Exxon Valdez Oil Spill
Gulf Ecosystem Monitoring and Research Project Final Report

Impacts of Seafood Waste Discharge in Orca Inlet, Prince William Sound

GEM Project 040725
Final Report

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Study History: The Prince William Sound Science Center (PWSSC) has had a long-term interest in the problem of seafood waste discharge practices. In 2003, PWSSC was contacted by Kenwyn George of the Department of Environmental Conservation, who had worked on a pilot seafood waste alternative project in Ketchikan Alaska. With his encouragement, PWSSC developed a proposal for a three-year study to examine alternative methods of seafood waste disposal. The initial year was to be devoted to planning the experiment and collecting background or baseline data, followed by two years of fieldwork and experimentation. The project was designed as a joint effort among the Prince William Sound Science Center (PWSSC), the Alaska Department of Environmental Conservation (ADEC) and Cordova seafood processors, as well as additional collaboration with the USDA Forest Service, Alaska Department of Fish and Game (ADF&G), the Native Village of Eyak and the City of Cordova.

The culmination of the first year's objectives included the outcome of a workshop in Cordova attended by 30 persons representing 18 different agencies and public/private entities. The workshop included discussions on the history and current situation of seafood waste disposal, the options for an alternative waste disposal experiment, and the desired future conditions. The final output of the 2004 planning process was an experimental plan that was formalized as a Statement of Work and submitted to Peter Hagen, NOAA, NMFS, Exxon Valdez Oil Spill Office on March 17, 2005. A detailed environmental assessment was also required since the proposed experiment involved dumping of unground seafood waste. A 29-page document was completed and transmitted on May 13, 2005 to Steven K. Davis, Regional NEPA Coordinator for NOAA Fisheries/Alaska Region and approved by the end of May.

The experimental design was finalized as an evaluation of the disposal of unground heads and carcasses as an alternative to grinding. The overall objectives of the experimental phase were to: 1) characterize the fish and wildlife assemblages that forage on the carcass disposal site(s), 2) compare and contrast these assemblages with those in the current disposal site and a control site with no deposit. The original design called for two experimental disposal sites. However, it quickly became apparent that two sites were not logistically feasible for two reasons: (1) fish carcasses were dispersed more rapidly than expected, and (2) the supply of fish carcasses was limited. In order to maximize the impact of the experiment, a single site was utilized and repeated the second year. In addition, tracking of waste dispersal using sonic tags was added in the final year of the study to help compensate for the rapid dispersal.

Abstract: In 1975 EPA produced effluent discharge guidelines for the seafood processor industry that required wastes to be ground to less than 1.27 cm prior to discharge. Subsequently, several negative impacts were observed around Cordova, including noticeable decreases in crab and halibut harvests and a substantial increase in numbers of gulls. We hypothesized that the change removed a food source for the large bottom-oriented animals and increased availability to the surface-oriented gulls. In 2004, we began a three year study to examine impacts of seafood waste discharge into Orca Inlet, including evaluation of alternative discharge and disposal methods. The study included model development and control-treatment experiments. We developed a dispersal model that incorporated both physical and biological transport mechanisms and demonstrated improvements over current practices. We dumped over 325,000 lbs of salmon heads and carcasses at an experimental site and monitored the biotic response. Methodologies included underwater cameras, traps, acoustic tags attached to salmon heads and visual surveys of birds and marine mammals. The results show that the heads and carcasses disperse rapidly and are efficiently incorporated into the food chain with no negative consequences, a very favorable contrast to the current EPA-mandated practice. The model also revealed that the historic practice of dumping fish carcasses was a far more effective recycling mechanism. In fact fish production may have been substantially reduced with the change in disposal practices since natural recycling is hindered by the discharge of ground waste. We conclude that it is overdue for some rethinking of fish waste practices. The policy of grinding fish waste to the same 1/2" grind size that was historically used for sewage wastes in the 1970's needs to change. We need to better understand natural recycling with regard to disposal practices. Fish processing waste is potentially a healthy source of food for marine fauna. In locations like Orca Inlet ground discharge of fish waste is not only deleterious but may also substantially reduce fish production by hindering natural recycling.

Key Words: acoustic tags, offal, Orca Inlet, pollution, recycling, regime change, seafood waste, underwater cameras

Project Data: Data collected as part of this project include physical oceanographic measurements, nutrient measurements, benthic samples, aerial surveys, camera surveys, trap catches and sonic tracking. Custodian of the data is Richard Thorne, Prince William Sound Science Center, P.O. Box 705, Cordova, AK 99574, 907 424-5800, rthorne@pwssc.org.

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Table of Contents

List of Tables

List of Figures

Executive Summary

The Prince William Sound Science Center has had a long history of interest in the problem of seafood waste discharge, possibly influenced by its location in Cordova Harbor. In 2003, that interest coincided with a similar one held by Kenwyn George, an engineer with Alaska Department of Environmental Conservation, Juneau, who was working on an experimental seafood waste disposal program in Ketchikan. The collaboration resulted in a 3-year study of impacts of seafood waste and potential alternatives to current practices that was funded by EVOS TC for FY2004-06. The initial year was devoted to planning the experiment and collecting background or baseline data, followed by two years of fieldwork and experimentation.

The first year's objectives included a workshop in Cordova attended by 30 persons representing 18 different agencies and public/private entities. The workshop included discussions on the history and current situation of seafood waste disposal, the options for an alternative waste disposal experiment, and the desired future conditions. There was an overwhelming consensus that existing seafood waste practices were unsatisfactory. Problems included water discoloration, surface scum, anoxic bottom sediment, odiferous gases in the vicinity of the discharge sites, and a build up of piles of ground offal that occasionally become so large that vessels have grounded on them at low tide, with associated release of large amounts of methane and hydrogen sulfide that have caused alarm to people living in Cordova. This phenomenon with piles of decomposing fish wastes ground to 1/2" in size and deposited ia a single large pile has created similar problems with off-gassing in other coastal communities where seafoods are processed. For example, in Ketchikan at a low tide the gasses expanded and brought a mat of decomposing fish waste over to the dock where tourists and locals were treated to foul odors from the offal. Further away, there is excessive algal growth in the intertidal, especially in the late spring to early fall months. Another major problem is the attraction of large numbers of gulls to the discharge, resulting in gull droppings that foul local drinking water and raise the specter of avian flu. Finally, there appeared to be strong linkages between the initiation of the current ground waste discharge practices and subsequent commercial fish collapses, including halibut and crabs. The consensus was that the current environmental conditions are worse than prior to initiation of the grinding mandate.

Our approach was predicated on the philosophy that offal from seafood processing is a useful byproduct, a food source for aquatic life. It should not be considered a waste because it is not being discharged in a manner to just dispose of the waste. Rather it is a byproduct with a useful purpose that requires time, effort and expense to place in the desired location and to distribute in a manner that it makes it readily available for total consumption in a relatively short period.

It became clear early in the planning process that the best working hypothesis was that unground fish carcasses would be more efficiently recycled into the local food web due to their utilization by higher trophic levels. Higher trophic organisms not only have the capacity to consume more offal, but would also disperse the offal over a larger range due to their temporal movements. This aspect of dispersing FPW was overlooked by the EPA when they made a decision to grind and treat the offal in a similar manner and size to the sewage wastes by the use of best management practice equipment that was available at the time. It should be noted that it is impossible to achieve complete maceration to 1/2" size for all fish wastes, especially skin, even with the most sophisticated and expensive grinders available today.

The experimental design was finalized as an evaluation of the disposal of unground heads and carcasses as an alternative to grinding. The overall objectives of the experimental phase were to: 1) characterize the fish and wildlife assemblages that forage at the carcass disposal site(s), 2) compare and contrast these assemblages with those at the current disposal site and a control site with no deposit. The experiment was coordinated with a modeling program that examined the fate of both ground and unground waste.

Specific techniques included underwater camera surveys for demersal fish and macroinvertebrates in the experimental area, control site and the current disposal site, aerial camera surveys of gull abundance at the current site, and grab samples for benthic invertebrates at the disposal area, experimental site and the control site.

Prior to the experiment, we made baseline bathymetric and oceanographic measurements to characterize potential study sites. Three suitable sites were identified. All had excellent bathymetric characteristics and substantial tidal mixing.

The original design called for two experimental disposal sites and a control site. However, it quickly became apparent that two experimental sites were not logistically feasible for two reasons: (1) fish carcasses were dispersed more rapidly than expected, (2) the supply of fish carcasses was limited. In order to maximize the impact of the experiment, a single site was utilized and repeated the second year. In addition, tracking of waste dispersal using sonic tags was added in the final year of the study to help compensate for the rapid dispersal.

Over the two year study period, we dumped more than 325,000 lbs of fish carcasses and heads at a single site. We identified many organisms that contributed to the rapid utilization of this food source, including halibut, other flatfish, crabs, starfish, shrimp, amphipods and even marine mammals. Despite the extensive loading, we found that the carcasses and heads were rapidly dispersed and utilized. The sonic tag tracking showed several instances of movement that were attributed to biological rather than physical sources. Through direct capture, we verified that halibut contributed to this biological transfer and removal.

We also conducted studies on the existing discharge site. These studies verified that the site had many deleterious characteristics, including 1000’s of gulls and noxious sediments that were essentially biological deserts. Elevated measures of harmful ammonia were detected several miles from the discharge site.

The modeling studies verified that unground waste was dispersed and utilized far better than the mandated ground form. In addition, the modeling study revealed that the current practice actually reduces natural recycling and may be a major factor in reducing fish, crab and shrimp production. The impact of existing practices could be costing US taxpayers millions of dollars in lost production. We know that a major change in the marine ecosystem occurred after 1978 and has been attributed to climate change. However, the model suggests an alternative, that the loss of a major food source, recycled seafood waste, could have caused the change. It is not clear how physical forcing could have caused the biological changes that were observed. However, the removal of nearly 2 million metric tons of food supply from the "conventional" food web clearly cause some changes. These potential impacts need to be evaluated with more sophisticated models. The changes included the collapse and current endangered listing of Steller sea lions, which are documented to utilize whole fish carcasses.

We conclude that there is an urgent need for some rethinking of fish waste practices, including the possible use of seafood waste to restore depleted, threatened and endangered populations of finfish and crustaceans. Currently under the NPDES permitting system for the discharge of fish wastes, fish waste has to be ground to 1/2" in size as was historically required for domestic sewage solids in the 1970's. This parctice needs to be changed. Fish processing waste has the potential to be a healthy source of food for marine fauna, while in some locations, such as Orca Inlet, discharge of ground fish waste is not only deleterious but may also substantially reduce fish production by hindering natural recycling.

Chapter 1 - Introduction

1.1 Historic seafood waste disposal practices

The fish processing industry produces at least 1.7 million metric tons (mt) of fish waste[1] a year (PPRC 1993). Historically, the waste was discharged back into the sea for recycling (Champ et al. 1981). Typically, the fish carcasses and other processing waste (FPW) were dumped off the docks of the processing plant (Ken Roemhildt, Cordova seafood processor, personal communication). This practice resulted in unsightly waste piles at coastal-sited processors that were highly visible at low tide, as well as floating carcasses in the vicinity of the processing plant. However, these waste piles of carcasses disappeared by the next fishing season and did not accumulate. Most likely, they were fully recycled back into the local food web.

The impact of this recycling process can be estimated by results from the mariculture industry. Tacon and Barg (1998) reported that the production of 3 million mt of farmed finfish and crustacean species in 1995 required the equivalent of 5 million mt of pelagic fish, a conversion ratio of 60%. Accordingly the historic annual level of FPW, 1.7 million mt, would be equivalent to a fish production yield of 1.0 million mt a year of nearshore fish production. Some of this potential production would be diverted by marine mammal and seabird utilization. However, this loss would be offset to some extent by the underestimation of fish lost from fishing gear, unused bycatch and foreign fishing. Therefore, an estimate of 1.0 million mt of annual fish production in nearshore waters as a result of recycling fish waste is a reasonable first estimate of the effect of historic seafood waste disposal practices.

1.2 A major change in regulations

In the 1970s, public pressure forced the government agencies to alter the historic practice. The changes focused on eliminating the negative aspects, but no consideration was given to the efficiency of the previous recycling process and possible adverse impacts of its loss. The primary assumption underlying changes, that the FPW would still be recycled back into the local food web of the near-shore environment, was never evaluated.

The change for Alaskan processors took place in 1977, when the Environmental Protection Agency (EPA) mandated that processors grind seafood waste to less than ½” (1.27 cm) prior to discharging in the environment (Clean Water Act 33 USCA/1251). The decision was consistent with the EPA guidelines for handling wastewater (NAS/NAE 1973), but did not address the issue of recycling. The primary assumption that EPA made when implementing the new FPW grinding practice was that the efficiency of the recycling would be enhanced. This assumption has never been tested. Today, the discharge of seafood waste resides under the NDPES permitting process (AK-G52-0000), which is required for processors to operate seafood waste discharges. Fear of large fines or shut downs forces processors to follow the government regulations without question (EPA Newsroom, 11/2/02 and 2/27/04).

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[1] The 1.7 million metric tons per year estimate of FPW is subject to several sources of bias that could lead to underestimation: 1) discarded bycatch (undesirable small fishes, young of year and juveniles); large fishes (grenadere and rockfishes, dogfish and benthic sharks, squid and others), 2) fish losses from gear (dropouts of gillnets, fish strained through trawl meshes, fish scaled by seines, discarded bycatch from traps), and 3) foreign fisheries catches.

The detrimental impact of concentrated, disposal of particulate, organic wastes is well documented in the literature (Clark 1989). FPW piles have been measured to exceed four acres in area and over 14 feet in height (EPA 1998). As a result, EPA, the Alaska Department of Environmental Conservation (ADEC), and the National Marine Fisheries Service (NMFS) have developed concerns for overloading bottom sediments with the ground FPW (Stevens and Haaga 1993). A common problem that has occurred at the fish processing discharge sites is the build up of large piles of ground offal. Overloading bottom sediments with organic materials causes high biological oxygen demands (BOD), anoxia, the release of toxic metals from the bottom sediments and the production of methane and hydrogen sulfide gases (Christie and Moldan 1977; Pearson and Rosenburg 1978; Ye et al. 1991). Miller et al. (1984) found that such degradation often led to "dead water zones" in Oregon estuaries. At times the piles have built up to such a large size that vessels have grounded on them at low tide. Large amounts of methane and hydrogen sulfide release are associated with these events and have caused alarm in local coastal communities. Obviously such conditions are detrimental to air and water quality, fish and invertebrate habitat and production, and in general environmental health. There have been limited studies of alternate uses of the FPW, such as fish meal conversion, but these practices have been generally considered impractical and the discharge of ground waste has continued.

1.3 The Orca Inlet Case History – A change in the local fisheries

At the time of the mandate to grind FPW, there were thriving fisheries for Dungness crab (*Cancer magister*) and groundfish, primarily Pacific halibut (*Hippoglossus stenolepis*), in Orca Inlet (Donaldson and Trowbridge 1988). These fisheries were reported to be in excess of 1000 mt/yr each. No one ever connected these fisheries to the practice of dumping carcasses in Orca Inlet by the processors despite the obvious linkage. However, about three years after the implementation of the grinding practices, the Dungeness crab and halibut commercial fisheries collapsed (Ken Romehildt, Cordova seafood processor, personal communication). Local sport and subsistence fishing were similarly affected. These fisheries have not recovered despite the cessation of harvests.

The ½" (1.27 cm) fish offal provides a food source for seabirds because of both its small size and its tendency to float on the surface. For the past couple of decades, glaucous-winged gulls (*Larus glaucescens*) and mew gulls (*Larus canus)* have become so abundant around Cordova that their feces create a bacterial contamination and infection risk (*Escherichia coli, Campylobacter, Salmonella)* for the fish processors and the people living in the local community (Bluhm and Bechtel 2003). Gull droppings foul local drinking water sources such as Lake Eyak and roof catchment systems. High numbers of gulls also fly regularly from the canneries to the city airstrip where they congregate on the runway creating a bird-strike threat for small aircraft.

Under the water, small flatfishes, sculpins and herring appear to dominate the fish assemblage, replacing historic halibut and cod abundance. However, as expected subsequent to the implementation of grinding regulations, the overloading of the discharge sites with organic waste transformed a diverse benthic community and healthy marine habitat into a distressed community and unhealthy environment, including large numbers of Capitella spps polychaete worms, a well-documented index of environmental stress (Caponigro 1979; Williams et al. 1999). Water discoloration, surface scum, anoxic bottom sediment, and odiferous gases are commonplace in the vicinity of the discharge sites. Further away, there is excessive algal growth in the intertidal, especially in the late spring to early fall months. Despite the fact that the environmental conditions are worse than prior to the grinding of FPW, there has been little attention paid to what was working prior to the mandate for grinding.

Currently, Cordova fish processors are limited to a 10 million pound (4,450 mt) cap on FPW discharge. This limits their ability to produce added value products, such as fish fillets, which produce four times as much FPW as frozen head-off product. Thus, the current guidelines have not only ignored a major mechanism that could affect the efficiency of FPW recycling, but they are constraining the local industry to a fraction of the possible value-added product that can be produced locally.

1.4 Genesis of the EVOS TC project

It was obvious that the new fish grinding guidelines were not as effective as the old practices in recycling the seafood waste back into the environment. The Prince William Sound Science Center (PWSSC) has had a long-term interest in this problem, dating back to a proposal for Saltonstall-Kennedy funds in 1993. In 2003, PWSSC was contacted by Kenwyn George of the Department of Environmental Conservation, who was working on a pilot seafood waste alternative project in Ketchikan Alaska, where the fate of different sizes of salmon wastes was studied (Anonymous 2004). With his encouragement, PWSSC developed a proposal for a three-year study to examine alternative methods of seafood waste disposal. The initial year was to be devoted to planning the experiment and collecting background or baseline data, followed by two years of fieldwork and experimentation. The approach was predicated on the philosophy that those parts of the fish presently considered offal or waste should instead be considered a seafood processing byproduct, a food source for aquatic life. It should not be considered a waste because it is not being discharged in a manner to just dispose of the waste. Rather it is a byproduct with a useful purpose that requires time, effort and expense to place in the desired location and distributed in a manner that it makes it readily available for total consumption in a relatively short period.

It became clear early in the planning process that the best working hypothesis was that unground fish carcasses would be more efficiently recycled into the local food web due to their utilization by higher trophic levels. Higher trophic organisms not only have the capacity to consume more offal, but would also disperse the offal over a larger range due to their temporal movements. This aspect of dispersing FPW was overlooked by the EPA when they made the decision to grind and treat the offal in a similar manner as sewage solids. The goal of this research is simple: to improve the quality of life for the communities that are affected by federal guidelines for handling FPW.

The project was designed as a joint effort among the Prince William Sound Science Center (PWSSC), the Alaska Department of Environmental Conservation (ADEC) and Cordova seafood processors, as well as additional collaboration with the USDA Forest Service, Alaska Department of Fish and Game (ADF&G), the Native Village of Eyak and the City of Cordova.

1.5 Workshop and Planning Phase

The first year's objectives included a workshop in Cordova attended by 30 persons representing 18 different agencies and public/private entities. Table 1-1 lists the attendees. The workshop included discussions on the history and current situation of seafood waste disposal, the options for an alternative waste disposal experiment, and the desired future conditions. The final output of the 2004 planning process, including the workshop, was an experimental plan that was formalized as a Statement of Work, and submitted to Peter Hagen, NOAA, NMFS, Exxon Valdez Oil Spill Office on March 17, 2005. Since the proposed experiment involved dumping of unground seafood waste, it required a detailed environmental assessment. A 29-page, document was completed and transmitted on May 13, 05 to Steven K. Davis, Regional NEPA Coordinator for NOAA Fisheries/Alaska Region and approved by the end of May.

The experimental design was finalized as an evaluation of the disposal of unground heads and carcasses as an alternative to grinding. The overall objectives of the experimental phase were to: 1) characterize the fish and wildlife assemblages that forage on the carcass disposal site(s), 2) compare and contrast these assemblages with those in the current disposal site and a control site with no deposit.

Specific techniques included underwater camera surveys for demersal fish and macroinvertebrates in the experimental area, control site and the current disposal site, aerial camera surveys of gull abundance at the current site, and grab samples for benthic invertebrates at the disposal area and the control site.

1.6 Project Evolution

The original design called for two experimental disposal sites. However, it quickly became apparent that two sites were logistically infeasible for two reasons: (1) fish carcasses were dispersed more rapidly than expected, (2) the supply of fish carcasses was limited. In order to maximize the impact of the experiment, a single site was utilized and repeated the second year. In addition, tracking of waste dispersal using sonic tags was added in the final year of the study to help compensate for the observed rapidity of the dispersal.

1.7 Structure of the final report

This final report is structured in ten chapters, reflecting the scope and diversity of the study. Baseline measurements of the physical characteristics of the overall study area are presented in two chapters: bathymetry (Chapter 2) and oceanography (3). The next four chapters describe results of measurements as part of the experimental comparison. The first two of these are biological observations at the current disposal site (4) and at the experimental disposal site (5). The latter two describe specific experiments, the dumping and visual monitoring of salmon carcasses and heads (6) and tracking of salmon heads with sonic tags (7). Chapter 8 describes the physical and biological modeling of the offal transport, while chapters 9 and 10 cover overall discussion/conclusions and literature citations.

Chapter 2. Physical Setting – Physiography of Orca Inlet

2.1 Introduction

Orca Inlet runs along the south side of Hawkins Island in the southeast corner of Prince William Sound (PWS). Water flows into the inlet from the Gulf of Alaska, via Strawberry Channel, northeastward to Nelson Bay, where it mixes with PWS water that has coursed along the north side of Hawkins Island. Extensive mud flats fill the lower portion of the inlet, through which two channels course and join near Mud Bay on the west side of the inlet opposite Cordova. From there, waters generally deepen and the inlet narrows slightly as it reaches northwestward to Nelson Bay (Fig. 2.1).

Cordova's fish processing plant waste is currently dumped into waters roughly 10 m deep. Given the predominance of the shallow mud flats in the Orca Inlet system, we assessed the relative amount and distribution of deeper areas (i.e., depth >10 m) with data visualization techniques. The objective was to quantify the distribution of the deeper portions of Orca Inlet, namely those areas at least as deep as the area between Spike Island and the Cordova Boat Basin where ground fish offal is presently dumped. The goal was to evaluate the existing dumping area in the context of the rest of the bathymetric features in the Inlet, in terms of size, proximity to Cordova, and exposure to currents that would disperse offal.

2.2 Materials and Methods

A georeferenced contour plot of Orca Inlet bathymetry was prepared by digitizing the bathymetry and landform polygons in a section of NOAA chart 16709. Data were obtained with a Wacom Intuos 2 digitizer tablet and processed with the Didger, Surfer and Grapher programs (Golden Software, Inc., Boulder, Colorado). Control points for calibrating the digitizing process were obtained with the Nobeltec Visual Navigation Suite. The projection was converted to 1983 State Plane Coordinates (Alaska Zone 3) to obtain meters as the unit of measure. Planar surface measurements of deeper areas of the inlet were obtained with Didger. Volumetric determinations of deeper basins were made with Surfer. Cross sectional profiles of basins of interest were made with Grapher on data extracted from contoured surfaces of bathymetric features calculated with Surfer.

2.3 Results

The mapping revealed that the present dump site – hereafter called Spike Island Basin (SIB) – is a small dead-end feature (maximum depth about 10 m) that extends off of a long 10+ m deep channel that runs about 9 km (5 nm) northwestward to Nelson Bay (Fig. 2.2). A smaller deep feature (maximum depth about 20 m) – hereafter called Mud Bay Trench (MBT) – runs along the shore of Hawkins Island west of Cordova (Fig. 2.2). It is at the junction of the two channels that run southwestward through the Orca Inlet mud flats to Strawberry Channel, the Inlet's connection to the Gulf of Alaska (Fig. 1). MBT is separated from the channel to Nelson Bay by a gentle rise of sandy bottom that stretches from Orca Inlet's inter- and subtidal mud flats just south of Cordova, northeastward through the center of the inlet (Figs. 2.2 and 2.3).
Strong tidal flows pass though MBT northeastward to Nelson Bay (see Chapter 3). Nelson Bay and adjacent waters are much deeper than Orca Inlet and are known to be good halibut habitat. Thus, the Inlet's channel to Nelson Bay provides access to large scavengers that may enter the Inlet from PWS waters.

The channel to Nelson Bay is roughly 775 acres (~3.1 km^2) in size, with a main basin – the area that extends northward from Spike Island to where it narrows distinctly to follow the coast – that covers roughly 560 aces (2.2 km^2). Mud Bay Trench is about 300 acres (~1.2 km^2). In comparison, SIB, where the brunt of Cordova's ground waste is dumped, is only about 70 acres (~0.3 km^2).

SIB extends southwestwardly from a small rise that separates it from the channel to Nelson Bay. At its southern end it shoals and disappears into the Orca Inlet mud flats (Fig. 2.4). A long, narrow bar extends from the southern end of Spike Island, further separating SIB from the more expansive area of the channel (Fig. 2.4). Seabirds flock to SIB and gather in feeding frenzies when waste is periodically discharged from the pipes reaching into SIB from the processing plants (see Chapter 4).

Chapter 3. Physical Oceanographic Characteristics of Sites in Orca Inlet Surveyed as Alternative Locations for Disposal of Fish Offal from Cordova Seafood Processors

Abstract

During the summer of 2004 and the spring of 2005 physical oceanographic conditions were measured in three regions of Orca Inlet, near Cordova Alaska, investigated as potential locations for the alternative disposal of fish offal from Cordova's seafood processors. Two of the regions were surveyed in July and September 2004, including a northern site next to Salmo Point and North Island and a southern site within lower Orca Inlet adjacent to Cordova. A third region was surveyed in May 2005 along a channel that connects the southeastern and northeastern portions of the inlet. The data included profiles of currents, temperature and salinity taken over semi-diurnal tidal cycles. All three sites differ significantly in both hydrography and circulation due to a number of factors including variation in bottom depths, basin geometry, sources of freshwater input, and the strength and pattern of the tidal currents. The northern site is characterized by both high stratification from freshwater originating from glacial runoff into the Rude River and deep inflow of cold, saline water advected from Orca Bay. This region therefore becomes highly stratified in the summer and baroclinic currents occur over depth throughout the tidal cycle. The currents also exhibit significant spatial variation ranging from < 5 to 50 cm/sec due to convergences and divergences caused by both estuarine input and bathymetric effects. In contrast, lower Orca Inlet is characterized by strong, barotrophic flows (>100 cm/sec), and all inputs of heat and freshwater (including glacial sources advected from the north) are rapidly dissipated due to turbulent mixing. The northeastern channel also exhibits barotrophic flows similar in magnitude to lower Orca Inlet, but in contrast to the latter site vertical mixing produces fronts extending to depth as stratified water from Nelson Bay is advected across a shallow region and undergoes tidal mixing. All three locations would potentially serve as fish offal discharge sites if maximum dispersion is the goal. The northern site, however, may achieve better results due to its deep (80m) basin and the baroclinic nature of the currents. The higher population of ground fish in this region would also benefit more from disposal of offal at this site.

Introduction

During the summer of 2004 the Prince William Sound Science Center (PWSSC) began a study of alternative sites for the disposal of fish offal from Cordova's seafood processors. This research was done in collaboration with the Alaska Department of Fish and Game (ADF&G), the Alaska Department of Environmental Conservation (ADEC), the Village of Eyak, the City of Cordova and Cordova seafood processors as part of an on-going effort to convince the U.S. Environmental Protection Agency (EPA) to rescind a regulation requiring that canneries grind fish offal to sizes ≤ 0.5 in. (1.27 cm.). This practice was intended to help disperse offal discharged near canneries and make it available to a wider range of consumers, but in actuality the small pieces accumulate along the bottom and slowly decompose creating anoxic conditions within the sediments (Williams, 1999). A portion of the offal discharge also upwells to the surface and thus nourishes a single higher trophic level: glaucous winged gulls and kittiwakes. Anecdotal accounts indicate that prior to 1978, when fish waste was discharged in the form of whole carcasses, offal piles were nearly eliminated each year by halibut, crab and other benthic dwelling fish and invertebrates.

The purpose of the present study was to monitor the above species usage of fish offal discharged in the form of large chunks at selected sites over the summer of 2005 and 2006. As part of this project, baseline oceanographic conditions were surveyed within three regions of Orca Inlet (Fig. 3.1). Two of the sites (Site A and B) were surveyed in both July and September 2004 and one in the May 2005 (Site C) (Table 3.1). A fourth location was also surveyed in May 2005 next to Mud Bay (see Fig. 3.16). This site (Mud Bay Trench) was eventually selected for the experimental phase of the study due to its close proximity to Cordova. The data collected included currents measured along transects repeated over semi-diurnal tide cycles (i.e. sequential ebb and flood tides ~ 14 hrs.), and temperature (T) and salinity (S) profiles taken at least four times over the tidal cycle at various oceanographic stations located along transects. To measure the extremes in flow, data were collected during both neap and spring tides, which occurred in mid July and early September 2004 respectively. A spring tide was also surveyed in May 2005. This report describes the physical conditions observed within the respective sites and discusses the factors that potentially influence their spatial variability.

Materials and Methods

The data on currents were collected with an RD Instruments 600 kHz acoustic Doppler current profiler (ADCP), towed with an aluminum Biosonics sled suspended from a davit on a small fishing vessel (Fig. 3.2a,b). Towing speeds ranged from 2.0 to 2.5 m s^{-1} and with 20 water pings and 10 bottom pings per ensemble, the estimated standard deviation and horizontal resolution for current vectors was 1.37 cm s^{-1} and 25 m respectively. Vertical (depth bin) resolution was 1m, which is four times the minimum stated bin size of the instrument (0.25 m bin depths). Transects were repeated at least 9 times during semi-diurnal tides giving a Nyquist frequency of ~ 0.333 cph (i.e. $1/(2\Delta t) = 1/(2*1.5 \text{ hr})$).Transects in the northern and lower portions of Orca Inlet were designed with an alternating cross-channel pattern covering lengths of ~ 1.0 km with an along-channel spacing of 0.5-0.6km (Fig 1). This resulted in a total distance of nearly 10 km and an area of coverage ranging from 2.7 to 1.9 km^2 within Sites A and B respectively. Site C also had a total transect length of nearly 10 km, but the pattern differed from the other sites in that transects were set up in a diagonal ('zig-zag') pattern following along, a narrow channel (Fig. 3.1). The total channel length at Site C was 5.1 km and the average cross-channel width was 0.65 km, giving this site an area of coverage of about 3.3 km^2.

The hydrography was measured using a Seabird Elecronics (SBE) 19.03 CTD profiler (Fig. 3.2a,c). This instrument has a maximum sample frequency of 2 Hz, which yields a resolution of 3-4 points per meter depending on the rate of descent. The number and spacing of stations is shown in figures in the text. This differed at each site depending in part on the expected variability in T/S properties due to differences in freshwater input, stratification and convergence of water masses with differing physical properties. Site B was the first location surveyed and therefore a large number of cross-channel stations were established (14-15) with a spacing of about 0.3 km. This resulted in over-sampling. However, this was deemed necessary to obtain a good initial measure of spatial variability in the T/S properties to be used as a basis for sampling in the other sites. This is described in more detail below for each location.

The hydrography data were processed with standard SBE algorithms for filtering data, removing spurious values, aligning sensors in time to remove salinity spikes, and averaging to 1m depth bins. The ADCP data were processed by first averaging the raw data into segments comprised of 2 ensembles (i.e. ~ 40 water pings) and checking for bad data based on percent good returns, error velocities and other diagnostic parameters. Further data processing involved merging Global Positioning System (GPS) data into midpoints for segments, filling in missing GPS coordinates by interpolation, removing spurious values (i.e. high $\Delta U/\Delta x$) and bin averaging. During runs with CTD casts, multiple current vectors were obtained over short distances due to vessel drift. These were smoothed by averaging u and v components to obtain single vectors. This procedure produced a final average vector spatial resolution of ~ 50 m.

Results

Site A: Salmo Point\North Island

Figure 3.4 shows the oceanographic transects and stations established within the northern region of Orca Inlet from Salmo Pt. to North Island. Slightly fewer stations were occupied at this site (12) relative to Site B, but these were laid out over a larger grid spacing (0.5 km) due to this site's proximity to Orca Bay and Nelson Bay, both of which are potential sources of water mass variation for this region of the inlet. The total area surveyed was ~ 2.7 km^2 and the distance traversed was 9.7 km.

Site A is relatively deep in comparison to the other locations surveyed and maximum depths there range from 70 to 80 m. This region of the inlet is also markedly influenced by cold, glacial water from Nelson Bay (Fig. 3.1). This is indicated by both a temperature inversion and low salinity (S = 20-21) in the nearsurface layer (Fig. 3.4). The summer of 2004 was unusually warm, and the high insolation was indicated by a relatively warm (~ 15^oC) subsurface layer underlying the glacial water. Vertical mixing of both heat and freshwater over the summer is shown by the deep (30m) thermoclines and haloclines respectively in September. Although salinity is the primary variable that determines the vertical distribution of density within the water column, the combined effects of heat and freshwater input create strong stratification in this region of the inlet (i.e. warm, fresher water in the upper 30m overriding colder, saltier water at depth).

Figure 3.5 shows the nearsurface (2-6m) tidal currents measured during the spring tide on September 2nd at Site A. By comparison, these flows were about half the magnitude ($U_{max} \leq 50$ cm/s) of the other two sites ($U_{max} \geq 100$ cm/s). However, the flow in this region is greatly influenced by the basin geometry. For example, during the ebb tide (Fig. 3.5a to e) regions of divergence and convergence occur as water flowing north is forced eastward and westward by the northern boundary across the inlet. Conversely, during the flood tide (Fig. 3.5a to i) surface water from the northeast flows towards Salmo Pt. and converges with inflow from Orca Bay. This convergence corresponds to an area of very low surface velocities, shown in Figure 6a. Beneath this layer the subsurface currents (Fig. 3.6b) flow eastward from Orca Bay, creating strong baroclinic flow (i.e. pressure varying over depth) shown in Figure 3.6c. Between Salmo Pt. and North Island water is forced southward during the flood tide causing advection of fresh surface water and saltier subsurface water towards Lower Orca Inlet. At the end of the flood stage (Fig. 3.5i) the flow vectors reverse and exhibit a pattern similar to the initial ebb (Fig. 3.5a).

Marked changes in the hydrography at Site A also occur over the tide cycle. For example, during the ebb tide the fresh surface layer appears to be replaced by slightly cooler, saltier water from the south due to flow divergence at the juncture of the three channels (Fig. 3.5a to e). During the initial phase of the flood tide, cool fresh glacial water from the northeast flows southwestward where it converges and forms a front across from Salmo Pt. (Fig. 3.7). As the flood tide progresses the subsurface inflow (Fig. 3.6b and c) brings in cooler saltier water at depth. This also appears to cause internal waves to develop within the pycnocline (Fig. 3.4). The subsurface inflow does not occur over the entire area, however, and appears to be confined to the deeper portion of the basin between Orca Bay and North Island. As the flood tide progresses, the deep inflow increases in strength, ultimately resulting in the interleaving of water masses and continuous dynamics in the T/S structure over the course of the tidal cycle. The density stratification in the upper 30m layer persists over time due to the stability of the highly buoyant surface water. However, the strong velocity shear induced by reversed flow across the interface of the pycnocline may be a mechanism causing gradual deepening the thermocline and halocline over the summer as observed in other fjords and regions of PWS (Muench and Schmidt, 1975; Vaughan et al., 2001; Gay and Vaughan, 2001).

Site B: Lower Orca Inlet

The oceanographic transects and stations surveyed within Lower Orca Inlet (Site B) are shown in Figure 3.8. The total area surveyed was 1.9 km^2 and the total transect distance was nearly 9.5 km. In contrast to the northern site, Site B differs substantially in terms of bathymetry and basin geometry. For example, the bottom is generally quite shallow (≤ 15m) and the basin is comprised of two parallel channels running in a northeast-southwest orientation, separated by a very shallow bar (< 5m) (see Fig. 2.3). Maximum depths in Site B are typically around 10m but a deeper channel (15-20m) extends northeast from Spike Island and connects into Site C (Fig. 3.1).

The physical oceanography at Site B is characterized by low freshwater input and strong vertical mixing from the tidal currents. In the summer, runoff into this site is negligible in comparison to Site A, and most freshwater input is advected into this region from the northern part of the inlet. In mid July 2004 the hydrography (Fig. 3.9) shows Site B to be cool (T = 11-12^{o}C) and brackish (S = 26-27) with very weak stratification (i.e. negligible thermoclines and haloclines). In early September the water temperatures increased to about 14^{o}C but the salinities ranged between 23.5 and 23.8 over the entire water column. This indicates that a substantial increase in freshwater flux occurs over the course of the summer due to advection from the northern region. A nearly non-existent pycnocline (due to uniform salinity) apparently is a result of both the shallow bathymetry and vertical mixing from strong tidal currents.

Figure 3.10 shows an example of the tidal currents measured at Site B during the spring tide on September 1, 2004. These flows are over twice the magnitude of currents at Site A (100 cm/s vs. ≤ 50 cm/s) and are predominately oriented along-channel during the majority of the tidal cycle. Examples of the spatial distribution of the *u* component of velocities during the early portion of the ebb tide and the middle of the flood tide are shown in Figure 3.11. From all of these plots it can be seen that the currents are highly barotrophic (i.e. uniform pressure over depth) but there appears to be significant horizontal shear, and this along with bottom drag and low stratification must induce thorough mixing of the water column even in the absence of strong winds in the summer. Near the end of the flood tide, however, slight stratification does occur on the northwest side of the inlet. Here, the presence of fresher surface water and saltier bottom water (Fig. 3.9, last panel) apparently result from southward advection of water from Site A (Fig. 3.5f,g,h). This further supports the contention that during dry periods in the summer the bulk of the freshwater flux that occurs in this region of the inlet is from allochthonous, or outside, sources.

Spike Island Basin. The primary site of offal outfall from the Cordova processing plants occurs within a small, relatively shallow (10 m) basin located between Spike Island and the Cordova water-front (Fig. 3.8). As in the other areas of lower Orca Inlet, the depth of this site nearly doubled at the flood tide on July 11, 2004 (7-13 m). The extreme change in volume due to the tidal prism creates a high flow through this basin, similar to other portions of the lower inlet (Fig. 3.10). However, the currents behind Spike Island appear to be slightly out of phase with respect to the other basins and possibly precede them (i.e. exhibit a positive lag) in terms of changes in flow between tide stages (Fig. 3.10c,g). The spatial variation in the flow field caused by Spike Island was frequently observed on the surface in the form of tide rips, particularly on the downstream (northern) side of the island during the peak of ebb tides.

With exception of the fine material advected to the surface by a plume of freshwater during the offal discharge, the coarse material deposited within the Spike Island basin does not exhibit re-suspension within the water column despite the relatively high flows that occur there. This is apparently due to both decomposition of the material into a paste-like ooze, which would require a significantly higher flow magnitude to set it into motion (i.e. a high Hjulstrom value), and reduction in flow velocity due to boundary layer effects (i.e. drag). The opposite would be true of dissolved material, however, such as nutrients created by decomposition and nitrification. These materials should be rapidly advected from the site by the tidal flows.

Site C: Northeast Orca Inlet

The locations of transects and hydrographic stations established within the northeastern region of Orca Inlet (Site C) are shown in Figure 3.12. The area surveyed essentially follows a channel leading northeastward from the eastern side of Site B towards Nelson Bay, ending just south of Humpback Creek (Figs. 3.1 and 3.12). Due to the relatively long length of this site (5.7km), the transits between transects crossing perpendicular to the channel were set up in a diagonal pattern. Site C had the lowest number of CTD stations (9) due to the larger distances between transects, but cross-channel station spacing was similar to Site B (0.3 km).

Site C was surveyed in May 10, 2005. This was earlier in the season in comparison to Sites A and B (July and early September). As expected, the hydrography (Fig. 3.13) exhibited weak stratification reflecting initial heat and freshwater inputs in the spring. These fluxes typically begin to intensify in near-shore basins sometime in June as air temperatures rise significantly and the release of stored precipitation commences from high elevations (Gay and Vaughan, 2001). Site C also exhibits strong barotrophic flows (>100cm/s) throughout the tide cycle (Fig. 3.14) similar to Site B (Fig. 3.11). However, in contrast to the latter region tidal mixing and advection produce horizontal T/S gradients throughout the water column. One of these features can be seen in the data at 4.5 to 6hr into the ebb tide on May 9, 2005 (Fig. 3.13, panel 2). In this case, slightly stratified water is advected southward from Nelson Bay during the flood tide (Fig. 3.13, panel 4). During the tidal cycle this water appears to undergo shoaling and mixing along a centrally located, narrow portion of the channel that functions as a sill separating Humpback Creek and the lower portion of the inlet (Fig. 3.15). As this water moves northward on the ebb tide a horizontal gradient (i.e. frontal zone) forms apparently due to turbulence in the water column. It should be noted that as heat and freshwater flux progress, particularly from enhanced glacial runoff into Nelson Bay, these fronts should intensify. This is indeed observed during the summer in the form of tide rips on the surface where glacial water from Nelson Bay converges with non-glacial water from lower Orca Inlet.

Site D: Mud Bay Trench (Experimental Site).

The site chosen for experimental dumping of large pieces of fish carcasses is located directly adjacent to Mud Bay (Fig. 3.16). This portion of Orca Inlet is essentially a southward extension of the western channel of Site B (see Fig. 2.3) and is comprised of a small isolated basin with a maximum depth of nearly 20m. The currents in this basin (Fig. 3.17) were surveyed on May 11, 2005 during the middle portion of a moderate flood tide ($\Delta h = 3.4m$). The flow at that time exhibited a similar barotropic pattern to that observed just to the north within Lower Orca Inlet in both July and September 2004 (Fig. 3.10). The currents in this site are quite strong (≥100 cm/s), however, even during one of the more moderate tidal prisms of the spring tide series that occurred in early May (max $\Delta h = 5m$). Figure 3.18 shows the spatial distribution of the u velocity component during the same flood tide. This component is predominately along-channel at this location, and it shows the marked barotropic nature of the flows. There is also little reduction in magnitude over the water column until close to the bottom (Figs. 3.17 and 3.18). This should result in substantial re-suspension and advection of bottom material, including fish offal, during most tides except perhaps some of the smallest neaps ($\Delta h = 2\text{-}2.5m$).

Discussion

Three sites were surveyed during this study as potential alternative locations for the disposal of large pieces of fish offal generated by Cordova's seafood processors. Each of these sites exhibits differences in hydrography (T/S structure) and circulation due to marked variability in freshwater input, bathymetric features and currents predominately generated by tides. For example, the region from Salmo Pt. to North Island (Site A) has a deep basin (80m) with a much more complex geometry in comparison to both Lower Orca Inlet (Site B) and Northeastern Orca Inlet (Site C) (10-20m). This site also exhibits a well stratified water column over the summer due to the influence of glacial runoff advected from the head of Nelson Bay. The currents in the northern site are therefore highly baroclinic in the summer, and exhibit strong vertical shear as well as divergences and convergences that tend to fluctuate between the ebb and flood and tides (Fig. 3.6). The convergence of water masses with differing physical properties in this region also creates spatial variation in the vertical structure of salinity and hence density stratification. This could be seen from the vertical sections of T/S during the course of the tidal cycle (Fig. 3.5).

Although the surface flow during the initial stages of the flood tide at Site A (Fig. 3.5f,g) suggests the possibility of estuarine outflow from Nelson Bay, it is doubtful this is a case of classical estuarine circulation, which is caused by a high volume point-source of runoff and vertical entrainment. These conditions have not been observed in the past within other fjords of PWS (Gay and Vaughan, 2001). Indeed, due to the prevalence of small streams which create a line source of freshwater input, relatively brackish surface conditions and deep vertical salinity gradients tend to be ubiquitous in distribution within PWS fjords. Although cross-channel density fronts do exist, these pressure gradients tend to be relatively minor in comparison to the tidal and bathymetric effects which predominately force circulation. Similar conditions exist in northern Orca Inlet, and the southwest surface outflow during the flood tide appears to be a result of both an estuarine surface gradient and horizontal entrainment caused by an acceleration in flow southward within the channel located between North Island and Salmo Point (Fig. 3.5f,g,h). The one predominate effect of the hydrography on circulation in this region, however, is the vertical fluctuations in flow due to density stratification (i.e. baroclinic tidal currents). This can be seen occurring beneath the estuarine surface layer, as denser water from Orca Bay is advected by the flood tide into the northeastern basin (Fig. 3.6a,b). Both water masses, however, appear to be advected southward by the flood tide into lower Orca Inlet via the western channel.

In contrast to the northern site, the regions in Lower Orca Inlet (Site B), including the Mud Bay experimental site, exhibit poor density stratification (i.e. weak thermoclines and haloclines) due to both relatively low freshwater input and strong vertical mixing from currents. This results in weak vertical T/S gradients at this site (Fig. 3.9), and the currents are predominately barotropic (i.e. unidirectional) and tend to follow the along-channel direction of the ebb and flood tides (Fig. 3.10). The flows are quite high in magnitude, however, due to the constrictive nature of the shallow channels in this region of the inlet and the high relative volume of the tidal prisms. The currents also tend to remain strong throughout most of the water column, and this would definitely enhance the dispersal of fish offal deposited in this region of the inlet. This scenario would only become more prevalent in the fall and winter when down inlet (katabatic) winds become a factor in enhancing circulation and turbulent mixing.

The third site, located along the northeast side of upper Orca Inlet (Site C), also exhibits barotrophic flows in late spring (Fig. 3.14) similar to Site B, but in contrast to the latter region vertical mixing produces fronts throughout the water column (Fig. 3.13, panel 2) as stratified water from Nelson Bay is advected over a shallow region of the channel and undergoes shoaling and mixing. During the summer, when glacial runoff reaches a maximum the hydrography of the northeastern channel probably becomes characterized by strong frontal regions, extending deep into the water column. These fronts are typically observed as a series of surface convergences that move up and down the channel during the tidal cycle. In this case, the highly stratified water from Nelson Bay probably penetrates below the sill and circulates into the lower inlet. A similar process may occur in the western channel. This was evident by the surface freshening within the western side of the lower inlet during the end of the flood tide (Fig. 3.9, panel 4).

Summary and Conclusions

In summary, the three regions investigated as potential alternative sites for the discharge of fish offal differ significantly in terms of oceanographic conditions. Factors contributing to this include variation in bottom depths and basin geometry, sources of freshwater input, and the strength and pattern of the tidal currents. The northern site is characterized by high fluvial freshwater input from the Rude River and inflow of deep cold, saline water from within Orca Bay. This region is therefore highly stratified and the tidal currents very complex and fluctuate in velocities over depth during the course of the tidal cycle. In contrast, the southern and northeastern sites are influenced by strong barotrophic flows, and due to turbulent mixing by tides (and at times wind) all heat and freshwater input (including glacial sources advected from the north) rapidly dissipate creating a more uniform local physical environment. All locations would potentially serve as fish offal discharge sites if maximum dispersion is the goal. The northern site, however, may achieve better results due to its deeper basin and the baroclinic nature of the tidal flows. The higher population of ground fish in this region would also probably benefit more from disposal of offal at this site.

Chapter 4. Characteristics of the historic fish processing waste dump site in Orca Inlet

4.1 Introduction

Cordova is a major fishing port for southcentral Alaska and is located in the southeast corner of Prince William Sound (Fig. 4.1). Seafood processing in Cordova takes place through much of the year, save for late fall and early winter. Early in the year (January-March), plants process black cod (*Anoplopoma fimbria*) and walleye pollock (*Theragra chalcogramma*). By mid-May the commercial salmon fishery has begun, first with the Copper River gillnet fishery followed in early June by the Prince William Sound purse seine fishery. Both gillnet and purse seine fisheries are finished by late September.

Fish processing waste (FPW) discharges from Cordova's processing plants peak in summer. Each of Cordova's four plants are limited to an annual cap of 10 million pounds of FPW, all of which flows into Orca Inlet (Fig. 4.2). In 1975 EPA produced effluent discharge guidelines for the seafood processor industry that required wastes to be ground to ½" in any dimension prior to discharge. In Cordova, processors implemented the ½" grind requirement around 1978, discharging FPW through underwater pipelines into the small channel area between Cordova's Small Boat Basin and Spike Island (Figs. 4.3, 4.4). Immediate benefits from the change to ½" grind included a decrease in odor and in visible fish carcasses along the shoreline. At the same time, several detrimental environmental changes were observed including an increase in the number of Glaucous-winged Gull (*Larus glaucescens*) and Mew Gull (*Larus canus*) around the processing area and FPW discharge plumes (Fig. 4.5). Seasonally, thousands of gulls feed on the FPW. When they are not feeding, the gulls gather on docks and roof tops, and in their abundance create a general nuisance with regard to public health and sanitation issues.

This study was undertaken to describe the ecosystem in and around the Cordova seafood processor's waste discharge area including nutrient concentrations, post-harvest benthic conditions, and avian response to FPW.

4.2 Study Area and Methods

Our study took place during fall 2004 and March through August 2005 in central Orca Inlet by Cordova, from Odiak Slough north to Fleming Spit and west towards Salmo Point.

Nutrient Sampling

In order to discern patterns of nutrient supply around FPW discharge site, we examined data from water column samples. The data was collected as part of a separate study of trophic interactions on the Copper River Delta funded by the Exxon Valdez Oil Spill Trustee Council (project EVOS-GEM 040635). During each of 6 sampling trips in 2005 (March, April, May, June, July, August) we collected 500-ml water samples for nutrient (nitrate, ammonia, phosphate, and silicate) and chlorophyll *a* measurements. We collected at the northwest corner of Spike Island, close to the channel where most of Cordova's FPW is discharged. Replicate (n =3) water samples were collected from 0.5 m below the surface and near bottom waters (~15-18m depth).

In the laboratory, we filtered 100 to 150 ml of each water sample through Whatman TM GF/C filters. We wrapped the filter in aluminum foil and froze it for chlorophyll *a* analysis. We also froze a 60 ml sample of the filtered liquid for inorganic nutrient analysis. We determined chlorophyll *a* concentrations using a Turner Designs Model 10 Fluorometer following the acidification method of Lorenzen (detailed in Strickland and Parsons 1972). We carried out nutrient analyses using standard wet chemical techniques (Alpkem Manual 1988) adapted for use on an Alpkem RFA/2 Nutrient Autoanalyzer. All chlorophyll *a* and nutrient samples were analyzed at the University of South Alabama's Dauphin Island Sea Lab. We plotted results with the Grapher program (Golden Software, Inc.) through points representing the closest agreement with two of the three samples (i.e., outliers were discarded), when possible. Otherwise, a mid-range value was used (e.g., July 2005 sample).

Benthic Sampling

We evaluated benthic conditions in and around the FPW discharge area shortly after the end of the 2004 salmon fishery. Our sampling locations (Fig. 4.6) and field methods were similar to those used by William et al. (1999) in his study of FPW discharge around Spike Island. At each sample site, we collected three replicate benthic samples using a Mini Ponar 0.1 m^2 grab. Our September 2004 sampling locations included discharge sites for each of the four processors, and at one site adjacent to each discharge site. We also collected samples in June and July 2005 at Mud Bay and near Humpback Creek and Observation Island to evaluate conditions at undisturbed sites for comparison. Within hours following our collections, grab samples were rinsed onto a 0.5-mm sieve and the contents placed in a 10% Formalin/Rose-Bengal solution. After 48 hours, we rinsed the formalin from the sample and stored the remaining material in 70% Ethanol. We examined samples for the presence or absence of crabs, clams, and worms.

Aerial Surveys for Gulls

We used aerial photographic surveys to estimate the distribution and abundance of gulls in and around the canneries and their respective FPW outfall areas. Trained personnel with the Cordova Ranger District of the Chugach National Forest flew the surveys. Methodology used was similar to those developed by Cooper (2007) to census beavers on the Copper River Delta.

Surveys were flown in a Cessna 206 wheel plane at a flight speed of ~160 km/hr. A Kodak DCS Pro 14N digital camera equipped with a Garmin global position system (GPS) V attachment was vertically mounted over a floor port near the aft bulkhead. An onboard technician monitored the camera via computer. A combination of 50mm focal length shot from an altitude of ~300m was used to produce photographs that each covered an approximate area of 220 x 150 m. Photos were taken at two-second intervals to allow overlap between photos. Six parallel, east-west flight lines spaced at 100 m intervals allowed for overlap while covering the area in and around the Cordova canneries from Odiak Slough to Fleming spit (Fig. 4.7). An observer seated adjacent to pilot tracked flight lines and guided the pilot using the computer program Tracker Analyst (Ducks Unlimited).

Following each flight, digital photos were transferred to a computer hard drive for post-flight analyses. Prince William Sound Science Center personnel then printed high-resolution (4500 x 3000 pixel) photos. We arranged survey photos in sequence by flight lines to prevent double counting. In order to determine gull distribution in relation to the dumping of FPW, we divided the survey area into 13 areas (Fig 4.7). We determined gull numbers for each area by visually counting individual gulls on the photos. No attempt was made to distinguish between Mew Gull and Glaucous-winged Gull in the photos.

4.3 Results and Discussion

Nutrient Levels

Our water chemistry results from around Spike Island revealed a typical pattern of nutrient recycling associated with a spring plankton bloom in Orca Inlet. The trend in chlorophyll *a* levels (a proxy for phytoplankton abundance) indicated that the phytoplankton bloom occurred during April and May. Chlorophyll *a* levels peaked in late May or early June, then declined precipitously by late June, indicating the phytoplankton bloom had ended (Fig. 4.8).

Nitrate is often a limiting nutrient in marine systems, meaning that as phytoplankton abundance increases, the uptake of nitrate can outstrip the supply. In 2005, nitrate levels dropped between 14 March and 22 May (Fig. 4.9) as the phytoplankton population bloomed. With less nitrate available, the phytoplankton community could no longer sustain itself and its population crashed (Fig. 4.8). We recorded a temporary increase in nitrate levels during June, most likely originating from nutrient recycling associated with grazers and decomposers feeding on the dying and dead phytoplankton. By July and continuing through August, nitrate levels dropped to low levels as diatoms and macrophytes depleted the nitrate supply again. Concentrations of phosphate and dissolved silica (Figs. 4.10, 4.11) tracked nitrate levels in Orca Inlet from March through August as their pattern of utilization and recycling is similar. Neither phosphate nor silica, however, appear to be limiting in Orca Inlet.

Interestingly, we recorded elevated variability in ammonia concentrations on 22 June (Fig. 4.12), roughly the time when fish processing from both gillnet and purse seine fisheries was in full operation. Sources of ammonia include bird droppings and FPW. Although gull flocks foraging on FPW are typically >100 m distant from the water sampling site, bird droppings could explain the source of the elevated surface reading on 22 June. However, bird droppings do not as easily explain the high variability in the near-bottom samples. In near-bottom water, sources of elevated ammonia levels are more likely FPW undergoing initial stages of decomposition. Ammonia is the initial breakdown product of protein decomposition. Nitrifying bacteria (e.g., *Nitrosomonas*) oxidize ammonia, forming nitrite, which is subsequently rapidly nitrified by other bacteria (e.g., *Nitrobacter*) into nitrate.

Given the onset of huge inputs of organic enrichment into the Spike Island Basin ecosystem, it is expected that the bacterial fauna would initially be too small to effectively “process” the large amount of ammonia waste being generated. That is, there would be a lag until the number of bacteria were sufficient for the job at hand. Thus, ammonia levels in one area may be locally lower than elsewhere due to nitrification in areas where nitrifying bacteria are more abundant. In a FPW study in Ketchikan (Anon. 2004), divers observing the waste pile reported observing a growth of a white layer of bacteria and/or mold about 2½ weeks after the piles were in place.

In addition, nitrification is an oxidative process and can be limited by the availability of oxygen (Valiela 1995). In their March and July water samples from Orca Inlet, Williams et al. (1999) did not find evidence of oxygen depletion and concluded that the water column was well mixed by tidal currents. However, our September benthic grab samples had the powerful odor of hydrogen sulfide gas, a potent indicator of anoxia. Hypoxic conditions around the waste piles likely further delay the development of the bacterial nitrification process, a condition that would be reflected in the spatial variability in ammonia levels.

Once the bacterial mat fully develops, bacterial processes proceed sufficiently fast so as to quickly oxidize ammonia into nitrite. Nutrient samples taken 21 July reveal elevated ammonia levels, however the variability between the replicates is greatly reduced, indicating the bacterial nitrification is underway. Nitrite levels on 21 July are also elevated (Fig. 4.13), also confirming nitrification. It is noteworthy that nitrification to nitrate is not occurring at the Spike Island sampling site (see the low July and August nitrate levels Fig. 4.9) as nutrients are being exported out of the system and into Orca Inlet.

A rapid export of nutrients from the Spike Island area certainly occurs from tidal flushing within lower Orca Inlet, particularly during spring tides when flows during both the ebb and flood tides exceed 100 cm/s (see Fig. 3.10). This highly energetic environment should promote vertical mixing and dilution of nutrients, and this is indeed suggested by the limited degree of stratification within the lower inlet (Fig. 3.9). Tidal circulation also determines the southern limits of nutrient dispersal such as ammonia arising from the FPW decomposition. Although no direct measurements have been made of the precise locations of tidal convergences and divergences between Orca Inlet and the Copper River Delta (i.e. Strawberry Inlet), it is common knowledge that the tidal breakpoint occurs in the vicinity of Big Point (Fig. 4.1). Therefore, it is highly doubtful that it is pure coincidence that Big Point is also the southern limit in the distribution of high concentrations of ammonia (Bishop and Powers, unpubl. data).

Benthic Sampling

On 28 September 2004, shortly after the end of the commercial salmon season, we sampled the benthos in and around FPW outfall pipes (Fig. 4.6, stations A-D). Our samples included decomposed fish waste consisting largely of tissue and bone mixture in a layer so thick that we were not able to collect sediments. The powerful smell of hydrogen sulfide indicated a high degree of hypoxia and anoxia in the waste mixture covering the bottom. During March 1999 sampling, Williams et al. (1999) also found decomposed fish waste (e.g., fish bones) scattered between all of the FPW outfall pipes (Fig. 4.6; stations 1-10). The waste they found, however, was odorless and consisted of small pieces of fish bones with little or no tissue matter associated (i.e., decomposition was essentially complete).

Worms of any kind were rare in our samples. Capitellids, traditional indicators of stressed environments were common, however, in our collections adjacent to the FPW discharge area (Fig. 4.6; stations E-H). Similarly, Williams et al. (1999) found the polychaete *Capitella capitata*, in large numbers at stations they classified as polluted (Fig. 4.6, stations 2,3,5,6,14,15). We did find amphipods in areas adjacent to FPW piles where the sampler brought up mud substrate as well (Fig. 4.6; stations E-H); however we found no amphipods within decomposing fish matter. At our undisturbed sites (Mud Bay, near Humpback Creek, and near Observation Island) we found hard bottom. These sites were too hard in fact to be properly sampled with a Mini Ponar device. Nevertheless, we concluded that the overall regional spread of polluted and non-polluted conditions identified by Williams et al. (1999) was characteristic of 2004 and 2005 conditions when we sampled, despite the vast difference in local conditions near Spike Island and the Cordova waterfront where FPW was discharged from pipes.

It is noteworthy that Williams et al. (1999) found an abundance of small (1-2 cm carapace length) juvenile *Cancer* crabs in the FPW outfall area during their March sampling. In fact, highest numbers occurred near the outfall pipes where crabs were apparently foraging on FPW that had been decomposing for several months. Crabs of this size would have been new recruits to the local population. Given the abundance of sea otters (*Enhydra lutris*) in Orca Inlet and their proclivity to consume cancer crabs (Kimker 1985), it is reasonable to assume that crab mortality would be quite high and their abundance would be much lower at the end of the summer, the time frame when we collected samples. Thus the difference in benthic conditions (e.g., the anoxic layer of waste covering the bottom) not withstanding, it is not surprising that there were no *Cancer* crabs in our collections in September of 2004.

Aerial Surveys for Gulls

Four aerial photographic surveys were flown in 2005: 18 and 24 May, 28 June, and 11 August. Gull numbers per survey ranged from a low of 71 (24 May) to a high of 8,678 (28 June; Fig 4.14). Gulls responded quickly to the presence of FPW. Approximately 1,000 gulls were observed around outfall areas on 18 May, shortly after the closure of the first gillnet opener (24h harvest, 16 -17 May). In contrast, during the 24 May surveys, no FPW was visible and the gull count was <75 birds. Total gull numbers were underestimated for both the 18 May and the 11 August surveys due to technical difficulties. On 18 May, photos in area 5 (the area with highest gull concentrations) were taken 6 seconds apart, causing a gap in the flight coverage. During the 11 August survey, there were several 8-second delays between photos.

The high numbers observed during the 28 June and 11 August surveys were associated with seafood processing related to both the Copper/Bering Rivers gillnet and the Prince William Sound purse seine fisheries. For both surveys, birds were concentrated in the water at FPW outfall areas (especially areas 3, 5, 8) and roosting adjacent to outfall areas. More than 1,200 and 535 gulls roosted on a combination of rooftops, docks and the breakwater during the 28 June and 11 August surveys, respectively.

In addition to the availability of FPW, the breeding behavior of gulls also influences gull numbers in and around the processing plants. The barrier islands of the Copper River Delta, in particular Egg Island (Fig. 4.1), are important breeding grounds for Glaucous-winged Gull and to a lesser extent Mew Gull. Egg Island hosts a large (>10,000 birds) Glaucous-winged Gull and a small (100's) Mew Gull breeding colony. Based on observations at Egg Island (Bishop, unpubl. notes) nest initiation occurs from 15-30 May for both gull species. After the last egg is laid, incubation time is approximately 18 d for Mew Gulls, and 27 d for Glaucous-winged Gulls (Verbeek 1993, Moskoff and Bevier 2002). By the end of June, adults of both species are busy provisioning chicks by flying to food sources and returning to their breeding area to regurgitate food to their unfledged chicks. It is highly probable, therefore, that higher numbers observed during the latter half of June are a result of adults feeding in order to provision their chicks. Mew gull chicks fledge approximately 27 days after hatch, whereas Glaucous-winged Gull chicks fledge anywhere from 37-53 days post hatch (Verbeek 1993, Moskoff and Bevier 2002). Thus by early August, young of the year gulls feeding on an easily accessible FPW are also adding to the relatively high population of gulls observed on and around the canneries.

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Chapter 5. Characteristics of the Study Site – Mud Bay Trench

5.1 Introduction

Our experimental site for disposal of unprocessed fish waste was located in Mud Bay Trench, which lies west of Cordova on the opposite side of Orca Inlet (Fig. 5.1). Historically, a variety of animals including crabs (e.g., Dungeness) and fish (e.g., halibut) consumed the fish wastes dumped by fish processors in Orca Inlet. During preliminary underwater video surveys of potential experimental dump site areas, we observed several members of the scavenger community (e.g., sea stars, crabs and fish), but specific identification was difficult. In this chapter, we describe two studies that were conducted to better understand the characteristics of our study site: (1) a detailed examination of the study area bathymetry to facilitate evaluation of the experimental study site in comparison with the existing dump site in Spike Island Basin, and (2) use of various traps to collect organisms that might be attracted to our experimental disposal.

5.2 Materials and Methods

Bathymetry

We used a recording fathometer (Lowrance XM-15 200 kHz digital recording echosounder coupled with a Lowrance GPS). A preliminary survey was conducted on June 3, 2006 to assess the area and develop the design for the final study year. Dumping of fish waste began in early June. The final survey, conducted on June 23, 2006, was designed to collect bathymetric details of the dump site and adjacent areas where observations suggested that waste was spread by currents. It consisted of 17 parallel transects oriented roughly orthagonally to the shoreline (i.e., parallel transect survey design). The transects were roughly evenly spaced along a 2-nm stretch from the north side of Mud Bay southwestward along the coast of Hawkins Island. The transects ran from near the shore of Hawkins Island, across the narrow trench where waste was being dumped, to the western edge of the broad sand flat that extends eastward and fills much of the rest of Orca Inlet. Depths ranged from >20 m in the trench to <1 m at the sand flat. We used the GPS/Mapping function of the LCX-15m to maintain a consistent transect pattern. We used the MapCreate program (Lowrance Electronics) to make maps of Orca Inlet and load them into the sounder.

The depth sounder's signal transmission repetition rate was 1.55 Hz (interval = 0.64 sec). Logging started at the beginning of the ebb flow and ended 2 hours and 37 minutes later. Survey speed was 6-8 km/hr. Depth measurements with latitude and longitude data from GPS (updated every second) were kept for analysis (9,359 total). We used the Sonar Viewer program (Lowrance Electronics) to download and visualize data as an "echogram chart" to facilitate data editing, such as removing spurious GPS values which occur now and then, as well as sections of sounder data where sounder lost bottom track.

Lowrance echo sounder instruments digitally store data in terms of "Lowrance mercator meters". They were converted to Latitude and Longitude with the following transformations taken from the Lowrance Customer Service Technical Note by Luke Morris (no date): "Bathymetric Survey and Depth Contours using Lowrance Sonar Log Data":

Longitude = (Position X * 57.2957795132) / 6356752.3142

Latitude = 57.2957795132 * (2 * atan (exp (Position Y / 6356752.3142)) – 1.570796327)

We measured the depth with the LCX-15m at a navigation buoy (red buoy #18) near Mud Bay at the beginning and the end of the survey to provide a correction for tidal change during the survey period (3.4 feet). We made a confirming determination with another depth sounder placed on a floating dock in the Cordova Boat Basin. Although a technical problem limited its operation to only half of the survey period, the derived total depth change determined with this instrument—assuming a linear rate of change—was 3.34 feet, close to the value determined at the buoy near the survey site. We used a factor derived from the -3.4 feet depth change value as a temporally linear adjustment to weight sequential depth measurements for tidal change.

We created a georeferenced contour map and a surface plot of the study area bathymetry at high tide by overlaying a grid of the corrected bathymetry data onto the digitized map of Orca Inlet shoreline features – taken from NOAA bathymetric chart 16709, digitized with an Intuos 2 digitizer pad – with the Didger and Surfer programs (Golden Software, Boulder, Colorado). We obtained control points for georeferencing the overlay of coastal features by collecting GPS latitude and longitude values with a Garmin GPS76 GPS receiver at five locations, including a prominent boulder in Mud Bay.

Trapping

We made special bag traps to collect small organisms (order 1 cm) attracted to fish waste bait (salmon heads). Each trap consisted of a pair of fine-mesh fabric bags large enough to hold one thawed salmon head. The fish head was placed in the slightly smaller interior bag, which was tied closed and then placed inside the outer bag. The outer bag was punctured with several ~ 6 mm holes to allow small animals (e.g., amphipods) to enter the outer bag and try to get to the head in the inner bag. The traps were set at the experimental dump site in Mud Bay trench, two sites in the north end of Orca Inlet (near Humpback Creek and near the north end of Observation Island), and near the end of one of the pipes where ground up waste was being discharged from one of the canneries.

We used larger traps to collect larger members of the scavenger community at the dump site. Two "Mini-Mag" brand shrimp pots (7/8' wire mesh; 30" x 24" x 12"; four tunnel entrances), baited with a one pound jar of commercially prepared prawn bait pellets ("Super Bait"), were set several times (24 h duration) in the experimental dump site area. The objective was to collect preliminary size frequency and catch rate data for the shrimp resource that had been observed in the underwater video recordings and tentatively identified as coonstripe shrimp (*Pandalus hypsinotus*) (Fig. 5.5). The goal was to preliminarily investigate the feasibility of a subsistence shrimp fishery on this resource, one that may have been enhanced by the addition of almost 200,000 pounds of potential shrimp food in their habitat.

5.3 Results

The contour plot of the experimental dump site area (Fig. 5.2) provided a base map that was used for field operations in the study area (e.g., referencing sonic tag drop locations in the field, Fig. 5.2). The contour plot of the section of Orca Inlet contained both the Spike Island Basin where dumping of processed waste is ongoing and the location of the experimental dump site area (Fig. 5.3). It facilitated our evaluation of the physiographic features between the two. The surface plot of the experimental dump site (Fig. 5.4) facilitated conceptual evaluation of the Mud Bay Trench and its uniqueness in the context of its juxtaposition to the adjacent expanse of Orca Inlet's mud flats. It also provided a context for interpreting the results of physical oceanographic surveys (see Chapter 3).

The bag traps set near Mud Bay and near Humpback Creek caught gammaridean (Lysianassidea) amphipods (Fig. 5.6). One small brittle star was collected at the Humpback Creek site. We also caught Sunflower seastars (*Pycnopodia helianthoides*) that clung to the outside of the traps set in these two areas. The traps set near the end of cannery's discharge pipe caught small nudibranchs (Fig 5.7). Traps set on rocky substrate near Observation Island did not catch anything.

The shrimp traps caught mostly Sunflower seastars (Figs. 5.8 and 5.9). The exception was one pot that was damaged when it was dragged through a boulder field in Mud Bay trench and the bait jar was dislodged from the trap. The door of the trap was bent and allowed egress to trapped animals that may have "lost interest" once the bait jar was lost. Nevertheless, the trap retained several small Sunflower seastars as well as juvenile Dungeness crabs (Fig. 5.10), adult spider crabs (Fig. 5.11), and several gastropods (Fig. 5.12). We did not catch any shrimp in any of the traps.

5.4 Discussion

The two most common organisms caught by the carrion traps were Lysianassid amphipods and Sunflower seastars. These are highly aggressive scavengers in the marine community, known to be attracted to carrion from considerable distances. Sunflower seastars are known to travel several miles at rates up to 3 m per minute (O'Clair and O'Clair. 1998). Despite the diversity of the benthic fauna visible in our video observations, the Sunflower seastars were often the only organism in the shrimp pots. Aside from the fact that these aggressive predators exude copius amounts of mucus and are likely offensive to be around, their aggressive behavior likely discourages other, more active organisms (e.g., shrimp and cancer crabs) from entering an area dominated by their presence, although Dungeness crabs are known to prey on them (O'Clair and O'Clair. 1998).

Lysianassid amphipods – the type we caught in the bag traps – are critical to the decomposition and recycling of organic matter in carrion. They occur worldwide and are distributed from the intertidal to abyssal zones. It is to be expected that fish waste in Orca Inlet would attract these organisms. In fact, a skeleton of a killer whale was prepared for local display by leaving the bones in Orca Inlet for "amphipod cleaning". However, it is notable that they were not in the carrion traps that we placed on the decaying piles of ground waste in Spike Island Basin. Given the high levels of hydrogen sulfide we detected in our benthic sampling (see Chapter 4), we conclude that the "sour" matter in the waste piles is not an attractant to these important scavengers.

Chapter 6. Monitoring the Natural Reduction of Unprocessed Fish Waste in Orca Inlet

6.1 Introduction

The experimental dump site (approximate latitude 60° 32.8 N, longitude 145° 50.8 W) was in a scoured channel that runs parallel to the shore of Hawkins Islands near Mud Bay (Mud Bay Trench). The trench is west of Cordova on the opposite side of Orca Inlet (Fig. 6.1). We dumped unprocessed fish waste (heads, skins and carcasses) in Mud Bay trench (Fig. 6.2) in summer in 2005 (155,250 pounds total) and 2006 (174,100 pounds total) (Table 6.1).

We conducted two projects to monitor the natural reduction of the experimental waste pile in the natural system. One was direct observation with underwater video. The other was indirect observation of scavenger activity by tracking the movement of sonically tagged carrion, namely salmon heads fitted with acoustic pingers (Chapter 7). The objective of the projects was to measure the general activity of scavengers at the dump site and evaluate the dispersal of waste in the trench. The goal was to assess the disposition of the waste in terms of a contribution to the system as a food source versus it being a "pollutant" in the context of the terms of NPDES.

During the course of the dumping, we also conducted numerous surveys of the shoreline by skiff, looking for evidence that fish offal had floated to shore.

6.2 Materials and Methods

During the summer of 2005, we lowered two tethered underwater video cameras, a Deep Blue X3 Splash Cam Color Camera and a Deep Blue X3 Splash Cam Black and White Camera, to the bottom to observe the benthic community at the dump site in Mud Bay trench before, during and after waste dumping. We also used the cameras at control sites in the northern section of Orca Inlet for comparisons. One site was near Observation Island and the other was in a trench near Humpback Creek where unprocessed fish waste was once dumped from a cannery that operated there in the early 20th century. Camera observations were made while the boat was anchored and while it was drifting.

We developed a camera sled to facilitate video observations of the benthic habitat for the 2006 field season (Fig. 6.2). The sled was designed to maintain the position of the two video cameras above the bottom as they were towed slowly through the dump site area. One camera (Deep Blue X3 Splash Cam Color Camera) faced forward at an oblique angle so the lower half of its field of view included the benthos and the upper half covered the near-bottom water column – to the limit of the lighting system. We positioned the camera Lighting consisted of three Pelican Mitylite Xenon Laser Spot Flashlights, modified to provide non-collimated (diffuse) illumination.

We oriented the other camera on the sled, a Deep Blue X3 Splash Cam Black and White Camera, downward. Two more of the modified Pelican Mitylites provided illumination. Given that this camera's height above the seabed was fixed, its field of view – 56 cm by 66 cm in air; 43 cm by 51 cm in water – produced a 2.2 m^2 "video quadrat" for estimating areal density (number per square meter) of epifauna and fish waste. A standard target (50 mm by 75 mm) at the edge of the video image area allowed size determination of viewed objects in the video quadrat.

As with the drop camera work, limited water clarity affected video observations. When turbidity was high, video images lacked contrast and image resolution was poor. The month of August, 2006, was extraordinarily rainy and large amounts of highly turbid glacial waters flowed into Orca Inlet reducing water clarity. At other times, particulate matter in the water column – apparently pieces of ground-up fish waste (roughly 1 cm chunks) being discharged from Cordova's canneries at the time – created "biological snow" that produced considerable backscatter from the lights illuminating the forward camera's view.

For example, when 15 totes of unground waste (about 18,000 pounds total) were dumped on 3 June 2006, field observers noted ground waste (e.g.,1 cm strings of fish tissue) drifting in the water column and a slight fish-oil smell, several hours after dumping had ceased. The waste had attracted large numbers of Pacific sand lance (*Ammodytes hexapterus*) but not many birds, albeit thousands of them were feeding in Spike Island Basin at the discharge pipes where the "biological snow" was considerably more concentrated (see Chapter 4). Water clarity at the dump site was markedly reduced by the "snow".

Another possible source of backscatter was gas bubbles in the water column. During the bathymetric survey of the Mud Bay Trench area, the acoustic system detected high levels of background "noise" at the main dump site that appeared as foam or micro bubbles in the echogram. It was assumed to be bubbles from decomposing waste as it was not detected elsewhere.

To minimize backscatter, the lights of the forward camera were purposely aimed "off axis" toward the lower half of that camera's field of view. Although this limited the maximum viewing distance in the upper portion of the image, light levels were sufficient to detect fish and other organisms near the bottom.

We typically deployed the sled by lowering it to sandy bottom near the mouth of the Mud Bay and then towing it slowly down the slope into the trench where waste was dumped.

We recorded the outputs from all cameras on VHS tape, and in the lab, we digitized and transferred images to DVD format. We processed video images with the Pinnacle Studio program, and used Photoshop to enhance selected frames for final evaluation.

6.3 Results

The drop cameras were more effective for observing fish because they created less disturbance during use. We observed several species at the control sites and at the experimental dump site, primarily rock fish (Fig. 6.4), rock sole (*Lepidopsetta* sp.) (Figs. 6.5-6.8) and halibut (*Hippoglossus stenolepis*) (Fig. 6.9). In contrast, observations of fish waste in Mud Bay trench with the drop cameras were rare. The drop cameras were easily disturbed by the action of currents, which made them difficult to control.

The camera sled was more effective for synoptic surveys of the benthic habitat in the dumping grounds since the cameras remained a fixed distance above the substrate as they were moved along by the pull of the drifting boat. Given their rather limited depth of field, maintaining camera altitude was critical when operating in the dynamic environment in the trench. Although we detected fewer fish with the sled, we did see more invertebrates, some of which were feeding on fish carrion that obviously had been dumped there.

On the Hawkins Island side of the trench, including Mud Bay, the bottom is firm and rocky, especially moving southwestward away from Mud Bay, an extension of the mountainous features of the Hawkins Island geology. The bottom slope is very steep and water depths of 10+ m are found adjacent to the shore. On the opposite, offshore side of the trench, the bottom rises gently up onto the extensive sand/mud flat that dominates the southern half of Orca Inlet. These sediments are actively worked by the tides, and their movement was evident in the existence of so-called mega ripples (Fig. 6.10), a pattern of sand waves caused by non-linear interaction between tidal currents and a non-cohesive sandy bottom. The sandy sediments extend throughout much of Orca Inlet and mega ripples are quite visible in hydroacoustic echograms collected in the area.

In marked contrast, the bottom of the Mud Bay trench is covered with a variety of substrates. In some areas there is a jumble of unconsolidated shell hash and mixed sediments (Fig. 6.11). The shell hash includes fragments of several bivalves (e.g., Tellinidae (*Macoma* spp., *Tellina lutea*, others), and Cardiidae - cockles). The poorly graded nature of the particulates is characteristic of scouring in an environment with high velocity water currents.

In other areas the bottom was covered with dense beds of the woody-stemmed kelp (*Pterygophora californica*) (Fig. 6.12), a brown alga (Order Laminariales). The algal fronds were typically stout and robust (Fig. 6.13), an adaptation to living in fast-flowing currents that were sometimes evident in the video images (Fig. 6.14). Roughly 0.2 nm SE of the targeted dump site lay a kelp-covered boulder field (Figs. 6.15 and 6.16) that provided habitat for fish and invertebrates (e.g., the coonstripe shrimp (*Pandalus hypsinotus*) in the lower right corner of the image).

The most prominent scavenger in the videos was the Sunflower star (*Picnopodia helianthoides*). According to O'Clair and O'Clair (1998), it is the "largest, heaviest, softest, and swiftest seastar in the North Pacific, and perhaps in the entire world". Among the organisms they list as its prey are bivalves and fish waste (included filleted halibut carcasses). Indeed, many of the Sunflower stars observed in our video recordings were feeding on FPW comprised of salmon heads and carcasses (Figs. 6.17 and 6.18), the kind of fish waste that we had dumped in the trench earlier. In fact, the Sunflower star was the most commonly observed organism actively involved in scavenging unprocessed fish waste.

We also observed several other species of sea stars (Fig. 6.19), including the leather star (*Dermasterias imbricata*) (Fig. 6.20), as well as brittle stars (Fig. 6.21). We also observed cancer crabs (including a juvenile Dungeness crab (*Cancer magister*) feeding on fish waste (Fig. 6.22)), gastropods (Fig. 6.23) (such as the moon snail, *Polinices lewisii*, and the Foliate Thornmouth, *Ceratostoma foliatum*)(Fig. 24), unidentified squid and coonstripe shrimp, *Pandalus hypsinotus* (Fig. 6.25), an eel (Fig. 26), and flat fishes (halibut and sole). In some areas, particularly along the rocky wall of the Hawkins Island side of the trench, anemones (Fig. 6.27) were common as well. We often observed sea otters (*Enhydra lutris*) near the dump site - large numbers (50+) were often rafted roughly mid-way across the inlet. Relatively few ventured over to the study area. When they did, occasionally one would be seen feeding on pieces of fish (Fig. 6.28). Perhaps the most unique observation of scavenging was the instance of a sunflower star that was consuming a decomposing fish head and in the process had become buoyant and was floating out of the study area (Fig. 6.29).

The most interesting observation of all was the general lack of fish waste in the Mud Bay trench, despite dumping over 325,000 pounds of salmon heads and carcasses. We expected the tidal currents to be strong in the trench. Fisherman travel that route to the fishing grounds whenever possible, and they have shared their local knowledge about these features with us. Our video surveys confirmed the abundance of the benthic fauna in the trench that would feed on fish waste we dumped there. Nevertheless, we were surprised that we could not detect an accumulation of fish waste at the dump site, particularly when some dumping occurred when tides were slack and the waste would have settled quickly to the bottom.

There were no detections of floating heads or carcasses during the skiff surveys of the nearshore, nor were any heads or carcasses found washed ashore on beaches.

Chapter 7. Tracking Scavenging with Sonic Tags

7.1 Introduction

Mud Bay Trench is a popular fishing ground for halibut (*Hippoglossus stenolepis*) and flatfishes (e.g., soles, *Lepidopsetta* sp.). It was also popular prior to the discharge of ground offal, including an artesanal pot fishery for Dungeness crab (*Cancer magister*). We expected that these and other species of scavengers would be attracted to unprocessed fish waste dumped in Mud Bay Trench and our observations with underwater video (see Chapter 6) confirmed this hypothesis.

Fish waste can be transported away from the dump site by the actions of larger scavengers. In the process, energy in the waste would be exported from the dumping area and rapidly recycled into higher trophic levels of the food web, rather than accumulate in the relatively slowly decomposing waste piles that currently accumulate near Spike island. During the course of this study, the public responded to our requests for catch reports regarding evidence that scavengers were transporting unprocessed waste away from the dumping grounds near Mud Bay. We received several reports in 2005 and 2006 that halibut taken by hook and line in the northern portion of Orca Inlet had salmon heads in their stomachs, confirming that these fish were eating the unprocessed waste we had dumped in Mud Bay Trench.

To augment these observations we conducted a study to directly observe the phenomenon of large scavenger activity at the experimental dump site. We attached sonic tags to fish heads and then tracked their location for up to three months. The objective was to assess physical displacement of the waste in the trench after it was deposited there. The goal was to track movement patterns and discern the relative degree of physical movement that could be attributed to tidal currents and the movement that could be attributed to scavengers.

7.2 Materials & Methods

We used a total of sixteen sonic tags (Vemco Model V9) to track sixteen fish heads dropped near the experimental dump site in Mud Bay Trench. We avoided the actual location where totes of waste were emptied (Fig. 7.1) to avoid accidentally burying a tag. The tags were “continuous pingers”, meaning they repeatedly transmitted a 10 ms pulse at a particular frequency (63, 66, 72, 75, 78, 81 or 84 kHz) and at a particular interval or period (2250, 2270, or 2300 ms). Thus, each tag was unique, and provided that tags of the same frequency were separated sufficiently (e.g., >0.5 nm), accomplished by using three release sites, all the tags could be at large and tracked simultaneously. We attached each tag to a thawed salmon head (Fig. 7.2) and dropped them in one of the three “tag release areas” near the experimental dump site (Fig. 7.3). We recorded the location (longitude and latitude) of the release site with a Garmin GPS76 receiver. We monitored tag position, beginning about ½ hr after release, over the course of up to 3 months by obtaining a directional “fix” to the tag from an anchored boat positioned at “listening sites” along the eastern side of Mud Bay Trench. We determined the direction to the tags with a Vemco VR60 receiver (Fig. 7.4) with a directional hydrophone (Vemco VH110). The hydrophone was rotated to the direction of peak signal strength and a magnetic fix on the direction was taken with a Weems & Plath Model 2004 hand bearing compass. We obtained two fixes per tag (i.e., bearings from two listening sites) so that we could estimate tag location with triangulation.

Triangulation involved plotting the location of a listening site on a georeferenced map of the study area and then plotting a line from a listening site toward the direction of a bearing to a tag (adjusted for magnetic deviation). We made maps that plotted the bearings for each tag as the study progressed. As the number of fixes to a tag from the various listening sites accumulated, the plots converged toward the position of the tag. If the area of convergence changed, it indicated that the fish head had moved, either by biological or physical disturbance. The distance between the release site and the first fix about 30 min later indicated how far the waste was carried by tides as it settled to the bottom. Subsequent changes in position were inferred to be due to biological disturbance. We assumed that small, gradual changes were due to crab activity whereby an animal would slowly drag a piece of waste along as it tore away the fish tissue. A large change in position – in some cases resulting in tag disappearance altogether – was inferred to indicate the tagged fish head had been carried off by a scavenger.

In practice, we observed some unexpected variation in the tag direction data, particularly for some specific tags (i.e., those that ended up in or near the boulder fields identified with the underwater video surveys (see Chapter 6). In these instances an error was assumed to arise when a tagged fish head happened to fall behind a boulder (i.e., the boulder would lie between the pinger and the hydrophone). If a tag was thus "shielded" from direct detection, the receiver would detect the acoustic signal that reflected off the wall of the trench behind the tag. In some cases this could lead to a false bearing to the target and generate an error. Thus, the resolution of actual tag location in most instances was "blurred" by this imprecision. Final plots of tag location during the course of the study included "probability zones" or circles about 100 m (0.05 nm) in diameter that were drawn where bearings converged and in which the true resting place of the tag lay.

We dropped tags in four groups (Table 7.1, Fig. 7.3), the first (group A) on 15 June 2006, about 2 weeks after experimental dumping into the Mud Bay Trench had begun. We released we released more tags in the same area on July 6. We dropped group A tags individually (i.e., each at its own site) in an area roughly 100-200 m northeast of the experimental waste dump site (Fig. 7.3). We dropped more tags on 13 September 2006, but all together at the same location, about 1 nm southwest of the targeted dump site. About a week later (21 September), we dropped another group of tags simultaneously at a location about midway between the other two (Fig. 7.3).

7.3 Results

We tracked the tags in Group A (Fig. 7.3) considerably longer than the other two groups. This was a sampling artifact that arose due to the prolonged rainy weather that occurred during the summer of 2006. Attempts to monitor movement and deploy more tags in July and August were delayed because our survey skiff had no shelter and the Vemco receiver was not weather resistant. Nevertheless, the results from the first group were revealing, especially when compared with the tags that were dropped at the end of the summer, about 3 months after dumping of waste had begun.

We determined that tidal currents in Mud Bay Trench were quite strong and nearly uniform from top to bottom (see Chapter 3). We also learned that peak velocities occur in the latter portion of a tidal cycle and continue to roughly the peak of the hydrostatic phase (i.e., maximum height).

That is, there is a lag between the hydrodynamic and hydrostatic elements of the tides. We released the first three tags in group A (Fig. 7) near the time of high tide and they moved about 100 m west southwest during descent to the bottom. We released the four remaining tags in the group after high tide and they settled to the bottom roughly below their release point. Thus, tag displacement by the tide followed predictions, according to our observations of current flow behavior.

After group A tags settled to the bottom, their movement appeared to be random and did not exceed about 100 m. Eventually tag movement ceased (about 3-4 weeks after release). We surmised that crabs had been feeding on the fish heads and by then the operculum (and its attached tag) had been disjointed from the skull and lay unmolested on the bottom for the remainder of the study.

We released group B tags southwest of the targeted dump site on 13 September 2006 when the tide was in full ebb flow. Three of the four tags settled roughly 150-200 m from the drop site. The fourth tag was displaced about 375 m by the tide. Although the first three tags in the group did not move very much during the next few weeks after release, the fourth tag ended up an additional 400 m further down the trench (SW) from its original resting spot. Given the behavior of this last tag, we assumed that biological disturbance (e.g., by crabs) could have displaced the fish head from the benthic boundary layer (perhaps by dragging it onto a rocky substrate) and exposed the waste to currents that rolled the head along further down the trench. Thus it might be possible that there is an interaction of biological and physical forces that can move waste considerable distances.

We dropped the last group of tags closer to the targeted dump site on 21 September 2006 (Fig. 7.3). The tide was near the time of high tide and surface current flow was slight. We detected four of the five tags near the drop site <1 hour after release. One of the tags had been moved away from the drop site during that time, but the amount of movement was not determined. (The bearing to that tag was on a line that placed at least 0.1 nm of separation between the tag and the drop site but only one reading was taken, precluding triangulation.) Four days later (September 25), that tag and two of the others were not detected at all. Presumably they had been carried out of the area by scavengers. The other two had been moved considerably, one about 500 m and the other about 1600 m southwest of the drop site. We assumed that all of these tagged fish heads had been moved by scavengers and that two of them had been consumed by fish and carried away.

Chapter 8-Modeling the Recycle of Fish Processing Waste in Orca Inlet, Alaska

8.1 Introduction

The primary assumption that justified the discharge or dumping of fish processing waste (FPW) into the near-shore waters of Orca Inlet is that it is assimilated into the trophic structure without any major deleterious environmental effects. Prior to 1978, whole carcasses were dumped under the docks of the processing plants. The processors used the fact that the piles of fish carcasses would completely disappear before the next fishing season to verify the primary assumption that the FPW was assimilated into the trophic structure (Ken Roemhildt, Cordova seafood processor, personal communication). However, no research has been conducted to document the mechanism of recycling FPW in the near-shore marine ecosystem.

The carcass dumping practice exposed large, unsightly and odiferous piles at low tide, and produced numerous floating carcasses in the vicinity of the dumping site. To remedy these problems, the Environmental Protection Agency (EPA) established a requirement for all processing plants in Alaska to grind the FPW to ½ inch (1.27 cm) before discharge into the water. EPA implemented this regulation by requiring all processing plants to have a National Pollution Discharge Elimination System (NPDES) permit. The grinding practices began in 1978.

The grinding of FPW solved the immediate problems by eliminating the carcass piles and floaters, but it also required EPA to be very lenient about its standards relative to what represents deleterious effect. Large piles of ground offal accumulated around the discharge sites where none had been before. These piles of organic material quickly became anoxic, which enhances the accumulation of organic material. In recent years the piles have grown to the point that surface vessels have become stuck on them at low tide, causing major releases of noxious gases. Elevated ammonia levels, excessive algal growth, water discoloration and surface scum also suggest poor water and habitat quality results from the grinding practice. In addition, the commercial fisheries for halibut and Dungeness crab in Orca Inlet collapsed and nuisance levels of Glaucus-winged and Mew gulls are attracted to the ground offal, which creates a secondary human health problem for the fish processors and local community. In recent years, EPA only appears to be rigorous about inspecting the discharge sites in search of unground FPW, and when they find it they issue major monetary fines to the processors for violating the NPDES permit.

We developed a model of the discharge system to help us better understand the mechanisms that contribute to the dispersal and assimilation of FPW into Orca Inlet. Our objective was to compare the discharge of ground to unground FPW with the intent of improving current discharge practices.

8.2 Models

We developed a static, deterministic model to describe how the discharge of FPW is recycled in the nearshore ecosystem of Orca Inlet. The mechanisms are intuitive and based upon measurements, the literature, historical records, traditional knowledge and personal observations. The two mechanisms that we focused on were the dispersal and the assimilation of the FPW, and each of these mechanisms have physical and biological components.

As it exists today, the discharge of ground FPW is at fixed-sites. Thus, there is a major problem with dispersal or transportation of the FPW away from the discharge site so it will not accumulate. We developed a FPW transport model (T) that includes both physical (P) and biological (B) mechanisms.

$$T = f(P+B)$$

P = physical transport of fish waste
B = biological transport of fish waste

<u>The physical transport component</u>: FPW is composed of liquid and solid components. The transport of liquefied FPW is primarily by tidal currents in Orca Inlet. Tides create the largest movement of water in estuaries (Attrill 1998) and can exceed 10 km/hr in Orca Inlet. However, since tidal currents move water in and out of the inlet the primary effect is to mix the liquefied FPW within the tidal field. Freshwater runoff is probably more important to the net transport of FPW out of the Inlet, but the June-August fishing season has the lowest precipitation of the year so this is not a major factor in the dispersal mechanism. As one would expect from diffusion, there is a significant gradient in the decreased liquid FPW with distance from the discharge site. In contrast, the physical transport of solid FPW is even more restricted and primarily limited to an area within 100 meters of the discharge. For example, the largest piles of solid FPW that have been observed exceeded 4 m in depth and covered areas over 1.6E+05 m^2 (EPA 1998). This is equivalent to 2 acres.

<u>The biological transport component</u>: Biological transport of FPW results from two processes: microbial decomposition and animal consumption. First, microbial decomposition liquefies solid FPW and enables tidal current dispersal. Bacteria and fungi are the principal agents of decomposition and are collectively known as decomposers. Such decomposition is most rapid when oxygen is present. Under low oxygen conditions, such as underwater, decomposition can become so slow that organic matter accumulates to a remarkable extent. This explains the build up of large offal piles at the discharge sites. Decomposition, or liquefaction of the FPW, is primarily limited to the surface area of the offal piles since the organic deposits are anoxic.

Second, solid FPW is not waste, it is food and many marine animals consume it. It is often used in mariculture operations to raise fish for human consumption. At the risk of being redundant, the assumption that solid FPW would be consumed and assimilate back into marine animal production was the original and primary assumption that justified the discharge of FPW into the nearshore marine ecosystem. Had a build up of carcasses under the processing plant docks not disappeared before each fishing season, and if the piles had produced anoxic conditions, it is unlikely that the processors would have continued the dumping practice for more that a couple of years. In contrast, during the years when whole carcasses were dumped into Orca Inlet there were thriving commercial, sport and subsistence fisheries for Pacific halibut *Hippoglossus stenolepis* and Dungeness crab *Cancer magister*. Corroborating this is traditional knowledge that the carcass piles were covered with feeding crab and halibut and other marine animals. This consumption of the fish carcasses enabled the marine fish and wildlife assemblage to play a major role in the transport the FPW away from the dumping site, which minimized negative effects of organic loading.

We modeled the relative biological transport, *B*, by species i as a function of the average size of species i (as body weight), the average consumption of species i in percent of body weight, and the average daily range of movement for species i,

$$B_i = (r_i)(w_i)(a_i)$$

where r_i = *average daily ration in the average percent body weight per day for species i,*
w_i = *average body weight of species i (kg)*
a_i = *average daily range of movement of species i (km)*

where for Orca Inlet i is:
1 = benthic marcroinvertibrates, such as Dungeness crabs whose average size is about 0.45 kg and average daily range in movement is less than one kilometer,
2 = small benthic and pelagic fishes, such as yellowfin sole and herring whose average size is 0.05 and average daily range in movement is less than 10 km
3 = seabirds, such as Glaucus-winged gulls whose average size is about 1.5 kg and average daily range is about 25km,
4 = large finfishes, such as Pacific halibut whose average size is about 10 kg and average daily range is over 25 km, and
5 = mammals, such as the harbor seal and Steller sea lions whose average sizes are about 75 and 150 kg, respectively, and average daily ranges are over 25 km

For simplicity, we assumed that the average daily ration for all species was 3%, which is a generalization from the literature.

The results show that large animal consumption and movement is a very important in the transport of FPW from a fixed dump or discharge site (Fig. 8.1). Such movements are commonplace for animals that make routine diel and daily migrations to feed, avoid predation and optimize their energetics. This biological transport distributes the solid FPW more evenly within the tidal range of the discharge site, and the larger animals even transport material outside of the region where the tides distribute and dilute the liquefied fraction of FPW. The results show that individually the larger finfish and the mammals can increase biological transport of FPW from a fixed site in an exponential fashion.

Furthermore, the consumption and biological transport of FPW increases with the density of large animals. This is where the feeding behavior of larger animals plays an important role since fish and wildlife are highly mobile during their summer feeding migrations and can be expected to aggregate in areas where food is plentiful, such as on piles of fish carcasses. Chumming with fish parts is a mechanism used by commercial, sport and subsistence fishers worldwide, so the mechanism is commonplace. Thus, the larger finfish and mammals are adapted to find and utilize food sources such as piles of fish carcasses that are dumped into nearshore areas. We model the cumulative biological transport by the assemblage as follows:

$$B_T = \sum_{i=1}^{i=5} n_i (B_i)$$

where n is the number of species i that are attracted to the dumpsite.

8.3 Assimilation model

A second aspect of the FPW recycling system is the assimilation of the material into the food web. This is a different function for the liquefied and solid components. First, the decomposers are primarily affiliated with the bottom substrate. Thus the rate of decomposition of the liquefied FPW can be modeled as a function of the substrate area with distance from the discharge or dumping site, which can be approximated as the area of a circle with a radius of the distance from the site. The actual deposition of the liquid FPW would be absorbed as an inverse function of the area as shown in Figure 8.2. The results show that there is major loading and decomposition of the liquid portion of the FPW on the bottom substrates in close proximity to the discharge site. This places even more importance on the animal transport mechanism to distribute FPW in a manner that it does not overload the receiving environment.

As stated earlier, the consumption of FPW is generally considered a function of the body weight of the animal, and in general marine animals satiate at about 3% of their body weight per day in captivity and aquaculture operations. Thus, as we saw in Figure 8.1 the larger the animals can handle proportionally larger amounts of FPW.

The consumption of the solid FPW by marine animals cannot be considered as complete assimilation into the trophic structure, because only part of the process results in growth. Metabolism and digestion produce excrement in the form of liquefied FPW. Thus, the portion that is evacuated by the animals is not removed from the organic loading in the area; it is just dispersed over a wider area due to the movements of the animals within and outside of the tidal range of the discharge site. Mariculture operations report conversion of fish parts to growth of finfish and crusteans at about 60%, with the remaining 40% going to metabolism and excrement. Thus, we assume that 60% of the FPW is converted into finfish growth and 40% is liquefied and evacuated via the digestive processes.

To proceed further with the assimilation modeling and integrate it with the transport mechanism, we assumed some general conditions for the Orca Inlet fish assemblage. For this retrospective analysis, we simplified the assemblage to two primary species: Pacific halibut and Dungeness crabs since both of these species once supported fisheries in Orca Inlet that yielded harvests in excess of million pounds per year.

8.4 Retrospective Analysis of FPW Recycling in Orca Inlet

During the fishing year there really are only about three months of heavy fishing and discharges: June, July and August. Approximately 10,000,000 pounds of fish waste are ground and discharged each year per site (Figure 8.3). Given the ½ inch-grinding requirement, using a surface-area to volume model we estimated that that about 50% of the fish carcasses are liquefied during grinding and the rest is discharged as small but solid particles.

In contrast, liquefaction of the FPW in the pre-1978 practices of dumping whole carcasses is reduced to 10% and the loading of solid particles is increased to 90% (Fig. 8.4). This reveals the primary purpose of EPA grinding regulation, which is to liquefy the fish waste for dilution and dispersion into the nearshore habitat. This conforms with the 1970s theme for wastewater treatment, which was "dilution is the solution to pollution."

Grinding produces five times the amount of liquid FPW compared with dumping the carcasses (Figs. 8.3, 8.4). Given that organic accumulation did not occur with the dumping of large carcasses despite the near doubling of the solid component, means that another mechanism was operating. With the dumping of large carcasses the waste does not settle in a solid mass and the space between carcasses maybe the key to maintaining an oxygenated environment that allowed for decomposition and foraging by the larger animals. In contrast, the ground offal has much less structure due to the maceration process that it has undergone. So it settles on the bottom and becomes much more compact, which cuts off the oxygen, reduces decomposition, creates an anoxic environment, which is avoided by most of the large benthic fish and crustacean, such as Pacific halibut and Dungeness crab. Large FPW piles represent years of organic accumulation.

To simulate the effects of halibut and crab consumption on present discharge conditions in Orca Inlet, we assume historical values of abundance of Pacific halibut and Dungeness crab in Orca Inlet. In the 1970s, Orca Inlet supported fisheries for both of these species that exceeded 1,000,000 lbs (455 mt) harvest each. By assuming the stocks were just the size of the harvested biomass (a conservative estimate) and a size structure common to GOA stocks from the literature, we computed the potential consumption of FPW for Pacific halibut and Dungeness crab and then for Pacific halibut alone relative to the discharge of FPW (Figure 8.5). The combination of halibut and crab consumption could process the entire FPW from a single discharge site. However, unlike the Pacific halibut stock, which is considered to be very healthy at its current status, the Dungeness crab stock is believed to be at an all time low. This has been hypothesized as the result from heavy predation by sea otters and suppression by a predator pit mechanism (Bakun and Broad 2003). Regardless, we estimated the consumption by halibut alone could handle over 5 million pounds of solid FPW at a discharge site, so it is our assumption that the solution is to experimentally determine the loading rates at several dumping sites and distribute the unground FPW appropriately.

The consumption of ground FPW by halibut and crab is only a fraction (8%) of what it is for the whole carcasses (Fig. 8.6). A number of other issues besides the size of FPW also need to be addressed with the change in discharge practices, such as extensive anoxic bottom conditions, ammonia-based avoidance, excessive intertidal algal growth, etc.

Figures 8.7 and 8.8 summarizes the fate of the current and a hypothetical pre-grinding FPW discharge system for Orca Inlet if the water and habitat quality were given the time to recover from existing conditions, and the animals given time to become accustomed to the new source of FPW as food. As we pointed out earlier, the function of the grinding of FPW was to liquefy and disperse it. However, we see that when you consider the total liquefaction of FPW by combining the mechanical and bioliquefied components, the liquefaction actually is higher when discharging the whole carcasses. When this is combined with the fact that the loading by the liquid component of the FPW is spread out over a much larger area by the animals it is a strong argument against grinding practices.

Also, figure 8.8 shows a unique aspect of the recycling process, which is animal growth. In the whole carcass dumping, the recycling of FPW into fish growth is almost 50% of all that is discharged, as opposed to less than 10% for the ground offal. This was the primary assumption that justified the dumping of waste back into the marine environment, and a mechanism that was ignored by the EPA when implementing the grinding regulations in Cordova in 1978.

Finally, figure 8.9 shows that the total carbon loading of ground FPW is about twice that of the unground FPW when you consider that the growth removes nearly half of the FPW right off the top. This combined with the liquefaction arguments makes it difficult to justify the grinding regulations. From our perspective, there appears to be an overwhelming conservation and management argument for the elimination of the grinding practices and the adoption of the discharge of whole carcasses as was done prior to the 1978 FPW grinding decision.

8.5 Discussion

The model results suggest that the entire premise of the EPA grinding regulations was faulty, and in fact grinding of the FPW produced all of the undesirable effects that EPA is mandated to eliminate as poor industrial practices as well as seriously impacted fish production. The model suggests the grinding practice may cost us on an ecological level as well. The annual discharge of FPW in Alaska is about 50% of the total landings so half the catch becomes FPW. One estimate of the average annual amount of ground FPW discharged into Alaskan waters was 1.7 million metric tons, but this varies widely on an annual basis because just the catch of walleye pollock has exceeded 4 million metric tons in a year. However, if we just consider the long-term average, 1.7 million metric tons as whole carcasses, it would result in 1 million metric tons of finfish and crustacean production. Both the absolute and the relative numbers are important. First, the potential 1 million metric tons of recycled finfish and crustacean production per year is only exceeded by one single species harvest, and that is for the walleye pollock, the largest fin fishery in the world. Furthermore, after three decades of the discharge of ground offal, this represents over 30 million metric tons of finfish and crustacean production. Obviously, some finfish production results from the trickle-up philosophy behind the grinding practice, but this could be negated by the degradation of local water quality and habitat.

Second, the relative numbers are important because as the annual harvest of finfish and crustaceans fluctuates between 2 and 5 million metric tons per year, the FPW remains a steady 50% of this harvest. Thus, what is being missed by the grinding practices is a consistent return of a large amount of carbon production from finfish and crustacean stocks directly back into the finfish and crustacean stocks. Everyone in the plant and animal harvest business knows that you cannot continue harvest rates at high levels indefinitely in natural systems without eventually depleting the building blocks of production, lowering the potential yields and in some cases causing system instability that could result in major unexpected change.

During the late 1970's and early 1980's, the time period of the change in discharge practices, there were major changes in the assemblage of the marine animals in the GOA (Anderson and Piatt 1999). The authors explain this change as a response to changing climate in the North Pacific, and that the trophic reorganization resulted in negative impact on the seabirds and mammals. However, they do not present a plausible argument for the physical-biological mechanisms that cause the trophic structure reorganization. An alternative scenario could be developed based on prey sheltering behavior. Virtually, all of the species that would be expected consumers of whole-carcass FPW (halibut, Pacific cod, walleye pollock, arrowtooth flounder) increased, but moved offshore into the areas where they would encounter their natural prey species (shrimp, crab, capelin and herring), all of which decreased in abundance. In addition, the small finfishes that are observed around the ground offal piles (flathead, yellowfin and rock soles, and starfish) increased. Noticeable decreases occurred in all the large crustacean species (king and tanner crabs). There are literally hundreds of papers and abstracts published that speculate on the reason for the change as a climate regime shift, and major programs have been dedicated to the study and early detection of regime shifts. However, none of the correlations with the complex climate- indices that have been developed appear as positively correlated to the change as the initiation of grinding offal. Corroborating this are simulations of fish growth with the bioenergetics model that suggest that growth rates are far more sensitive to the availability of forage than to physical conditions.

Chapter 9-General Discussion and Conclusions

Two major impressions were derived from this study (1) there are a multitude of organisms in Orca Inlet's near-shore ecosystem that thrive on unground waste, and (2) we could not make a negative impact despite over 325,000 lbs of salmon heads and carcasses that were dumped at a single site, including single dump events over 50,000 lbs. These impressions were supported by the oceanographic observations, which indicated substantial physical transport, and the model results, which suggested biological transport would far exceed physical transport.

The lack of a negative impact was confirmed by extensive underwater camera observations and boat surveys of the shoreline. We were unable to locate any concentrations of fish heads or carcasses. The camera observations only detected scattered remains. The boat surveys did not detect any floating heads or carcasses, and none were washed ashore.

While the camera effort was not designed to obtain a quantitative measure of the biota, it was sufficient to characterize the fish and benthic organisms that could, and did, utilize the waste by-product, and was sufficiently intensive to detect any concentrations of waste that might have, but did not, accumulate.

These observations must be evaluated in the context that our disposal quantities were less than 2% of the quantity allowed Cordova processors. We were limited in this study by the logistics of supply. Cordova processors provided the supply at no cost, but at considerable inconvenience. Plant operations had to be modified to divert supply from the grinder to the totes that we used to transport heads and carcasses. This was a hassle for them when they were very busy with normal operations. We were further limited by boat availability to transport the totes of heads and carcasses, and by the cost of the transport operation relative to our study budget. On the other hand, the location that we used was a very small portion of potential dumping locations. Further, accelerated biological utilization would be expected with a more consistent supply that would attract large consumers.

The dumping of unground waste in Orca Inlet clearly appears to be feasible in the context of ecosystem response, although further research is needed to determine optimal loading levels at various sites. The economic issues are another question. Transport of unground FPW to dump locations would require expenses beyond the current investment in grinding equipment and discharge pipes. However, the improvements to the environment should provide sufficient incentive should current restrictions be eliminated.

There is no doubt that the current practice is extremely deleterious. That was the clear consensus of our planning effort and the clear conclusion of our field observations. We find it surprising that there appears to be a major disconnect between EPA, the responsible agency, and those who are familiar with the impact of current practices.

We recommend greater community and regional involvement in the development of more suitable disposal practices.

While the current government-mandated pollution of the near-shore environment is serious, it may pale in comparison to the ecosystem impact of non-recycling. It is well documented that a major change in the marine ecosystem occurred after 1978 and has been attributed to climate change. However, the model suggests an alternative, that the loss of a major food source, recycled seafood waste could have caused the change. For example, the timing of the commencement of fish offal grinding by Alaskan processors has an eerie relationship to the collapse of the western stock of Steller sea lions (Fig. 9.1; 9.2). We have observed that Steller sea lions appear to be one of the first scavengers to associate with fish offal discharges, from newly erected sportfish cleaning stations to our experimental sites where we discharged the unground fish offal. The processors in Alaska were processing at least 1.7 million metric tons of FPW in the late 1970s, which was all disappearing or was assimilated into the food web by the end of winter. The implementation of grinding immediately removed this immense quantity from the scavengers' food supply. Coincidentally, in the early 1980s after the grinding practices were implemented, Steller sea lions showed up in large numbers at the offshore sites where pollock fishers operated.

We conclude that there is an urgent need for some rethinking of fish waste practices, including the possible use of seafood waste to restore depleted, threatened and endangered populations of finfish and crustaceans. Currently under the NPDES permitting system for the discharge of fish wastes, the waste has to be ground to 1/2" in size as was historically required for domestic sewage solids in the 1970's. This parctice needs to be changed. Fish processing waste has the potential to be a healthy source of food for marine fauna, while ground discharge of fish waste can be not only deleterious but may also substantially reduce fish production by hindering natural recycling.

These conclusions are based on a relatively small effort in one locality. We were unable to make a negative impact in Orca Inlet with our whole carcass disposal, nor was it our objective to conduct an intensive examination of the current disposal site and practices. However, our effort was sufficient for us to recognize that there is a need for better understanding of recycling rates to provide a basis for effective dispersal. Studies of fish waste disposal practices elsewhere need to more fully evaluate both the positive aspects of rapid recycling through whole carcass disposal and the negative delayed or blocked recycling from current practices. Such consideration needs to extend to potential land disposal options, which would further block natural recycling. Finally, a more comprehensive evaluation needs to be made of the impact of the 1978 change in disposal practices as it relates to subsequent large-scale ecosystem changes in Alaskan waters.

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Table 1-1. Seafood Waste 2004 Workshop Participants

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Table 3.1. Dates, times, tidal ranges and number of ADCP transects and CTD stations

Location	Date	Tides: Stage	Start	End	Period hr	Range m	Transects: Start	End	Period hr	No. of Trans.	Total Samples	Total Trans.	CTD Stations	No. of Samples*	Total Stns.
Site B	7/11/2004	Ebb1	10:13	15:21	5.13	1.22	10:15	15:30	5.3	8	3	21	14	1	14
		Flood 2	15:21	22:00	6.65	2.22	15:30	20:50	4.5	8	4	35	12	2	24
		Ebb2	22:00	5:01	7.00	3.02	20:50	0:00	3.2	8	2	14	7	1	7
				totals	18.78				12.9		9	56			45
Site A	7/13/2004	Flood 1	5:55	12:27	6.53	2.37	8:40	12:34	3.9	8	3	21	12	1	12
		Ebb1	12:27	17:29	5.03	1.13	12:34	17:33	5.0	8	3	24	12	2	24
		Flood 2	17:29	23:29	6.00	2.10	17:33	22:04	4.5	8	3	27	12	1	12
				totals	17.56				13.4		9	72		4	48
Site B	9/1/2004	Ebb1	3:24	9:31	6.12	4.48	5:30	9:23	3.9	8	3	24	9	1	9
		Flood 2	15:21	22:00	6.65	4.42	9:23	15:45	6.4	8	4	32	9	2	18
		Ebb2	22:00	5:01	7.00	4.08	15:45	18:35	2.8	8	2	16	9	1	9
				totals	19.77				13.1		9	72			36
Site A	9/2/2004	Flood 1	5:55	12:27	6.53	2.37	8:40	12:34	3.9	8	3	21	12	1	12
		Ebb1	12:27	17:29	5.03	1.13	12:34	17:33	5.0	8	3	24	12	2	24
		Flood 2	17:29	23:29	6.00	2.10	17:33	22:04	4.5	8	3	27	12	1	12
				totals	17.56				13.4		9	72		4	48
Site C	5/10/2005	Ebb1	2:46	9:27	6.68	4.60	3:40	9:27	5.8	10	5	50	9	2	18
		Flood 1	9:27	16:03	6.60	3.80	9:27	15:00	5.6	10	5	50	9	2	18
				totals	13.28				11.3		10	100			36
Site D	5/10/2005	Flood 1	9:27	16:03	6.60	3.80	15:16	15:34	0.3	5	1	5	na	na	na
	5/11/2005	Flood 1	10:06	16:42	6.60	3.40	13:14	13:53	0.7	10	1	10	na	na	na

Table 6.1. The amount and type of fish waste dumped at the experimental dump site in Mud Bay Trench in Orca Inlet.

	2005	2006
Sockeye salmon heads and carcasses		
dump dates	16 june-1 jul	2-22 june
# days w dumps	6	10
total amount of waste dumped (lbs.)	39,000	138,200
Pink salmon carcasses		
dump dates	28-Jul	none
# days w dumps	1	
total amount of waste dumped (lbs.)	54000	
Coho salmon carcasses and heads		
dump dates	14-25 sept	3-9 sept
# days w dumps	7	3
total amount of waste dumped (lbs.)	62250	35900
total pounds for season	**155,250**	**174,100**
total dump days	**14**	**13**

Table 7.1. Tag Tracking Field Work Summary:

Date (2006)	Activity	Comments
June 15	Set 2 tags	Group A tags
23	Checked tags	
July 6	Set 5 tags, checked others	Additional Group A tags (7 total)
18	Checked all tags	
July 19 – August 20	Suspend experimental dumping and obs.	Fish waste transport vessel inoperable; frequent stormy weather in study area
August 29	Checked tags	
September 13	Set 4 tags, checked all others	Group B tags
15	Checked all tags	
18	Checked all tags	
21	Set 5 tags, checked all others	Group C tags
25	Checked all tags	
October 19	Checked all tags	

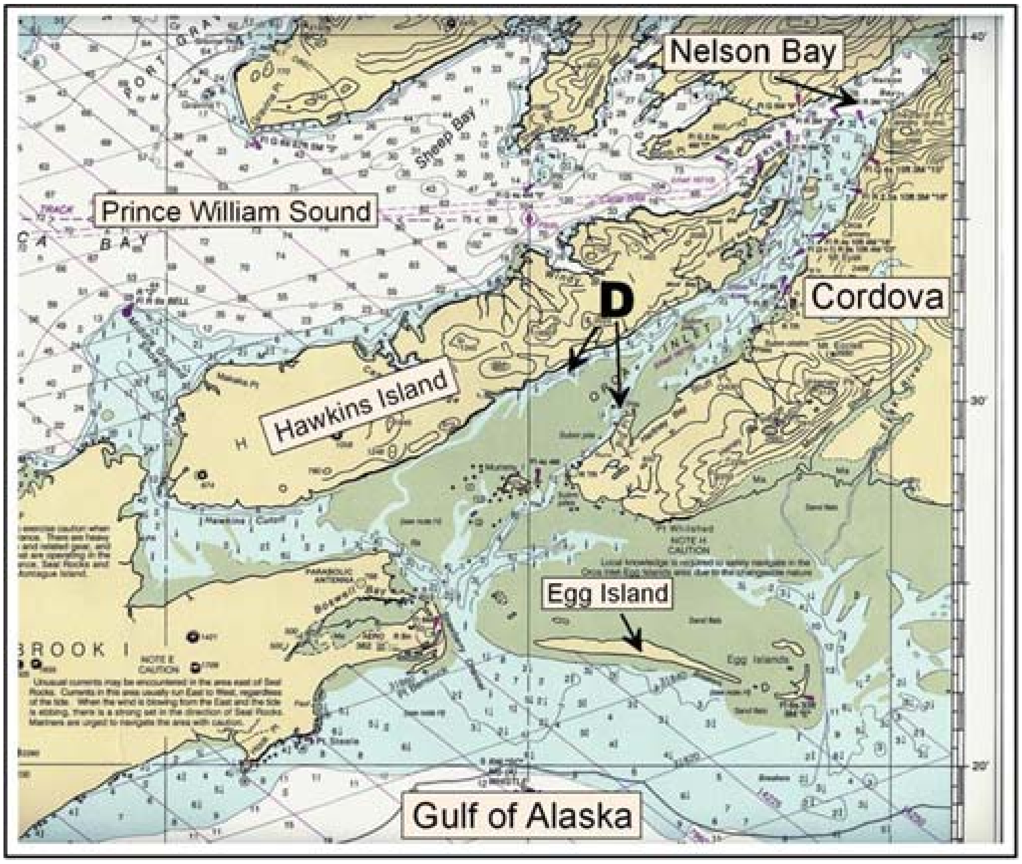
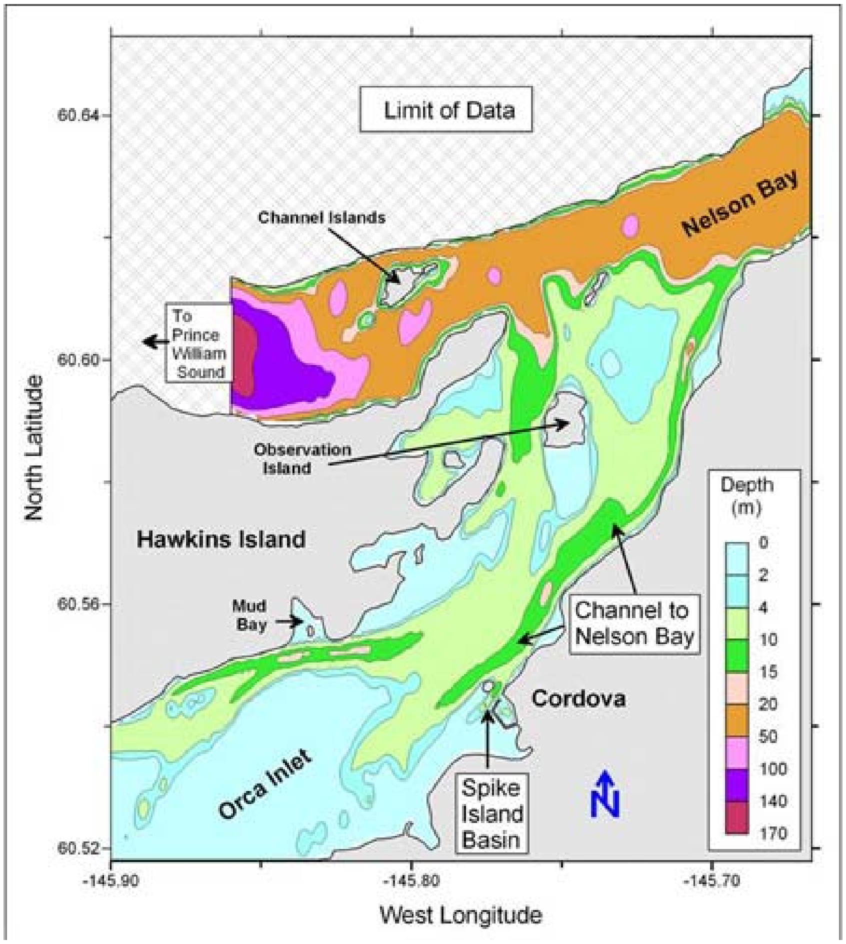


Figure 2.1. Orca Inlet extends from the Gulf of Alaska, via Strawberry Channel, northeastward to Nelson Bay. Extensive mud flats fill the lower portion of the inlet, through which two channels (D) course and join near Mud Bay, opposite Cordova. From there, flows generally join and mix with waters flowing through the channel that leads to Nelson Bay.



2.2. The distribution of ~10 m deep areas (green) in the northern end of Orca Inlet. The existing dump site for ground waste from Cordova's seafood processors is largely in the small 10+ m deep basin next to Spike Island (Spike Island Basin). It is a small offshoot of a much larger 10+ m bathymetric feature, a channel that extends about 5 nm northward to 20+ m deep Nelson Bay and adjacent waters. A smaller 10+ m deep feature – where we dumped unground waste – lay west of Cordova on the opposite side of Orca Inlet, near Mud Bay (Mud Bay Trench).

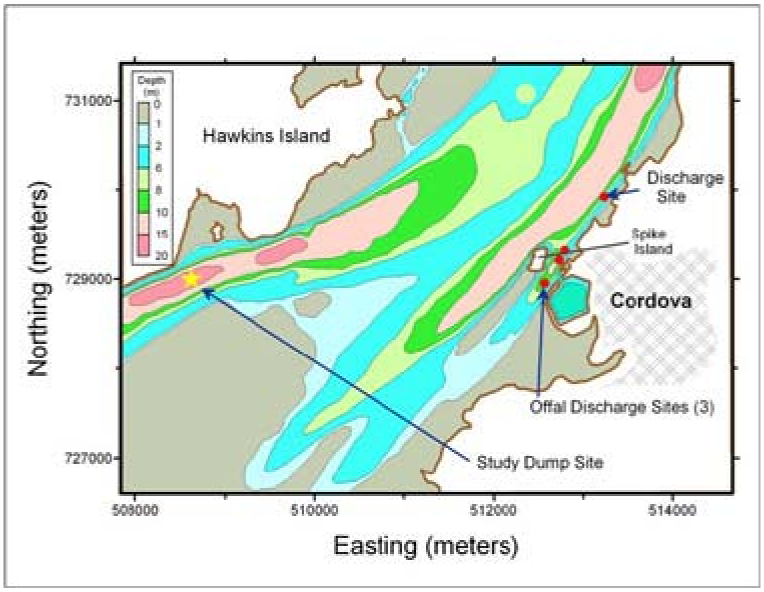


Figure 2.3. An expansive inter- and subtidal mud flat (grey) reaches almost the full width of Orca Inlet to Mud Bay Basin. The northern extension of the mud flat runs northeastward along the center of the inlet, separating the basin from the channel that runs from Spike Island to end of the inlet at Nelson Bay. Tidal flows through the basin and channel areas are vigorous and waters are well mixed. Three of Cordova's four offal discharge pipes discharge into the small basin next to Spike Island, which is cut off from the channel by the island and a sand bar that extends southwestward from it. Unprocessed fish waste was dumped in Mud Bay Basin at the study dump site.

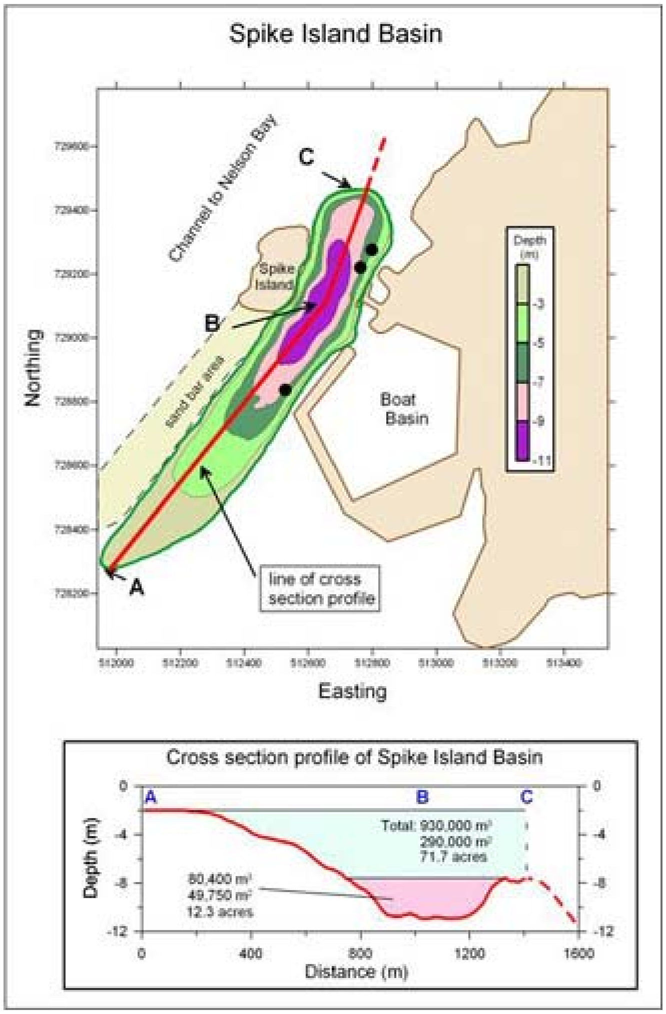


Figure. 2.4. Spike Island Basin's (SIB) deepest area (locus "B" of cross section profile) is at the entrance to the Cordova Small Boat Basin. A shallow sill separates SIB from the deeper water in the channel to Nelson Bay (see locus "C" of the cross section profile) at the northern end of the basin. The other end (locus "A" of cross section profile) gradually shoals into the Orca Inlet mud flats. The east side of the basin is generally confined by the breakwater of the Cordova Boat Basin. The west side is constrained by Spike Island and its long, narrow, partially intertidal sand bar that extends to the southwest. Thus, water flows and transport through the confined, "dead end" basin are less than in the larger spaces of the channel to Nelson Bay on the west side of Spike Island.

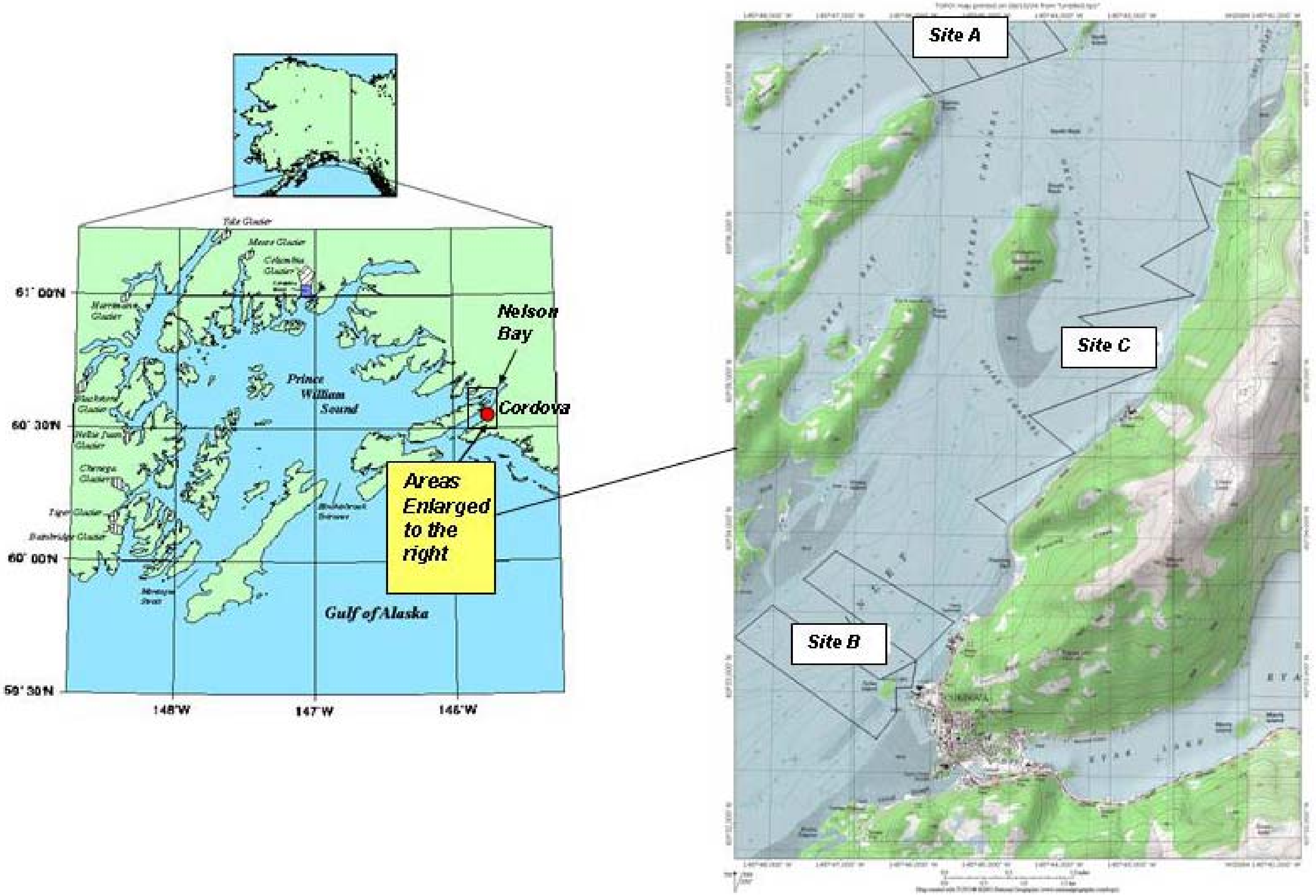


Fig. 3.1. Locations of three sites within Orca Inlet, Prince William Sound, Alaska surveyed for potential discharge sites of seafood offal.

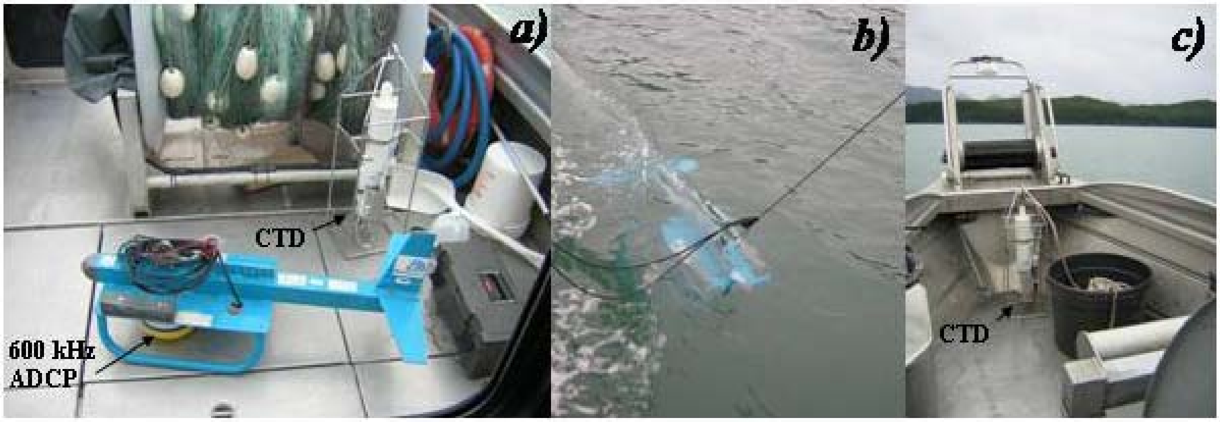


Fig. 3.2. Various equipment used during study of physical oceanography of Orca Inlet: a) 600 kHz ADCP mounted to a Biosonics tow-sled and SBE 19.03 CTD profiler; b) ADCP being towed during surveys; and c) CTD and line tub deployed using a bow-roller on a small (10 m) fishing vessel.

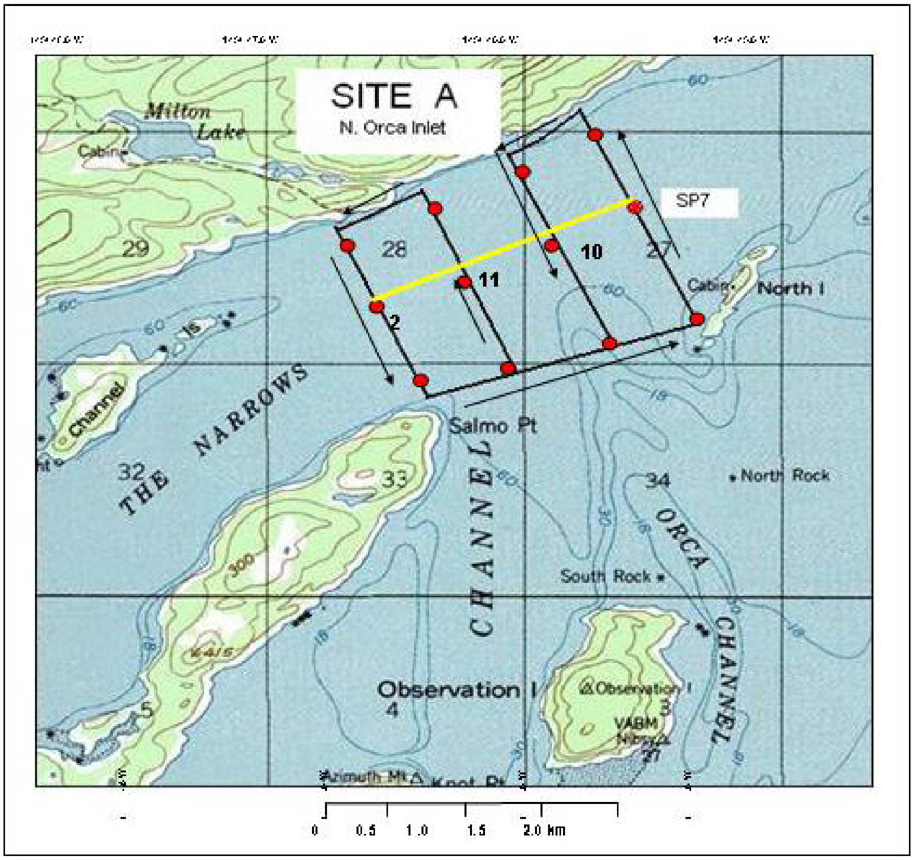


Fig. 3.3. Locations of ADCP transects and hydrographic stations within northern Orca Inlet, between Salmo Point and North Island (Site A). The CTD stations shown in vertical T/S sections in Figure 3.5 are outlined along the yellow transect. Note that the direction of transects is indicated by the arrows.

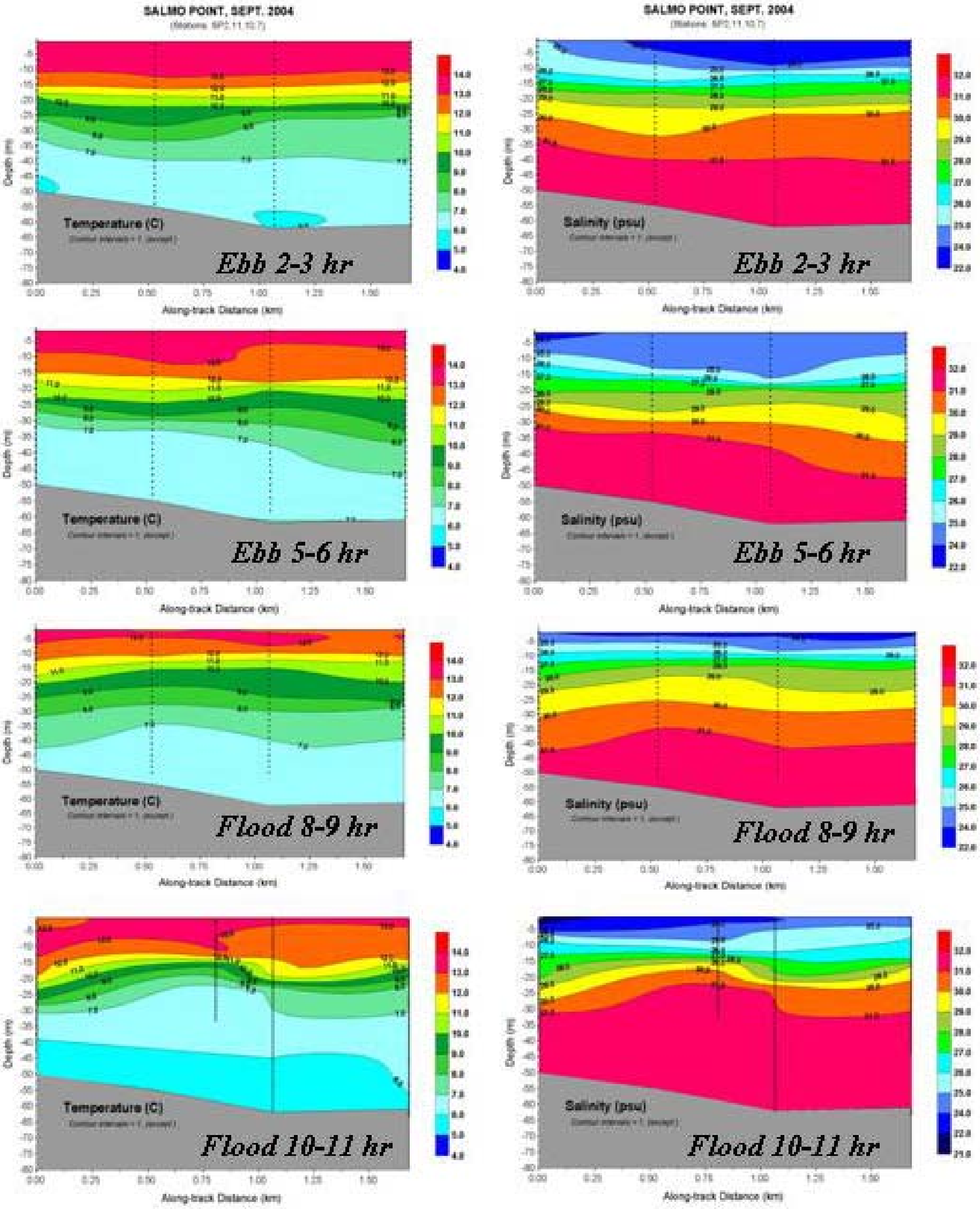
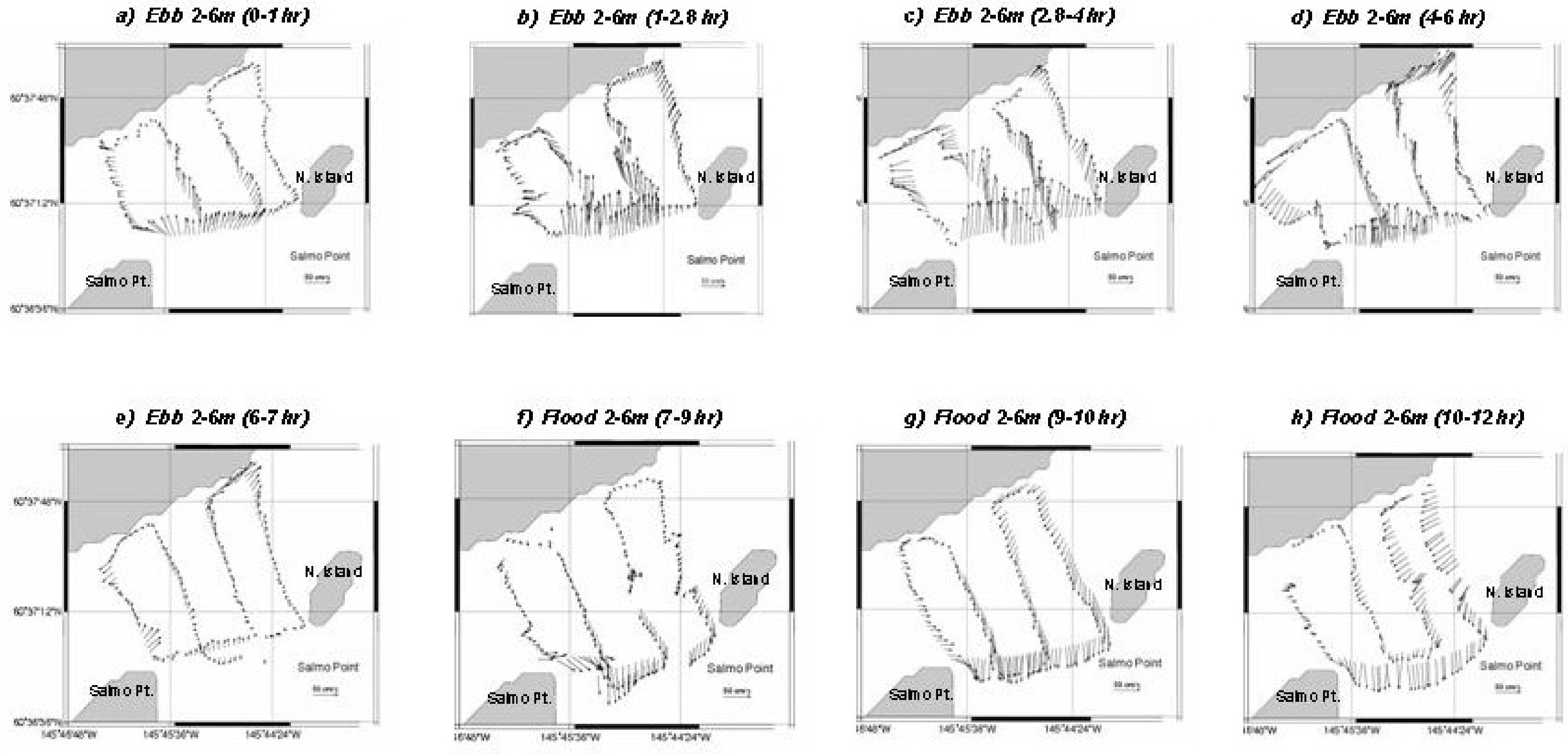


Fig. 3.4. Temperature and salinity changes over a semidiurnal spring tidal cycle at Northern Orca Inlet (Site A) showing relatively deep thermoclines and haloclines, and hence well developed density stratification.


a) Ebb 2-6m (0-1 hr)

b) Ebb 2-6m (1-2.8 hr)

c) Ebb 2-6m (2.8-4 hr)

d) Ebb 2-6m (4-6 hr)

e) Ebb 2-6m (6-7 hr)

f) Flood 2-6m (7-9 hr)

g) Flood 2-6m (9-10 hr)

h) Flood 2-6m (10-12 hr)

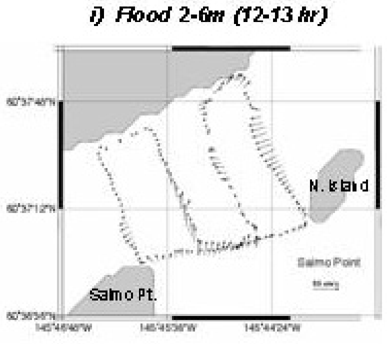
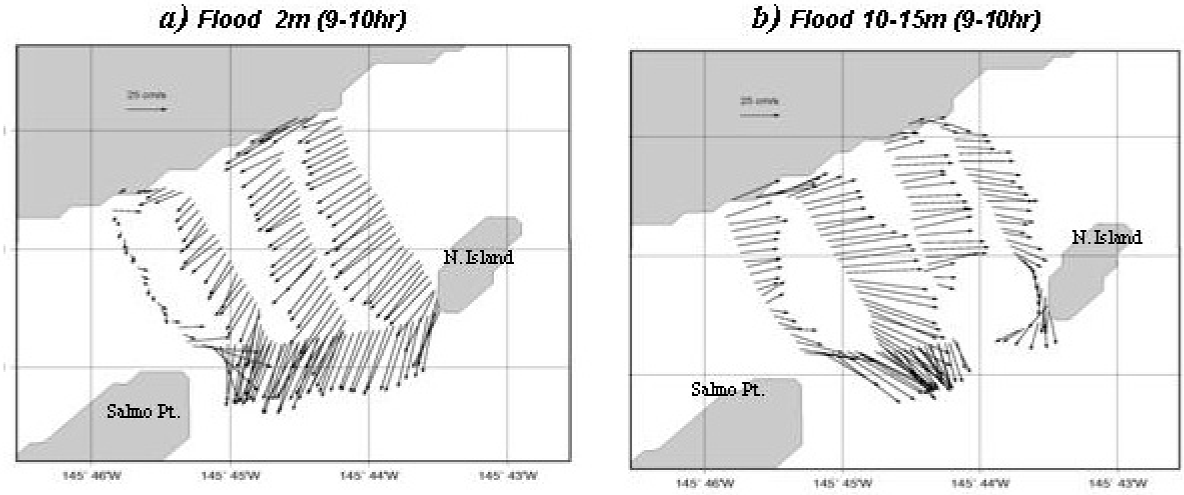

i) Flood 2-6m (12-13 hr)

Fig. 3.5. Surface currents at Site A for a semidiurnal spring tide in early September, 2004 showing regions of divergence and convergence as water flowing north is forced eastward and westward by the basin geometry (i.e. northern boundary). During the flood tide (d,e,f), surface water from the northeast flows towards Salmo Pt. and converges with inflow from Orca Bay (d). Beneath this layer, the subsurface currents (e) flow eastward from Orca Bay creating highly baroclinic flows (Fig. 3.6a). Between Salmo Pt. and N. Island water is forced southward causing advection of fresh surface water and saltier subsurface water towards Mid Orca Inlet. At the end of the flood stage (f) the flow vectors reverse and exhibit a pattern similar to the early stage of the ebb (a).


a) Flood 2m (9-10hr)

b) Flood 10-15m (9-10hr)

c) u velocity component for flood tide (9-10hr)

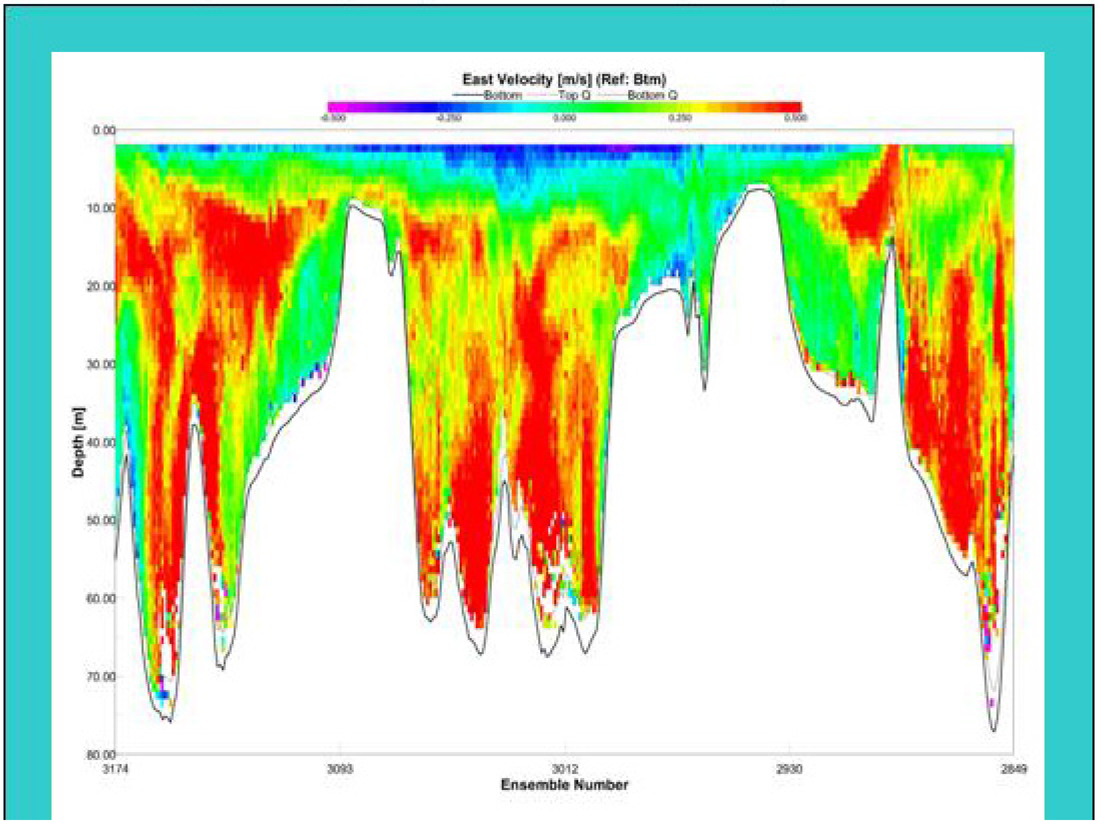


Fig 3.6. Tidal currents and *u* velocity component at Site A during the early phase of the flood tide at 9 to 10hr into the ADCP transects in early September, 2004.

Fig. 3.7. During flood tide, outflowing glacial water from Orca Inlet converges with saltier (denser) water within Orca Bay creating a front which can be seen across from Salmo Pt. The view is looking westward towards PWS.

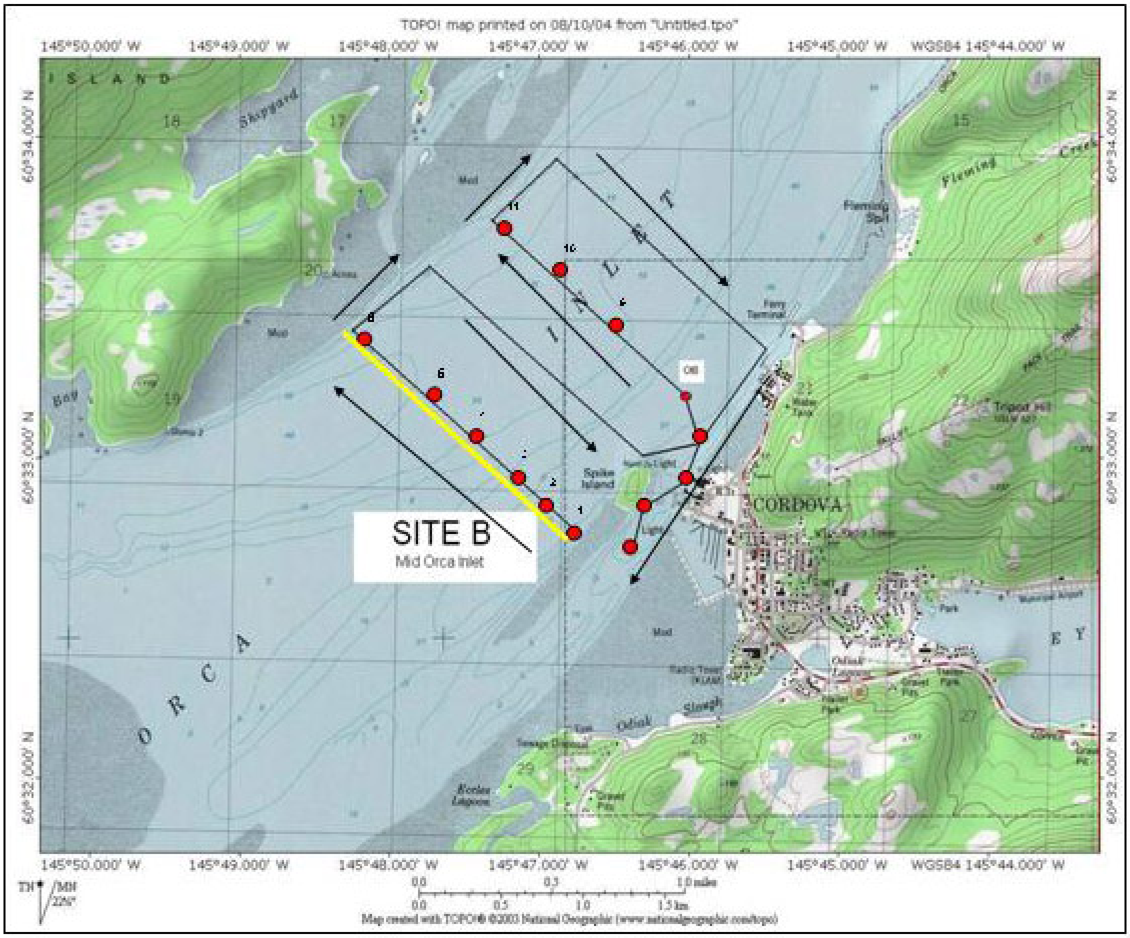


Fig. 3.8. Locations of ADCP transects and hydrographic stations within lower Orca Inlet, (Site B). The CTD stations shown in vertical T/S sections in Figure 3.10 are outlined along the yellow transect. Note that the direction of transects is indicated by the arrows.

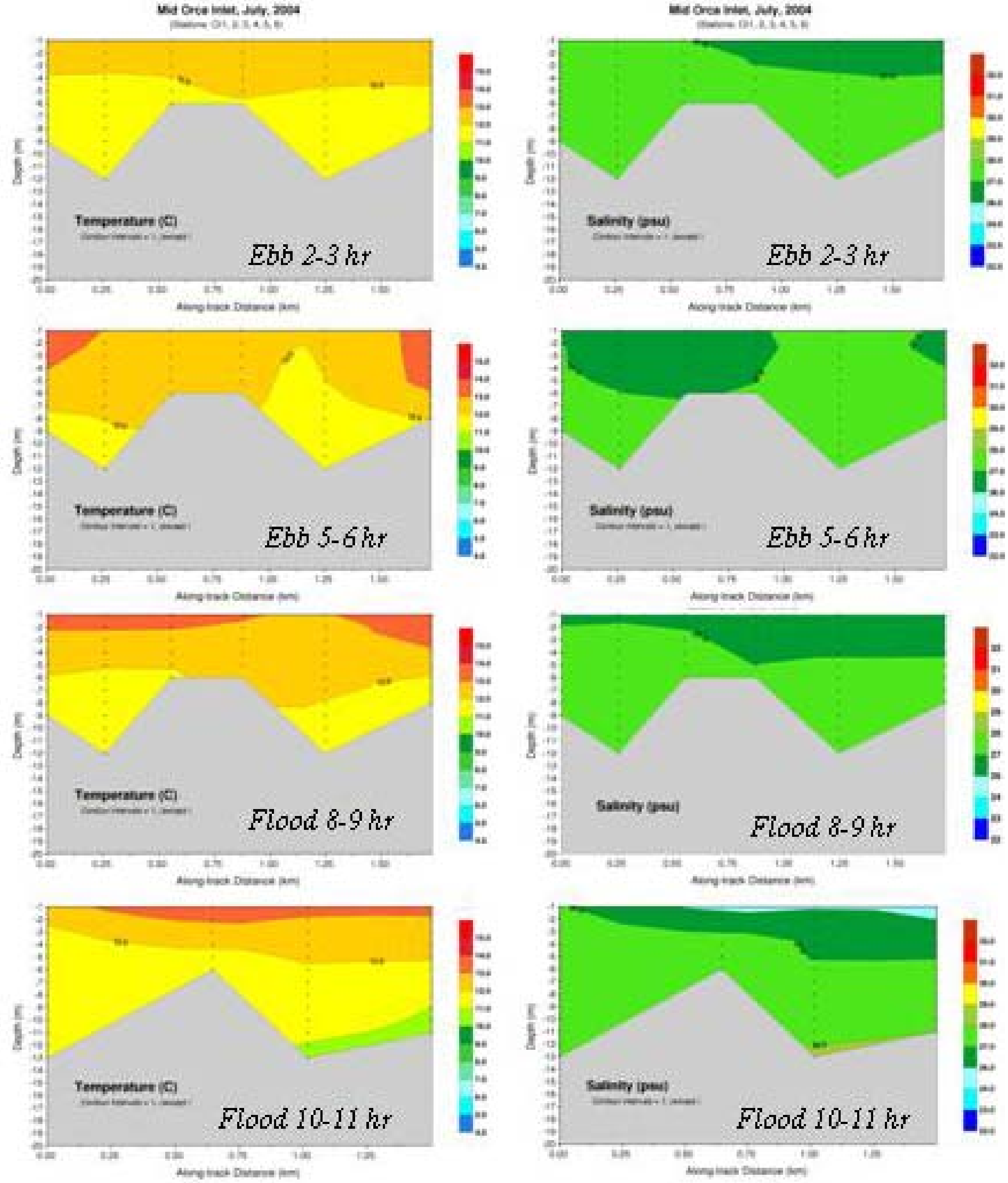


Fig. 3.9. Temperature and salinity changes over a semidiurnal neap tidal cycle at Lower Orca Inlet (Site B) showing poorly developed thermoclines and haloclines (i.e. weak density stratification) due to the effects of tidal mixing.

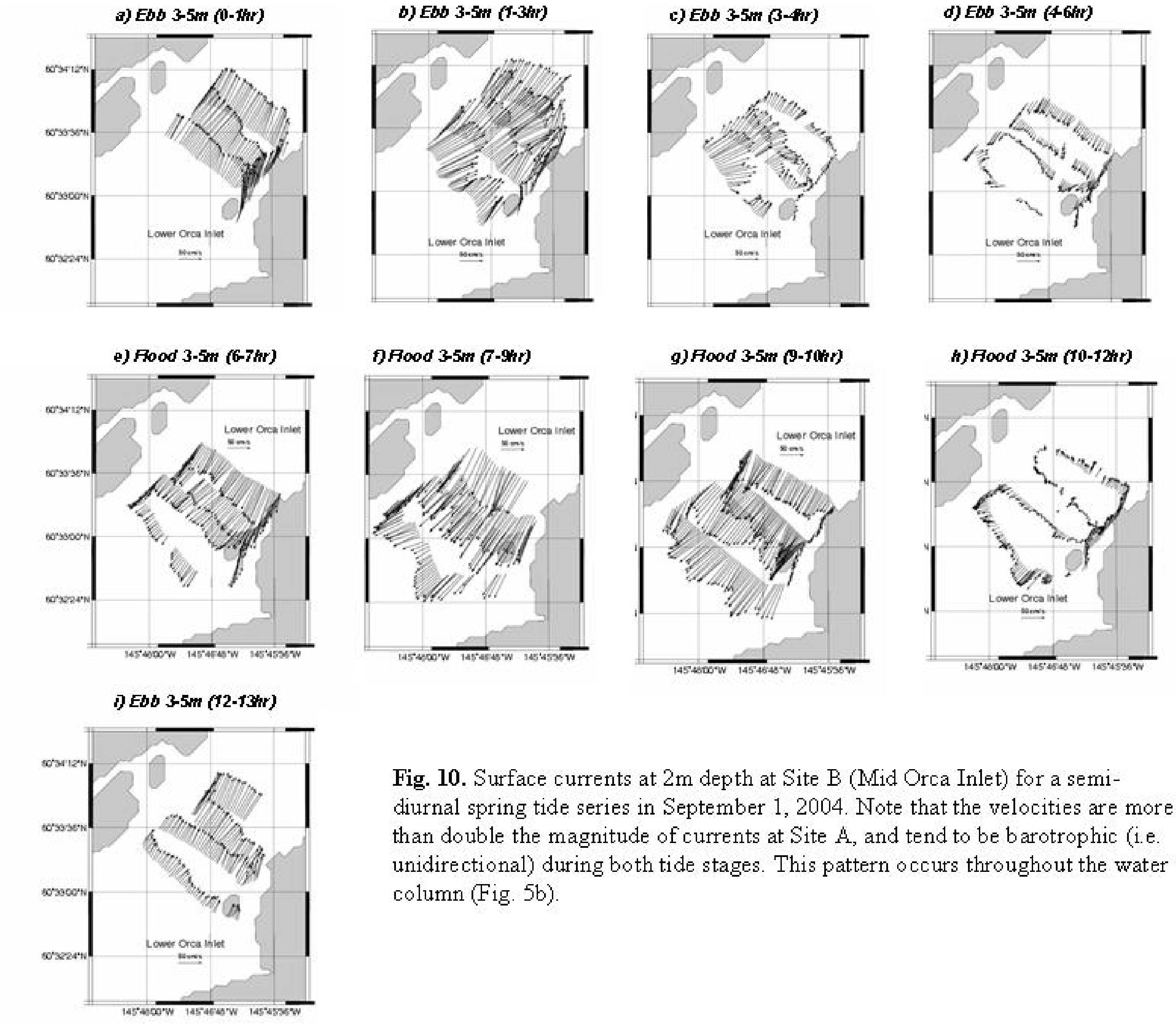


Fig. 10. Surface currents at 2m depth at Site B (Mid Orca Inlet) for a semi-diurnal spring tide series in September 1, 2004. Note that the velocities are more than double the magnitude of currents at Site A, and tend to be barotrophic (i.e. unidirectional) during both tide stages. This pattern occurs throughout the water column (Fig. 5b).

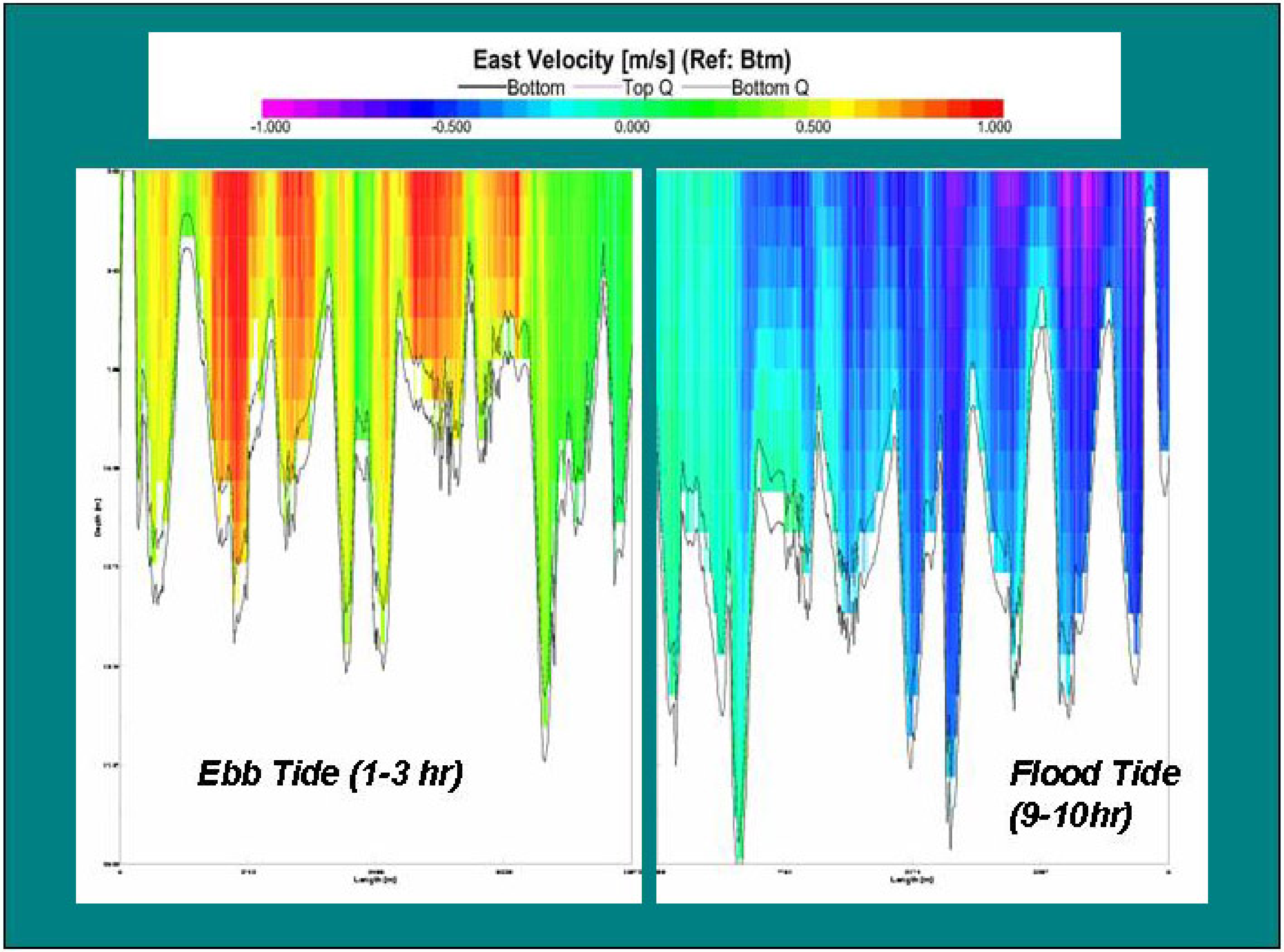


Fig. 3.11. Spatial distribution of the *u* velocity component at Site B early in the ebb tide and later in the flood tide. The currents are highly barotropic but exhibit horizontal and vertical shear, causing strong tidal mixing.

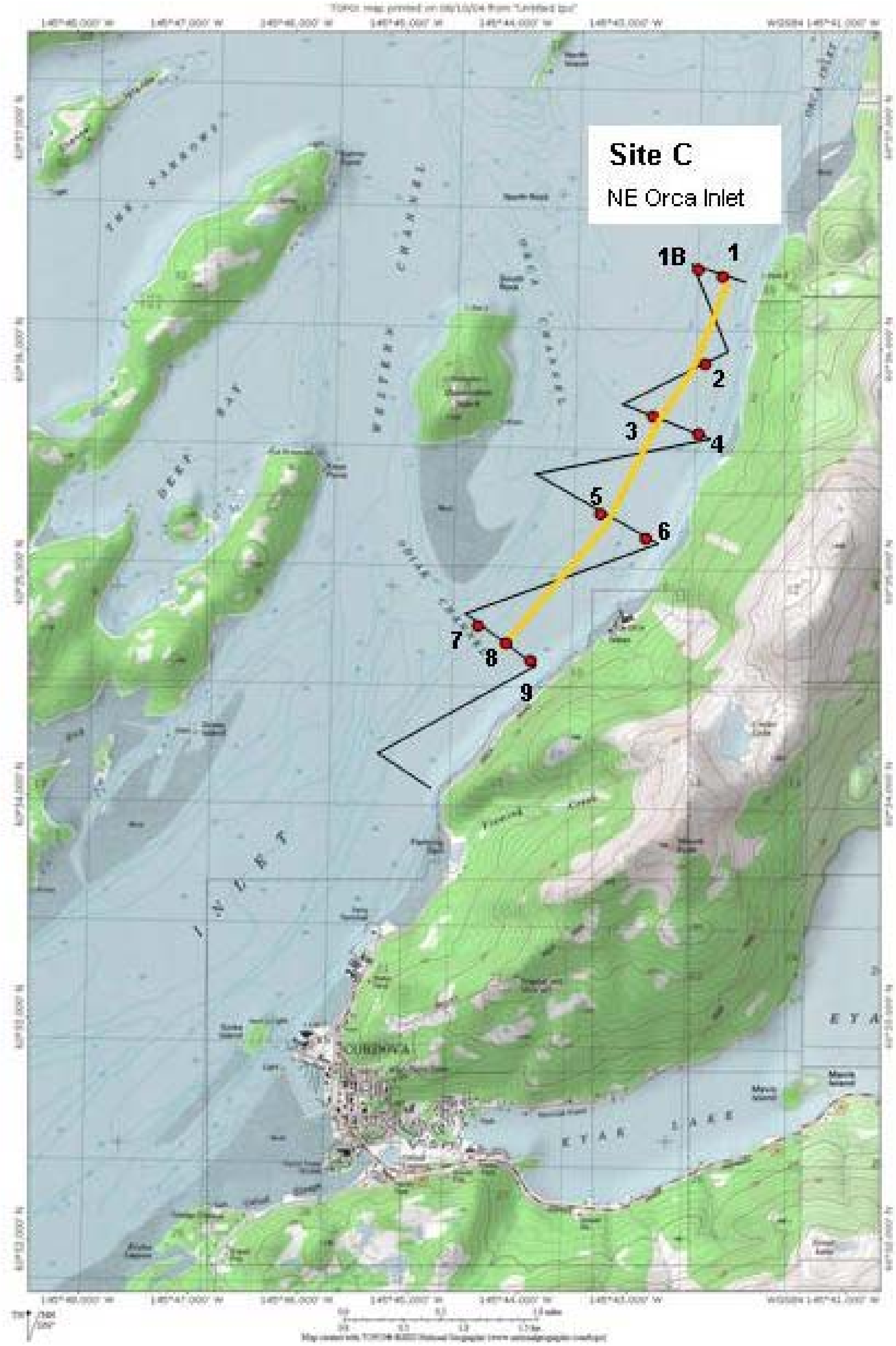


Fig. 3.12. Locations of ADCP transects and hydrographic stations in Northeastern Orca Inlet (Site C). This site extends from the northeast side of the lower inlet (Site B) to Humpback Creek, just south of Nelson Bay. The CTD stations shown in vertical T/S sections in Figure 3.14 are outlined in the yellow transect. Note that transects were started from the southern end and continuously repeated back and forth.

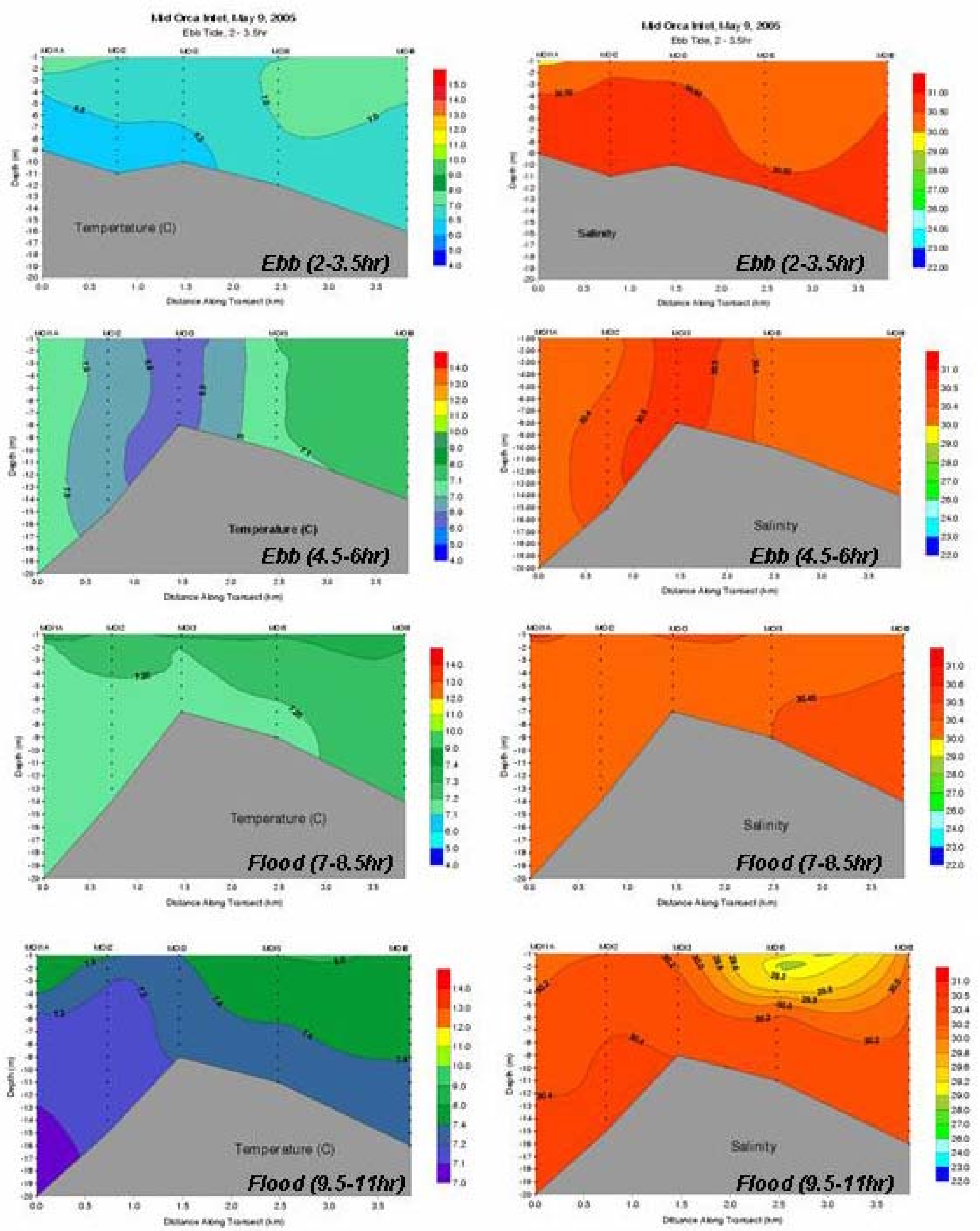


Fig. 3.13. Temperature and salinity changes over a semidiurnal spring tidal cycle at Northeast Orca Inlet (Site C) showing effects of mixing from strong barotropic tides and the redistribution of water masses between the northern and mid portions of Orca Inlet. During the later portion of the ebb tide (4-6.5 hr), tidal motions create a horizontal front throughout the water column, whereas during the later portion of the flood tide (9.5-11 hr) slightly stratified water from Nelson Bay is advected southward.

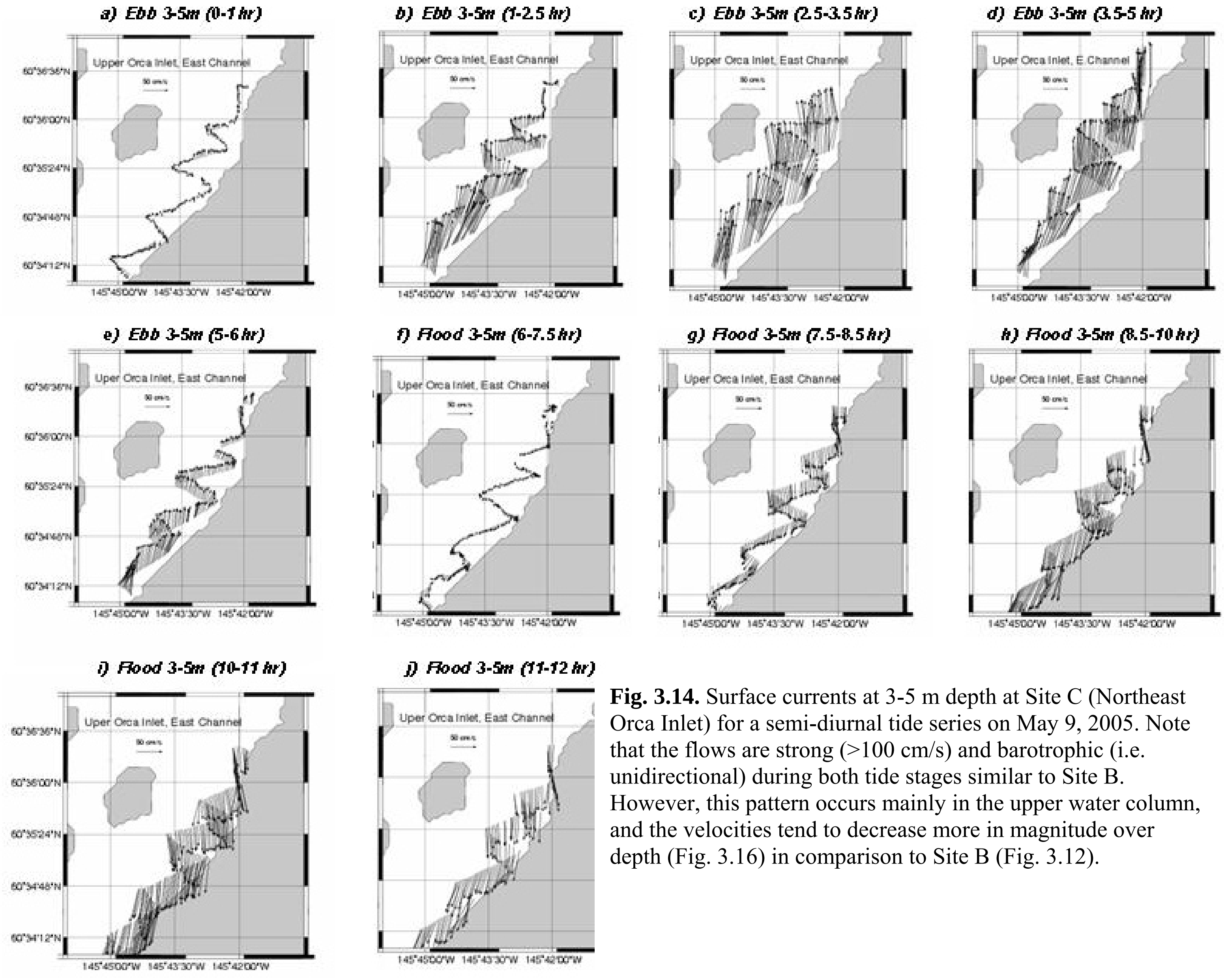


Fig. 3.14. Surface currents at 3-5 m depth at Site C (Northeast Orca Inlet) for a semi-diurnal tide series on May 9, 2005. Note that the flows are strong (>100 cm/s) and barotrophic (i.e. unidirectional) during both tide stages similar to Site B. However, this pattern occurs mainly in the upper water column, and the velocities tend to decrease more in magnitude over depth (Fig. 3.16) in comparison to Site B (Fig. 3.12).

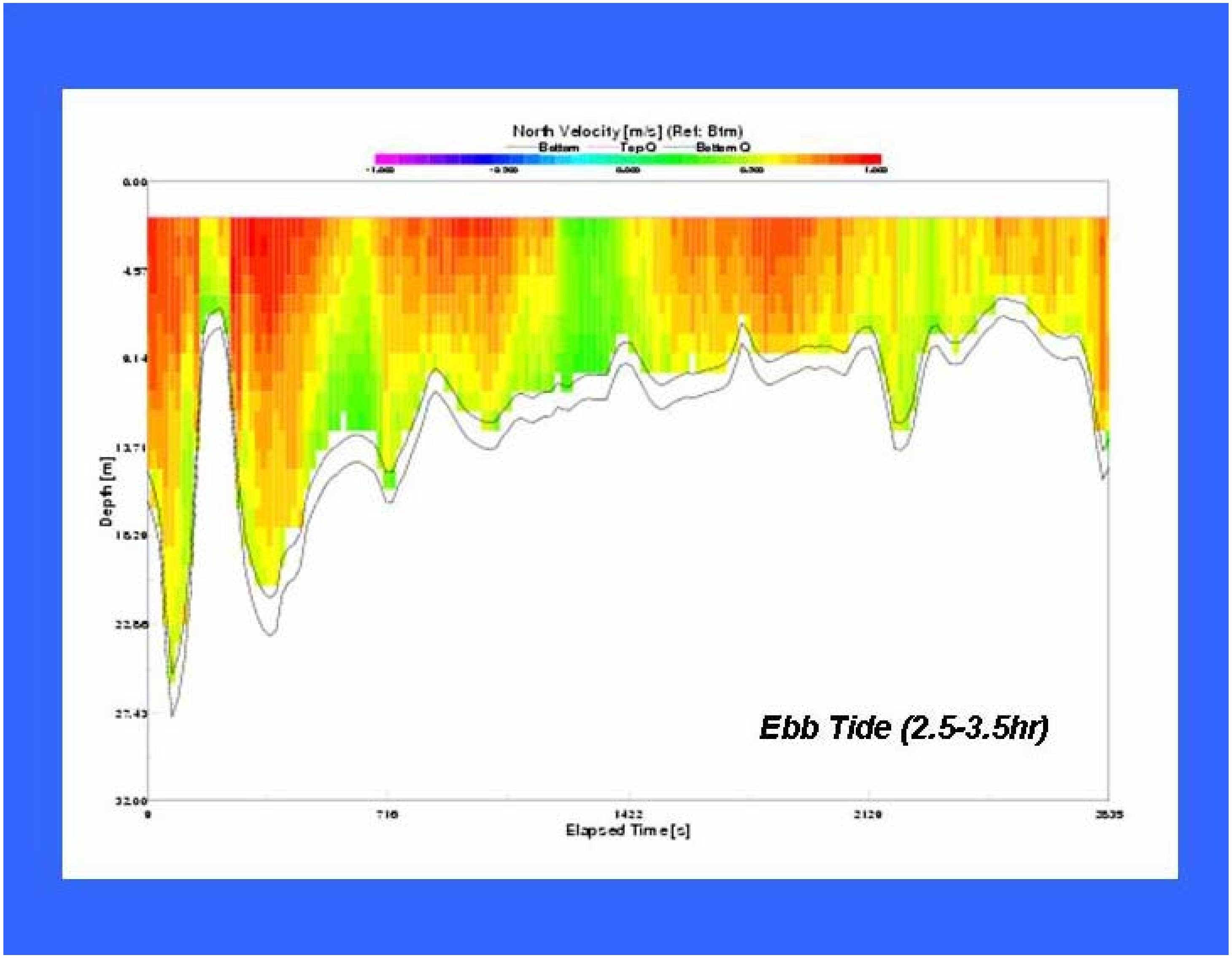


Fig. 3.15. Spatial distribution of the *v* component of velocity at Northeast Orca Inlet during the middle portion of the ebb tide showing high magnitudes in the upper water column within the main channel

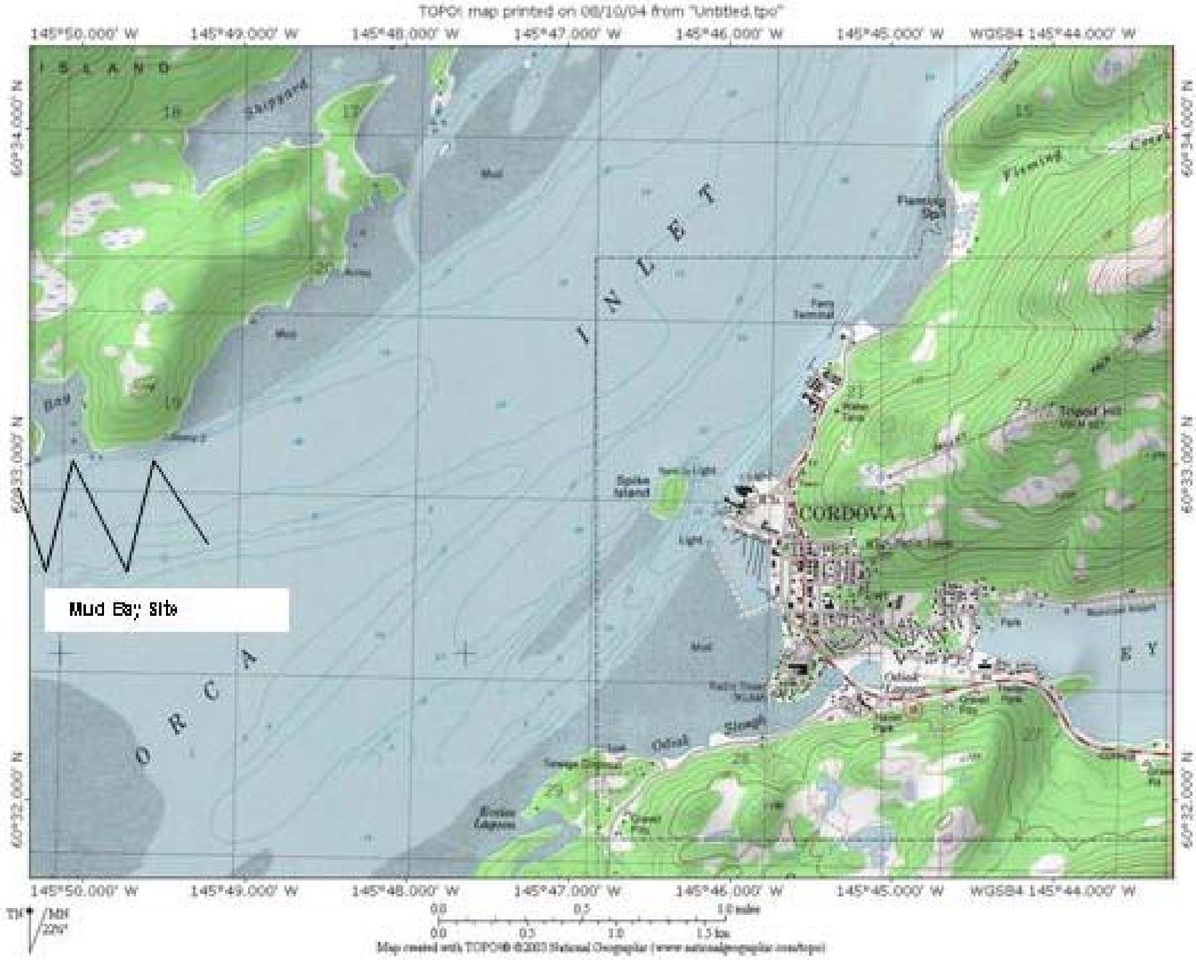


Fig. 3.16. Location of experimental site next to Mud Bay for disposal of fish offal in the summers of 2005 and 2006.

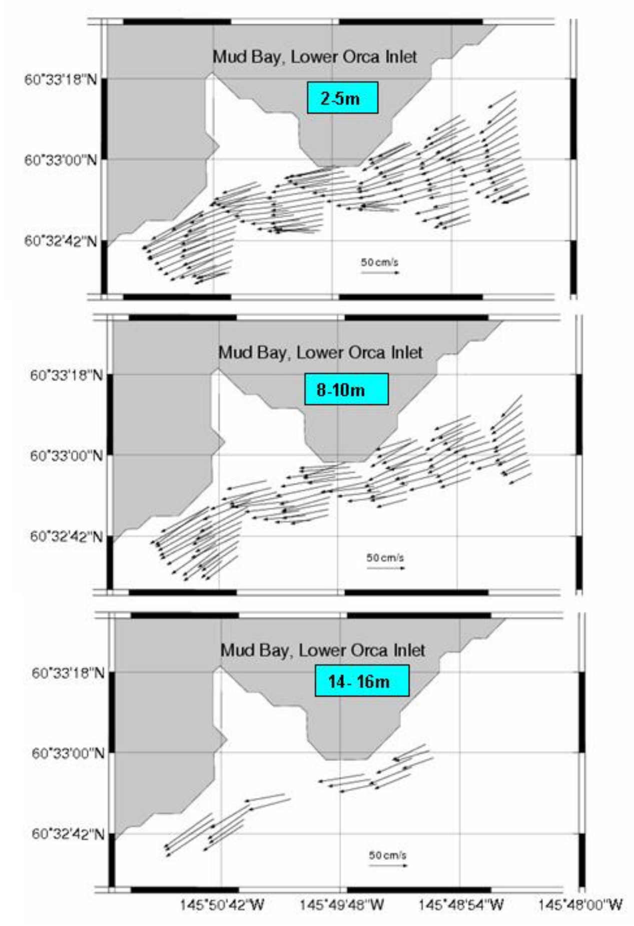


Fig. 3.17. Currents at the Mud Bay experimental site measured during the middle portion of the flood tide (1300-1400 hrs) on May 11, 2005.

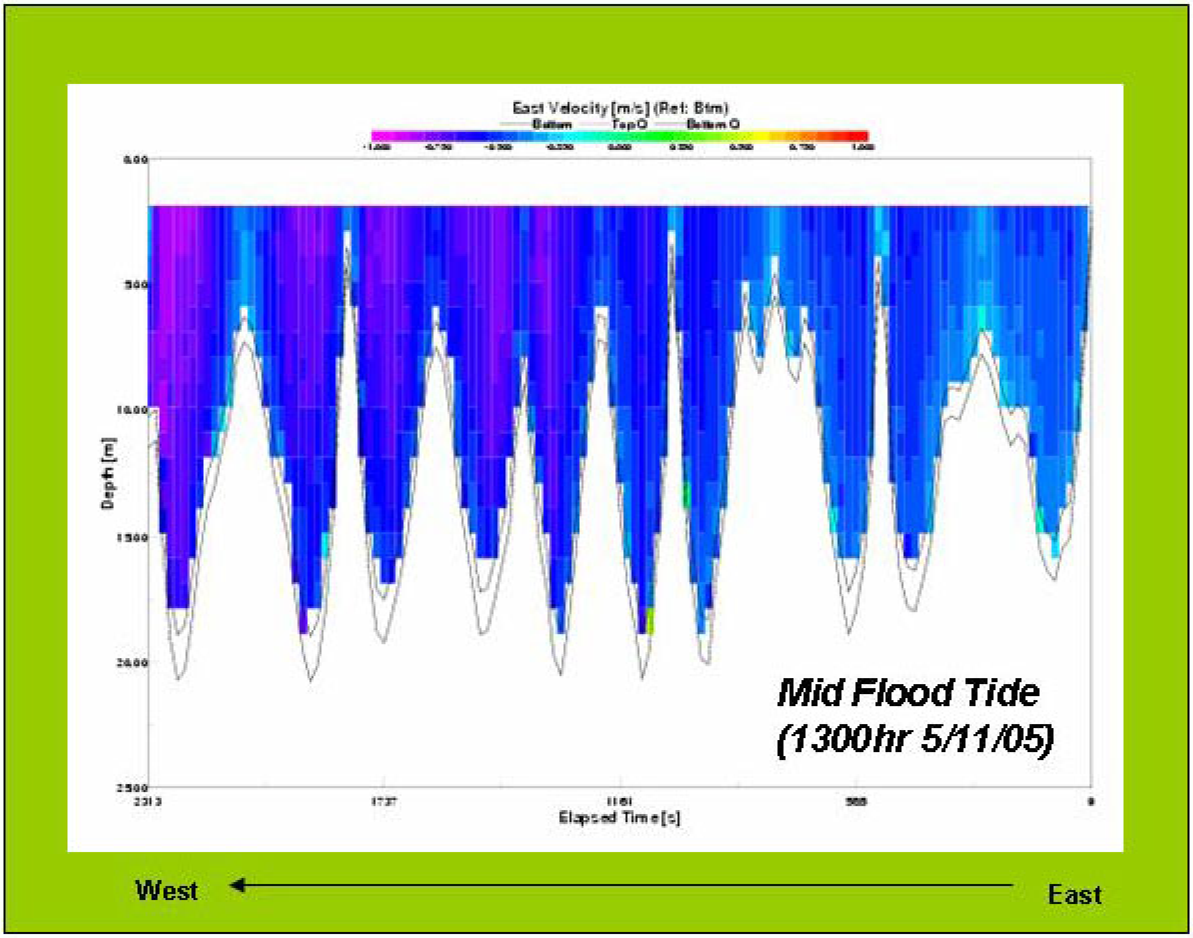


Fig. 3.18. Spatial distribution of the *u* velocity component at the Mud Bay experimental site during the flood tide on May 11, 2005.

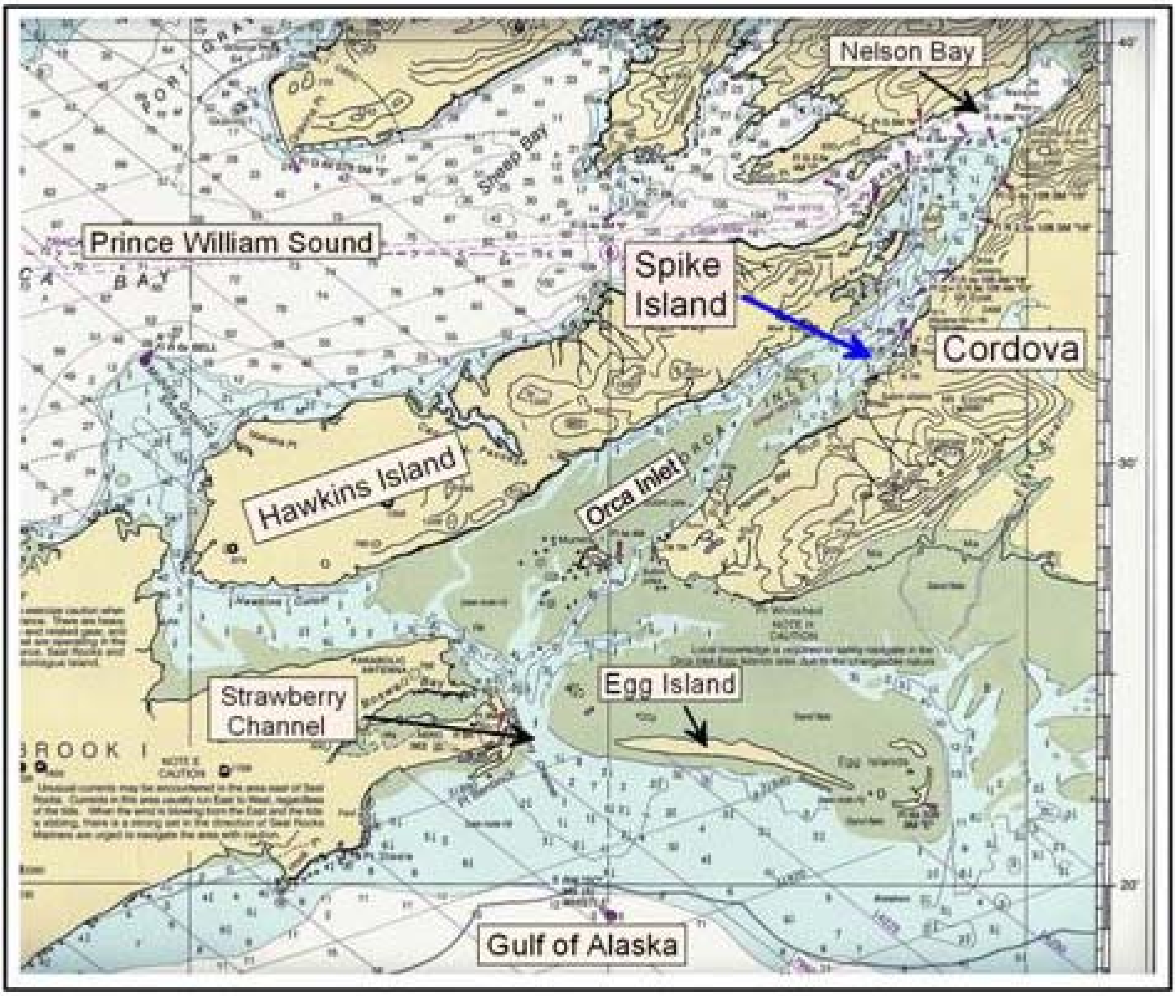


Fig. 4-1. General location of seafood waste discharge area (Spike Island) in Orca Inlet, southeast Prince William Sound. Egg Island hosts a large (>10,000 birds) Glaucous-winged Gull and a small (100's) Mew Gull breeding colony.

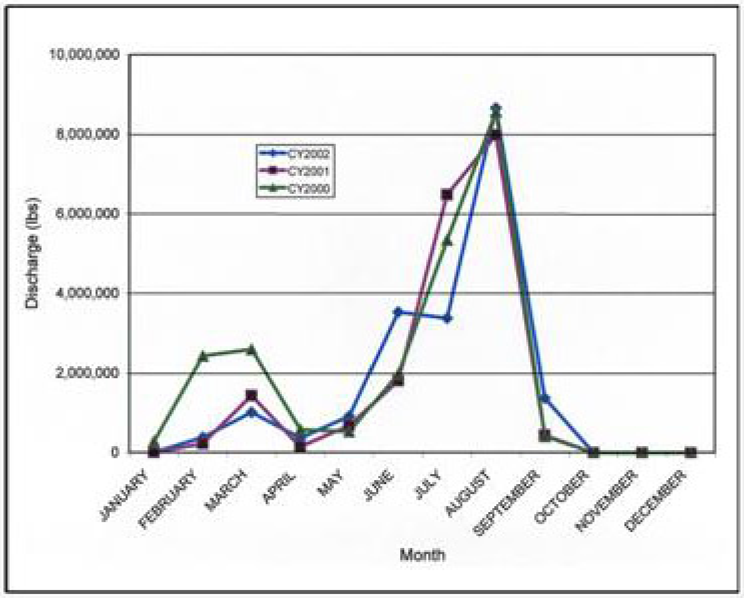


Fig. 4-2. Cordova seafood processors handle fish through much of the year. Discharges peak in summer, with each of the four plants limited to an annual cap of 10 million pounds of ground waste, all of which flows into Orca Inlet.

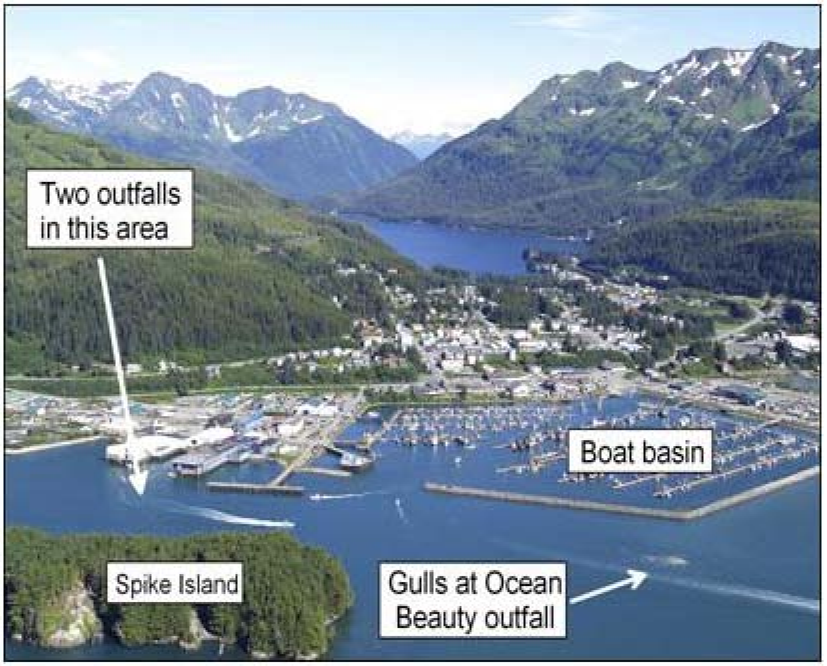


Fig. 4-3. The seafood processors in Cordova discharge ground waste via underwater pipelines into the small channel area between the Small Boat Basin and Spike Island. Thousands of gulls are attracted to the discharge plumes. When not feeding on the waste matter, the birds gather on the docks and roof tops, and in their abundance create a general nuisance with regard to public health and sanitation issues.

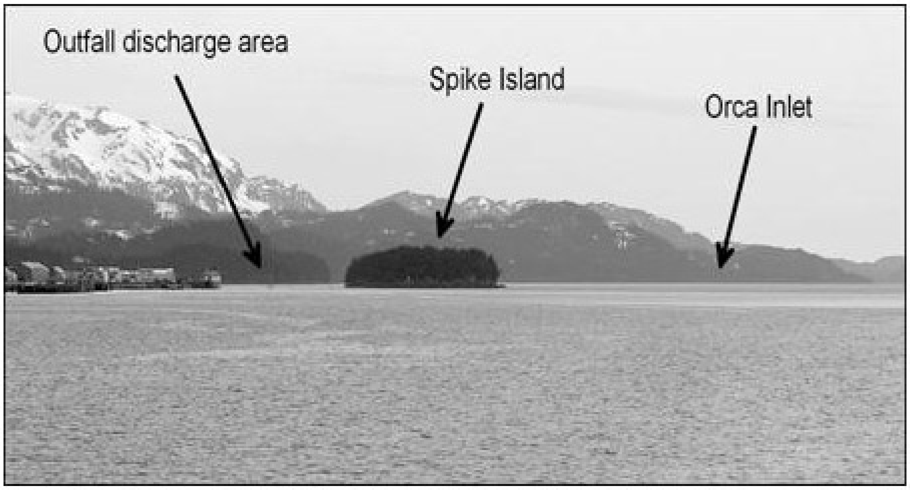


Fig. 4-4. Most of the waste from Cordova's fish processing plants is discharged in the channel that passes between Spike Island and the waterfront. The island constrains water flow through the area and thousands of seabirds gather daily during processing season to feed on the plume of ground waste that rises to the surface in the outfall discharge area.

Fig. 4-5. Dense aggregations of gulls at the entrance to the Cordova Boat Basin create a nuisance and a hazard for the fishing boats traveling to the productive fishing grounds nearby

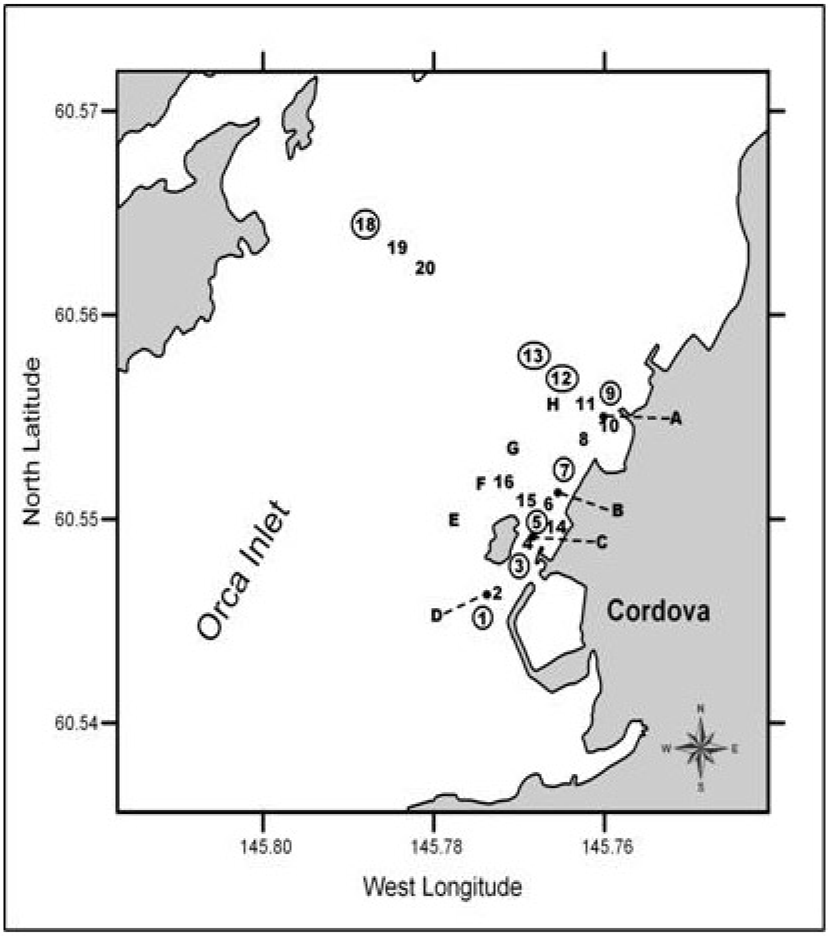


Fig. 4-6. Benthic sampling stations. Lettered stations sampled by this study September 28, 2004. Numbered stations sampled by Williams et al. (1999; note: no station 17.) Depth profiles of salinity, temperature and dissolved oxygen concentration collected at circled locations, July 1999.

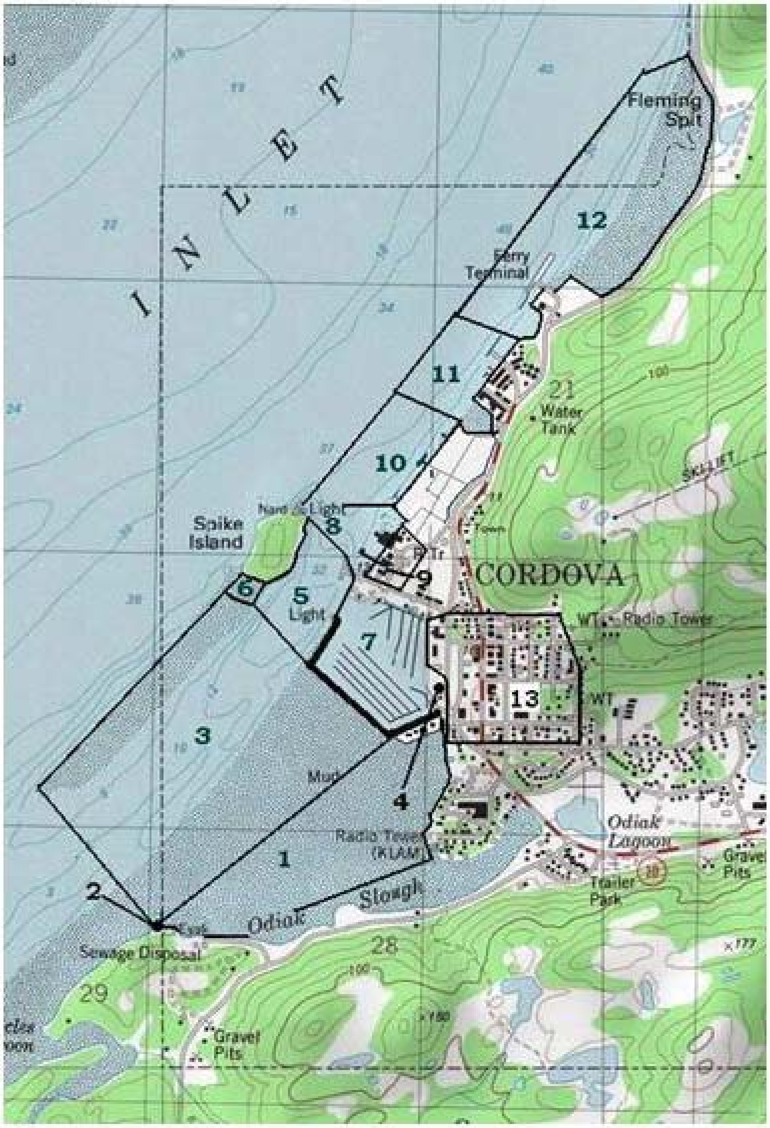


Fig. 4-7. Gull surveys at Cordova, 2005. Numbers indicate survey areas counted for gulls. 1. Odiak Slough; 2.Southfill/sewage treatment outfall; 3. Silver Lining outfall; 4. Silver Lining facility; 5. mixing zone 1; 6. Spike Island south spit; 7. Cordova Boat Harbor; 8. Ocean Beauty & Bear & Wolf outfalls; 9. Ocean Beauty & Bear & Wolf facilities; 10. Mixing Zone 2; 11. Copper River Seafood outfall. 12. Ferry dock/Fleming Spit; 13. Downtown Cordova.

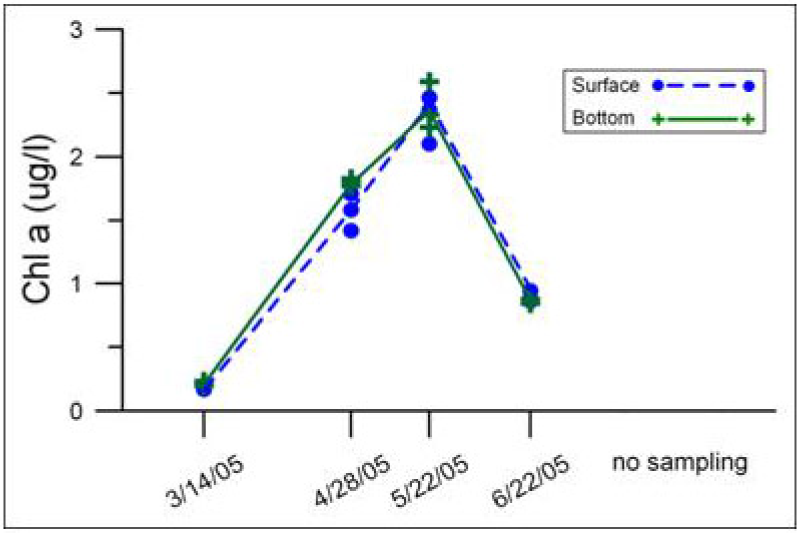


Fig. 4-8. Chlorophyll *a* levels are a proxy for phytoplankton concentrations in the water column. In 2005, elevated Chl *a* levels in April and May marked the spring bloom that peaked in late May or early June. Chl *a* levels declined precipitously by late June, indicating the phytoplankton bloom had ended.

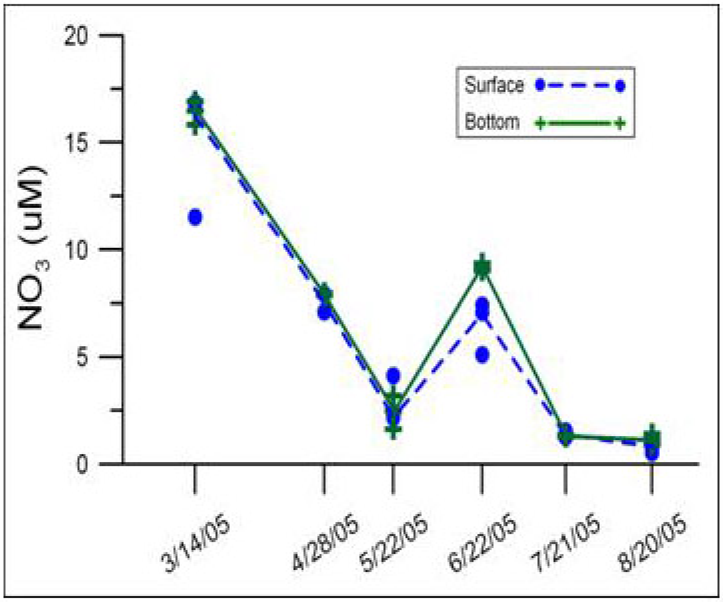


Fig.4-9. Nitrate is often a limiting nutrient in marine systems, meaning that as the phytoplankton community abundance increases (Fig. 4-8) and its utilization of dissolved nutrients such as nitrate increases, the uptake can outstrip the supply. Eventually nutrients become depleted (see 5/22/05 levels) and the phytoplankton community can no longer sustain itself and the population crashes (Fig. 4-8). As the dying and dead phytoplankton cells are lysed by grazers and decomposers, nutrients are released back into the water column, resulting in a temporary increase (see 6/22/05 levels) until continued uptake by the prolonged diatom bloom (see Fig. 4-11) and macrophytes (e.g., woody-stemmed kelp) depletes the nutrient supply again.

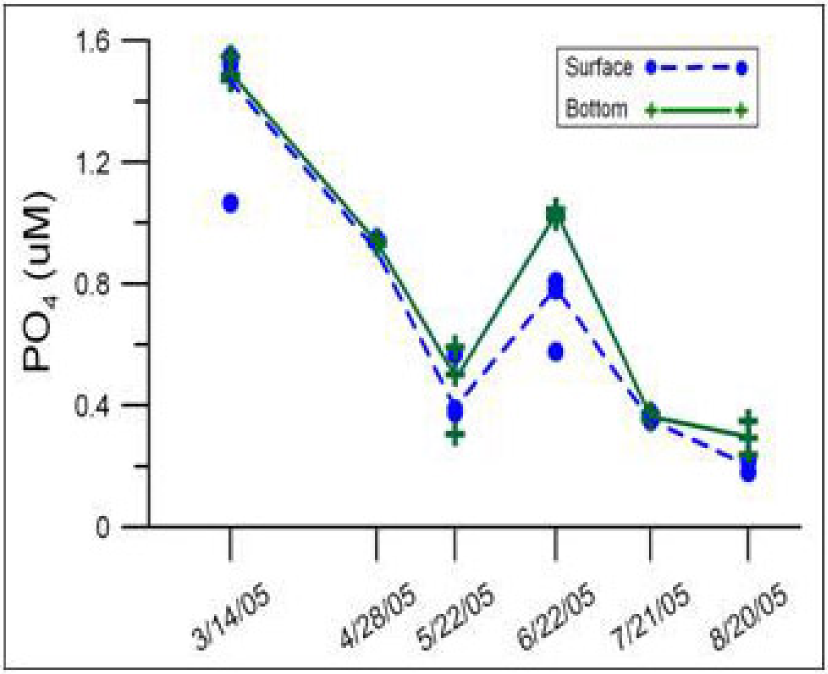


Fig. 4-10. Phosphate levels tracked nitrate levels, as the pattern of utilization and recycling is similar for both (see Fig. 4-9). Usually phosphate is not limiting, as it appears to be in this case, where roughly 0.4 µM levels remained after the phytoplankton bloom had ended.

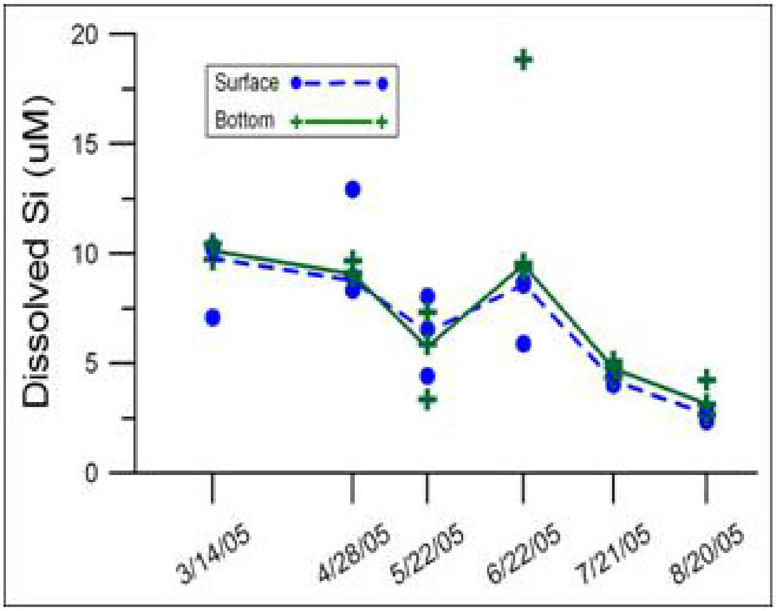


Fig. 4-11. Dissolved silica is utilized by diatoms for test development. As the number of diatoms increase during the spring bloom, dissolved silica is depleted, only to increase again after the diatom population crashes.

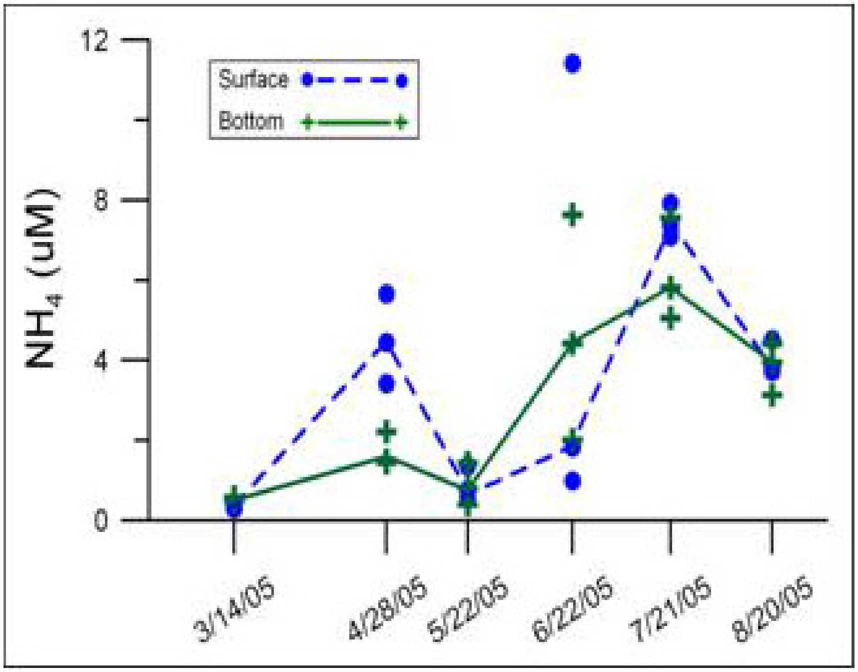


Fig. 4-12. Ammonia levels are coupled with the dynamics of organic loading to the ecosystem resulting from the addition of the discharged fish waste as well as from droppings from large numbers of gulls that gather to feed on the waste.

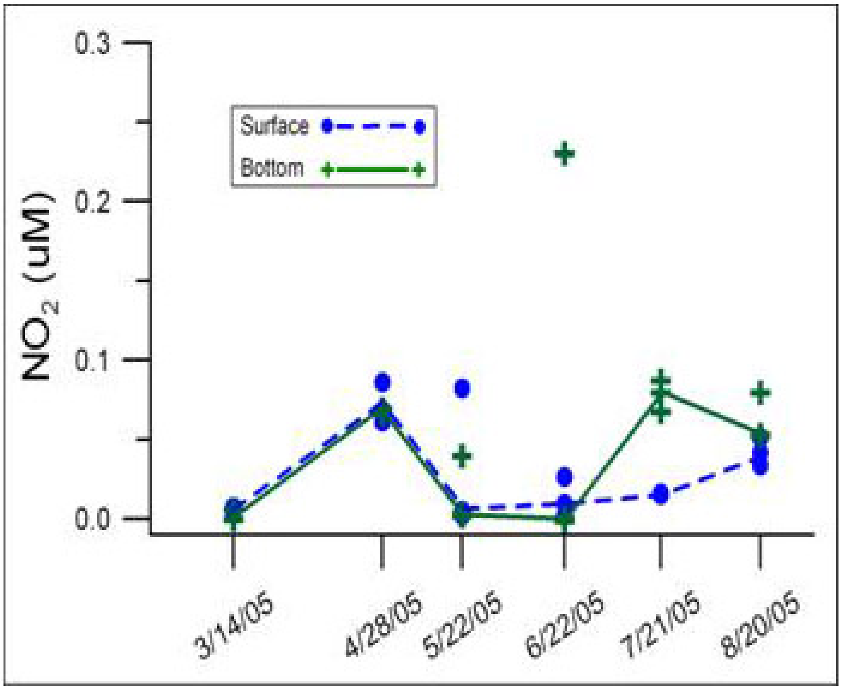


Fig. 4-13. Nitrite levels also reflect nutrient cycling arising from the loading of nitrogenous waste in the form of ground fish waste and bird droppings.

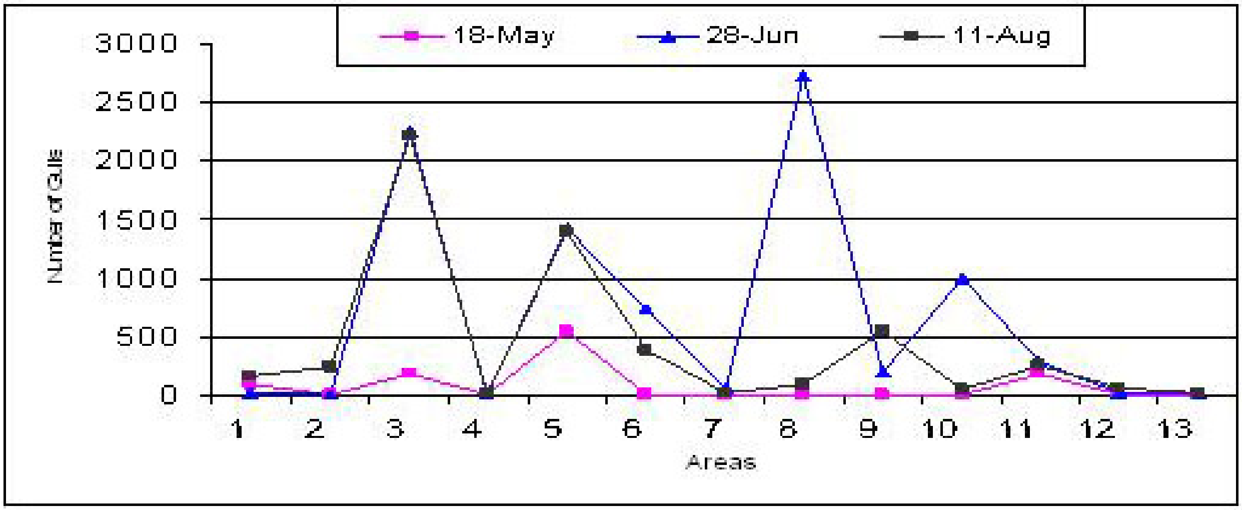


Fig. 4-14. Gull counts by aerial survey date and area, Cordova, 2005. Not shown is 24 May survey when <75 gulls were observed. Numbers indicate survey areas counted for gulls. 1. Odiak Slough; 2.Southfill/sewage treatment outfall; 3. Silver Lining outfall; 4. Silver Lining facility; 5. mixing zone 1; 6. Spike Island south spit; 7. Cordova Boat Harbor; 8. Ocean Beauty & Bear & Wolf outfalls; 9. Ocean Beauty & Bear & Wolf facilities; 10. Mixing Zone 2; 11. Copper River Seafood outfall. 12. Ferry dock/Fleming Spit; 13. Downtown Cordova.

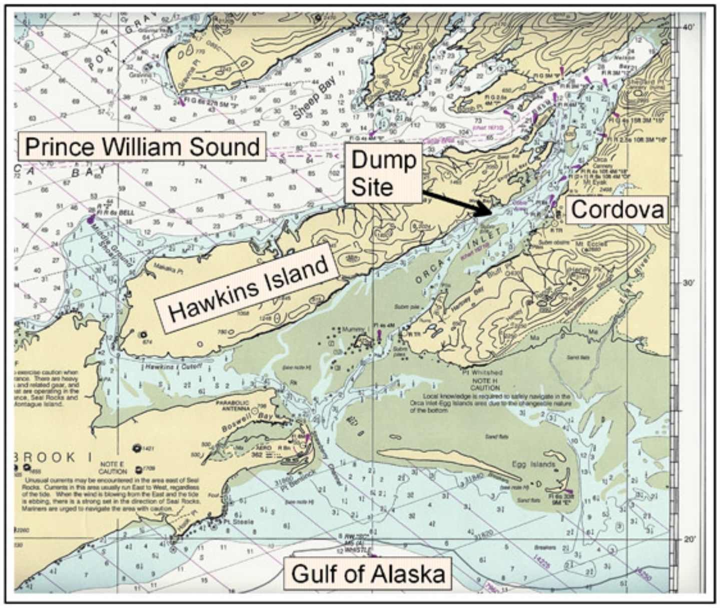


Figure 5.1. The experimental dump site on the west side of Orca Inlet, opposite Cordova.

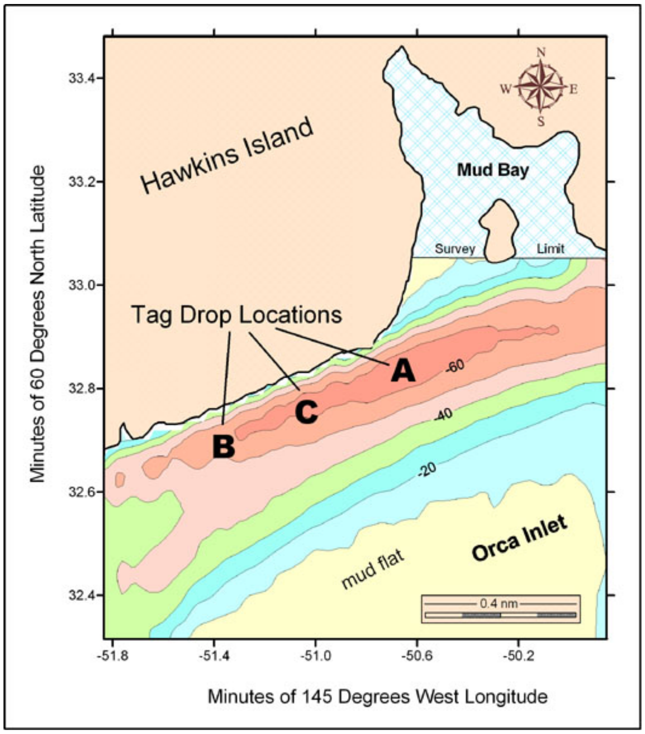


Figure 5.2. Contour plot (depths in feet at high tide) of the experimental dump site near Mud Bay, Hawkins Island. Unprocessed fish waste was dumped near location marked “A”. Fish heads fitted with sonic tags were dropped in locations A, B, and C (see Table x) so we could track scavenger activity at the site. Maximum depth at the dump site is about 65 feet at high tide.

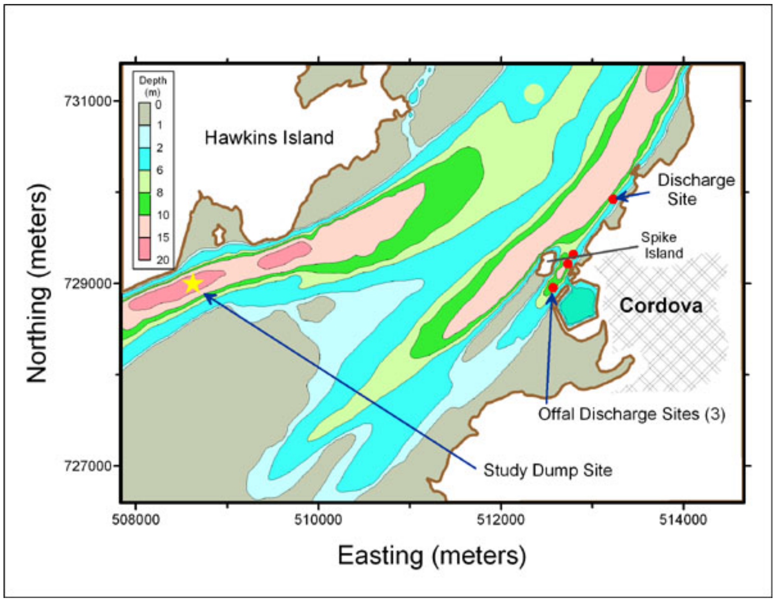


Figure 5.3. The experimental dump site, where we dumped unprocessed fish waste, was about due west of Cordova on the opposite side of Orca Inlet, near Mud Bay on Hawkins Island.

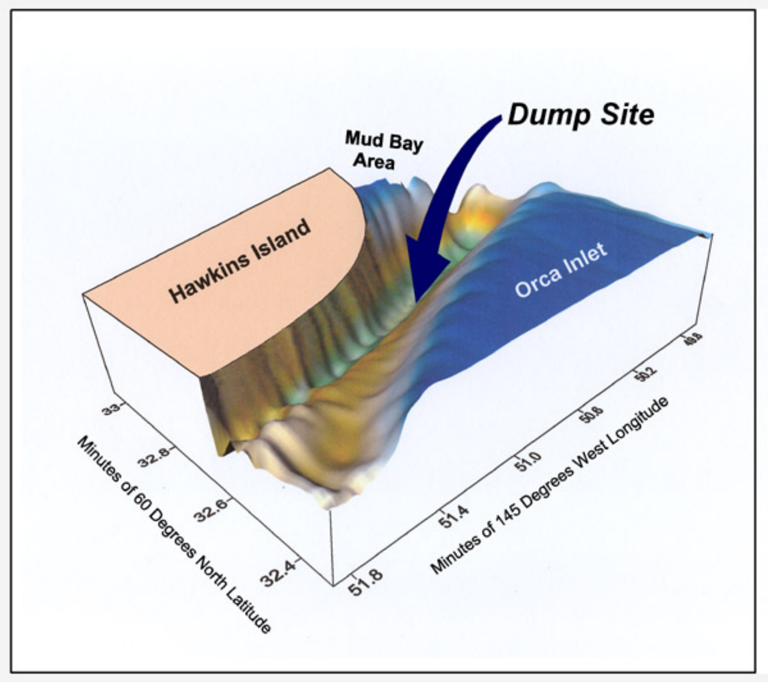


Figure 5.4. This surface plot of the experimental dump site area (to the extent of survey limits) reveals the steepness of the slope along the Hawkins Island’s coast and the narrow trench into which fish waste was dumped. The broadening of the trench in lower central portion of the graphic is where two channels that cut across the extensive mud flats meet (see Fig. 5.1).

Figure 5.5. Target species of the shrimp pot trapping exercise, Coonstripe shrimp (*Pandalus hypsinotus*).

Figure 5.6. Necrophagus gammaridean amphipods caught at several places in Orca Inlet but not at the shredded fish waste pile in Spike Island Basin.

Figure 5.7. An unidentified nudibranch caught on the fish waste pile in Spike Island Basin in August, 2006, at the peak of waste stream discharge. The specimen is about 3 mm long.

Figure 5.8. Shrimp pot with catch of Sunflower seastars (*Picnopodia helianthoides*) taken at the experimental dump site.

Figure 5.9. The catch of Sunflower seastars shown in the previous figure. The measuring stick is 12 inches (25 cm) long.

Figure 5.10. Juvenile Dungeness crabs (*Cancer magister*), 5-6 cm carapace length, caught in a shrimp pot in Mud Bay Trench (December 2006).

Figure 5.11. Carcass of a spider crab (Graceful Decorator Crab, *Oregonia gracilis*) caught in a shrimp pot at the experimental dump site in Mud Bay Trench.

Figure 5.12. Gastropod (~2.5 cm longest axis) caught in a shrimp pot; possibly a moon snail, *Polinices lewisii*.

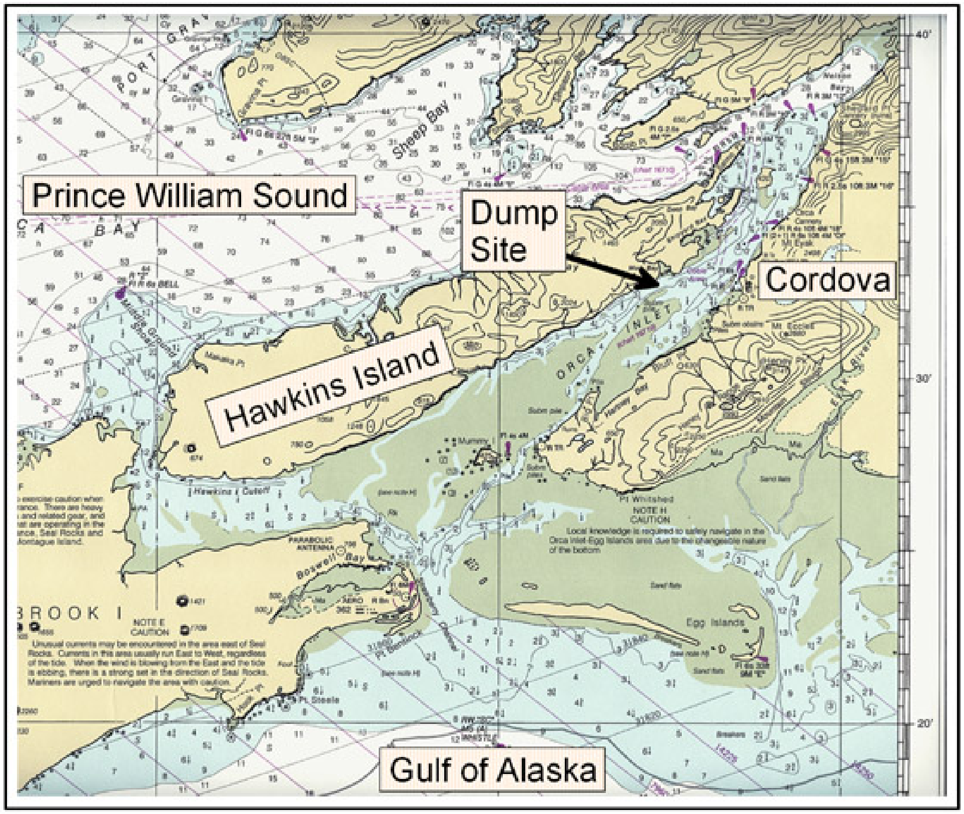


Figure 6.1. The experimental dump site was located near Mud Bay on Hawkins Island.

Figure 6.2. A tote of filleted red salmon waste (roughly 1100 pounds or 500 kg) being dumped from the F/V KyleDavid at the experimental dump site.

Figure 6.3. We constructed a video camera sled for monitoring the disposition of unprocessed fish waste at the experimental dump site and the relative abundance and distribution of scavengers feeding on the waste. The sled held two cameras that filmed the seabed as the sled was slowly pulled through the experimental dump site area.

Figure 6.4. A rockfish (putatively Quillback rockfish, *Sebastes maliger*, or tiger rockfish, S. *nigrocinctus*) at the control site near Observation Island, Orca Inlet.

Figure 6.5. A rock sole (*Lepidopsetta* sp.) on the shell heap and algal mat in the experimental dumping area in Mud Bay trench.

Figure 6.6. Two rock sole (*Lepidopsetta* sp.) at the control site near Humpback Creek, Orca Inlet.

Figure 6.7. A rock sole (*Lepidopsetta* sp.) at the experimental dump site near Mud Bay.

Figure 6.8. A rock sole (*Lepidopsetta* sp.) at the control site near Humpback Creek, Orca Inlet.

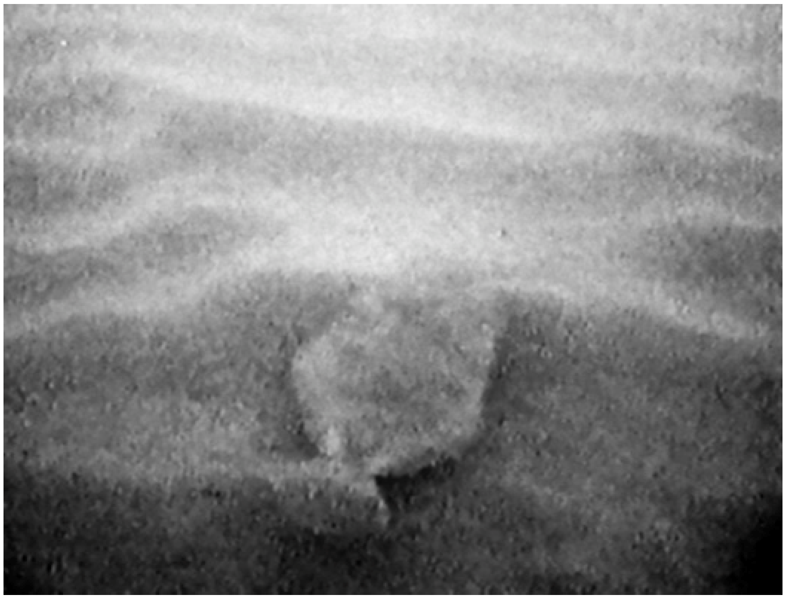


Figure 6.9. A halibut (*Hippoglossus stenolepis*) gliding over sand-flat ripples near the experimental dump site. The expanse of sand and mud flats make this a very common substrate in Orca Inlet, quite unlike the complexity of the bottom types found in the deeper, scoured channels and the trench near Mud Bay where we dumped unprocessed cannery waste.

Figure 6.10. In many places in the northern half of Orca Inlet, the sandy bottom has been worked into mega-ripples, sand waves that indicate the presence of high-velocity water currents flowing across the bottom. In some places, the waveforms are about 1 m high.

Figure 6.11. In many places, the bottom of the trench where waste was dumped – Mud Bay Trench – was covered with shell hash – broken valves of a variety of bivalves (e.g., Tellinidae and Cardiidae).

Figure 6.12. Some areas of the trench are covered with the brown alga, woody-stemmed kelp (*Pterygophora californica*), sometimes in meadows that provide a complex habitat for fish and invertebrates.

Figure 6.13. A specimen of woody-stemmed kelp (P. *californica*) 21 cm in length. The fronds of the plant are short and heavy, an adaptation to living in fast flowing currents in the trench.

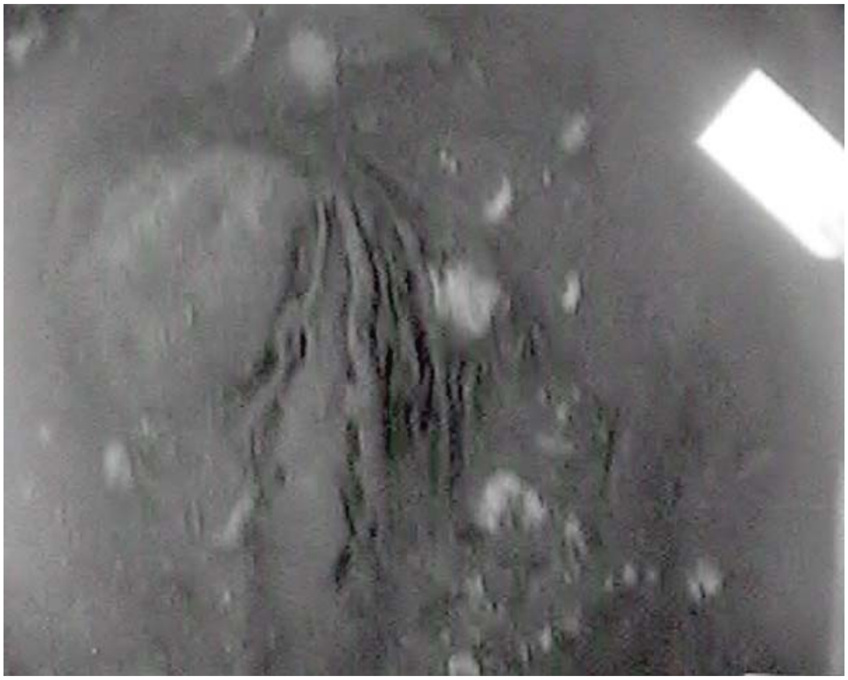


Figure 6.14. Tidal currents were strong in the trench, as is evident in this image of a 23 cm long woody-stemmed kelp streaming in the current flow. Note the scouring of sediments around the rock the kelp is attached to. For size reference, the white target (upper right corner) is 50 mm wide and 75 mm long (longest dimension).

Figure 6.15. In some places in Mud Bay Trench, the bottom consists of boulder fields distributed among kelp beds. In some places, as in the site pictured here, the surface of the boulders are relatively clean, apparently scoured by currents and perhaps but grazing invertebrates, such as limpets and chitons.

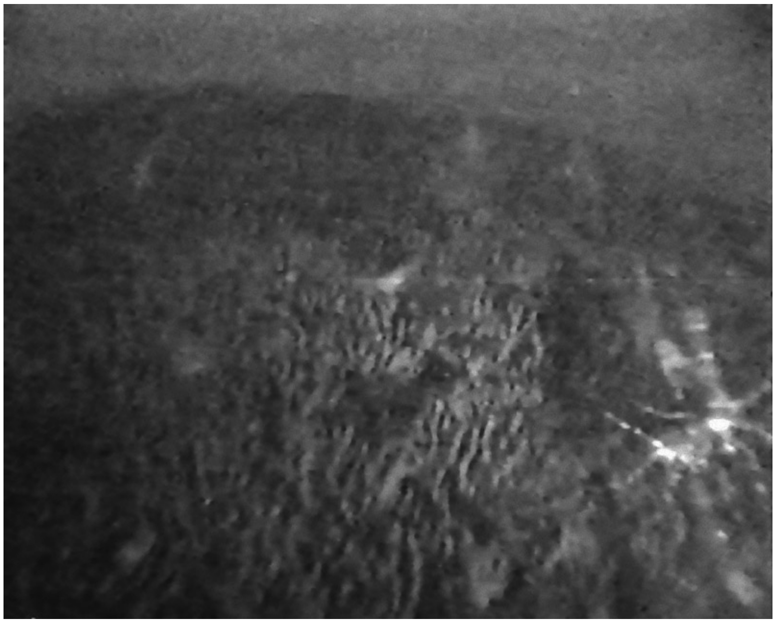


Figure 6.16. In some areas of the experimental dump site trench, large boulders are covered with fields of stunted kelp that provides habitat for fish and invertebrates (e.g., the coonstripe shrimp in the lower right corner of the image).

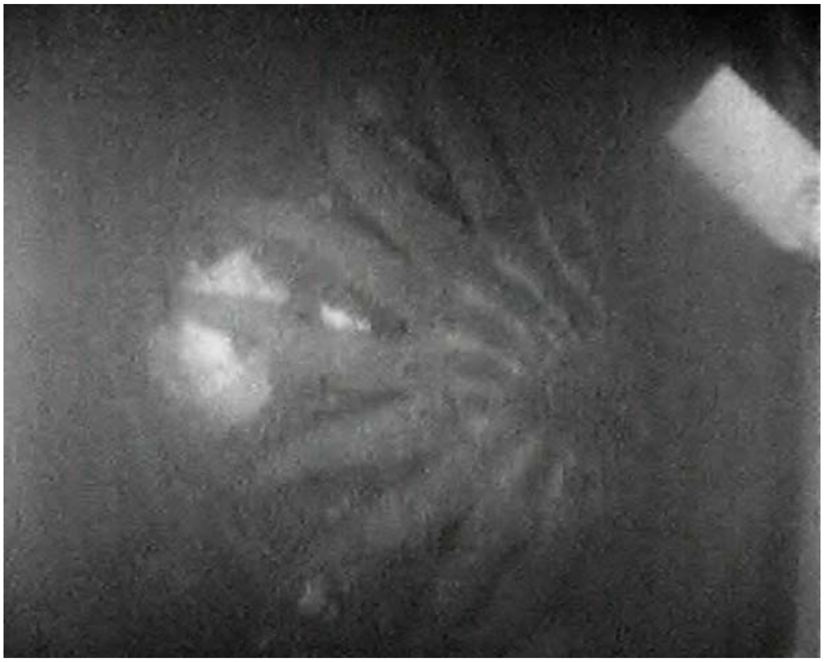


Figure 6.17. In this image, a sunflower star (*Picnopodia helianthoides*) – about 45 cm in diameter – has located a piece of fish waste and is positioning its body to feed on it.

Figure 6.18. In the lower right corner of this image, a sunflower seastar has encircled a piece of fish waste to position it in front of its stomach and is consuming it.

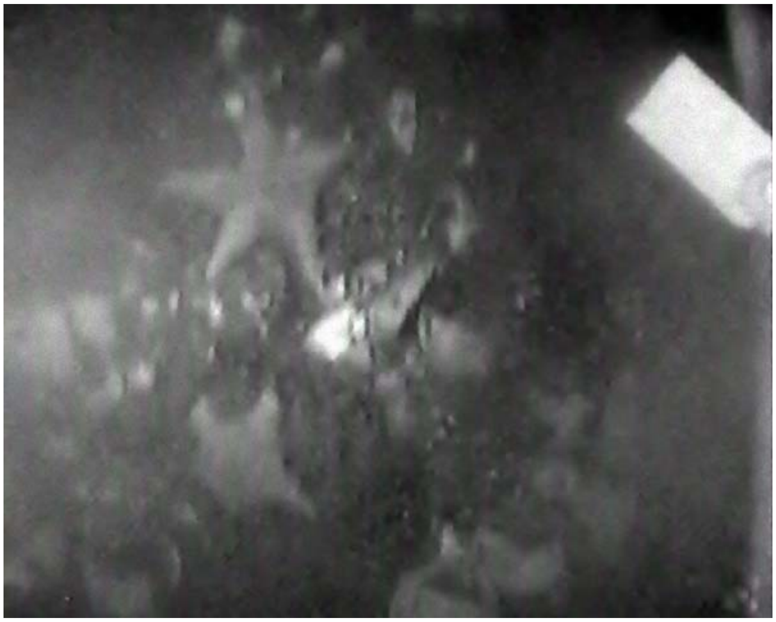


Figure 6.19. Two species of seastars (body disk diameter 6-7 cm), a fish and broken shells on a substrate of mixed sand and gravel.

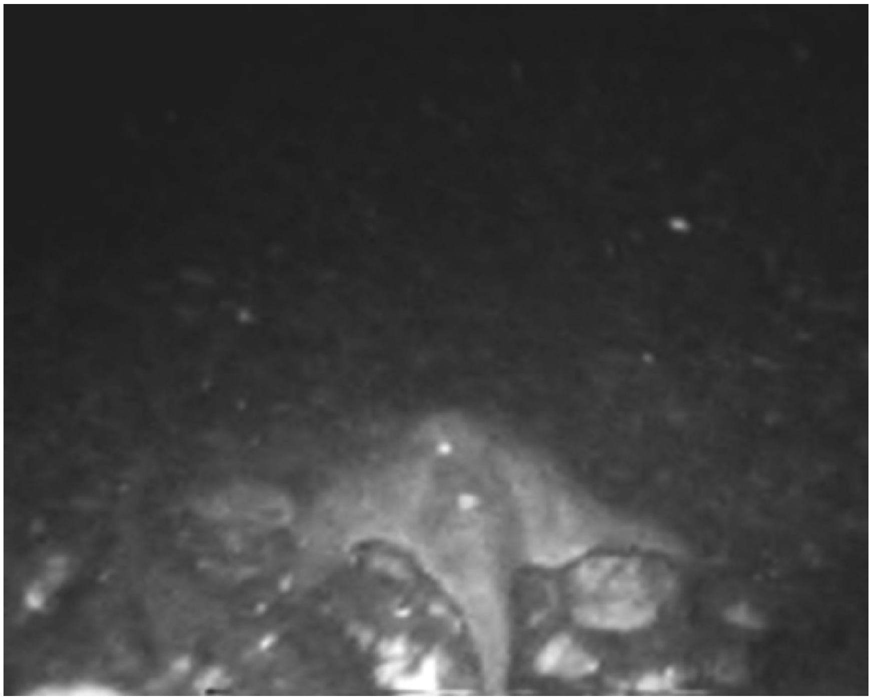


Figure 6.20. A large, robust seastar, possibly a leather star (*Dermasterias imbricata*), in the rocky habitat in Mud Bay Trench.

Figure 6.21. A brittle star (lower left corner) moving through a woody-stemmed kelp meadow near some broken bivalve shells in the trench.

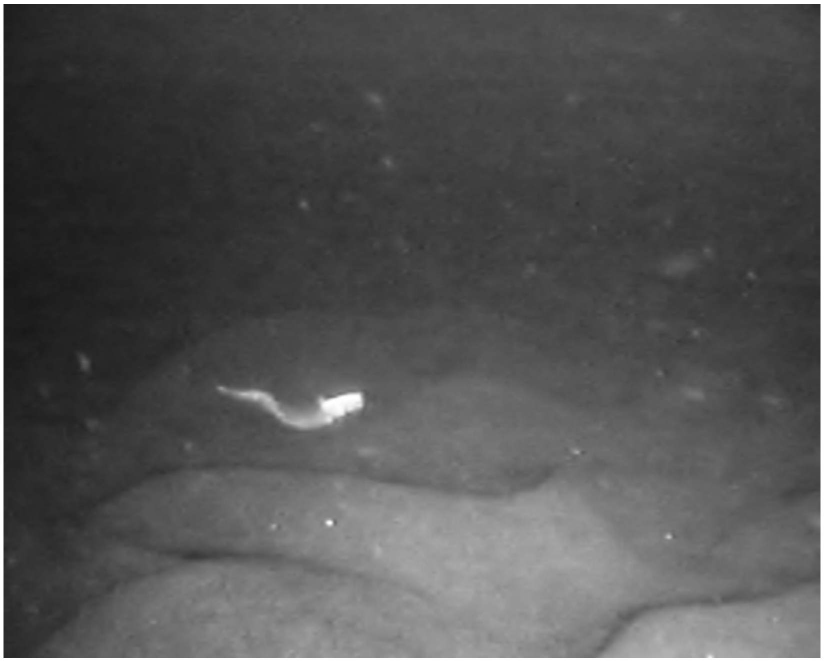


Figure 6.22. An image of a piece of filleted salmon waste on sandy bottom taken from a two minute segment of video when the camera sled was at rest. A small Cancer crab was feeding on this piece of fish waste as it was filmed.

Figure 6.23. An aggregation of gastropods, sea urchins, and other scavengers apparently feeding on a small mound of fish waste.

Figure 6.24. This necrophagus gastropod, the Foliate Thornmouth (*Ceratostoma foliatum*), was one of the more abundant scavengers observed at the experimental dump site (e.g., Fig. 6.23).

Figure 6.25. An assemblage of a variety of scavengers including coonstripe shrimp (lower right corner), squid (upper right corner) and fish, in the rocky habitat at the experimental dump site.

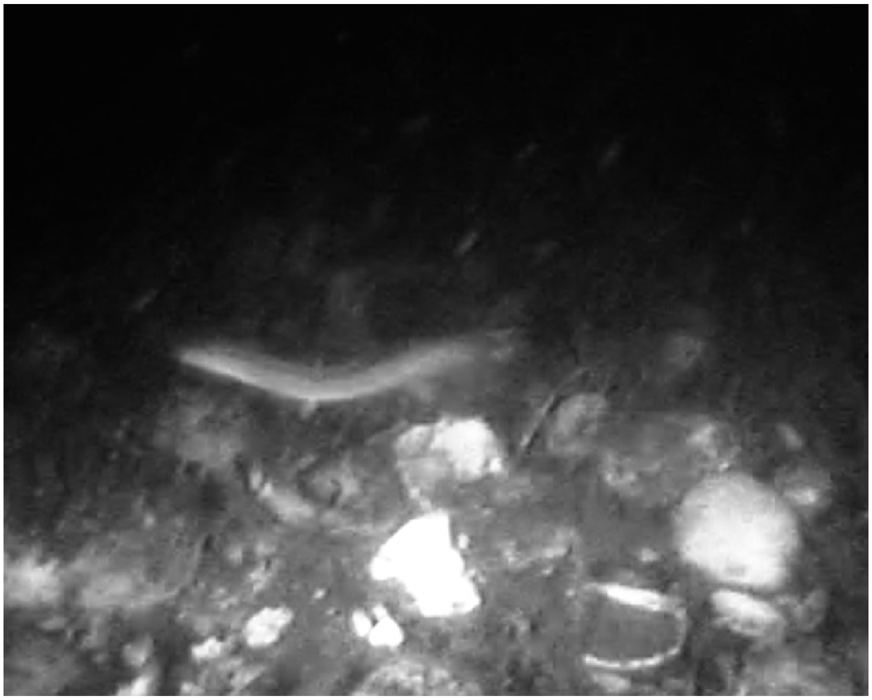


Figure 6.26. The sighting of an eel in the shell-hash habitat of Mud Bay Trench was unexpected, as this is a rarely observed visitor to Orca Inlet.

Figure 6.27. Sea anemones were contagiously distributed on the shell hash and rocky substrate in Mud Bay Trench.

Figure 6.28. Sea otters (*Enhydra lutris*) were often observed in the dump site area and infrequently could be seen to be eating fish waste.

Figure 6.29. On 15 June 2006, a Sunflower seastar was observed floating in the Mud Bay dump site area. It was feeding on a bolus of food similar in size to a salmon head and was being carried along in the flow of tidal currents sweeping through the experimental dump site.

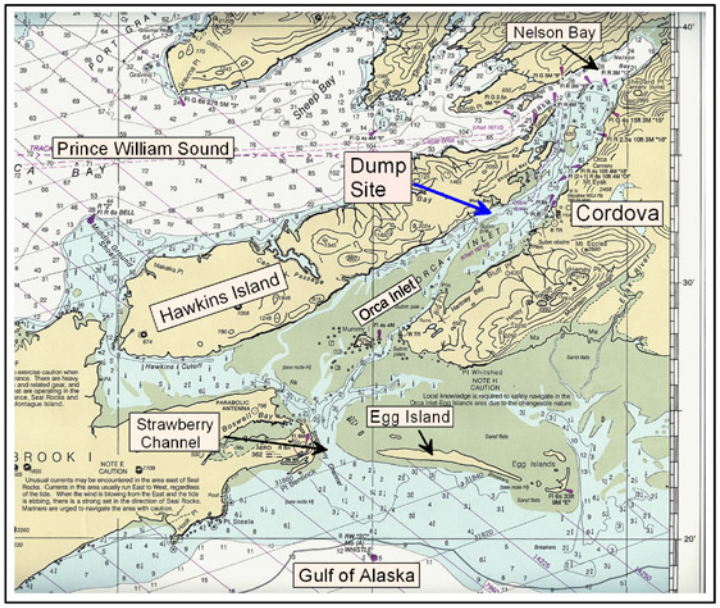


Figure 7.1. Tagged carrion (salmon heads with sonic tags) was released at the dump site in Mud Bay Trench in Orca Inlet.

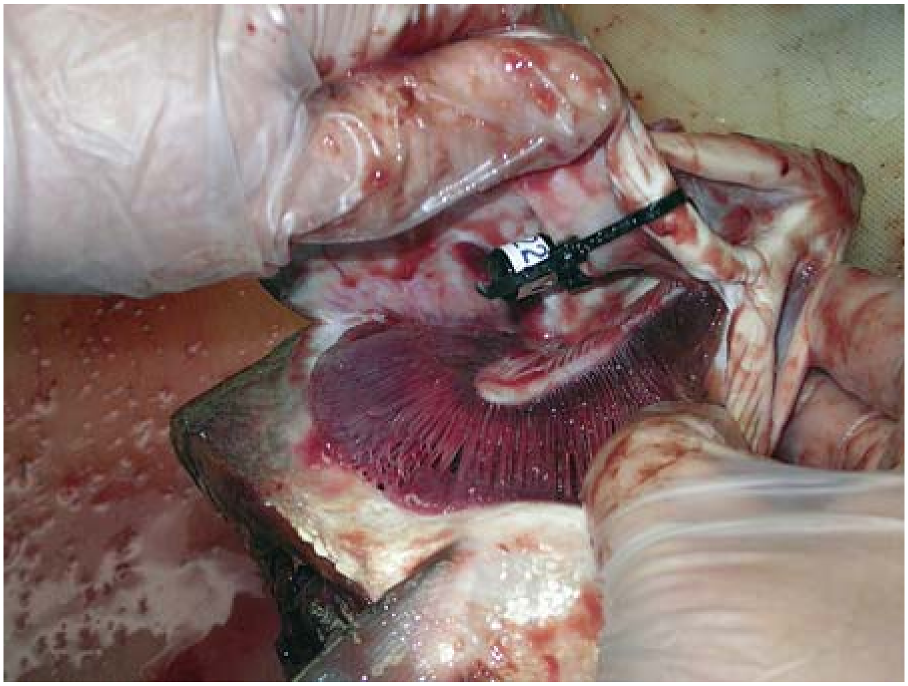


Figure 7.2. The acoustic tags were attached to opercula and positioned so they were in the protection of the opercular cavity of the fish heads.

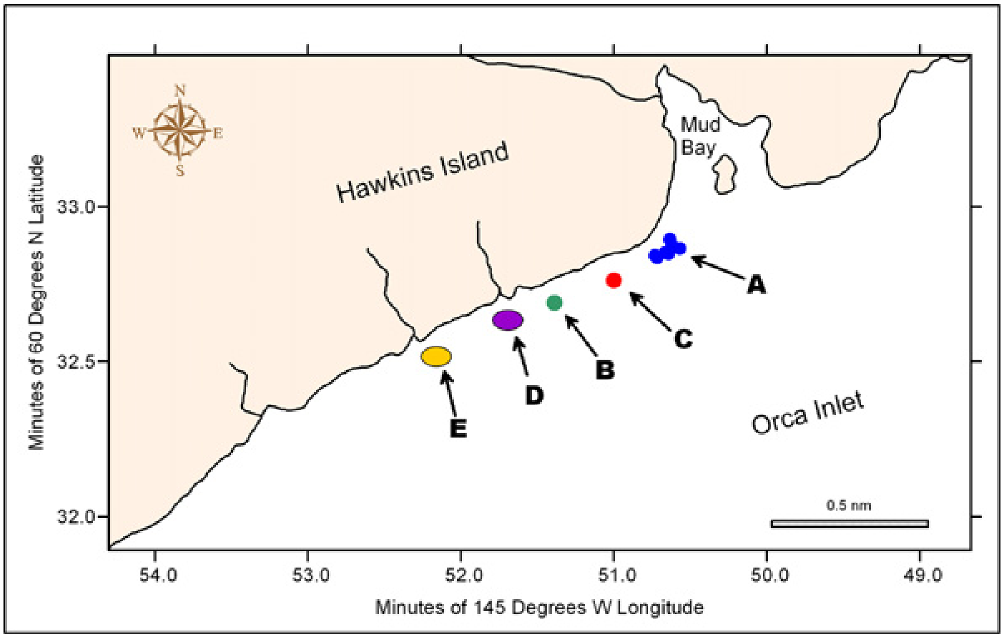


Figure 7.3. Tagged fish waste – fish heads with sonic tags - were released at three locations during the study. Key to symbols in the figure: "A" - site where eight tagged fish heads were dropped on 15 June 2006; also where 150,000 pounds of fish waste dumped. Tagged fish heads remained in the same area for the duration of the study (~ 3 months). "B" - Site where four fish heads were dropped on 13 September 2006. "C" - Site where five tagged fish heads were dropped on 21 September 2006. "D" - Area where three of four tags dropped at site B were detected two days later, possibly moved by tides as they settled to the bottom after release. "E" - Area where the other tag dropped at site B was detected two days after release.

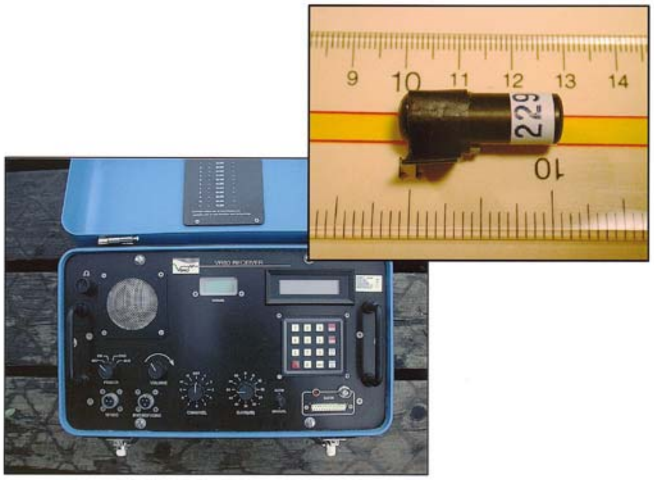


Figure 7.4. Vemco VR60 receiver (left) and a Vemco V9 acoustic tag (right) used to track movement of salmon heads dropped at several locations in the experimental dumping area near Mud Bay.

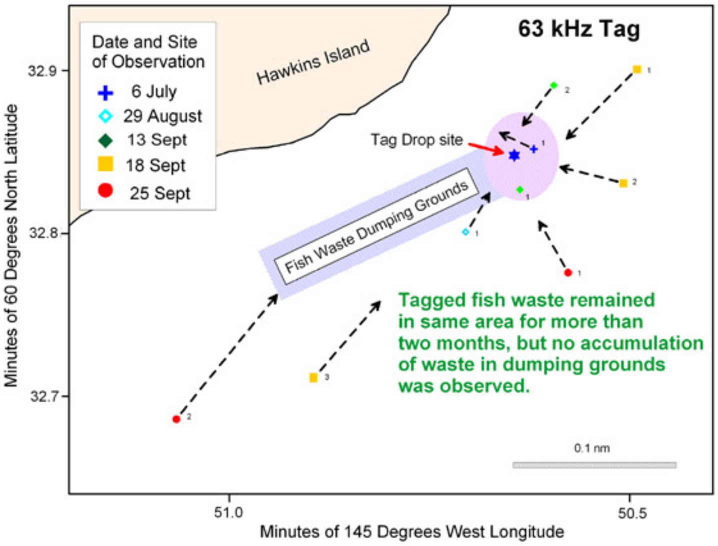


Figure 7.5. Detection bearings for one of eight tags dropped in Area A, at the north end of the fish waste drop zone at the southeast corner of the mouth of Mud Bay (see Fig. 7.3). All eight Area A tags remained near where they were dropped throughout the study.

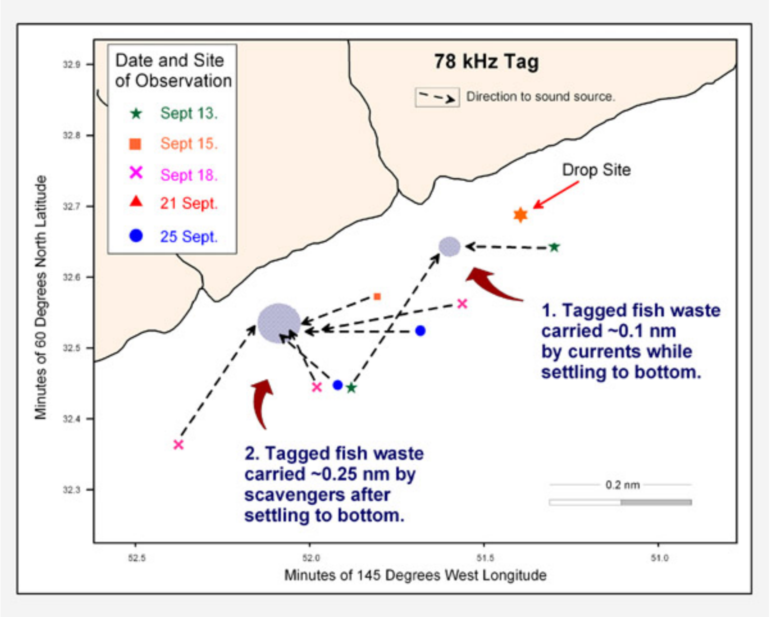


Figure 7.6. Record of detection bearings for one of four sonic tags dropped at Site B on 13 September 2006 (see Fig. 7.3). Tidal ebb flow currents carried the tag about 0.1 nm southwestward until it settled to the bottom in the Mud Bay trench. Two days later, the tag had been moved, presumably by scavengers, an additional 0.25 nm to the SW. The tag remained in that area for the duration of the study, until 19 October 2006.

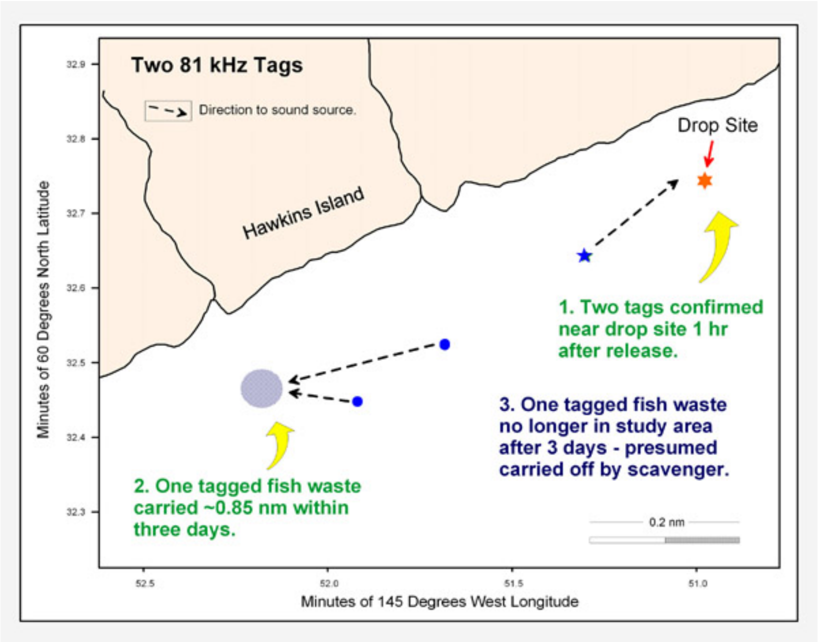


Figure 7.7. Five tags were dropped at site C (see Fig. 7.3) on 21 September 2006. Two of them, considered here, were confirmed to have settled and remained on the bottom near the drop site an hour after release. Three days later, one tag had been moved 0.85 nm to the SW. The other tag was not detected in a search area that extended several miles in both the SW and NE directions from the drop site and was presumed to have been carried out of the study area by a scavenger. By the end of the study (19 October), four of the five tags were no longer detected in the study area.

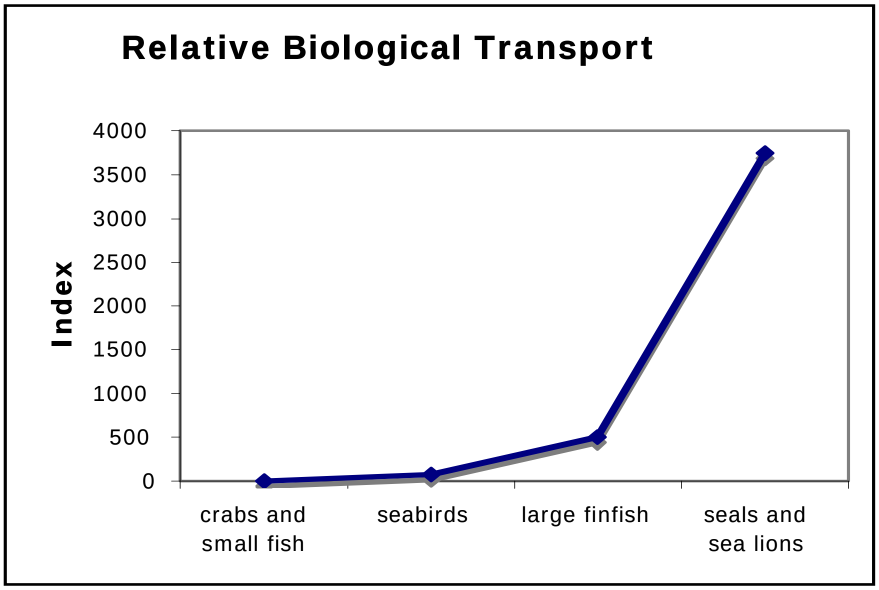


Figure 8.1. Relative biological transport

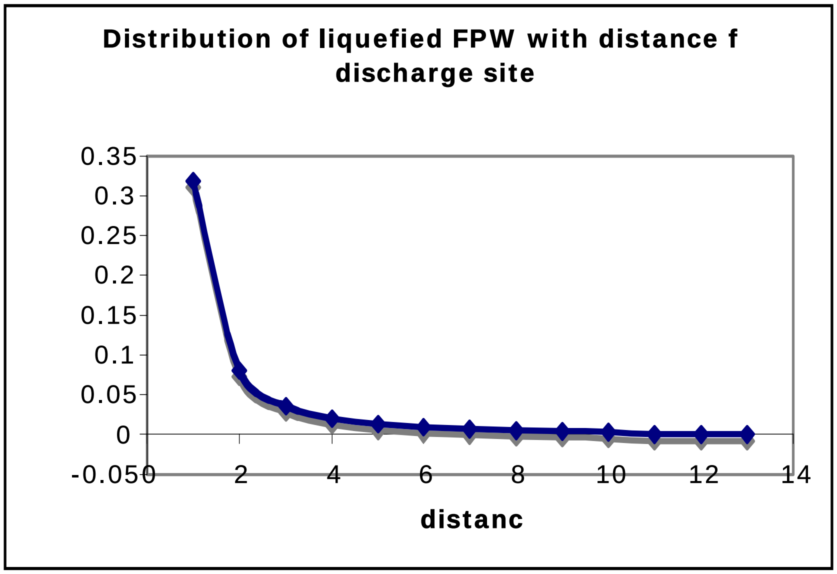


Figure 8.2. Distribution of liquefied FPW with distance from discharge site

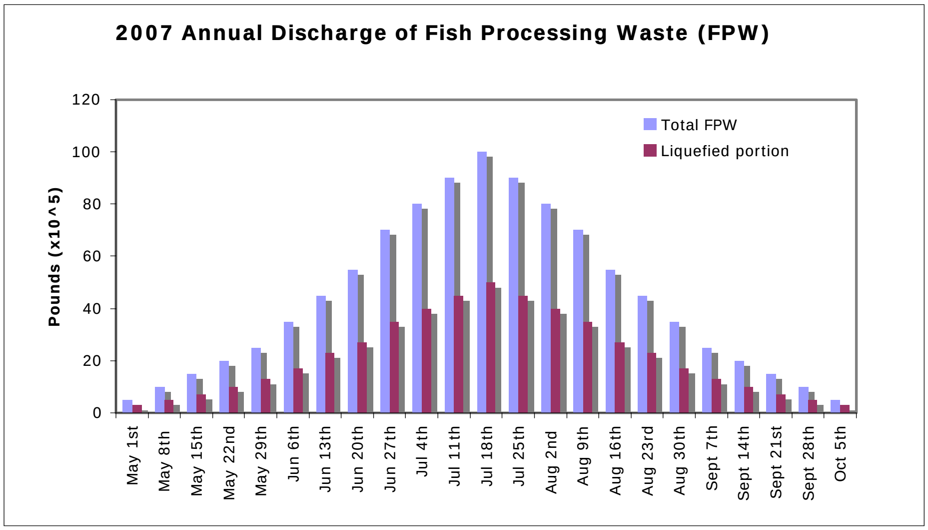


Figure 8.3. 2007 annual discharge of fish processing waste

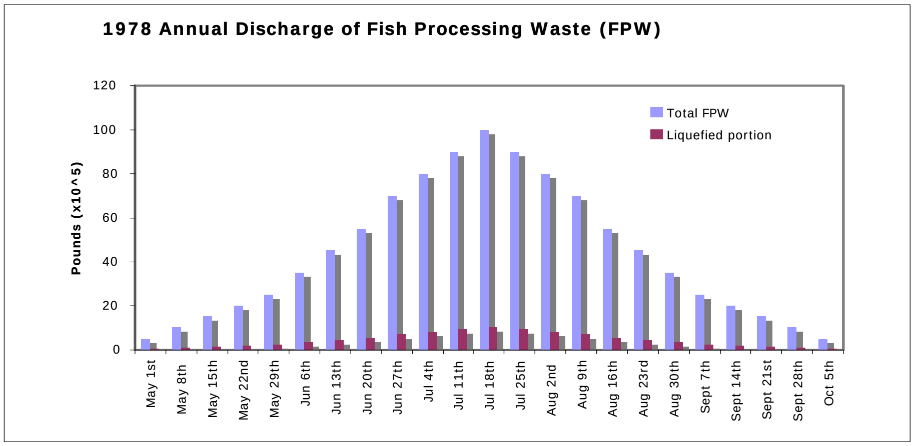


Figure 8.4. 1978 annual discharge of fish processing waste

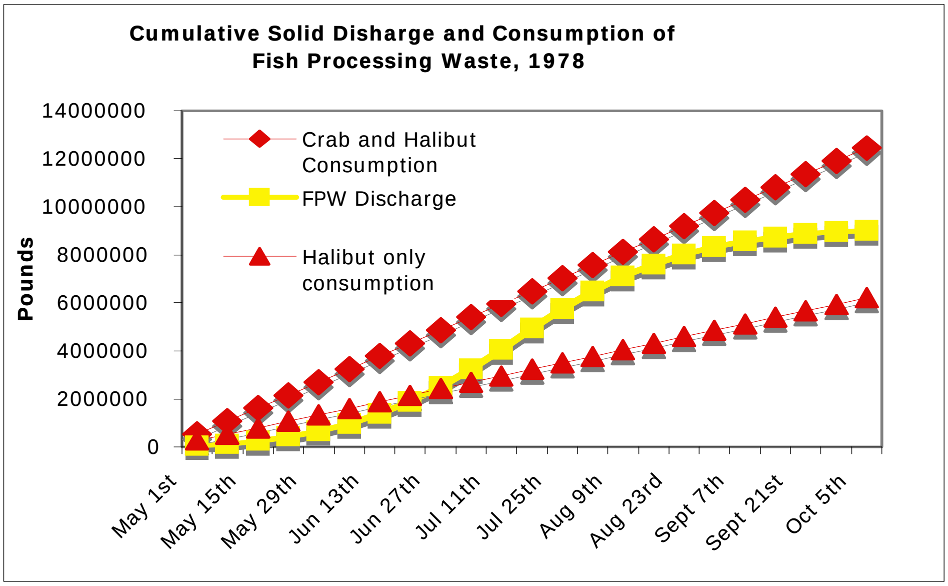


Figure 8.5. Cumulative solid discharge and consumption of fish processing waste, 1978

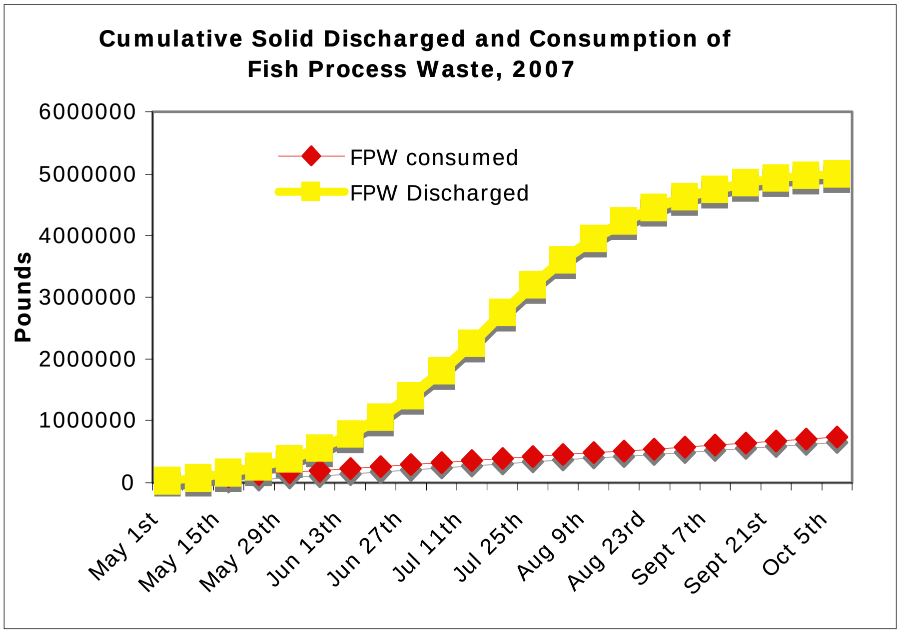


Figure 8.6. Cumulative solid discharge and consumption of fish processing waste, 2007

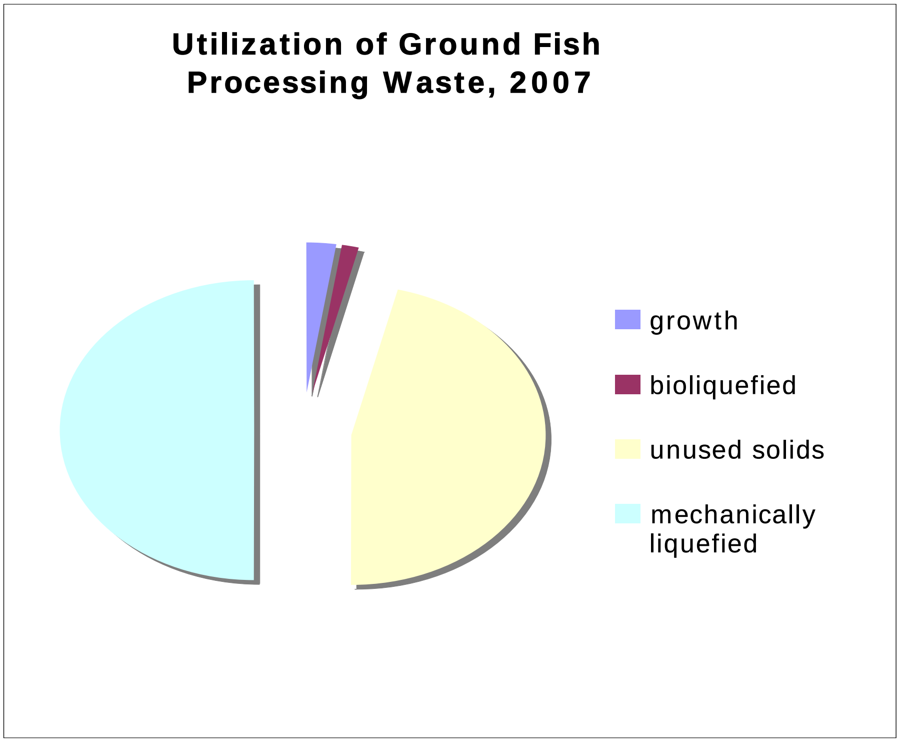


Figure 8.7. Utilization of ground fish processing waste, 2007

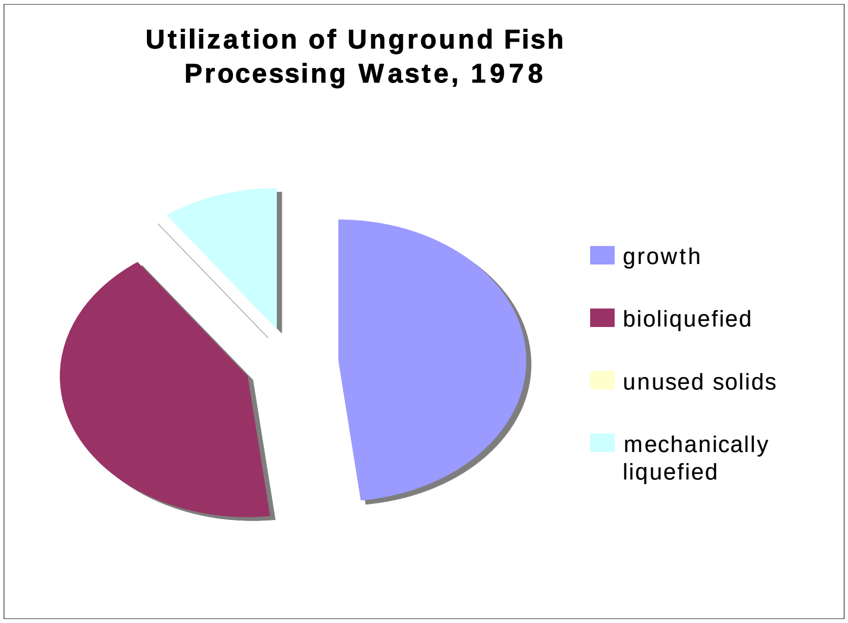


Figure 8.8. Utilization of ungound fish processing waste, 1978

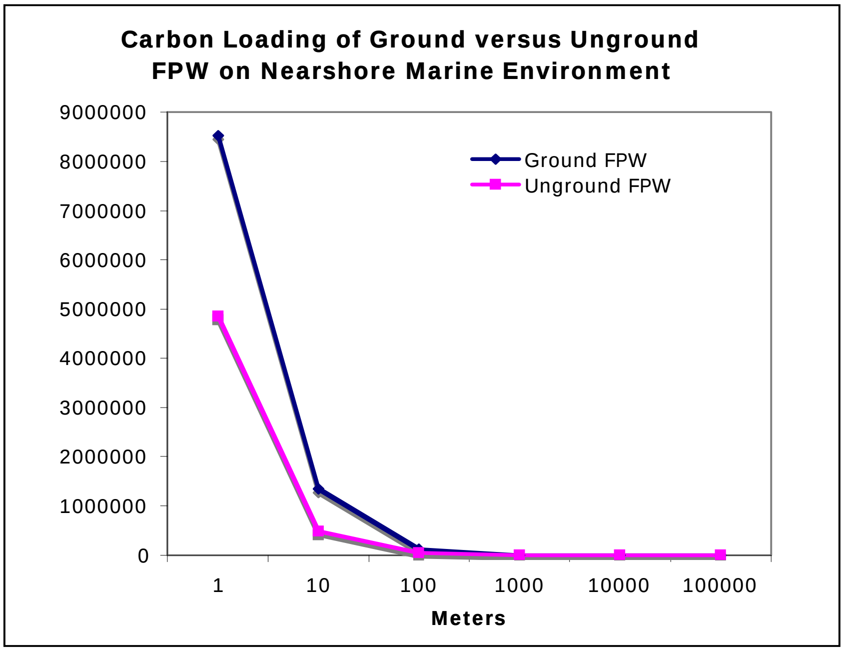


Figure 8.9. Carbon loading of gound versus unground FPW on the nearshore marine environment.

Figure 9.1. Steller sea lion feeding on fish carcasses in Orca Inlet

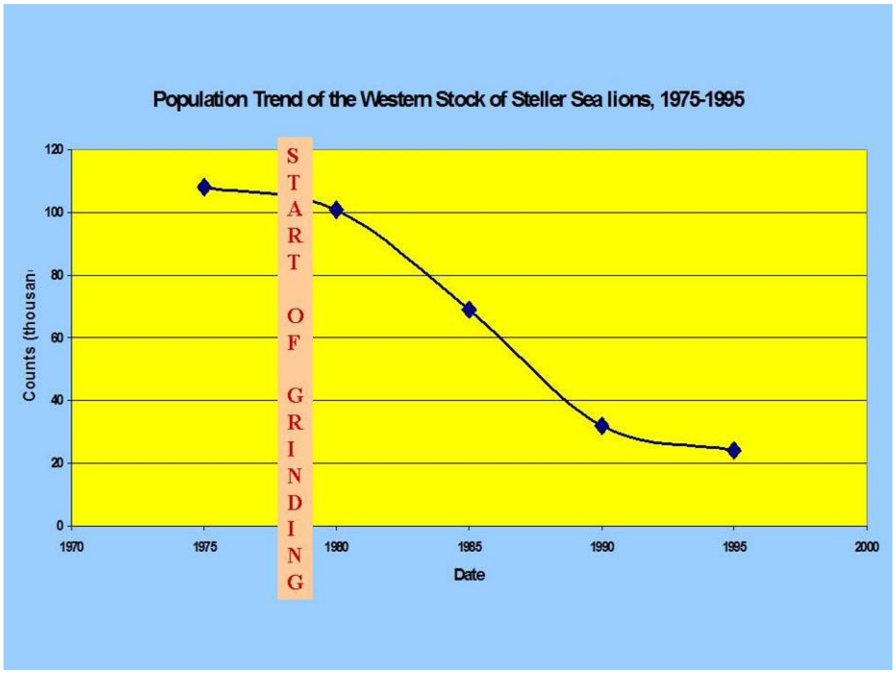


Figure 9.2. Population trend of the western stock of Steller sea lions, 1975-1995