Exxon Valdez Oil Spill
Restoration Project Final Report

Nearshore Data Management and Monitoring Project

Restoration Project 070750
Final Report

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Study history: This is the initial and final report for project 070750, Nearshore Data Management and Monitoring. The work conducted here is an extension of a previous project (EVOS project 050750) that provided planning for long-term monitoring in the nearshore, including areas affected by the Exxon Valdez Oil Spill and was subsequently adapted and implemented by the National Park Service Southwest Alaska Network.

Abstract: We developed a web-based geospatial database system that will serve as a means of preserving and retrieving past and future nearshore datasets, particularly as related to long-term monitoring. We also initiated sampling and data collection for the nearshore monitoring program that was developed in the precursor to this project (EVOS project 050750) in western Prince William Sound (WPWS). Through EVOS projects 050750 and 03687 we developed several alternate long-term nearshore monitoring programs within provided budgetary and scoping guidelines. Ultimately one of the proposed programs was chosen and standard operating procedures (SOP) were developed and tested. The goal of the program is to identify changes that may be occurring in the nearshore and help to identify causes for those changes. If changes are identified through the monitoring program, appropriate resource managers will be notified and potential studies suggested to assign cause and predict potential effects. Resource managers will then determine if any corrective actions can or should be taken. Continued monitoring can then determine the impact of such actions. The monitoring program was initiated with lessons of the *Exxon Valdez* Oil Spill (EVOS) in mind and was intended to provide information to facilitate recovery from effects of the spill. During the SOP development and testing portion of the program, the National Park Service Southwest Alaska Network (SWAN) began collaborating with U.S. Geological Survey and Coastal Resources Associates to adopt and adapt the monitoring design for the National Park Service Vital Signs Monitoring Program (Fancy et al. 2009). Thus, implementation of the monitoring program in WPWS largely replicates the SWAN adaptation of the initial program developed for WPWS monitoring. This report evaluates a suite of metrics for three vital signs: intertidal communities, black oystercatchers, and sea otters. Observations include a possible recent increase in the abundance of mussels and a decrease in the abundance of clams (especially littleneck clams) in the intertidal. This was concomitant with an increase in the proportion of mussels and a decrease in the proportion of clams in the diet of sea otters. We also observed an increase in number of sea otters in Northern Knight Island, suggesting possible initiation of recovery from oil spill impacts. We found no evidence of continued injury to intertidal communities as a result of the spill, although statistical power was low.

Key words: *Exxon Valdez* oil spill, intertidal, nearshore, monitoring, oystercatcher, sea otter

Project Data: Data gathered include estimates of abundance of intertidal invertebrates and algae, sizes of key invertebrate species, abundance of black oystercatcher nest sites, number of black oystercatcher chicks and eggs per nest, abundance and sizes of prey remains at black oystercatcher nest sites, abundance of sea otters, abundance and sizes of prey obtained by sea otters, foraging success rates for sea otters. These are available in Microsoft Excel or Access datasets. Data are housed at: US Geological Survey, Alaska Science Center, 4210 University Dr., Anchorage, Alaska 99508, Contact: James Bodkin (jbodkin@usgs.gov)

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Executive Summary

In this project, we had two objectives: 1) development of a web-based data management system for nearshore data and 2) initiation of a long-term nearshore monitoring program in western Prince William Sound (WPWS). The data management system, the "Nearshore Data Portal" <http://www.pwsherringportal.org/USGS_Nearshore/index.cfm> is a web-based geospatial database and display system that will serve as a means of preserving and retrieving past and future nearshore datasets. Currently, the database contains geospatial bibliographic and metadata information for nearshore resources in the Gulf of Alaska. Aerial survey data sets for sea otters in Prince William Sound have been added to the portal and other historical nearshore data sets are currently being added.

During summer 2007, we initiated sampling for a long-term monitoring program in Prince William Sound, including areas affected by the 1989 *Exxon Valdez* oil spill (EVOS). The goals of the program are to identify changes that may be occurring within the system, identify potential causes for change, and inform appropriate resource managers, especially if management actions could facilitate recovery of resources injured by the spill. Continued monitoring can then determine the impact of such actions. The monitoring program was initiated with lessons of the *Exxon Valdez* Oil Spill (EVOS) in mind and was intended to facilitate recovery from effects of the spill. During the SOP development and testing portion of the program, the National Park Service Southwest Alaska Network (SWAN) began collaborating with USGS and Coastal Resources Associates to adopt and adapt the monitoring design for the National Park Service Vital Signs Monitoring Program (Fancy et al. 2009). Thus, implementation of the monitoring program in WPWS largely replicates the SWAN adaptation of the initial program developed for WPWS monitoring. This report evaluates a suite of metrics for three vital signs: intertidal communities, black oystercatchers, and sea otters. For WPWS, the remaining vital signs (marine birds, kelps and seagrasses, and marine water quality) and associated metrics are being evaluated by other EVOS projects. We also provide data to help assess recovery of intertidal communities from injuries caused by the spill.

In the intertidal community, we focused on algae and intertidal invertebrate communities on sheltered rocky shorelines and on bivalves on gravel and sand/gravel beaches. Sampling in both habitats was conducted at randomly selected sites and at locations that were oiled following the spill and (in the sheltered rocky habitat) that were sampled previously as part of assessments of injury following the spill. The intertidal communities on sheltered rocky shores are characterized by the brown alga, *Fucus gardneri*, and various red, green, and brown algae in the lower intertidal, and by barnacles and *Fucus* and the mussel, *Mytilus trossulus*, in the mid intertidal zone. Comparisons between our 2007 results and those from studies conducted in the mid 1990s suggest a possible increase in the abundance of *Mytilus trossulus* (especially in the lower intertidal) and *Fucus gardneri* (in the mid intertidal). Determining whether these findings represent significant temporal trends will require additional years of sampling. We found no significant differences with respect to the abundances of dominant intertidal algae or invertebrates between oiled and unoiled reference sites.

The bivalve assemblage at gravel or sand/gravel beaches in WPWS consisted almost entirely of five taxa: *Protothaca staminea, Saxidomus gigantea, Mya spp., Macoma* spp., and *Hiatella arctica*. Densities of all species were generally low. The relatively low densities of clams, and especially the littleneck clam, *Protothaca staminea*, in our sampling may reflect a wide-spread trend of declining littleneck clam abundance in WPWS. At our randomly selected sites, we observed a mean density of 0.65 *Protothaca* per 0.25 m^2, substantially lower than the mean of over 30 *Protothaca* per 0.25 m^2 observed at unoiled sites in similar habitats between 1991 and 1996. We found no significant differences in clam abundance between oiled and unoiled reference sites. However, the low densities and high inter-site variability we observed results in little power to detect differences.

For black oystercatchers, we estimated nest site density from boat surveys. We also evaluated nest site productivity (number of chicks or eggs at each nest site) and examined remains of prey provisioned to chicks by adults to determine prey composition. The nest site density and the productivity of nests in 2007 were similar to that observed in studies in WPWS in the early 1990s. Limpets (*Tectura and Lottia spp.)* and mussels (*Mytilus trossulus*) were the dominant prey items present in shell remains around nest sites. In WPWS in 2007, mussels comprised 28% of the prey remains collected. This is lower than the 42% estimate for the proportion of mussels in prey fed to chicks in the early 1990s. However, methods for obtaining prey composition data differed between studies and may account for the differences.

Sea otter abundance in WPWS and in the heavily oiled Knight Island portion of WPWS was estimated based on aerial surveys. We also examined diets of sea otters based on foraging observations made at sites near our randomly selected sheltered rocky intertidal sampling locations. In 2007, we estimated there were 2,380 sea otters in WPWS. This is slightly lower than observed in the previous three years, but within the range of population estimates observed between 1993 and 2006. At northern Knight Island, sea otter abundance was relatively stable between 1993 and 2001 but remained at less than half of a minimum estimate of abundance at the time of the spill. In 2007, we estimated 71 sea otters which is an increase of 33 otters above the mean of the prior four surveys. The 2007 estimate may signal the initiation of recovery for sea otters at northern Knight Island. However, confirmation of this trend will require further survey efforts. The sea otters we observed foraging in WPWS in 2007 were successful in obtaining prey on 88% of their dives, and diet was dominated by clams and mussels. This success rate was generally similar to those observed in prior studies in WPWS. However, we observed a reduction in the proportion of clams and an increase in the proportion of mussels in the diet when compared to earlier studies, spanning the prior two decades. The proportion of clams in the diet was approximately half that observed previously. Possible explanations for the change in prey composition include: 1) a seasonal effect resulting from observing foraging earlier in the year than prior studies, 2) an increase in the availability or profitability of mussels due to increasing abundance or energetic content, or 3) a reduction in the previously more common clam prey. We do not have sufficient data to rigorously test these alternatives, but data from intertidal sampling suggest a possible recent reduction in clam abundance (especially for littleneck clams *Protothaca staminea*) and an increase in mussel abundance.

The results from this study as well as from several other *Exxon Valdez* Trustee Council (Trustee) sponsored studies complement similar monitoring efforts being carried out in Katmai and Kenai

Fjords National Parks for the National Park Service Southwest Alaska Network of Parks. Examination of data collected from WPWS, Katmai, and Kenai Fjords in 2007 suggests possible differences among regions. However, what will be of greater interest in the future will be the extent to which temporal trends within the regions track one another over time. Such comparisons will allow an evaluation of the geographical extent of changes that may occur and will provide some insights as to their causes.

1. Introduction

Most of the resources injured as a result of the *Exxon Valdez* oil spill (EVOS) are associated with the nearshore environment. This is not surprising given that most of spilled oil was deposited in the intertidal zone where a small but significant fraction still remains (Short et al. 2007). The evaluation of injured resources in the nearshore has relied, and will continue to rely, largely on long-term data sets of abundance and other demographic characteristics of nearshore populations. In 2007, the EVOS Trustee Council provided funding for a project to examine two important aspects related to study of the nearshore system impacted by the spill. The objectives of this project were to:

1) Establish an integrated data management system that will ensure the preservation of nearshore monitoring data, allow for more integrated assessments of nearshore recovery, and provide a structure for future data gathered as part of long-term restoration monitoring by developing a database management system for nearshore monitoring data, and
2) Initiate long-term restoration monitoring in the nearshore in WPWS in areas affected by the spill to identify trends in status of the system and inform appropriate resource managers to facilitate remediation of adverse human impacts.

The first objective has been met through the development of a web-based geospatial database and display system termed the "Nearshore Data Portal". This is similar to the "Herring Portal" also developed for the Trustees. Currently, the database contains geospatial bibliographic and metadata information for nearshore resources in the Gulf of Alaska (presented in Appendix A, Bodkin and Dean 2004). An updated version of the Nearshore Portal is currently in review by USGS. Other historical data sets including those pertaining to survival and foraging of sea otters, survival of harlequin ducks, and abundance of intertidal invertebrates and algae are to be added to the Nearshore Portal in the future. The data portal can be accessed through the following URL: <http://www.pwsherringportal.org/USGS_Nearshore/index.cfm>.
The remainder of this report presents data and analyses from the long-term nearshore restoration monitoring program initiated in WPWS in 2007. This program is based largely on the long-term monitoring plan developed for the Trustees (Dean and Bodkin 2006*a*, Figure 1) but is reduced in terms of geographic scope and elements funded under this project number (070750). Within this plan it is recognized that 1) restoration of resources injured by the spill will benefit from contemporary information on the status and trends of those injured resources on a variety of spatial scales within the Gulf, and 2) changes independent of the oil spill are likely to occur, and may result from a number of different agents (e.g., global climate change, shoreline development and associated inputs of pollutants). Further, in order to guide restoration of injured resources it is essential to separate EVOS related effects from other sources of change.

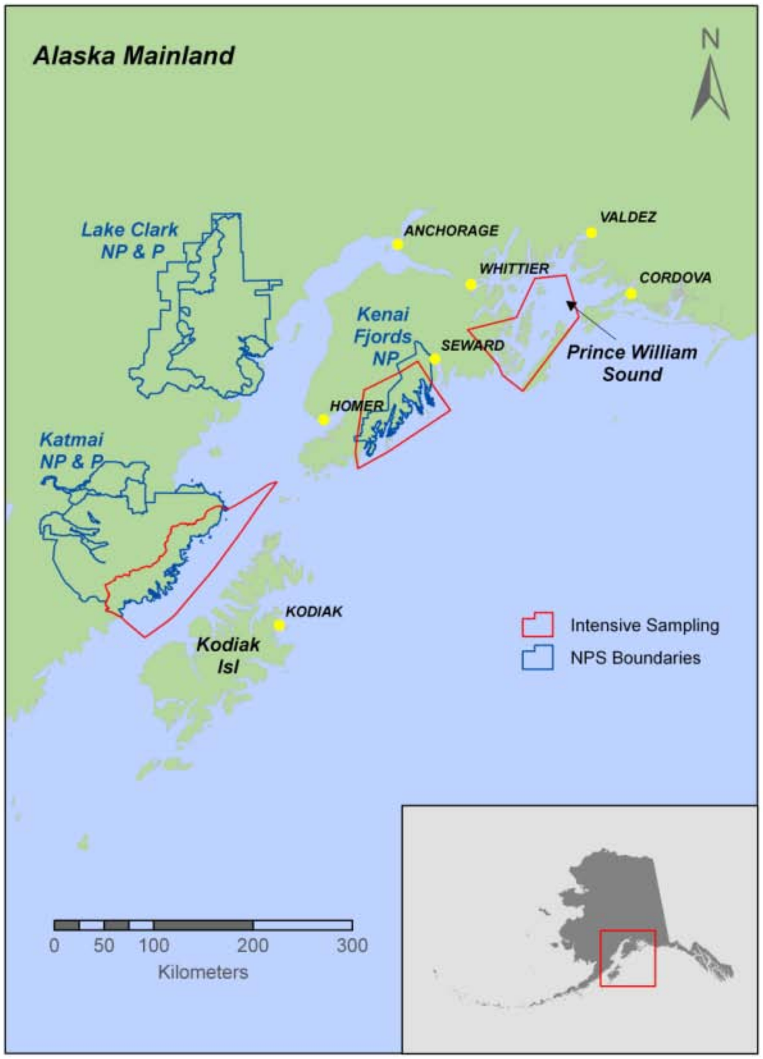

Figure 1. Overview of sampling locations of the nearshore monitoring program. To date, three blocks in three separate regions have been sampled: western Prince William Sound (region = Prince William Sound), Katmai National Park and Preserve (region = Alaska Peninsula) and Kenai Fjords National Park (region = Kenai Peninsula). Boundaries of sampled blocks (intensive blocks) are outlined in red. Park boundaries are outlined in blue.

Implementation of the monitoring program in WPWS largely replicates the SWAN adaptation of the initial program developed for WPWS monitoring. The long-term monitoring program being conducted in the Katmai and Kenai National Parks is part of the National Park Service national long-term "Vital Signs" monitoring program (Figure 1). This effectively expands the nearshore monitoring program allowing for evaluation of trends in PWS in a larger geographic context. Monitoring in the Katmai and Kenai Fjords National Parks focuses on six "vital signs" as indicators of trends in the health of the nearshore system (Dean and Bodkin 2006*b*). These vital signs and the various sub-elements of each included in the monitoring are:

1) Marine Intertidal Communities - Intertidal Invertebrates and Algae
    - Large scale patterns of abundance (based on shorezone mapping)
    - Percent cover or density of dominant sessile intertidal invertebrates (e.g., barnacles, mussels, snails, and limpets) and algae on sheltered rocky shores
    - Abundance and size distribution of clams on gravel and sand-gravel shores
2) Marine Birds
    - Densities of marine birds and mammals along coastal transects
3) Black Oystercatcher
    - Nest density
    - Number of eggs/chicks per nest
    - Species composition and sizes of prey returned to nests
4) Sea Otter
    - Sea otter abundance (based on aerial surveys)
    - Prey species composition, prey number, prey sizes, and foraging success
    - Survival (based on ages at death from recovered carcasses)
5) Kelps and Seagrasses
    - Larger scale trends in the occurrence of canopy forming kelps and eelgrass (based on shorezone mapping)
    - Surveys of cover and size of eelgrass beds (based on boat towed-video surveys)
6) Marine Water Quality
    - Temperature at selected nearshore sampling sites
    - Concentration of contaminants (metals, PCBs, and PAHs) in the tissue of mussels

For PWS monitoring, several of these elements are being conducted by separate projects and are not reported here (Table 1). These include shorezone mapping of intertidal habitats, kelp, and eelgrass; surveys of the abundance of marine birds; and collection of carcasses for estimation of sea otter survival rates. We focus primarily on those elements funded under this project including distribution and abundance of invertebrates and algae on rocky shores; distribution and abundance of clams on gravel/sand shores; nest density, chick and egg production, and prey composition of black oystercatchers; prey composition and prey energy consumption rate for sea otters. We focus on results from the monitoring in WPWS only. Monitoring results for Katmai and Kenai Fjords National Parks were funded under contract to the National Park Service and are reported elsewhere (Bodkin et al. 2007, 2008).

Analyses to detect longer-term trends will require additional sampling. Guidelines for future analyses to detect longer-term trends are given in Dean and Bodkin (2009). Briefly, we will

Table 1. Components of the nearshore monitoring program and their status in Katmai National Park, Kenai National Park, and western Prince William Sound in 2007. For Prince William Sound, we indicate which components are addressed by other EVOS projects. For Katmai and Kenai Fjords, "X" indicates work completed in 2007 as reported in Bodkin et al. (2008).

	Katmai	Kenai	PWS -2007
Marine Intertidal			
Shorezone mapping	X	X	EVOS 070805 - Lindeberg
Sheltered rocky	X	Scheduled 2008	This report
Soft sediment	X	X	This report
Marine Birds			
Density	X	X	EVOS 08075 - Irons
Black Oystercatcher			
Nest density	X	X	This report
Chick & eggs/nest	X	X	This report
Prey composition	X	X	This report
Sea Otter			
Abundance	Scheduled 2008	X	EVOS 080808– Bodkin
Survival	X	None	EVOS 080808 - Bodkin
Forage success	X	X	This report
Kelp and Eelgrass			
Shorezone mapping	X	X	EVOS 070805 – Lindeberg
Bed cover and size	X (Methods development)	None	None [1]
Marine Water Quality			
Temperature	X	X	None [2]
PAH contaminants	X	X	None [2] (but historical data available)
Other contaminants	X	X	None [2]

[1] Eelgrass mapping not conducted in PWS because methods were still in the development phase
[2] Not conducted in PWS due to uncertainty for long-term funding and our ability to retrieve instruments.

examine trends using linear, log-linear, or segmented regression models. Several hypotheses (models) will be selected a priori that might provide reasonable explanations of trends in the observed data, and we will use an information-theoretic criterion to rank these models based on their relative support and select the best-fitting model to generate our trend estimate (Burnham and Anderson 2002, 2004). Each model will contain a different combination of covariates thought to be most influential for predicting trend or other factors of interest. Where appropriate, models examined will also include terms that might account for potential biases in the data, such as the years of observer experience or observer identity for a given sea otter aerial survey. Terms that might further explain trends over time (e.g., mean annual temperature, location relative to a particular local disturbance, or time period relative to a particular disturbance event) will also be included where appropriate. Terms such as observer identity that are likely to lack independence in influencing dependent variables in successive years be will be treated as random effects. The modeling will be performed using the mixed function procedure in SAS (SAS Institute Inc, 2002-2003, Cary, NC, USA) or comparable software.

We will gain some insights as to possible causes for change using two primary analytical approaches. First, the spatial and temporal patterns of change will suggest possible causes. For example, a change that occurs over decades and is roughly of equal magnitude at all locations (a time effect of ecological importance, but no location or time by location effect) would suggest that the change was due to some large-scale event (e.g., global climate change or pacific decadal oscillation), rather than a more localized one (e.g., a release of a toxicant from boat harbors). Second, inclusion of explanatory variables in models might also suggest cause. For example, if inclusion of the concentration of contaminants in mussels helps to provide a better fit of temporal trends in black oyster catcher abundance, then this might suggest that a decline in oyster catchers was related to an increase in contaminants. However, we will not be able to definitively assign causes for changes based solely on the data generated in the proposed monitoring plans. Assigning cause will rely heavily on further process studies that are designed to test hypotheses regarding specific cause and effect relationships.

Results presented here represent an initial effort that is potentially part of a longer-term program. As such, the data provided are clearly insufficient to establish longer-term trends and we focus primarily on descriptive analyses. We also provide results and analyses that could be used to help assess potential lingering effects of the spill. We report results of 2007 sea otter abundance surveys funded under Project 070808 and to be reported in more detail in the report for that project. Furthermore, we report data to help assess potential impacts and recovery in intertidal communities. While not part of our original proposal, we were able to sample several intertidal sites that were oiled following the 1989 spill. Several rocky intertidal sites sampled were the same as those sampled by Highsmith et al. (1994). Gravel/sand sites sampled were ones where subsurface oil remained in 2004 (Short et al. 2007 and M. Lindeberg, NOAA, personal communication). We contrast results from 2007 sampling at oiled and unoiled intertidal sites (in both rocky and soft sediment habitats) and compare these to results of oiled/unoiled comparisons reported previously. The sampling of each of the previously oiled intertidal sites in 2007 was opportunistic and clearly not rigorous enough to provide definitive answers regarding the status of injured resources. However, we report data obtained as it provides some additional information on the current status of these communities that may be helpful in assessing recovery and potential impacts of possible future efforts to remove lingering oil from the intertidal.

In this report we present methods, results, and discussion independently for each of the four principal elements, or “vital signs” of the monitoring we conducted. These include in section 2, Intertidal Invertebrates and Algae on Sheltered Rocky Shores, section 3, Intertidal Invertebrates on Soft Sediment Beaches, section 4, Black Oystercatchers, and section 5, Sea Otters. In section 6 we provide a general discussion of the project and preliminary interpretations.

2. Intertidal Invertebrates and Algae on Sheltered Rocky Shores

Introduction

Intertidal invertebrate and algal communities provide an important source of primary production, are an important conduit of energy, nutrients, and pollutants between terrestrial and marine environments, provide resources for subsistence, sport, and commercial harvests, and are important for recreational activities such as wildlife viewing and fishing. The intertidal is particularly susceptible to human disturbance including oil spills, trampling by recreational visitors, harvesting activities, pollutants from terrestrial, airborne and marine sources, and shoreline development. Changes in the structure of the intertidal community serve as valuable indicators of disturbance, both natural (e.g., Dayton 1971, Sousa 1979) and human induced (e.g., Barry et al. 1995, Jamieson et al. 1998, Keough and Quinn 1998, Sagarin et al. 1999, Shiel and Taylor 1999, Peterson 2001, Peterson et al. 2003).

In this section, we describe results of intertidal sampling conducted on sheltered rocky shores in 2007 in PWS (Section 3 contains results for soft sediment sampling). We report on data collected at sites selected as locations for long-term monitoring. In addition, we report on results from comparisons of intertidal communities at oiled and unoiled sites sampled in 2007 in order to help evaluate long-term oil spill impacts and the status of recovery in rocky intertidal communities.

Methods

Sampling was conducted at eight sites in sheltered rocky habitat in WPWS (Figure 2). Five of these sites were selected using a generalized random-tessellation stratified (GRTS) sampling protocol (Stevens and Olsen 2004) designed to provide a random, spatially-balanced design. We selected sites using this method in order to be able to make inferences to the WPWS region yet maintain more spatial balance that afforded by a strictly random selection. Sheltered rocky shorelines were identified using the Environmental Sensitivity Index database (Research Planning Institute 1983) and selected sites chosen using the S-Draw GRTS site selection software (McDonald 2005). This same procedure was used to identify sites selected for monitoring in Katmai and Kenai Fjords National Parks. Four of the five GRTS sites were on shorelines that were not oiled following the spill. The other GRTS site was oiled and was on the same shoreline sampled as part of previous assessments of injury to intertidal communities (Herring Bay, Site 1522 sampled by Highsmith et al. 1994). In order to facilitate oiled vs. unoiled comparisons, we also sampled at three additional oiled sites previously sampled by Highsmith et al. (1994) in Herring Bay, Disk Island, and Northwest Bay.

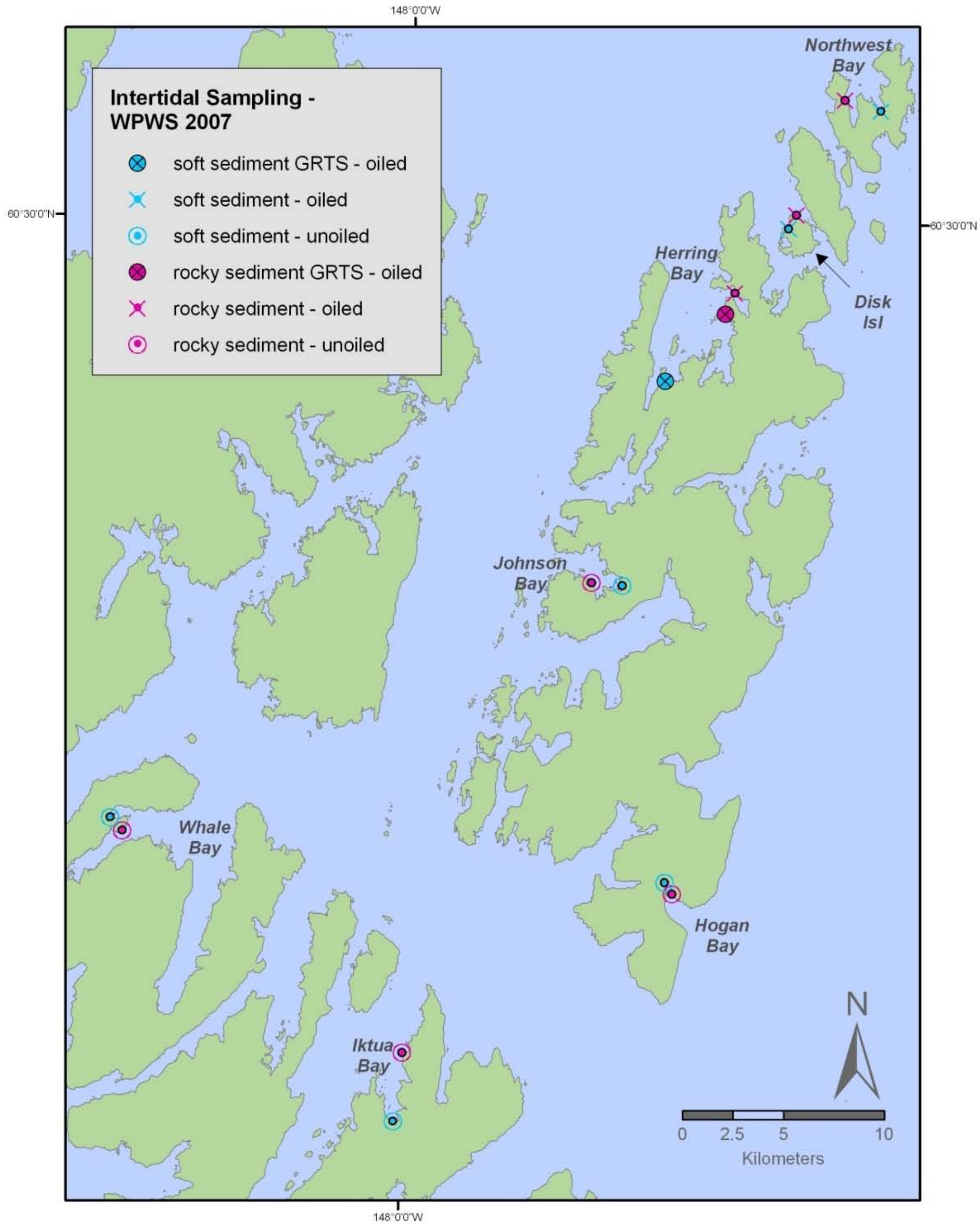

Figure 2. Locations of sheltered rocky and soft sediment intertidal monitoring sites sampled in western Prince William Sound in 2007. Sites selected using the GRTS sampling procedure are indicated with a circle with a dot or an X in the center. An X in the center indicates that it was oiled. Previously established (selected) sites are indicated by a circled X. Soft sediment sites are in blue and rocky sediment sites are in red.

Permanent markers were installed at the 0.5-m and 1.5-m tidal elevations at each site. Detailed descriptions of the methods used to sample intertidal algae and invertebrates are available in (Dean and Bodkin 2006*a*). The following is a general description of the methods employed. Fifty meter tapes were stretched from the permanent markers along the shoreline parallel to the water's edge at the 0.5-m (lower intertidal) and 1.5-m (mid-intertidal) above mean lower low water (MLLW) heights. Sea stars and sea urchins were counted within a 4-m wide band that extended 4-m upslope from MLLW along the 50-m transect at each site. Only those individuals that were visible without moving rocks or overlying algae were counted. The percent cover of substrate types, percent cover of algae, and percent cover of sessile invertebrates were determined within 12 evenly spaced 0.25-m^2 quadrats placed along the 2 tapes. Quadrats were placed at a random start point and at equally spaced intervals thereafter. Counts of small motile invertebrates were made within 0.25-m^2 quadrats. Intermediate size motile invertebrates (primarily larger snails and limpets) were counted within 1.0-m^2 quadrats. Percent cover was estimated by determining the percentage occurrence under 49 systematically placed points within each quadrat.

The results with respect to long-term monitoring are largely descriptive. To evaluate possible oil spill impacts and the status of recovery in rocky intertidal communities, we examined possible differences between oiled and reference sites. We relied primarily on comparisons of abundance estimates for dominant taxa that had been reported by Highsmith et al. (1994) and Dean et al. (2000). These included the abundance of bare substrate, barnacles, *Mytilus trossulus*, *Fucus gardneri*, perennial algae other than *Fucus*, ephemeral algae, Lottiidae, *Littorina* spp., *Nucella* spp. Perennial algae included *Odonthalia flocossa* and *Neorhodomela* spp. while ephemeral algae included *Pilayella* sp., *Cladophora* spp., and green algae of the family Ulvacae (*Ulva* sp. *Enteromorpha* spp., and *Monostroma* spp.). We tested the hypothesis of no difference between oiled and reference sites using randomization tests (Fisher 1935).

Results

The number of algal and sessile invertebrate species observed at each of the two tidal elevations at each site ranged from 11 to 29 (Table 2). At the lower elevation, dominant species (those with an average percent cover of 10% or more) included *Fucus gardneri*, *Mytilus trossulus*, the green algae *Cladophora* and *Rhizoclonium* spp., and the red alga *Pterosiphonia bipinnata*) (Appendix A). In the mid intertidal, *Fucus gardneri*, *Mytilus trossulus*, the green algae *Cladophora* and *Rhizoclonium* spp., and various barnacle species dominated. The number of small motile species identified at the two tidal elevations at each site ranged from 3 to 9 (Table 2). The most abundant small motile species at both elevations were littorine snails (*Littorina scutulata* and *Littorina sitkana*) and small limpets (Lottiidae < 10 mm) (Appendix B). The snail *Nucella lamellosa* and the sea stars *Dermasterias imbricata* and *Pycnopodia helianthoides* were the most commonly encountered larger invertebrate predators (Appendices C and D).

Neither number of species nor abundances (either percent cover or density) for dominant taxa or groups of taxa differed significantly between oiled and reference sites in 2007 (Tables 2 and 4 and Appendix E). These results are similar to those reported for sites sampled as part of the CHIA program and the NOAA program (reported in Dean et al. 2000) that found no differences between oiled and reference sites for any of these taxa or groups after 1994. Similarly, there was no significance difference between oiled and reference sites for the mean size of limpets, *Tectura persona* (Table 5).

Discussion

The intertidal communities on sheltered rocky shores in WPWS are typical of those found elsewhere in the Gulf of Alaska (Nybakken 1969, Haven 1971, Feder and Kaiser 1980, O'Clair and Zimmerman 1986, Highsmith et al. 1994, 1996) and are characterized by *Fucus* and various red, green, and brown algae in the lower intertidal and by barnacles and *Fucus* and *Mytilus* in the mid-intertidal zone. There was considerable variation in the species composition and relative abundance of species between sites. This is not surprising given that site locations were randomly selected and represent differing habitats with respect to exposure, slope, substrate type, and other physical characteristics.

The species composition and abundances observed at the long-term monitoring sites (GRTS sites) established in 2007 were similar to those observed at unoiled reference sites sampled as part of the Coastal Habitat Injury Assessment Program (CHIA) by Highsmith et al. (1994) and M. Lindeberg (NOAA) and S. Saupe (Cook Inlet Regional Citizen's Advisory Council) (reported in Dean et al. 2000). The mean percent cover by dominant taxa or groups of taxa at our GRTS sites in 2007 was generally within the range of yearly means observed at reference CHIA sites between 1992 and 1996 (Table 3), with the exception of *Mytilus* and *Fucus*.

Comparisons between our 2007 results vs. those for studies conducted in the mid 1990s suggest a possible increase in the abundance of *Mytilus trossulus* (especially in the lower intertidal) and *Fucus gardneri* (in the mid intertidal). We did not test to determine if mean abundances differed statistically because methods used in the two studies differed with respect to sampling sites and sampling protocols. Therefore, we cannot be certain that the higher abundances of *Fucus* and *Mytilus* we observed represent a temporal trend. Further sampling at our same sites over time is required to determine if there are significant trends. However, observations of a possible increase in the prevalence of *Mytilus* in the diet of sea otters between the 1990s and 2007 (see Section 5 below) support the hypothesis of an increase in *Mytilus* abundance over this time period.

Similar to previous work in nearshore habitats in PWS that indicated diminishment of spill effects (Houghton et al. 1996, Dean et al. 1996, Dean et al. 1998) our results do not provide evidence of long term injury to intertidal communities from the spill. However, our sample sizes were small and power to detect differences was low. The lack of evidence for a continuing effect of the spill is in contrast to other nearshore studies (Jewett et al. 1999, Fukuyama et al. 2000, Peterson et al. 2003, Lees et al. 2007) and studies of lingering subsurface oil (Short et al. 2007) that suggest that impacts persisted through 2006 with respect to nearshore habitats or attributes.

Table 2. Mean number of taxa of sessile invertebrates, algae, and small motile invertebrates observed in the lower (0.5 m above MLLW) and mid (1.5 m above MLLW) intertidal in western Prince William Sound in 2007. Means are given for three groupings of sites: all randomly selected (GRTS) sites, sites that were oiled in 1989, and reference sites that were not oiled. Probabilities that oiled and reference sites (randomization test) did not differ (alpha = 0.05) are also given.

Site Name	Site Group	Sessile Inverts and Algae		Small Motile Inverts	
		Lower	Mid	Lower	Mid
Northwest Bay	Oiled	16	17	3	5
Disk Island	Oiled	23	26	8	7
Herring Bay 598	Oiled	29	11	6	4
Herring Bay 1522	Oiled/GRTS	29	25	9	6
Hogan Bay	Reference /GRTS	23	21	7	5
Iktua Bay	Reference /GRTS	25	24	9	7
Whale Bay	Reference /GRTS	22	16	7	6
Johnson Bay	Reference /GRTS	18	17	7	8
Oiled sites	Mean	24.3	19.8	6.5	5.5
	N	4	4	4	4
	SE	6.2	7.1	2.6	1.3
Reference sites	Mean	22.0	19.8	7.5	6.5
	N	4	4	4	4
	SE	2.9	3.4	1.0	1.3
GRTS sites	Mean	23.4	20.8	7.8	6.4
	N	5	5	5	5
	SE	4.0	3.8	1.1	1.1
Oiled vs. Ref.	P(T<=t)	0.45	1.00	0.70	0.46

Table 3. Percent cover of dominant taxa or groups of taxa at lower (0.5 m above MLLW) and mid (1.5 m above MLLW) intertidal monitoring sites in western Prince William Sound in 1992-1995 and. 2007. The 1992-1995 data are ranges of yearly means from the Coastal Habitat Injury Assessment Program (CHIA) reference sites reported by Dean et al. (2000) and the 2007 data are means from five randomly selected (GRTS) sites from this study.

Taxa or group	Lower		Mid	
	1992-1995	2007	1992-1995	2007
	CHIA	GRTS	CHIA	GRTS
Fucus gardneri	28-50	32	28-40	59
Ephemeral algae	5-30	7	0-10	4
Perennial algae	4-8	3	2-5	4
Barnacles	1-13	3	7-27	19
Mytilus trossulus	0-3	9	2-7	8

Table 4. Mean percent cover of dominant taxa at the lower (a, 0.5 m above MLLW) and mid (b, 1.5 m above MLLW) intertidal monitoring sites in western Prince William Sound in 2007. Means are given for three groupings of sites: all randomly selected (GRTS) sites, sites that were oiled in 1989, and reference sites that were not oiled. Probabilities that oiled and reference sites (randomization test) did not differ (alpha = 0.05) are also given. Appendix E gives standard deviations as indicators of variance between quadrats at each site.

a, 0.5 m above MLLW

Site Name	Site Group	Bare Substrate	Barnacles	*Mytilus trossulus*	*Fucus gardneri*	Perennial Algae	Ephemeral Algae	*Lottiidae*	*Littorina* spp.
		Mean percent cover						number per 0.25m^2	
Northwest Bay	Oiled	6.80	11.10	5.20	18.40	0.30	0.00	7.00	0.00
Disk Island	Oiled	4.30	0.00	17.30	13.40	5.80	4.60	6.25	0.08
Herring Bay 598	Oiled	2.70	0.00	7.00	87.20	3.60	4.50	5.58	4.67
Herring Bay 1522	Oiled /GRTS	3.40	1.90	18.70	57.70	2.70	1.80	2.33	1.00
Hogan Bay	Reference /GRTS	7.50	0.20	4.80	18.70	5.70	24.40	10.50	5.58
Iktua Bay	Reference /GRTS	2.90	8.20	0.00	36.90	3.80	5.70	3.33	0.25
Whale Bay	Reference /GRTS	17.00	1.70	20.80	18.40	1.60	0.20	48.17	34.67
Johnson Bay	Reference /GRTS	15.30	1.00	0.90	31.00	0.20	1.30	17.67	18.75
Oiled sites	Mean	4.30	3.25	12.05	44.18	3.10	2.73	5.29	1.44
	N	4	4	4	4	4	4	4	4
	Std	1.8	5.3	6.9	34.9	2.3	2.23	2.1	2.2
Reference sites	Mean	10.68	2.78	6.63	26.25	2.83	7.90	19.92	14.81
	N	4	4	4	4	4	4	4	4
	Std	6.6	3.7	9.7	9.2	2.4	11.3	19.7	15.4
GRTS sites	Mean	9.22	2.60	9.04	32.54	2.80	6.68	16.40	12.05
	n	5	5	5	5	5	5	5	5
	Std	6.6	3.2	10.0	16.2	2.1	10.1	18.8	14.7
Oiled vs. Ref.	P(T<=t)	0.15	0.78	0.31	0.44	0.83	0.57	0.13	0.09

b, 1.5 m above MLLW

Site Name	Site Group	Bare Substrate	Barnacles	*Mytilus trossulus*	*Fucus gardneri*	Perennial Algae	Ephemeral Algae	*Lottiidae*	*Littorina* spp.
		Mean percent cover						number per 0.25m^2	
Northwest Bay	Oiled	12.60	18.70	0.00	28.20	0.50	1.00	46.83	0.67
Disk Island	Oiled	6.60	14.10	7.00	40.30	10.10	3.40	48.75	7.50
Herring Bay 598	Oiled	25.20	27.20	6.10	33.80	0.00	0.10	49.83	175.33
Herring Bay 1522	Oiled /GRTS	7.70	10.90	8.60	70.60	2.50	2.80	21.58	8.17
Hogan Bay	Reference /GRTS	12.40	14.50	1.60	54.40	3.20	16.40	40.42	22.5
Iktua Bay	Reference /GRTS	8.50	23.60	0.10	80.10	1.30	1.40	62.33	0.08
Whale Bay	Reference /GRTS	19.60	14.50	26.80	41.00	1.80	0.30	32.67	57.33
Johnson Bay	Reference /GRTS	19.40	31.00	3.70	51.00	0.00	1.10	19.25	135.08
Oiled sites	Mean	13.03	17.73	5.43	43.23	3.28	1.83	41.75	47.17
	N	4	4	4	4	4	4	4	4
	Std	8.5	7.1	3.8	18.9	4.7	1.5	13.5	83.5
Reference sites	Mean	14.98	20.90	8.05	56.63	1.58	4.80	38.67	53.75
	N	4	4	4	4	4	4	4	4
	Std	5.5	8.0	12.6	16.7	1.3	7.8	18.0	59.1
GRTS sites	Mean	13.52	18.90	8.16	59.42	1.76	4.40	35.25	44.63
	n	5	5	5	5	5	5	5	5
	Std	5.7	8.2	10.9	15.7	1.2	6.8	17.4	55.1
Oiled vs. Ref.	P(T<=t)	0.72	0.60	0.91	0.32	0.78	0.76	0.79	0.84

Table 5. Mean shell length (mm) of *Tectura persona* measured in western Prince William Sound in 2007. Limpet sizes were sampled for three groupings of sites: all randomly selected (GRTS) sites, sites that were oiled in 1989, and reference sites that were not oiled. Probabilities that oiled and reference sites (randomization test) did not differ (alpha = 0.05) are also given. Size frequency distributions for each site are given in Appendix F.

Site Name	Site Group	Mean size (mm)
Northwest Bay	Oiled	10.66
Disk Island	Oiled	13.27
Herring Bay - 598	Oiled/GRTS	10.63
Herring Bay -1522	Oiled	10.79
Hogan Bay	Reference/GRTS	12.38
Iktua Bay	Reference/GRTS	16.93
Whale Bay	Reference/GRTS	12.43
Johnson Bay	Reference/GRTS	13.43
Oiled sites	Mean	11.34
	N	4
	Std	1.29
Reference sites	Mean	13.79
	N	4
	Std	2.15
GRTS sites	Mean	13.19
	N	5
	Std	2.29
Oiled vs. Ref.	P(T<=t)	0.08

3. Intertidal Invertebrates on Soft Sediment Beaches

Introduction

Intertidal invertebrates on soft sediment (gravel and mixed sand-gravel) beaches are important nearshore resources in the Gulf of Alaska (GOA). Soft sediment beaches comprise approximately 25% of the intertidal zone in the GOA (Ford et al. 1996), and are a rich source of invertebrate production that includes clams, snails, polychaete worms, and small crustaceans. These in turn are a primary food source for a variety of vertebrate and invertebrate predators such as sea stars, sea otters and subsistence users. Intertidal soft-sediment communities are particularly vulnerable to both natural and human-induced disturbance. In the GOA, soft sediment communities have been particularly vulnerable to earthquakes (Baxter 1971), hydrocarbon contamination from the spill (Houghton et al. 1997), and changes in sediment composition as a result of spill related clean-up activity (Lees and Driskell 2007).

The soft sediment intertidal community in the GOA is comprised primarily of infaunal species that live under the surface, but in the upper several centimeters of sediments. Species of particular importance are the larger clams (*Protothaca staminea, Saxidomus gigantea, Clinocardium spp.,* and *Macoma spp*.) that are often the dominant organisms in terms of biomass and are critical prey for larger predators including sea otters (Calkins 1978, Doroff and Bodkin 1994, Dean et al. 2002). In addition, *Protothaca* are harvested by subsistence users and are of commercial importance in an expanding mariculture industry.

In this section, we describe results of intertidal sampling conducted on soft sediment beaches in 2007 in WPWS. We report on data collected at sites selected for long-term monitoring. In addition, we report on results from comparisons of intertidal communities at oiled and unoiled sites sampled in 2007 in order to evaluate long-term oil spill impacts and the status of recovery in soft sediment communities.

Methods

A total of seven soft sediment beaches were sampled to estimate the abundance and size distribution of infaunal clams (Figure 2). Five of these sites were identified based on their proximity to the GRTS rocky intertidal sites and the presence of bivalve shell litter. Two additional soft sediment sites that had oil in subsurface sediments in 2002, based on data of Short et al. (2007) and M. Lindeberg (NOAA, personal communication) were also sampled to facilitate oiled vs. unoiled comparisons.

At each site, a 50-m transect tape was positioned horizontally along the beach at 0.5 m above MLLW tide level. A random starting point was selected and 12 0.25-m^2 quadrats placed roughly 4.2 m apart were excavated to a depth of 25 cm. Sediments were sieved on site through a 10-mm mesh screen and all clams were identified to the lowest possible taxa, counted, and measured to the nearest millimeter using dial calipers. Sediments were returned to the quadrat during the sieving process.

At each site, we report the abundance (number of individuals per unit area) of bivalve species. We tested the hypothesis of no difference in density of dominant clam species between oiled and reference sites using randomization tests. Too few bivalves were recovered to obtain meaningful estimates of size distributions.

Results

The bivalve assemblage at soft sediment sites in WPWS consisted almost entirely of five taxa: *Protothaca staminea, Saxidomus gigantea*, *Mya spp.*, *Macoma* spp., and *Hiatella arctica*. Densities of all species were generally low, with the exception of *Macoma* spp. in Whale Bay, and *Saxidomus gigantea* at the Disk Island site (Table 6). Abundances for dominant taxa did not differ significantly between oiled and reference sites in 2007 (Table 6).

Discussion

At our randomly selected sites, we observed a mean density of 0.65 *Protothaca* per 0.25 m^2. This is substantially lower than the mean of over 30 *Protothaca* per 0.25 m^2 (range of approximately 27 to 35) observed at unoiled sites in similar habitats between 1991 and 1996 by Houghton et al. (1997). The relatively low densities of clams, and especially the littleneck clam, *Protothaca staminea,* in our sampling may reflect a wide-spread trend of declining littleneck clam abundance in WPWS. Sampling conducted by G. Shigenaka et al. in 2007 (NOAA, unpublished data) indicated the same trend. The declining clam abundance may also be reflected in the lower proportion of clams in the diet of sea otters in 2007 compared to previous sampling (see section 4 below).

The lack of differences in mean density of clams between oiled and reference sites we observed may be a reflection of low densities, high inter-site variability, and therefore low power to detect differences. Other more comprehensive sampling by Lees et al. (2007) suggests that there may indeed be lower densities at oiled sites that were treated using high pressure washes compared to unoiled reference sites.

Table 6. Mean densities (number per 0.25 m^2) and standard deviation (in parentheses) of bivalves collected from soft sediment monitoring sites in western Prince William Sound in 2007. Means are given for three groupings of sites: all randomly selected (GRTS) sites, sites that were oiled in 1989, and reference sites that were not oiled. Probabilities that oiled and reference sites (randomization tests) did not differ (alpha = 0.05) are also given.

Site Name	**Site Group**	***Protothaca staminea***	***Saxidomus gigantea***	***Mya spp.***	***Macoma* spp.**	***Hiatella arctica***	**All clams**
Disk Island	Oiled	0.17 (0.58)	4.67 (4.87)	0.00 (--)	0.25 (0.87)	0.08 (0.29)	5.17 (4.90)
Northwest Bay	Oiled	0.09 (0.30)	0.00 (--)	0.00 (--)	0.00 (--)	0.18 (0.40)	0.27 (0.47)
Herring Bay -Kn126	Oiled /GRTS	1.17 (1.95)	0.17 (0.39)	0.00 (--)	0.00 (--)	0.92 (2.87)	2.25 (3.55)
Hogan Bay	Reference /GRTS	0.08 (0.29)	0.17 (0.39)	0.25 (0.62)	0.00 (0.00)	0.92 (1.78)	1.42 (1.93)
Iktua Bay	Reference /GRTS	0.42 (0.79)	0.17 (0.39)	0.83 (1.19)	2.92 (6.72)	1.50 (1.68)	5.92 (6.89)
Whale Bay	Reference /GRTS	1.50 (1.88)	0.00 (--)	0.00 (--)	10.17 (10.82)	1.50 (2.65)	13.17 (13.38)
Johnson Bay	Reference /GRTS	0.08 (0.29)	0.00 (--)	2.00 (3.22)	0.00 (--)	0.00 (--)	2.08 (3.18)
Oiled	Mean St dev N	0.48 (0.60) 3	1.61 (2.65) 3	0.00 (--) 3	0.08 (0.14) 3	0.39 (0.46) 3	2.15 (2.64) 3
Reference	Mean St dev N	0.52 (0.67) 4	0.09 (0.10) 4	0.77 (1.86) 4	3.27 (4.80) 4	0.98 (0.71) 4	5.65 (5.39) 4
GRTS sites	Mean St dev N	0.65 (0.65) 5	0.10 (0.09) 5	0.62 (1.69) 5	2.62 (4.41) 5	0.97 (0.61) 5	5.65 (5.11) 5
	P(T<=t) two-tail	1.00	0.34	0.22	0.42	0.29	0.39

4. Black Oystercatchers

Introduction

The black oystercatcher (*Haematopus bachmani*) is a common and conspicuous member of the rocky and gravel intertidal marine communities of eastern Pacific shorelines and is completely dependent on nearshore marine habitats for all critical life history components including foraging, breeding, chick-rearing, and resting (Andres and Falxa 1995). During the breeding season, pairs establish and defend both nest and forage areas, and these territories and nest sites can persist over many years (Groves 1984, Hazlitt and Butler 2001) with individual life expectancy exceeding 15 years (Andres and Falxa 1995). The diet consists primarily of mussels (*Mytilus* spp.) and a variety of limpets (*Lottia*, *Tectura*, *Acmea*, and *Colisella* sp.) (Andres and Falxa 1995), both of which are ecologically and culturally important constituents of the intertidal community.

As a "keystone" species (Power et al. 1996), the black oystercatcher has a large influence on the structure of intertidal communities that is disproportionate to its abundance. As a consequence of reduced limpet densities and the diminished grazing intensity that results, algal populations respond through increased production and survival, resulting in enhanced algal populations (Marsh 1986, Meese 1990, Wootton 1992, Lindberg et al. 1998). Additionally, the oystercatcher's diet consists of a large fraction of mussels, an important filter feeding bivalve that provides energy to a wide array of invertebrate, avian, and mammalian predators in the nearshore (Knox 2000, Menge and Branch 2001). Because the oystercatcher brings limpets, mussels and other prey back to its nest to provision chicks (Webster 1941, Hartwick 1976, Frank 1982, Lindberg et al. 1987), collections of those shell remains at nests provides an opportunity to obtain an independent sample of the species composition and size distribution of common and important nearshore invertebrate prey species.

Because of the critical nature of intertidal habitats for both breeding and foraging, black oystercatchers are particularly sensitive indicators of disturbances in the nearshore (Lindberg et al. 1998). Specifically, black oystercatchers nest exclusively just above high tide levels where eggs are laid in exposed nests consisting of depressions in pebbles, sand, gravel, and shell materials. During the 26-32 d incubation phase of reproduction, eggs are susceptible to predation by other birds (primarily C*orvids*; Lentfer and Meier 1995) and mammals (Vermeer et al. 1992), as well as human disturbance and trampling. Similar disturbance effects occur during the chick rearing stage, which lasts approximately 38 d (Andres and Falxa 1995). Thus, for several months during May-August, typically when human presence in nearshore habitats in Alaska is highest, black oystercatchers are actively incubating or caring for young in a habitat that affords little protection from disturbances. Chronic disturbance from human activities poses a significant threat to breeding black oystercatchers, either preventing nesting altogether, causing nest abandonment after eggs have been laid (Andres 1998), or through direct mortality of eggs or chicks. Monitoring of black oystercatcher abundance, breeding territory density and occupancy, and prey provides a potentially powerful tool to identify the magnitude and causes of eventual change in Gulf of Alaska nearshore habitats and communities, particularly in response to the anticipated increased use and influence of those habitats by humans.

Methods

Black oystercatcher nest site density, nest occupancy, and prey data were collected along 5 20-km transects each centered on a rocky intertidal invertebrate and algal site in WPWS (Figure 3). Nest sites were located and sampled by three observers traveling slowly along prescribed transects in small skiffs at speeds of approximately 5 knots. Observers searched the shorelines and intertidal zone for black oystercatchers with the aid of high resolution binoculars. Upon detection of one or more oystercatchers, the observers monitored the behavior of the birds to determine if a nest was likely present, and its approximate location. Potential nest sites were then searched for on foot taking care not to damage eggs or chicks.

The status of each nest site was categorized as either active (eggs or chicks present or adult behavior indicative of the presence of chicks) or failed (evidence of egg shell or presence of adults, but no chicks). At each nest site the number adults, eggs, and chicks were recorded. We used the number of eggs plus chicks per nest as an index of productivity. Logistical constraints prevent us from making multiple visits to nest sites in each year. The inability to make multiple visits and the asynchronous nature of hatching at various nests sites precluded us from measuring true productivity (number of chicks produced per nest site). At active nest sites, observers searched for and collected any shell prey remains indicative of adult birds provisioning their chicks. Each prey item was identified to species and measured to the nearest mm.

Results

A total of ten black oystercatcher nests were observed, with a mean density of 0.09 nests per km of shoreline surveyed (Tables 7 and 8). A pair of adult oystercatchers was present at each nest, except at one nest site in Herring Bay where 4 adults were observed. Of the 10 nests found, 8 were active and 2 had failed. There was an average of 1.4 eggs and 0.6 chicks per active nest site.

Prey remains were recovered from four active nest sites and from one failed nest where the remains of an egg were present. We collected and measured 490 shell remains from five nests representing six prey species. The species composition of prey items returned to provision chicks varied among nests (Figure 4, Appendix G), but limpets and mussels were found at all nest sites where prey were recovered. Limpets (*Lottia* sp. and *Tectura* sp.) comprised 70%, and mussels (*Mytilus trossulus*) 28% of prey items recovered (Figure 4). The other remaining prey species was an unidentified chiton which comprised about 2% of the prey recovered. Sizes of prey varied by species (Figure 5).

Discussion

The nest site density and productivity of nests observed in 2007 were similar to that observed in previous studies in Prince William Sound (Andres and Falxa 1995, Andres 1997). Our estimate of nest site density in WPWS in 2007 (0.09 per km) was identical to that observed in 1992 and 1993 (Andres and Falxa 1995). Nest productivity in 2007 was

2.03 eggs + chicks per nest, somewhat higher than found by Andres (1997) at Green Island shortly after the spill in 1989 (1.5 eggs per nest in surveys conducted earlier in the year before eggs hatched), but similar to the 2.4 eggs per nest observed by Andres (1997) at Green Island in 1991.

Limpets (*Tectura and Lottia* spp.*)* and mussels (*Mytilus trossulus*) were the dominant prey item represented in the shell remains. In WPWS in 2007, mussels comprised 28% of the prey remains collected. This is lower than the 42% estimate for the proportion of mussels in prey fed to chicks in 1992 and 1993 (Andres 1999). However, methods for obtaining prey composition data differed between studies and may account for the discrepancies.

Strong dietary diversity was evident at the level of the individual nest (Appendix G) and may represent prey availability or dietary specialization. *Tectura persona* brought to nests by oystercatchers were near the largest sizes measured under the intertidal invertebrate sampling (Table 5) suggesting size selective predation by the adult oystercatchers.

Table 7. Black oystercatcher nest site numbers, nest status, number of adults, number of eggs, number of chicks and whether prey remains were collected per nest in western Prince William in 2007. A = active nest; F= failed nest.

Site	Nest site #	Status	# Adults	# Eggs	# Chicks	Prey collected
Hogan Bay	No nests found.	.	.	.	.	-
Iktua Bay	1-07	A	2	3	0	N
Iktua Bay	2-07	A	2	1	1	N
Iktua Bay	3-07	A	2	0	0	Y
Iktua Bay	4-07	A	2	0	2	Y
Whale Bay	1-07	A	2	3	0	N
Johnson Bay	1-07	F	2	0	0	Y
Herring Bay	1-07	A	4	0	2	Y
Herring Bay	2-07	A	2	0	0	Y
Herring Bay	3-07	A	2	1	1	N
Herring Bay	4-07	F	2	0	0	N

Table 8. Black oystercatcher nest site density and numbers of eggs and chicks per active nest in western Prince William Sound in 2007.

Site	Nest density (# per km)	# Eggs	# Eggs per nest	# Chicks	# Chicks per nest	# Eggs + Chicks per nest
Hogan Bay	0	.	.	.	.	.
Iktua Bay	0.2	4	1	3	0.75	1.75
Whale Bay	0.05	3	3	0	0	3
Johnson Bay	0.05	.	.	.	.	.
Herring Bay	0.15	1	0.33	3	1	1.33
Mean	**0.09**		**1.44**		**0.58**	**2.03**
Se	**0.04**		**0.80**		**0.30**	**0.50**

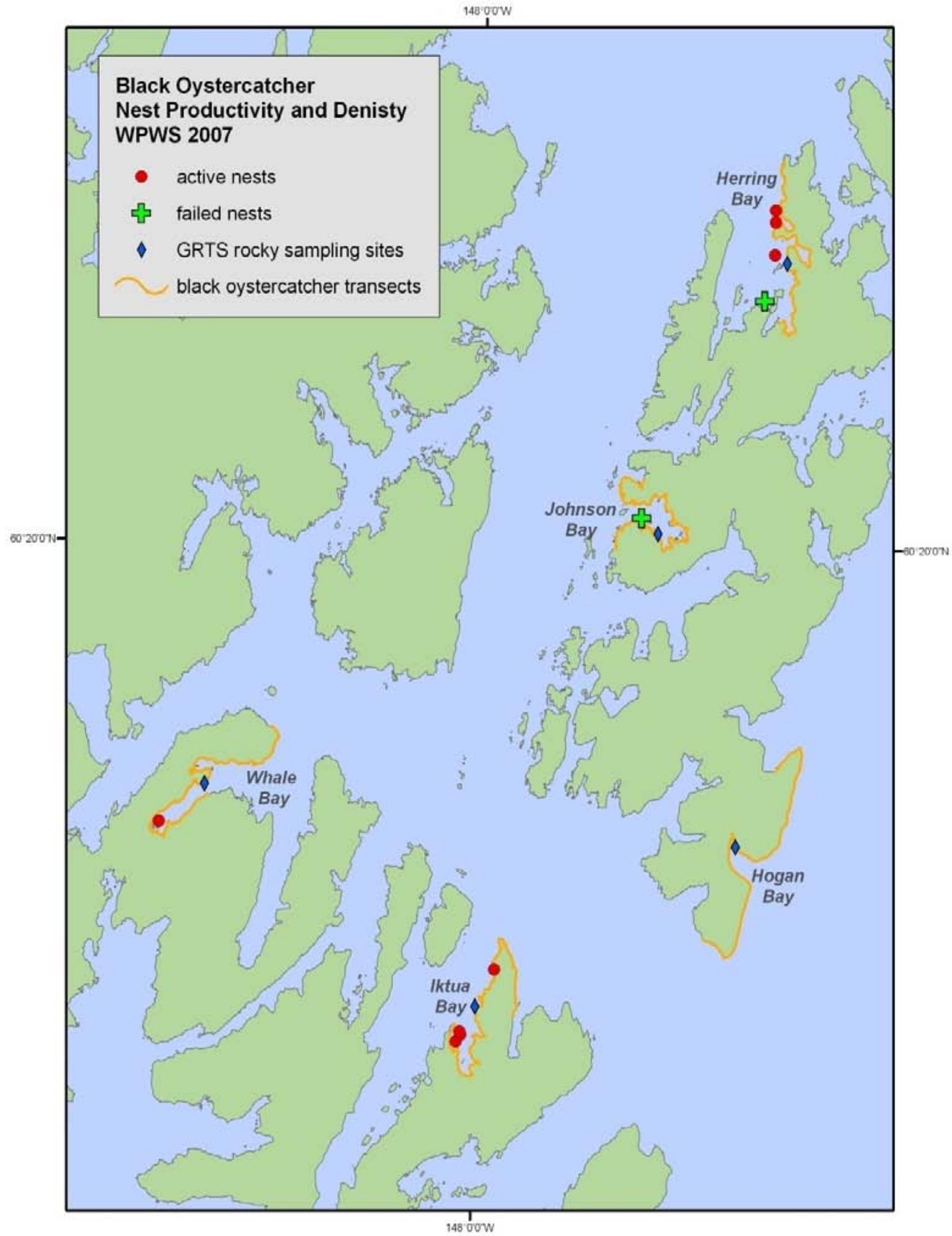

Figure 3. Location of transects surveyed and black oystercatcher nest sites observed in western Prince William Sound in 2007. Also shown are the randomly selected sheltered rocky sampling sites around which the oystercatcher transects are centered.

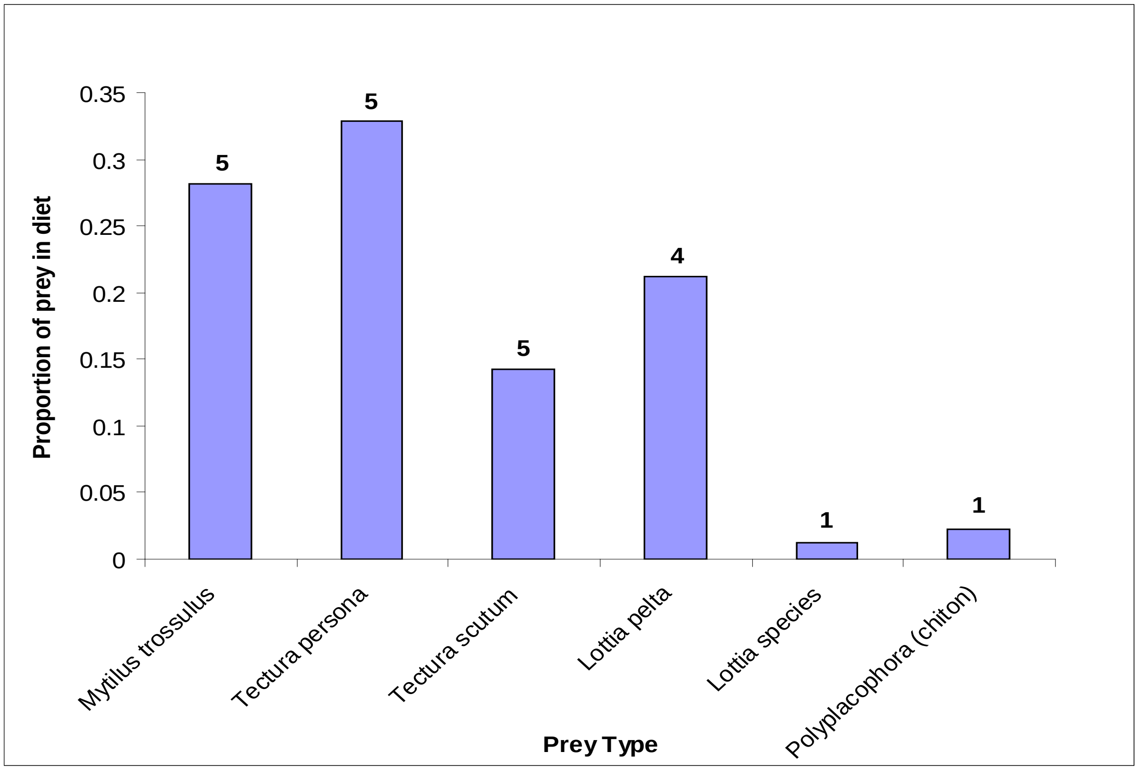

Figure 4. Mean proportion of various species reflected in prey remains collected from black oystercatcher nest sites in western Prince William Sound in 2007. Numbers on the tops of each bar indicated the number of nest sites from which prey remains were collected.

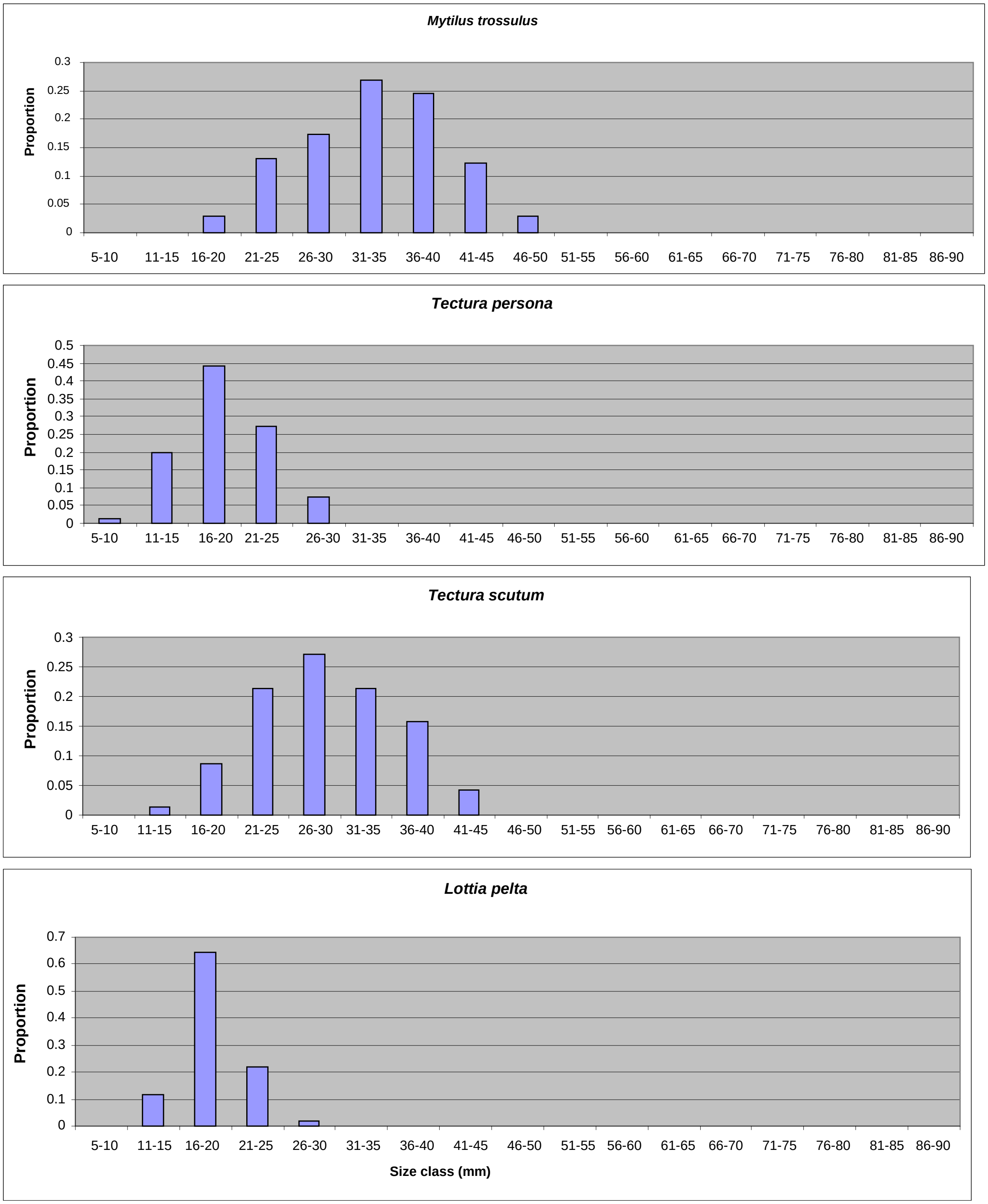

Figure 5. Size distribution of mussels and limpets collected from black oystercatcher nest sites in western Prince William Sound in July 2007. Sample sizes were 104 for *Lottia pelta*, 161 for *Tectura persona*, 70 for *Tectura scutum*, and 138 for *Mytilus trossulus*.

5. Sea Otters

Introduction

The sea otter (*Enhydra lutris*) may be the most common and conspicuous mammal in nearshore marine habitats in the north Pacific. It also may be the best understood marine mammal, in ecological terms, because of its well described role as a “keystone” predator in nearshore marine benthic ecosystems (Estes and Palmisano 1974, Estes and Duggins 1995). The sea otter is limited in distribution to shallow coastal waters by a diet that consists largely of benthic marine invertebrates (crabs, clams, urchins, snails) and a foraging depth range from the intertidal to about 100 m (Bodkin et al. 2004*a*). The species aggregates to rest, typically in nearshore areas, has relatively small home ranges (tens of kilometers of coastline), usually forages alone, has dive times that average < 2 minutes, and brings their prey to the surface for consumption. These characteristics support direct visual observation and provide for accurate and precise estimates of abundance.

Because sea otter foraging is limited to relatively shallow waters (Bodkin et al. 2004*a*, *b*), shore based observers equipped with high power and high resolution telescopes can accurately identify the type, number, and sizes of prey consumed. Observations of sea otter foraging success and intensity are measured using focal animal foraging observations (Altmann 1974) adapted for sea otter work in past studies (Calkins 1978, Estes et al. 1986, Doroff and Bodkin 1994).

Observations of foraging sea otters provide information on food habits, foraging success, (mean proportion of feeding dives that are successful) and efficiency (mean kcal per dive) based on prey numbers, types and sizes obtained by feeding animals. Because sea otter populations are often prey limited, data on foraging behavior is useful in evaluating reasons for differences in sea otter densities or trends among regions or years (Estes et al. 1982, Bodkin et al. 2002, Dean et al. 2002, Gelatt et al. 2002).

Due to high spatial variability in marine invertebrate populations (e.g., extreme patchiness) and difficulty in sampling underwater prey populations, observations of foraging sea otters provide an alternative method to direct sampling of subtidal invertebrates. Following a successful foraging dive, sea otters return to the surface to consume their prey. This provides the opportunity to identify, enumerate, and determine the size of the benthic organisms they consume. Therefore, sea otter foraging data provides data on species composition and sizes of subtidal invertebrate prey populations that are difficult to obtain directly. Observations collected over time may allow inference to changes in the species composition and sizes of the nearshore benthic invertebrate communities.

Data on sea otter food habits, foraging efficiency, and prey sizes should prove useful when examining differences (if any) obtained through direct measures of densities, and size-class distributions of the invertebrates obtained through the intertidal invertebrate and algal data collection (Section 2 and 3 above). Data collected on species composition and sizes of invertebrates recovered by sea otters will allow evaluation of changes in intertidal and subtidal benthic communities in different regions and over time. Sea otter foraging data, including diet composition, foraging efficiency, and prey sizes will also be useful in evaluating the role of food limitation as a factor in changing sea otter population sizes over time.

In this section we report estimates of sea otter abundance from aerial surveys for WPWS and northern Knight Island and estimates of sea otter diet from visual observations of foraging sea otters in WPWS.

Methods

Estimates of abundance of sea otters were obtained using aerial survey methods detailed in Bodkin and Udevitz (1999). Sea otter habitat was sampled in two strata representing habitats of expected high and low sea otter density. These strata were distinguished by distance from shore and water depth. Survey effort was allocated proportional to expected sea otter abundance by adjusting the systematic spacing of transects within each stratum. Transects with a 400-meter strip width on one side of a fixed-wing aircraft were surveyed by a single observer at an air speed of 65 mph (29 m/sec) and altitude of 300 feet (91 m). The observer searched forward as far as conditions allowed and out 400 m, indicated by marks on the aircraft struts, and recorded otter group size and location on a transect map. A group is defined as one or more otters spaced less than three otter lengths apart. Intensive search units (ISUs) were used to estimate the proportion of sea otters not detected on strip transect counts. ISUs were flown at intervals dependant on sampling intensity throughout the survey period, and were initiated by the sighting of a group, then followed by five concentric circles flown within the 400-m strip perpendicular to the group that initiated the ISU. Replicate surveys were conducted in the intensive oiled (northern Knight Island) area to gain precision in estimates for this relatively small area. Rates of change in population estimates over time were calculated by regressing the log (N) of estimates over years.

Food habits and foraging success were estimated from shore based observations of randomly selected foraging otters located in proximity to each of the five intensive rocky intertidal sites sampled in 2007 (Figure 2). Observations were made in April and July 2007. High power telescopes (Questar Corp., Hew Hope, PA.) and 10X binoculars were used to record prey type, number, and size during foraging bouts of focal animals. A bout consists of observations of repeated dives for a focal animal while it remains in view and continues to forage (Calkins 1978). We assume that each foraging bout records the feeding activity of a unique individual, and that bouts represent independent observations while dives do not. Thus the length of observation for any one foraging bout was limited to 20 dives or one hour.

Foraging observations were made within a 10-km radius of each of the five rocky intensive sites for intertidal invertebrates and algae sampling (Section 2 above). For each bout the otter’s estimated age (juvenile or adult, based on total length, extent of grizzle on head, and behavior), sex (based on presence/absence of penile bulge, pup or mammary glands, or undetermined), and reproductive status (independent or with pup) was recorded. For each feeding dive, observers recorded dive times (time underwater searching for and retrieving prey) and surface intervals (time on the surface between dives) along with dive success (prey captured or not). In addition, prey identification (lowest possible taxa), prey number, and prey size were recorded. Prey size was categorically estimated using the otter's fore paw width as a reference with an average width of 52 mm. The mean success rate, mean prey number, mean prey size, and most common prey type were determined. Metrics analyzed include the frequency distribution of prey types consumed, and the mean size of prey recovered.

Results

Estimated sea otter abundance in WPWS in 2007 was 2,380 individuals (se=372) (Figure 6). With the exception of 2001, annual estimates of sea otter abundance have been made since 1993 in WPWS. From 1993 through 2000, the average annual rate of change was 0.04 (r^2=0.56 p=0.03). In 2002 it appeared as though there was an overall decline in WPWS sea otter abundance, but subsequent estimates confirm the long-term trend toward in increasing sea otter population in WPWS. Results since 2003 suggest that the increasing trend has moderated, averaging 0.011 annually and that the WPWS population as a whole has stabilized.

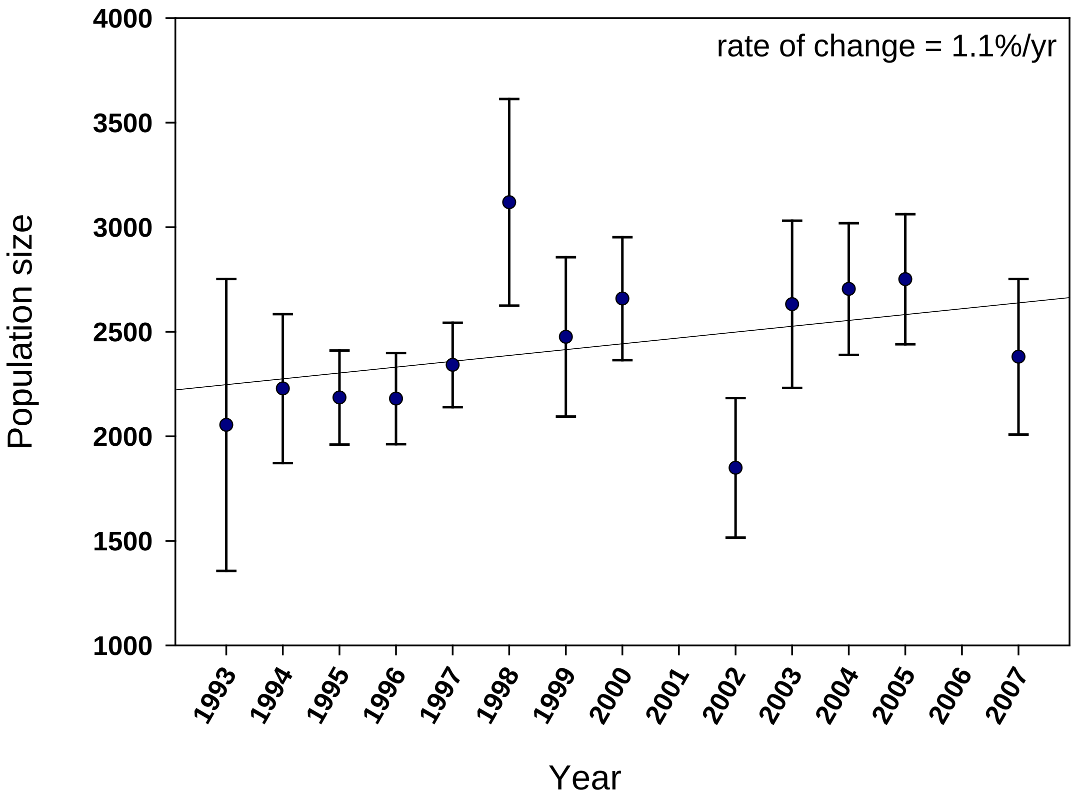

Figure 6. Sea otter population trend in western Prince William Sound, 1993-2007. Line is linear regression fitted to all points, bars equal ± 1 SE.

Estimated sea otter abundance at northern Knight Island in 2007 was 71 individuals (se=14) (Figure 7). This value remains less than half the 164 estimated number of sea otters present in this region at the time of the spill (Bodkin et al. 2002). The average rate of change between 1993 and 2007 remains negative at -0.06 (p=0.07). However, the 2007 estimate represents an increase of 33 individuals (0.86) over the average of 38 individuals estimated from 2002-2005, and is nearly equal to the average of 77 individuals estimated from 1993-2001.

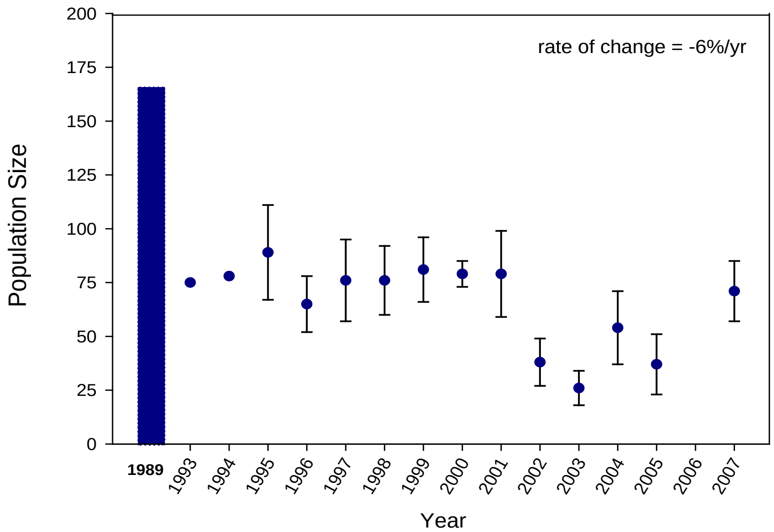

Figure 7. Sea otter population trend at northern Knight Island, western Prince William Sound. The 1989 bar represents the number of live and dead sea otters that were captured or recovered during March and April of 1989 from the northern Knight Island area where aerial surveys were conducted from 1993-2007. This number of 164 does not include animals that survived or that died and were not recovered from in this area. It may include animals that died elsewhere but were recovered here.

From observations based at Knight Island (including Bay of Isles, Lower Pass, Herring Bay, Johnson Cove, Aguliak and Squirrel Islands) and Iktua Bay in Prince of Wales Pass and Green Island, we observed 81 sea otter forage bouts, consisting of 652 dives in WPWS in April-July 2007. To date, the data set is too small to perform analyses on a per site basis. Therefore we present the results of foraging observations for all sites combined. The prey recovery success rate was 88% for dives with known results. Mean (se) dive times were 132.3s (90) and surface intervals were 94s (77).

Sea otter diet composition was dominated by clams (species of *Mya, Saxidomus, Protothaca, Humilaria,* and *Clinocardium*), that comprised 42% of the prey items identified. Mussels (*Mytilus trossulus*) comprised 22%, crabs (primarily *Telmessus cheiragonus*) 8%, and other prey (chitons, octopus, snails, sea stars, sea urchins) 23% (Figure 8). The mean number of prey recovered by foraging sea otters was dependent on prey type (Figure 9) and ranged from 11.4 mussels per dive to 1.0 crab per dive. The predominant prey, clams, averaged 51 mm in length (Figure 10). Mussels were generally the smallest prey, averaging about 22 mm, and crabs averaged 62 mm.

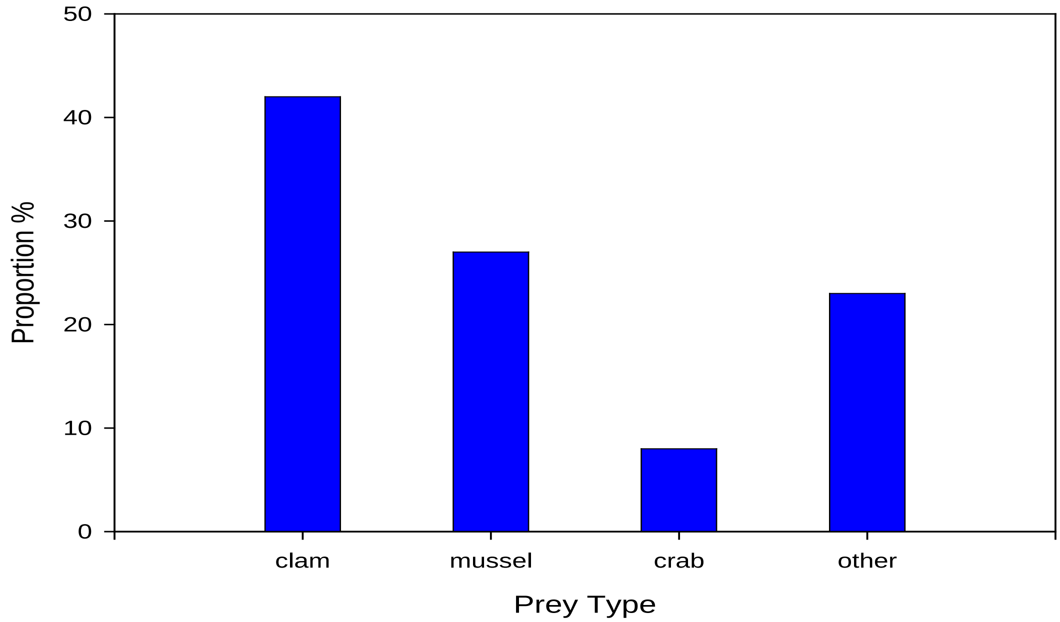

Figure 8. Sea otter diet composition of 652 prey items retrieved in western Prince William Sound in 2007. Clams include species of *Saxidomus*, *Protothaca*, *Mya*, *Humilaria*, and *Clinocardium*. Mussels are *Mytilus trossulus*, crabs include *Telmessus cheiragonus*, and other includes various species of snails, stars, and chitons.

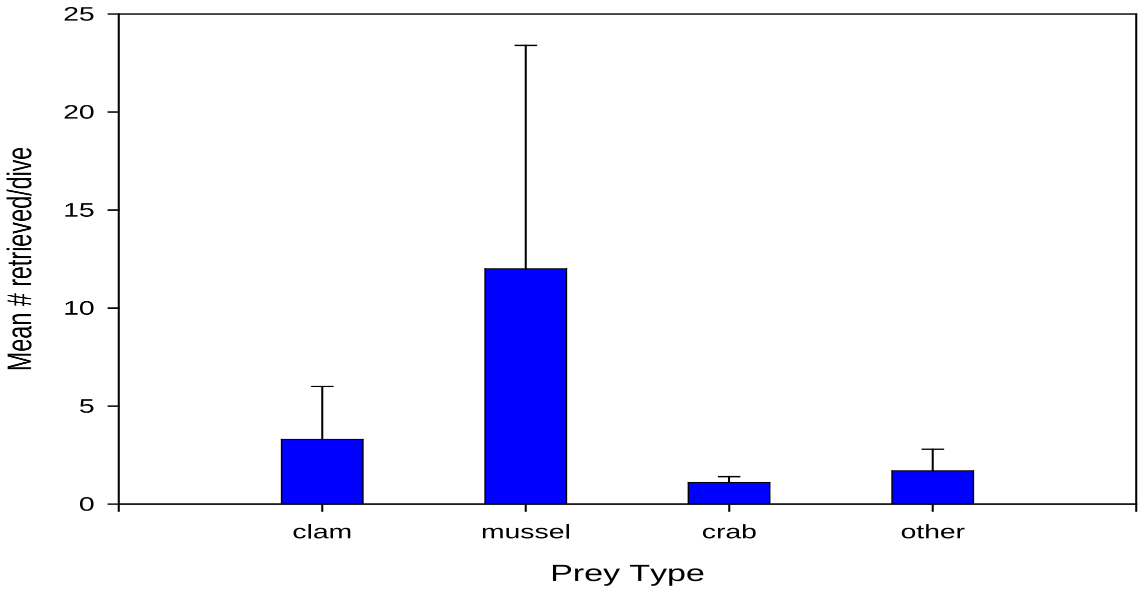

Figure 9. Mean number of prey (+ 1 se) retrieved per dive by prey type for sea otters foraging in western Prince William Sound in 2007.

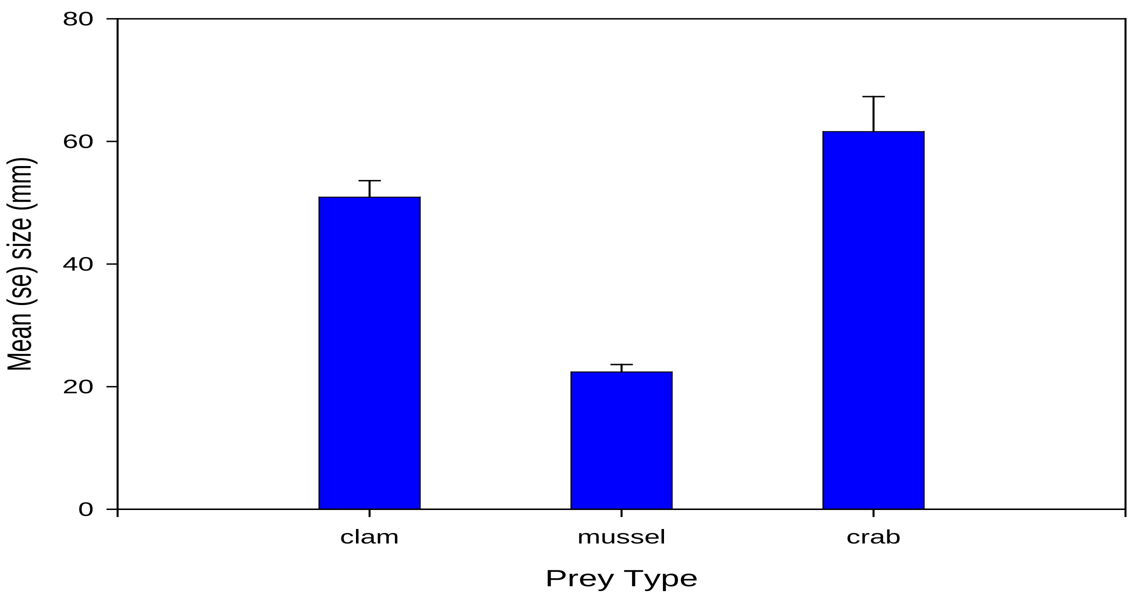

Figure 10. Mean size of prey in millimeters (+ 1 se) recovered by prey type for sea otters foraging in western Prince William Sound in 2007.

Discussion

From the time we initiated detection corrected aerial surveys of sea otter abundance in WPWS in 1993, there has been a significant increase through 2005 in the number of sea otters of about 4% per year. This is approximately half of the annual rate of increase observed in PWS during the 20th century (Bodkin et al. 2002), but is interpreted as recovery from spill related mortality. The most recent estimate for WPWS of 2,380 individuals is lower than observed in the previous three years, but it is uncertain if this represents a longer-term trend.

At northern Knight Island, sea otter abundance was relatively stable between 1993 and 2001 but remained at less than half of a minimum estimate of abundance at the time of the spill. This pre-spill estimate was based on the number of carcasses recovered and the number of live animals removed for rehabilitation in the months following the spill. It does not include animals that died and drifted out of the area or those that survived the spill and continued to reside there. It may include individuals that died elsewhere and drifted into the area, but this is assumed to be negligible as Knight Island is near the origin of the spill, where sea otter mortality approached 88% (Bodkin and Udevitz 1999) and the spill trajectory was to the southwest and eventually out of PWS and away from northern Knight Island (Spies et al. 1996).

Between 2002 and 2005 there appeared to be a decline in sea otter abundance at northern Knight Island from a mean of 77 to 39. In 2007 we estimated an increase of 33 individuals above the mean of the prior four surveys. The estimate of 71 individuals may signal the initiation of a period of recovery for sea otters at northern Knight Island. However, confirmation of this trend will require further survey efforts.

The sea otters we observed foraging in WPWS in 2007 were successful in obtaining prey on 88 % of their foraging dives. Diet was dominated by clams and mussels. The success rate we observed in 2007 was generally similar to those for sea otters observed in prior studies in WPWS (Calkins 1978, Doroff and Bodkin 1994, Dean et al. 2002). However, previous studies have generally recorded higher proportions of clams in the diet of WPWS sea otters, averaging about 80% (Calkins 1978, Doroff and Bodkin 1994, Dean et al. 2002), nearly twice what we observed in 2007. The reduction in the proportion of clams we observed was compensated for by an increase in the proportion of mussels consumed. Mussels are generally regarded as an inferior prey (Garshelis 1983, Doroff and Bodkin 1994), based on small size and relatively low caloric value, and are typically relied on by juvenile sea otters following weaning (VanBlaricom 1988). Mussels were however observed to constitute up to 40% of the diet in eastern Prince William Sound at one location (Estes et al. 1981), and in 2007 mussels constituted 53% of the sea otters' diet in nearby Kenai Fjords, National Park, Alaska (Bodkin et al. 2008).

The high proportion of mussels (*Mytilus trossulus*) we observed in sea otter diets in WPWS in 2007 represents a marked increase over previous years. Possible explanations for the change in prey composition include; 1) a seasonal effect resulting in an increased proportion of mussel foraging in the spring versus summer that has not been observed in previous studies, such as an increased energetic content (i.e., reproductive organ maturation), 2) an increase in the availability or profitability of mussels due to increasing abundance or energetic content, or 3) a reduction in the previously more common clam prey. While we have inadequate data to rigorously test these alternatives, some data from other components of this and prior nearshore studies in WPWS provide some insight. During the period 1993-1996 the percent cover of mussels in lower rocky intertidal habitats at non-oiled reference sites ranged from 0 to 3% (See Section 2). During sampling WPWS in 2007, using similar methods, we estimated the percent cover of mussels in the lower intertidal zone at 9%. This contrast suggests that mussel abundance may have increased over the past decade, may be more available to foraging sea otters than previously, and may have contributed to the change in diet we detected.

6. General Discussion

The data presented herein represent the initial sampling of what could be a long-term monitoring program designed to detect changes in the nearshore ecosystem. Because it is the initial sampling, we are generally unable to establish long-term trends and to indicate possible long-term changes within the system with some certainty. However, there are several data sets that represent extensions of sampling done as part of the estimation of effects of the spill that allow us to make some estimation of changes that might be occurring. Some of these (e.g., sea otter studies) are being conducted using the same methods that were employed previously and allow for rigorous evaluations of temporal trends. For other data sets (e.g., for black oystercatchers and intertidal communities on both rocky and sand/gravel shorelines) methods differ from those employed previously and provide for less rigorous evaluations. While there are clear limitations to the inferences we can draw from sampling in 2007, there are several possible trends that deserve comment and warrant further investigation. Perhaps of most interest is that we observed a change in the proportion of various prey items in the diet of sea otters between the mid 1990s and 2007, with an increase in the proportion of mussels taken and a reduction in the proportion of clams taken. This trend was accompanied by indication of a possible increase in mussels and a reduction in some clam species (especially *Protothaca staminea*) in intertidal communities over this same time period. Further sampling will be required to verify this trend, but it suggests an important change in the system, the causes for which are unknown at present. Other metrics examined including black oystercatcher nest density and productivity appear little changed from observations made in the early 1990s.

The results from this study as well as from several other Trustee sponsored studies complement other similar monitoring efforts being carried out in the Katmai and Kenai National Parks for the National Park Service. A brief summary comparing estimates for some key metrics among regions (WPWS, Katmai, and Kenai) is given in Table 9. We have not yet examined differences between regions in a rigorous statistical comparison, but these data suggest possible differences among regions. However, what will be of greater interest will be the extent to which temporal trends within the regions track one another over time. Such comparisons will allow an evaluation of the geographical extent of changes that may occur and will provide some insights as to their causes.

We also provided data that allow some additional insights into the recovery of intertidal communities in Prince William Sound from injuries resulting from the spill. In general, we found little evidence for continued injury to intertidal communities, although power to detect changes was poor. These more recent samplings may also provide valuable baseline data for evaluation of the impacts of possible future restoration efforts in the intertidal.

Table 9. Comparison of regional mean values for several key monitoring metrics from western Prince William Sound (WPWS, this study), Katmai National Park, and Kenai Fjords National Park in 2007 (NPS unpublished data). Percent cover estimates are from 12 0.25-m^2 quadrats sampled at each site.

Vital sign	Metric	WPWS	Katmai	Kenai Fjords
Intertidal – sheltered rocky	% cover *Fucus* – lower intertidal	32	19	No data
	% cover *Fucus* – mid intertidal	59	36	No data
	% cover *Mytilus* – lower intertidal	9	<1	No data
	% cover *Mytilus* – mid intertidal	8	11	No data
	% cover bare – lower intertidal	9	7	No data
	% cover bare – mid intertidal	14	6	No data
Intertidal – gravel/sand	*Protothaca* density (#/0.25 sq. m)	<1	1	1
	Saxidomus density (#/0.25 sq. m)	3	23	22
	Macoma density (#/0.25 sq. m)	<1	6	1
Black oystercatcher	Nest site density (#/km)	0.09	0.13	0.07
	Eggs+chicks/nest	2.03	1.9	1.68
	% mussels in diet	28	18	48
	% limpets in diet	69	78	52
Sea otter	Abundance (total no. in region)	2380	No data	1511
	% clams in diet	42	62	22
	% mussels in diet	22	3	56

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9. Appendices

Appendix A. Mean percent cover of sessile species observed in the low (0.5 m above MLLW) and mid (1.5 m above MLLW) intertidal by site in western Prince William Sound in 2007.

Low SessileSpeciesName	Northwest Bay	Disk Island	Herring Bay 598	Herring Bay 1522	Whale Bay	Iktua Bay	Hogan Bay	Johnson Bay	Mean All sites
Analipus japonicus	0.0	0.0	0.0	0.0	0.2	0.3	0.0	0.0	0.1
Balanus/Semibalanus sp	0.7	0.0	1.4	0.2	2.6	0.0	3.2	6.1	1.8
barnacle spat	1.0	0.0	0.5	0.0	0.9	1.0	4.9	4.9	1.7
Chthamalus dalli	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.1
Clodophora/Rhizoclonium	27.2	40.8	8.3	33.8	28.9	22.8	30.8	33.5	28.3
Corallina sp.	0.0	3.4	0.5	5.1	0.0	0.3	2.7	0.9	1.6
Cryptosiphonia woodii	0.3	0.5	2.2	0.2	1.0	1.2	6.3	0.0	1.5
Elachista fucicola	1.0	0.0	3.4	5.4	1.0	0.5	3.2	0.0	1.8
encrusting bryozoa	0.0	0.7	0.0	0.2	0.0	0.0	0.0	0.0	0.1
foliose coraline	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Fucus gardneri	36.7	13.4	87.2	57.7	18.5	36.9	18.7	31.0	37.5
Gloiopeltis furcata	0.0	0.0	0.2	0.0	0.5	0.0	0.2	0.2	0.1
Halosaccion glandiforme	1.7	7.0	8.0	13.3	0.0	11.4	2.4	0.0	5.5
Hiatella sp.	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Laminaria saccharina	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.1
Leathesia	0.0	0.3	0.3	0.5	0.5	0.0	0.0	0.0	0.2
Lithothamnion sp.	0.0	0.0	0.0	9.0	0.0	0.0	0.0	0.2	1.1
Mastocarpus papillatus	3.4	4.1	0.7	2.9	0.0	6.0	2.2	0.0	2.4
Melanosiphon intestinalis	2.4	0.0	1.0	0.5	0.3	0.0	2.2	8.2	1.8
Mytilus trossulus	10.5	35.4	14.3	38.1	42.3	0.0	9.9	1.9	19.0
Neorhodomela larix	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Neorhodomela oregona	1.0	11.9	7.3	5.4	3.2	6.6	11.6	0.3	5.9
Odonthalia floccosa	0.0	0.0	16.5	8.7	8.2	4.1	0.0	19.4	7.1
Palmaria callophylloides	0.3	4.9	0.5	8.5	0.2	7.5	2.9	0.0	3.1
Palmaria hecatensis	0.0	0.0	0.3	0.0	0.0	8.0	0.0	0.0	1.0
Palmaria mollis	0.0	22.1	0.0	0.7	0.0	0.5	0.2	0.0	2.9
Palmaria spp.	0.0	0.3	1.4	6.1	0.0	2.2	1.4	0.0	1.4
Phycodrys riggii	0.3	11.4	0.0	0.9	0.0	3.2	0.9	0.0	2.1
Pilayella littoralis	0.0	0.3	9.0	2.0	0.3	0.3	16.2	2.7	3.9
Plocamium cartilageneum	0.0	0.0	0.3	0.2	0.0	0.7	0.0	0.0	0.1
Polysiphonia sp.	0.0	1.2	0.2	2.0	0.5	1.7	0.0	0.2	0.7
Porphyra spp.	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Pterosiphonia bipinnata	59.5	5.4	5.6	11.2	0.5	46.9	5.6	0.2	16.9
Ralfsia sp.	0.0	0.5	0.3	2.7	0.0	0.0	0.0	6.1	1.2
Semibalanus balanoides	0.0	0.0	0.0	0.0	0.2	0.2	0.5	0.0	0.1
Semibalanus cariosus	0.0	0.0	0.7	0.0	0.9	0.0	2.4	1.0	0.6
Soranthera ovoidea	0.0	0.0	0.3	0.3	0.5	0.2	0.0	0.3	0.2
Spirorbidae	0.3	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.3
Tokidadendron kurilensis	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Ulothrix flacca	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.2
Ulva sp.	0.0	9.0	0.2	1.7	0.0	11.2	33.7	0.0	7.0
unidentified brown alga	0.0	0.2	0.0	0.2	0.0	0.0	0.5	0.0	0.1
unidentified red alga	0.0	0.2	1.2	0.2	0.3	0.0	0.0	1.7	0.4
unidentified green alga	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total # of Taxa	16	23	29	29	22	25	23	18	43

Appendix A Continued.

Mid SessileSpeciesName	Northwest Bay	Disk Island	Herring Bay 598	Herring Bay 1522	Whale Bay	Iktua Bay	Hogan Bay	Johnson Bay	Mean All sites
Acrosiphonia sp.	0.0	0.0	0.0	0.0	0.2	0.0	0.7	0.0	0.1
Balanus / Semibalanus spp.	0.3	6.5	9.9	5.3	14.3	1.0	0.0	27.9	8.1
Balanus glandula	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
barnacle spat	16.7	3.9	17.2	4.4	0.0	20.6	14.5	3.1	10.0
Chthamalus dalli	1.7	3.7	0.2	1.2	0.0	2.0	0.0	0.0	1.1
Clodophora/Rhizoclonium sp.	6.8	8.3	4.1	28.9	4.6	8.8	7.3	13.1	10.2
Corallina sp.	0.0	4.3	0.0	1.4	0.0	0.0	0.2	0.0	0.7
Cryptosiphonia woodii	1.4	6.1	0.0	0.0	0.0	0.0	6.3	0.0	1.7
Elachista fucicola	3.1	2.4	4.9	3.7	0.2	10.5	5.4	7.8	4.8
encrusting bryozoa	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
foliose coraline	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Fucus gardneri	56.5	40.3	33.8	70.6	41.0	80.1	54.4	51.0	53.5
Gloiopeltis furcata	0.0	1.4	0.5	0.5	1.5	0.2	1.5	0.5	0.8
Halosaccion glandiforme	0.0	8.3	0.0	3.7	0.0	6.6	0.7	0.0	2.4
Leathesia	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.1
Lithothamnion sp.	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.1
Mastocarpus papillatus	0.7	1.4	0.0	1.0	0.0	5.1	0.3	0.0	1.1
Melanosiphon intestinalis	6.8	0.2	0.0	1.0	0.3	0.0	0.3	1.4	1.3
Microcladia borealis	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mytilus trossulus	0.0	14.3	12.4	17.5	54.8	0.2	3.2	7.5	13.7
Neorhodomela larix	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Neorhodomela oregona	1.4	20.6	0.0	5.1	3.6	2.6	6.5	0.0	5.0
Odonthalia floccosa	0.0	0.0	2.2	6.3	2.9	0.9	0.0	1.2	1.7
Palmaria callophylloides	0.0	0.3	0.0	0.3	0.0	1.9	0.0	0.0	0.3
Palmaria hecatensis	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.1
Palmaria mollis	0.0	11.7	0.0	0.3	0.0	0.0	0.0	0.0	1.5
Palmaria spp.	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.1
Phycodrys riggii	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pilayella littoralis	0.0	3.4	0.2	5.6	0.7	0.7	20.4	1.5	4.1
Plocamium cartilageneum	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.1
Polysiphonia sp.	0.0	4.4	0.0	0.0	0.0	1.2	0.2	0.5	0.8
Prionitis lanceolata	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Pterosiphonia bipinnata	25.5	0.9	0.0	0.7	0.0	5.6	0.0	0.0	4.1
Ralfsia sp.	1.0	0.7	0.0	1.7	0.0	0.0	0.9	0.5	0.6
Scytosiphon simplicissimus	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Semibalanus balanoides	0.0	2.6	0.0	0.0	0.0	0.7	0.0	0.0	0.4
Semibalanus cariosus	0.3	0.2	16.3	0.0	2.2	2.7	31.1	7.5	7.5
Soranthera ovoidea	0.0	0.9	0.0	0.2	0.2	0.2	0.0	0.4	0.2
Ulothrix flacca	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Ulva sp.	2.0	7.0	0.0	0.2	0.0	2.2	13.1	0.7	3.1
unidentified brown algae	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
unidentified red alga	0.0	0.2	0.0	0.0	0.0	0.0	1.2	0.2	0.2
unidentified green algae	3.4	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.5
Total Number of Taxa	17	26	11	25	16	24	21	17	43

Appendix B. Mean density (number per 0.25 m^2) of small motile species observed in the low (0.5 m above MLLW) and mid (1.5 m above MLLW) intertidal in western Prince William Sound in 2007 by site. In order to avoid double counting species in estimating total species counts, Lottiidae <10 mm were considered *Lottia pelta* and *Littorina* spp. were considered *Littorina scutulata*.

Low SmallMotileSpeciesName	Northwest Bay	Disk Island	Herring Bay 598	Herring Bay 1522	Whale Bay	Iktua Bay	Hogan Bay	Johnson Bay	Mean All sites
Amphiporus formidabalis	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Bittium sp.	0.00	0.00	0.08	0.08	0.00	0.00	0.00	0.00	0.02
Buccinum baeri	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.08	0.03
Emplectonema gracile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.01
Hemigrapsus sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.08	0.03
Lacuna spp	0.00	7.42	0.00	0.00	0.00	0.00	0.75	0.08	1.03
Lirabuccinum dirum	0.00	1.25	0.00	0.00	0.00	0.00	0.75	0.00	0.25
Littorina scutulata	0.00	0.00	3.75	0.58	24.08	0.08	5.58	18.75	6.60
Littorina sitkana	0.00	0.08	0.92	0.42	10.58	0.17	0.00	0.00	1.52
Littorina spp	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.06
Lottia pelta	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.33	0.06
Lottiidae ≤10	7.00	6.25	5.58	2.33	48.00	3.33	10.50	17.33	12.54
Margarites pupillus	0.17	0.42	0.00	0.08	0.08	0.42	0.00	0.00	0.15
Margurites helicinus	0.00	0.08	3.08	1.33	0.08	0.17	0.00	0.00	0.59
Neomolgus littoralis	0.00	0.00	0.00	0.08	0.00	1.33	0.00	0.00	0.18
Pagurus sp.	0.50	0.17	0.92	0.75	0.67	0.08	0.42	0.50	0.50
Paranemertes perigrina	0.00	0.00	0.00	0.00	0.08	0.00	0.08	0.00	0.02
Siphonaria thersites	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.02
Unknown chiton	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.01
Total Number of taxa	3	8	6	9	7	9	7	7	7.00

Mid SmallMotileSpeciesName	Northwest Bay	Disk Island	Herring Bay 598	Herring Bay 1522	Whale Bay	Iktua Bay	Hogan Bay	Johnson Bay	Mean All sites
Amphiporus formidabalis	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.01
Hemigrapsus sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.01
Lacuna sp.	0.67	11.33	0.00	0.08	0.00	0.08	1.25	0.00	1.68
Lirabuccinum dirum	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.02
Littorina scutulata	0.67	0.50	165.33	7.42	38.92	0.08	20.67	133.83	45.93
Littorina sitkana	0.00	7.00	7.00	0.75	18.42	0.00	1.83	1.25	4.53
Littorina spp	11.33	0.17	0.00	0.00	0.00	0.00	0.00	0.00	1.44
Lottia digitalis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.01
Lottia pelta	0.17	0.00	1.00	0.17	0.08	0.42	0.08	0.08	0.25
Lottiidae ≤10	46.67	48.75	48.83	21.42	32.58	61.92	40.33	19.00	39.94
Margarites pupillus	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Margurites helicinus	0.00	0.17	0.00	0.58	0.00	0.00	0.00	0.00	0.09
Neomolgus littoralis	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.03
Pagurus sp.	0.50	0.33	1.25	1.83	3.67	1.58	2.25	0.42	1.48
Pentidotea wosnesenskii	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.08	0.02
Siphonaria thersites	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.13
Tectura persona	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Tectura scutum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.01
Total Number of taxa	5	7	4	6	6	7	5	8	6.00

Appendix C. Mean density (number per 0.25 m^2) of intermediate size motile species observed in the low (0.5 m above MLLW) and mid (1.5 m above MLLW) intertidal in western Prince William Sound in 2007 by site.

Low Species	Northwest Bay	Disk Island	Herring Bay 598	Herring Bay 1522	Whale Bay	Iktua Bay	Hogan Bay	Johnson Bay	Mean All sites
Hemigrapsus spp	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Katharina tunicata	0.00	0.42	0.00	0.00	0.00	0.08	0.00	0.00	0.06
Lirabuccinum dirum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nucella lamellosa	1.33	22.75	0.25	0.58	0.08	0.17	0.08	0.00	3.16
Nucella lima	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.06
Total # of Taxa	2	2	1	1	2	2	1	0	1.38

Mid Species	Northwest Bay	Disk Island	Herring Bay 598	Herring Bay 1522	Whale Bay	Iktua Bay	Hogan Bay	Johnson Bay	Mean All sites
Hemigrapsus spp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Katharina tunicata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lirabuccinum dirum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.03
Nucella lamellosa	1.00	0.00	0.25	12.17	0.00	2.67	0.00	0.00	2.01
Nucella lima	0.17	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.07
Total # of Taxa	2	0	1	1	1	1	0	1	0.88

Appendix D. Mean density (number per 0.25 m^2) of sea stars and sea urchin species observed in western Prince William Sound in 2007 by site.

Species	Northwest Bay	Disk Island	Herring Bay 598	Herring Bay 1522	Whale Bay	Iktua Bay	Hogan Bay	Johnson Bay	Mean All sites
Dermasterias imbricata	0	5	1	2	24	2	2	7	5.38
Evasterias troschelii	0	2	1	2	0	1	1	0	0.88
Pisaster ochraceus	6	11	0	0	0	0	0	0	2.13
Pycnopodia helainthoides	0	3	7	4	0	1	3	0	2.25
Strongylocentrotus droebachiensis	0	0	0	0	1	0	0	0	0.06
Total # of taxa	1	4	3	3	2	3	3	1	2.50

Appendix E. Mean density (number per 0.25 m^2) and standard deviation for dominant intertidal algae and invertebrates at low (0.5 m above MLLW) and mid (1.5 m above MLLW) intertidal elevations at each site sampled in western Prince William Sound in 2007. In cases, n=12 quadrats were sampled at each site.

0.5 m MLLW

Taxa

Site Name	Site Designation	Bare Substrate (%)		Barnacles (%)		*Mytilus trossulus* (%)		*Fucus gardneri* (%)		Perenial algae (%)		Ephemeral algae (%)		Lottiidae (No./0.25 m^2)		*Littorina spp.* (No./0.25 m^2)		*Nucella spp.* (No/sq. m)	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Northwest Bay	Oiled	6.8	4.7	11.1	8.7	5.2	6.3	18.4	10.0	0.3	0.6	0.0	0.0	7.0	8.4	0.0	0.0	1.3	1.2
Disk Island	Oiled	4.3	4.4	0.0	0.0	17.3	9.3	13.4	16.9	5.8	9.3	4.6	4.8	6.3	11.4	0.1	0.3	22.8	36.3
Herring Bay 498	Oiled	2.7	4.4	0.0	0.0	7.0	7.0	87.2	19.5	3.6	6.2	4.5	6.9	5.6	6.5	4.7	6.1	0.3	0.5
Herring Bay 1522	Oiled/GRTS	3.4	4.4	1.9	5.9	18.7	11.7	57.7	22.4	2.7	3.0	1.8	2.1	2.3	3.3	1.0	1.2	0.6	1.0
Hogan Bay	Reference/GRTS	7.5	3.7	0.2	0.6	4.8	7.3	18.7	26.1	5.7	7.3	24.4	16.3	10.5	18.1	5.6	13.4	0.1	0.3
Iktua Bay	Reference/GRTS	2.9	3.1	8.2	12.5	0.0	0.0	36.9	22.1	3.8	6.7	5.7	5.1	3.3	7.1	0.3	0.5	0.2	0.4
Whale Bay	Reference/GRTS	17.0	13.1	1.7	2.0	20.8	13.6	18.4	20.0	1.6	2.2	0.2	0.6	48.2	54.6	34.7	21.5	0.6	1.0
Johnson Bay	Reference/GRTS	15.3	15.3	1.0	1.8	0.9	1.5	31.0	20.9	0.2	0.6	1.3	2.3	17.7	16.6	18.8	23.4	0.0	0.0

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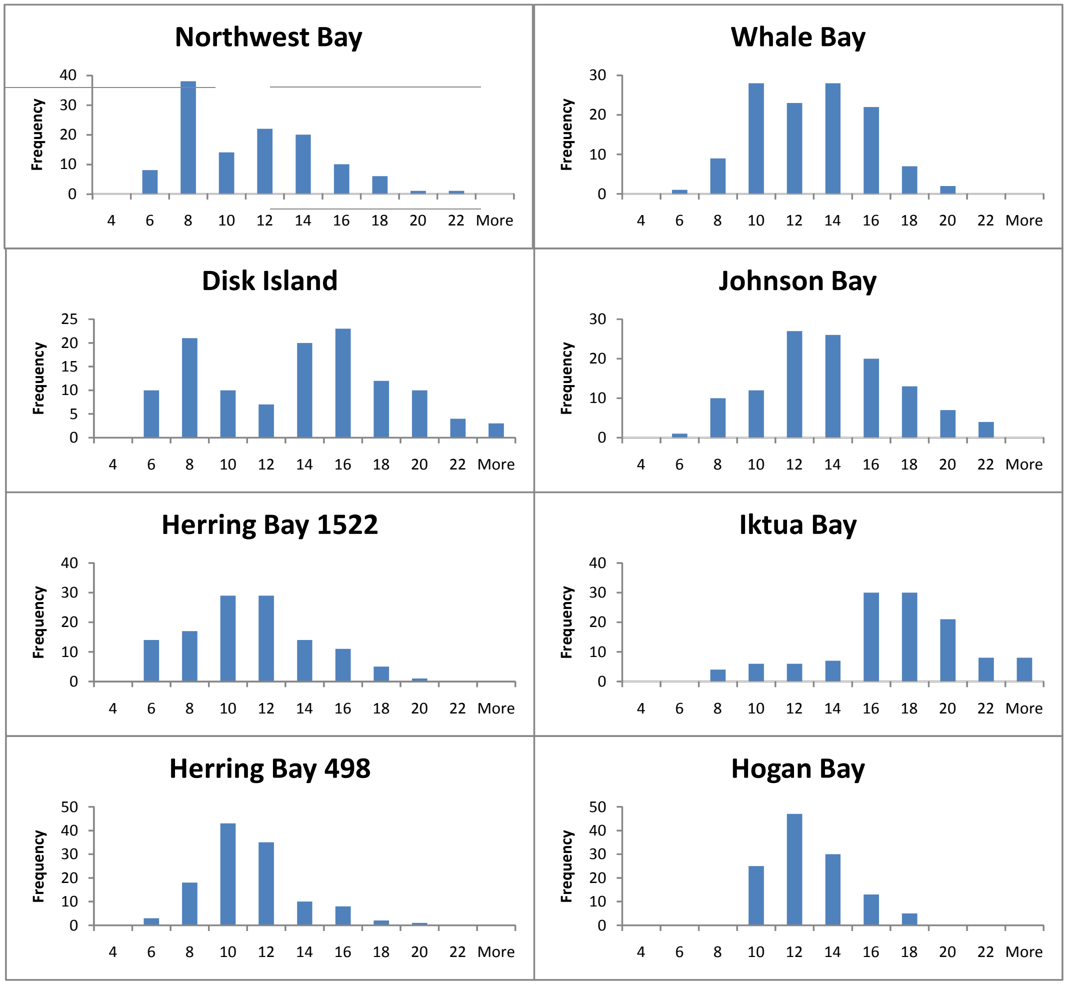
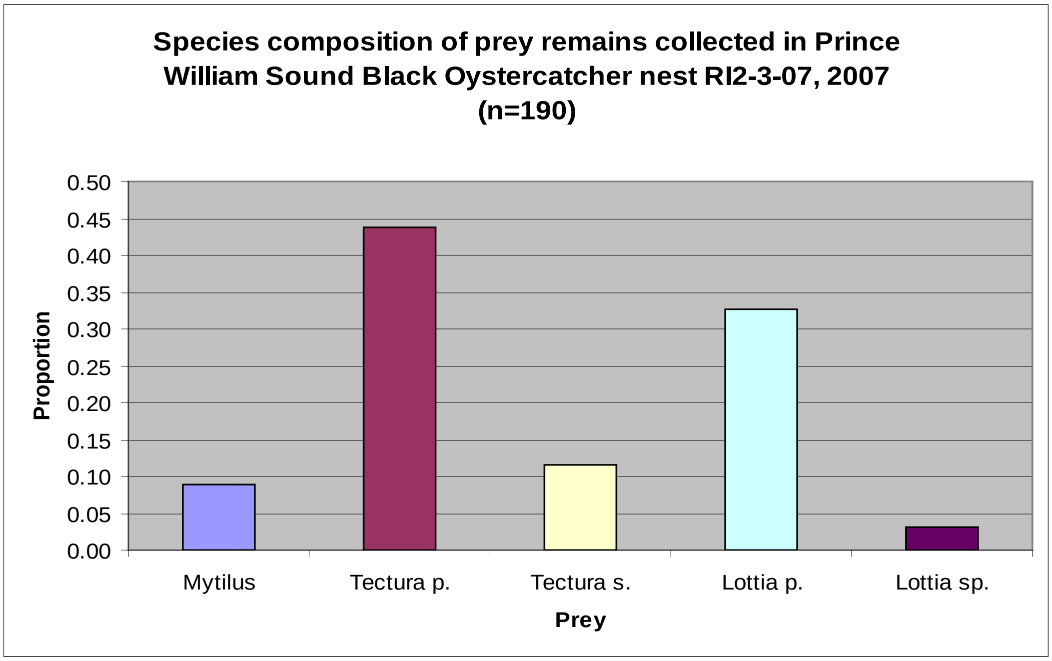
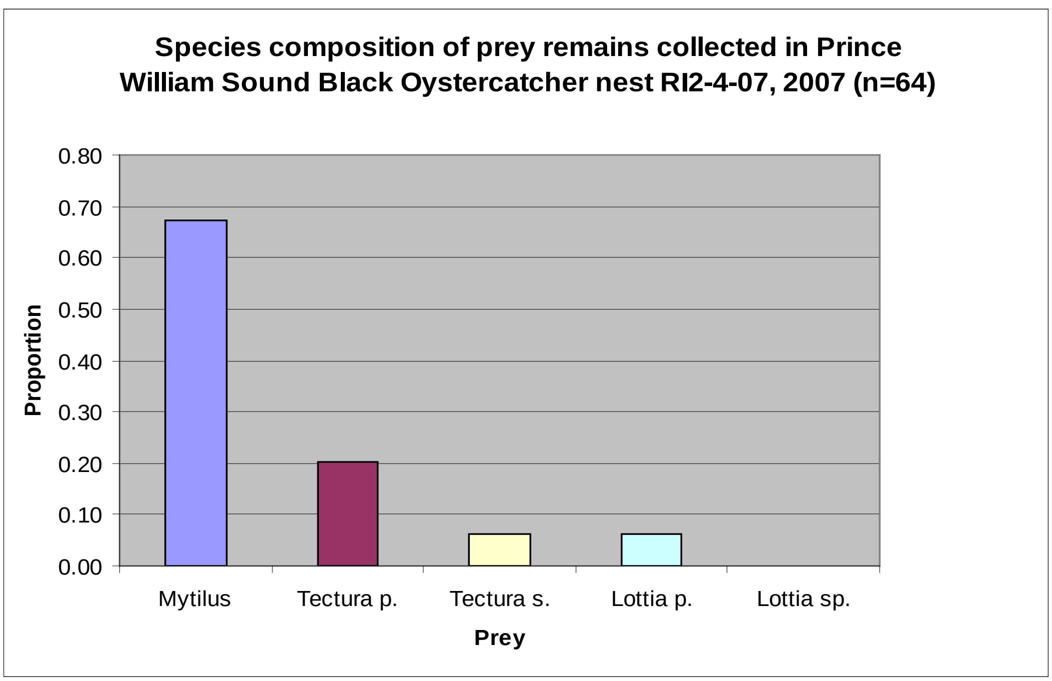
Site Name	Site Designation	Bare Substrate (%)		Barnacles (%)		*Mytilus trossulus* (%)		*Fucus gardneri* (%)		Perenial algae (%)		Ephemeral algae (%)		Lottiidae (No./0.25 m^2)		*Littorina spp.* (No./0.25 m^2)		*Nucella spp.* (No/sq. m)	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Northwest Bay	Oiled	12.6	10.7	18.7	18.0	0.0	0.0	28.2	35.0	0.5	1.2	1.0	0.8	46.8	33.3	0.7	1.2	1.2	1.7
Disk Island	Oiled	6.6	7.2	14.1	18.6	7.0	8.0	40.3	29.3	10.1	12.0	3.4	4.3	48.8	55.9	7.5	12.3	0.0	0.0
Herring Bay 498	Oiled	25.2	19.0	27.2	21.9	6.1	5.3	33.8	28.2	0.0	0.0	0.1	0.3	49.8	25.0	172.3	110.1	0.3	0.9
Herring Bay 1522	Oiled/GRTS	7.7	8.0	10.9	15.7	8.6	8.8	70.6	21.9	2.5	8.0	2.8	7.4	21.6	25.3	8.2	4.8	12.2	33.7
Hogan Bay	Reference/GRTS	12.4	12.7	14.5	20.1	1.6	2.2	54.4	26.4	3.2	5.5	16.4	2.5	40.4	34.8	22.5	26.5	0.0	0.0
Iktua Bay	Reference/GRTS	8.5	10.2	23.6	16.7	0.1	0.3	80.1	19.1	1.3	2.1	1.4	1.6	62.3	46.7	0.1	0.3	2.7	3.1
Whale Bay	Reference/GRTS	19.6	23.7	14.5	17.8	26.8	9.8	41.0	39.1	1.8	2.8	0.3	0.9	32.7	41.3	57.3	32.1	0.4	1.2
Johnson Bay	Reference/GRTS	19.4	12.4	31.0	22.6	3.7	3.5	51.0	23.9	0.0	0.0	1.1	1.8	19.3	14.0	135.1	193.3	0.0	0.0

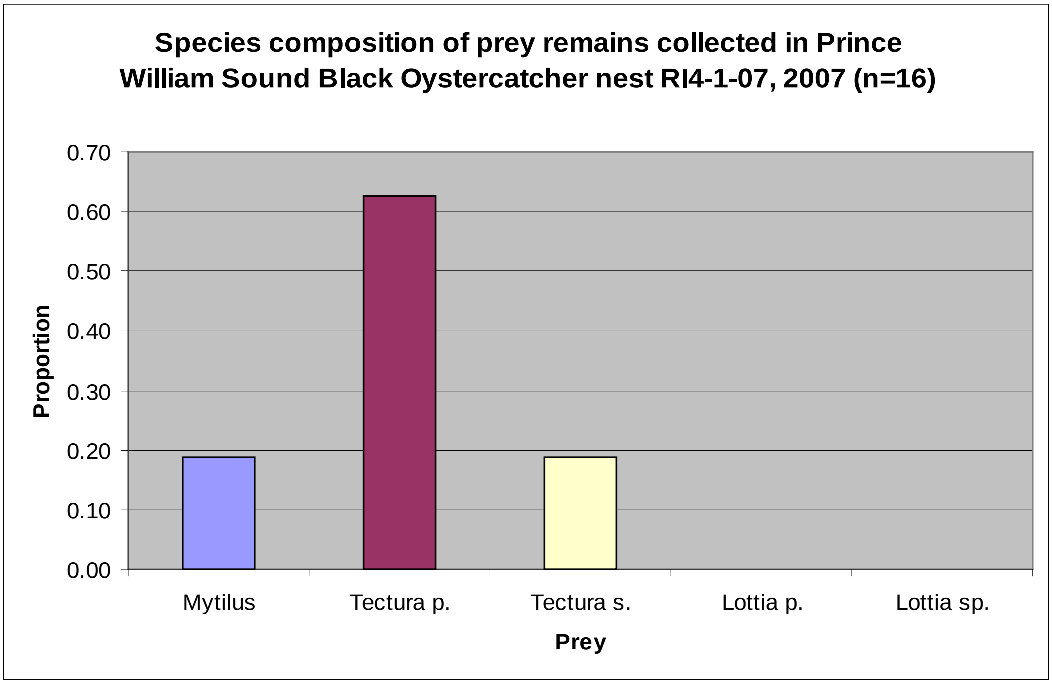
Appendix F. Size frequency distribution of limpets (*Tectura persona*) at sites in western Prince William Sound in 2007. In all cases, n=120.

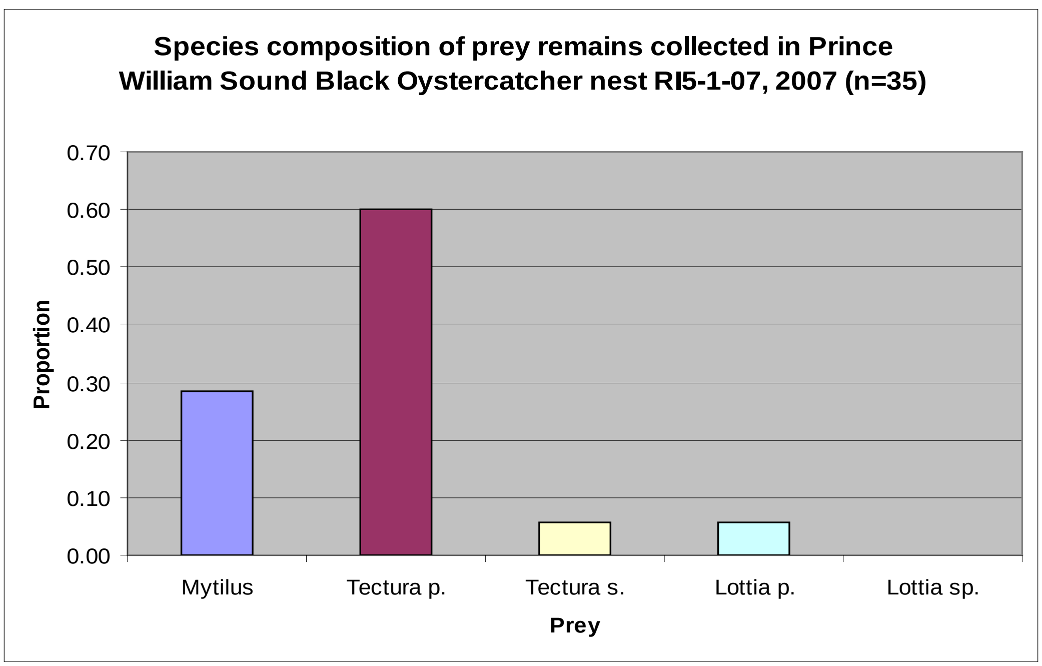


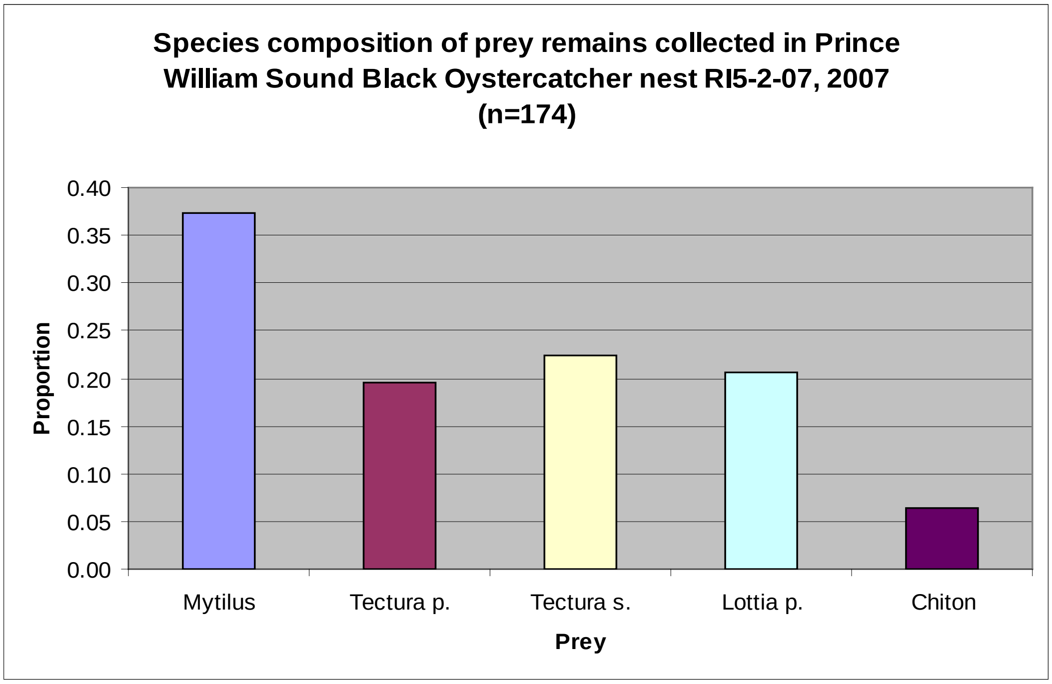
Appendix G. Dietary diversity among the individual black oystercatcher nests in western Prince William Sound in 2007.






Species composition of prey remains collected in Prince William Sound Black Oystercatcher nest RI4-1-07, 2007 (n=16)
Proportion
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Mytilus
Tectura p.
Tectura s.
Lottia p.
Lottia sp.
Prey


Species composition of prey remains collected in Prince William Sound Black Oystercatcher nest RI5-1-07, 2007 (n=35)
Proportion
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Mytilus
Tectura p.
Tectura s.
Lottia p.
Lottia sp.
Prey


Species composition of prey remains collected in Prince William Sound Black Oystercatcher nest RI5-2-07, 2007 (n=174)
Proportion
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Mytilus
Tectura p.
Tectura s.
Lottia p.
Chiton
Prey