Initial Turbulent
Mixing**

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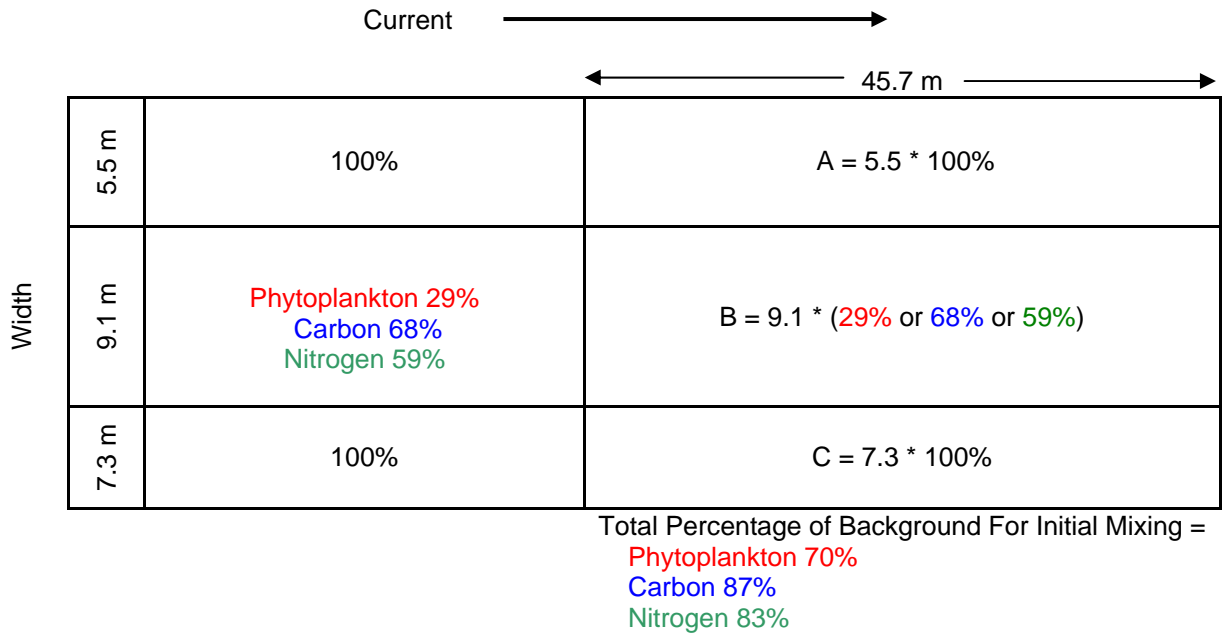


Figure 20. Illustration of Initial Mixing Model.

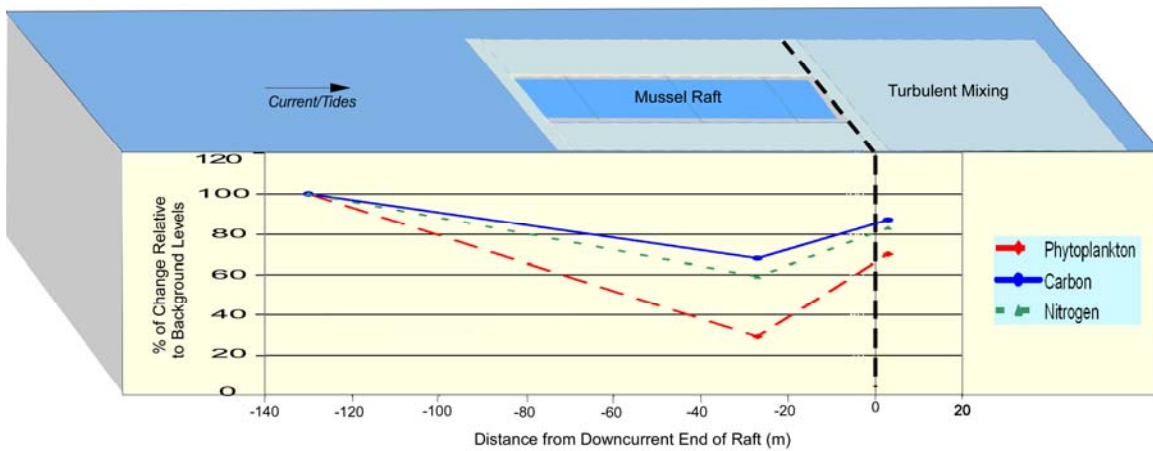


Figure 21. Raft Related Effects on Phytoplankton, Carbon, Nitrogen.

Mixing Model and Primary Production

In order to further understand mussel raft effects on phytoplankton populations beyond the initial mixing zone, the simple mixing model was combined with primary production based on a carrying capacity model developed by Dame and Prins (1998) which was then applied on a local scale. Dame and Prins (1998) suggest that an effect on phytoplankton from a mussel raft occurs when the mussel filtration rate is greater than or equal to phytoplankton turnover time and the plankton turnover time is shorter than the water residence time. In simple terms, the removal is greater than the regeneration rate. Applying this to the mid-field area is a two-part process that includes calculating residence time for a given area and applying phytoplankton turnover times or primary production rates.

Residence times were calculated based on the currents calculated for the North Totten Inlet site (0.27 cm/sec – Table 2) and the distance of travel. Turnover times were set at 0.64 division per day (Welch et al. 1984) and primary production was based on WDOE observations in Totten Inlet (WDOE 2002). The rate of cell division is based on *Skeletonema* sp. and may overestimate division times for smaller phytoplankton species or underestimate division times for some dinoflagellates.

The input parameters and the results of the model run for phytoplankton are presented in Table 4 and Figure 22. In this case, removal was based on the empirical data from the Deepwater Point raft experiments. Based on the data collected by PSI, phytoplankton abundance at the center of the raft were 29% of reference (NBY; Figures 18 and 19). As stated above, “recovery” of phytoplankton abundance and chlorophyll a in the near-field area was a result of initial mixing, not regeneration. This near-field prediction is based on empirical data and therefore incorporates interactions with the rafts and changes in current flow as a result of the raft structure. At the beginning of the mid-field area, after initial mixing, phytoplankton abundance was calculated at 70% of reference. Based on this model, phytoplankton abundance would reach 80% of background approximately 2000 m from the raft end background densities at 5,500 m from the raft end. On an outgoing tide that would take the parcel of water through the mouth, an area of extreme mixing. Because of dramatic changes in the bathymetry south of Gallagher Cove, it is difficult to determine how much additional mixing would occur towards the south.

The parameters and results for chlorophyll a are presented in Table 5 and Figure 22. As with phytoplankton abundance, chlorophyll concentrations are reduced to 15% of reference at the center of the raft (Table 3). At the end of the turbulent-mixing zone, chlorophyll a concentrations are 66% of reference (Table 5). Based on the production model, chlorophyll a would reach 90% of background in 2000 m and 100% of background approximately 2500 m from the raft. This area would extend from inside the Inlet mouth to the north and near Gallagher Cove to the south.

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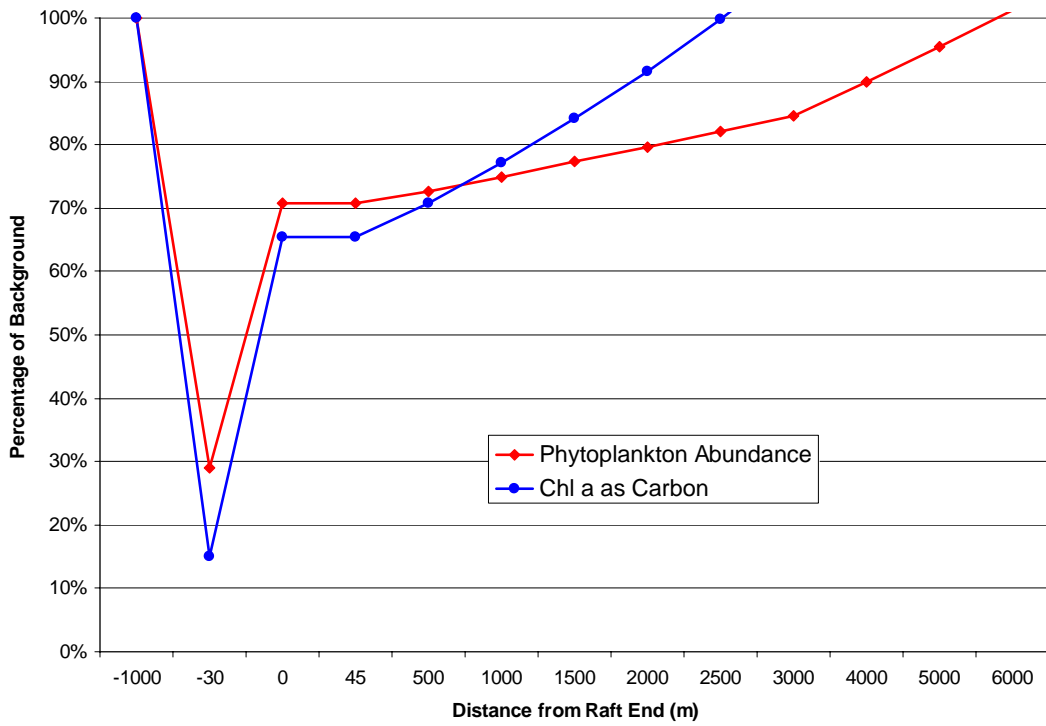


Figure 22. Recovery Distances Generated by Numerical Recovery Model.

An Assessment of Potential Impacts of Mussel Raft Culture
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Table 4. Model Input and Results for Phytoplankton Abundance (cells/L)

Distance from Raft (m)	Length of Run (m)	% of Reference Beginning of Run	Current (cm/sec)	Residence Time (min)	Proportion Increase in Abundance	Predicted Abundance (cells/L)	%Reference End of Run
Background	--	--	--	--	--	409,571	100%
Initial mixing	--	--	--	--	--	290,795	71%
45*	45	71%	0.27	2.78	0.0028	289,716	71%
500	455	71%	0.27	28.09	0.0281	297,854	73%
1000	500	73%	0.27	30.86	0.0309	307,047	75%
1500	500	75%	0.27	30.86	0.0309	316,523	77%
2000	500	77%	0.27	30.86	0.0309	326,293	80%
2500	500	80%	0.27	30.86	0.0309	336,363	82%
3000	500	82%	0.27	30.86	0.0309	346,745	85%
4000	1000	85%	0.27	61.73	0.0617	368,149	90%
5000	1000	90%	0.27	61.73	0.0617	390,874	95%
6000	1000	95%	0.27	61.73	0.0617	415,002	101%

* End of Turbulent Zone

Table 5. Model Input and Results for Chlorophyll a (g C/m²).

Distance from Raft (m)	Length of Run (m)	Percent of Reference Beginning of Run	Current (cm/sec)	Residence Time (min)	Proportion Increase in Abundance	Predicted Chl a (gC/m ²)	Percent Reference End of Run
Background	--	--	--	--	--	12	100%
Initial mixing	--	--	--	--	--	8	66%
45*	45	65%	0.27	2.78	0.0081	8	66%
500	455	66%	0.27	28.09	0.0814	9	71%
1000	500	71%	0.27	30.86	0.0895	9	77%
1500	500	77%	0.27	30.86	0.0895	10	84%
2000	500	84%	0.27	30.86	0.0895	11	92%
2500	500	92%	0.27	30.86	0.0895	12	100%
3000	500	100%	0.27	30.86	0.0895	13	109%
4000	1000	109%	0.27	61.73	0.1790	15	128%
5000	1000	128%	0.27	61.73	0.1790	18	151%
6000	1000	151%	0.27	61.73	0.1790	21	178%

* End of Turbulent Zone

The difference between the two estimates is primarily due to the primary production rates versus cell-division rates. Primary production rates were based on water samples collected from Totten Inlet, which incorporated variety of phytoplankton species and nutrient conditions present in Totten Inlet. Phytoplankton abundance estimates were empirically derived based on laboratory cell division rates using Puget Sound waters. The species of phytoplankton used in these experiments is found in Totten Inlet and is a centric diatom, the dominant phytoplankton class found in Totten Inlet. However, cell division rates vary by species and can be as fast as two divisions per day depending on light and nutrient conditions (Alpine and Cloern 1988; Furnas 1990).

These estimates are based on a simple flow model using average values for cell division rates and for primary production. Slower currents occurring during less extreme tidal shifts would presumably result in recovery over shorter distances, while faster currents would reduce removal rates. This model does not include refluxing of water at the mouth and is limited in its ability to predict affects to the south beyond Gallagher Cove.

Production rates used here do not incorporate stimulation as a result of nitrogen released to the water column by the mussels and fouling organisms. As mentioned earlier, nutrient studies conducted by WDOE (2002) indicate that Totten Inlet phytoplankton communities increase production rates with nitrogen additions, increasing over 200% in early summer.

Seasonal differences in phytoplankton assemblage, productivity, and mussel feeding and excretion rates would also alter the model output. Winter primary production and cell division rates are considerably slower due to winter primary production (400 mg C/m²/d). However, mussel feeding rate, based on cold-adapted *M. edulis*, are also significantly reduced during the winter months (Widdows and Bayne 1971). Further data on site-specific cell division rates and water movement between north and central Totten Inlet would increase the predictive ability of this model.

On an inlet-wide basis, Brooks (2000) determined that bivalve and zooplankton resources including the proposed mussel rafts would be at 10% of the carrying capacity. If this trend is true for the mid-field area and we assume that capture efficiency is not altered at a 10% to 25% reduction in phytoplankton abundance and biomass, then the carrying capacity of the mid-field area would not be exceeded. Data regarding zooplankton and bivalve populations in the near-field and mid-field areas would allow for a more accurate prediction of carrying capacity in the mid-field area.

4.3. Potential Impacts to Species of Concern

An estimate of annual carbon removal from mussel raft harvest was applied to the food-web model developed for each of the species of concern to determine whether there would be food web impacts as a result of mussel harvesting,

The Carbon Budget

The initial step in this process was to estimate the impact of carbon removal on the potential production of phytoplankton. The proposed expansion of mussel culturing in north Totten Inlet will produce approximately 38,600 kg dry wt.) of mussel tissue on an annual basis (or 52,800 kg DBW at harvest). As discussed in Section 4.1, the estimated net annual removal of carbon and nitrogen would be 15,412 kg C and 3,275 kg N (Table 1). Based on an estimated biomass of fouling organisms of 33% and average carbon and nitrogen content equivalent to that of mussels, annual removal associated with the fouling community is estimated at 5,096 kg C and 1,083 kg N.

Using average primary production estimate for Totten Inlet of 4.3 g C/m²/day and a surface area of 21 X 10⁶ m², the carbon removed by mussel tissues and associated fouling organisms is equivalent to approximately 0.06% of the Totten Inlet water column carbon used in phytoplankton production annually. This did not include the additional transfer of approximately 0.11% of carbon from the water-column to the sediment, some of which would be regenerated. Thus, the total loss of potential carbon for primary productivity as a result of the proposed mussel rafts would range from 0.06 to 0.17% for Totten Inlet.

Based on the conservative estimate of 0.17% reduction in phytoplankton production, losses for subsequent trophic levels was calculated using trophic transfer weighted for the proportional contribution to diets. Diet proportions used here are based on those presented in Figure 11. Transfer efficiency is that energy or biomass that is transferred between trophic levels. Transfer efficiency incorporates both ecotrophic efficiency (that consumed energy or biomass that is assimilated into bodily functions) and growth efficiency (that assimilated energy that is used for growth, thereby increasing the standing stock). Transfer efficiency for marine organisms is often estimated at 10% of intake. However, recent evidence indicates that for many marine organisms this value is higher (Parsons 2003). For the purposes of this evaluation, transfer efficiency between the zooplankton and phytoplankton will be estimated at 20% (Parsons 2003). For transfer to bivalves, the estimate of 10% will be used, with the exception of mussels, which have been calculated at 14.5% (Section 4.1). Transfer at the upper trophic levels (juvenile salmonids, herring, and adult salmonids) is estimated at 15%.

As stated above, percentage reduction in the standing stock for a given trophic level is based on transfer efficiency, the proportion of diet from the previous trophic level, and the percentage reduction in standing stock for the previous trophic level. Based on this model, percentage reduction on standing stock would be calculated as:

$$\%SS_{R_{II}} = \%Diet_I * (SS_{R_I} \times TE_{II}) \quad Eq. 4$$

where:

- % SS_{R_{II}} = percentage reduction in standing stock of the Trophic Level II;
- % Diet_{II} = percentage of Trophic Level II diet represented by Trophic Level I;
- TE_{II} = transfer efficiency of Trophic Level II.

Values for the standing stock and percentage of diet are presented in Section 3.1. This simple equation would be true for true herbivores, such as microzooplankton. The calculations for heterotrophic consumer, as well as for secondary and tertiary consumers, are slightly more complex. Heterotrophic consumers would experience both direct reductions when consuming phytoplankton directly and indirect reductions through predation on microzooplankton or smaller zooplankton and bacterioplankton. Species such as bivalves, small copepods, and larval crab and barnacles fall into this category. Upper trophic level consumers would consume prey on several trophic levels. With mixed diets, percentage reduction in standing stock is the sum of each trophic level consumed. The same basic formula presented in equation 4, adjusted for the selected prey, would be used to calculate the percentage reduction of standing stock of each receptor. An example based on bivalves is presented below:

Based on a bivalve diet comprised of ~70% phytoplankton (Trophic Level I) and ~25% microzooplankton (Trophic Level II):

$$\% SS_R = [70\% \times (0.17\% \times 10\%)] + [25\% \times ((0.17\% \times 20\%) \times 10\%)] \quad Eq. 5$$

The percentage reduction in standing stock is then used to determine the projected reduction in standing stock (Eq 6).

$$\text{Projected reduction in standing stock} = SS_0 \times \% SS_R \quad Eq. 6$$

Table 6 provides a summary of input and projected reductions in standing stock for key taxa supporting the salmonid and bivalve food webs. Based on this trophic transfer model, it is clear that the taxa feeding lower on the food chain are most affected by the reduced phytoplankton abundance. The predicted reductions in bivalve standing stock ranged from 0.005% to 0.018%. This would likely be experienced as a reduction of total biomass across an area, rather than a reduction in the number of individuals. It is also possible that this reduction would be skewed towards the location of the North Totten Inlet rafts. However, without more localized standing stock and current data it is difficult to predict the local extent of these reductions.

Effects of phytoplankton reductions to juvenile salmonids and adult salmonids are substantially less, primarily due to the dilution effect with additional trophic transfer steps. Juvenile salmonids are predicted to have standing stock reductions of 0.0016%. Fish on the fourth trophic level would be relatively unaffected, with 0.0006 to 0.0008% reductions in standing stock. Returning adults will probably be impacted less than resident adults due to the short residence time in Totten Inlet and reduced feeding and growth during their return.

Table 6. Reduction in Standing Stock of Key Taxa as a Result of Reductions in Phytoplankton Standing Stock.

Species	Standing Stock (kg dry wt.)	Standing Stock (kg C)	Trophic Level	Percentage Reduction in Standing Stock	Projected Reduction in Standing Stock (kg dry wt.)
Clams ¹	179,000	71,600	II/III	0.012%	214
Geoducks ¹	7,562	3,025	II/III	0.005%	3.78
Oysters ¹	20,000	8,000	II/III	0.012%	24.0
mussels ¹	34,000	13,600	II/III	0.018%	61.2
Zooplankton ¹	22,271	8,908	II/III	0.016%	35.6
Forage Fish ²	24,675	11,104	III	0.0021%	5.18
Chum smolts entering ²	1802	811	III	0.0016%	0.288
Exiting Chum Salmon ²	608	273	III	0.0016%	0.097
Returning Chum salmon ²	57,000	25,650	IV	0.0008%	4.56
Coho smolts entering ²	338	152	IV	0.0016%	0.054
Exiting Coho salmon ²	674	303	IV	0.0016%	0.108
Returning Coho salmon ²	15,188	6,834	IV	0.0008%	1.22
Resident salmonids ²	9,342	4,203	IV	0.0006%	0.560

¹Dry wt. to carbon conversion based on 40%.

²Dry wt. to carbon conversion based on 45%.

It is important to understand the assumptions and limitations of this model in predicting the effects of carbon removal. Perhaps the most important assumption is that the receptors are food limited and that reductions in prey standing stock directly result in reductions in receptor standing stock. Brooks (2000) estimated that, with the proposed rafts in place, Totten Inlet would be at approximately 10% of carrying capacity for bivalves and zooplankton. This indicates that on an annual basis, Totten Inlet may not be food limited and that the current estimate would provide a conservative estimate for annual trends in Totten Inlet. Based on an estimated decrease of 0.016% for zooplankton, it is unlikely that the tertiary consumers, such as juvenile salmonids and herring are within 0.02% of the carrying capacity.

A second assumption is that phytoplankton and microzooplankton comprise nearly all of the bivalve diet. However, many bivalves feed on benthic diatoms

and detritus, as well as bacterioplankton (Brooks 2000, Sorokin and Giovanardi 1995; Ward et al. 2003; Cognie et al 2001). However, the proportion of diet represented by these other sources over the population of bivalves throughout Totten Inlet is unclear. Again, the projected impacts presented here represent a conservative estimate.

It is also important to note that other fish and invertebrate species that share the same trophic level and feeding habits as those species described here would be predicted to experience the same effects. The robustness of this model would be improved with additional data specific to the proposed site.

As stated above, nitrogen is also removed from Totten Inlet during harvest. Based on the percentage of nitrogen entering the raft system, approximately 22% is transferred into harvested biomass. Approximately 3,275 kg N/yr is removed with mussel harvest and 1,083 kg N is removed with the associated fouling community. As Brooks (2000) points out, this represents a small percentage of the annual point source and non-point source inputs of nitrogen using Budd Inlet. While very little of the discharge into Budd Inlet likely pass into Totten Inlet (LOTT 1998), the point that mussel harvest may help to offset anthropogenic sources of nitrogen is important consider.

The Nitrogen Budget

Current investigations of depressed dissolved oxygen concentrations in Hood Canal, Washington have identified nitrogen as a contributing factor to eutrophication and enhanced algal growth (PSAT/HCCC 2004). Aside from oceanic sources of nitrogen, anthropogenic sources, particularly on-site septic systems are considered to be the major source of nitrogen into Hood Canal. Based on an EPA study of on-site septic systems (PSAT/HCCC 2004), much of the ammonia-nitrogen that passes through an on-site septic system is oxidized to NO_3 and NO_2 , with 30% to 70% of nitrogen entering the groundwater. Once in the groundwater, the nitrates and nitrites are conservative and eventually move down-gradient into the receiving marine waters. An estimate for sewage-related nitrogen in Hood Canal is provided based on population in the watershed, annual nitrogen release from untreated sewage per person (average 9 mg/person/day), and the percentage removal by septic systems (30% to 70%).

The Kennedy/Schneider watershed is an area of population growth, particularly along the southeastern shore of Totten Inlet similar to the Hood Canal vicinity. Land use in this watershed is transitioning from rural/agricultural uses to residential uses (WDOE 2003a). Unlike Hood Canal and Budd Inlet, there is little data to support a detailed nitrogen budget from these sources for Totten Inlet. Based on estimates from WDOE (2002), stream/watershed input of dissolved inorganic nitrogen (DIN) to Totten Inlet is approximately 47,450 kg N/yr. This estimate does not distinguish between nitrogen sources.

Also similar to Hood Canal, much of this area is served by on-site septic systems. Based on the formula used in the Hood Canal Dissolved Oxygen Study and year 2000 Census data (Golder 2003; US Census Bureau 2000), an estimated 10,939 to 25,524 kg N/yr is predicted to enter Totten Inlet from human sewage related sources. On an inlet-wide basis, the nitrogen removed

by the mussel raft system proposed for North Totten Inlet represents 17.1% to 39.8% of the nitrogen introduced by the on-site septic systems and 9.2% of the nitrogen projected to enter the watershed via the watershed creeks. It is important to note that the non-point sources of nitrogen are spread throughout Totten Inlet, whereas the removal of nitrogen by the rafts occurs in North Totten Inlet. It is also important to note that, due to its shallow depths and wind-driven mixing, Totten Inlet is less susceptible to the stratification observed in Hood Canal, reducing the possibility of eutrophication.

The mussel rafts may also be a localized source of nitrogen, through the transfer of seston to nitrogenous wastes. Approximately one-third of nitrogenous wastes are in the form of feces and are incorporated into the fouling community or in the benthic community. As discussed previously, this form of nitrogen may again become incorporated into the water column community over a period of time. Approximately 7,000 kg N/yr is released directly into the water column via excreta. As demonstrated by Ecology (WDOE 2003b), during the late spring/early summer, a portion of this nitrogen is likely used in increased phytoplankton growth. During the fall and winter, the phytoplankton community is less likely to respond to the increased nitrogen; however, this is a time when mussel feeding and excretion is also decreased. The magnitude and nature of phytoplankton community response to the forms of nitrogen available downstream from the rafts is still unclear.

5. Conclusions

Taylor Resources, Inc. is considering the placement of a floating mussel raft facility on the northeastern portion of Totten Inlet, approximately 1,000 m north of Gallagher Cove. The goal of this technical report was to characterize the nature and extent of possible effects of this proposed facility to water-column organisms in Totten Inlet, within the requirements of an environmental impact statement.

Evaluation of the mussel raft effects from Totten Inlet was divided into three regions: near-field, mid-field, and far-field. Near-field included those areas where the physical processes of water passage through and around the mussel raft array occur and included the mixing and entrainment of water from under and to either side of the array. The mid-field was defined by extent of tidal excursion and the resulting horizontal transport from the rafts. Far-field represented Totten Inlet and focused on effects related to the annual removal of carbon and nitrogen during harvest.

In the near-field, the bounds of turbulent mixing were based on models and field experiments at mussel rafts in Totten Inlet. The near-field area was considered to be 46 m down current from the end of the rafts and 5.5 to 7.1 m to either side of the rafts. With typical current speeds of ~27 cm/sec, transport across the near-field area was predicted to occur within the first 5 minutes of exposure to the raft environment. Significant reductions in phytoplankton abundance were observed in the center of the raft complex at Deepwater Point, with average reductions at the raft center of phytoplankton abundance (29% of background), carbon (68% of background), and nitrogen (59% of background). Samples collected 10 ft. downcurrent from the terminal face of the mussel rafts showed less of an effect than anticipated, with phytoplankton abundance, carbon and nitrogen content of 71%, 87%, and 83% of background. This increase was primarily due to turbulent mixing and entrainment of water from beside and below the rafts. There may be some limited additional mixing that occurs within the near-field zone; however, for the purposes of this exercise we have made the assumption that the concentrations of phytoplankton, carbon and nitrogen observed at 10 ft. from the terminal face will be retained throughout the near-field environment.

The mid-field area, based on the additional transport occurring during a tidal cycle, was estimated at approximately 1.59 nautical miles (2,947 m) from the terminal face of the raft. Processes expected to occur within the mid-field area include cell divisions of entrained phytoplankton, responses to the regenerating nutrients released by the mussel/fouling community complex, fixation of carbon and nitrogen through photosynthesis, settlement of the more rapidly settling particles (generally pseudofeces from mussels and detrital materials from the fouling community), and regeneration of nutrients from these settled particles. Field samples collected at Deepwater

Point showed no statistically significant difference in phytoplankton abundance, chlorophyll a, and nitrogen content between water samples collected 230 ft. down current from the raft terminal face and background concentrations. It is believed that this recovery to background levels is primarily due to advection and entrainment of adjacent water masses that have not passed through the mussel rafts. Further predictions using a model based on cell division rates and residence times indicate that phytoplankton populations will return to within 80% to 90% of background within the mid-field area. However, the ability to predict changes in highly mixed areas and impacts to associated resources in the mid-field area are limited by the available data.

The far-field area was defined as Totten Inlet. An estimate of the potential influence of the proposed mussel rafts in the far-field area was based on removal of carbon and nitrogen during harvest. The proposed expansion of mussel culturing in North Totten Inlet was predicted to produce approximately 38,600 kg dry wt. of mussel tissue on an annual basis and an estimated 15,440 kg C and 3,281 kg N annually. Harvesting of fouling organisms is predicted to remove an additional 5,096 kg C/yr and 1,083 kg N/yr.

The net removal of carbon is expected to occur over the average surface area of Totten Inlet, approximately $21 \times 10^6 \text{ m}^2$. Estimated effects of this removal were based on the assumption that losses will occur throughout the Totten Inlet food web through a reduction of carbon flowing through food webs. Based on an average primary productivity estimate for Totten Inlet of $4.3 \text{ g C/m}^2/\text{d}$ and a surface area of $21 \times 10^6 \text{ m}^2$, the carbon removed by mussel tissues and associated fouling organisms is equivalent to approximately 0.06% of the Totten Inlet water column carbon used in phytoplankton production annually. This does not address the additional transfer of approximately 0.11% of carbon from the water-column to the sediment, some of which would be regenerated. The total loss of potential carbon for primary productivity as a result of the proposed mussel rafts would range from 0.06 to 0.17% for Totten Inlet.

Using a trophic transfer model that incorporates both feeding preferences and transfer efficiencies of 10% to 20% depending upon receptor species, percentage reduction in standing stock were estimated for key receptor species. The predicted reductions in bivalve standing stock ranged from 0.005% to 0.018%. This would likely be experienced as a reduction of total biomass across an area, rather than a reduction in the number of individuals. Zooplankton standing stock was projected to decrease by 0.016%. Juvenile salmonids and forage fish are predicted to have standing stock reductions of 0.0016% and 0.0021%, respectively. Fish on the fourth trophic level would be relatively unaffected, with 0.0006 to 0.0008% reductions in standing stock. This model assumes that the system is food limited and that changes in phytoplankton abundance would be directly transferred through the food web. Based on previous predictions of carrying capacity for zooplankton and bivalves, Totten Inlet is at 10% of carrying capacity for bivalves and zooplankton.

The total projected nitrogen removal during harvest was 4,364 kg N/yr. Based on estimates of watershed and human sources, this would represent 9.2% of the DIN entering Totten Inlet from entering streams, and 17.1% to 39.8% of the nitrogen entering from area septic systems. Nitrogenous wastes from the mussel raft result in some increase in DIN concentrations within the raft complex; however, concentrations return to background within 230 ft. of the raft's terminal face.

Estimates of the mussel raft effects to receptors in the vicinity of the North Totten Inlet site were limited due to a lack of site specific data regarding bivalve populations, local currents, and zooplankton populations in Totten Inlet. In addition, all data regarding raft interactions in Totten Inlet were recorded from Deepwater Point site and are assumed to be similar to what might occur at the North Totten Inlet site. Validation of model predictions would require placement of a mussel raft at the North Totten Inlet site and subsequent monitoring.

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