Sea Otter Studies in Glacier Bay National Park and Preserve

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James L. Bodkin[1]
Brenda E. Ballachey[1]
Kimberly A. Kloecker[1]
George G. Esslinger[1]
Daniel H. Monson[1]
Heather A. Coletti[1]
James A. Estes[2]

[1]United States Geological Survey
Alaska Science Center
1011 East Tudor Road
Anchorage, Alaska 99503

[2] United States Geological Survey
Western Ecological Research Center
Santa Cruz, California 95060

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Table of Contents

List of Tables v
List of Figures vi
Summary vii
Introduction 1
Distribution and Abundance of Sea Otters in Glacier Bay and Cross Sound 5
INTRODUCTION 6
METHODS 6
Distribution Surveys 6
Abundance Surveys 6
RESULTS 7
Distribution Surveys 7
Abundance Surveys 7
DISCUSSION 9
Sea Otter Foraging Behavior in Glacier Bay 13
INTRODUCTION 14
METHODS 14
Site and focal animal selection 14
Data collected 15
Analysis 15
RESULTS 15
Success Rate 15
Prey Composition 17
Prey Number and Size 20
DISCUSSION 22
Horse mussel (*Modiolus modiolus*) sampling in Glacier Bay 25
INTRODUCTION 26
SPECIES DESCRIPTION 26
METHODS 26
Site Selection 26
Sampling Protocol 27
Analysis 27
RESULTS 27
Modiolus modiolus sites, density, and size 27
Strongylocentrotus droebachiensis sites, density, and size 29
Conclusions 34
Acknowledgements 35
References 36
Appendices 38
APPENDIX A. TORCH AND SURGE BAY TRIP REPORT 39
Background 39
Purpose 39
Methods 40
Results 41
Preliminary Interpretations 42
Recommendations 44
References 44
Field Personnel 45
Figures and Tables 45
APPENDIX B. SAMPLING PROTOCOL FOR AERIAL SURVEYS 51

DRAFT

Overview of survey design *51*
Preflight *52*
Observation conditions *53*
Observer fatigue *53*
Vessel activity *53*
Special rules regarding ISU's *54*
Unique habitat features *54*
Planning an aerial survey *55*
APPENDIX C. PROTOCOL FOR DETERMINING SEA OTTER DIET BASED ON VISUAL OBSERVATION 58
General Description *58*
Forage observation protocol *58*
Site and Focal Animal Selection *58*
Data Collected *59*
References *63*
DRAFT

List of Tables

Table 1. Counts or sea otter population size estimates (*) for Lower Glacier Bay, AK. .. 2
Table 2. Results of Cross Sound/Icy Strait sea otter distribution surveys and abundance surveys in Glacier Bay proper in 1999 - 2003 (abundance estimates bolded). Counts are presented as # adults/# pups, while a period means 'no data'. Abundance estimates include pups (Bodkin and Udevitz 1999). (* 2001 estimate of 1,590 revised from 2001 reported value following re-analysis). 8
Table 3. Sea otter foraging success rates in Glacier Bay and sites within Glacier Bay, 1993-2003. 15
Table 4. Prey items observed being consumed by sea otters in Glacier Bay, 1993-2003. 16
Table 5. Percentage of dives with each prey type present, 1993-2003. 'Other' category consists of snails, starfish, worms, octopus, fish, sponge, sea cucumber, chiton, and non-clam/mussel bivalve. 'Unid' category represents prey that could not be identified due to visual obstruction. Unsuccessful dives and those with unknown success were not included in #dive values. Number of dives in this table can total more than the total number of successful dives (3,770) reported earlier because more than one prey item can be retrieved per dive. 18
Table 6. Mean densities (se) of *Modiolus* and *Strongylocentrotus* and the number of quadrats sampled at eight subtidal sites in Glacier Bay in 2003. See Figure 11 for site locations..... 29
Table 7. Mean (se) sizes of *Modiolus* and *Strongylocentrotus* and the number of individuals sampled at eight subtidal sites in Glacier Bay in 2003. See Figure 11 for site locations..... 29
Table A1. Densities and percent covers of dominant macroalgae and suspension feeders at Torch and Surge bay sample sites in 1988 and 2003. 50
Table A2. Summary of population data on sea urchins from Torch Bay, Surge Bay, and Sitka Sound obtained in 1988 and 2003. 50
Table A3. Results of marine bird and mammal, and other species boat surveys in Surge and Torch Bays, June 2003. See Figures 2 and 3 for a map of the area surveyed. Avian species W = waterfowl, S = seabird, B = shorebird, O = other. Sea otter numbers are # independent/# pups..... 51
Table A4. UTM coordinates for sample sites in Torch and Surge bays, 2003. 51

DRAFT

List of Figures

Figure 1. Study areas in Glacier Bay National Park, Icy Strait, and Cross Sound, Southeast Alaska. The Lower Bay portion of Glacier Bay is mottled on this figure. 3
Figure 2. One of five transect designs used during a sea otter abundance aerial survey in Glacier Bay National Park, May 2003. 11
Figure 3. Sea otter group locations from 5 replicate aerial abundance surveys in Glacier Bay National Park, May 2003 (spot size proportional to group size). 12
Figure 4. Locations of sea otter foraging observation data collection, 1993-2003. Each red dot represents a set of observations that have been grouped into the 18 site names noted on the map. 17
Figure 5. Prey composition of 3,770 successful sea otter foraging dives in Glacier Bay, 1993-2003. This figure shows the percentage of all dives with a successful outcome (prey retrieved) that include each prey item. For example, sea otters retrieved at least one clam on 40.1% of their dives in Glacier Bay. 18
Figure 6 A, B, C, D. Prey composition of sea otter foraging dives in Glacier Bay, for 18 sites (# dives) where data was collected. See Figure 4 for site locations. This figure shows the percentage of all dives with a successful outcome (prey retrieved) that include each prey item. 'Other' includes prey items such as snails, stars, non-clam/mussel bivalves, worms, fish, chitons, shrimp, sponges, sea cucumbers, and octopus. 'Unid' repersents prey items not identified due to visual obstruction of some variety. 19
Figure 7 A, B. Prey composition of sea otter foraging dives in Glacier Bay, for 4 sites where >100 successful dives were observed in more than 1 year (# dives). See Figure 4 for site locations. This figure shows the percentage of all dives where prey was retrieved for each prey category. 20
Figure 8. Mean number per dive and standard deviations of the primary prey items recovered by sea otters during observations of foraging in Glacier Bay, 1993-2003. Numbers in bars indicate number of bouts. 21
Figure 9. Mean size and standard deviations of the primary prey items recovered by sea otters during observations of foraging in Glacier Bay, 1993-2003. Numbers in bars indicate number of bouts. 22
Figure 10. Proportion of foraging bouts (1993-2003) that had mean prey size/dive in each of four size categories. Size categories were pulled from forage observation data collection protocols and are based on the mean size of a sea otter paw width (data obtained from sea otter capture studies): Size 1 = 0-52 mm, Size 2 = 52-104 mm, Size 3 = 104-156 mm, and Size 4 > 156 mm. 22
Figure 11. Locations of horse mussel (*Modiolus modiolus*) and green urchin (*Strongylocentrotus droebachiensis*) sampling in Glacier Bay in 2003. 28
Figure A1. Frequency distributions of the numbers of adult and juvenile kelps sampled per one-quarter m^2 quadrat at Torch and Surge bays in 1988 and 2003. 46
Figure A2. Location of sea otter census and benthic sampling in Torch Bay, AK 2003. 48
Figure A3. Location of sea otter census and benthic sampling in Surge Bay, AK 2003. 49
Figure B1. Data sheet for aerial survey strip transects 56
Figure B2. Intensive Search Unit (ISU) data collection form. 57
Figure C1. Sea otter foraging data form. 60
Figure C2. Foraging data variables and codes. 61

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Summary

The sea otter population in Glacier Bay is the only known increasing population in Alaska. Since 1995, the number of sea otters in Glacier Bay proper has increased from around 5 to approximately 1,866 in 2003. Sea otter distribution is mostly limited to the Lower Bay, south of Sandy Cove, and is not continuous within that area. Concentrations occur in the vicinity of Sita Reef and Boulder Island and between Pt. Carolus and Rush Pt. on the west side of the Bay, although there have been occasional sightings north of Sandy Cove (Figure 1). Large portions of the Bay remain unoccupied by sea otters, but recolonization is occurring rapidly.

Most prey recovered by sea otters in Glacier Bay are ecologically, commercially, or socially important species. In 2003, we observed 873 foraging dives. Of the 863 dives where success was determined, 810 (94%) resulted in the retrieval of one or more prey items. Sea otter diet in 2003 consisted of 31% clam, 31% mussel, 3% crab, 14% urchins, 6% other, and 14% unidentified. During the period 1993-2003, we observed 4,258 foraging dives. Of the 4,136 dives where success was determined, 3,770 (91%) resulted in the retrieval of one or more prey items. Sea otter diet in 1993-2003 consisted of 40% clam, 21% mussel, 4% crab, 16% urchins, 5% other, and 13% unidentified. Dominant clam species include the butter clam, *Saxidomus gigantea*, the Greenland cockle, *Serripes groenlandicus*, and the littleneck clam, *Protothaca staminea*. Urchins are almost exclusively green urchins, *Strongylocentrotus droebachiensis*, and the mussel is primarily *Modiolus modiolus*. Crabs observed include the Dungeness, *Cancer magister*, the tanner crab *Chionoecetes bairdi*, the kelp crab *Pugettia gracilis*, and the helmet crab, *Telmessus cheiragonus*. Although we characterize diet at the geographic scale of Glacier Bay inclusively, we have previously found diet to vary between sites separated by as little as several hundred meters. Dietary variation among sites and within sites over time can reflect differences in prey availability and individual dietary specialization.

We counted and measured density of subtidal horse mussels (*Modiolus modiolus*) and green urchins (*Strongylocentrotus droebachiensis*) from eight sites in Glacier Bay, with an average of 24 quadrats sampled at each site. All sites were selected based on the presence of abundant mussels and the absence of sea otters, and to achieve a broad geographic sample of dense subtidal mussel beds within Glacier Bay prior to occupation and foraging by sea otters. There was no direct evidence of sea otter foraging at any of our sampling sites. Mussel density averaged 109/m^2 (range 22-303), and green urchin density averaged 37/m^2 (range 0-122). Mussel sizes averaged 105 mm and green urchin size averaged 25 mm.

Sea otters are now well established in large portions of lower Glacier Bay. Their distribution and numbers likely will continue to increase in the near future, as Glacier Bay supports large and diverse populations of clams and other benthic invertebrates that are unexploited by sea otters at present. It is predictable that the density and sizes of prey populations, including various species of clams, mussels, crabs and urchins, will decline in response to otter predation. This will result in fewer opportunities for human harvest of invertebrates, but will also trigger ecosystem level changes as prey available for other predators are modified. Species directly affected will likely include octopus, sea stars, sea ducks, and river otters. Indirect or cascading effects, such as increased kelp production and modified prey availability, will extend to a larger number of mammal,

bird and fish species. Sea otters will also modify benthic habitats through excavation of sediments required to extract burrowing infauna such as clams. Effects of sediment disturbance by foraging sea otters are not understood.

As the colonization of Glacier Bay waters by sea otters continues, it is likely that dramatic changes will occur in the species composition, abundance, and size class distribution of many components of the nearshore marine ecosystem. Many of the changes will occur as a direct result of predation by sea otters, while others will result from indirect or cascading effects of sea otter foraging. Without recognizing and quantifying the extent of change initiated by the colonization of Glacier Bay by sea otters, management of nearshore resources will be severely constrained for many decades.

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Introduction

Sea otters (*Enhydra lutris*) began recolonizing Glacier Bay in 1993, following at least two centuries of absence. Profound changes in the structure and function of the nearshore marine community, mediated largely through prey consumption by this top-level carnivore, can be anticipated. Understanding the effects of sea otter recovery in Glacier Bay requires at least three types of data: 1) estimates of sea otter abundance and distribution, 2) estimates of sea otter diet and predation rates, and 3) measures of the species composition, abundance and sizes of species comprising the nearshore marine community prior to sea otter colonization. Our purpose here is to report on the status of each of these data sets following work accomplished in 2003.

Sea otters provide one of the best-documented examples of top-down forcing effects on the structure and functioning of nearshore marine ecosystems (Estes and Duggins 1995; Kenyon 1969; Riedman and Estes 1990; VanBlaricom and Estes 1988). During most of the early 20th century, sea otters were absent from large portions of previously occupied habitat. Our understanding of the role of sea otters as a source of community variation has been aided by the spatial and temporal patterns of sea otter population recovery over the past 50 years. During the absence of sea otters, many of their prey populations responded to reduced predation. Typical population responses included increasing mean size, density, and biomass. One well-documented case (sea urchin, *Strongylocentrotus* spp) illustrates the direct prey population response and subsequent profound changes in community organization, and cascading effects throughout the nearshore ecosystem that result from the removal of sea otters (Estes and Palmisano 1974).

Nearshore marine communities in the north Pacific are described as occurring in two alternative stable states, one in the absence of sea otters, and the other in their presence (Simenstad et al. 1978). When sea otters are present in the nearshore system, herbivorous sea urchin populations are limited in density and size by sea otter predation. Grazing and the role of herbivory is a relatively minor attribute of this system and attached macroalgae or kelps dominate primary production. This nearshore ecosystem, commonly referred to as a *kelp-dominated* system, is characterized by high diversity and biomass of red and brown kelps that provide structure in the water column and habitat for invertebrates and fishes that, in turn, support higher trophic levels, such as other fishes, birds and mammals. Once sea otters are removed from the *kelp-dominated* system, sea urchin populations respond through increases in density, mean size and total biomass. Expanding urchin populations exert increasing grazing pressure, eventually resulting in near complete removal of kelps. This system is characterized by abundant and large sea urchin populations, a lack of attached kelps and the associated habitat structure they provide, and reduced abundances of kelp-dependent invertebrates, fishes and some higher trophic level fishes, birds and mammals. The urchin-dominated community is commonly referred to as an "*urchin barren*".

Other species of sea otter prey respond similarly, at least in terms of density, size and biomass, to reduced sea otter predation. In some instances, humans eventually developed commercial fisheries for species of marine invertebrates that would likely not have been possible had sea otters not been eliminated. Examples of Pacific coast fisheries that exist (or existed), at least in part, because of sea otter removal include abalone (*Haliotis* spp), sea urchin (*Strongylocentrotus* spp.), clams (*Tivela sultorum*, *Saxidomus spp.*, *Protothaca*

sp.), crab (*Cancer* spp, *Chionoecetes* spp, *Paralithoides* spp), and spiny lobster (*Panuliris interruptus*).

Since the middle of the 20th century, sea otter populations have been rapidly reclaiming previous habitats, due to natural dispersal and reintroductions by state and federal agencies. Following the recovery of sea otters, scientists have continued to provide descriptions of nearshore marine communities and therefore have been able to provide contrasts in those communities observed before and after the sea otters return. At least three distinct approaches have proven valuable in understanding the effects of sea otters (Estes and Duggins 1995; Estes and Van Blaricom 1988; Kvitek et al 1992). One is contrasting communities over time, before and after recolonization by sea otters. This approach, in concert with appropriate controls, provides an experimentally rigorous and powerful study design allowing inference to the cause of the observed changes in experimental areas. Another approach consists of contrasting different areas at the same time, those with, and those without the experimental treatment (in this case sea otters). A third approach entails experimentally manipulating community attributes (e.g., urchin grazing) and observing community response, usually in both treatment and control areas. All three approaches currently present themselves in southeast Alaska, including Glacier Bay National Park and Preserve.

Beginning in 1965, sea otters were reintroduced into southeast Alaska (Jameson et al. 1982). Although small numbers of sea otters have been present on the outer coast of SE Alaska for at least 30 years, only in the past few years have they been found in Icy Strait and Glacier Bay proper (Pitcher 1989, J. Bodkin unpub. data). It is a reasonably safe prediction, based on data from other sites in the north Pacific, that profound changes in the abundance and species composition of the nearshore benthic invertebrate communities (including economically, ecologically, and culturally valuable taxa such as urchins, clams, mussels, and crabs) can be anticipated as sea otters reoccupy prior habitat and enter new areas. Furthermore, it is likely that cascading changes in the vertebrate fauna such as fishes, sea birds and possibly other mammals, of Glacier Bay can be expected over the next decade. It is apparent that those changes are beginning now. During 2003 we estimated that greater than 1800 sea otters were present in the Lower Bay (Figure 1 and Table 1). However, large areas of suitable sea otter habitat remain unoccupied in Glacier Bay, providing appropriate controls. The current distribution of sea otters in Icy Strait and Glacier Bay provides the setting for the use of the before/after control/treatment design that has proven so powerful elsewhere, and will permit assigning cause to changes observed in Glacier Bay as a result of sea otter colonization.

Table 1. Counts or sea otter population size estimates (*) for Lower Glacier Bay, AK.

Year	# Sea Otters	% Increase
1994	0	.
1995	5	.
1996	39	.
1997	21	.
1998	209	.
1999	384*	.
2000	554*	44.3
2001	1238*	123.5
2002	1266*	2.3
2003	1866*	47.7

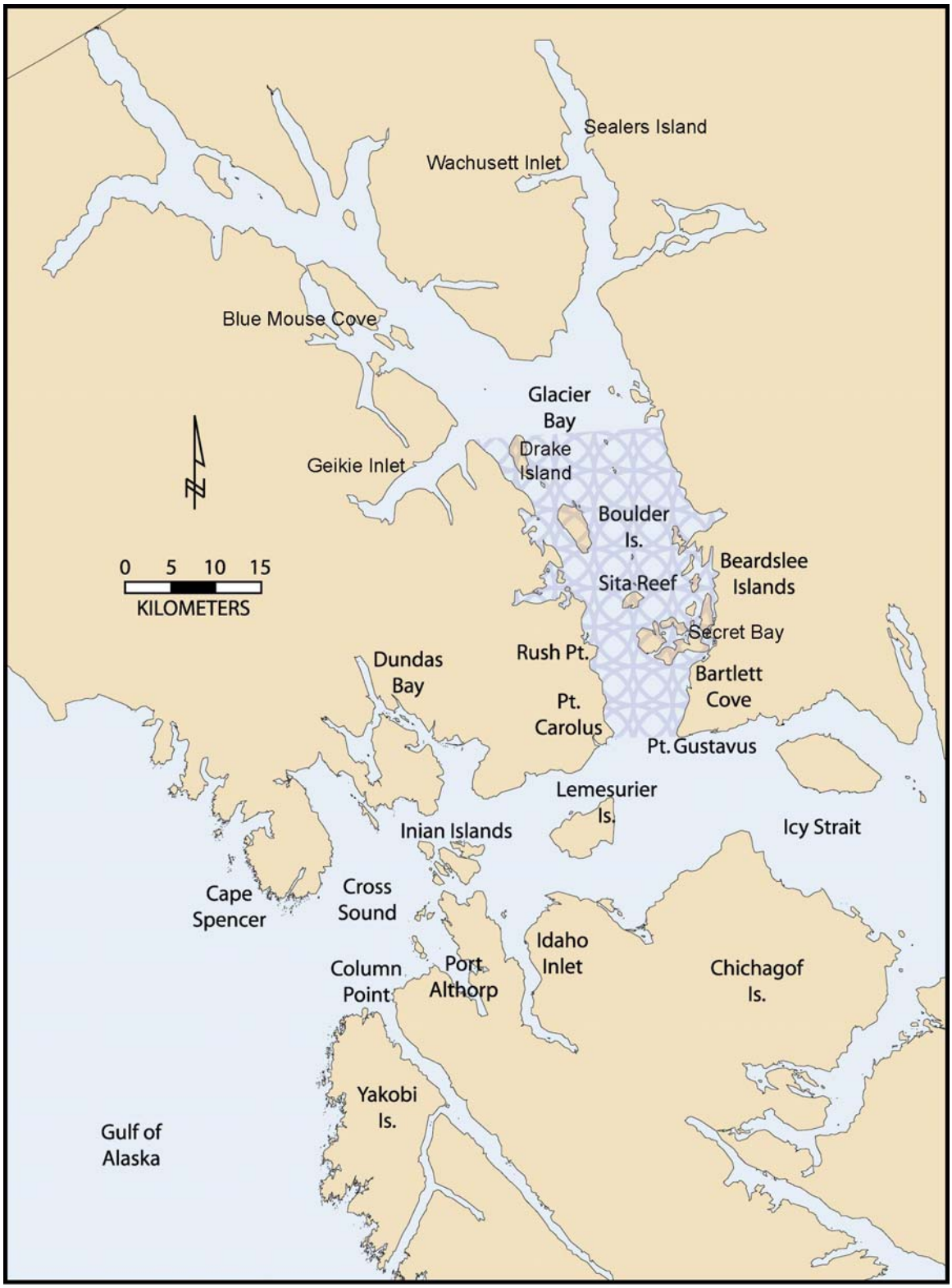

Figure 1. Study areas in Glacier Bay National Park, Icy Strait, and Cross Sound, Southeast Alaska. The Lower Bay portion of Glacier Bay is mottled on this figure.

Impacts of sea otters, if not quantified, will likely preclude or at least severely limit the ability of Park management to identify changes or cause of variation in coastal communities. At worst, Park management could misinterpret the cause of observed ecosystem changes. Infaunal bivalves currently constitute a major proportion of the biomass in benthic marine habitats of Glacier Bay (Bodkin et al. 2001, 2002, 2003). These bivalves support large populations of both vertebrate (fishes, birds, and mammals) and invertebrate (octopus and sea stars) predators. It is likely that otter foraging will result in reduced infaunal bivalve densities that will subsequently drive changes in species composition and abundance of other predator populations (Kvitek et al. 1992; 1993). Understanding the effects of sea otter predation will be critical to appropriately managing the Park's marine resources. Because the effects of sea otters will likely be large, understanding changes in the community independent of sea otters will be difficult if managers are unable to account for sea otter effects.

In 1993 the Alaska Science Center began work to understand the effects of sea otters in Glacier Bay, including study of sea otter abundance, diet and prey populations. The objective of this report is to describe studies specific to understanding community level effects of sea otter colonization in Glacier Bay, particularly trends in sea otter population, diet, and subtidal clam populations. A secondary aim of this report is to identify expected changes in benthic marine communities in Glacier Bay that may result from sea otter colonization.

This annual report presents the result of surveys of sea otter abundance and distribution completed during 1994 to 2003, a description of sea otter food habit studies from 2003 with a summary of our dietary findings over the period 1993-2003, and surveys of horse mussel (*Modiolus modiolus*) in 2003. In Appendix A, we report on long-term contrasts of benthic community composition on the outer coast at Torch and Surge Bays. This report represents the cooperative efforts of the USGS, ASC and the NPS, Glacier Bay National Park and Preserve.

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Distribution and Abundance of Sea Otters in Glacier Bay and Cross Sound

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Distribution and Abundance of Sea Otters in Glacier Bay and Cross Sound

Introduction

Surveys of sea otters are conducted to estimate distribution and abundance, and how they change over time. The results of the surveys provide one of the three critical data sets required to understand how the ecosystem responds to sea otter recolonization. We conduct two types of surveys of in Glacier Bay and surrounding waters. The first type, carried out since 1994, is designed to estimate distribution and relative abundance (count), and is referred to as a distribution survey. During distribution surveys, all otters observed are recorded on maps and search intensity is not controlled. The results of distribution surveys cannot be used as estimates of total abundance, as detection rates are not estimated and observers, aircraft, and pilots change between surveys. The intent of the distribution survey is to provide a picture of areas that are occupied and not occupied by sea otters, and to quantify relative abundance. The second survey type is an abundance survey with a systematic sampling of transects within a specific area of interest. Survey conditions are closely controlled and detection of otters is estimated independently for each abundance survey. The results of abundance surveys provide a measure of distribution, as well as an estimate of abundance, and can be used to calculate densities and trends. Although abundance surveys provide more information, they are more costly. Abundance surveys in Glacier Bay were completed annually from 1999-2003.

Methods

Distribution Surveys

All shoreline habitats in Cross Sound, Icy Strait and Glacier Bay where sea otters occur, out to at least the 40 m bathymetric contour, were surveyed in 1994-2001 (Table 2). In 2002, a distribution survey was not conducted because an aerial survey of abundance of northern SE Alaska was conducted. In 2003, a distribution survey of Icy Strait and Cross Sound was completed on 28th August. Distribution data for Glacier Bay in 2003 were obtained from the May abundance survey for that year. A single flight track was flown parallel to shore where the 40 m depth contour was within 1 km of the shoreline. When the 40 m depth contour was greater than 1 km from shore (e.g., Dundas Bay, Gustavus Flats), multiple tracks were flown parallel to the shore. Surveys were flown at the slowest speed safe for the aircraft in use, and at the lowest safe altitude.

Abundance Surveys

Abundance surveys are designed to provide accurate estimates of sea otter abundance by estimating the proportion of animals that are not detected. Aerial surveys follow methods outlined by Bodkin and Udevitz (1999) and included in detail in Appendix B, and consisted of two components: 1) strip transects of 400 m width, and 2) intensive search units to estimate the probability of detecting otters along strips. Sea otter habitat is sampled in two strata, an expected high and low density, distinguished by distance from shore and bathymetry (Figure 2). Survey effort is allocated proportional to expected abundance by systematically adjusting spacing of transects within each stratum. Transect end points are identified by latitude/longitude coordinates in ARC/INFO and displayed visually in an aeronautical global positioning system (GPS) in the aircraft. A single observer surveys transects at an airspeed of 65 mph (29 m/sec) and an altitude of 300 ft (91 m). Strip transect data include date, transect number, location, group size and

activity. A group is defined as one or more otters separated by less than 4 m. Pups are combined with adults for population estimation because large pups are often indistinguishable from adults and small pups can be difficult to sight from aircraft. All group locations are digitized by survey into ARC/INFO coverages (Figure 3). Intensive searches were conducted systematically along strip transects to estimate the proportion of animals not detected during strip counts.

The survey design consisted of 32 strip transect projections constructed in a GIS coverage (ARC/INFO) comprised of 4 possible sets of high density transects and 8 sets of low density transects (Figure 2). Transects are charted throughout Glacier Bay, but this survey focused only on the lower Bay (Figure 2) since sea otters do not yet occur in the upper Bay. The 2003 lower Bay survey area included 272 km^2 of high-density stratum and 278 km^2 of low-density stratum. Five replicates were randomly selected from the 32 possible combinations. Between 5 and 10 May 2003, a single observer surveyed five replicates from a Bellanca Scout.

Results

Distribution Surveys

Distribution surveys in Cross Sound and Icy Strait were conducted each year from 1994-2003, with the exception of 2002 (Table 2). In June 2002, we conducted an abundance survey of northern SE Alaska, from Cape Ommaney on Baranof Island to Icy Pt. north of Cape Spencer and included Cross Sound and Icy Strait. Because this survey was designed to estimate abundance, results of numbers of otters observed are not comparable to prior years' distribution surveys and are not included in Table 2. Sea otter distribution in Cross Sound and Icy Strait in 2003 was similar to that observed in previous several years. Primary changes in sea otter distribution from 1994-2003 include population expansion into Glacier Bay and east of Gustavus (Porpoise Island and Excursion Inlet). Relatively little expansion has occurred along the south side of Icy Strait.

Abundance Surveys

The five replicate surveys required approximately 50 hours of flight time to complete, including transit to and from Bartlett Cove. The mean of these five individual replicates yielded an adjusted population size estimate of 1,866 (se = 458) (Table 2). All group locations were digitized into ARC/INFO coverages (Figure 3).

The estimate of 1,866 sea otters in 2003 represents a 47.4% increase over the 2002 estimate (Table 1). The 2002 estimate represented only a 2% increase over the 2001 estimate. In contrast, the 2001 estimate represented an increase of 123% above the 2000 estimate.

In 2002, we completed an abundance survey that included all areas of known sea otter occupation in northern Southeast Alaska (from Cape Ommaney on Baranof Island and north to Cape Spencer, including Cross Sound and Icy Strait). Our estimate of sea otter abundance in this survey area (excluding Glacier Bay) was 1,922 (se=317). Including the 1,266 sea otters estimated in Glacier Bay in 2002, the total sea otter population in northern Southeast Alaska is 3,188. The most recent prior sea otter survey of northern Southeast Alaska was conducted in 1987 (Pitcher 1989) resulted in a count of 2,248. It

appears as though growth in sea otter abundance in northern waters of Southeast Alaska since 1987 is largely manifested in recolonization and increase within Glacier Bay. In 2003, we completed a similar abundance survey of southern Southeast Alaska (from Cape Ommaney south to Cape Chacon on Prince of Wales). The abundance estimate from that survey was 5,844, resulting in a Southeast Alaska sea otter population estimate of 9,032.

In 2003 we also conducted skiff surveys of sea otter abundance in Torch Bay, along the outer coast of Glacier Bay National Park and Preserve, and in Surge Bay on Yakobi Island, south of Cross Sound (Appendix A). Sea otter abundance was relatively low at both locations. We observed 40 adults and 17 pups at Torch Bay and 26 adults and 4 pups at Surge Bay (Table A3).

Table 2. Results of Cross Sound/Icy Strait sea otter distribution surveys and abundance surveys in Glacier Bay proper in 1999 - 2003 (abundance estimates bolded). Counts are presented as # adults/# pups, while a period means 'no data'. Abundance estimates include pups (Bodkin and Udevitz 1999). (* 2001 estimate of 1,590 revised from 2001 reported value following re-analysis).

Date	1994 May	1995 May	1996 Mar	1996 Aug	1997 May	1998 Mar	1999 May	2000 May	2001 Jun	2002 Jun	2003 Jun/Aug
Plane			172	172						Scout	Scout 206
Survey Area											
Spencer – Pt Wimbledon	69 /20	60 /9	31 /4	19 /2	43 /3	8	6	7	52 /27	.	18
Pt Wimbledon -Pt Dundas	37 /1	23	18	52	24	52	27	46	38 /2	.	60 /2
Pt Dundas – Pt Gustavus	0	12 /1	41 /1	178 /4	10	1	17	0	8 /1	.	7
Glacier Bay Proper	.	5	39	0	21	209	**384**	**554**	**1238***	**1266**	**1866**
Excursion Inlet	.	.	.	.	.	7	1	0	0	.	0
Pt Couverden	.	.	.	.	.	2	.	0	0	.	0
Pt Gustavus Porpoise Is	29	94 /1	73	2 /1	161	8	18	57	129 /1	.	15
Cannery Pt -Crist Pt	0	0	0	0	0	0	0	.	.	.	0
Crist Pt – Gull Cove	55	15 /3	30 /1	17 /1	92 /15	23	97 /3	2	62 /19	.	38
Lemesurier	33 /8	62 /23	56 /2	47 /8	143 /32	10	67 /17	11	76 /33	.	10
Gull Pt – Pt Lavinia	77	81	48	141	94	3	90	139	95	.	28
Inian Is	31 /19	36 /16	11 /1	30 /12	31 /8	10	18 /4	9	46 /16	.	9
Pt Lavinia-Column Pt	100 /31	159 /73	42 /3	94 /21	148 /25	31	21 /7	88 /11	84 /26	.	53 /3
TOTAL	**431 /69**	**547 /126**	**389 /12**	**580 /49**	**767 /83**	**364**	**746 /31**	**913 /11**	**1828 /125**	**1266**	**2104 /5**

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Discussion

The results of the sea otter distribution and abundance surveys suggest a large-scale pattern of population redistribution and growth in the region of Icy Strait and Glacier Bay. As recolonization of previously occupied habitat has occurred in Icy Strait over the past five years, sea otters had at least two choices in their direction of emigration, either east in Icy Strait, toward Lynn Canal, or north into Glacier Bay (Figure 1). Our distribution and abundance survey data suggest movement of portions of the Icy Strait/Cross Sound sea otter population into Glacier Bay beginning in the mid 1990's, and continuing through 2003.

The 2003 abundance estimate for Glacier Bay was greater than the 2002 estimate by 47% (Table 1). The distribution of sea otters in Glacier Bay and Cross Sound/Icy Straits in 2003 was similar to prior years. The largest concentrations of sea otters in Glacier Bay continue to be in areas surrounding Boulder Island, Flapjack Island, and Sita Reef (Figure 3). Point Carolus also continues to harbor large groups of sea otters. The sea otters counted around Boulder Island likely are predominantly male as few pups were observed and large groups of males have been observed here in the past. Meanwhile, at nearby Sita Reef, females with pups were abundant (Figure 3).

The number of sea otters occupying Glacier Bay is increasing rapidly, from a count of 5 in 1995 to an estimated 1,866 in 2003 (Table 1). This increase is undoubtedly due to both immigration of adults and juveniles and reproduction by females in the Bay, as evidenced by the increasing number of dependent pups. Annual increases in abundance observed in 2003, 2001 and 2000 are well above the theoretical maximum population increase of about 19% (Estes 1990) and previously observed rates of increase in SE Alaska (Bodkin et al. 1999).

Since 1999, the sea otter population in Glacier Bay has been increasing at an average rate of 49% per year. In contrast, since 1994, the average annual rate of change of sea otter abundance in Southeast Alaska as a whole has been -3%. At present, the Glacier Bay sea otters are the only population in Alaska known to be increasing.

This rapid increase in sea otters within the Park has serious and immediate consequences to management of marine resources in Glacier Bay. Predation by sea otters on a variety of invertebrates, including several species of crab, clams, mussels, and urchins will have profound effects on the benthic community structure and function of the Glacier Bay ecosystem (see discussion on foraging observations). Continuing sea otter surveys and studies of benthic communities will provide valuable information to those responsible for managing Park resources.

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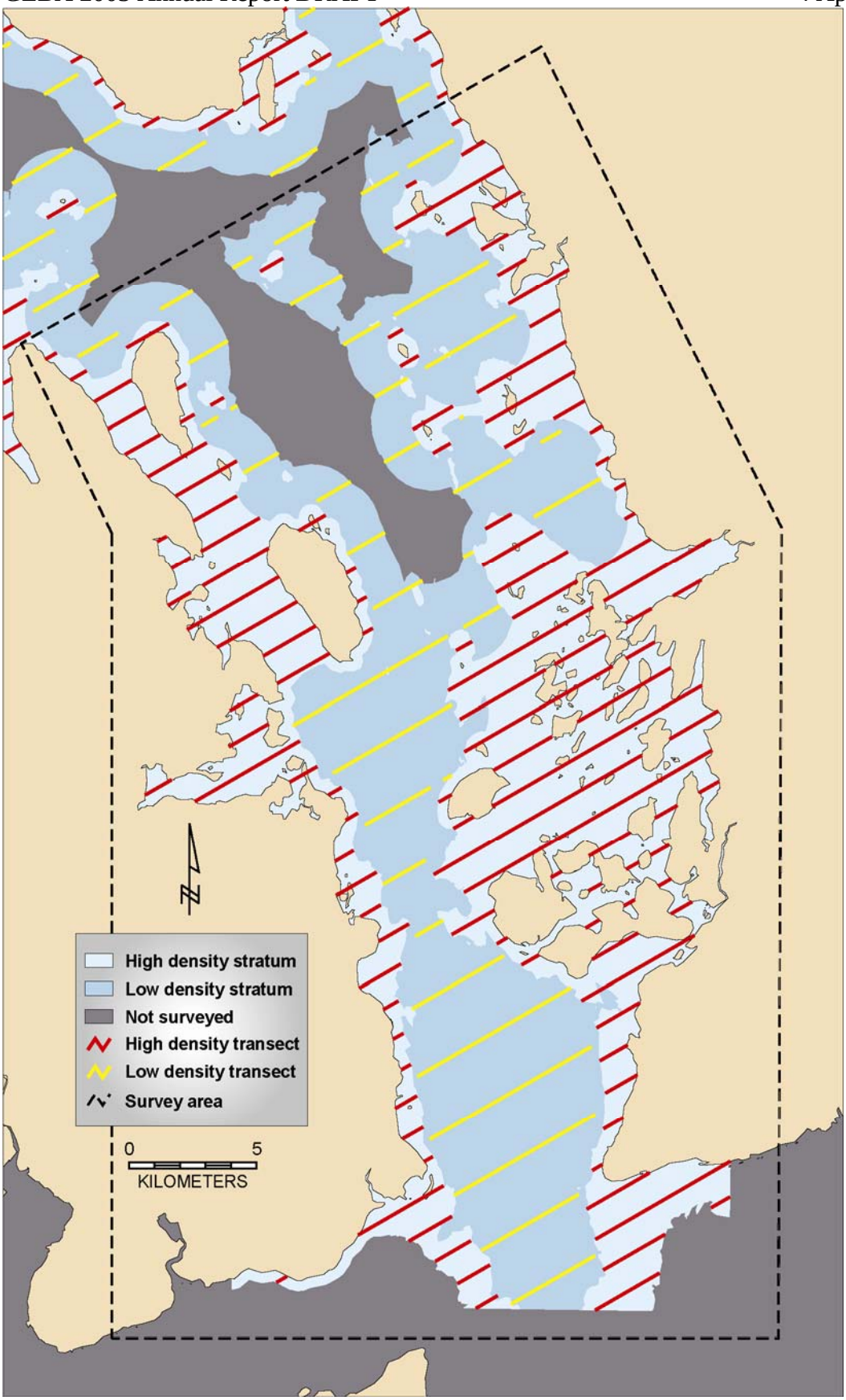

Figure 2. One of five transect designs used during a sea otter abundance aerial survey in Glacier Bay National Park, May 2003.

Figure 3. Sea otter group locations from 5 replicate aerial abundance surveys in Glacier Bay National Park, May 2003 (spot size proportional to group size).

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Sea Otter Foraging Behavior in Glacier Bay

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Sea Otter Foraging Behavior in Glacier Bay

Introduction

Observations of sea otter foraging behavior in 2003 were carried out in Glacier Bay to determine prey types, numbers, and sizes consumed by sea otters. Foraging data from nearly 5,000 dives, collected from 1993 to 2000 in Southeast Alaska, are reported in the 2000 Annual Report (Bodkin et al. 2001), data from the ~450 successful dives observed in 2001 in Glacier Bay are reported in the 2001 Annual Report (Bodkin et. al. 2002), and data from >200 successful dives observed in 2002 in Glacier Bay are reported in the 2002 Annual Report (Bodkin et. al. 2003). Here, we re-analyze all the Glacier Bay data (1993-2003) in order to present a broad picture as well as some annual and site specific patterns.

Foraging work presented in this report consist primarily of shore based observations at sites within Glacier Bay. Occasionally, if conditions allowed, foraging observations were collected from the deck of the R/V *Alaskan Gyre*. Observations of foraging sea otters provide information on food habits, foraging success (proportion successful feeding dives), and efficiency, based on prey numbers, types and sizes obtained by feeding animals. Data on sea otter food habits and foraging efficiency will prove useful when examining differences (if any) in prey densities, and size-class distributions between areas impacted by sea otters and those not affected. These data will also aid managers in identifying resources and habitat crucial to the Park's sea otter population.

Methods

Sea otter diet was estimated during shore- or boat-based observations of foraging otters following a standard protocol (Appendix B). Observations are limited to sea otters feeding within approximately 1 km of the observation location. High power telescopes (Questar Corp., New Hope, PA) and 10X binoculars were used to observe and record prey type, number, and size during foraging "bouts" of focal animals. A "bout" consists of observations of a series of dives by a focal animal while it remains in view and continues to forage (Calkins 1978). Prey sizes are estimated relative to an estimated mean sea otter paw width. As we collect additional morphometric data in other studies, this reference value can change. Sea otters in the study area are generally not individually identifiable. Therefore, individuals may have been observed more than once without our knowledge. To minimize this potential bias, foraging observations were made throughout the major study areas, and attempts were made to record foraging observations from as many sites and as many individuals as possible.

Site and focal animal selection

Information regarding feeding locations for sea otters was gathered during travels throughout the Park for other aspects of this study (see Sea Otter Surveys) as well as from Park personnel and other visitors. Foraging data were collected from as many identified feeding locations as possible. If more than one foraging animal was detected at any particular observation site, then the first animal sampled was randomly selected, and after completion of the bout the process repeated with the remaining animals. Observations continued at the site until each available animal was observed for a maximum of 30 dives, or otters had stopped foraging or left the area. Data were not collected on dependent pups.

Data collected

For each bout, the date, site, focal animal's location, observer, estimated age (adult or juvenile), sex, and reproductive status (independent or with pup) were recorded. For each dive, observers recorded starting and ending foraging bout times, dive time (time underwater), surface interval (time on the surface between dives), dive success (prey captured or not), prey identification (lowest possible taxon), prey number, and prey size category (see Appendix B, revised since 2001 Annual Report prepared). Individual dives within a bout were numbered sequentially, and individual bouts were uniquely numbered within the data set.

Analysis

For each site where foraging data were collected, we calculated (1) prey composition as the proportion of dives that resulted in the recovery of at least one of six different prey types (clam, crab, mussel, urchin, other, or unidentified); (2) mean number of prey items captured per dive; (3) mean size of prey captured per dive; and (4) success rate (prey brought to the surface or not, excluding dives with unknown outcomes). We report summary statistics (mean and sd where appropriate) for the latter three variables, on a per bout basis.

Results

Success Rate

In 2003 we observed 873 foraging dives, of which 810 were successful (94%), 51 were unsuccessful and 12 were of undetermined outcome. During 1993-2003, we observed 4,258 sea otter foraging dives; 3,770 where the focal otter recovered at least one prey item (91% success), 366 that were unsuccessful, and 122 dives with unknown outcomes (Table 3). Foraging observations were collected from many locations and grouped into 18 sites (Figure 4). Observations from these 18 sites may be further grouped or split out as more observations are collected and as sea otter distribution surveys warrant. Since 1993, we have observed sea otters feeding on at least 35 different prey items in Glacier Bay including 14 species of bivalves, 6 crab species, 4 mollusks, 6 echinoderms, and rare items such as worms, fish, sponges, shrimp, and octopus (Table 4).

Table 3. Sea otter foraging success rates in Glacier Bay and sites within Glacier Bay, 1993-2003.

Area/Site	Year	Success Rate	N (# dives observed)
GB-All Sites	1993-2003	91%	4,136
GB-All Sites	1993	91%	471
GB-All Sites	1996	93%	435
GB-All Sites	1997	89%	222
GB-All Sites	1998	95%	467
GB-All Sites	1999	93%	87
GB-All Sites	2000	90%	779
GB-All Sites	2001	86%	533
GB-All Sites	2002	87%	281
GB-All Sites	2003	94%	861

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Table 3 continued…

Area/Site	Year	Success Rate	N (# dives observed)
Beardslee	1993-2003	84%	607
Berg	1993-2003	98%	98
Boulder	1993-2003	94%	614
Carolus	1993-2003	94%	405
E of Boulder	1993-2003	94%	49
Fingers	1993-2003	86%	125
Flapjack	1993-2003	94%	142
Leland	1993-2003	92%	52
Lester	1993-2003	99%	71
Marble	1993-2003	86%	83
N Beardslee	1993-2003	90%	475
Pt. Gustavus	1993-2003	91%	471
Rush/Ripple	1993-2003	95%	404
Secret	1993-2003	83%	172
Sita	1993-2003	94%	203
Strawberry	1993-2003	97%	39
SE Beardslee	1993-2003	96%	69
Young	1993-2003	98%	57

Table 4. Prey items observed being consumed by sea otters in Glacier Bay, 1993-2003.

Bivalves: Clams
Clinocardium nuttallii
Entodesma navicula
Gari californica
Mactromeris polynyma
Macoma spp.
Mya arenaria
Mya truncata
Protothaca staminea
Saxidomus gigantea
Serripes groenlandicus
Bivalves: Mussels
Modiolus modiolus
Mytilus trossulus
Bivalves: Others
Pododesmus macroschisma
Scallop
Gastropods:
Fusitriton oregonensis
Neptunea spp.
Limpet
Mollusks-Others:
Cryptochiton stelleri
Octopus dofleini

Echinoderms: Stars
Gorgonocephalus caryi
Ophiuroid sp.
Pycnopodia helianthoides
Solaster spp.
Echinoderms: Urchins
Strongylocentrotus droebachiensis
Echinoderms: Other
Cucumaria fallax
Crustaceans:
Cancer magister
Chionoecetes bairdi
Paralithodes camtschatica
Paguridae spp.
Pugettia spp.
Telmessus cheiragonus
Pandalus sp.
Other:
Worm: *Echiurus* spp.
Porifera: Sponge
Chordate: fish

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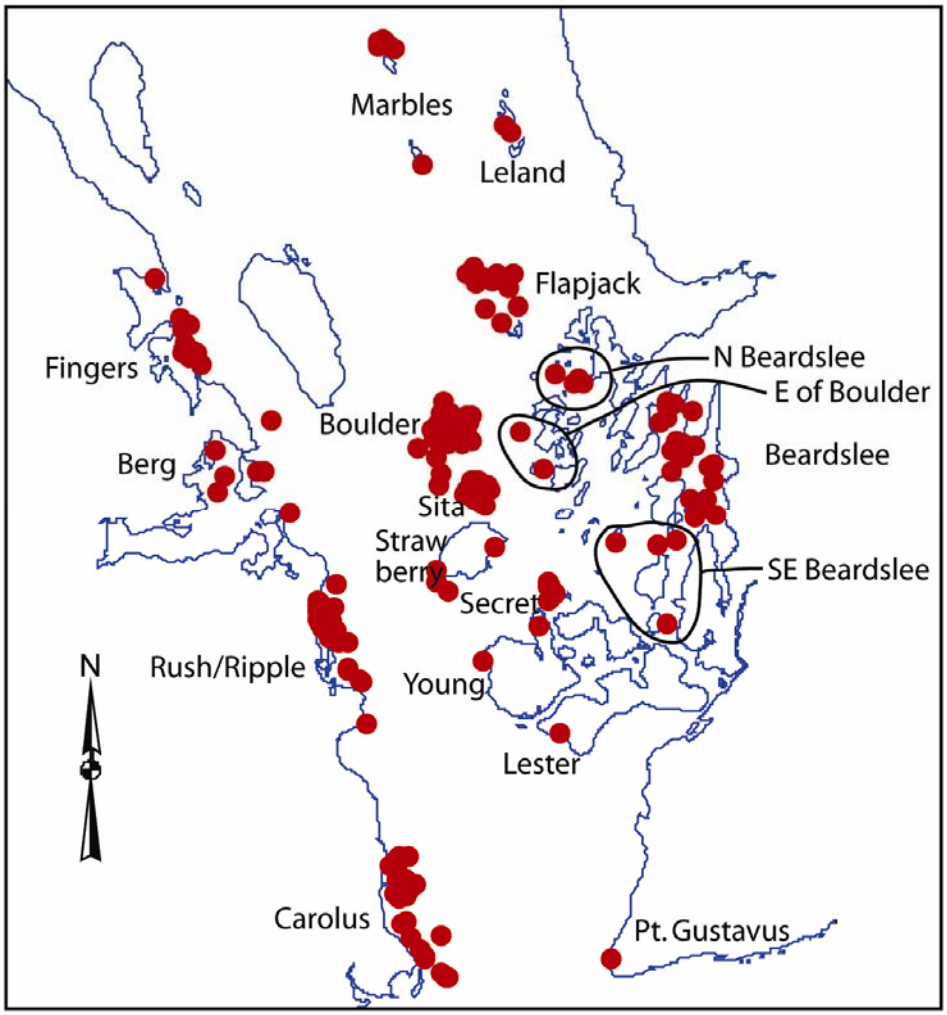

Figure 4. Locations of sea otter foraging observation data collection, 1993-2003. Each red dot represents a set of observations that have been grouped into the 18 site names noted on the map.

Prey Composition

Sea otter diets in 2003 consisted of 31% clam, 31% mussel, 3% crab, 14% urchin, 6% other, and 14% unidentified (Table 5). Of the 3,770 successful foraging dives we observed in Glacier Bay in 1993-2003, 40% resulted in retrieval of clam species, 21% in mussel, 4% in crab, 16% in urchin, 5% other, and 13% unidentified (Figure 5, Table 5).

Prey composition varied among sites (Figure 6 A-D). For example, at the 6 sites where >350 successful dives were observed between 1993 and 2003 (Carolus, Rush/Ripple, Pt. Gustavus, Beardslee, N Beardslee, and Boulder), the percentage of dives where clams were retrieved ranged from 14% to 76%, mussels from 0 to 44%, crabs from 1 to 12%, and urchins from 1 to 61%. Among years, 4 sites (Carolus, Rush/Ripple, Beardslee, and Boulder) had at least 2 years each with >=100 successful dives observed. At Beardslee and Rush/Ripple, prey composition was relatively similar across years, whereas at

Boulder and Carolus, prey composition varied to a greater extent across years (Figure7 A-B).

Table 5. Percentage of dives with each prey type present, 1993-2003. 'Other' category consists of snails, starfish, worms, octopus, fish, sponge, sea cucumber, chiton, and non-clam/mussel bivalve. 'Unid' category represents prey that could not be identified due to visual obstruction. Unsuccessful dives and those with unknown success were not included in #dive values. Number of dives in this table can total more than the total number of successful dives (3,770) reported earlier because more than one prey item can be retrieved per dive.

All GB sites Year (# dives)	Clam	Crab	Mussel	Urchin	Other	Unid
All yrs (4,015)	40%	4%	21%	16%	5%	13%
1993 (441)	14%	4%	0%	61%	7%	14%
1996 (412)	34%	5%	45%	7%	4%	5%
1997 (205)	80%	9%	0%	1%	6%	3%
1998 (486)	40%	3%	16%	13%	6%	22%
1999 (86)	85%	3%	5%	2%	1%	3%
2000 (770)	42%	3%	21%	15%	4%	16%
2001 (480)	62%	9%	15%	4%	4%	7%
2002 (261)	34%	3%	25%	10%	6%	21%
2003 (874)	31%	3%	31%	14%	6%	14%

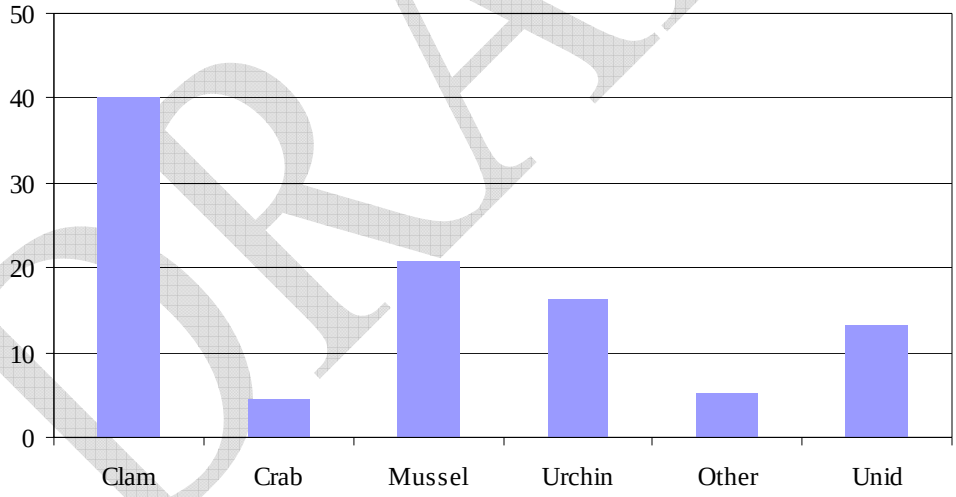

Figure 5. Prey composition of 3,770 successful sea otter foraging dives in Glacier Bay, 1993-2003. This figure shows the percentage of all dives with a successful outcome (prey retrieved) that include each prey item. For example, sea otters retrieved at least one clam on 40.1% of their dives in Glacier Bay.

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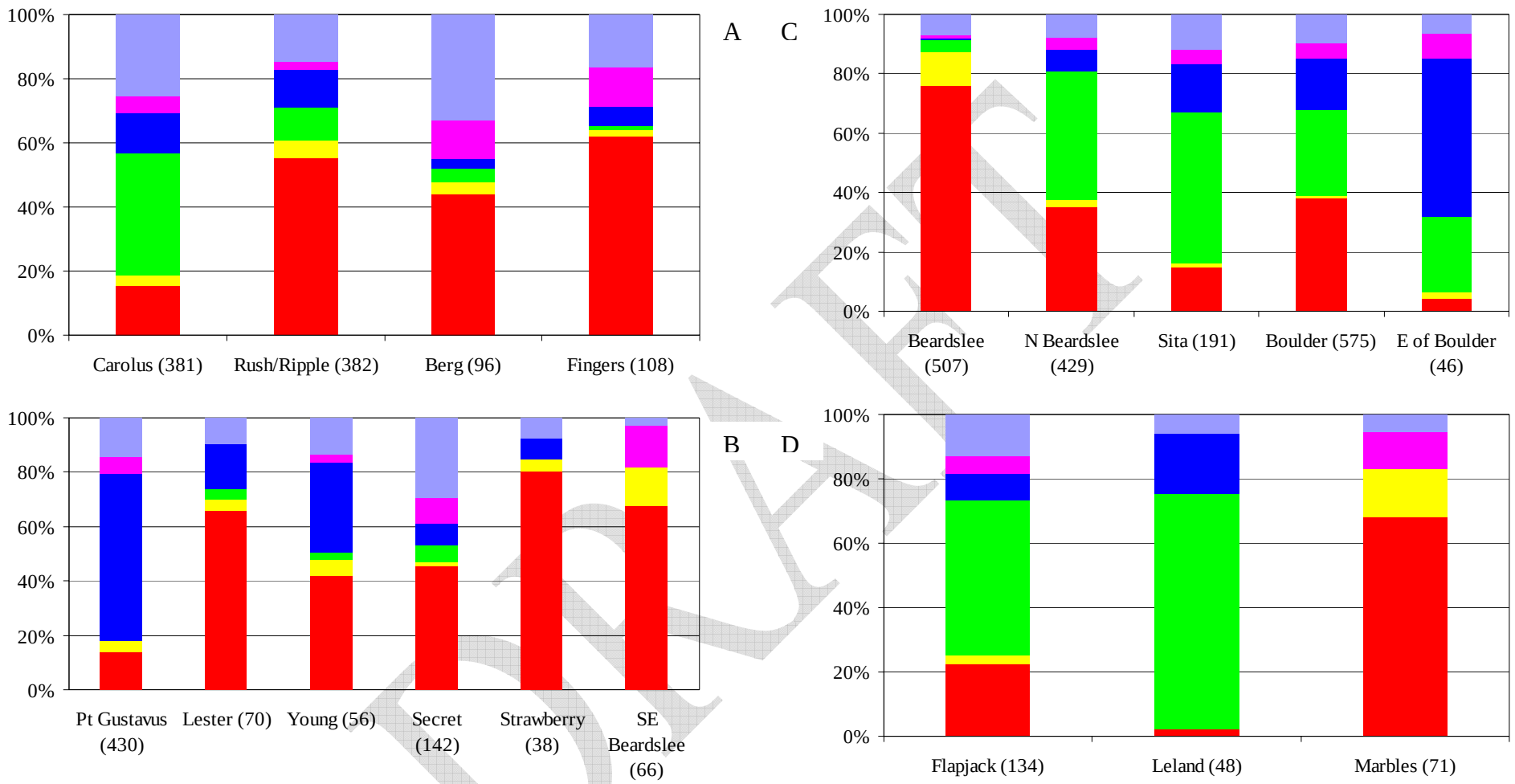

Figure 6 A, B, C, D. Prey composition of sea otter foraging dives in Glacier Bay, for 18 sites (# dives) where data was collected. See Figure 4 for site locations. This figure shows the percentage of all dives with a successful outcome (prey retrieved) that include each prey item. 'Other' includes prey items such as snails, stars, non-clam/mussel bivalves, worms, fish, chitons, shrimp, sponges, sea cucumbers, and octopus. 'Unid' repersents prey items not identified due to visual obstruction of some variety.

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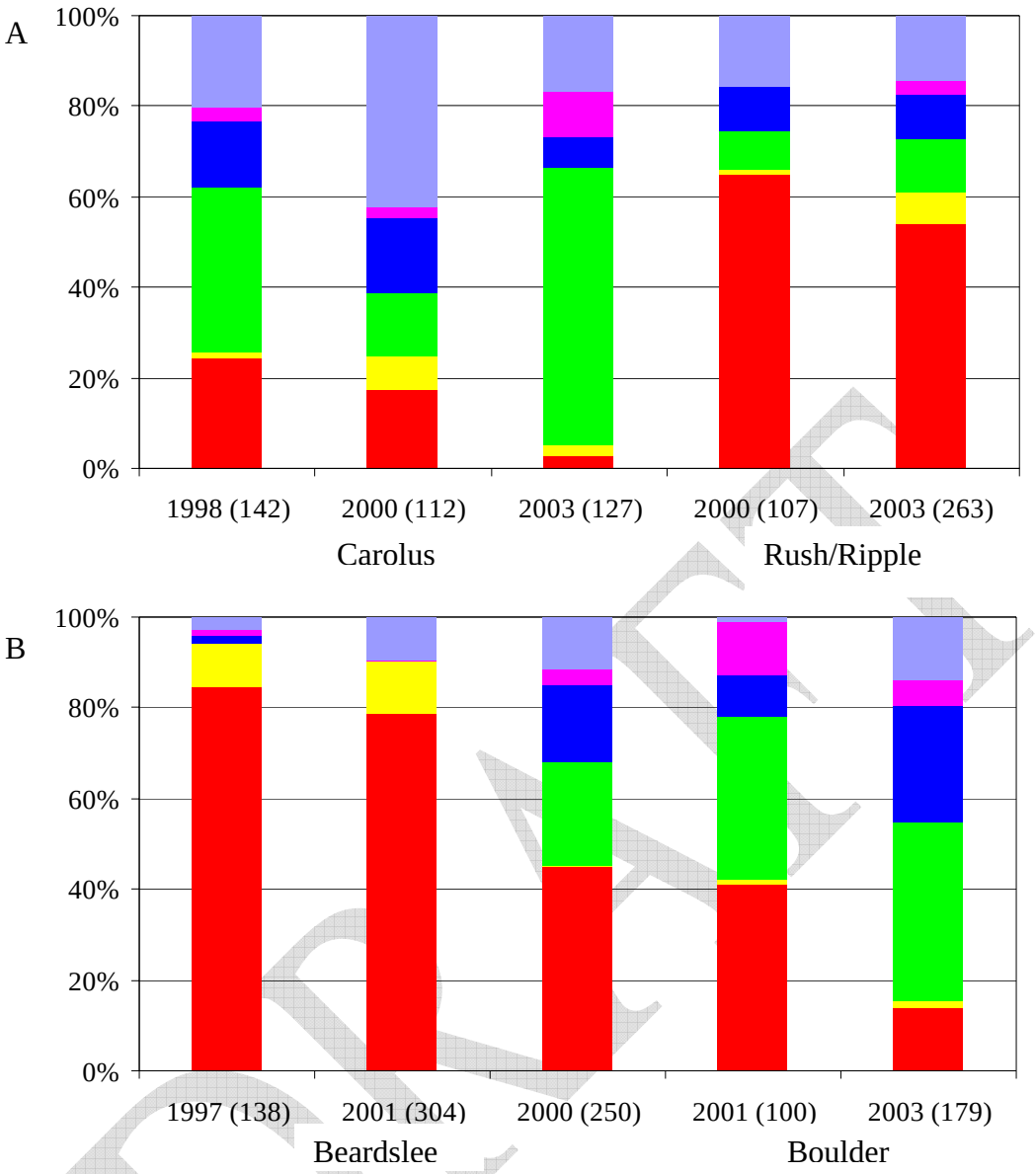

Figure 7 A, B. Prey composition of sea otter foraging dives in Glacier Bay, for 4 sites where >100 successful dives were observed in more than 1 year (# dives). See Figure 4 for site locations. This figure shows the percentage of all dives where prey was retrieved for each prey category.

Prey Number and Size

The mean number of prey/dive and mean prey sizes varied by prey type during 1993-2003 (Figures 8, 9). In Glacier Bay, on average, sea otters recovered 2.5 (1.7) prey items per dive (653 bouts). Sea otters retrieved an average (sd) of 1.9 (1.0) clams, 1.2 (0.5) crab, 2.5 (1.7) mussels, or 4.1 (2.6) urchins per dive. The mean size (sd) of clams recovered was 70.3(24.1) mm, crabs: 96.7 (38.7) mm, mussels: 107.3 (25.5) mm, and urchins: 56.4 (26.6) mm. Size frequency distributions were calculated by summing the

number of bouts in each size category, where size per bout is the mean size of all similar prey items retrieved on all dives within the bout (Figure 10).

In 2003, the mean number of prey/dive and mean prey sizes varied by prey type (Figures 8, 9). On average, sea otters recovered 3.0 (1.9) prey items per dive (157 bouts). The numbers of prey items retrieved per dive were similar to the 1993-2003 values. Sea otters retrieved an average (sd) of 2.0 (1.0) clams, 1.7 (0.9) crab, 2.7 (1.8) mussels, or 4.4 (2.3) urchins per dive. The mean sizes of prey items recovered per dive were smaller in 2003 than in the entire sampling period, 1993-2003. The mean size (sd) of clams recovered was 59.3(20.4) mm, crabs: 58.3 (31.8) mm, mussels: 100.4 (22.5) mm, and urchins: 44.5 (23.1) mm.

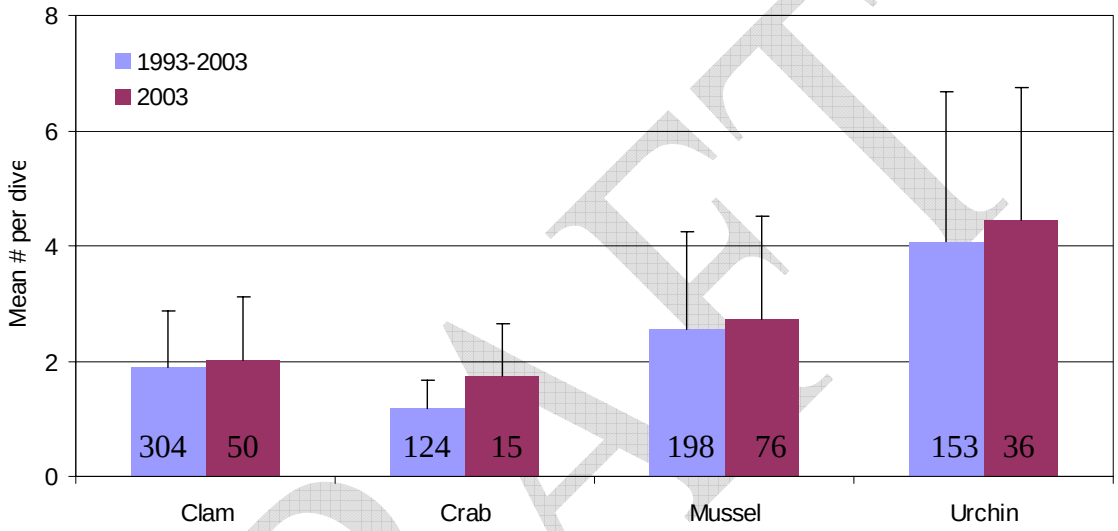

Figure 8. Mean number per dive and standard deviations of the primary prey items recovered by sea otters during observations of foraging in Glacier Bay, 1993-2003. Numbers in bars indicate number of bouts.

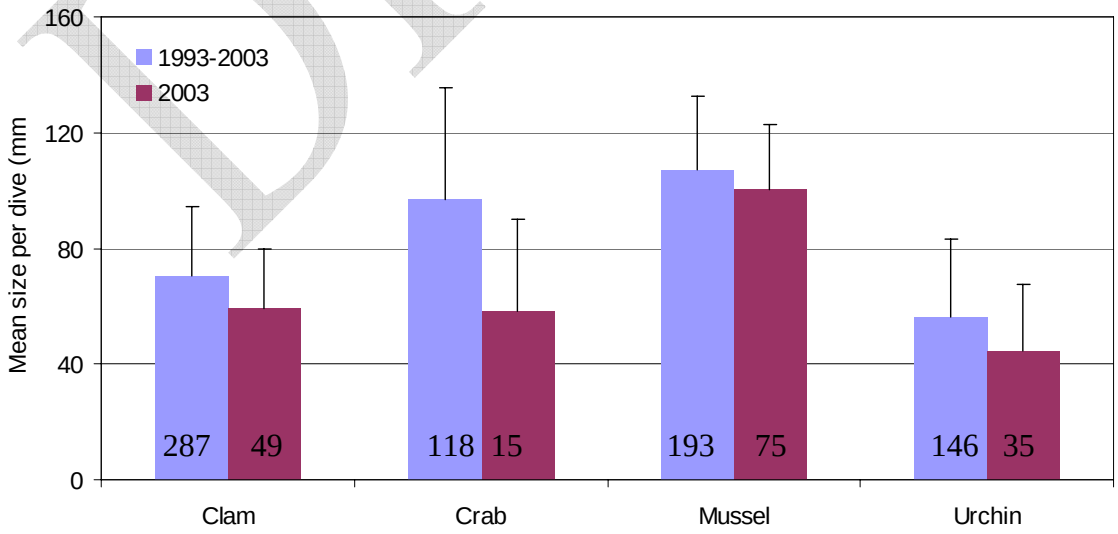

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Figure 9. Mean size and standard deviations of the primary prey items recovered by sea otters during observations of foraging in Glacier Bay, 1993-2003. Numbers in bars indicate number of bouts.

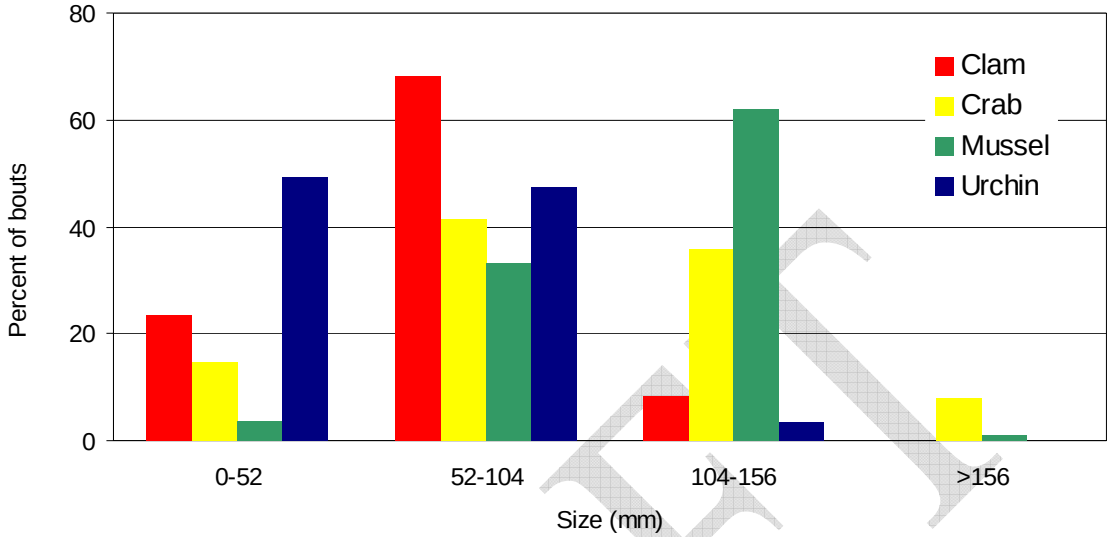

Figure 10. Proportion of foraging bouts (1993-2003) that had mean prey size/dive in each of four size categories. Size categories were pulled from forage observation data collection protocols and are based on the mean size of a sea otter paw width (data obtained from sea otter capture studies): Size 1 = 0-52 mm, Size 2 = 52-104 mm, Size 3 = 104-156 mm, and Size 4 > 156 mm.

Discussion

Sea otters we observed are foraging with an average success rate of about 91% in Glacier Bay. This value exceeds the range of values reported for California and Alaska of 70-90% (Riedman and Estes 1990, Doroff and Bodkin 1994). Perhaps more importantly, in Glacier Bay they are recovering large, calorically valuable and often multiple prey. The rapid rate of energy acquisition likely results in reduced foraging times required to obtain necessary calories, with the consequence of additional time available for other behaviors, such as traveling and resting.

The diet of sea otters in and around Glacier Bay consists largely of invertebrates that reside in unconsolidated sediments such as mud, sand, gravel or cobble (Tables 4, 5). Bivalve clams dominated the diet at most sites, although in some areas other prey were more important components of the diet. For example, at Leland Is., Sita reef, Flapjack Is, and Pt. Carolus, horse mussels (*M. modiolus*) dominated the diet. At Pt. Gustavus green urchins (*S. droebachiensis*) dominated at the diet (Figure 6). It seems likely that dietary variation among sites is at least in part a consequence of spatial variation in the species composition and densities of invertebrate prey populations.

Some patterns of changing diet within sites over time are evident in the data (Figure 7). At Boulder Is. clams declined from > 40% in 2000, to less than 20% in 2003. During that same time at Boulder Is. horse mussels increased from about 20% to about 40% of the diet. The extent to which these patterns reflect temporal changes in prey populations, or

differences in sampling is unknown. However, it may be reasonable to assume that persistent sea otter foraging will result in changes in prey populations over time, as evident elsewhere in rocky marine habitats (Estes et al. 1974, VanBlaricom and Estes 1988, Estes and Duggins 1995).

There is also evidence of reductions in the sizes of prey recovered in 2003, compared to all years (Figure 9). It is likely that some of the reduction in mean prey sizes observed in 2003 is the result of sea otter predation in prior years. As additional years data are collected at sites that remain occupied we should be able to better describe such trends. Our studies of intertidal and subtidal prey populations, in conjunction with foraging observations will allow us to determine the extent to which sea otter foraging has contributed to changes in benthic communities.

Our understanding of processes that affect coastal marine communities, particularly in unconsolidated sediment habitats, is relatively poor. Continued observations of sea otter foraging in Glacier Bay as colonization continues will provide a critical component to our understanding of how sea otter foraging affects coastal marine communities.

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Horse mussel (*Modiolus modiolus*) sampling in Glacier Bay

Photo by Andrew J. Martinez

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Horse Mussel (*Modiolus modiolus*) sampling in Glacier Bay

Introduction

Our efforts to sample sea otter prey populations in Glacier Bay prior to sea otter recolonization initially focused on intertidal clams and urchins (Bodkin et al. 2000). In 2000 and 2001 we expanded sampling to subtidal areas, but still concentrated on clams and urchins (Bodkin et al. 2001, 2002). Our decision to sample clam and urchin populations was predicated on prior work, and our own observations of the high frequency of these taxa in the sea otters diet in soft-sediment habitats (Kvitek et al. 1993, Doroff and DeGange 1994). Our observations of sea otter foraging during early stages of recolonization in Glacier Bay identified the horse mussel (*Modiolus modiolus*) as an important dietary component (Bodkin et al. 2000). On average, horse mussels were recovered in 18% of the 2,399 foraging dives we observed prior to 2001 (Bodkin et al. 2000). At two locations where sea otters established early occupancy, NW Beardslee Is. and Sita Reef, horse mussels were observed on 47% of the foraging dives. The horse mussels being consumed were large, averaging more than 80 mm in total length (Bodkin et al. 2000), and often gravid. Because of the high frequency of horse mussels in the otters' diet, and the relatively large caloric contribution to the otters' metabolic budget, in 2003 we began sampling horse mussel beds in areas not yet colonized by sea otters.

Species Description

Modiolus modiolus (Linnaeus, 1758) Northern Horse mussel. Occurs attached to rock, shell, or gravel, from low intertidal to depths of 200-300m. In the North Pacific *Modiolus* ranges from Monterey, CA to the Arctic Ocean and west to Japan. Size to 23 cm (9 in), and age to > 25 years. Can stabilize sediments and form large biogenic reefs up to several meters high through attachment of sediments, shell materials and live mussel with byssal threads. Important as a filter feeder in transporting organic matter from the plankton to the benthos. Recruitment may be sporadic and juveniles are preyed upon by crabs and sea stars.

Methods

Site Selection

Work in 2003 was largely exploratory, in that locations of *Modiolus* beds not affected by sea otter predation were largely unknown. Initial efforts to locate potential *Modiolus* beds included reviewing notes from previous subtidal surveys and reconnaissance dives.

Our goal in 2003 was to locate 8-10 *Modiolus* beds in lower Glacier Bay that had not been depredated by sea otters so we could estimate density and biomass in the absence of sea otters. Site selection considerations included the following criteria: 1) proximity to areas occupied by sea otters, 2) spatial separation from other sites, 3) relatively high *Modiolus* densities, as determined by the search method detailed below. Due to the rapid increase in the Glacier Bay sea otter population, our search and sampling efforts in 2003 were concentrated in the lower Bay. Because no sites were selected randomly or systematically, we do not make inference to areas beyond each site sampled.

We used a fisheye underwater drop camera or divers to locate the presence of *Modiolus* beds. Searching the benthos with a drop camera made it possible to scan the bottom quickly and cover more area than we could via SCUBA divers. Due to the logistical

constraints of underwater sampling at deeper depths, we narrowed our search to subtidal habitats less than 15 meters deep at high water, even though sea otters are capable of diving to depths of 100 m (Newby 1975). When abundant *Modiolus* populations were located, GPS coordinates were recorded so divers could relocate the site for sampling.

Sampling Protocol

All *Modiolus* sampling was conducted in situ by SCUBA divers. Divers descended to the sea floor from a skiff anchored at the coordinates where *Modiolus* were determined to be relatively abundant. Several minutes were spent evaluating the spatial extent of the bed and to locate a central location within the bed. Sites where *Modiolus* were rare or of limited distribution (e.g. bed < 25 m in diameter) were not included in our sampling. Once a *Modiolus* bed was located we attempted to sample a minimum of 20 quadrats to estimate density of *Modiolus*. Green urchins *(Strongylocentrotus droebachiensis)* were also counted in each quadrat. Counts of *Modiolus* and urchins were made in randomly placed quadrats. Quadrat sizes were either 0.25 or 0.0625 meter ^{2}. The larger quadrat size was used when mussel densities were less than about 100-200/m^2, and the smaller quadrat when densities were greater. Mussels and urchins were counted following blind placement of the quadrat upon the substrate, following a random number of swimming kicks (1-9) from the starting point, or the previous sampling location.

Modiolus and urchins were collected from quadrats to estimate size distributions. Collections were made from one or more quadrats, as required to obtain a target sample size of more than 20 mussels at each site. Mussels and urchins were placed in mesh bags and brought to the surface where they were measured to the nearest millimeter with calipers and returned to the water.

Analysis

For each site sampled, we calculated mean densities, sizes, and size distributions of *Modiolus* and green urchins. Mean densities and sizes of species were contrasted with one-way ANOVA. Because tests for normality failed we used Kruskal-Wallis one way ANOVA on Ranks. Dunn's multiple pair wise comparison procedure was used to isolate sites that differed from one another. Alpha for all tests of significance was set a priori at 0.05. Mean values are presented in Tables 6 and 7, and medians in Figures 12-15.

Results

Modiolus modiolus sites, density, and size

We located and sampled eight *Modiolus* beds in lower Glacier Bay in 2003 (Figure 11). At each site, we sampled an average of 24 quadrats (range 20-29). Median *Modiolus* densities differed significantly among sites ($H = 77.39$, $P < 0.001$). Median densities at Francis Is. were significantly greater than at all other sites, and densities at Johnson Cove and Strawberry Is. were significantly greater than at Geikie Is. *Modiolus* densities averaged 109/m^2 (se = 29.8) and ranged from 22/m^2 at Geikie Inlet to 303/m^2 at Francis Is. (means in Table 6, medians in Figure 12). *Modiolus* densities exceeding 300/m^2 were found in quadrats at Whidbey Pass, Francis Is., and Johnson Cove. *Modiolus* densities less than 20/m^2 were found in quadrats at all sites except Francis Is.

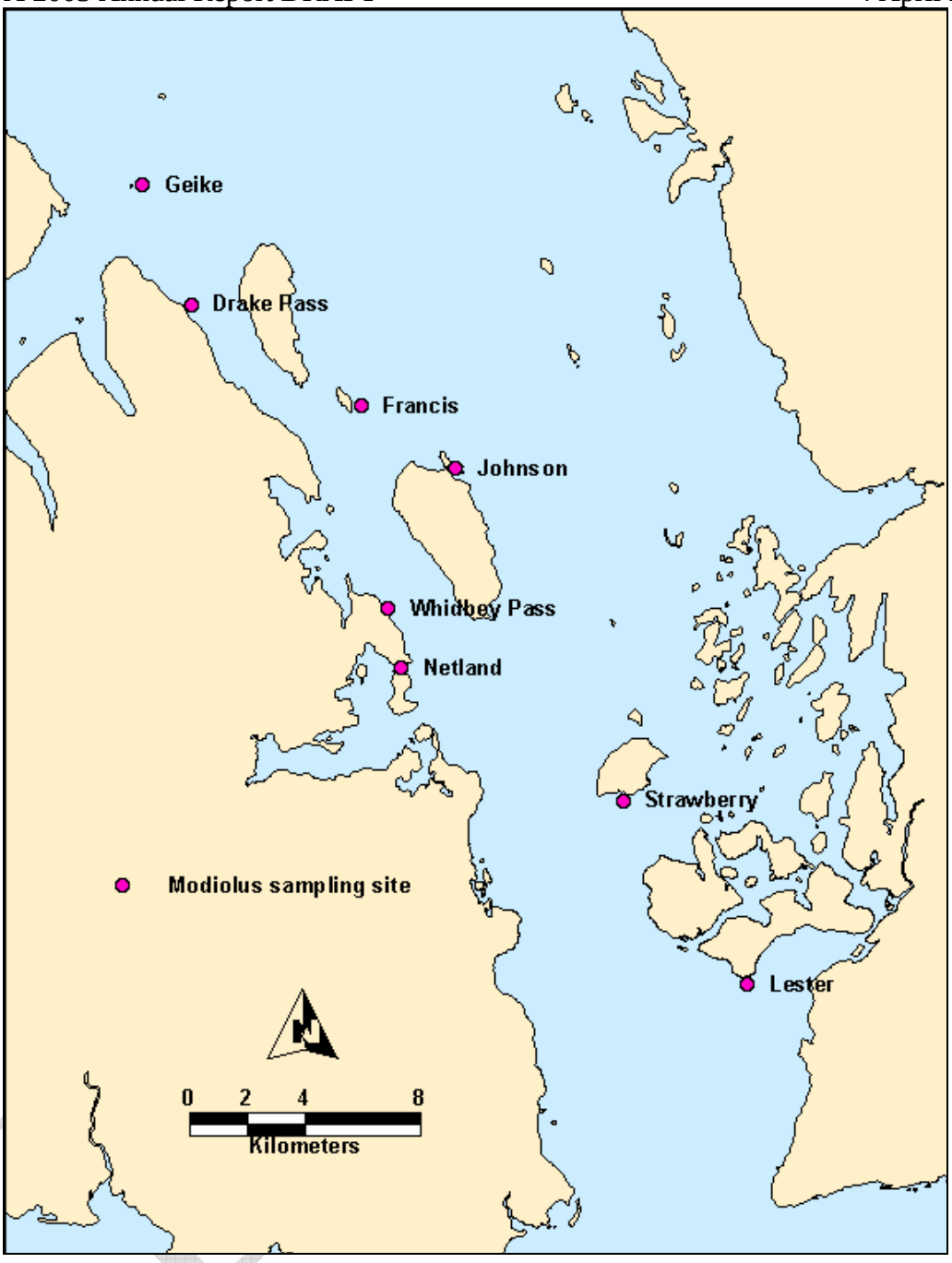

Figure 11. Locations of horse mussel (*Modiolus modiolus*) and green urchin (*Strongylocentrotus droebachiensis*) sampling in Glacier Bay in 2003.

Median *Modiolus* sizes were significantly different among sites (H=69.47, P < 0.001; Figure 3). Mussels at Francis were significantly larger than mussels at Whidbey Pass, Lester, Drake Pass, Johnson, and Geikie Mussels at Netland were significantly larger than at Whidbey Pass, Lester, and Drake Pass, and mussels at Strawberry were larger than those at Whidbey Pass (Table 7). Over all sites, the mean size of *Modiolus* was 104.8 mm (se = 3.7 mm) (Table 7,). The largest average *Modiolus* were 122 mm and found at Francis, and the smallest *Modiolus* averaged 90 mm and were found at Whidbey Pass. The largest *Modiolus* measured was 147 mm and was found at Francis, and *Modiolus* greater than 140 mm also were found at Drake Pass and Geikie.

Strongylocentrotus droebachiensis sites, density, and size

We found green sea urchins at seven of the eight sites where we sampled *Modiolus* (Table 6). Median urchin densities varied significantly among sites (H=94.71, P<0.001; Figure 14). The Johnson, Netland, and Whidbey Pass urchin densities were significantly greater than at Geikie, Francis, and Strawberry Urchin densities at Drake Pass were significantly greater than at Geikie and Strawberry. *Strongylocentrotus* densities averaged 36.8/ m^2 (se=15.3) and ranged from zero at Lester to 122/m^2 at Johnson (Table 7). Urchin densities exceeded 80/m^2 at Netland and Johnson, and averaged less than 10/m^2 at Francis, Geikie, and Lester.

Median urchin sizes differed significantly among sites (H=292.8, P<0.001; Figure 15). Urchins at Francis Island were larger than at all other sites. Urchins at Strawberry were larger than at Netland, Johnson, Drake and Whidby Pass. Urchins at Geikie were larger than those at Netland, Johnson and Drake Pass. Urchins at Whidby and Drake Pass were larger than those at Netland and Johnson. The mean urchin size among sites was 24.7 mm, and ranged from 18 mm at Netland to 39 mm at Francis The largest urchin measured was 76 mm and found at Geikie. Urchins greater than 45 mm were found only at Geikie, Francis, Strawberry, and Whidby pass.

Table 6. Mean densities (se) of *Modiolus* and *Strongylocentrotus* and the number of quadrats sampled at eight subtidal sites in Glacier Bay in 2003. See Figure 11 for sites.

Site	# Quadrats sampled	*Modiolus*	*Strongylocentrotus*
		Density #/m^2 (se)	
Strawberry	26	119 (22)	12 (1.7)
Johnson	22	105 (18.8)	122 (32.6)
Francis	29	303 (17.2)	7 (1.2)
Drake Pass	26	65 (7.1)	31 (5.4)
Netland	26	60 (6.0)	81 (10.6)
Whidbey Pass	21	104 (32.1)	36 (3.9)
Geikie	23	22 (3.8)	6 (1.4)
Lester	20	94 (17.1)	0
Means	**24**	**109 (29.8)**	**36.8 (15.3)**

Table 7. Mean (se) sizes of *Modiolus* and *Strongylocentrotus* and the number of individuals sampled at 8 subtidal sites in Glacier Bay, 2003. See Figure 11 for sites.

Site	*Modiolus*		*Strongylocentrotus*	
	# individuals sampled	Mean size mm (se)	# individuals sampled	Mean size mm (se)
Strawberry	26	109 (2.1)	74	35 (1.15)
Johnson	40	104 (2.0)	227	20 (0.36)
Francis	37	122 (3.8)	39	39 (1.6)
Drake Pass	67	95 (3.6)	173	24 (0.67)
Netland	23	116 (1.6)	292	18 (0.37)
Whidbey Pass	67	90 (3.1)	171	26 (0.75)
Geikie	38	103 (3.4)	30	36 (2.7)
Lester	40	100 (1.3)	0	0

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Means	**42**	**104.8 (3.7)**	**126**	**24.75 (0.95)**

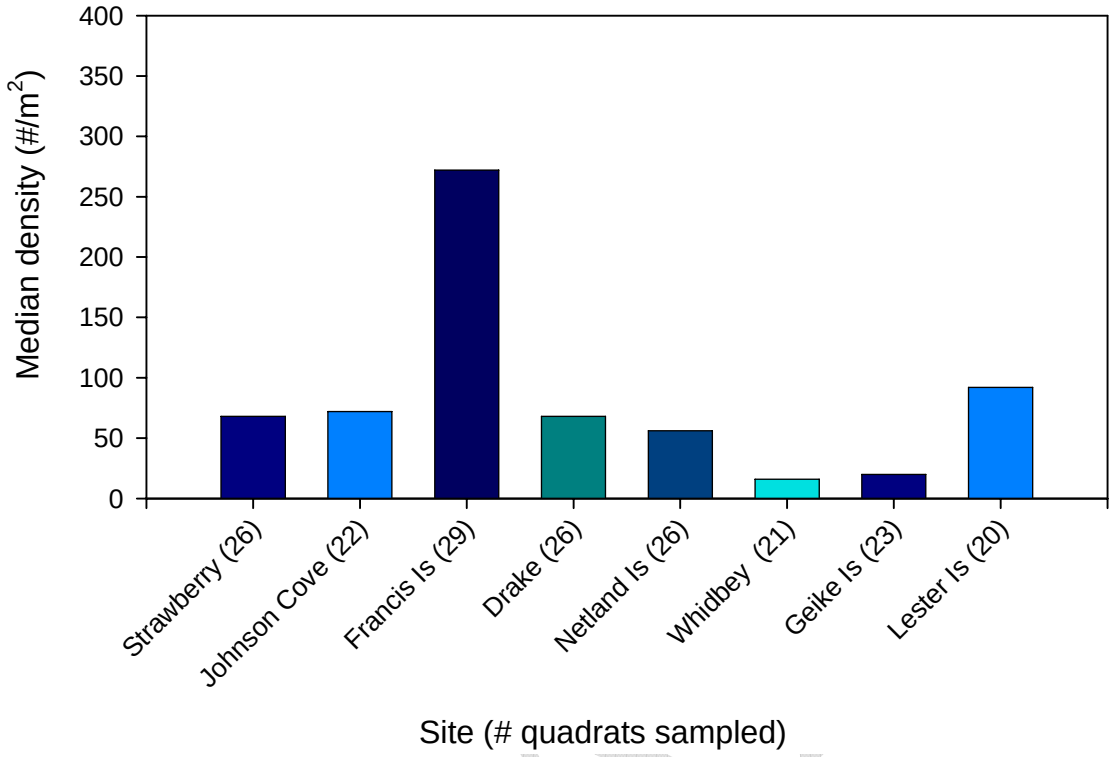

Figure 12. Median *Modiolus modiolus* (horse mussel) density at 8 sites in Glacier Bay, 2003.

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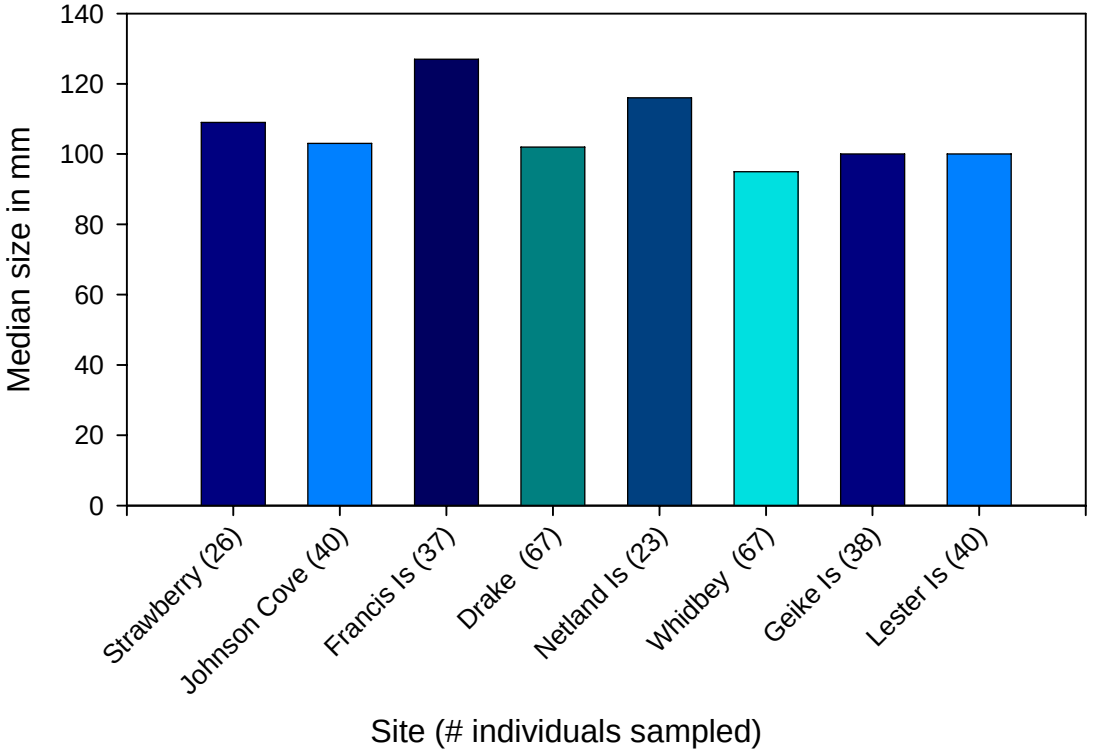

Figure 13. Median *Modiolus modiolus* (horse mussel) sizes at 8 sites in Glacier Bay, 2003.

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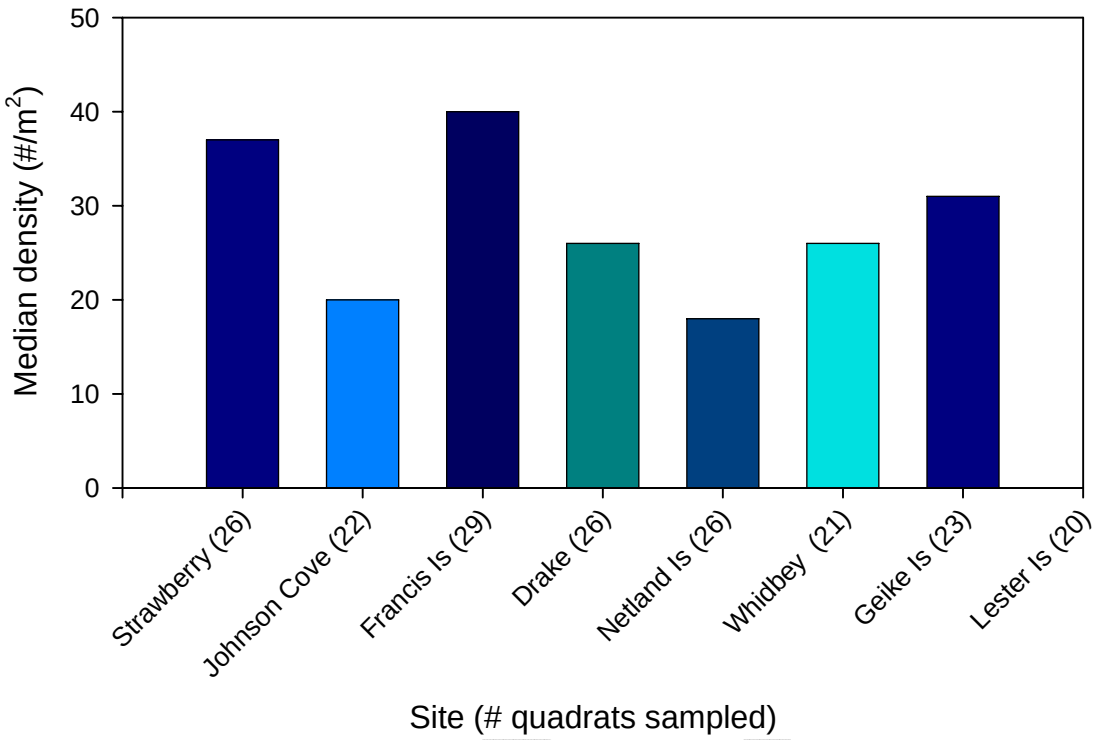

Figure 14. Median *Strongylocentrotus droebachiensis* (green urchin) density at 8 sites in Glacier Bay, 2003.

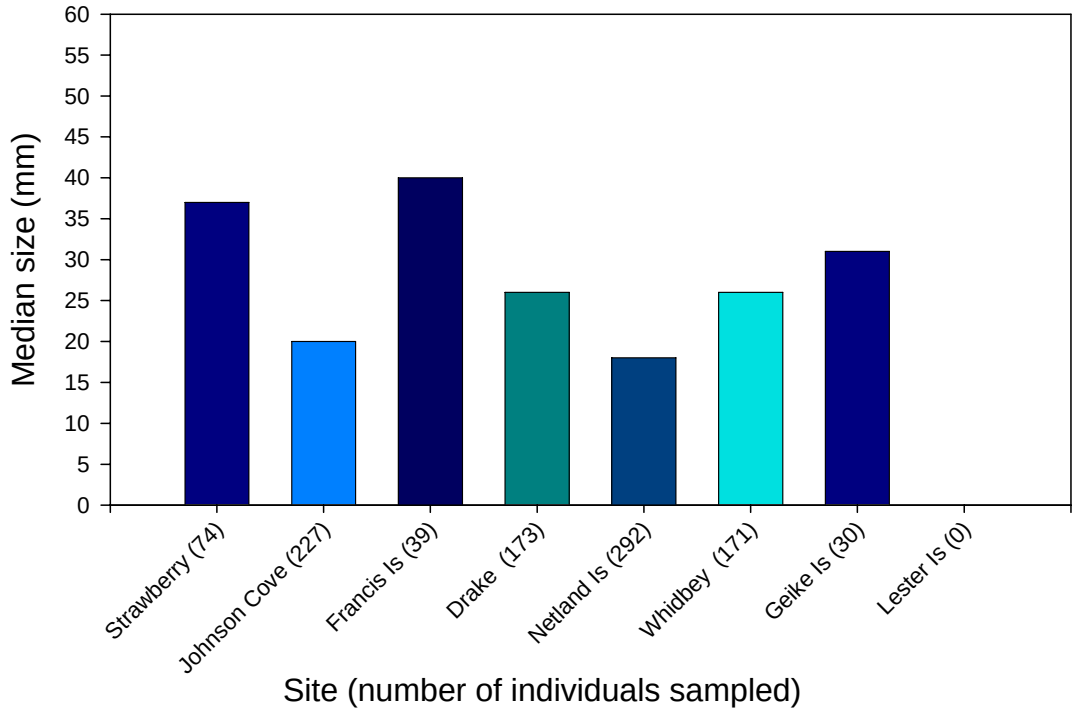

Figure 15. Median *Strongylocentrotus droebachiensis* (green urchin) sizes at 8 sites in Glacier Bay, 2003.

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Conclusions

Sea otter populations in the vicinity of Glacier Bay continue to increase following the successful translocation of sea otters to southeast Alaska nearly 40 years ago, and are the only sea otter population in Alaska known to be increasing. The rate of growth observed in Glacier Bay between 1995 and 2002 exceeds both theoretical and empirical growth rates for sea otter populations (Bodkin et al. 1999; Riedman and Estes 1990). The explanation for this exaggerated growth is likely the combined contributions of pup production from within the Bay and immigration of juveniles and adults from outside the Bay. The rapid rate of growth of the Glacier Bay sea otter population requires an intensified effort to acquire pre-sea otter colonization data if we are to understand the range of effects sea otters will eventually have on the Glacier Bay marine ecosystem.

Sea otters are known to consume in excess of 100 species of prey (Riedman and Estes 1990), predominantly invertebrates, but also fishes and birds. Thus far we have observed 34 species consumed by sea otters in Glacier Bay. In most studies of diet, sea otter prey typically reflects the habitat characteristics of the study area (e.g., burrowing infauna in soft sediment habitats). Through the year 2003, we have observed 4,258 foraging dives in Glacier Bay. Foraging success is generally high, ranging from 86-95%, and averaging 91% across years. Considering sites with more than 350 successful dives, clams represented 14 to 76% of the diet, crabs 1 to 12%, mussels 0-44%, and urchins 1-61%. Variation in prey species composition among sites likely reflects differences in species composition and abundance, or prey availability among those sites, rather than differences in prey selection by sea otters.

Our work in 2003 is generally consistent with prior years work in Glacier Bay in terms of foraging success, dietary composition, number of prey per dive, and prey sizes (Bodkin et al 2001, 2002). As clams and mussels remain the largest component of the sea otters' diet in Glacier Bay, it is likely that their density and average size will eventually decline as a result of sea otter predation. The effects of these changes on other predators that consume clams and mussels (e.g. sea ducks, sea stars and octopus), or in the recruitment of invertebrates that may be limited by filter feeders such as clams and mussels, are unknown. In Glacier Bay, mussels, (*Mytilus trossulus* and *Modiolus modiolus)* are important prey for sea ducks, shore birds and sea stars. As sea otters reduce densities and sizes of mussels, populations of other predators that rely on mussels may be affected. Green sea urchins (*S. droebachiensis*) are also an important sea otter prey item in Glacier Bay. If the patterns of reduced urchin populations and increased algal production observed elsewhere are observed in Glacier Bay, we will see large increases in the extent of under-story and canopy-forming kelps in Glacier Bay. It is likely that effects on kelps will be most pronounced in areas of consolidated substrate that are capable of supporting kelps. We have observed a variety of crab species as sea otter prey in this study, some of which support commercial and subsistence fisheries. It is unlikely these fisheries will be able to persist coincident with an increasing sea otter population. An exception may be those crab species that achieve a refuge from predation by living beyond the foraging depths of sea otters (e.g. *Chionoecetes* and *Paralithodes*). However, if prey exhibit vertical movement that brings them within sea otters' foraging depth (maximum approximately 100m, Bodkin et al. 2004), they may be adversely affected by sea otter predation.

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Glacier Bay currently supports a diverse and abundant assemblage of large invertebrates, including species of bivalves, echinoderms, and crustaceans. To date there is little evidence from our Glacier Bay studies of sea otter effects on intertidal and subtidal species. This probably results from too few otters foraging over too large an area over too short a time period. However, given the rapid rate of increase in sea otter density in recent years, changes in the nearshore ecosystem of Glacier Bay can be expected in the near future. The ability of marine resource managers to detect change and implement appropriate management actions in Glacier Bay will be severely constrained unless the effects of sea otter colonization and foraging are well documented and understood, as the otters will have a major influence on the composition and function of nearshore marine communities. Furthermore, our ability to detect other changes that are occurring in the Glacier Bay marine ecosystem will be diminished unless the sea otter effect is recognized and quantified. The window of opportunity to acquire the needed information will close at a rate positively related to the rate of sea otter increase.

Acknowledgements

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Appendices

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Appendix A. Torch and Surge Bay Trip Report

Southeast Alaska, Spring 2003
James A. Estes and James L. Bodkin

Background

The outer coast of Glacier Bay National Park is characterized by exposed headlands and deep fjords. In contrast with the more protected inner waters of the Park, where unconsolidated soft-sediment habitats predominate, outer coast habitats are almost continuously exposed to large ocean waves and typically feature consolidated, rocky habitats in the intertidal and shallow subtidal zones. These exposed, rock-substrates support diverse kelp forest ecosystems.

The cool, nutrient-rich waters common to higher latitude seas interact with high summer light levels and unlimited water resources to make kelp forests among the most productive of global ecosystems on a per area basis. These systems support a diverse array of macroalgae, invertebrates, fishes, and marine bird and mammal species (Dayton 1985, Foster and Schiel 1985, Steneck et al. 2003). Research over the past several decades has also demonstrated that many kelp forest ecosystems are under the strong influence of "top-down control" (Pace et al. 1999, Steneck et al. 2003), a condition wherein population abundances of many of the component species are not regulated solely by resource availability, but instead by the limiting influences of higher trophic level consumers.

In the eastern North Pacific Ocean, sea otters (*Enhydra lutris*) often exert important top-down influences on kelp forest ecosystems, especially at higher latitudes (Estes and Bodkin 2002). Sea otters feed primarily on benthic invertebrates, some of which in turn consume kelps and other macroalgae. This is especially true of sea urchins, a favored sea otter prey organism and a potentially important consumer of kelps and other macroalgae. Sea otters are known to maintain kelp forest ecosystems by limiting the distribution and abundance of sea urchins (Estes and Palmisano 1974). Thus, coastal habitats with sea otters typically feature healthy kelp forests whereas otherwise similar habitats in which sea otters are rare or absent are extensively overgrazed by sea urchins, resulting in what have often been termed "sea urchin barrens" (Steneck et al. 2003). Because kelps provide food (directly to herbivores and detritivores, indirectly to higher trophic level consumers) and habitat for many other species, the potential influences of sea otters on this community is wide-ranging and diverse (Estes 1996, Estes et al. in press). Sea otters are thus commonly recognized as a "keystone species" (Power et al. 1996).

Purpose

Some of the earlier research demonstrating the dynamic influences of sea otter predation on kelp forests was done in Glacier Bay National Park. This research was initiated by Dr. David Duggins (Friday Harbor Laboratories, University of Washington) at Torch Bay in the 1970s, during which time sea otters were absent from that area. Sea otters were eliminated from southeast Alaska by the Pacific maritime fur trade. Thus the Torch Bay system that Duggins studied had been devoid of sea otters for a century or more, and was characterized at the time by extensive sea urchin barrens (Duggins 1980).

Sea otters were reintroduced into southeast Alaska in the late 1960s (Jameson et al. 1982). Most of the reintroduced animals were released to an area south of Cross Sound, in the vicinities of Deer Harbor and Surge Bay. Duggins' early studies also included kelp forest habitats in Surge Bay, an area in which he reported kelps to be abundant and urchins rare (Duggins 1980). The distribution and abundance of sea otters increased rapidly in the years following their reintroduction. By the early to mid- 1980s, their range had expanded across Cross Sound and into Torch Bay.

In May of 1987, Glacier Bay National Park supported an expedition to Torch Bay aboard the M/V Nunatak (led by D.O. Duggins and J.A. Estes) to chronicle the distribution and abundance of sea otters within the Park north of Cape Spencer, and to document any change in Torch Bay's kelp forest ecosystem that may have occurred since the time of Duggins' earlier studies. Comparable data were obtained from Surge Bay. The observed changes in Torch Bay were stunning. Three common sea urchin species (red urchins, *Strongylocentrotus franciscanus*; purple urchins, *S. purpuratus*; and green urchins, *S. drobachiensis*) dominated Duggins' study sites in the 1970s; kelps and other fleshy macroalgae were rare and patchily distributed. Sea urchins were rare and kelps abundant at the time of the 1987 expedition. In contrast, Surge Bay remained kelp-dominated and was largely unchanged over this same period. These findings were published in a more comprehensive analysis of sea otter-kelp forest relationships in Alaskan waters (Estes and Duggins 1995).

The kelp forest systems in Torch and Surge bays have not been closely examined since the 1987 expedition. We decided to revisit and resample the study sites in 2003 for the following reasons:

1. An interim of 16 years had passed since the 1987 survey. The Torch Bay system had changed considerably from the 1970s to 1987. We wished to determine if either of these systems had undergone further change or remained stable since that time.

2. Given the nature of the earlier data, we felt this information would be useful to Glacier Bay National Park as part of their monitoring program for coastal marine resources. Future sampling can provide a unique and relatively long time perspective on ecosystem change.

3. Sea otter numbers recently have declined dramatically throughout much of southwestern Alaska (Doroff et al. 2003). The kelp forest ecosystem has collapsed as a result of this decline (Estes et al. 1998, Estes et al., in press). Although there presently is no indication that the sea otter/kelp forest ecosystem collapse has spread to southeast Alaska, it seems wise to remain vigilant, especially give that significant numbers of sea otters are taken in a subsistence harvest from near-by areas.

Methods

Sampling methods were identical to those used in the earlier Torch Bay surveys and to those we have used elsewhere in Alaska. Briefly, superimposing a square grid over a map of the region and noting the grid intersections with the coastline determined potential sample sites. A random sample of these potential sites was then selected for the actual sample. GPS coordinates are recorded from the skiff on site immediately preceding the dive (Table A4).

A team of two divers sampled each site by recording the common benthic organisms within a one-quarter square meter quadrat that was placed on the seafloor. The dive skiff was anchored in 20' of water at the site coordinates. Beginning at the anchor, the quadrats were located at random intervals, determined by the number of diver kicks, along the 20' depth contour. Species were identified to the lowest possible taxon and recorded either by number of individuals or percent cover. Twenty quadrats were sampled at each site. Sea urchin species, size (maximum test diameter) and number were also recorded. When sea urchins are abundant (as was the case in Sitka Sound, but not at either Torch or Surge bays during the present study period), they are sampled separately until a minimum of 200 individuals has been counted from the site. The data were entered into a computerized database for analysis and archiving. A copy of the database, including the 1988 and 2003 data from both Torch and Surge bays, accompanies this report. For further detail on the sampling methods and protocol, see Estes and Duggins (1995).

GPS coordinates are not available from these earlier studies. Thus, we were not able to resample precisely the same locations in 1988 and 2003 and cannot provide paired site analyses over the time interval between the two samples. We can, however, provide overall patterns of change for both locations.

In conjunction with the subtidal sampling of benthic communities we also surveyed the shorelines and nearshore coastal waters of Torch and Surge Bays for sea otter abundance. Surveys were conducted from 25' skiffs traveling at speeds < 12 knots. Survey crews consisted of 2 observers and one skiff operator. Two observers searched nearshore waters, aided with 10x binoculars from the skiff and recorded observations of sea otters, seabirds and other mammals, directly onto navigation charts. Data from the navigational chart were later compiled into tabular form. The surveys were intended as a census of sea otter abundance, and all waters from the shoreline out to approximately the 20 fathom bathymetric contour were searched.

Results

Sea urchins

Sea urchins were rare at Torch and Surge bays in both 1988 and 2003 (overall density, 0.025 individuals per $0.25m^2$). In total, only 11 individual urchins were encountered in the 576 quadrats sampled during 1988, and only 22 individuals were encountered in the 723 quadrats sampled during 2003. Both red and green urchins were encountered in 1988; their test diameters ranged from 15-50mm (mean = 26.8mm; s.d = 9.6). Only green urchins were encountered in 2003. Their test diameters ranged from 5-41mm (mean = 16.4mm; s.d. = 11.3). In contrast, comparable habitats in Sitka Sound in 1988 (sea otters absent) supported an average urchin density of 3.36 individuals per $0.25m^2$ (Table A2). Of the 1320 urchins sampled in Sitka Sound, 1285 (97.3%) were reds and the remaining 2.7% were greens. Sitka Sound red urchins had test diameters ranging from 5-186mm (mean = 84.9mm; s.d. = 40.0). Sitka Sound green urchins had test diameters ranging from 10-49mm (mean = 25.5mm; s.d. = 9.7).

Macroalgae and suspension feeders

Fleshy macroalgae covered the rocky benthos at Torch and Surge bays in both 1988 and 2003. In order to determine the degree of consistency in algal abundance across study locations and through time, we computed mean densities by species/taxa and plotted the

frequency distributions of algal abundance by sample quadrat for adult kelps and new recruits.

Laminaria spp. was the numerically dominant species at both locations in both years (Table A1). Fleshy red algae were somewhat more common at Surge Bay than at Torch Bay. Densities of both kelp recruits and total adult kelps were greater at Torch Bay in 1988 than in any of the other three data sets (i.e., Torch Bay 2003, Surge Bay 1988 and 2003). The frequency distributions of adult and juvenile kelp abundance across sample quadrats were generally similar in Surge Bay in 1988 and 2003 (Figure A1). The modal density of adult plants was about 5-7 individuals per quadrat and young plants (recruits) were absent from about half of the quadrats sampled. These same patterns characterized Torch Bay in 2003. However, in 1988, the modal density of adult plants in Torch Bay was greater and nearly all of the quadrats contained recruits (Figure A1).

Sea otters

Within the area identified as Torch Bay (Figure A2) we observed 40 adult sea otters and 17 dependent pups (Table A3). The proportion of pups to adults is 0.425. Within the area identified as Surge Bay (Figure A3) we observed 26 adults and 4 independent pups. The proportion of pups to adults at Surge Bay was 0.16. The abundance of sea otters in Surge Bay was far less than the several hundred reported in about 1978 (Estes and Duggins 1995). The species and numbers of other birds and mammals that were observed during these surveys are reported in Table A3.

Preliminary Interpretations

The kelp forest survey data obtained in 2003 indicate that outer coastal habitats in the vicinity of Torch and Surge bays are under the strong influence of sea otter predation, despite the fact that otter numbers are relatively low in this region. That is, grazing macroinvertebrates (especially sea urchins) are rare and the rocky benthos is dominated by fleshy macroalgae.

In general, the community patterns documented in 2003 were similar to those measured in 1988 and reported by Estes and Duggins (1995), with several interesting exceptions. Although sample sizes of sea urchins are very small (owing to the rarity of these organisms in shallow coastal habitats), species composition differed between 1988 and 2003. Both red and green urchins were encountered in the sample quadrats in 1988 whereas only green urchins were encountered in 2003. Red urchins appear to have been the numerically dominant species in this region prior to the reestablishment of sea otters (based both on the report by Duggins 1980 and the 1988 data from Sitka Sound). Thus, the recovery of sea otters not only greatly reduced the overall abundance of sea urchins, it seems to have caused a shift in numerical dominance from red to green urchins. Red urchins now appear to be effectively absent from these habitats. We suspect that these changes were caused by species differences in growth and recruitment, coupled with the tendency of sea otters to select the largest available prey. Interannual recruitment appears to occur more commonly in green than red urchins, at least in outer coastal habitats of Cross Sound (purple urchin recruitment in this region is also highly episodic). Red urchins also attain larger maximum sizes than green urchins. The fact that 17 of the 21 urchins sampled in 2003 had test diameters less than 20mm suggests that these animals were derived from a recent recruitment pulse.

In 1988, sea otters had occupied the Torch Bay area for no more than several years, having just recolonized this area during the northward range expansion of a colony that was relocated into the Deer Harbor/Surge Bay region in the late 1960s. Upon entering Torch Bay, this expanding sea otter population caused a sharp transition in the benthic habitats by foraging on and reducing then abundant sea urchins, thus allowing kelps and other macroalgae to settle and recolonize shallow rocky substrates. The kelp demographic data suggest that this transition was still underway in Torch Bay in 1988. Recruitment in that year was widespread, probably because adequate space was still available for the young recruits to successfully become reestablished. Adult kelp densities were also greater in 1988, probably because insufficient time had elapsed since the removal of sea urchins for the larger adult plants to exert a limiting influence on recruitment or the survival of smaller individuals. It appears that the Torch Bay system has now achieved a more stationary organizational state, as least so far as kelp demography is concerned.

Although sea otters are important drivers of the dynamic interactions between sea urchins and kelps across large areas of coastal Alaska, the systems in southeast Alaska differ in several important ways from those we have been studying in the Aleutian Islands. It would appear that the Aleutian Islands systems intrinsically may be capable of supporting substantially higher sea otter densities than comparable systems in southeast Alaska. This is probably not a result of differences in primary production between the regions but rather an interregional difference in recruitment dynamics of sea urchins, one of the sea otter's principal prey. Sea urchins recruit heavily and frequently in the Aleutian Islands, owing both to settlement and the upward movements of animals from deep to shallow water habitats. The settlement-based recruitment is probably a consequence of larval entrainment in nearshore waters by physical oceanographic processes (although this has not been rigorously demonstrated for the Aleutian Islands). The movement-based recruitment from deep to shallow water probably results from the facts that the depth to which sea otters can effectively dive to prey on sea urchins is constrained by their diving ability on the one hand and the nutritional value of sea urchins on the other. In general, sea otters in the Aleutian Islands rarely dive deeper than about 10m to capture sea urchins (Watt et al., 2000 and USGS, unpublished data). Vast numbers of sea urchins occur at depths beyond the effective foraging range of sea otters, owning in large measure to the great depths to which rocky substrates occur in this region. The broad extent and great depth of rocky substrate in the Aleutian archipelago is probably in turn the consequence of two unique geological features of that region—the absence of a continental shelf (the Aleutians are oceanic islands) and the absence of significant sediment transport from land to sea owing to the lack of large rivers, glaciers, and loessal soils. These patterns fuel a high potential carrying capacity for sea otters in the central and western Aleutian archipelago. Conversely, the potential carrying capacity of southeast Alaskan kelp forests for sea otters may be substantially less. We speculate that this is due to the region's reduced recruitment potential. Coastal upwelling and Eckman transport, both of which are strong along the continental margins of western North America, tend to move larval organisms produced in nearshore habitats offshore. In addition, the continental shelf and sediment input from the large continental land mass (resulting from glaciers, loessal soil production, and large rivers to transport sediments from land to sea) create an extensive soft-sediment barrier to deep-water rocky habitats and thus to the movement-recruitment of sea urchins from deep to shallow-water habitats. These features of the coastal ecosystem in southeast Alaska probably limit prey production and thus the potential carrying capacity for sea otters in rock-substrate ecosystems.

The interpretations expressed in the preceding paragraph may explain why low sea otter densities in the Aleutian Islands and southeast Alaska result from different ecosystem dynamics between these two regions. Low otter densities in the Aleutian Islands are the consequence of a precipitous recent population decline (Doroff et al., 2003), the purported consequence of increased predation on sea otters by killer whales (Estes et al., 1998). This decline has resulted in widespread phase shifts within the rocky benthos from kelp forests to urchin barrens (Estes et al., 1998 and in press). In this sense, sea otters are now functionally extinct in the Aleutian archipelago. Although sea otter densities in southeast Alaska are relatively low, considering the availability of unoccupied habitat, these densities appear to be the more natural state of affairs in the outer-coast kelp forest ecosystems of this region. There is no evidence that outer coast sea otter populations in southeast Alaska have recently declined to their current numbers and it would appear that current population densities are capable of maintaining the shallow rocky benthos in a kelp-dominated community state. However, the episodic nature of sea urchin recruitment in southeast Alaska creates a potential mechanism whereby the kelp forest ecosystem might persist for some time in the absence of sea otters (see Soulé et al, 2003 for further discussion). Native hunters are currently removing substantial numbers of sea otters from parts of southeast Alaska. Thus, sea otters in the outer coast waters of Cross Sound may still be below equilibrium levels. We suspect that measures of the kelp forest ecosystem would provide a less sensitive indicator of such changes than has proven to be the case in the Aleutian archipelago.

Recommendations

Considering the episodic nature of sea urchin recruitment, continued periodic monitoring of the kelp forest ecosystem and studies of sea urchin recruitment dynamics will likely provide further insight into the trophic dynamics of this system. Any such studies should be accompanied by the local monitoring of sea otter abundance and distribution.

Our work to date has focused solely on the dynamic relationships among sea otters, sea urchins, and macroalgae. An expanded focus on other kelp forest species would be of interest, especially considering the strong indirect effects of sea otters on other consumers that have been documented or proposed in other regions (Duggins et al., 1989, Estes 1996, Estes et al., in press). Particular attention to kelp forest fishes is recommended, especially considering the unique protection afforded to coastal marine environments by Glacier Bay National Park and the likely fact that unexploited rockfish populations probably occur in some of the more remote regions of the Park.

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Field Personnel

James Bodkin, USGS, Alaska Science Center, Anchorage, AK
Heather Colletti, USGS, Alaska Science Center, Anchorage, AK
Michael Donellan, Glacier Bay National Park, Gustavus, AK
George Esslinger, USGS, Alaska Science Center, Anchorage, AK
James Estes, USGS, Western Ecological Research Center, Santa Cruz, CA
Michael Kenner, University of California, Santa Cruz, CA
Daniel Monson, USGS, Alaska Science Center, Anchorage, AK
Jim de la Bruere, USGS, Alaska Science Center, Gustavus, AK

Figures and Tables

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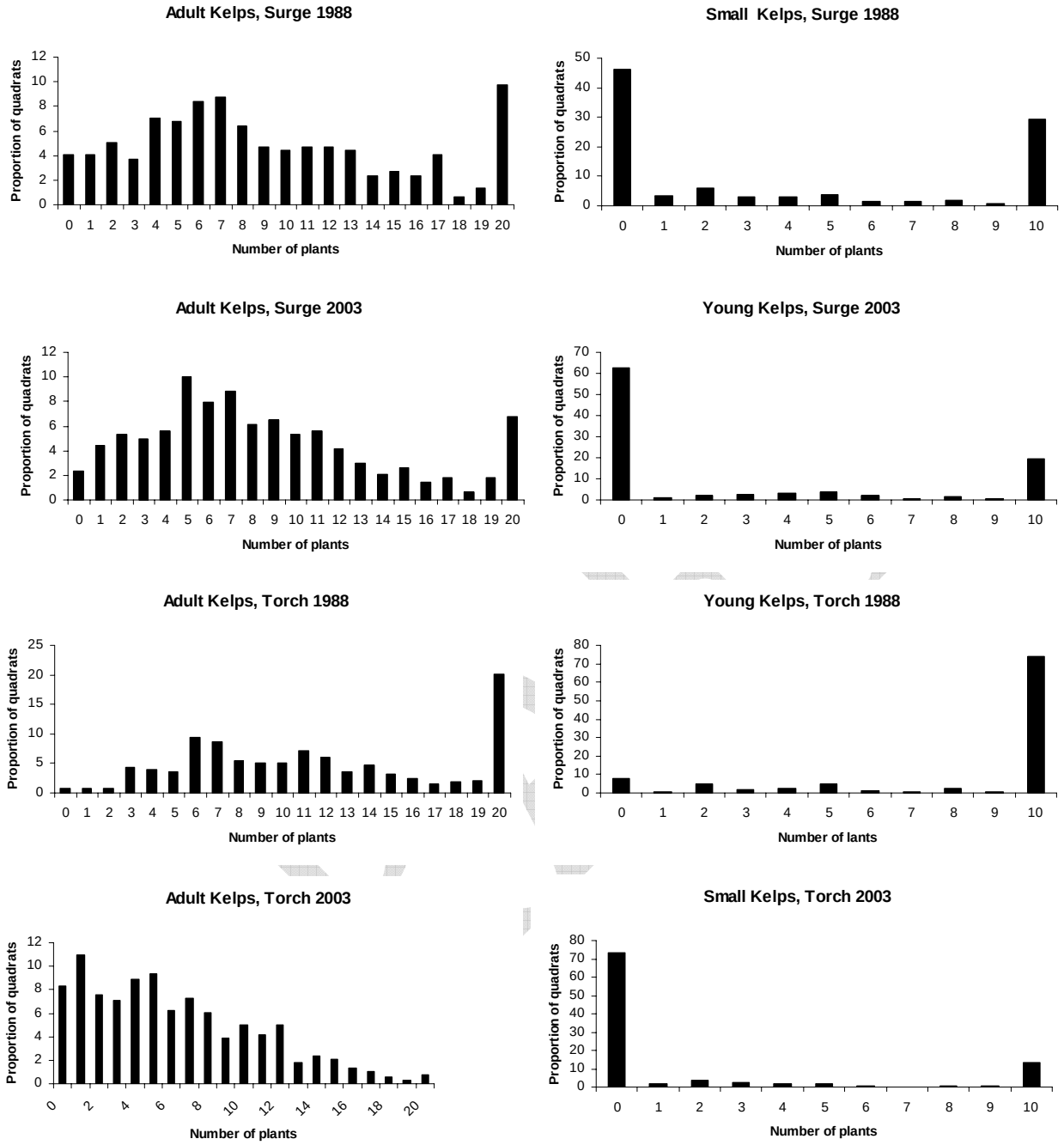

Figure A1. Frequency distributions of the numbers of adult and juvenile kelps sampled per one-quarter m^2 quadrat at Torch and Surge bays in 1988 and 2003.

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Figure A2. Location of sea otter census and benthic sampling in Torch Bay, AK 2003.

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Figure A3. Location of sea otter census and benthic sampling in Surge Bay, AK 2003.

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Table A1. Densities and percent covers of dominant macroalgae and suspension feeders at Torch and Surge bay sample sites in 1988 and 2003.

	Surge Bay		Torch Bay	
	1988	2003	1988	2003
Species	**Density (No 0.25m2)**			
Agarum cribrosum	0.24	0.42	0.00	0.13
Alaria marginata	0.57	0.59	2.07	0.00
A. fistulosa	0.00	0.00	0.41	0.18
Costaria costata	0.07	0.25	0.22	0.08
Cymathera triplicata	0.12	0.00	0.13	0.50
Laminaria spp.	7.48	5.39	8.74	3.35
L. yezoensis	0.51	1.12	0.35	0.51
Macrocystis integrifolia	0.02	0.11	0.00	0.00
Nereocystis leutkeana	0.07	0.25	0.99	0.15
Pleurophycus	0.71	0.63	1.59	1.83
Total large kelps	9.79	8.76	14.50	6.72
Small kelps	7.86	6.33	32.92	4.45
	Percent Cover Class			
Codium sp.	2.50	2.87	2.50	2.59
Fleshy red algae	24.04	22.63	8.88	16.40
Suspension feeders	12.49	6.65	9.22	9.16

Table A2. Summary of population data on sea urchins from Torch Bay, Surge Bay, and Sitka Sound obtained in 1988 and 2003.

Location	Year	# quadrats sampled	# urchins counted	Density (#/0.25m2)
Torch Bay	1988	279	9	0.032
	2003	383	13	0.034
Surge Bay	1988	297	2	0.007
	2003	340	9	0.027
Sitka Sound	1988	406	1320	3.251

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Table A3. Results of marine bird and mammal, and other species boat surveys in Surge and Torch Bays, June 2003. See Figures 2 and 3 for a map of the area surveyed. Avian species W = waterfowl, S = seabird, B = shorebird, O = other. Sea otter numbers are # independent/# pups.

	Avian Species	Torch Bay Count	Surge Bay Count
PALO	Pacific Loon (W)	0	2
YBLO	Yellow-billed Loon (W)	1	0
UNLO	Unidentified Loon (W)	2	3
PECO	Pelagic Cormorant (S)	4	42
SUSC	Surf Scoter (W)	13	0
WWSC	White-winged Scoter (W)	0	21
HADU	Harlequin Duck (W)	43	0
UNME	Unidentified Merganser (W)	0	1
BAEA	Bald Eagle (O)	5	0
BLOY	Black Oystercatcher (B)	4	0
BLKI	Black-legged Kittiwake (S)	0	25
UNGU	Unidentified Gull (S)	4	2
PIGU	Pigeon Guillemot (S)	2	6
	Marine Mammals		
HASE	Harbor Seal	4	9
STSL	Steller Sea Lion	1	0
SEOT	**Sea Otter**	**40/17**	**26/4**
	Other Mammals		
BLBE	Black Bear	2	0
BRBE	Brown Bear	1	0
MOGO	Mountain Goat	4	0

Table A4. UTM coordinates for sample sites in Torch and Surge bays, 2003.

Location	Site #	UTM coordinates	
		Easting	Northing
Torch Bay	1	392598	6464345
	3	393525	6464928
	4	393985	6465573
	5	394327	6465919
	6	394073	6466516
	7	393808	6466917
	8	393548	6467501
	11	394273	6468946
	12	394285	6468316
	13	394169	6467527
	14	394637	6466984
	15	395368	6466859
	16	396015	6466744
	18	396145	6466087
	19	395479	6465941
	20	395233	6465550
	21	395203	6464887
	22	394996	6464360
	25	395365	6462578
	26	395947	6462247
	27	396047	6461952

Location	Site #	UTM coordinates	
		Easting	Northing
Surge Bay	1	407265	6431809
	2	407483	6431093
	3	407409	6430521
	7	408783	6430561
	9	409192	6431023
	10	409148	6430397
	11	409100	6429942
	12	409324	6429393
	13	408998	6429081
	15	408900	6428527
	16	408520	6427917
	18	408029	6427172
	19	408560	6427412
	21	407580	6426618
	22	407205	6425917
	23	406986	6425177
	24	406909	6424302

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Appendix B. Sampling Protocol for Aerial Surveys

Overview of survey design

The survey design consists of 2 components: (1) strip transect counts and (2) intensive search units.

1) Strip Transect Counts

Sea otter habitat is sampled in two strata, high density and low density, distinguished by distance from shore and depth contour. The high density stratum extends from shore to 400 m seaward or to the 40 m depth contour, whichever is greater. The low density stratum extends from the high density line to a line 2 km offshore or to the 100 m depth contour, whichever is greater. Bays and inlets less than 6 km wide are sampled entirely, regardless of depth. Transects are spaced systematically within each stratum. Survey effort is allocated proportional to expected otter abundance in the respective strata.

Prior to surveying a geographic area (e.g. College Fjord, Prince William Sound), the observer will determine which side of the transect lines (N, S, E, or W) has less glare. A single observer in a fixed-wing aircraft will survey the side with less glare. Transects with a 400 meter strip width are flown at an airspeed of 65 mph (29 m/s) and an altitude of 300 feet (91 m). The observer searches forward as far as conditions allow and out 400 m, indicated by marks on the aircraft struts, and records otter group size and location on a transect map. A group is defined as 1 or more otters spaced less than 3 otter lengths apart. Any group greater than 20 otters is circled until a complete count is made. A camera should be used to photograph any groups too large and concentrated to count accurately. The number of pups in a group is noted behind a slash (e.g. 6/4 = 6 adults and 4 pups). Observation conditions are noted for each transect and the pilot does not assist in sighting sea otters.

2) Intensive Search Units

Intensive search units (ISU's) are flown at intervals dependant on sampling intensity*, throughout the survey period. An ISU is initiated by the sighting of a group and is followed by 5 concentric circles flown within the 400 m strip perpendicular to the group that initiated the ISU. The pilot uses a stopwatch to time the minimum 1-minute spacing between consecutive ISU's and guide the circumference of each circle. With a circle circumference of 1,256 m and an air speed of 65 mph (29 m/s), it takes 43 seconds to complete a circle (e.g. 11 seconds/quarter turn). With 5 circles, each ISU takes about 3.6 minutes to complete. ISU circle locations are drawn on the transect map and group size and behavior is recorded on a separate form for each ISU. For each group, record number observed on the strip count and number observed during the circle counts. Otters that swim into an ISU post factum are not included and groups greater than 20 otters cannot initiate an ISU.

Behavior is defined as "whatever the otter was doing before the plane got there" and recorded for each group as either diving (d) or nondiving (n). Diving otters include any individuals that swim below the surface and out of view, whether traveling or foraging. If any individual(s) in a group are diving, the whole group is classified as diving. Nondiving otters are animals seen resting, interacting, swimming (but not diving), or hauled-out on land or ice.

* The targeted number of ISU's per hour should be adjusted according to sea otter density. For example, say we have an area that is estimated to take 25 hours to survey and the goal is to have each observer fly 40 "usable" ISU's; an ISU must have more than one group to be considered usable. Because previous data show that only 40 to 55% of the ISU's end up being usable, surveyors should average at least 4 ISU's per hour. Considering the fact that, one does not always get 4 opportunities per hour - especially at lower sea otter densities, this actually means taking something like the first 6 opportunities per hour. However, two circumstances may justify deviation from the 6 ISU's per hour plan:

1) If the survey is not progressing rapidly enough because flying ISU's is too time intensive, *reduce* the minimum number of ISU's per hour slightly

2) If a running tally begins to show that, on average, less than 4 ISU's per hour are being flown, *increase* the targeted minimum number of ISU's per hour accordingly.

The bottom line is this: each observer needs to obtain a preset number of ISU's for adequate statistical power in calculation of the correction factor. To arrive at this goal in an unbiased manner, observers must pace themselves so ISU's are evenly distributed throughout the survey area.

Preflight

Survey equipment:

binder: random map set selections

map sets (observer, pilot, & spare copies)

strip forms (30)

ISU forms (60)

survey protocol

Trimble GPS procedures

data entry formats

laptop computer for data entry

floppy disk with transect waypoints

Solidstate data drive with power adaptor & interface cable

RAM cards with transect waypoints

RAM card spare batteries

low power, wide angle binoculars (e.g. 4 X 12)

clipboards (2)

pencils

highlighter pen

stopwatch for timing ISU circles

35 mm camera with wide-angle lens

high-speed film

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survival suits

Airplane windows must be cleaned each day prior to surveying.

Global Positioning System (GPS) coordinates used to locate transect starting and end points, must be entered as waypoints by hand or downloaded from an external source via a memory card.

Electrical tape markings on wing struts indicate the viewing angle and 400 m strip width when the aircraft wings are level at 300 feet (91.5 m) and the inside boundary is in-line with the outside edge of the airplane floats.

The following information is recorded at the top of each transect data form:

Date - Recorded in the DDMMMYY format.

Observer - First initial and up to 7 letters of last name.

Start time - Military format.

Aircraft - Should always be a tandem seat fixed wing that can safely survey at 65-70 mph.

Pilot - First initial and up to 7 letters of last name.

Area - General area being surveyed.

Observation conditions

Factors affecting observation conditions include wind velocity, seas, swell, cloud cover, glare, and precipitation. Wind strong enough to form whitecaps creates unacceptable observation conditions. Occasionally, when there is a short fetch, the water may be calm, but the wind is too strong to allow the pilot to fly concentric circles. Swell is only a problem when it is coupled with choppy seas. Cloud cover is desirable because it inhibits extreme sun-glade. Glare is a problem that can usually be moderated by observing from the side of the aircraft opposite the sun. Precipitation is usually not a problem unless it is extremely heavy.

Chop (C) and glare (G) are probably the most common and important factors effecting observation conditions. Chop is defined as any deviation from flat calm water up to whitecaps. Glare is defined as any amount of reflected light that may interfere with sightability. After each transect is surveyed, presence is noted as C, G, or C/G and modified by a quartile (e.g. if 25% of the transect had chop and 100% had glare, observation conditions would be recorded as 1C/4G). Nothing is recorded in the conditions category if seas are flat calm and with no glare.

Observer fatigue

To ensure survey integrity, landing the plane and taking a break after every 1 to 2 hours of survey time is essential for both observer and pilot. Survey quality will be compromised unless both are given a chance to exercise their legs, eat, go to the bathroom, and give their eyes a break so they can remain alert.

Vessel activity

Areas with fishing or recreational vessel activity should still be surveyed.

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Special rules regarding ISU's

1. Mistaken identity - When an ISU is mistakenly initiated by anything other than a sea otter (e.g. bird, rock, or floating debris), the flight path should continue for one full circle until back on transect. At this point the ISU is to be abandoned as if it was never initiated and the normal fight path is resumed.
2. Otters sighted outside an ISU - Otters sighted outside an ISU that are noticed during ISU circles are counted only when the ISU is completed, normal flight path has been resumed, and they are observed on the strip.

Unique habitat features

Local knowledge of unique habitat features may warrant modification of survey protocol:

1. Extensive shoaling or shallow water (i.e. mud flats) may present the opportunity for extremely high sea otter densities with groups much too large to count with the same precision attainable in other survey areas. Photograph only otters within the strip or conduct complete counts, typically made in groups of five or ten otters at a time. Remember, groups >20 cannot initiate an ISU.

   Example: Orca Inlet, PWS. Bring a camera, a good lens, and plenty of film. Timing is important when surveying Orca Inlet; the survey period should center around a positive high tide - plan on a morning high tide due to the high probability of afternoon winds and heavy glare. Survey the entire area from Hawkin's cutoff to Nelson Bay on the same high tide because sea otter distribution can shift dramatically with tidal ebb and flow in this region.
2. Cliffs - How transects near cliffs are flown depends on the pilot's capabilities and prevailing weather conditions. For transects which intersect with cliff areas, including tidewater glaciers, discuss the following options with the pilot prior to surveying.
   - In some circumstances, simply increasing airspeed for turning power near cliffs may be acceptable. However, in steep/cliff-walled narrow passages and inlets, it may be deemed too dangerous to fly perpendicular to the shoreline. In this case, as with large groups of sea otters, obtain complete counts of the area when possible.
   - In larger steep-walled bays, where it is too difficult or costly to obtain a complete count, first survey the entire bay shoreline 400 m out. Then survey the offshore transect sections, using the 400 m shoreline strip just surveyed as an approach. Because this is a survey design modification, these data will be analyzed separately.

     Example: Herring Bay, PWS. Several high cliffs border this area.

     Example: Barry Glacier, PWS. Winds coming off this and other tidewater glaciers may create a downdraft across the face. The pilot should be aware of such unsafe flying conditions and abort a transect if necessary.
3. Seabird colonies - Transects which intersect with seabird colonies should be shortened accordingly. These areas can be buffered for a certain distance in ARC dependant on factors such as colony size, species composition, and breeding status.

   Example: Kodiak Island. Colonies located within 500 m of a transect AND Black-legged Kittiwakes > 100 OR total murres > 100 OR total

birds > 1,000 were selected from the seabird colony catalog as being important to avoid.

4. Drifters - During calm seas, for whatever reason - possibly a combination of ocean current patterns and geography - large numbers of sea otters can be found resting relatively far offshore, over extremely deep water, miles (up to 4 miles is common) from the nearest possible foraging area.

   Example: Port Wells, PWS. Hundreds of sea otters were found scattered throughout this area with flat calm seas on 2 consecutive survey years. As a result, Port Wells was reclassified and as high density stratum.

5. Glacial moraine - Similar to the drifter situation, sea otters may be found over deep water on either side of this glacial feature.

   Example: Unakwik, PWS. Like Port Wells, Upper Unakwik was reclassified as high density stratum.

Planning an aerial survey

Several key points should be considered when planning an aerial survey:

1. Unless current sea otter distribution is already well known, it is well worth the effort to do some reconnaissance. This will help define the survey area and determine the number of observers needed, spacing of ISU's, etc.
2. Plan on using 1 observer per 5,000 otters.
3. Having an experienced technical pilot is extremely important. Low level flying is, by nature, a hazardous proposition with little room for error; many biologists are killed this way. While safety is the foremost consideration, a pilot must also be skilled at highly technical flying. Survey methodology not only involves low-level flying, but also requires intimate familiarity with a GPS and the ability to fly in a straight line at a fixed heading with a fixed altitude, fixed speed, level wings, from and to fixed points in the sky. Consider the added challenge of flying concentric 400 meter circles, spotting other air traffic, managing fuel, dealing with wind and glare, traveling around fog banks, listening to radio traffic, looking at a survey map, and other distractions as well. Choose the best pilot available.

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Figure B1. Data sheet for aerial survey strip transects

Date:	Observer:	Start Time:
Aircraft:	Pilot:	Area:

Transect Number	Side (N,S,E, or W)	Strip Count (Adults/Pups)	Chop (1-4)	Glare (1-4)	ISU Number(s)

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Figure B2. Intensive Search Unit (ISU) data collection form.

Date:	Observer:

Transect #:		ISU #:
Group #	Strip Count	Circle Count
1		
2		
3		
4		
5		

Transect #:		ISU #:
Group #	Strip Count	Circle Count
1		
2		
3		
4		
5		

Transect #:		ISU #:
Group #	Strip Count	Circle Count
1		
2		
3		
4		
5		

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Appendix C. Protocol for Determining Sea Otter Diet Based on Visual Observation

General Description

Sea otter foraging success and intensity will be measured using focal animal foraging observations, and activity scan sampling techniques (Altmann, 1974) adapted for sea otter work in past studies (Calkins 1978, Estes et al. 1981, Doroff and Bodkin 1994). Both will consist of shore based, near shore observations at selected sites within major study areas: One area will be within Glacier Bay proper, one in South Icy Strait, one in Althorp. Site selection will be based on the presence of sea otters and our ability to observe foraging animals. Observational effort will be allocated approximately proportional to the density and distribution of sea otters in each area.

Observations of foraging sea otters will provide information on food habits, foraging success (proportion successful feeding dives) and efficiency (convertible to mean kcal/dive) based on prey numbers, types and sizes obtained by feeding animals.

Data on sea otter food habits, foraging efficiency, and intensity should prove useful when examining differences (if any) in prey densities, and size-class distributions between study areas. Ultimately they will be used to elucidate questions regarding the difference in sea otter densities between study areas, and whether or not these differences are due primarily to differences in prey or habitat availability/quality or whether other factors may be involved (e.g. the length of occupation by sea otters).

Forage observation protocol

Food habits, foraging success and efficiency will be measured during shore or ship based observations of selected foraging otters. Shore based observations limit data collection to sea otters feeding within approximately 1 km of shore, while ship based observations extend data collection throughout the range of possible foraging depths. High power telescopes (Questar Corp., New Hope, PA) and 10X binoculars will be used to record prey type, number, and size during foraging bouts of focal animals. A bout will consist of observations of repeated dives for a focal animal while it remains in view and continues to forage (Calkins 1978). Assuming each foraging bout records the feeding activity of a unique individual, bouts will be considered independent while dives within bouts will not. Thus the length of any one foraging bout will be limited to one hour after which a new focal animal will be chosen.

Sea otters in the study area are generally not individually identifiable. Therefore individuals may be observed more than once without our knowledge. To minimize this potential bias foraging observations will be made throughout the study areas, attempts will be made to record foraging observations from as many sites as possible.

Site and Focal Animal Selection

Site and focal animal selection will be relative to sea otter density. Because the areas of interest are recently re-occupied by sea otters, densities can be low and foraging animals difficult to locate. Additionally, because of their social organization they frequently are aggregated in their distribution at resting areas and disperse individually to foraging

locations. We will concentrate foraging observations in areas of, and adjacent to recognized resting areas as identified in the distribution and abundance surveys.

If more than one foraging animal is available for observation at any particular observation site then the first one will be randomly selected (coin toss between pairs), and after completion of the bout the process repeated with the remaining animals. Observations will continue at the site until each available animal is observed or they have stopped foraging/left the area. If recognizable (tagged) individuals are available for observation their identification will be recorded and observations will be limited to no more than 3 bouts/individual for the length of the study period. Data will not be collected on dependent pups.

Data Collected

For each bout the otter's identification (if possible) estimated age (juvenile or adult) sex, and reproductive status (independent or with pup) will be recorded. Estimated distance from shore will be recorded and foraging location will be mapped. From the mapped location the foraging depth and habitat type will be determined or estimated from available GIS bathymetric and sonar data.

For each feeding dive observers will record dive times (time underwater searching for prey) and surface intervals (time on the surface between dives) along with dive success (prey captured or not). In addition, prey identification (lowest possible taxon), prey number, and prey size, (based on average paw widths, see forage data variables and codes) will be recorded. The mean success rate, mean prey number, mean prey size, and most common prey type will be determined for each bout, and an estimate of mean kcal/dive derived for prey items using reported caloric values and weight/length relationships (see Kvitek et al. 1992).

The goal for forage observations will be to collect data from at least 750 foraging dives over at least 45 foraging bouts collected over all daylight hours and tide levels. A bout will contain a minimum of 10 dives. Because the bout is the sample unit there is no need to limit the maximum number of dives in any given bout. However, in order to maximize the number of bouts observed, a new focal animal will be selected following one hour of observation or 30 dives from an individual otter.

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Figure C1. Sea otter foraging data form.

Sea Otter Foraging Data

				Otter #	
Date	Region	Site	Latitude	Longitude	
Observer	Time Begin	Time End	Age	Sex	Pup

Bout #	Dive #	Dive time	Surf time	Success	Prey item	Prey #	Prey size	Give	Take

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Figure C2. Foraging data variables and codes.

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Data Variables

OTTER #	otter identification number	
DATE	MM/DD/YY "05/09/98"	
REGION	up to 8 letters indicating a large geographic area or feature "GLACIER"	
SITE	up to 8 letters indicating closest chart description "FLAPJACK"	
LATITUDE	sea otters' position in decimal degees "5822.83"	
	. = no data	
LONGITUDE	sea otters' position in decimal degees "13602.21"	
	. = no data	
OBSERVER	first initial + up to 7 letters of last name "JBODKIN"	
TIME BEGIN	military time "18:45"	
	. = no data	
TIME END	military time "20:30"	
	. = no data	
AGE	P = pup	A = adult
	J = juvenille	U = unknown
SEX	F = female	U = unknown
	M = male	
PUP	Y = yes	U = unknown
	N = no	
BOUT #	number changes every time there is a break in the dive sequence	
DIVE #	numbered by bout	
DIVE TIME	in seconds	
	. = no data	
SURFACE TIME	in seconds	
	. = no data	
SUCCESS	Y = yes	U = unknown
	N = no	
PREY NUMBER	number of prey items	
	. = no data	
PREY ITEM	use prey codes on right side of page	
	. = no data	
	* go to next line if more than 1 item	
PREY SIZE	use appropriate code from table below	
	. = no data	
	* go to next line if more than 1 size	

SIZE CLASS (mm)	CODE	MID SIZE
0 - 26	1A	13
0 - 52	1B	26
26 - 52	1C	39
52 - 78	2A	65
52 - 104	2B	78
78 - 104	2C	91
104 - 130	3A	117
104 - 156	3B	130
130 - 156	3C	143
> 156	4Z	156+

GIVE	number of prey given away, stolen or lost	
TAKE	number of prey this otter took from another	

Alaska Sea Otter Prey Data Codes

CLAMS AND COCKLES		
CLN	*Clinocardium nuttallii*	Nuttall cockle
GAC	*Gari californica*	California sunset clam
ENN	*Entodesma navicula*	Ugly clam
HUK	*Humilaria kennerleyi*	
MAS	*Macoma* sp.	
MAP	*Mactromeris polynyma (Spisula)*	Arctic surf clam
MYA	*Mya arenaria*	
MYT	*Mya truncata*	
MYS	*Mya* sp.	
PRS	*Protothecа staminea*	Pacific littleneck clam
SAG	*Saxidomus giganteus*	Butter clam
SEG	*Serripes groenlandicus*	Greenland cockle
TRC	*Tresus capax*	Gaper clam
CLA		clam
URCHINS		
STD	*Strongylocentrotus droebachiensis*	Green
STF	*Strongylocentrotus franciscanus*	Red
URC		urchin
CRABS		
CAM	*Cancer magister*	Dungeness
CAP	*Cancer productus*	Red rock
CHB	*Chionoecetes bairdi*	Tanner
ORG	*Oregonia gracilis*	Decorator
HYL	*Hyas lyratus*	Pacific lyre
PAC	*Paralithodes camtschatica*	Red king
PUG	*Pugettia* sp.	Kelp
TEC	*Telmessus cheiragonus*	Helmet
CRA		crab
MUSSELS		
MOM	*Modiolus modiolus*	Horse
MTR	*Mytilus trossulus*	Blue
MUS		mussel
SNAILS		
FUO	*Fusitriton oregonensis*	Hairy triton
NES	*Neptunea* sp.	
SNA		snail
STARS		
GOC	*Gorgonocephalus caryi*	Basket
OPS	Ophiuroid sp.	Brittle
PYH	*Pycnopodia helianthoides*	Sunflower
SOS	*Solaster* sp.	Sun
STA		star
OTHER		
APV	*Aptocyclus ventricosus*	Smooth lumpsucker
BIV		bivalve
BAS	*Balanus* sp.	barnacle
CHI		chiton
CRS	*Cryptochiton stelleri*	Gumboot chiton
CUF	*Cucumaria fallax*	Sea cucumber
ECS	*Echiurus* sp.	Fat inkeeper
FIS		fish
HAA	*Halocynthia aurantium*	Sea peach
LIM		limpet
OCD	*Octopus dofleini*	Octopus
PHA	*Phascolosoma agassizii*	Peanut worm
POM	*Pododesmus macroschisma*	Rock jingle
SCA		scallop
SPO		sponge
UNI		unidentified
WOR		worm

NOTE: ultimately, bouts will be numbered consecutively by day, *across obs*

NOTE: save raw data as filename.csv (comma delimited) for SAS

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