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Sea Otter Studies in Glacier Bay National Park and Preserve

Shell litter from foraging sea otters, 2004.
Photo by Mike Conti

DRAFT ANNUAL REPORT 2004

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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 fewer than 10 to greater than 2,000 in 2004. 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 culturally important species. In 2004, we observed 1,232 foraging dives. Of the 1,210 dives where success was determined, 1,120 (92.6%) resulted in the retrieval of one or more prey items. Sea otter diet in 2004 consisted of 56% clam, 18% mussel, 2% crab, 9% urchins, 4% other, and 13% 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 butter clams, (*Saxidomus gigantean)*, Greenland cockles (*Serripes groenlandicus)*, littleneck clams (*Protothaca staminea)*, softshell clams (*Mya* spp.) and Macoma clams (*Macoma* spp.). Urchins are almost exclusively green urchins (*Strongylocentrotus droebachiensis)*, and the mussel is primarily the horse mussel *(Modiolus modiolus).* Crabs observed include Dungeness (*Cancer magister)*, tanner, (*Chionoecetes bairdii)*, kelp (*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.

Sea otters are now well established in large portions of lower Glacier Bay and monthly surveys of distribution indicate a consistent presence throughout the year in the Lower 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. We are beginning to see some of the direct effects of sea otter foraging, reflected in reductions of clam densities and biomass at sites where sea otter foraging has been observed. 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.

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 2004.

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 20^{th} 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 2004 we estimated that greater than 2,300 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
2004	2381*	27.6

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 intertidal 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 2004, a description of sea otter food habit studies from 2004 with a summary of our dietary findings over the period 1993-2004, and the preliminary results of distribution and movement surveys of sea otters in Glacier Bay and inter-annual variability in the species composition, density, and sizes of intertidal clams. This report represents the cooperative efforts of the USGS, ASC, and the NPS, Glacier Bay National Park and Preserve.

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.

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

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 in Glacier Bay and surrounding waters. The first type, carried out annually 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. Monthly distribution surveys were initiated in January 2004 as part of an NRPP study. The purpose of monthly surveys is to provide information on the presence and relative abundance of sea otters at our benthic sampling sites (Appendix C: NRPP Study Plan). 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 1999-2004.

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, 2003, and 2004 (Table 2). In 2004, a distribution survey of Icy Strait and Cross Sound was completed on 3 May. Distribution data for Glacier Bay in 2004 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 (65 knots), and at the lowest safe altitude.

Beginning in January 2004, monthly distribution surveys were flown in Glacier Bay as part of the USGS's NRPP work (Appendix C). These surveys will continue through December 2006. Surveys are flown in a Cessna 206 carrying at least one observer in addition to the pilot. Surveys are flown at 90 knots, and 500', and the flight track spacing allows complete coverage of all occupied sea otter habitat. The flight track extends at least 10km beyond the last sea otter sighting or areas of known sea otter occupation. Both the pilot and all observers contribute independent observations with the intent to record all sea otters present. The primary observer records the flight path and any otter sightings on a set of survey maps. The data is then digitized and summarized. Complete GIS analyses will be performed at the end of the study to integrate otter distributions to inter-and subtidal benthic study data.

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 A, 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 2004 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 2 and 6 May 2004, a single observer surveyed four replicates from a Bellanca Scout.

Results

Distribution Surveys

Distribution surveys in Cross Sound and Icy Strait were conducted each year from 1994-2004, with the exception of 2002 (Table 3). 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, the 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 2004 was similar to that observed in recent years. Primary changes in sea otter distribution from 1994-2004 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, or east of Porpoise Islands.

In 2004 we were able to perform 10 monthly distribution surveys (Table 2). Inclement weather and conflicting pilot/observer schedules precluded surveys in August and October. The average count over the 10 surveys was 666 sea otters (range 263-1083) in Glacier Bay proper. Overall mean group size was 8, (range of monthly means 3.8-19.4 otters). Single otters were routinely observed and the largest group observed during the 10 surveys was 350. Figure 4 displays data from 4 of the monthly distribution surveys as well as intertidal clam sampling sites. Spatial analysis of otter locations and benthic sampling sites will not occur until after the surveys are completed in late 2006.

Table 2. Summary of monthly surveys of sea otter abundance in Glacier Bay, 2004.

Survey Date	# Groups	Sum of Counts	Mean Group size
1/19/2004	66	459	7.0
2/26/2004	96	847	8.8
3/23/2004	71	875	12.3
4/10/2004	70	711	10.2
5/10/2004	158	1083	6.9
6/4/2004	69	425	6.2
7/8/2004	35	679	19.4
9/1/2004	157	647	4.1
11/12/2004	69	263	3.8
12/7/2004	117	669	5.7
Means	**91**	**666**	**8**

Abundance Surveys

The four replicate surveys required approximately 40 hours of flight time to complete, including transit to and from Bartlett Cove. The mean of the individual replicates yielded an adjusted population size estimate of 2,381 (se = 594) (Table 3). All group locations were digitized into ARC/INFO coverages (Figure 3).

The estimate of 2,381 sea otters in 2004 represents a 28% increase over the 2003 estimate (Table 1). The 2003 estimate represented 48% increase over the 2002 estimate. Since we began estimating the abundance of sea otters in Glacier Bay in 1999, the average annual rate of increase has been 49%.

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 Icy Point, 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 Island). The abundance estimate from that survey was 5,844, resulting in a Southeast Alaska sea otter population estimate of 9,032.

Table 3. Results of Cross Sound/Icy Strait sea otter distribution surveys and abundance surveys in Glacier Bay proper in 1999 - 2004 (Glacier Bay abundance estimates bolded). Counts are presented as # adults/# pups, while a period means 'no data'. Abundance estimates include pups (Bodkin and Udevitz 1999). * Glacier Bay estimate revised from previously reported 2001 value following re-analysis.

Survey	Survey Area: Cape Spencer – Pt Wimbledon	Pt Wimbledon - Pt Dundas	Pt Dundas – Pt Gustavus	Glacier Bay Proper	Excursion Inlet	Pt Couverden	Pt Gustavus-Porpoise Is	Cannery Pt-Crist Pt	Crist Pt – Gull Cove	Lemesurier Is	Gull Pt – Pt Lavinia	Inian Is	Pt Lavinia-Column Pt	Total
May 94	69 /20	37 /1	0	.	.	.	29	0	55	33 /8	77	31 /19	100 /31	**431 /69**
May 95	60 /9	23	12 /1	5	.	.	94 /1	0	15 /3	62 /23	81	36 /16	159 /73	**547 /126**
Mar 96	31 /4	18	41 /1	39	.	.	73	0	30 /1	56 /2	48	11 /1	42 /3	**389 /12**
Aug 96	19 /2	52	178 /4	0	.	.	2 /1	0	17 /1	47 /8	141	30 /12	94 /21	**580 /49**
May 97	43 /3	24	10	21	.	.	161	0	92 /15	143 /32	94	31 /8	148 /25	**767 /83**
Mar 98	8	52	1	209	7	2	8	0	23	10	3	10	31	**364**
May 99	6	27	17	**384**	1	.	18	0	97 /3	67 /17	90	18 /4	21 /7	**746 /31**
May 00	7	46	0	**554**	0	0	57	.	2	11	139	9	88 /11	**913 /11**
Jun 01*	52 /27	38 /2	8 /1	**1238**	0	0	129 /1	.	62 /19	76 /33	95	46 /16	84 /26	**1828 /125**
Jun 02	.	.	.	**1266**	.	.	.	.	.	.	.	.	.	**1266**
Jun 03	18	60 /2	7	**1866**	0	0	15	0	38	10	28	9	53/3	**2104 /5**
May 04	52/4	85 /12	4	**2381**	0	0	57	0	63/5	69 /27	77	32 /12	60 /12	**2904 /72**

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 over the past decade. As recolonization of previously occupied habitat has occurred in Icy Strait, sea otters had at least two options in terms of 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 2004.

The 2004 abundance estimate for Glacier Bay was greater than the 2003 estimate by 28% (Table 1). The distribution of sea otters in Glacier Bay and Cross Sound/Icy Straits in 2004 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 and Flapjack Island, 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 2,381 in 2004 (Table 1). The average rate of increase in Glacier Bay since 1999 (49%) is about twice the maximum theoretical growth rate for the species (Estes 1990) and more than twice the long term growth rate (19%) observed in Southeast Alaska (Bodkin et al 1999). 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. The exceptional rate of growth in Glacier Bay sea otter populations can be explained by both reproduction of resident sea otters as evidenced by the increasing number of dependent pups observed in Glacier Bay and immigration of individuals from outside the Park. In 2004, 17% of the individual sea otters detected on intensive searches during the abundance surveys were dependent pups. Reasons for this exceptional rate of growth likely include abundant food resources and unoccupied habitat. It is also possible that the Park is serving as a refuge from the human harvests that occur outside Park boundaries.

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.

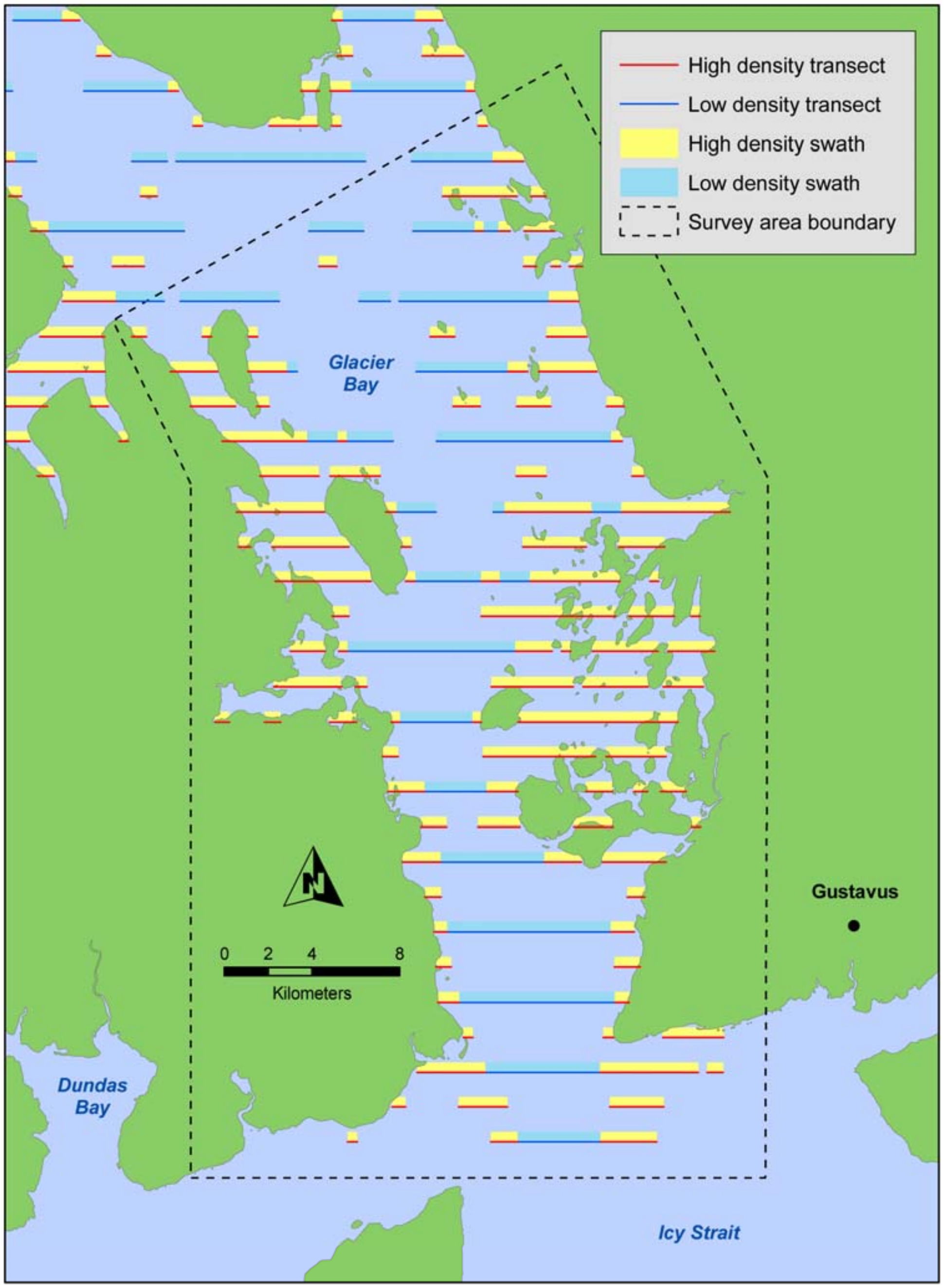


Figure 2. One of four transect designs used during a sea otter abundance aerial survey in Glacier Bay National Park, May 2004.

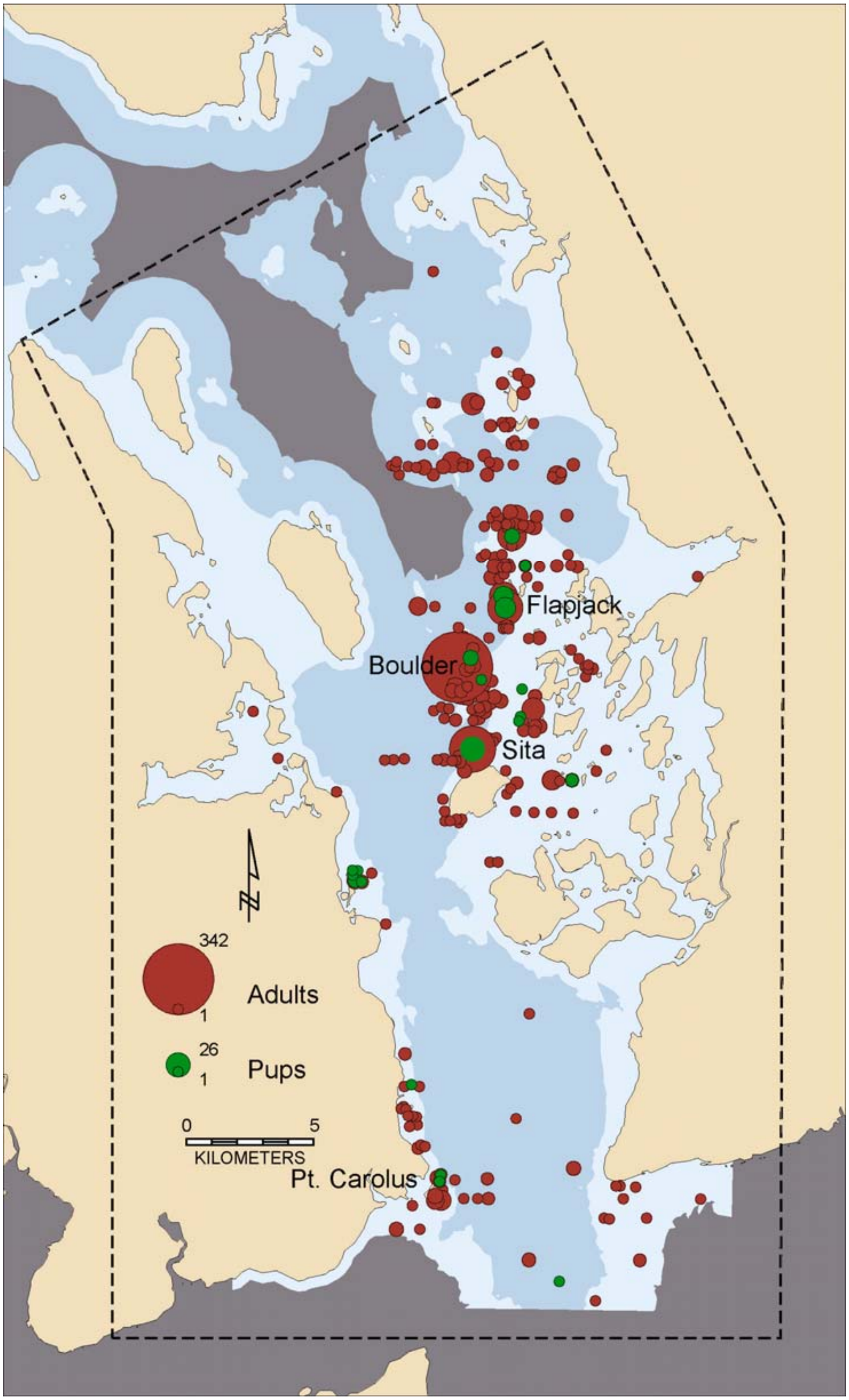


Figure 3. Sea otter group locations from 4 replicate aerial abundance surveys in Glacier Bay National Park, May 2004 (spot size proportional to group size).

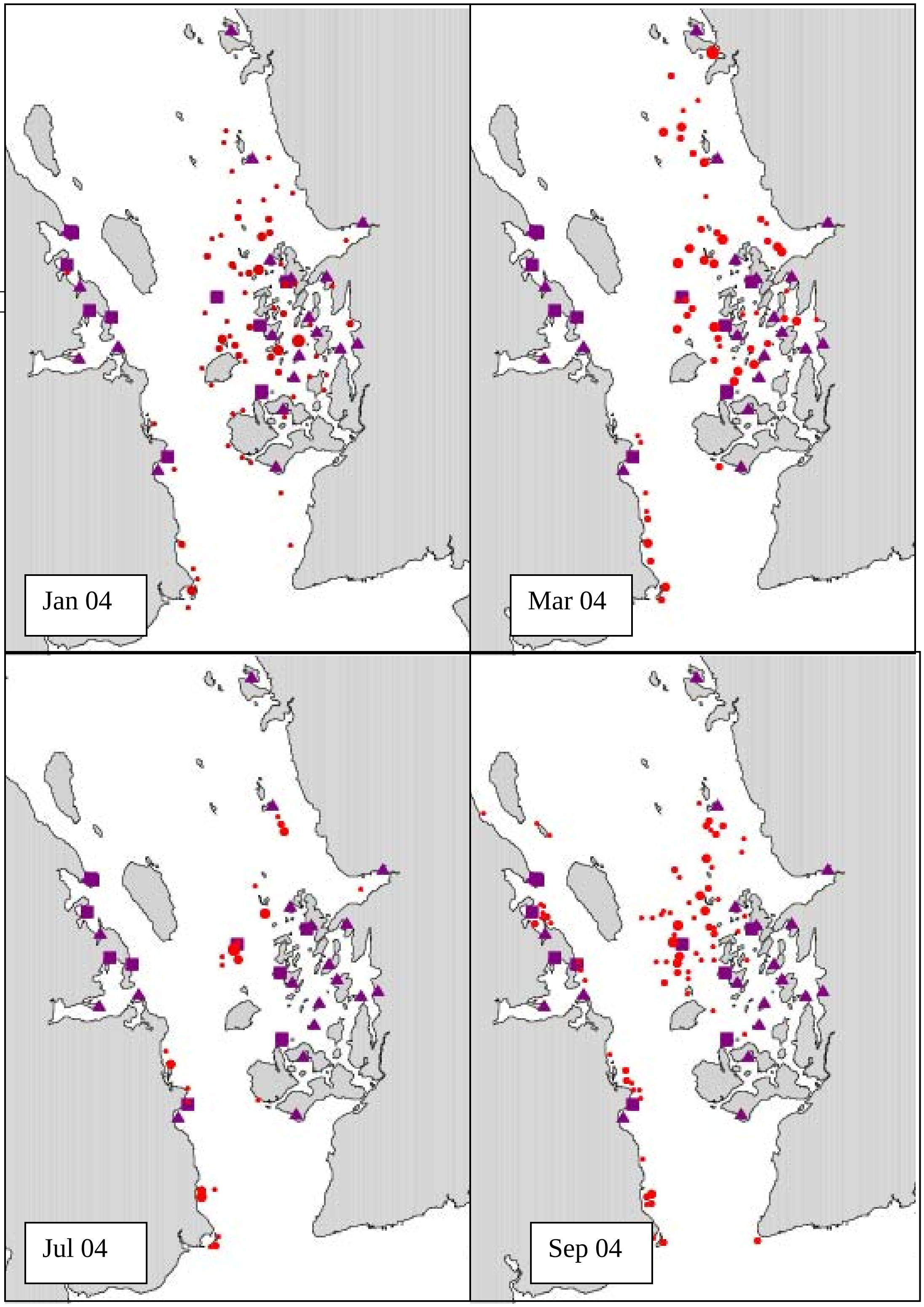


Figure 4. Sea otter group locations from 4 monthly distribution surveys in 2004. Red dots represent sea otter group locations and dot sizes are proportional to abundance. Purple squares (PCH) and triangles (random) represent intertidal benthic sampling study sites.

Sea Otter Foraging Behavior in Glacier Bay

Saxidomus gigantea shell and siphon left behind by a foraging sea otter, outside Secret Bay, 2004.

Photo by Mike Conti.

Sea Otter Foraging Behavior in Glacier Bay

Introduction

Observations of sea otter foraging behavior in 2004 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). In the 2003 Annual Report (Bodkin et. al. 2004), we re-analyzed the Glacier Bay data (1993-2003) in order to present a broad picture as well as some annual and site specific patterns. In this report we give an overview of the data collected during the 2004 field season.

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). 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 2004 we observed 1,232 foraging dives, of which 1,120 were successful (92.6%), 90 were unsuccessful, and 22 were of undetermined outcome (Table 4). Foraging observations were collected from many individual locations in 2004 and grouped into 10 sites (Figure 5). Observations from these 10 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 5).

Table 4. Sea otter foraging success rates in Glacier Bay and sites within Glacier Bay, 1993-2004.

	# dives	# successful	Success rate
GLBA all years: 93-04	5508	4910	91.5%
GLBA 2004	1232	1120	92.6%
2004 individual sites:			
Boulder	86	80	95.2%
Pt. Carolus	44	42	93.3%
Fingers	82	66	80.5%
Flapjack	167	160	95.8%
Leland	275	239	90.5%
Marble	14	14	100.0%
Mid-Beardslee	173	156	92.3%
Rush/Ripple	116	110	96.5%
Strawberry	15	15	100.0%
Sandy Cove	260	238	93.0%

Table 5. Prey items observed being consumed by sea otters in Glacier Bay, 1993-2004.

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.
Barnacle spp.
Other:
Worm: *Echiurus* spp.
Porifera: Sponge
Chordate: fish

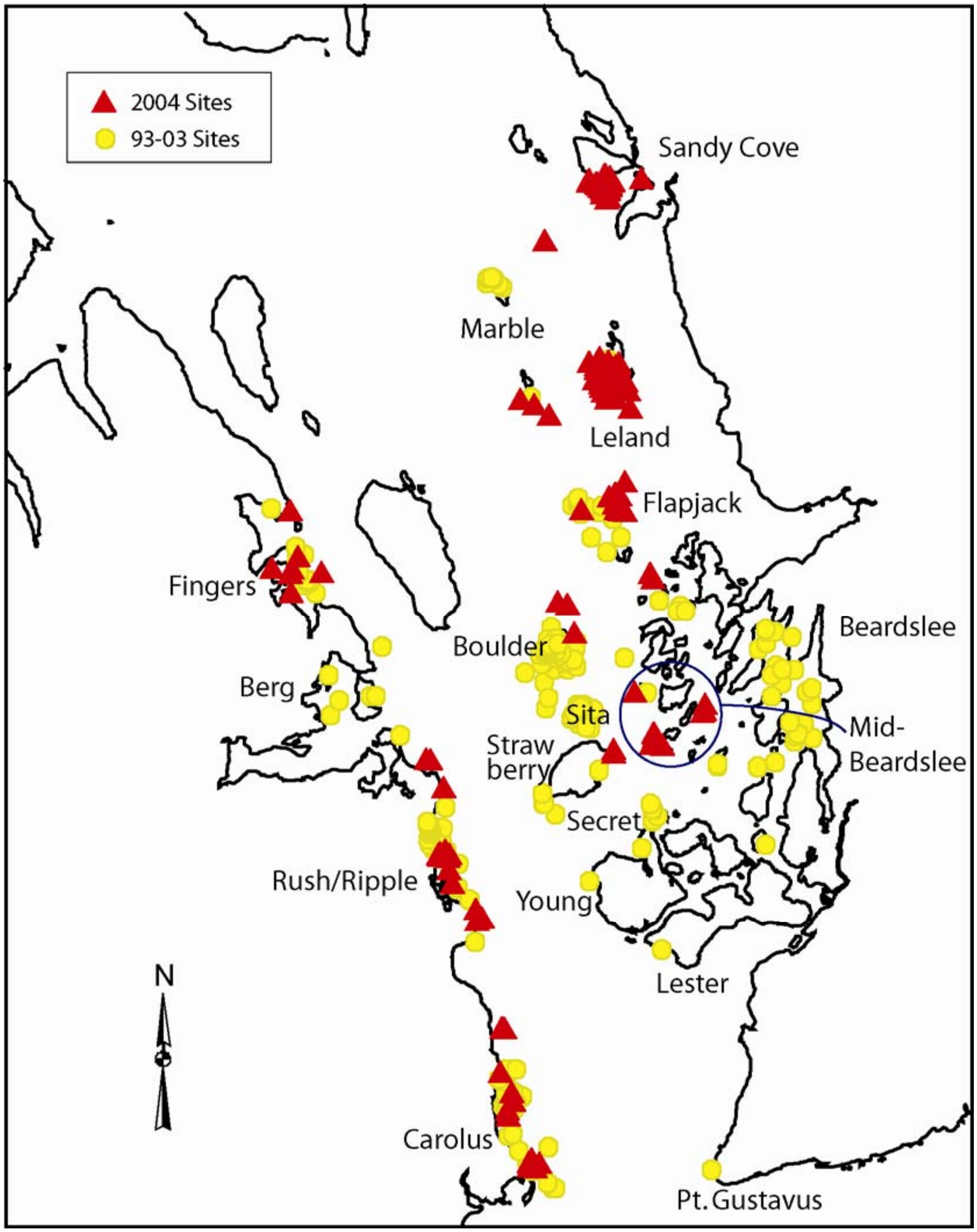


Figure 5. Locations within Glacier Bay of sea otter foraging observation data collection, 1993-2004. 2004 locations (red triangles) are grouped into 10 sites in the summary analyses: Pt. Carolus, Rush/Ripple, Fingers, Strawberry, Boulder, Mid-Beardslee, Flapjack, Leland, Marble, and Sandy Cove.

Prey Composition

Of the 1,120 successful foraging dives we observed in Glacier Bay in 2004, 56% resulted in retrieval of clam species, 18% in mussel, 2% in crab, 9% in urchin, 4% other, and 13% unidentified (Figure 6, Table 6).

Prey composition varied among sites (Figure 7, Table 6). For example, at the 5 sites where >100 successful dives were observed in 2004 (Flapjack, Leland, Mid-Beardslee, Rush/Ripple, and Sandy Cove), the percentage of dives where clams were retrieved ranged from 24% to 84%, crabs from 0 to 3%, mussels from 0 to 27%, and urchins from 3 to 34%.

Prey Number and Size

The mean number of prey/dive and mean prey sizes varied by prey type in 2004 but were similar to 2003 values (Bodkin et al 2004) (Figures 8, 9). In Glacier Bay, on average, sea otters recovered 2.9 (2.4) prey items per dive (179 bouts). Sea otters retrieved an average (sd) of 1.8 (1.0) clams, 1.1 (0.5) crab, 3.5 (2.4) mussels, or 4.6 (3.3) urchins per dive. The mean size (sd) of clams recovered was 65.0(19.0) mm, crabs: 71.8 (36.9) mm, mussels: 85.2 (24.3) mm, and urchins: 44.9 (16.0) mm.

Table 6. Percentage of dives with each prey type present, 1993-2004. Number in parentheses is the number of successful dives observed. '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. Percentages in this table can total more than 100% because more than one prey item can be retrieved per dive.

	Clam	Crab	Mussel	Urchin	Other	Unid
All GLBA 93-04 (4910)	44%	4%	21%	15%	5%	14%
04 All GLBA (1120)	56%	2%	18%	9%	4%	13%
04 Flapjack (160)	64%	2%	13%	3%	3%	16%
04 Leland (239)	56%	0%	19%	5%	0%	20%
04 Mid-Beardslee (156)	62%	3%	15%	4%	2%	21%
04 Rush/Ripple (110)	25%	1%	27%	34%	12%	5%
04 Sandy Cove (238)	84%	3%	0%	5%	3%	10%

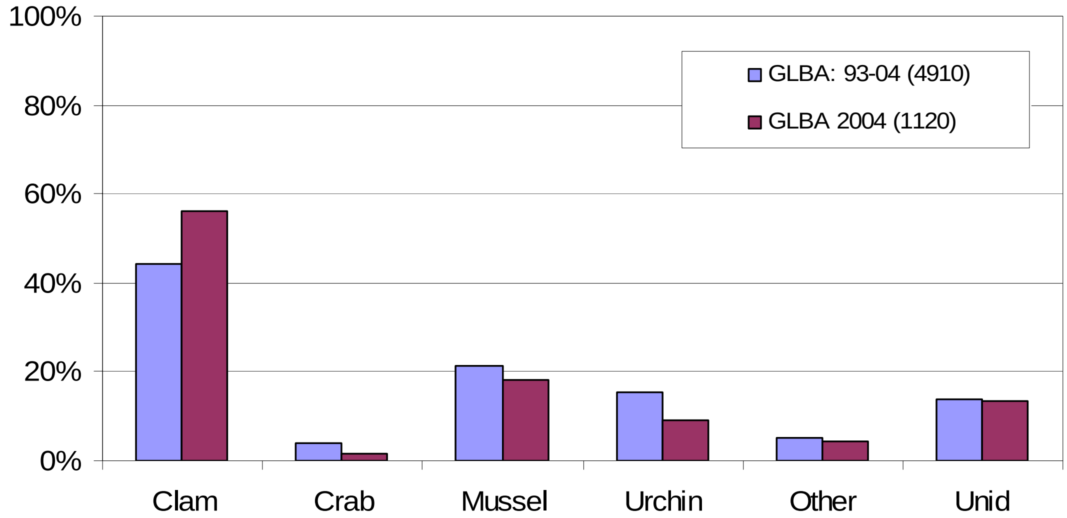


Figure 6. Prey composition of successful sea otter foraging dives (# successful in parentheses in legend) in Glacier Bay, 1993-2004. This figure shows the percentage of all dives with a successful outcome (prey retrieved) that include each prey item. For example, sea otters retrieved at least one clam on 56% of their dives in Glacier Bay in 2004.

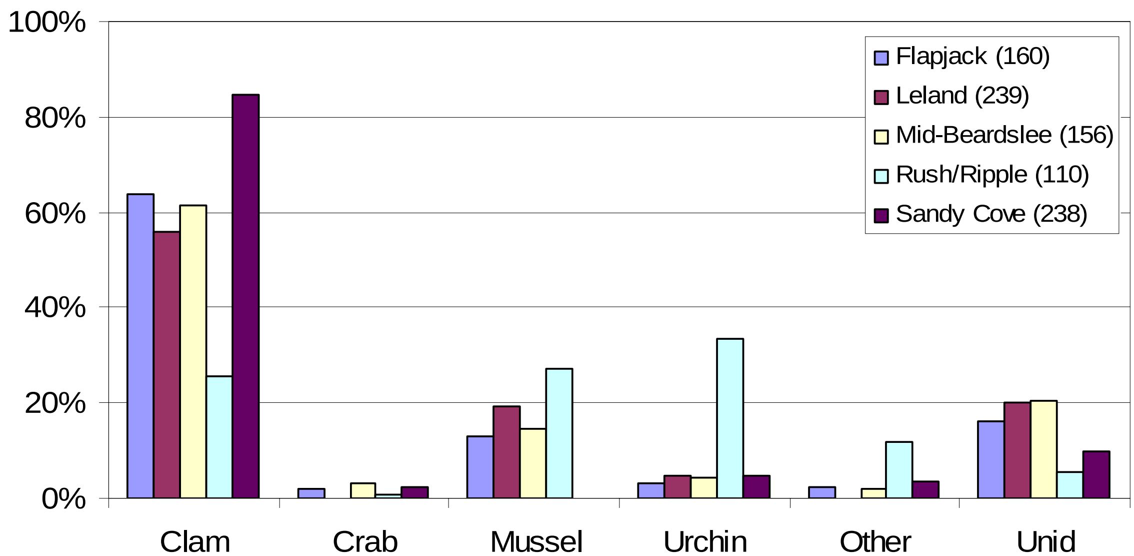


Figure 7. Prey composition of sea otter foraging dives in Glacier Bay, for 5 sites (# dives) where data on more than 100 successful dives was collected. See Figure 5 for site locations. This figure shows the percentage of all dives with a successful outcome (prey retrieved) that include each prey item. '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.

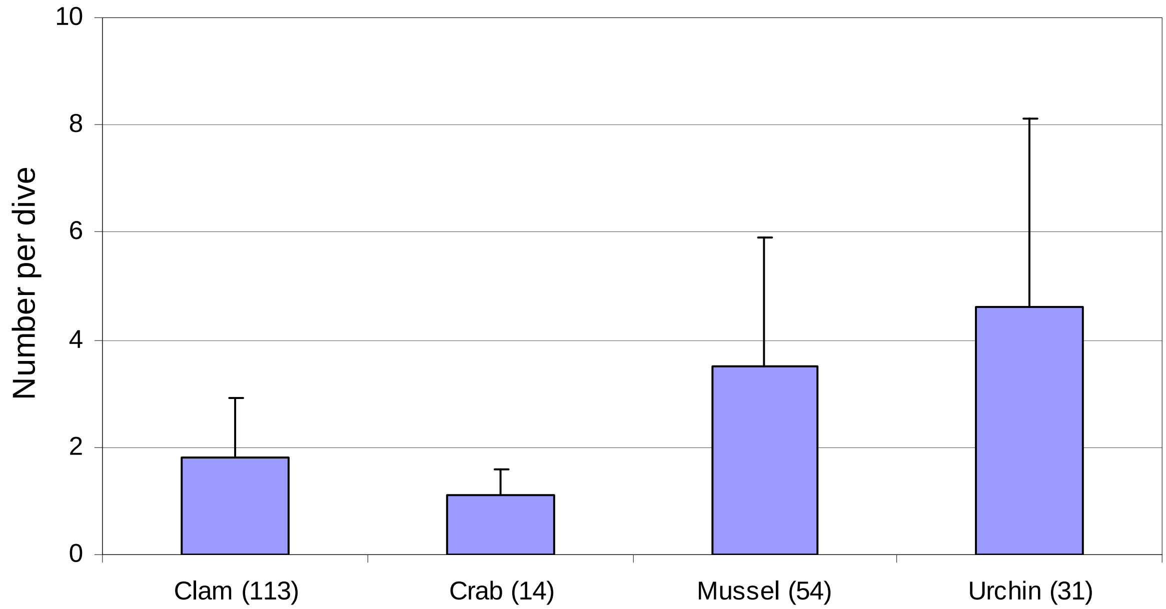


Figure 8. Mean number per dive and standard deviations of the primary prey items recovered by sea otters during observations of foraging in Glacier Bay, 2004. Numbers in parentheses indicate number of bouts with that prey type predominant.

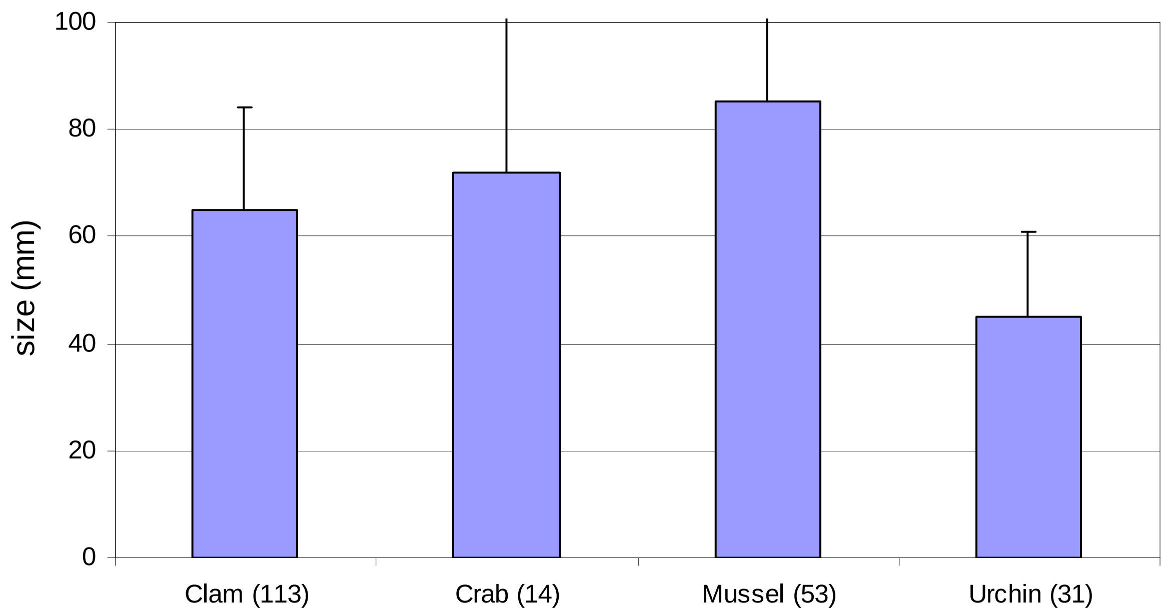


Figure 9. Mean size and standard deviations of the primary prey items recovered by sea otters during observations of foraging in Glacier Bay, 2004. Numbers in parentheses indicate number of bouts with that pre type predominant .

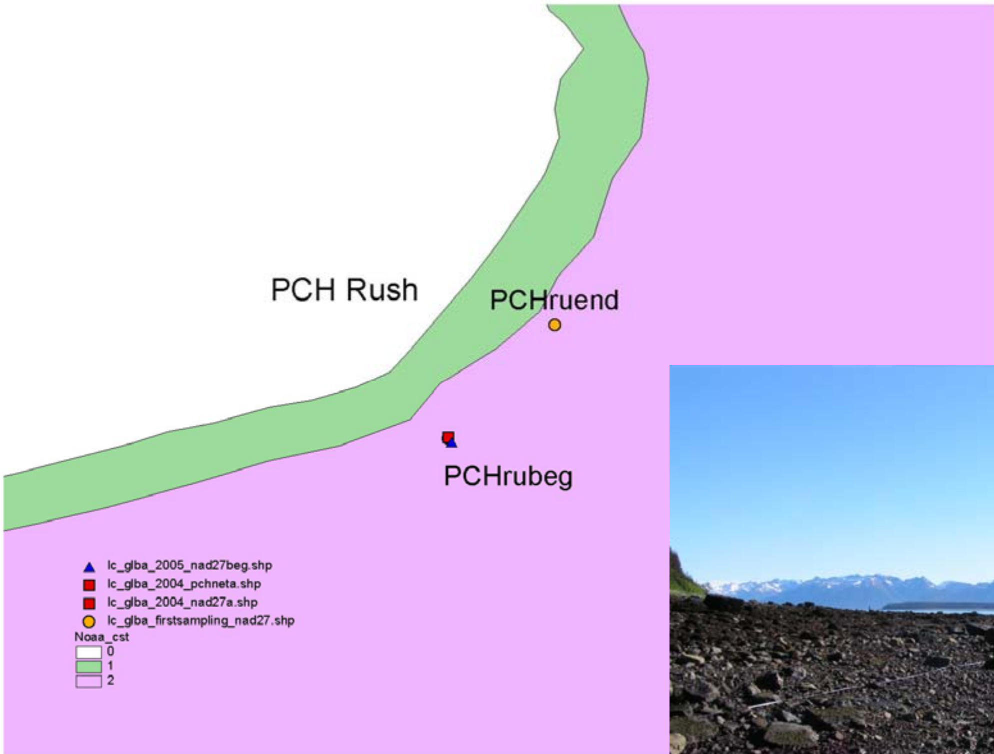
Discussion

In 2004, sea otters we observed are foraging with an average success rate of about 93% 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. It is likely that these abundant prey resources are a contributing factor to the high rate of sea otter population growth in Glacier Bay.

The diet of sea otters in Glacier Bay consists largely of invertebrates that reside in unconsolidated sediments such as mud, sand, gravel or cobble (Table 5). Bivalve clams dominated the diet at most sites, although in some areas other prey also important components of the diet (Table 6). For example, at Leland Is., mid-Beardslees sites, Flapjack Is, and Rush Pt/Ripple Cove, horse mussels (*M. modiolus*) were a large proportion of the diet. Also at Rush Pt/Ripple Cove, green urchins (*S. droebachiensis*) were a major dietary component. 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, but also may reflect individual prey preferences.

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.

Intertidal Clam Resampling in Glacier Bay



Intertidal Clam Sampling in Glacier Bay

Introduction

The Alaska Science Center (ASC) and Glacier Bay National Park and Preserve (GBNPP) in 1993 established a program to determine the effects of recolonizing sea otters on the marine ecosystem in Glacier Bay (Bodkin et al. 2001, Bodkin et al. 2002, Donellan and Bodkin 2002). Work to date has included establishing and sampling nearly 100 intertidal and subtidal sites to describe and quantify the nearshore benthic marine communities prior to sea otter recolonization. (Bodkin et al. 2001, Bodkin et al. 2002, Bodkin et al. 2003). Pre-treatment sampling of communities was completed in 2003. Since 1995 the number of sea otters has increased in Glacier Bay from approximately 5 to nearly 2,400 in 2004. The distribution of sea otters is not uniform relative to our community sampling sites, allowing for spatial control over the experimental treatment (the sea otter) (Figure 4 & 10). In 2004 we implemented research to define the magnitude of sea otter proximity and persistence relative to our benthic sampling sites (Figure 10), and to repeat our earlier sampling of intertidal clams at a subset of the sites sampled in 1998-2000 (Appendix C). Monthly sea otter distribution surveys are described and reported in the Distribution and Abundance section of this report. In this section we will report on the resampling of intertidal clam populations that was conducted in 2004.

Methods

Site Selection

Forty-eight randomly selected sites (random) and 12 preferred clam habitat sites (PCH) were sampled for intertidal bivalves and urchins (species composition, size distributions, and population abundance) in 1998-2000 (Figure 10) (see Bodkin et al. (2000) for a detailed description of the initial clam sampling site selection procedure). In 2004 we randomly selected a subset of those 60 sites for the purposes of resampling clam beds to assess intra-annual variability within sites. Based on forage observations and the presence of sea otters during surveys, sites that were likely to have been impacted by foraging sea otters were excluded from the sample we drew. The remaining sample included 15 sites, 9 random and 6 preferred clam habitat (PCH) sites that had been previously sampled.

Sampling Protocol

A handheld GPS was used to navigate to the site. At each site a 200 m transect was positioned horizontally along the 0 MLLW tide level. The 0 MLLW level was determined using the tide station closest to the site and tide reports from Tides & Currents software (Nautical Software, Beaverton OR). A starting point that optimized separation from quadrats previously sampled was selected and ten 0.25 m^2 quadrats placed 20 meters apart were excavated to a depth of 25 cm. All sediments were sieved through a 10 mm mesh screen, then all clams (and urchins and crabs if present) were identified to the lowest possible taxa, counted, and measured to the nearest millimeter using dial calipers. Sediments were returned to the quadrat during the sieving process, while biota was returned following measurements. In order to facilitate resampling the same site during subsequent efforts, 2 – 3 ft rebar stakes were installed at the starting end of the 200 m transect at 0 MLLW. Additionally, GPS readings were collected for the starting and ending points and tracklines saved for the segments.

Analysis

For each site sampled we calculated the following: 1) Shannon-Weiner diversity index (H'), 2) mean density of clams (# / 0.25 m^2)by species and in aggregate, 3) mean biomass (g/0.25 m^2) by species and in aggregate, and 4) mean size of each species. Because the data set collected to date is intended to be compared against identical data collected from the same sites in a third resampling year, we do not perform or report statistical tests of significance in this report.

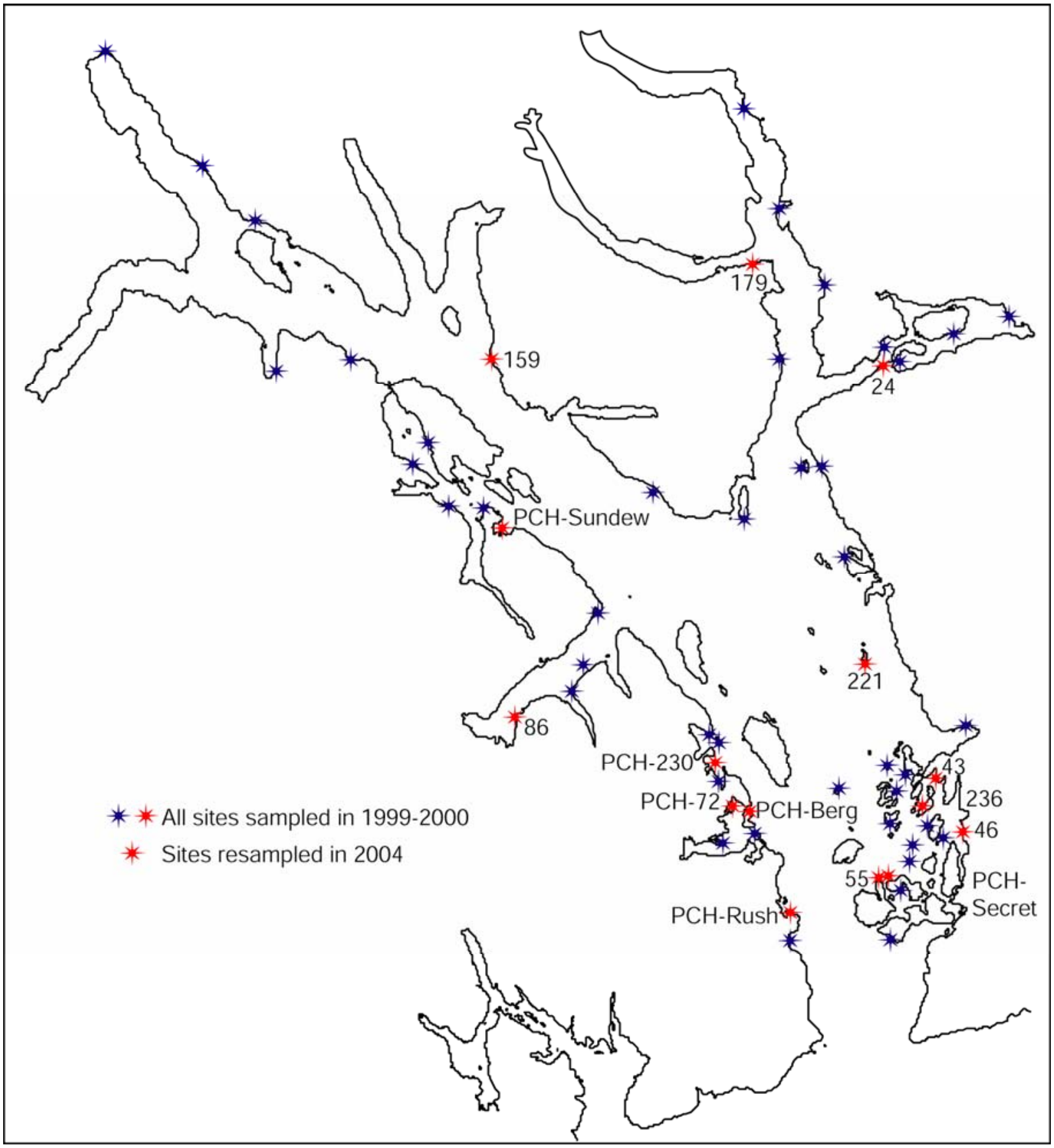


Figure 10. Map of Glacier Bay National Park showing initial intertidal clam sampling sites and the pool of 2004 resample sites. Preferred clam habitat sites are prefaced by PCH-, all others are randomly selected sites. Only those sites resampled in 2004 are identified in this figure.

Results

Clam Species Diversity

The Shannon-Wiener diversity index (H’) was calculated for each site after the initial sampling in 1998-2000 and after the first resampling in 2004. This index accounts for species richness (total number of species present) as well as their relative proportions, so rare individuals do not have undue influence on H’. The theoretical maximum for H’ equals $\log_2$ (total number of species possible), in our study H'_{max} equals 3.60 for the initial sampling and 3.70 for the resampling. Mean and site-specific diversity values for random and PCH sites are presented in Table 7. In this report means are presented only for the sites included in the individual resampling subset and for the random and PCH resampled subset of sites (see Bodkin et al. 2000 for the inclusive means). Mean species diversity decreased slightly in random sites between the two sampling events, while the opposite was true for PCH sites.

In our 1999-2000 sampling we found 11 different species: *Clinocardium nuttallii* (CLN), *Entodesma navicula* (ENN), *Gari californica* (GAC), *Hiatella arcticus* (HIA, now HIS for *Hiatella* spp.), *Humilaria kennerleyi* (HUK), *Macoma* spp. (MAS), *Mya* spp.(MYS), *Panomya ampla* (PAA) *Protothaca staminea* (PRS), *Pseudopythina compressa* (PSC), and *Saxidomus gigantea* (SAG). We also found a few clams that were lumped under the category other (CLA). We lumped *Mya arenaria* and *M. truncata* (MYS). We lumped all *Macoma* species (MAS) because many are unidentifiable without dissection. In the 2004 resampling, we did not encounter ENN, GAC, or HUK; however we did sample a new species, *Zirphaea pilsbryi* (ZIP).

Table 7. Shannon-Weiner diversity index values (H’) for intertidal clam sampling areas. H’ = 0 when only 1 species is present. LB = Lower Bay, EA = East Arm and WA = West Arm.

Site	N	Location	Initial H’ (mean (sd))	Resample H’ (mean (sd))
Random Sites	**9**		**1.18 (0.73)**	**1.16 (0.58)**
24	.	EA	1.15	1.37
43	.	LB	1.26	1.49
46	.	LB	1.70	1.33
55	.	LB	1.51	1.45
86	.	WA	0.78	0.53
159	.	WA	0.00	0.00
179	.	EA	0.24	1.04
221	.	LB	2.19	1.98
236	.	LB	1.81	1.27
PCH Sites	**6**		**1.68 (0.39)**	**1.72 (0.41)**
72	.	LB	1.40	1.62
230	.	LB	1.31	1.30
Berg	.	LB	2.00	2.15
Rush	.	LB	2.03	1.85
Secret	.	LB	2.07	2.18
Sundew	.	WA	1.26	1.22

Clam Density

Overall, the number of clams per quadrat was similar between the initial and resampling efforts, although for a few sites this was not the case. In the initial sampling effort, mean densities of all clams per 1/4m^2 quadrat ranged between 0.1 – 137, and 37 – 121 for Random and PCH sites (Figures 11 and 12, Table 8), while in the 2004 resampling effort the mean densities were 1 – 165 and 29 – 151. For the random sites, the pattern was for a higher density in the resampling than in the initial except for sites 221 and 236. PCH Berg and Rush had lower densities per quadrat in 2004 than in the initial sampling while the other sites had higher densities in 2004.

As in the initial sampling, *Macoma* and *Protothaca* were the predominant species at most sites, both random and PCH. A few exceptions were the prevalence of *Hiatella* at sites 24 in Adam's Inlet, 159 south of Queen Inlet, 221 on Leland Island, and PCH230 in Fingers Bay.

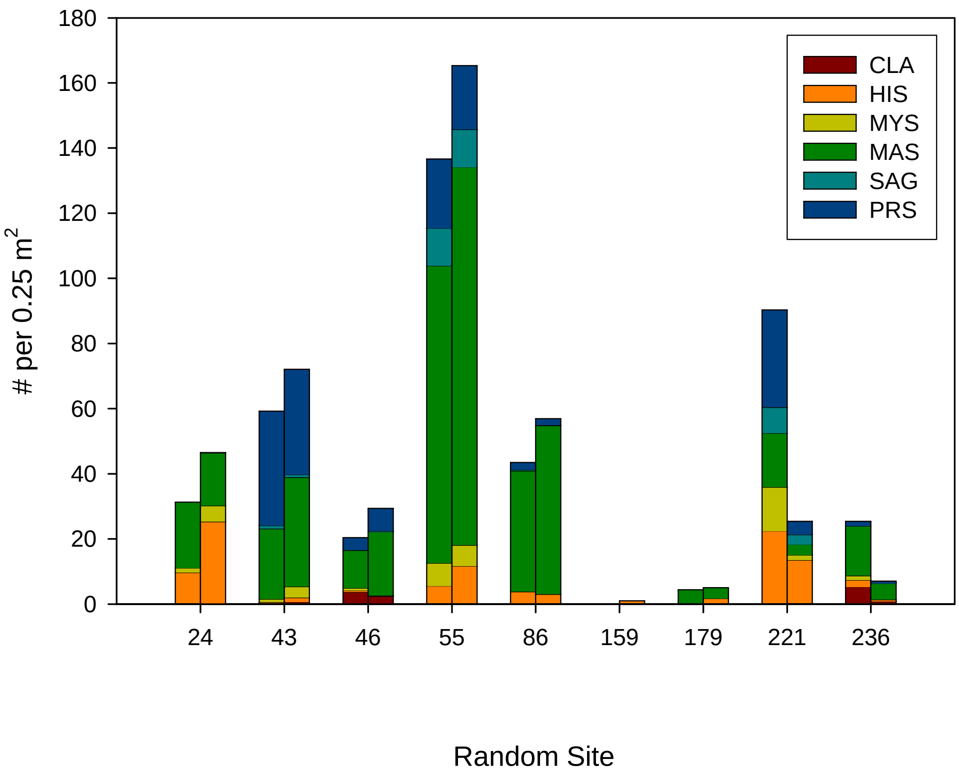


Figure 11. Intertidal clam densities at 9 randomly selected sites at initial sampling (1999-2000, left bar) and resampling (2004, right bar). PRS = *Protothaca staminea,* SAG = *Saxidomus gigantea,* MAS = *Macoma* spp., MYS = *Mya spp.*, HIS = *Hiatella* spp. and CLA = unidentified clams.

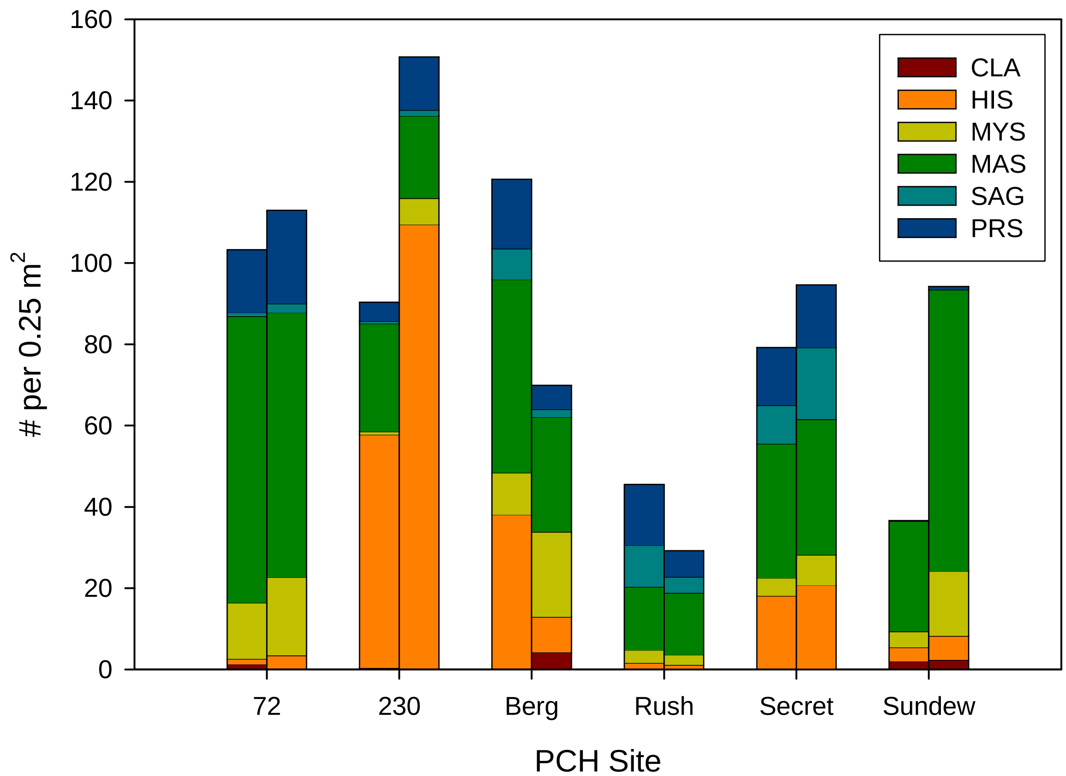


Figure 12. Intertidal clam densities at 6 preferred clam habitat (PCH) sites at initial sampling (1999-2000, left bar) and resampling (2004, right bar). PRS = *Protothaca staminea*, SAG = *Saxidomus gigantea*, MAS = *Macoma* spp., MYS = *Mya spp.*, HIS = *Hiatella* spp. and CLA = unidentified clams.

Clam Biomass

As in the initial sampling effort, the biomass of clams per quadrat varied extensively among sites (Figures 13 & 14, Table 8). Mean biomass of all clams per quadrat ranged between 0.01 – 102 for random sites and10 – 117 for PCH sites in the first sampling and 0.09 - 107 and 27 - 110 for the 2004 resampling (Figures 13 &14). For the random sites, there is no apparent pattern of differences in biomass between the two sampling efforts. PCH Berg and Rush had lower biomass per quadrat in 2004 than in the initial sampling while the other sites had higher densities in 2004.

Although *Macoma* and *Protothaca* dominated intertidal clam densities, biomass estimates are influenced by the size of the different species of clams. At both random and PCH sites in 2004, *Saxidomus*, *Mya*, and to a lesser extent, *Protothaca* contributed most to the biomass estimates.

Table 8. Mean total density (#/0.25 m^2) and total biomass (grams dry wt./0.25 m^2) of intertidal clams in Glacier Bay.

	Initial Sampling		2004 Resampling	
Sites	Density all clams (#/0.25 m^2)	Biomass all clams (g/0.25 m^2)	Density all clams (#/0.25 m^2)	Biomass all clams (g/0.25 m^2)
PCH	79.3 (33)	59.5 (39)	91.9 (41)	75.8 (29)
Random	45.7 (44)	31.9 (41)	45.4 (51)	24.7 (35)

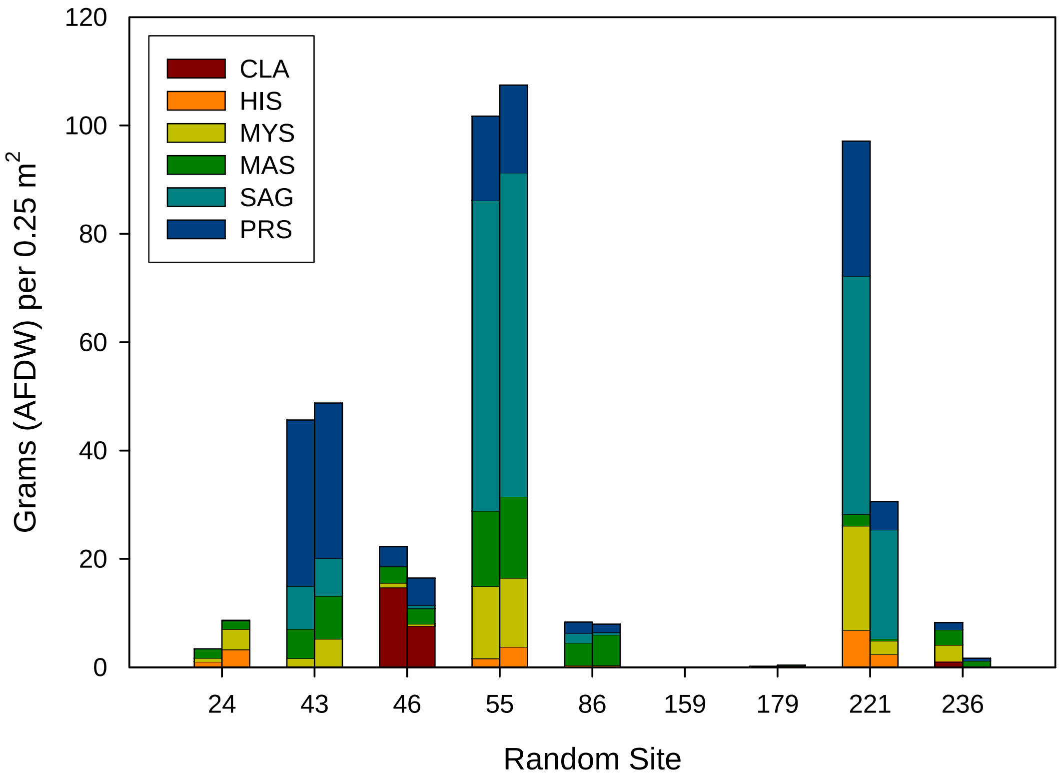


Figure 13. Intertidal clam biomass estimates at 9 random sites at initial sampling (1999-2000, left bar) and resampling (2004, right bar). PRS = *Protothaca staminea*, SAG = *Saxidomus gigantea*, MAS = *Macoma* spp., MYS = *Mya spp.*, HIS = *Hiatella* spp. and CLA = unidentified clams.

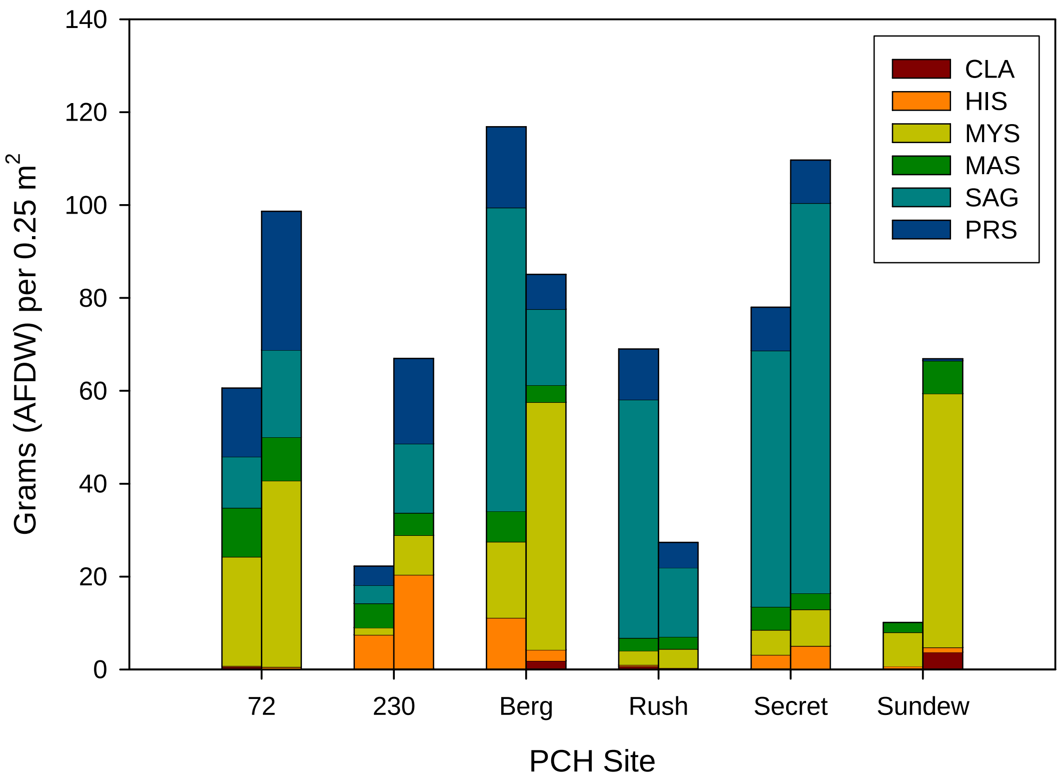


Figure 14. Intertidal clam biomass estimates at 6 preferred clam habitat (PCH) sites at initial sampling (1999-2000, left bar) and resampling (2004, right bar). PRS = *Protothaca staminea*, SAG = *Saxidomus gigantea*, MAS = *Macoma* spp., MYS = *Mya spp.*, HIS = *Hiatella* spp. and CLA = unidentified clams.

Mean Size

Mean clam sizes measured by species are presented in Figures 15 and 16. Mean size of all clam species was similar among sites. At random sites, there was no apparent pattern in differences between the initial sampling and the 2004 resampling for mean size of clams. However, for 80% of the PCH sites where *Saxidomus* occurred, mean size of *Saxidomus* was smaller in 2004, while mean size was larger in 2004 for *Protothaca*, *Macoma*, *Mya*, and *Hiatella.*

Discussion

In general, few striking differences were observed in this pool of sites between the initial sampling and the 2004 resampling. However, this is based on a cursory examination of the data and further analysis after completion of the 2005 resampling may lead to a revised assessment.

Species diversity of intertidal clams was similar between by site and by category (random, PCH). In general, sites in the Upper Bay had lower species diversity values than sites in the Lower Bay. Also, the PCH had a higher mean diversity than the random category, although individual sites within groups varied. Causes of observed differences in species diversity between the Upper

Arms and Lower Bay are unknown; but may be related to size structure of the sediments, primary productivity, circulation and fresh water inputs, or may be an artifact of time since de-glaciation and varying dispersal capabilities among clam species. It was expected that PCH would have greater diversity than random sites as they were chosen for being good clam habitat.

Clam densities were greater at PCH sites in both the initial and resampling. Several sites (221, 236, PCH-Berg) that had striking declines in clam density also showed evidence of sea otter impacts, such as numerous foraging pits and/or clam debris (shell litter with characteristic otter-preyed cracking patterns and siphons that had not been consumed). Patterns of differences in clam biomass were similar to the patterns observed in clam densities.

Although mean size was similar among sites, there were some differences that need to be further explored once the 2005 sampling is completed. The apparent reduction in mean size of *Saxidomus* at PCH sites is possible evidence of a sea otter predation effect. *Saxidomus* is known to be a preferred prey item of sea otters (Kvitek and Oliver 1992, JLB unpub. data) and is frequently observed being consumed during our foraging observations in Glacier Bay. Also we found the mean size of *Saxidomus* was more than twice as large in Glacier Bay as in Port Althorp and Idaho Inlet, locations with well-established sea otter populations (Bodkin et al. 2002). We've predicted that those locations provide a reasonable view of the future of Glacier Bay intertidal clam populations as changes induced by sea otters occur.

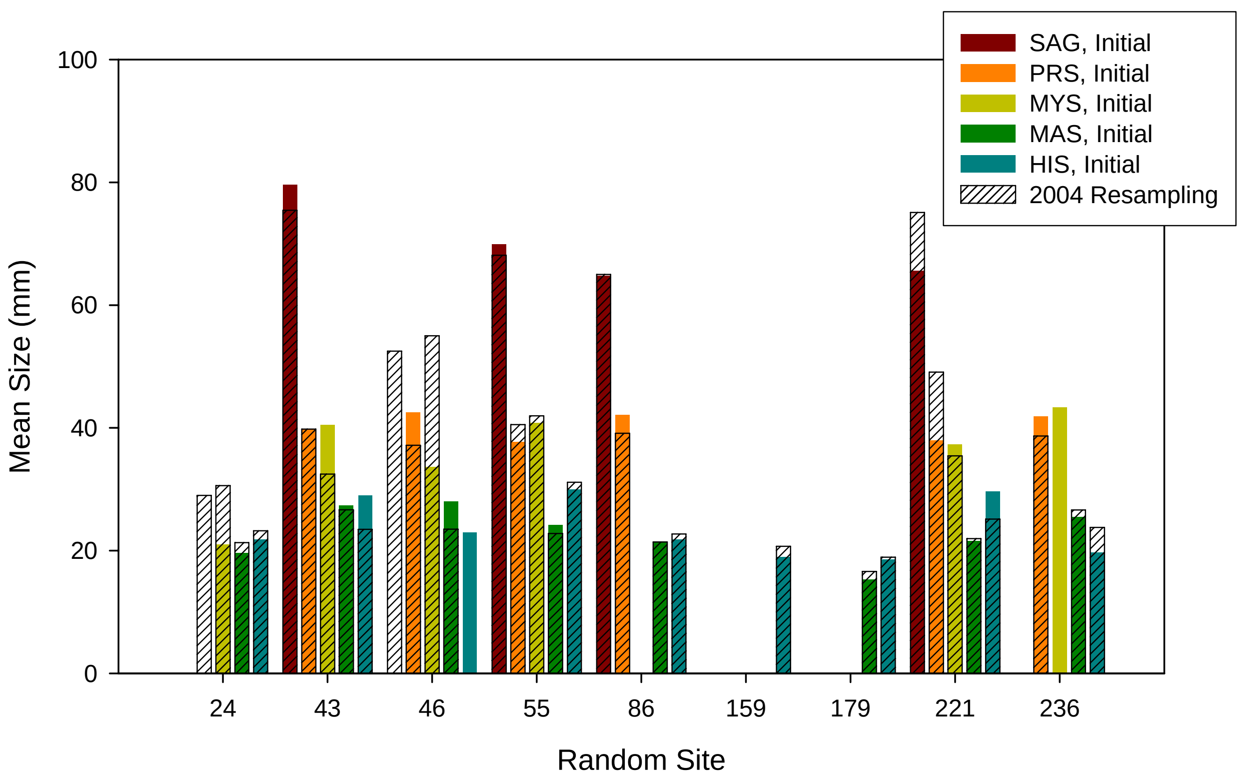


Figure 15. Mean sizes of intertidal clams at 9 random sites at initial sampling (1999-2000) and resampling (2004). SAG = *Saxidomus gigantea*, PRS = *Protothaca staminea*, MYS = *Mya spp.*, MAS = *Macoma* spp., and HIS = *Hiatella* spp.

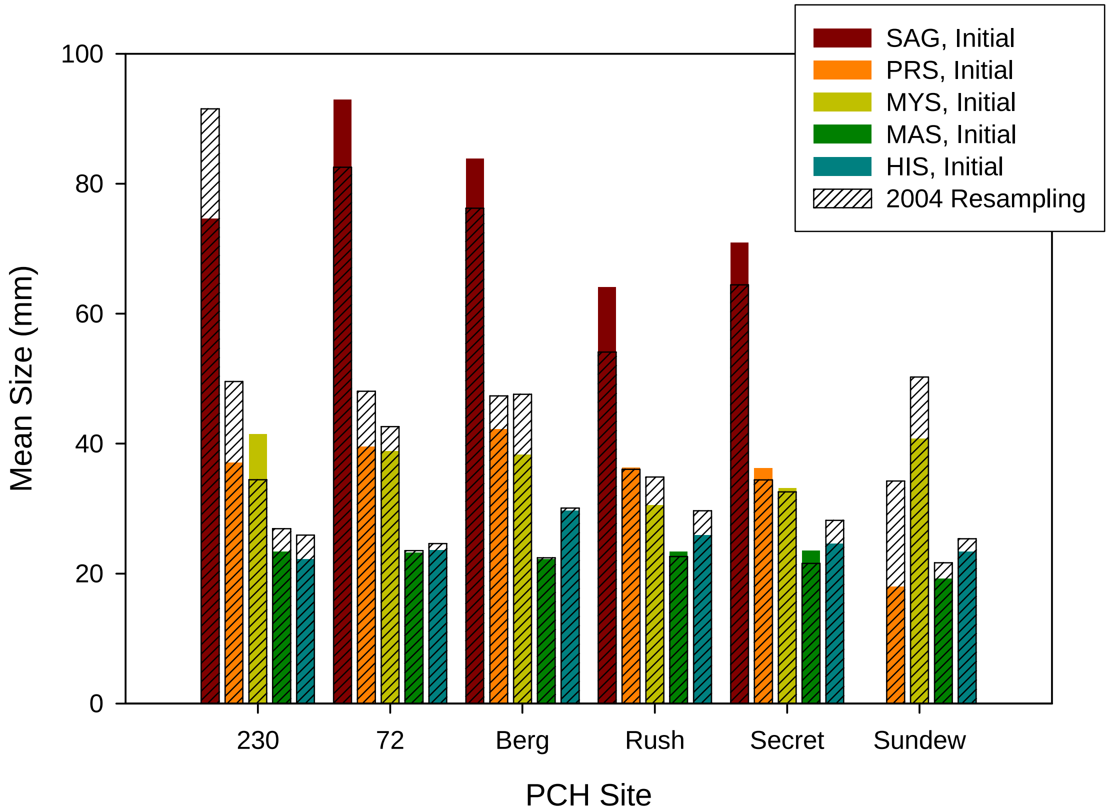


Figure 16. Mean sizes of intertidal clams at 6 preferred clam habitat (PCH) sites at initial sampling (1999-2000) and resampling (2004). SAG = *Saxidomus gigantea*, PRS = *Protothaca staminea,* MYS = *Mya spp.*, MAS = *Macoma* spp., and HIS = *Hiatella* spp.

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 average annual rate of growth observed in Glacier Bay between 1995 and 2004, 49%, 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 35 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 2004, we have observed 4,910 successful foraging dives in Glacier Bay. In 2004, foraging success was high, ranging from 81% - 100%, and averaging 93%. Considering sites with more than 100 successful dives observed, clams represented 25 to 84% of the diet, crabs 0 to 3%, mussels 0-27%, and urchins 3-34%. 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 2004 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, 2003). As clams, mussels, and urchins remain the largest components 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, and possibly sea grasses 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.

In 2003 we completed our initial sampling of nearshore marine communities and populations in Glacier Bay. This initial sampling was intended to provide quantitative descriptions of the species composition, abundance, and size class distributions of the conspicuous and dominant algae and invertebrates, with emphasis on the invertebrates most likely to be consumed by recolonizing sea otters, e.g. clams, mussels, and urchins. In 2004 we initiated work to measure the potential magnitude of sea otter foraging at each of our pre-otter sampling sites, in terms of the abundance, proximity, and persistence of sea otters. Also in 2004 we instituted resampling of a subset of the intertidal calm sampling sites that were initially sampled in 1998 - 2000. Preliminary results of the work initiated in 2004 identify a sea otter population in Glacier Bay that numbers nearly 2,400 and whose distribution, while varying seasonally, remains concentrated within the lower Bay. This distribution retains the integrity of our Before/After/Control/Treatment (BACI) sampling design, by providing sites that are both exposed and not exposed to our experimental treatment, the sea otter.

Our resampling of intertidal clam sites in 2004 revealed relatively little differences in terms of species diversity, density, biomass, and sizes of clams over the 4-5 years between sampling. In general, differences in intertidal clam populations were much greater among sites than within sites over time that should provide confidence in assigning cause to differences we may detect in the future as sea otters continue exerting their foraging mediated influences. There were indications in the data of declines in density and biomass of clams at a few of the sites (e.g. 221, PCH Rush) where otters have been observed foraging and intertidal foraging pits were detected. Completion of the monthly surveys in 2005 and the 2005 repeated sampling of intertidal sites will provide the data required to more fully evaluate these trends.

Glacier Bay currently continues to support a diverse and abundant assemblage of large invertebrates, including species of bivalves, echinoderms, and crustaceans. Our preliminary analysis of resampling of intertidal clam sites indicates sea otters may be beginning to exert detectable changes in the structure of nearshore communities. 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.

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Appendices

Appendix A. 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

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.

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 A1. 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)

Figure A2. 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		

Appendix B. 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.

Figure B1. 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 B2. Foraging data variables and codes.

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	*Prototheca 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 obse*

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

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DRAFT 5/1/2006

Appendix C: Sea Otter Movements and Life History in GBNPP

STUDY PLAN

Process Structuring Coastal Marine Communities in Alaska.

Sea otter movements in Glacier Bay National Park and Preserve

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SUMMARY

The Alaska Science Center (ASC) and Glacier Bay National Park and Preserve (GBNPP) in 1993 established a program to determine the effects of recolonizing sea otters on the marine ecosystem in Glacier Bay (Bodkin et al. 2001, Bodkin et al. 2002, Donellan and Bodkin 2002). Work to date has included establishing and sampling nearly 100 intertidal and subtidal sites to describe and quantify the nearshore benthic marine communities prior to sea otter recolonization. Pre-treatment sampling of communities was completed in 2003. Since 1995 the number of sea otters has increased in Glacier Bay from approximately 5 to about 1800 in 2003. The distribution of sea otters is not uniform relative to our community sampling sites, allowing for control over the experimental treatment (the sea otter). There are two objectives to this study plan. One will provide an index of the magnitude of the sea otter effect at each of our sites. This will be accomplished by conducting monthly surveys of the abundance and distribution of sea otters in Glacier Bay from January 2004 through December 2006. Results of this work will provide a relative measure of the magnitude of the sea otter treatment at each of our community sampling sites, and allow us to make informed decisions regarding post-treatment sampling of study sites. The second objective will be to acquire temporal replication of a subset of our community sampling sites during the period we are measuring the proximity and prevalence of sea otters to those sites (objective 1).

INTRODUCTION

Sea otters (*Enhydra lutris*) provide one of the best-documented examples of top-down forcing effects on the structure and functioning of nearshore marine ecosystems in the North Pacific Ocean (Kenyon 1969, VanBlaricom and Estes 1988, Riedman and Estes 1990, Estes and Duggins 1995). Much of our knowledge of the role of sea otters as a source of community variation resulted from the spatial/temporal pattern of sea otter population recovery since their near extirpation nearly 100 years ago. During most of the early 20th century sea otters were absent from large portions of their habitat in the North Pacific. During the absence of sea otters, many of their prey populations responded to reduced predation. Typical prey population responses included increasing mean size, density and biomass. In at least one well-documented example (the sea urchin, *Strongylocentrotus* spp), the removal of sea otters resulted in profound changes in community organization with cascading effects throughout the nearshore ecosystem (Estes and Duggins 1995). 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 the system and attached macroalgae or kelps dominate primary production. This nearshore ecosystem 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 support higher trophic levels, such as other fishes, birds and mammals. This system is commonly referred to as the kelp dominated system. 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 the kelps. This modified system is characterized by abundant populations of large sea urchins, a lack of attached kelps, associated habitat structure, and reduced abundances of nearshore kelp dependent invertebrates forage fishes and the higher trophic level fishes, birds and mammals. The urchin-dominated community is commonly referred to as an “urchin barren”. Other factors can influence urchin abundance (e.g. disease) and kelp forests can exist in the absence of sea otters, however, “urchin barrens” are unknown in the presence of equilibrium sea otter populations and the generality of the otter effect in nearshore communities is widely recognized (Estes and Duggins 1995).

Other species of sea otter prey responded similarly, at least in terms of density, size and biomass, to the reduction in sea otter predation. In some instances humans eventually developed commercial extractions that would likely not have been possible had sea otters not been eliminated. Examples of fisheries that probably existed as a result, at least in part, because of sea otter removal include, abalone (*Haliotis* spp), sea urchin, 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 recovering previous habitats, due to natural dispersal and translocations. Following the recovery of sea otters scientists have continued to provide descriptions of nearshore marine communities and since 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. 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. One of the requirements in employing the before/after experimental design is quantification of the experimental treatment. In this particular case the treatment being applied is the sea otter.

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 for at least 30 years, only in the past few years could they be found in Icy Straits and Glacier Bay proper (Table 1, Figure 2, J.L. Bodkin unpublished data).

It is a reasonably safe prediction, based on data from other sites in the north Pacific, that profound change 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) will occur. 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 also apparent that those changes are beginning now. During 2002 about 1200 sea otters were observed in the lower Bay (Figures 1 and 2). However, large areas of Glacier Bay remain without sea otters, providing suitable controls. The current distribution of sea otters in Icy Straits and Glacier Bay provides for the rigorous, 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 Glacier Bay, AK.

Year	**Number of sea otters observed**
1994	0
1995	5

1996	39
1997	21
1998	209
1999	384*
2000	594*
2001	1256*
2002	1288*
2003	1866*

Since 1993 the Alaska Science Center has been actively acquiring the pre-treatment data required to document and understand the effects of sea otter recolonization in Glacier Bay (Bodkin et al. 2001, Bodkin et al. 2002, Donellan and Bodkin 2003). Annual surveys of sea otter abundance (Table 1) clearly demonstrate the rapid rate of colonization, particularly since 1998 (Figure 1). Establishment and sampling of permanent intertidal and subtidal study sites (Figure 2) has resulted in quantitative descriptions of the species composition, density and size class composition of nearshore marine communities, with emphasis on conspicuous macro-invertebrates that otters will consume and attached algae and kelps. To date more than 5,000 sea otter foraging dives have been observed to quantify sea otter foraging success and dietary composition. Because sea otters are capable of, and regularly exhibit movements up to tens of kilometers, and are fairly dispersed in lower Glacier Bay (Figure 1), we require data on the movements and abundance of the current sea otter population in Glacier Bay in order to accurately determine if and when pre-otter sampling sites receive the otter treatment.

There are two objectives to the proposed work. One is to estimate the relative magnitude of sea otter foraging potential, in terms of the proximity and abundance of sea otters to previously established and sampled inter-tidal and sub-tidal study sites in Glacier Bay. The second objective will be to acquire temporal replication of a subset of our community sampling sites during the period we are measuring the proximity and prevalence of sea otters to those sites (Objective 1). To meet these objectives we will quantify the abundance and proximity of sea otters in relation to existing study sites through 36 monthly surveys, and obtain temporal replication of a sub-set of our inter-tidal and sub-tidal community sampling sites.

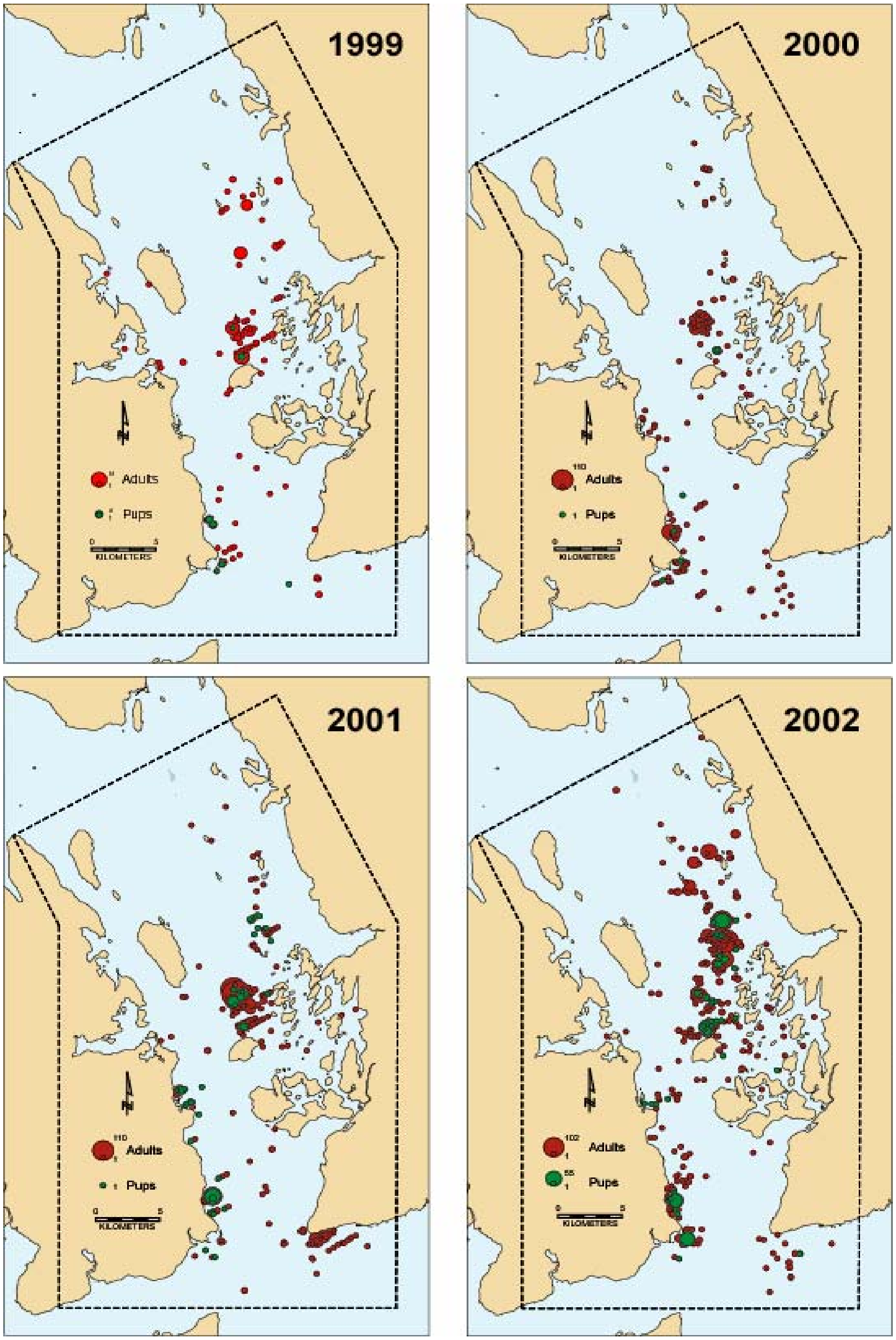

Figure 1. Distribution and abundance of sea otters in Glacier Bay from 1999 to 2002.

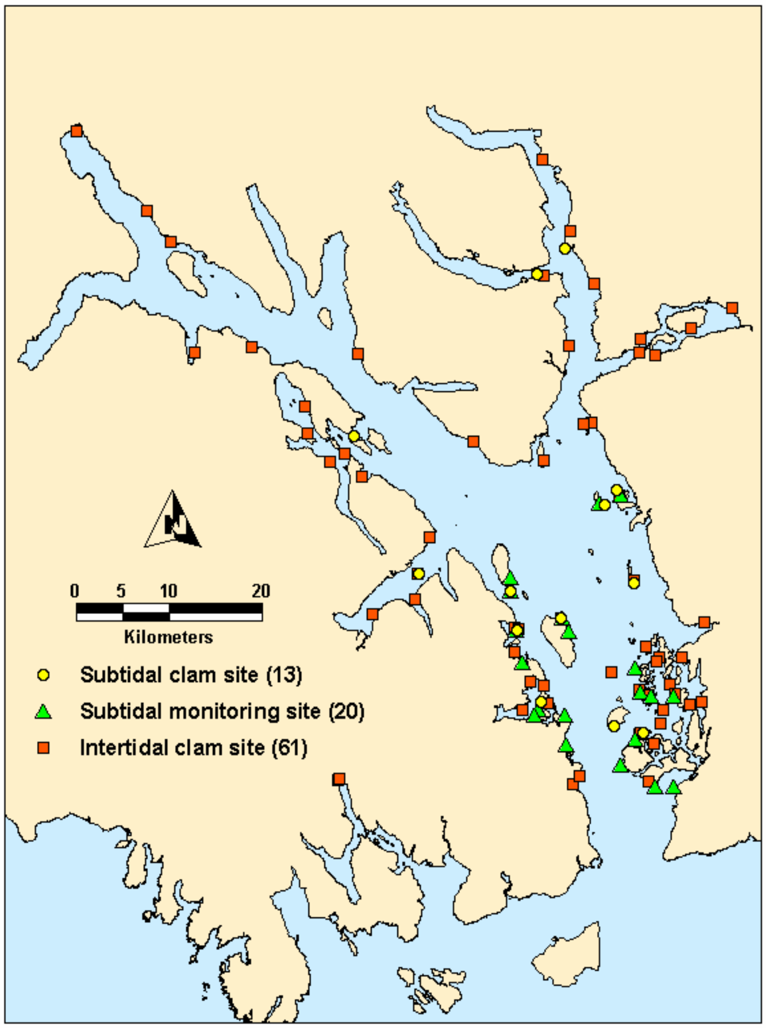

Figure 2. Locations of intertidal and subtidal community sites sampled prior to the recolonization of sea otters in Glacier Bay.

Justification:

First, sea otters, a significant source of ecological change, are currently becoming established in the near shore marine ecosystem of Glacier Bay National Park and Preserve, whose effects, 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 wrongly assign cause to observed changes. Infaunal bivalves constitute a major proportion of the biomass in benthic marine habitats of Glacier Bay and support large populations of vertebrate predators (other invertebrates, fishes, birds and mammals). 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. Although we conduct annual intensive aerial surveys to estimate sea otter abundance in Glacier Bay, the survey offers only a snapshot of the distribution of sea otters in Glacier Bay. We have no measure of their relative abundance and proximity to our community study sites on continuous or seasonal time scales. In order to fully understand, and correctly interpret potential changes in intertidal and subtidal communities, and those cascading effects in the marine ecosystem, we need an objective measure of the relative abundance and proximity of sea otters to our community study sites.

Second, because imposition of the sea otter treatment on our community sampling sites is not manipulated, but rather opportunistic, it is anticipated that several years will be required for the treatment to be imposed at a magnitude sufficient to cause detectable change in community structure. Thus, acquiring temporal replication of community structure is necessary to control for change in community structure as a consequence of time, as opposed to sea otter foraging.

Objectives:

1. Determine the relative abundance and locations of sea otters in Glacier Bay on a monthly basis, over a three year period, from January 2004- December 2006.

2. Estimate the species composition, density and size class distributions of bivalves and sea urchins at a sub-set of inter-tidal community sites previously sampled, throughout Glacier Bay annually during 2004-2006.

The following specific hypotheses will be tested in this study:

Hypotheses:

- H_o The relative abundance of sea otters is not uniform with respect to intertidal and subtidal sampling sites

- H_o Species composition, density and size distributions of bivalves and urchins do not change annually

METHODS:

Objective one will be met through monthly aerial surveys of sea otter abundance and distribution within Glacier Bay. Surveys will be standardized in terms of aircraft, flight attributes (altitude 500' and air speed < 80 knots), environmental conditions (winds < 12 knots, calm sea surface, and unobstructed visibility) and search pattern and intensity. During the aerial surveys the observer will plot the flight track and record the numbers and locations of all sea otters observed on maps of Glacier Bay. Data on pilot, aircraft, start and end times and environmental conditions will be recorded. The maps and associated data of each survey will be transcribed into a GIS (ArcView 3.3) data base layer over the Glacier Bay shoreline. Another data layer will include the location of each inter-tidal and sub-tidal community sampling site. From these three data layers we will calculate a mean number of sea otters per month within each of three categories of distances to each community study site (<2 , 5, and 10 km). The mean and cumulative numbers of sea otters and their proximity to each community site will provide an index to the relative magnitude of the sea otter treatment at each community study site.

Objective two will be met through annual sampling of a subset of the intertidal clam study sites distributed throughout Glacier Bay (Figure 2). Site selection will consider the spatial distribution of sites to obtain an equal number of sites that are likely to be affected by sea otters after 2006 and sites not likely to be affected by sea otters until after 2010. Those sites that potentially have been affected by sea otters since their initial sampling (e.g. Boulder I.) will not be included as temporal variation may be confounded by a sea otter effect. A subset of 15 intertidal clam sites will be sampled following the protocols described in the ASC study plan *Ecological relations between sea otters and benthic marine communities in Southeast Alaska* (Bodkin 2001) and summarized below.

Ten equally spaced 0.25 m^2 quadrats will be sampled to a depth of 25 cm along a 200 meter transect at the zero tidal height. Urchins will be counted and removed prior to excavation of sediments. All material will be sieved through 10 mm (14 mm diagonal) stainless steel mesh screens. Macro invertebrates (primarily clams and additional urchins) will be removed and the remaining material returned to the pits. The clams will be identified to the lowest possible taxon, measured to the nearest tenth of a millimeter using dial calipers, then returned to the pits. Data for each quadrat will include site name, transect start and end point coordinates, date, time of zero height tide, time of sampling, quadrat placement along 200 m transect, clam identification and size. Data will be entered into an excel spreadsheet for management and analyzed in SAS or Sigma Stat.

DATA ANALYSIS

Abundance and proximity to community study sites

The results of the monthly aerial surveys of sea otters will provide a means to quantify the relative abundance and proximity of sea otters in Glacier Bay to our pool of intertidal and subtidal study sites. For each survey we will map the location of abundance of all sea otter sightings. From these locations and counts of otters within a 500 m buffer, we will use Arc-Info to measure distances to study sites that are within 2, 5, and 10 km (Figure 3). These distances are based on published estimates of daily movements and home range sizes for male and female sea otters in Alaska and California (Kenyon 1969, Jameson et al. 1989, Riedman and Estes 1990). It is unlikely that individuals travel > 5 km from a resting location to a foraging location. The table in

Figure 3 illustrates the type of data we expect to recover from each survey and how the otter counts will be used to estimate sea otter abundance and proximity to intertidal and subtidal study sites. In the example, only the Leland and Flapjack study sites would be exposed to sea otter foraging, all other sites would receive no potential exposure. Further the Leland site has a higher relative exposure to sea otter foraging at distances < 2 and <5 km, but at < 10 km, relative exposure to sea otter foraging is equal between the 2 sites. Each of the 36 aerial surveys will result in calculations similar to those in Fig 3. A cumulative and average sea otter density per unit distance (< 2, 5, and 10 km) to each study site < 10 km distant will be calculated over each 3-month period and ending after 36 months. The resulting table of sea otter density/proximity measures will allow assignment of the relative exposure each sea otter resighting group represents to each of our intertidal and subtidal sampling sites (Figure 1 and 3). It should be clear from the distribution of sampling sites in Figure 1 and distribution of sea otters in 2002 (Figure 2) that many, if not most, of the intertidal and subtidal sampling sites currently receive no exposure to sea otter foraging as defined above. We anticipate that the locations and densities resulting from 36 monthly aerial surveys approximately will provide a relative measure of exposure to sea otter foraging that ranges from zero at many sites to very high values (many 1000's of otters < 2 km). This information will be used to provide guidance in identifying those intertidal and subtidal sites that remain unaffected by sea otter foraging (control sites), and those that could be considered as sites with a high probability of being affected by sea otter foraging (treatment sites). Based on average daily movements of individuals we will consider sea otter relocations > 10 km from a study site to represent no effect.

Prey Abundance, Density, and Size Class Distribution:
Frequency of occurrence, density, and size class distributions of each prey species studied will be calculated and pooled for each site. Frequency and size distributions will be contrasted with the chi-square statistic. Density data will be contrasted with one-way ANOVA, with time as the factor.

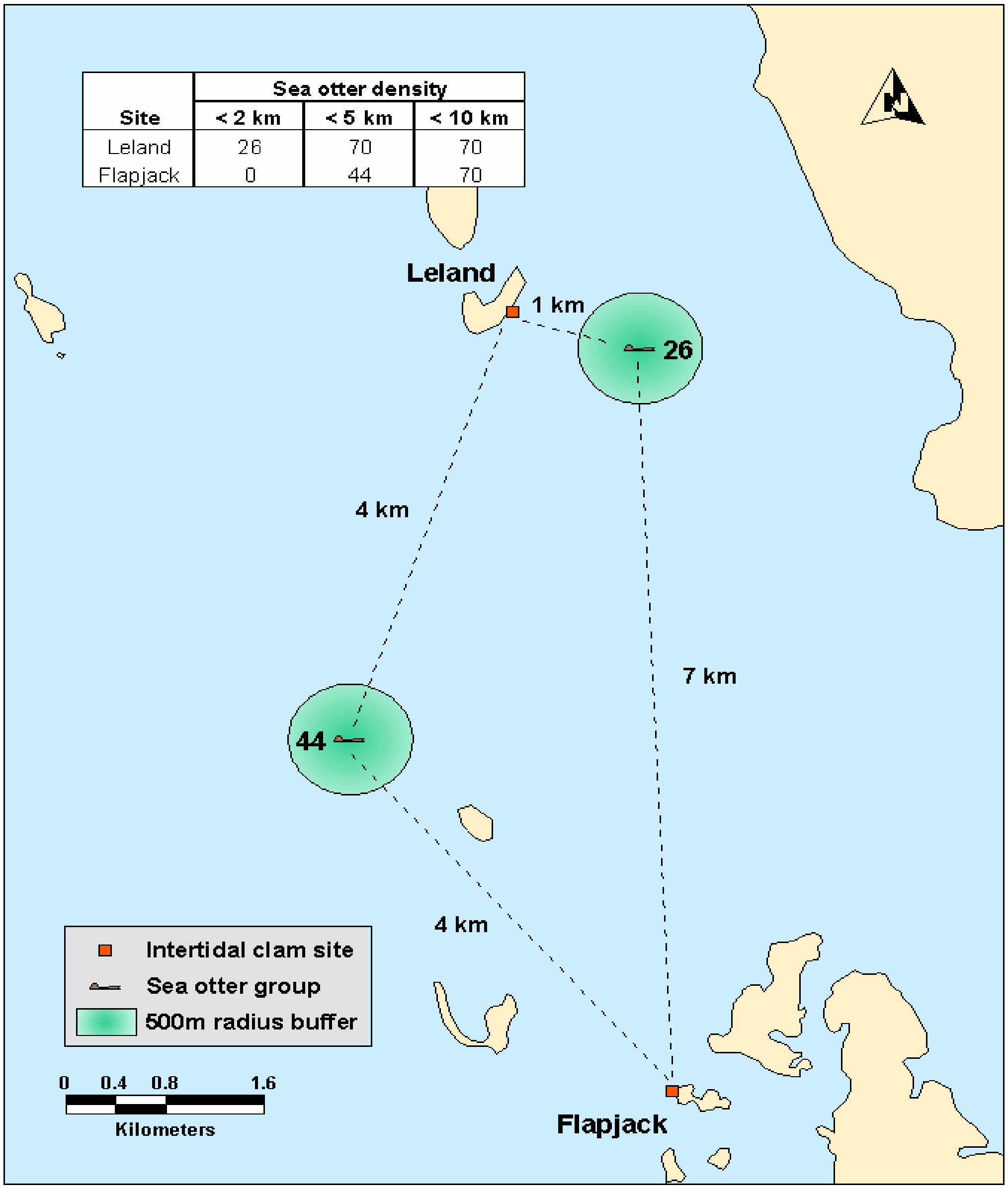

Figure 3. Example of method using sea otter abundance and distribution data to estimate the relative abundance and proximity of sea otters to established intertidal and subtidal study sites.

SCHEDULE

Initiation of the project will commence in January 2004 with the aerial surveys of sea otter abundance and distribution that will continue through December 2006. Repeated sampling of community sites will commence in spring 2004 and sites will be sampled once each year through 2006.

ANIMAL HEALTH AND WELFARE

We do not anticipate the handling of live sea otters in this project. Disturbance to sea otters during aerial surveys and community sampling will be intermittent and minimized to the extent possible. Activities will be discontinued if large-scale influence on animal behavior is observed.

SECTION 7 CONSIDERATIONS

I know of no listed species that may be impacted within the suggested areas of study. Intra-agency consultations have revealed no conflicts with other listed species.

STAFFING

Staffing requirements for all components of this study will be met by the principal investigator, a primary assistant and/or additional Center staff. Additional staffing may be supplied by NPS and/or through cooperative agreements with universities or through contractual agreements.

LOGISTICS

The study will be under the direction of the ASC sea otter project leader in collaboration with NPS scientists. Studies will be conducted out of field camps, research vessels or Bartlett Cove. NPS may provide logistic support, such as temporary lodgings in Gustavas, transportation and supplies to field camps and miscellaneous supplies.

RELATIONSHIP TO OTHER PROJECTS

The design of this study is largely in support of the following existing studies to determine the effects of sea otters on marine communities in Glacier Bay. These adjunct components are under the direction of J.L. Bodkin, Alaska Science Center. The results of this study will have direct benefit to resource managers and scientists in Glacier Bay and elsewhere in the coastal north Pacific. This project will be conducted under consultation with NPS and other ASC biologists.

BUDGET

FY04	ASC	NRPP
Personnel		
GS 13 Principal Investigator 6 pp @ 4.0	24.0	
GS 9 Wildlife Biologist 6 pp @ 2.1		12.6
GS 9 Wildlife Biologist 6 pp @ 2.1	12.6	
Travel		
21 R/T Anchorage-Gustavus		12.6
Food and Lodging in Gustavus 123 d @25/d		3.1
Contractual		
Aerial surveys 48 hr at 300/hr		14.4
Vessel contract (15 d @ 500/d)		7.5
Commodities		
Community sampling equipment		2.0
Misc supplies		2.0
Subtotal		54.2
ASC Overhead (30%)		16.3
Annual Total	**36.6**	**70.5**

FY05	ASC	NRPP
Personnel		
GS 13 Principal Investigator 6 pp @ 4.0	24.0	
GS 9 Wildlife Biologist 6 pp @ 2.1		12.6
GS 9 Wildlife Biologist 6 pp @ 2.1	12.6	
Travel		
15 R/T Anchorage-Gustavus		7.5
Food and Lodging in Gustavus 123 d @25/d		3.1
Contractual		
Aerial surveys 36 hr at 300/hr		10.8

Vessel contract (16 d @ 1000/d)		16.0
Commodities		
Community sampling equipment		3.0
Misc supplies		3.0
Subtotal		57.2
ASC Overhead (18%)		10.3
Annual Total	**36.6**	**67.5**
FY06	**ASC**	**NRPP**
Personnel		
GS 13 Principal Investigator 6 pp @ 4.0	24.0	
GS 9 Wildlife Biologist 6 pp @ 2.1		12.6
GS 9 Wildlife Biologist 6 pp @ 2.1	12.6	
Travel		
15 R/T Anchorage-Gustavus		7.5
Food and Lodging in Gustavus 123 d @25/d		3.1
Contractual		
Aerial surveys 36 hr at 300/hr		10.8
Vessel contract (16 d @ 1000/d)		16.0
Commodities		
Community sampling equipment		3.0
Misc supplies		3.0
Subtotal		57.2
ASC Overhead (18%)		10.3
Annual Total	**36.6**	**67.5**
Project Total	**109.8**	**205.5**

Although initial funding was received in FY 2003 no expenditures against the account were made until January 2004 (FY 2004) when aerial surveys were begun. ASC contributions include principal investigator and staff salary (included in budget Table), equipment and commodities such as computers, software, and vehicles are not included in the budget Table.

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