Sea Otter Studies in Glacier Bay National Park and Preserve

ANNUAL REPORT 2002

James L. Bodkin[1]
Kimberly A. Kloecker[1]
George G. Esslinger[1]
Daniel H. Monson[1]
Heather A. Coletti[1]
Janet Doherty[2]

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

[2]United States National Park Service
Glacier Bay National Park and Preserve
1 Park Road
P.O. Box 140
Gustavus, Alaska 99826

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Summary

Since 1995, the number of sea otters in Glacier Bay proper has increased from around 5 to more than 1200. Sea otter distribution is mostly limited to the Lower Bay, south of Sandy Cove, and is not continuous within that area. Concentrations occur in the vicinity of Sita Reef and Boulder Island and between Pt. Carolus and Rush Pt. on the west side of the Bay, although there have been occasional sightings north of Sandy Cove (Figure 1). Large portions of the Bay remain unoccupied by sea otters, but recolonization is occurring rapidly.

Most prey recovered by sea otters in Glacier Bay are ecologically, commercially, or socially important species. In 2002 sea otter diet consisted of 35% clam, 26% mussel, 3% crab, 3.0% snail, 2% starfish, 11% urchins, 2% other, and 20% unidentified. Dominant clam species include the butter clam, *Saxidomus gigantea*, the Greenland cockle, *Serripes groenlandicus*, and the littleneck clam, *Protothaca staminea.* Urchins are primarily green urchins, *Strongylocentrotus droebachiensis*, and the mussel is *Modiolus modiolus.* Crabs observed in 2002 include the Dungeness, *Cancer magister*, the kelp crab *Pugettia gracilis,* and the helmet crab, *Telmessus cherigonus.* Although we characterize diet at broad geographic scales, we have previously found diet to vary between sites separated by as little as several hundred meters. Dietary variation among and within sites can reflect differences in prey availability as well as individual specialization.

We estimated species composition, density, biomass, and sizes of subtidal clams, urchins, and mussels at 13 sites in Glacier Bay and 5 sites in nearby Port Althorp, where sea otters have been present for at least 20 years. All sites were selected based on the presence of abundant clam siphons and the absence of sea otters (Glacier Bay) or abundant shell litter and the presence of sea otters (Port Althorp). Glacier Bay sites were selected to achieve a broad geographic sample of dense subtidal clam beds within Glacier Bay prior to occupation and foraging by sea otters. Port Althorp sites were chosen to achieve a representative sample of subtidal clam beds already under prolonged foraging pressure by sea otters. There was no direct evidence of otter foraging at any of our Glacier Bay sampling sites.

In Glacier Bay, we sampled 15,338 bivalves (average of 1,180/site) representing 14 species of clam, 2 species of mussel, and a single scallop and we sampled 6,917 urchins (average of 513/site). In Port Althorp, we sampled 1,034 bivalves (average of 207/site) representing 14 species of clam. We found only 5 urchins, all *S. droebachiensis.* Mean densities and biomass of all subtidal clams were significantly greater in Glacier Bay (59.2 and 99/0.25m^2 compared to Port Althorp (10.3 and 5.8/0.25m^2 ($p<0.002$ for both).

Our contrasts of subtidal clam populations between Glacier Bay and Port Althorp suggest that clam densities will likely decline by about a factor of six and that clam biomass estimates will decline by more than a factor of ten. Numerically dominant species of clams, *P. staminea, S. gigantea, Macoma sp. and Mya sp.* were all significantly greater in density and biomass in Glacier Bay, while *C. nutalli* density was low but significantly higher in Port Althorp. Subtidal clam species diversity was significantly greater in Port Althorp compared to Glacier Bay, although this may simply reflect habitat differences. Sea urchin densities were high in Glacier Bay, while in Port Althorp urchins were virtually absent.

Sea otters are now well established in limited areas of the lower portions of Glacier Bay. It is likely that distribution and numbers of sea otters will continue to increase in Glacier Bay in the near future. Glacier Bay supports large and diverse populations of clams that are largely unexploited by sea otters at present. It is predictable that the density and sizes of clam populations will decline in response to otter predation. This will result in fewer opportunities for human harvest, but will also trigger ecosystem level changes, as prey for other predators, such as octopus, sea stars, fishes, birds and mammals are modified. 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. Glacier Bay also supports large populations of other preferred sea otter prey, such as king (*Paralithodes sp.*), tanner (*Chionoecetes sp.)* and dungeness (*Cancer magister)* crabs and green sea urchins (*S. droebachiensis*). As the colonization of Park waters by sea otters continues, it is also 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. Others will result from indirect or cascading effects of sea otter foraging, such as increased kelp production and modified prey availability for other nearshore predators. 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 2002.

Sea otters provide one of the best-documented examples of top-down forcing effects on the structure and functioning of nearshore marine ecosystems (Estes and Duggins 1995; Kenyon 1969; Riedman and Estes 1990; VanBlaricom and Estes 1988). During most of the early 20th century, sea otters were absent from large portions of previously occupied habitat. Our understanding of the role of sea otters as a source of community variation has been aided by the spatial and temporal patterns of sea otter population recovery over the past 50 years. During the absence of sea otters, many of their prey populations responded to reduced predation. Typical population responses included increasing mean size, density, and biomass. One well-documented case (sea urchin, *Strongylocentrotus* spp) illustrates the prey population response, 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 (*Halitosis* 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 2002 we estimated that greater than 1200 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 Observed/Estimated	Percentage 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

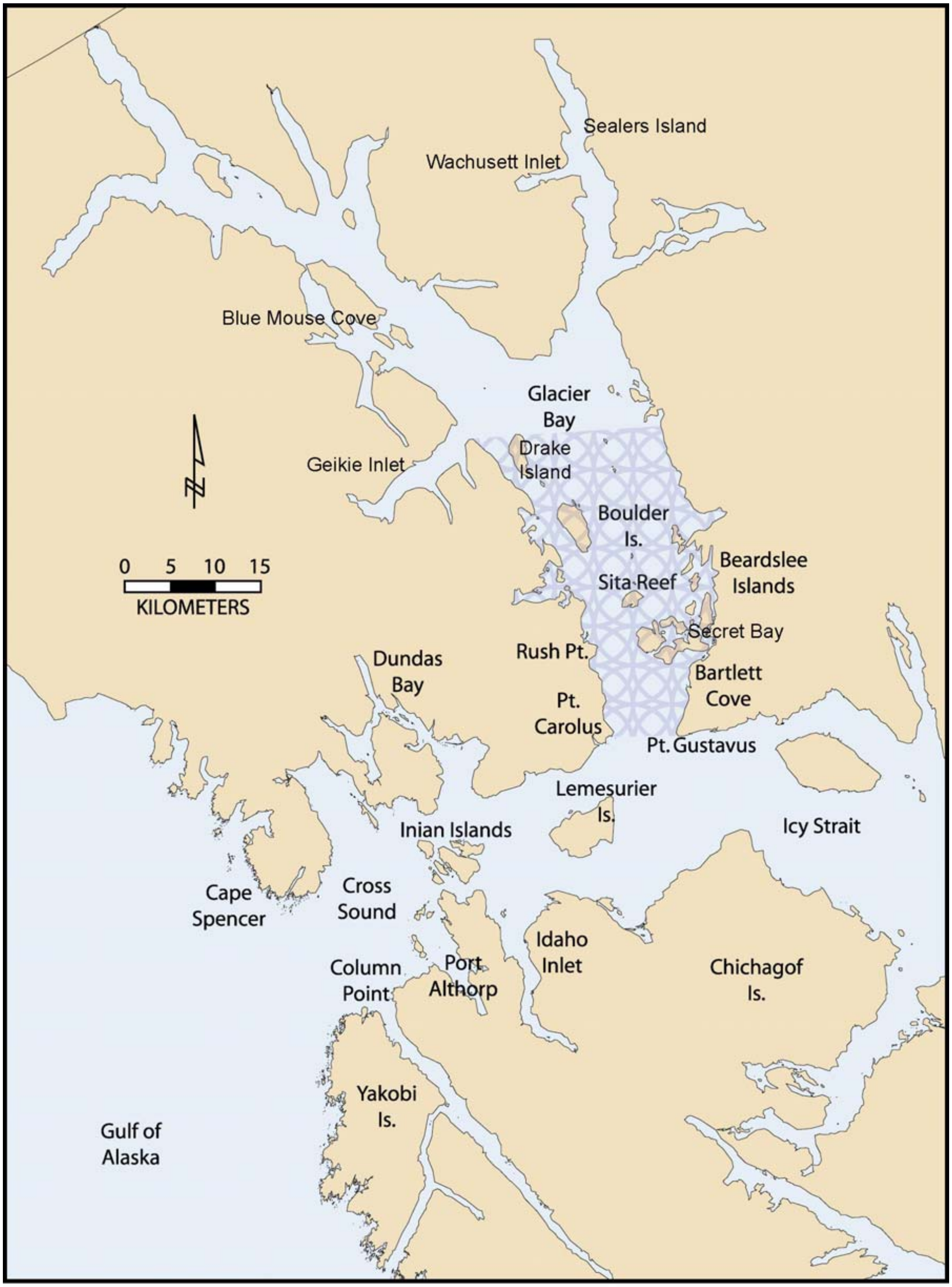


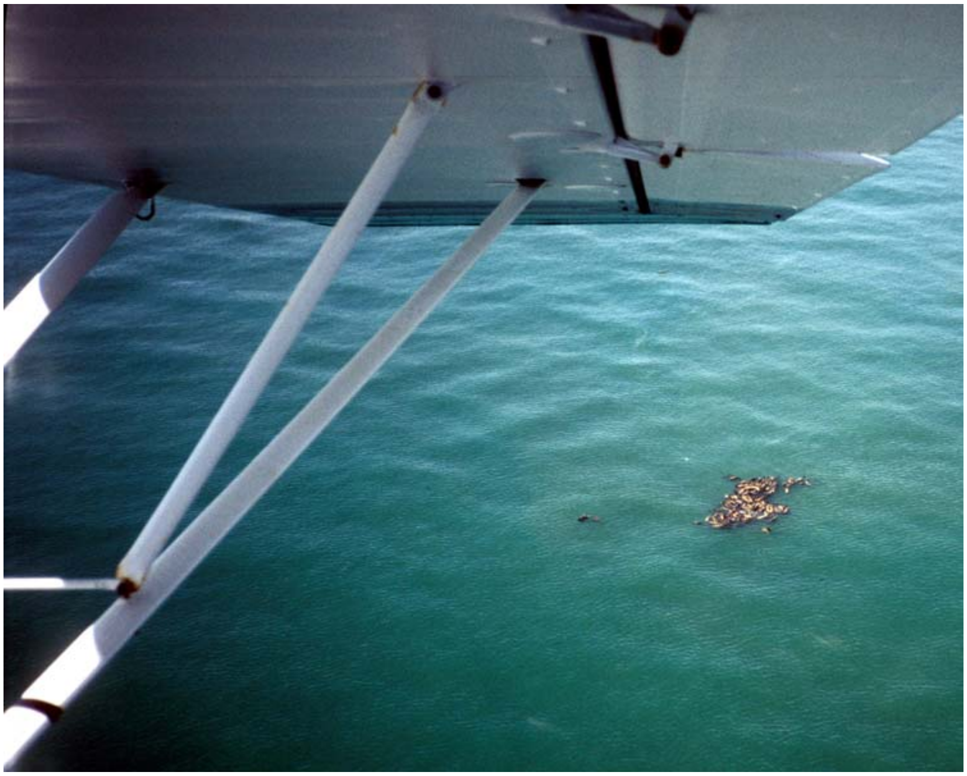
Figure 1. Study areas in Glacier Bay National Park, Icy Strait, and Cross Sound, Southeast Alaska. The Lower Bay portion of Glacier Bay is mottled on this figure.

Impacts of sea otters, if not quantified, will likely preclude, or at least severely limit the ability of Park management to identify changes or cause of variation in coastal communities. At worst, Park management could misinterpret the cause of observed ecosystem changes. Infaunal bivalves currently constitute a major proportion of the biomass in benthic marine habitats of Glacier Bay (Bodkin et al. 2001, 2002). 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 unless sea otter effects can be controlled for.

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

This annual report presents the result of work completed from 1993 to 2002 on surveys of sea otter abundance and distribution and subtidal clam surveys. Because we summarized sea otter food habit studies over the period 1993-2000 in our 2000 Annual Report (Bodkin et al. 2001) and 2001 observations in that year's annual report (Bodkin et. al. 2002), we include in this report results of foraging observations made in calendar year 2002 and also present a summary of previous forage results relative to prey sizes in Appendix D. We include here results of our subtidal clam sampling in 2001 and 2002. This report represents the cooperative efforts of the USGS, ASC and the NPS, Glacier Bay National Park and Preserve.

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



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

Surveys of sea otters are conducted to estimate how distribution and abundance 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 conducted two types of surveys of in Glacier Bay and surrounding waters. The first type, carried out since 1994, is designed to estimate the distribution and relative abundance, 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 other 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 1999-2002.

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. Flight tracks were flown parallel to shore when water < 20 m extends > 1 km from the shoreline (e.g. Dundas and Berg bays). Surveys were flown at the slowest speed safe for the aircraft in use, and at the lowest safe altitude. In May 1999 and 2000, and June 2001, distribution surveys were flown at 65 mph and 91m in a Bellanca Scout. From 1994-2001, distribution surveys were conducted in Cross Sound and Icy Strait. However, a distribution survey of Cross Sound and Icy Straits was not conducted in 2002 because an aerial survey of abundance of northern SE Alaska was conducted. This abundance survey provides distribution information, but not relative abundance data.

Abundance Surveys

Aerial survey methods followed Bodkin and Udevitz (1999) and consisted of two components: 1) strip transects, 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. A single observer surveys transects 400 m wide at an airspeed of 65 mph (29 m/sec) and an altitude of 300 ft (91 m). Strip transect data included 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). 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.

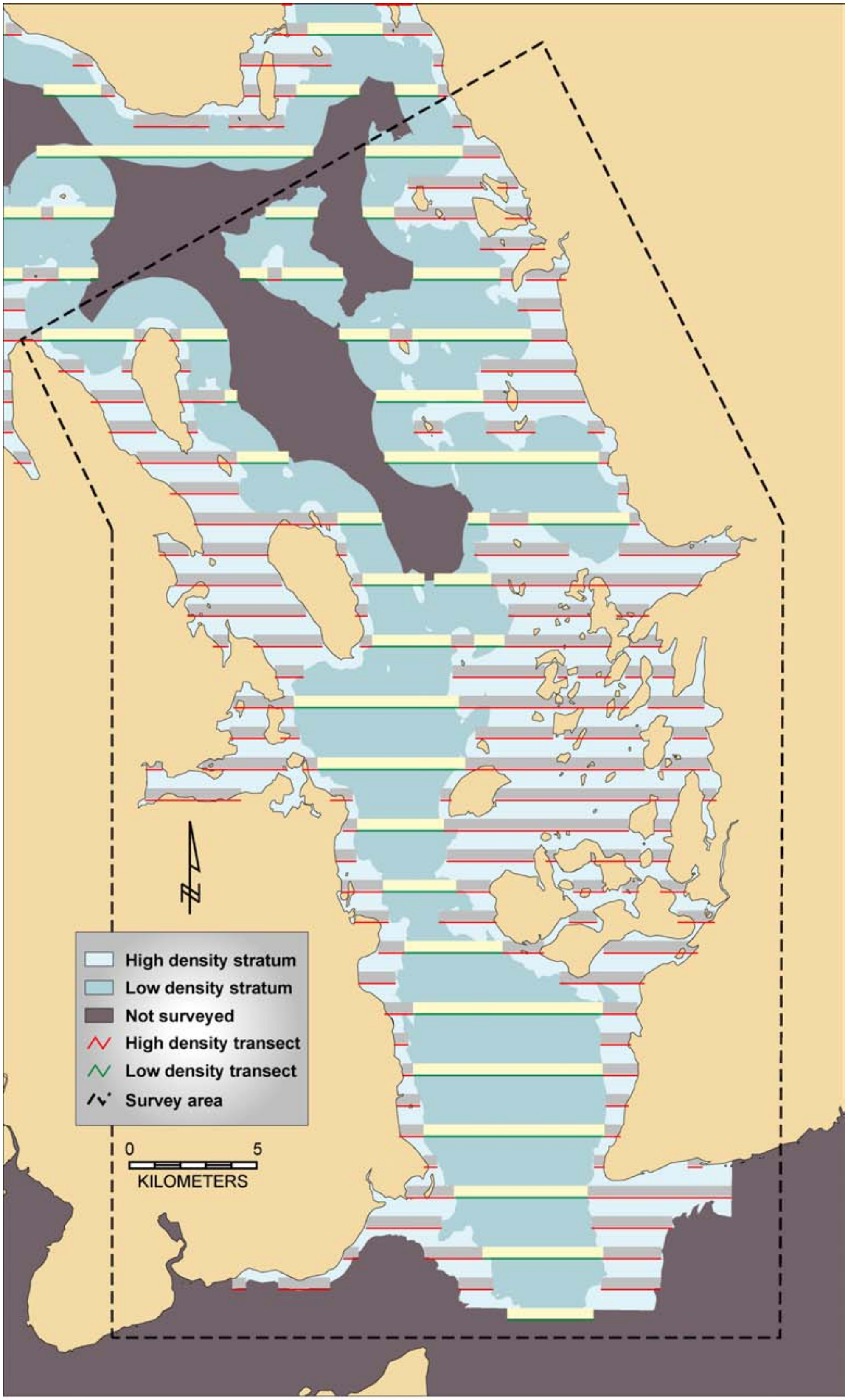


Fig. 2. One of five transect designs used during a sea otter abundance aerial survey in Glacier Bay National Park, May 2002.

Intensive searches were conducted systematically along strip transects to estimate the proportion of animals not detected during strip counts.

The survey design consisted of 18 strip transect projections constructed in a GIS coverage (ARC/INFO) comprised of 3 possible sets of high density transects and 6 sets of low density transects (Figure 2). Transects are charted throughout Glacier Bay, but this survey focused on the lower Bay (Figure 2) since sea otters do not yet occur in the upper bay. The 2002 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 18 possible combinations. Between 6 and 18 May 2002, a single observer surveyed four replicates from a Bellanca Scout. One observer flew the 1999 and 2000 abundance surveys, while another observer flew the 2001 and 2002 surveys. The same pilot flew all four Glacier Bay abundance surveys. See Appendix A for a detailed description of the survey methods used.

Results

Distribution Surveys

Distribution surveys in Cross Sound and Icy Strait were conducted each year from 1994-2001. 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 Straits. Because this survey was designed to estimate abundance, results of numbers of otters observed are not comparable to prior years distribution surveys and are not included in Table 2. In terms of sea otter distribution in Cross Sound and Icy Strait, the pattern we observed in 2002 was similar to the previous several years (Table 2). Primary changes in sea otter distribution from 1994-2002 include population expansion into Glacier Bay and east of Gustavus (Porpoise Island and Excursion Inlet). Relatively little expansion has occurred along the south side of Icy Strait.

Abundance Surveys

The four replicate surveys required approximately 40 hours of flight time to complete, including transit to and from Bartlett Cove. The mean of these four individual replicates yielded an adjusted population size estimate of 1266 (SE = 196) (Table 2). All group locations were digitized into ARC/INFO coverages (Figure 3).

The estimate of 1266 sea otters in 2002 represents a 2% increase over the 2001 estimate. The 2001 estimate represented an increase of 123% above the 2000 estimate and likely resulted from both production of sea otters within Glacier Bay and immigration of sea otters from outside the Bay. The 2% increase observed in 2002 is below the theoretical maximum population increase of about 19% (Estes 1990) and previously observed rates of increase in SE Alaska (Bodkin et al. 1999).

The larger sea otter survey we conducted in 2002 included all areas of known sea otter occupation in northern Southeast Alaska (Cape Ommaney on Baranof Island and north to Cape Spencer, and 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, 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 2,248. It appears as though growth in sea otter abundance since 1987 is largely manifested in recolonization and increase within Glacier Bay.

Table 2. Results of Cross Sound/Icy Strait sea otter distribution surveys and abundance surveys in Glacier Bay proper in 1999 - 2002 (abundance estimates **bolded**). Counts are presented as # adults/# pups, while a period means 'no data'. Abundance estimates include pups (Bodkin and Udevitz 1999). (* 2001 estimate of 1,590 revised from 2001 reported value following re-analysis)

Date	**May-94**	**May-95**	**Mar-96**	**Aug-96**	**May-97**	**Mar-98**	**May-99**	**May-00**	**Jun-01**	**Feb-02**	**Jun-02**
Aircraft	Scout	Scout	172	172	Scout	185	Scout	Scout	Scout	Scout	Scout
Survey Area											
Spencer – Pt Wimbledon	69/20	60/9	31/4	19/2	43/3	8	6	7	52/27	.	.
Pt Wimbledon- Pt Dundas	37/1	23	18	52	24	52	27	46	38/2	.	.
Pt Dundas – Pt Gustavus	0	12/1	41/1	178/4	10	1	17	0	8/1	.	.
Glacier Bay Proper	.	5	39	0	21	209	**384**	**554**	**1238***	308/4	**1266**
Excursion Inlet	.	.	.	.	.	7	1	0	0	.	.
Pt Couverden	.	.	.	.	.	2	.	0	0	.	.
Pt Gustavus - Porpoise Is	29/0	94/1	73	2/1	161	8	18	57	129/1	63	.
Cannery Pt - Crist Pt	0	0	0	0	0	0	0	.	.	.	.
Crist Pt – Gull Cove	55	15/3	30/1	17/1	92/15	23	97/3	2	62/19	.	.
Lemesurier Is	33/8	62/23	56/2	47/8	143/32	10	67/17	11	76/33	48	.
Gull Pt – Pt Lavinia	77	81	48	141	94	3	90	139	95	.	.
Inian Is	31/19	36/16	11/1	30/12	31/8	10	18/4	9	46/16	.	.
Pt Lavinia - Column Pt	100/31	159/73	42/3	94/21	148/25	31	21/7	88/11	84/26	.	.
TOTAL	431/69	547/126	389/12	580/49	767/83	364	746/31	913/11	1828/125	.	.

Discussion

The results of the sea otter distribution and abundance surveys suggest a large-scale pattern in population distribution and growth in the region of Icy Strait and Glacier Bay. As recolonization of previously occupied habitat has occurred in Icy Strait over the past several years, sea otters had at least two choices in their direction of immigration, 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 during 2001/2002.

The 2002 abundance estimate for Glacier Bay is essentially unchanged from the 2001 estimate (Table 2). The distribution of sea otters in Glacier Bay and Cross Sound/Icy Straits in 2002 was similar to prior years. The largest concentrations of sea otters in Glacier Bay continue to inhabit areas surrounding Boulder Island, Flapjack Island, and

Sita Reef (Figure 3). The north side of Point Carolus also continues to harbor large groups of sea otters. The sea otters counted south of Point Gustavus are likely males since no pups were observed and large groups of males have been periodically observed here in the past.

The number of sea otters occupying Glacier Bay is increasing rapidly, from a count of 5 in 1995 to an estimated 1266 in 2002 (Table 1). This increase is undoubtedly due to both immigration of adults and juveniles, as well as reproduction by females in the Bay, as evidenced by the increasing number of dependent pups.

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

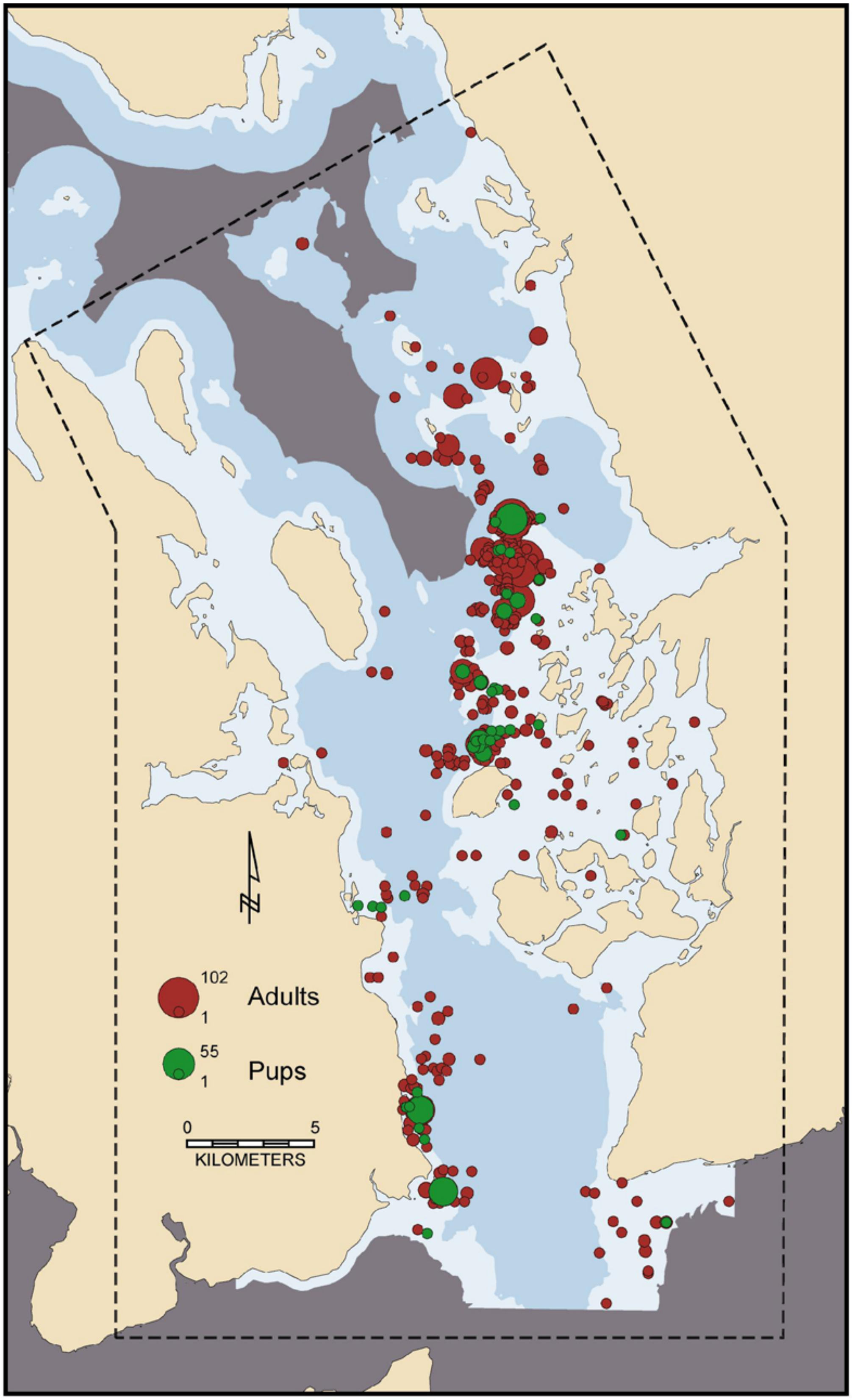


Figure 3. Sea otter group locations from 4 replicate aerial surveys in Glacier Bay National Park, May 2002 (spot size proportional to group size).

Sea Otter Foraging Behavior

Sea Otter Foraging Behavior

Observations of sea otter foraging behavior in 2002 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, are reported in the 2000 Annual Report (Bodkin et al. 2001) and data from the ~450 successful dives observed in 2001 are reported in the 2001 Annual Report (Bodkin et. al. 2002). Here we report the 2002 data independently.

Foraging work in 2002 consisted of shore based observations at sites within Glacier Bay. 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-based observations of foraging otters following a standard protocol (Appendix B). Shore based observations limit data collection to sea otters feeding within approximately 1 km of shore. 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. The data from 2002 was analyzed with a revised value for sea otter mean paw width. Results from the re-analysis of forage prey size data from the 2000 and 2001 Annual Reports (Bodkin et al. 2000, 2001) are found in Appendix D. Because dives within a bout are not independent (Doroff and DeGange 1994) we report forage success and prey sizes on a per bout basis.

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

Analysis

For each site where foraging data were collected, we calculated (1) prey composition as the proportion of dives that resulted in the recovery of at least one of eight different prey types (clam, crab, mussel, snail, sea star, 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). We report summary statistics (mean and sd where appropriate) for the latter three variables, on a per bout basis.

Results

During 2002, we observed 285 sea otter foraging dives; 244 where the focal otter recovered at least one prey item, 37 unsuccessful and 4 dives with unknown outcomes. Five dives were observed in the Beardslee Islands, 53 from Leland Island, 174 in Secret Bay, and 53 at Sita Reef (Figure 1). Sea otters successfully recovered prey on 85% of these dives. Mean dive time was 65 seconds (s) and mean surface interval was 64s. Since 1993, we have observed sea otters feeding on at least 30 different prey items including bivalves, decapod crustaceans, gastropods, and echinoderms (Table 3). One new prey species in Glacier Bay was observed in 2002. In March, we observed one sea otter recover and consume a kelp crab (*Pugettia* sp.) at the mouth of Secret Bay.

Prey Composition

The prey composition of sea otter diets in 2002 was similar to previous years. In 2002 we observed 408 prey items recovered in 244 successful foraging dives. Overall diet was composed of 36% clam, 3% crabs, 26% mussel, 11% urchin, 2% other and 20% unidentified (Table 4). At the Leland Island site otters ate mainly mussels (*M. modiolus* and unknown mussels, 74%), followed by green urchins (*S. droebachiensis,* 18%) (Table 4). At the Secret Bay site, otters ate clams (46%), urchins (9%), and mussels (*M. modiolus* and *M. trossulus*) (6%) (Table 4). At Sita Reef, mussels (all *M. modiolus*) comprised 37% of the diet, clams 36%, and urchins 10% (Table 4).

Table 3. List of prey items that sea otters were observed consuming in southeast Alaska, 1993-2002.

Phylum (Subphylum)	**Class (Order)**	**Prey Item (Genus, species)**
Porifera		sponge
Mollusca		
	Polyplacaphora	*Cryptochiton stelleri*
	Gastropod	*Fusitriton oregonensis, Neptunea* spp., limpet
	Bivalvia	*Entodesma navicula*, *Gari californica*, *Macoma* spp., *Mya truncata*, *Mya* spp., *Protothaca staminea*, *Saxidomus gigantea*, *Clinocardium nutallii*, *Serripes groenlandicus*, *Modiolus modiolus*, *Mytilus trossulus*, *Pododesmus macroschisma, Chlamys* spp.
	Cephalopoda	*Octopus dofleini*
Echiura		*Echiurus* spp.
Arthropoda (Crustacea)		
	Cirripedia	
	(Decapoda)	*Cancer magister*, *Chionoecetes bairdi*, *Oregonia gracilis*, *Pandalus* sp., *Paralithodes camtschatica*, *Telmessus cheiragonus, Pugettia* sp.
Echinodermata		
	Asteroidea	*Pycnopodia helianthoides*, *Solaster* spp.
	Ophiuroidea	*Ophiurid* spp., *Gorgonocephalus caryi*
	Echinoidea	*Strongylocentrotus droebachiensis*, *S. franciscanus*
	Holothuroidea	*Cucumaria fallax*
Chordata		
	Osteichthyes	fish (unknown species)

Table 4. Percentage of dives with each prey type present, 2002. 'Other' category consists of worms, octopus, fish, sponges, sea cucumbers, chitons, non-clam/mussel bivalves, barnacles, and sea peaches. 'Unid' category represents prey that could not be identified due to visual obstruction. Values for individual sites are given below the area (**GLBA,** and bold values represent the total values by area). Unsuccessful dives and those with unknown success were not included in #dive values.

Area (#dives) Site	Clam	Crab	Mussel	Snail	Star	Urchin	Other	Unid
GLBA (244)	**34.7**	**2.6**	**25.7**	**3.0**	**1.5**	**10.6**	**1.9**	**20**
Beardslee (4)	0	100	0	0	0	0	0	0
Leland Is. (48)	2.0	0	73.5	0	0	18.4	0	6.1
Secret Bay (142)	45.8	1.3	6.5	4.6	2.6	8.5	2.6	28.1
Sita Reef (50)	35.6	1.7	37.3	1.7	0	10.2	1.7	11.9

Prey Number and Size

On dives when specific prey types were observed, the mean number and sizes of individuals of that prey type were calculated (Figures 4 and 5). On average, sea otters recovered 1.9 prey items per dive in 2002. In Glacier Bay, sea otters retrieved an average (sd) of 1.2 clams (0.3), 1.0 crab (0), 2.2 mussels (0.9), or 2.4 urchins (1.3) per dive. The mean size (sd) of clams recovered was 58.6mm (18), crabs: 78.0mm (52), mussels: 77.9mm (31), and urchins: 54.5mm (13).

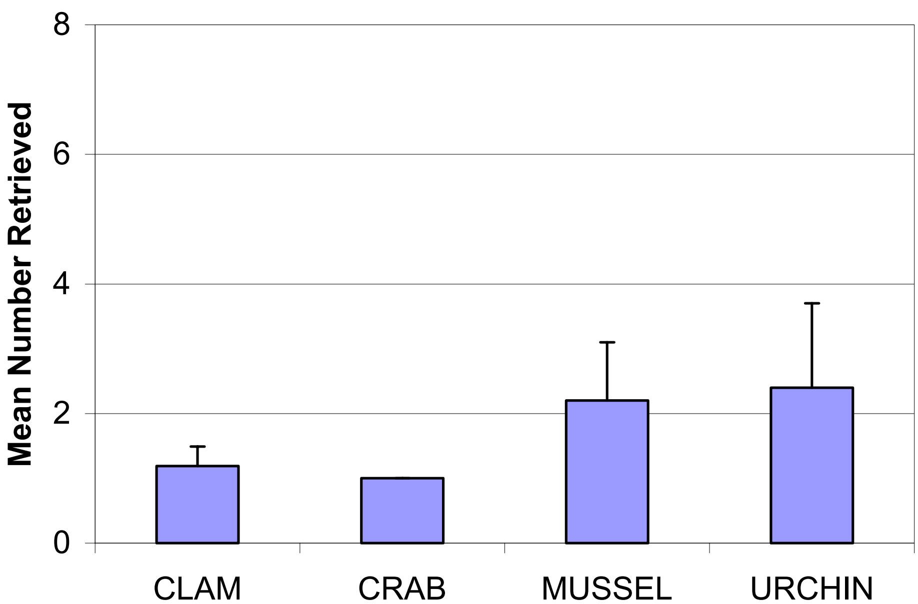


Figure 4. Mean number per dive and standard deviations of the primary prey items recovered by sea otters during observations of foraging behavior in Glacier Bay in 2002. The number of bouts for each prey type was: clam 9, crab 3, mussel 7, and urchin 6.

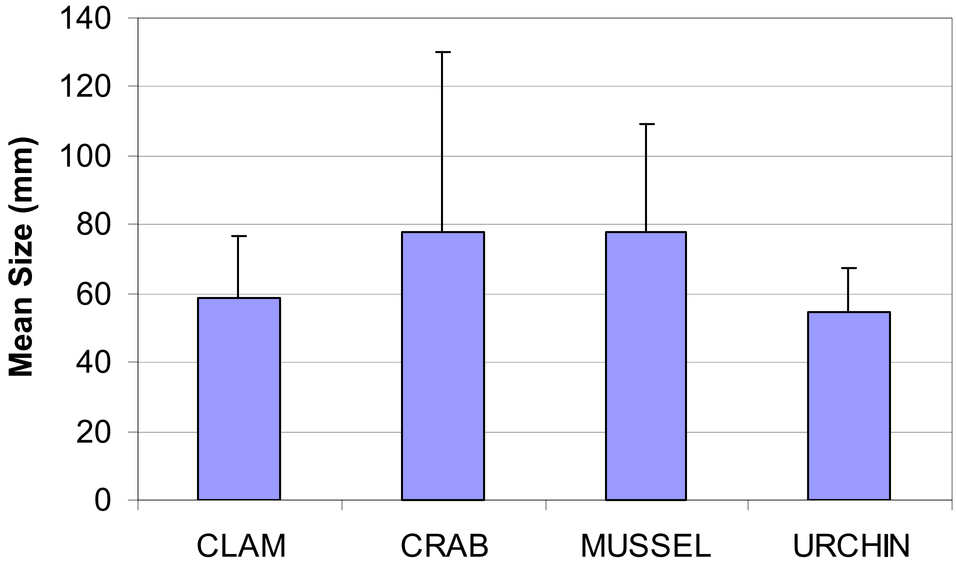


Figure 5. Mean size and standard deviations of the primary prey items recovered by sea otters during observations of foraging behavior in Glacier Bay in 2002. The number of bouts for each prey type was: clam 9, crab 3, mussel 7, and urchin 6.

Discussion

Sea otters we observed are foraging with an average success rate of about 86% in Glacier Bay. This is similar to rates 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, and often multiple, calorically valuable prey. The diet of sea otters in and around Glacier Bay consists largely of invertebrates that reside in unconsolidated sediments such as mud, sand, gravel or cobble (Tables 3, 4). Bivalve clams dominated the diet, although in some areas other prey can be important components of the diet. In 2002 we found mussels (*M. modiolus*) and green urchins (*S. droebachiensis*) to be relatively important at Leland Island and Sita Reef. These differences likely reflect habitat differences among areas and corresponding differences in macro-invertebrate populations available to sea otters.

Our understanding of processes that affect coastal marine communities, particularly 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.

Subtidal Clam Populations
in Areas with and without Sea Otters

Subtidal Clam Populations in Areas with and without Sea Otters

We studied subtidal clam populations to document species composition, abundance, and size distributions of the dominant invertebrate prey prior to the sea otter's occupation of benthic habitats in Glacier Bay. Proper documentation will allow description of eventual changes resulting from sea otter foraging. In this annual report, we describe subtidal clam species composition, species diversity, size distribution, density, and biomass from our sampling of unconsolidated sediment habitats in Glacier Bay in 2001/2002 and in Port Althorp in 2002. Our intent in sampling subtidal clams in Port Althorp was to provide a contrast to Glacier Bay, from a nearby and similar habitat, where sea otters have been present for at least 20 years. In prior years we studied intertidal clam populations in Glacier Bay and Port Althorp. Results of earlier work are reported in Bodkin et al. (2001, 2002).

Methods

Site Selection

Our goal was to locate 8-10 subtidal clam beds in lower Glacier Bay that had not been depredated by sea otters so we could estimate subtidal clam species diversity, density, and biomass in the absence of sea otters. In 2001, nine sites (Figure 6) were identified and sampled based on the following criteria: 1) proximity to areas occupied by sea otters, 2) spatial separation from other sites, 3) relatively high clam densities, as determined by the search method detailed below. Due to the rapid increase in the Glacier Bay sea otter population, the initial goal of sampling lower Bay was expanded to include the upper Bay. In 2002, 4 additional sites were sampled in Glacier Bay (Figure 6) and 5 sites were sampled in nearby Port Althorp (Figure 7). The five 2002 Glacier Bay sites were chosen from both arms of the upper Bay while still utilizing criteria 2 and 3 (above). Port Althorp was chosen because sea otters have been resident there for >20 years, we have extensive foraging data on sea otters from that area, and we sampled 12 intertidal sites in 2000 (Bodkin et al. 2001). Port Althorp site selection was based on the following criterion: 1) proximity to areas of known sea otter foraging, 2) spatial separation from other sites, and 3) relatively high clam densities as estimated by the observation of abundant shell litter on scouting dives. Because no sites were selected randomly or systematically, we do not make inference to areas beyond each site sampled.

We used a fisheye underwater drop camera or divers to locate the presence of clam siphons or clam shell litter to identify clam beds. Searching the benthos with a drop camera made it possible to scan the bottom quickly and cover more area than we could via SCUBA divers. Due to the logistical constraints of underwater sampling at deeper depths, we narrowed our search to subtidal habitats less than 12 meters deep at high water, even though sea otters are capable of diving to depth of 100 m (Newby 1975). When abundant clam populations were located, GPS coordinates were recorded so divers could relocate the site for sampling. It is recognized that this method of site selection is potentially biased in favor of clams with longer, larger, or more visually striking siphons. For example, *Clinocardium nuttallii* siphons are large (2.5-5 cm) with hairy tips and white globules on the rim; *Saxidomus gigantea* siphons are large and cream colored with black tips; while *Macoma* spp siphons are small (<2.5 cm) and lie along the substrate; *Mya truncata* siphons are small, smooth, and dark; and mussel siphons are short or nonexistent (Harbo 1997).

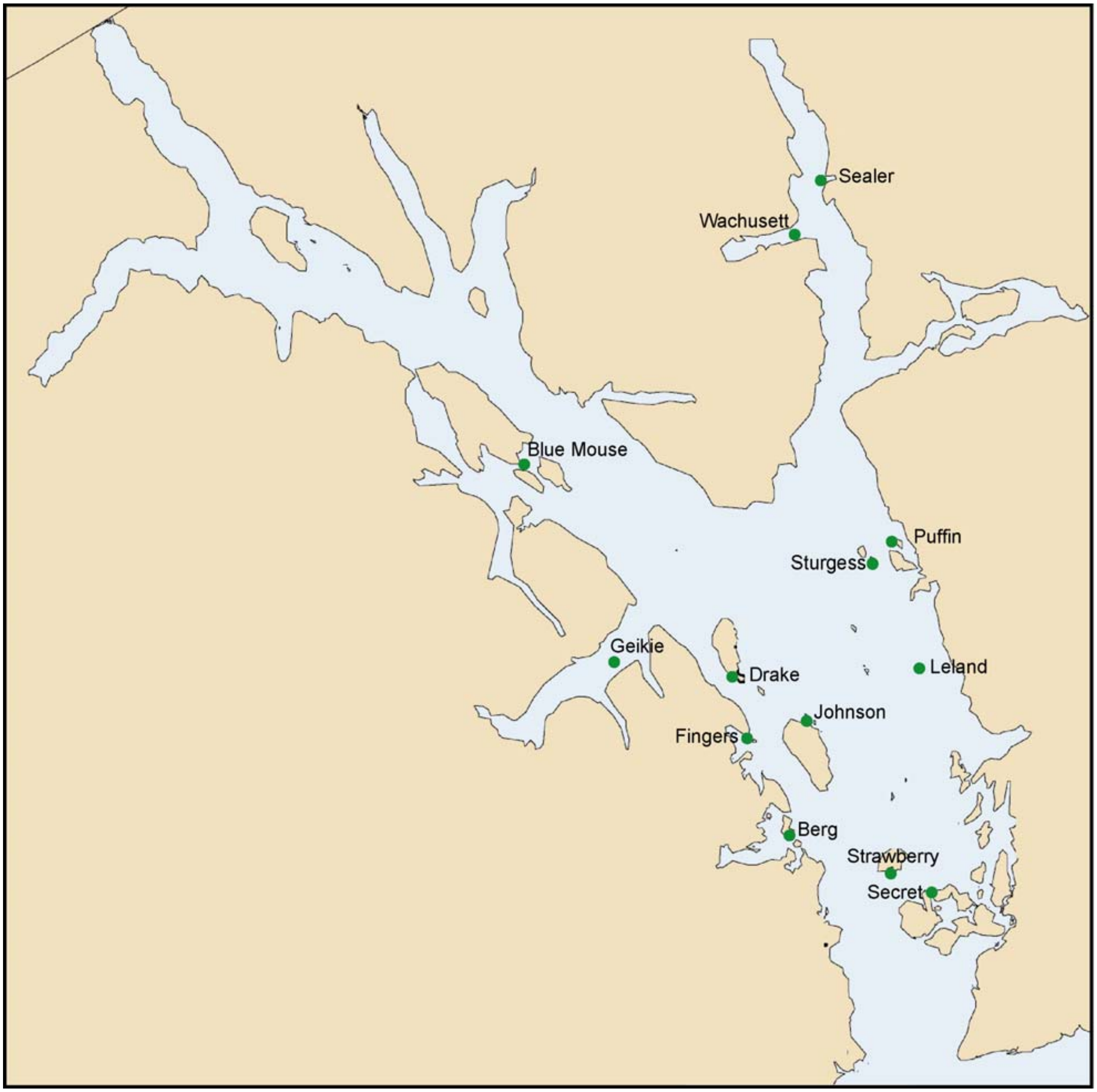


Figure 6. Subtidal sampling sites in Glacier Bay, 2001 and 2002. Geikie, Blue Mouse, Wachusett, and Sealer were sampled in 2002, all others in 2001. Green circles indicate sampling sites.

Figure 7. Subtidal sampling sites in Port Althorp, Alaska, in 2002. Green circles indicate sampling sites.

Sampling Protocol

The sampling protocol was adapted from a subtidal clam sampling protocol used in Prince William Sound, Alaska (Appendix C). Power analyses based on data from preliminary dredging in Glacier Bay indicated that we needed to sample 20 quadrats ($0.25m^2$) per site in order to detect a 50% change in clam densities with 90% confidence. We originally planned to sample along a 50 m long by 0.5 m wide transect (25 m^2) because this size seemed large enough for the acquisition of 20 samples, small enough to fit within the spatial scale of most clam beds, and small enough to minimize the amount of time spent moving dredging equipment. However, we soon discovered that a 50 m long transect could include areas outside the identified clam bed, leading to increased variance in sample estimates. To reduce variance, we modified our design to sample a 20 m x 20 m grid (400 m^2). The sampling design looks similar to a wheel with 12 spokes (Figure 8). The spokes are simply compass headings separated from one another by 30 degrees. Quadrat locations were determined by overlaying a 20 x 20 meter grid and randomly selecting cells until we had 20 cells that intersected with spokes. Quadrats that intersected a spoke less than 2 meters from a previously selected quadrat were eliminated along with any that fell outside the circle. This modified sampling design increases the area we sample (314 m^2), reduces variance among quadrats sampled and requires less time to sample. The field methodology employed to carry out this sampling design is briefly described below, and thoroughly in the 2001 Annual Report (Bodkin et al, 2002).

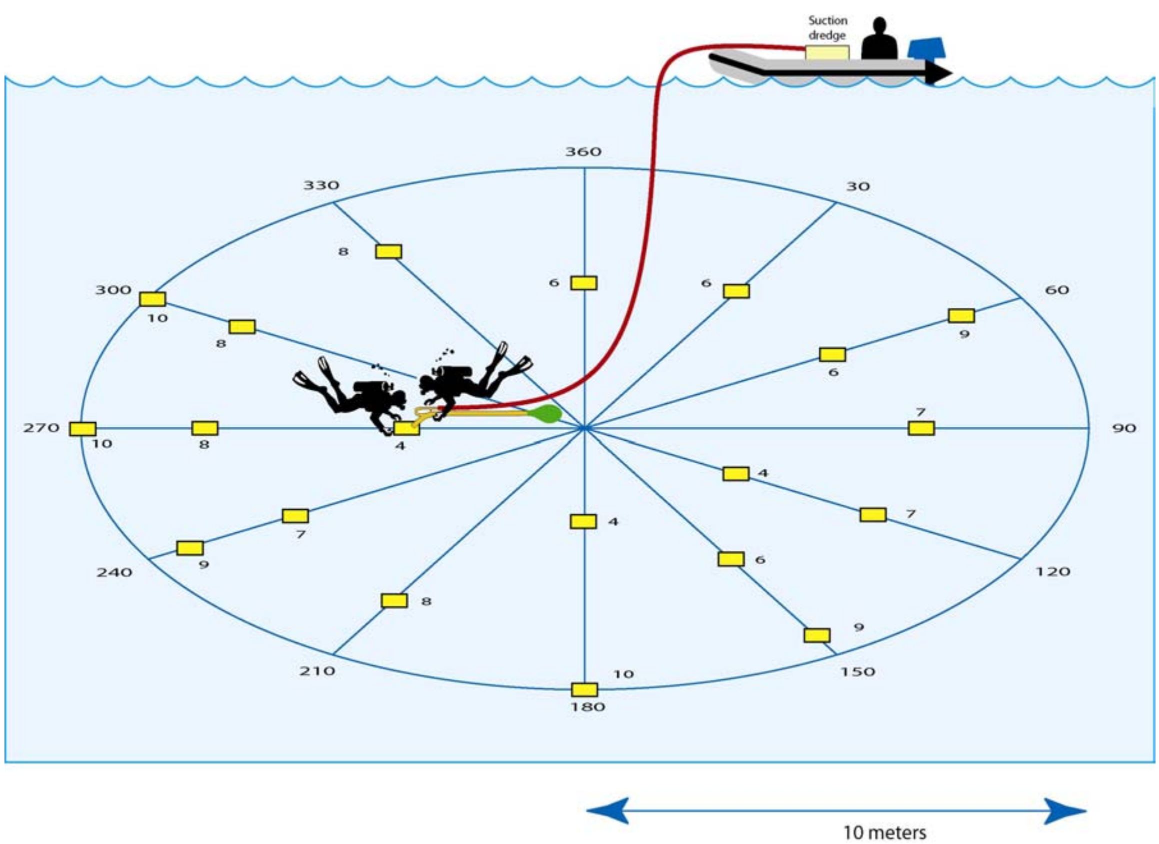


Figure 8. Subtidal sampling design used in Glacier Bay National Park and Port Althorp, 2001 and 2002.

Divers prepared the site for sampling by installing a sand anchor to mark the center of the 20 m diameter-sampling circle (origin). Divers then clipped into this anchor and swam fiberglass tapes out to 10 m on N, S, E, and W compass headings to look for clam siphons and clam shell litter. The origin was moved when necessary to ensure that the sampling circle was located, as entirely as possible, over the clam bed. Once the final origin was established, a new set of GPS coordinates were taken and a temporary buoy line was attached to the anchor. During subsequent dives, divers navigated to the predetermined quadrat location and position a 0.5 x 0.5 m aluminum quadrat frame (0.25 m^2). After recording siphon count and substrate classification, divers collected urchins, crabs, and visible clams by hand. Then one diver dredged the quadrat while the other diver manually removed larger clams. Smaller clams were sucked along with the sediment into another mesh bag on the exhaust hose. Quadrats were excavated to a depth of at least 25cm or until no more clams were found. Divers then returned to the boat, the mesh bags were recovered and the sediments sieved through 10mm mesh screens to locate smaller clams. All bivalves (as well as crabs and urchins) were identified to the lowest possible taxa, counted, and measured to the nearest millimeter. Sediments and fauna were returned to Glacier Bay following data collection.

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) the size class distribution of clams collected from each area by species. Biomass was estimated from published length to biomass conversions specific to clam taxa (Dean et al 2002). H' was compared between areas (Glacier Bay sites grouped vs. Port Althorp sites grouped) using a t-test. The mean density of bivalves / 0.25 m^2, including all bivalves in aggregate as well as individual species separately, were compared between Glacier Bay and Port Althorp with t tests. Mean biomass (g/0.25 m^2) and mean size were compared between areas with t tests, although mean size was only analyzed by species. Mean sizes of species within Glacier Bay were contrasted with one-way ANOVA. Mann-Whitney rank sum tests (T) were used when the data failed the normality test. Size frequency distributions were compared between areas using the Kolomogorov-Smirnov test. Chi-square tests were used for comparisons of size class distributions within Glacier Bay. Statistical tests were only used for species represented adequately in both areas (N>38). Because *Clinocardium nutalli* occurred in only a few sites we present only between area results. A further reminder must be stated, that our sampling of subtidal clams does not allow inference beyond the approximately 400 m^2 sampled at each site.

Results

We sampled subtidal clam and sea urchin populations at 9 sites in Glacier Bay in 2001, 4 in 2002 (Figure 6), and 5 in Port Althorp in 2002 (Figure 7). In Glacier Bay we identified 14 clam species, 2 species of mussels, 1 scallop, 1 snail, and 1 urchin species (Table 5). In Port Althorp we identified 14 clam species, 1 snail, 1 crab, and 1 urchin species (Table 5). The species of bivalves and urchin we encountered and their frequencies of occurrence are presented in Table 5. P*rotothaca staminea*, and *Macoma* sp. were the most common bivalves at Glacier Bay; while *Protothaca staminea*, and *Mya truncata* were the most common at Port Althorp subtidal sites.

Table 5. Species of bivalves and urchins and frequency of occurrence from sites in Glacier Bay and Pt Althorp. () is abbreviation used in figures. More than one species have been given the same abbreviation when lumped in analyses. SCA is a scallop, MOM and MUS are mussels, STD is an urchin, while the remaining species are clams. Percent is percent of all bivalves; urchins are not included in the bivalve calculation. Species (or lumped species) with a frequency for both areas ≥ 39 were included in between area t-tests.

	Glacier Bay Sites		Pt Althorp Sites	
Species	**Frequency**	**Percent**	**Frequency**	**Percent**
Chlamys sp. (SCA)	1	<0.1	.	.
Modiolus modiolus (MOM)	59	0.4	.	.
Unidentified mussel (MUS)	13	0.1	.	
Clinocardium nutalli (CLN)	43	0.3	39	3.8
Entodesma navicula (ENN)	9	0.1	.	.
Gari californica (GAC)	.	.	3	0.3
Hiatella arctica (HIS)	37	0.2	.	.
Hiatella sp. (HIS)	636	4.2	1	0.1
Humalaria kennerleyi (HUK)	3	<0.1	.	.
Solen sicarius (SSI)	.	.	1	0.1
Lucinoma annulata (LUA)	.	.	28	2.7
Macoma sp. (MAS)	4608	30.0	46	4.5
Macoma nasuta (MAS)	.	.	69	6.7
Mactromeris polynyma (MAP)	304	2.0	2	0.2
Mactridae sp. (MSP)	.	.	10	1.0
Mya arenaria (MYS)	.	.	1	0.1
Mya sp. (MYS)	42	0.3	1	.01
Mya truncata (MYS)	1584	10.3	224	21.7
Panomya ampla (PAA)	9	0.1	.	.
Parvalucina tenuisculpta (PAT)	.	.	174	16.8
Protothaca staminea (PRS)	4722	30.8	301	29.1
Saxidomus gigantea (SAG)	2643	17.2	93	9.0
Serripes groenlandicus (SEG)	462	3.0	1	0.1
Tellina bodegensis (TES)	.	.	1	0.1
Tellina modesta (TES)	.	.	39	3.8
Tellina sp. (TES)	5	<0.1	.	.
Yoldia sp. (YOS)	153	1.0	.	
Unidentified clam (CLA)	3	<0.1	.	.
Strongylocentrotus droebachiensis (STD)	6917	.	5	.

Bivalve Species Diversity

The Shannon-Wiener diversity index (H') was calculated for the bivalve community at each site. 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'. Diversity values for each of the 13 Glacier Bay and 5 Port Althorp sites we sampled are presented in Table 6. Mean species diversity among Glacier Bay sites sampled was 1.73

(sd = 0.33) and 2.21 (0.51) for Port Althorp sites (t = -2.333, 16DF, p = 0.033). The theoretical maximum H', based on the total number of different species observed, is 4.0 and 3.81 for Glacier Bay and Port Althorp, respectively.

Table 6. Shannon-Weiner diversity index values (H') for subtidal bivalve samples.

Glacier Bay Sites	H'	Port Althorp Sites	H'
Berg	1.40	Head-Althorp	2.23
Blue Mouse	1.26	Library	1.62
Drake	2.05	Oyster Farm	2.76
Geikie	2.00	Saltchuck	2.65
Johnson	2.41	Strawberry	1.76
Leland	1.54		
N. Fingers	1.89		
Puffin	1.80		
Sealer	1.64		
Secret	1.34		
Strawberry	1.39		
Sturgess	1.91		
Wachusett	1.84		
Mean	**1.73***	**Mean**	**2.21**

* Difference between areas significant, t=-2.33, p=0.033

Density

Average densities of subtidal bivalves were nearly 6 times greater in Glacier Bay compared to Port Althorp (Table 7). The mean number of bivalves per quadrat over all sites sampled was significantly greater in Glacier Bay (59.2) than in Port Althorp (10.3) (T=15.0, p<0.002). At Glacier Bay sites, the mean numbers of bivalves per quadrat ranged from 18.0 at Secret Bay to 151.4 at Johnson Cove (Table 7). At Port Althorp sites, the mean numbers of bivalves per quadrat ranged from 5.1 at the Head of Althorp site to 14.7 at the Oyster Farm site (Table 7).

Mean clam density varied by species. *P. staminea* had the highest mean density in both study areas (Table 8). In Glacier Bay, *P. staminea* was followed by *Macoma* sp., *S. gigantea*, *Mya* sp., and *S. groenlandicus*. In Port Althorp, *P. staminea* was followed by *P. tenuisculpta*, *Macoma* sp., *Mya* sp., and *S. gigantea*. There were fewer than 0.5/ 0.25 m^2 of the other bivalve species. Mean density and standard error of these clams are presented by site in Figures 9-14. In all figures Port Althorp data are represented by red bars and Glacier Bay by blue bars.

The mean numbers of green urchins, *S. droebechiensis* (STD), per quadrat over all sites sampled was 26.7 for Glacier Bay. The mean numbers of urchins per quadrat ranged from 10.8 at Leland Island to 47.2 at N. Fingers (Table 7). At all Port Althorp sites combined, only five urchins were observed, so descriptive statistics were not calculated.

Table 7. Mean density (#/0.25 m^2) and biomass (grams ash free dry weight /0.25 m^2) of subtidal bivalves and green urchins in Glacier Bay and Port Althorp.

Glacier Bay Sites	Density: bivalves	Estimated Biomass: bivalves	Density: urchins	Estimated Biomass: urchins	Port Althorp Sites	Density: bivalves	Estimated Biomass: bivalves
Berg	42.3	78.6	23.7	58.3	Head-Althorp	5.1	2.6
Blue Mouse	24.6	27.5	14.1	63.1	Library	8.8	5.5
Drake	48.2	77.5	41.6	39.1	Oyster Farm	14.7	8.0
Geikie	62.7	62.6	26.9	19.8	Saltchuck	10.9	5.1
Johnson	151.4	313.3	22.2	46.0	Strawberry	12.4	7.6
Leland	53.2	38.7	10.8	23.9			
N. Fingers	55.3	168.3	47.2	103.1			
Puffin	100.7	145.1	16.7	64.1			
Sealer	56.5	71.0	36.4	60.6			
Secret	18.0	71.7	22.9	30.1			
Strawberry	23.3	51.0	36.7	100.6			
Sturgess	73.7	151.7	24.0	32.9			
Wachusett	59.9	31.0	24.9	59.0			
Mean*	**59.2**	**99.1**	**26.7**	**53.9**	**Mean**	**10.3**	**5.8**

* Mean number (bivalves/quad T=15.0, p = 0.002) and mean biomass (bivalves)/quad, T=15.0, p = 0.002) estimates between areas are significantly different.

Table 8. Mean and maximum number per quadrat and biomass per quadrat of subtidal bivalves from Glacier Bay and Port Althorp (sites within areas combined).

Bivalve	Mean # (max) / Quadrat Glacier Bay	Mean # (max) / Quadrat Pt Althorp	Mean Biomass (max) / Quadrat Glacier Bay	Mean Biomass (max) / Quadrat Pt Althorp
Protothaca staminea (PRS) [1]	18.2 (97)	3.0 (11)	20.2 (93)	1.6 (9)
Macoma sp. (MAS) [2]	17.9 (98)	1.2 (18)	1.5 (11)	0.9 (17)
Saxidomus gigantea (SAG) [1]	10.2 (63)	0.9 (11)	53.4 (484)	0.7 (10)
Mya sp. (MYS) [3]	6.3 (94)	1.2 (25)	6.3 (133)	1.9 (17)
Serripes groenlandicus (SEG)	1.8 (41)	0	5.5 (25)	0
Parvalucina tenuisculpta (PAT)	0	1.7 (11)	0	0.02 (0.3)
Clinocardium nutalli (CLN) [4]	0.2 (4.0)	0.4 (5.0)	0.2 (4.1)	0.2 (6.4)

[1] mean number and biomass of PRS and SAG/quadrat was significantly greater in Glacier Bay than Port Althorp, p <0.001.
[2] mean number and biomass of MAS/quadrat was significantly greater in Glacier Bay than Port Althorp, p < 0.001 and p = 0.01, respectively.
[3] mean number and biomass of MYS/quadrat was significantly greater in Glacier Bay than Port Althorp, p =0.01 and p = 0.006, respectively.
[4] mean number of CLN/quadrat was significantly less in Glacier Bay than Port Althorp, p = 0.003.

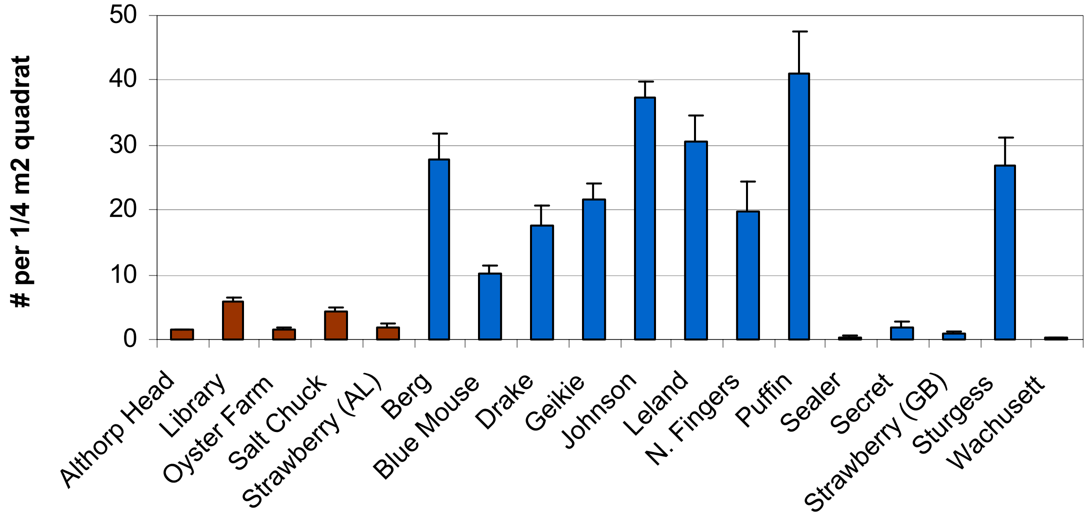


Figure 9. Mean densities of littleneck clams *Protothaca staminea,* (PRS) at five Port Althorp (mean = 3.0) and 13 Glacier Bay subtidal sites (mean=18.2, p<0.001). Port Althorp bars are red, while Glacier Bay bars are blue. See Figures 6 and 7 for locations of sampling sites.

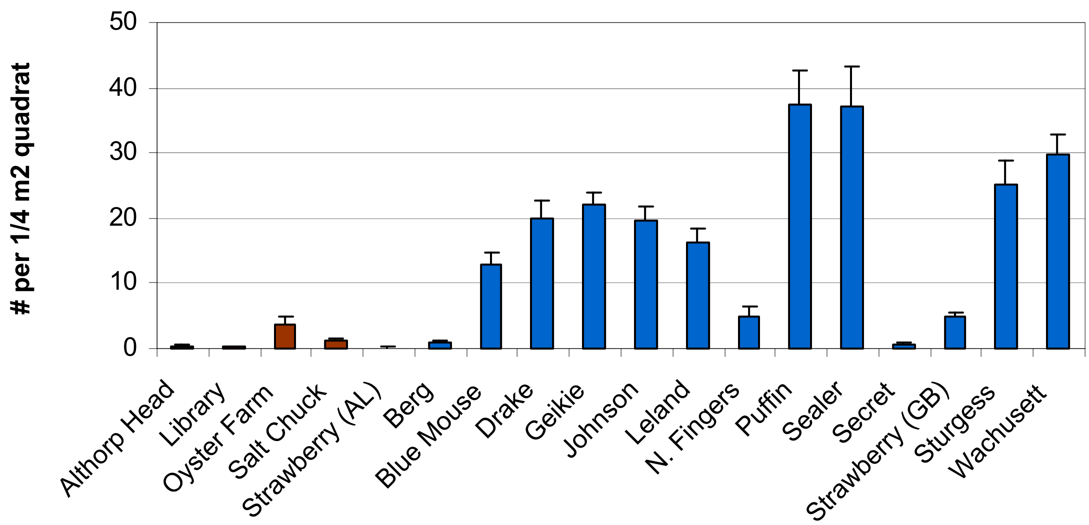


Figure 10. Mean densities of *Macoma* sp. (MAS) at five Port Althorp (mean=1.5) and 13 Glacier Bay (mean=17.9, p<0.001) subtidal sites. Port Althorp bars are red, while Glacier Bay bars are blue. See Figures 6 and 7 for locations of sampling sites.

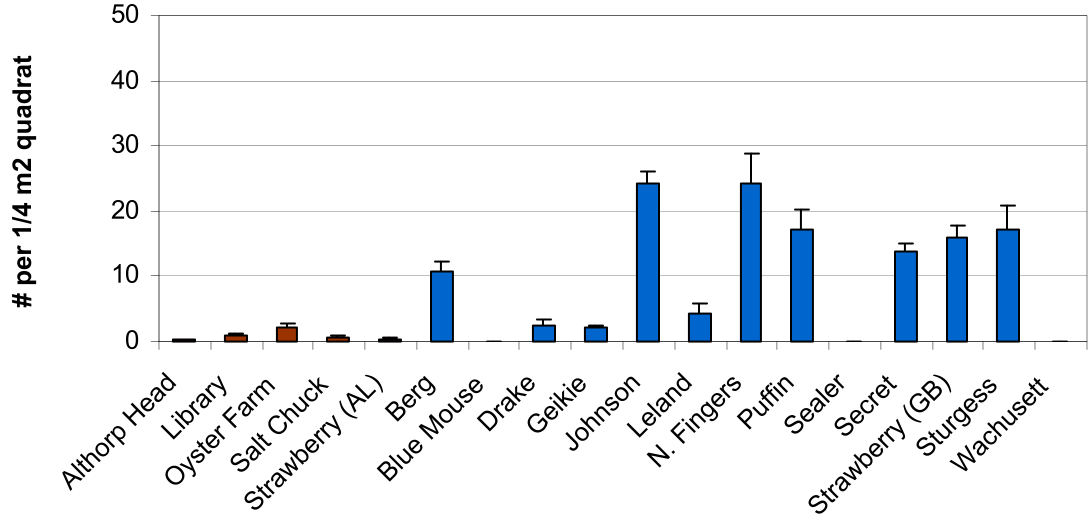


Figure 11. **A**. Mean density of butter clams, *Saxidomus gigantea* (SAG) at five Port Althorp (mean=0.9) and 13 Glacier Bay (mean=10.2, $p<0.001$) subtidal sites. Port Althorp bars are red, while Glacier Bay bars are blue. See Figures 6 and 7 for locations of sampling sites.

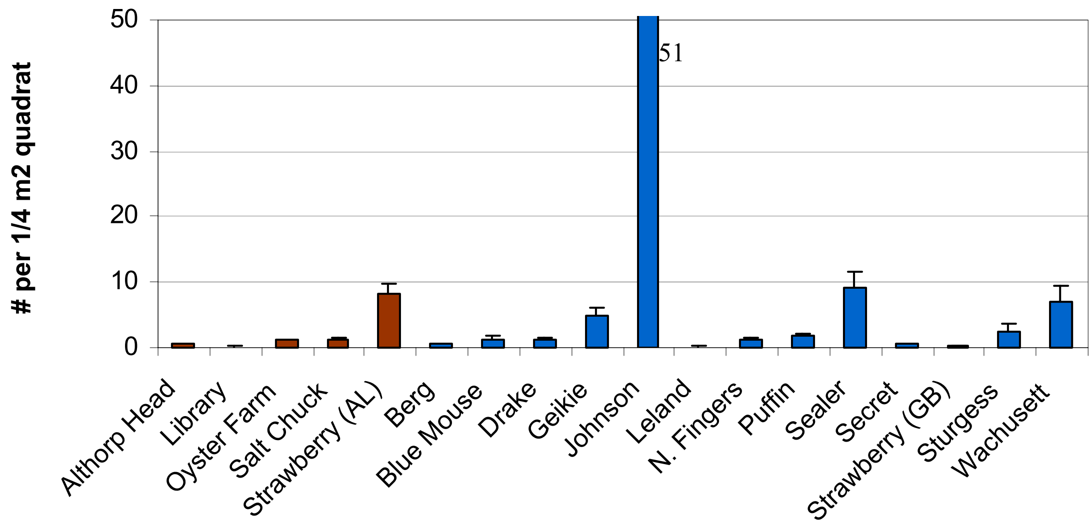


Figure 12. **A**. Mean densities of soft shell clams, *Mya* sp. (MYS) at five Port Althorp (mean=1.2) and 13 Glacier Bay (mean=6.3, $p=0.01$) subtidal sites. Port Althorp bars are red, while Glacier Bay bars are blue. See Figures 6 and 7 for locations of sampling sites.

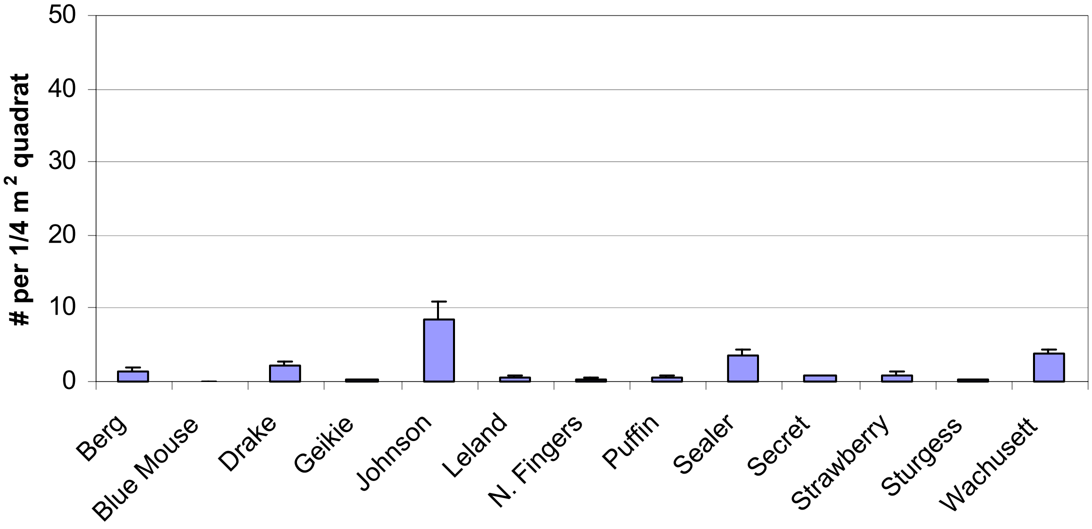


Figure 13. Mean densities of the Greenland cockle, *Serripes groenlandicus* (SEG) at each of the 13 subtidal sites (mean=1.8) we sampled in 2001-02 in Glacier Bay (see Figure 6 for site locations).

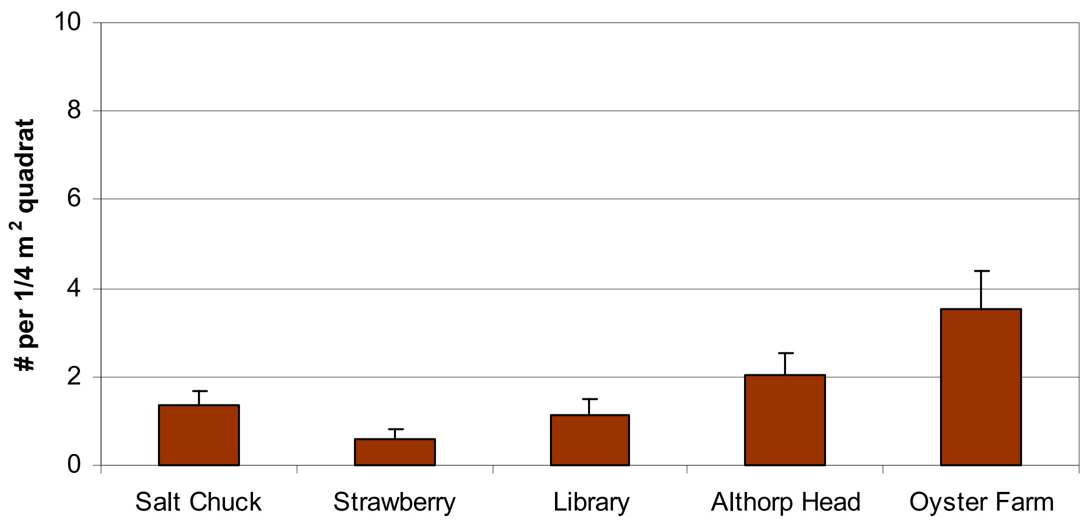


Figure 14. Mean density of *Parvalucina tenuisculpta* (PAT) at each of the 5 subtidal sites (mean=1.7) we sampled in 2002 in Port Althorp (see Figure 7 for site locations).

Estimated Biomass

Mean biomass of all bivalves was 17 times greater at Glacier Bay sites compared to Port Althorp. The mean bivalve biomass (grams ash free dry weight) per quadrat over all sites sampled was significantly greater in Glacier Bay (mean=99.1) than Port Althorp (mean=5.8, T=15, p<0.002). In Glacier Bay, biomass per quadrat ranged from 27.5g at Blue Mouse to 313.3g at Johnson Cove (Figure 15, Table 7); while at Port Althorp biomass ranged from 2.6g at the Head of Althorp to 8.0g at Oyster Farm (Figure 15, Table 7).

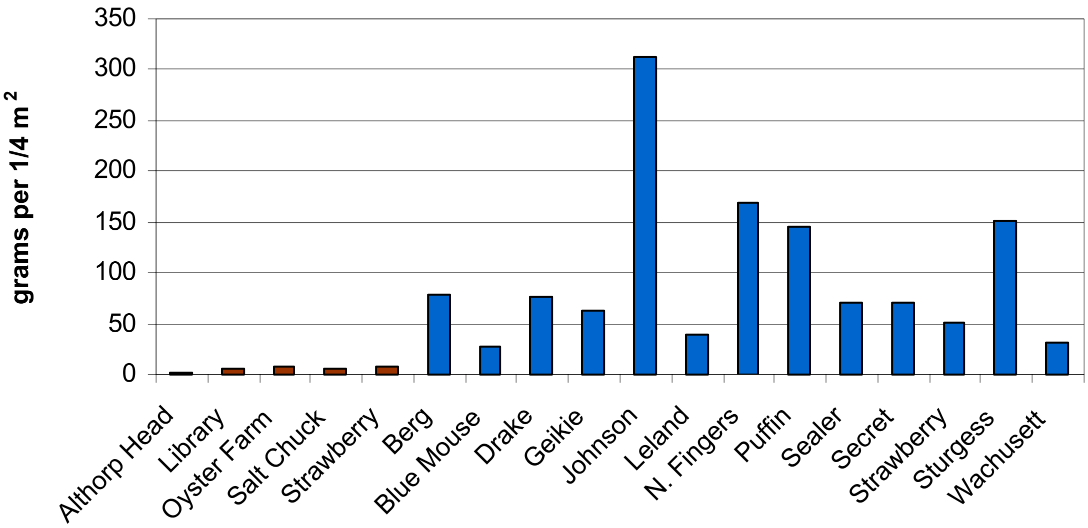


Figure 15. Total estimated biomass (grams ash free dry weight) of bivalves per quadrat at 5 Port Althorp (mean=5.8) and 13 Glacier Bay (mean=99.1, T=15, $p<0.002$) subtidal sites. Port Althorp bars are red, while Glacier Bay bars are blue. See Figures 6 and 7 for locations of sampling sites.

Although *P. staminea* and *Macoma* sp. were the numerically dominant species, *S. gigantea* was the key species in terms of biomass (average >53 g/0.25m^2), followed by *P. staminea*, *Mya* sp., and *S. groenlandicus*. (Table 8, Figures 16-19). All other bivalve species were <2 g per quadrat. Generally, sites with higher densities had higher estimated biomass (Table 7, Figure 15), however some exceptions to this trend were noted. For example, the Geikie Inlet site ranked 10th in terms of bivalve density but 5th in biomass (1 = lowest, 13 = highest). Alternatively, Secret Bay ranked lowest in bivalve density, but 7th in biomass.

In Port Althorp, the total estimated biomass per quadrat varied little among sites. Only the Strawberry site in Port Althorp had any urchins. The biomass per quadrat with the inclusion of urchins was 7.7g at Strawberry (7.6 g without urchins). Generally, sites with higher densities had higher estimated biomass (Table 7). While *P. staminea* and *P. tenuisculpta* were the numerically dominant species, in terms of biomass, *Mya* sp. and *P. staminea* were the key species, followed by *Macoma* sp., and *S. gigantea* (Figures 18, 17, 20, and 16). All other bivalve species observed had biomass means <0.5 g per quadrat.

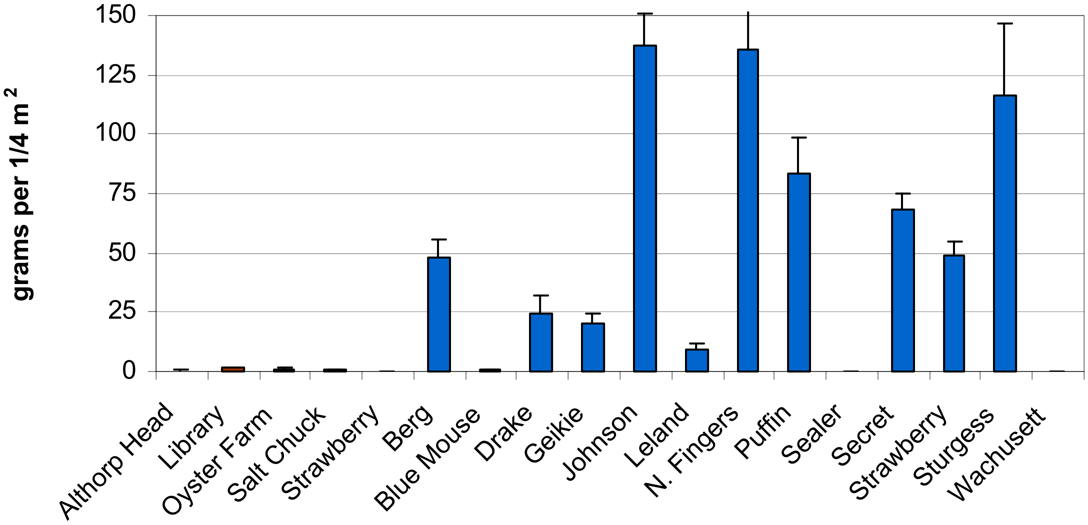


Figure 16. Mean estimated biomass (grams ash free dry weight) of butterclams (*S. gigantea*, SAG) per quadrat at 5 Port Althorp (mean=0.7) and 13 Glacier Bay (mean=53.3, $p<0.001$) subtidal sites. Port Althorp bars are red, while Glacier Bay bars are blue. See Figures 6 and 7 for locations of sampling sites.

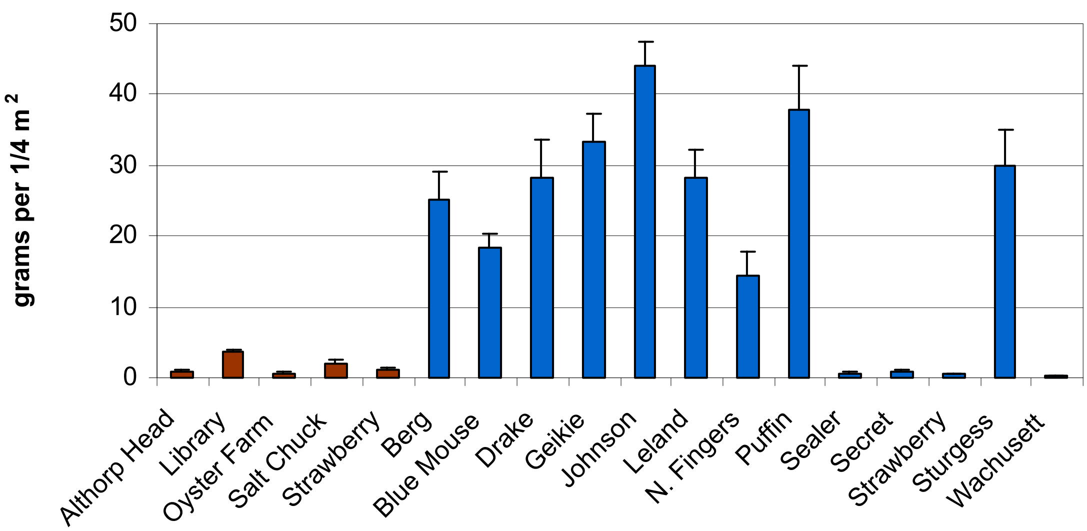


Figure 17. Mean estimated biomass (grams ash free dry weight) of littleneck clams (*P. staminea*, PRS) per quadrat at 5 Port Althorp (mean=1.6) and 13 Glacier Bay (mean=20.2, $p<0.001$) subtidal sites. Port Althorp bars are red, while Glacier Bay bars are blue. See Figures 6 and 7 for locations of sampling sites.

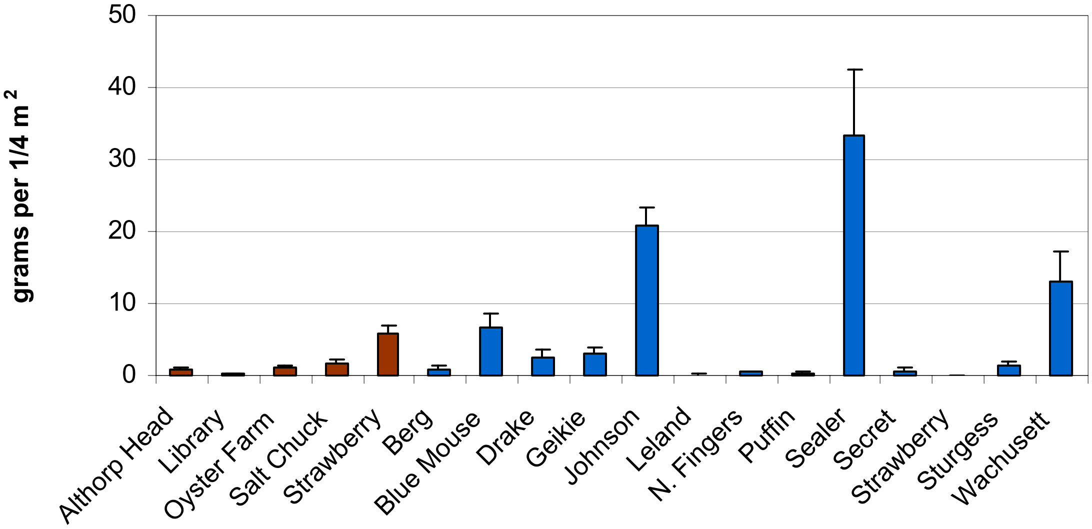


Figure 18. Mean estimated biomass (grams ash free dry weight) of softshell clams (*Mya* sp., MYS) per quadrat at 5 Port Althorp (mean=1.9) and 13 Glacier Bay (mean=6.3, p=0.006) subtidal sites. Port Althorp bars are red, while Glacier Bay bars are blue. See Figures 6 and 7 for locations of sampling sites.

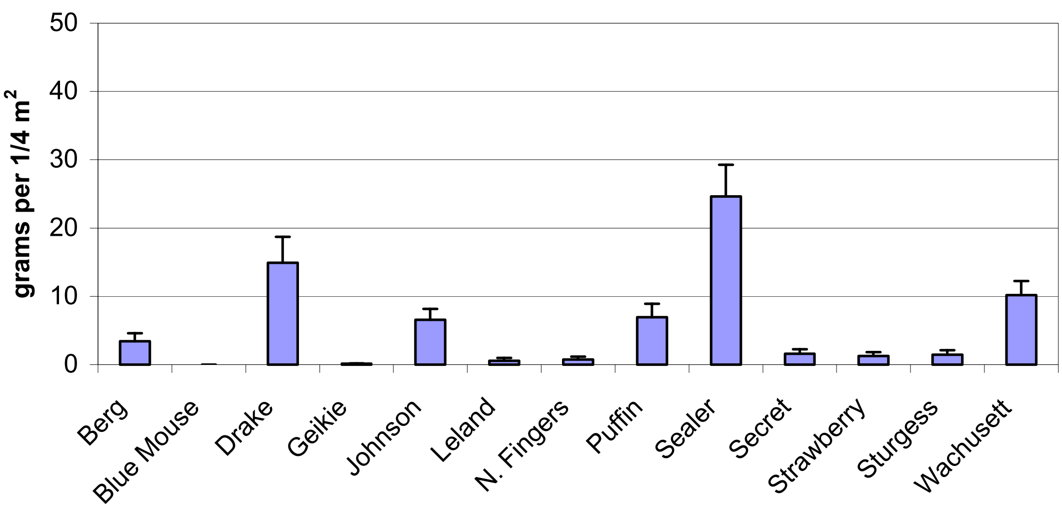


Figure 19. Mean estimated biomass (grams ash free dry weight) of Greenland cockles (*S. groenlandicus*, SEG) per quadrat at 13 subtidal sites in Glacier Bay (mean=5.5). See Figure 6 for site locations.

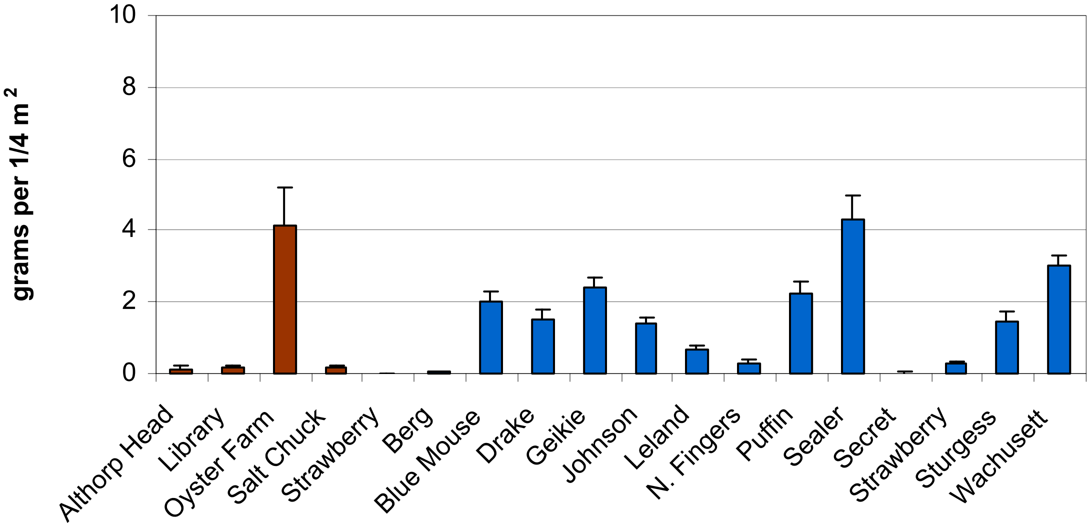


Figure 20. Mean estimated biomass (grams ash free dry weight) of *Macoma* sp. (MAS) per quadrat at 5 Port Althorp (mean=0.9) and 13 Glacier Bay (mean=1.5, p=0.01) subtidal sites. Port Althorp bars are red, while Glacier Bay bars are blue. See Figures 6 and 7 for locations of sampling sites.

In Glacier Bay, the estimated biomass of urchins per site varied among sites (Figure 21, Table 7). Mean biomass of urchins per site ranged from 19.8g at Geikie Inlet to 103.1g at N. Fingers and averaged 53.9g. Maximum *S. droebachiensis* biomass was 318.1g at Strawberry Island.

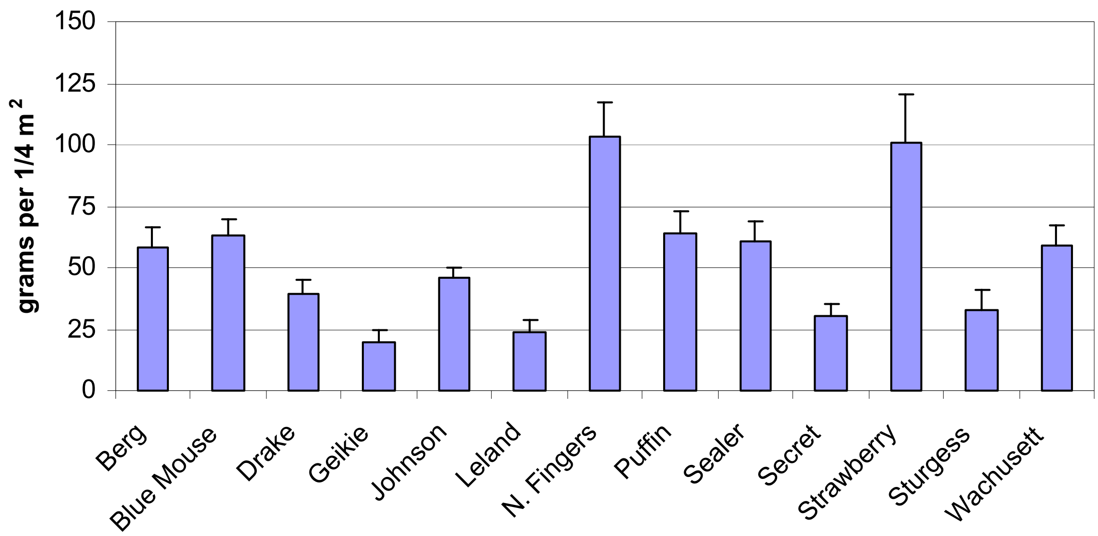


Figure 21. Total estimated biomass (grams ash free dry weight) of green urchins (*S. droebachiensis*, STD) per quadrat at 13 subtidal sites (mean=53.9) in Glacier Bay. See Figure 6 for site locations.

Mean Size and Size Distributions

Mean subtidal bivalve and urchin sizes were generally larger in Glacier Bay than Port Althorp, and mean sizes by species are presented for each study area in Figure 22. *Clinocardium nutalli*, *P. staminea,* and *S. gigantea* were significantly larger at Glacier Bay sites than Port Althorp. Mean size of species of *Macoma* sp. and *Mya* sp.was significantly larger at Port Althorp. Mean size varied by site for *P. staminea, Mya* sp., and *S. gigantea* in Glacier Bay and *Macoma* sp. in Port Althorp (Figure 23). However mean sizes were relatively uniform for *Macoma* sp. and S. droebachiensis in Glacier Bay and P. tenuisculpta, *P. staminea, Mya* sp., and *S. gigantea* in Port Althorp (Figure 24 A & B).

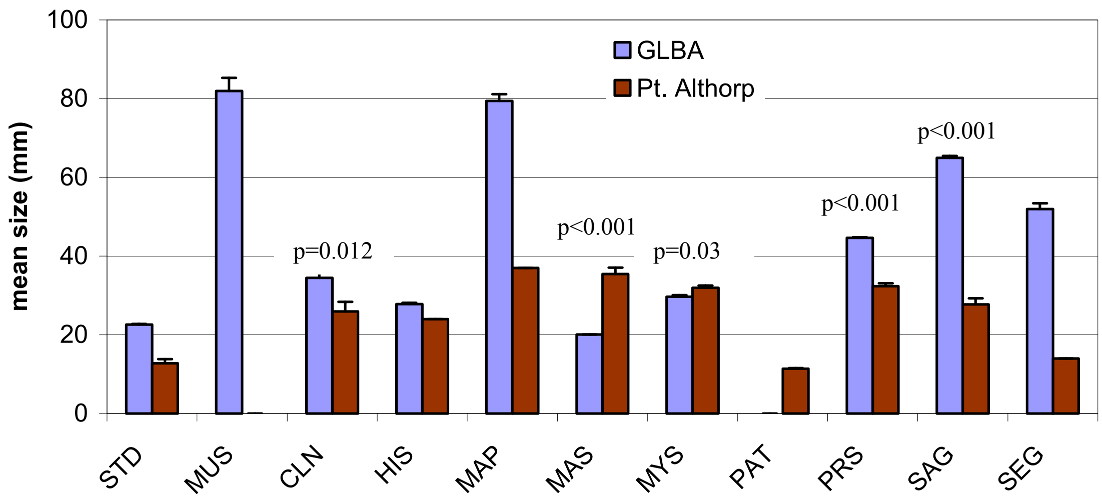
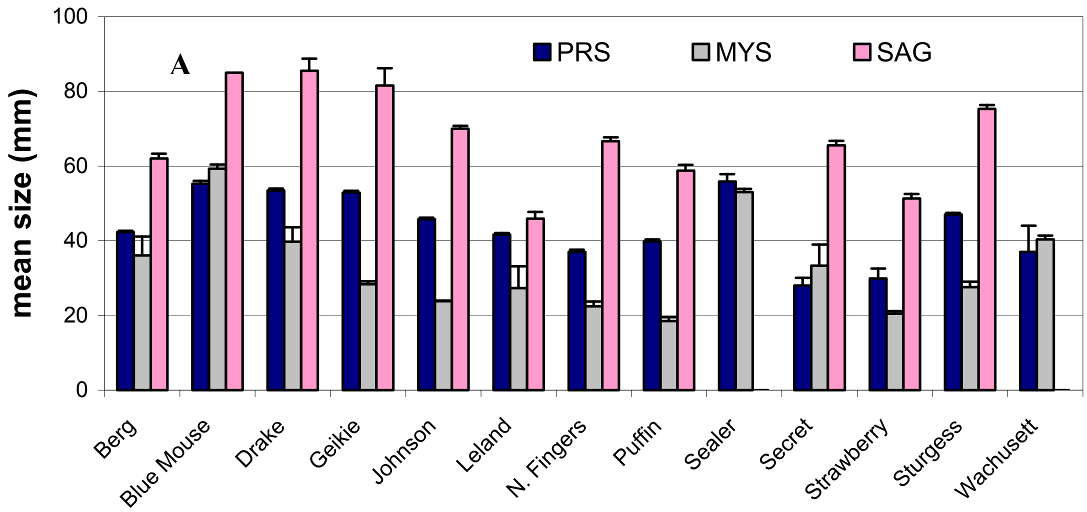


Figure 22. Mean sizes (n: GLBA, Pt. Althorp) of subtidal green urchins: S. *droebachiensis,* (STD, n=6657, 5); mussels: *M. modiolus*, *M. musculus*, and *M. trossulus* (MUS, n=72, 0); and clams: *C. nutalli*. (CLN, n=41, 38), *Hiatella* sp. (HIS, n=640, 1), *M. polynyma,* (MAP, n=299, 1), *Macoma* sp. (MAS, n=4394, 112), *Mya* sp. (MYS, n=1466, 197), *P. tenuisculpta* (PAT, n=0, 171), *P. staminea* (PRS, n=4553, 289)*, S. gigantea* (SAG, n=2613, 90), *S. groenlandicus* (SEG, n=402, 1) collected from Glacier Bay and Port Althorp in 2001-02. (Numbers of individuals measured may be less than number counted (Table 7).

In addition to mean size differences in clams and urchins between areas, we also detected significant differences in mean size of some species among sample sites within areas (Figure 23). In Glacier Bay, mean sizes (se) of *P. staminea* were significantly different among sites (F=88.8, p<0.001, range 28.1mm (2.0) at Secret Bay to a maximum of 55.8mm (2.0) at Sealer) (Figure 23). In Port Althorp, mean sizes (se) of *P. staminea* ranged from a minimum of 28.5mm (2.1) at Oyster Farm to a maximum of 36.2mm (2.3) at the Head of Althorp (Figure 23). In Glacier Bay, mean sizes of *S. gigantea* were significantly different among sites (F=40.8, p<0.001, range 45.9mm (1.8) at Leland to 85.5mm (3.3) at Drake Island) (Figure 23). In Port Althorp, mean sizes were similar among sites (range 23.1 (1.9) – 36.4mm (4.0)) (Figure 24). In Glacier Bay, mean sizes of *Macoma sp.* were significantly different among sites (F=154.1, p<0.001, range13.8mm (0.8) at Secret Bay to 24.5mm (0.4) at Blue Mouse) (Figure 24). In Port Althorp, mean sizes of *Macoma sp*. were significantly different among sites (F=12.06, p<0.001) ranged from 13.0 (0.0) to 41.8mm (1.9) (Figure 23). In Glacier Bay, mean sizes (se) of species of *Mya* were significantly different among sites (F=177.8, p<0.001, range 18.5 mm (1.0) at Puffin to a maximum of 59.3mm (1.1) at Blue Mouse) (Figure 23). In Port Althorp, mean sizes (se) of *Mya* were significantly different (F=4.3, p<0.002, range 30.7 (0.6) mm at Strawberry to 37.0 (1.5) Library (Figure 24). In Glacier Bay, mean sizes (se) of S. *droebachiensis* were significantly different among sites (F=246.6, p<0.001, range 15.9 mm (0.19) at Geikie to 33.3mm (0.23) at Blue Mouse) (Figure 24). In Port Althorp, inadequate numbers of S. *droebachiensis* were present to perform statistical comparisons of sizes among sample sites. In Port Althorp, mean sizes (se) of *P. tenuisculpta* were significantly different (F=4.8, p<0.001, range 10.5 (0.2) mm at Althorp Head to 13.3 (0.61) Salt Chuck (Figure 24).



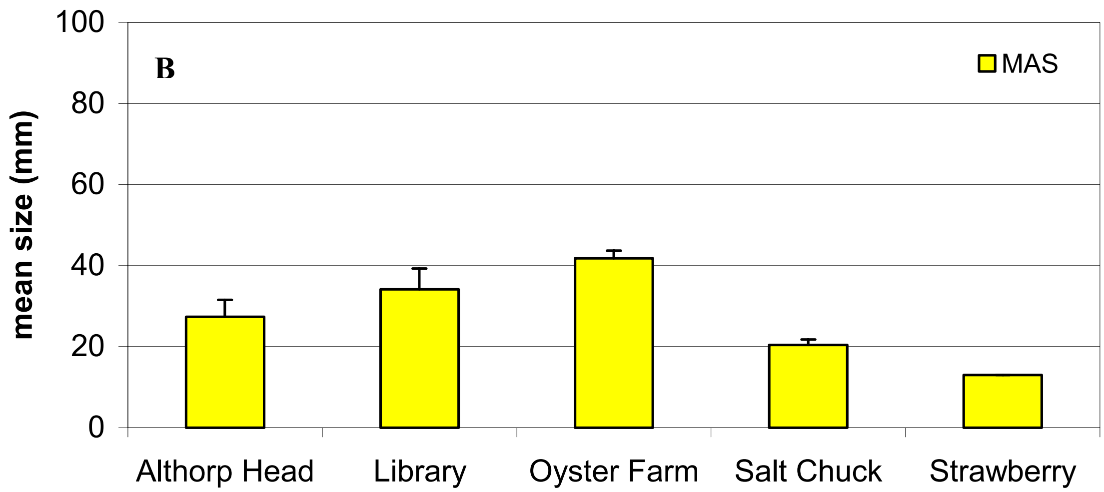


Figure 23. Mean size (mm) of *P. staminea* (PRS), *Mya (*MYS), *S. gigantea* (SAG) in Glacier Bay (**A**) and species of *Macoma* in Port Althorp (**B**).

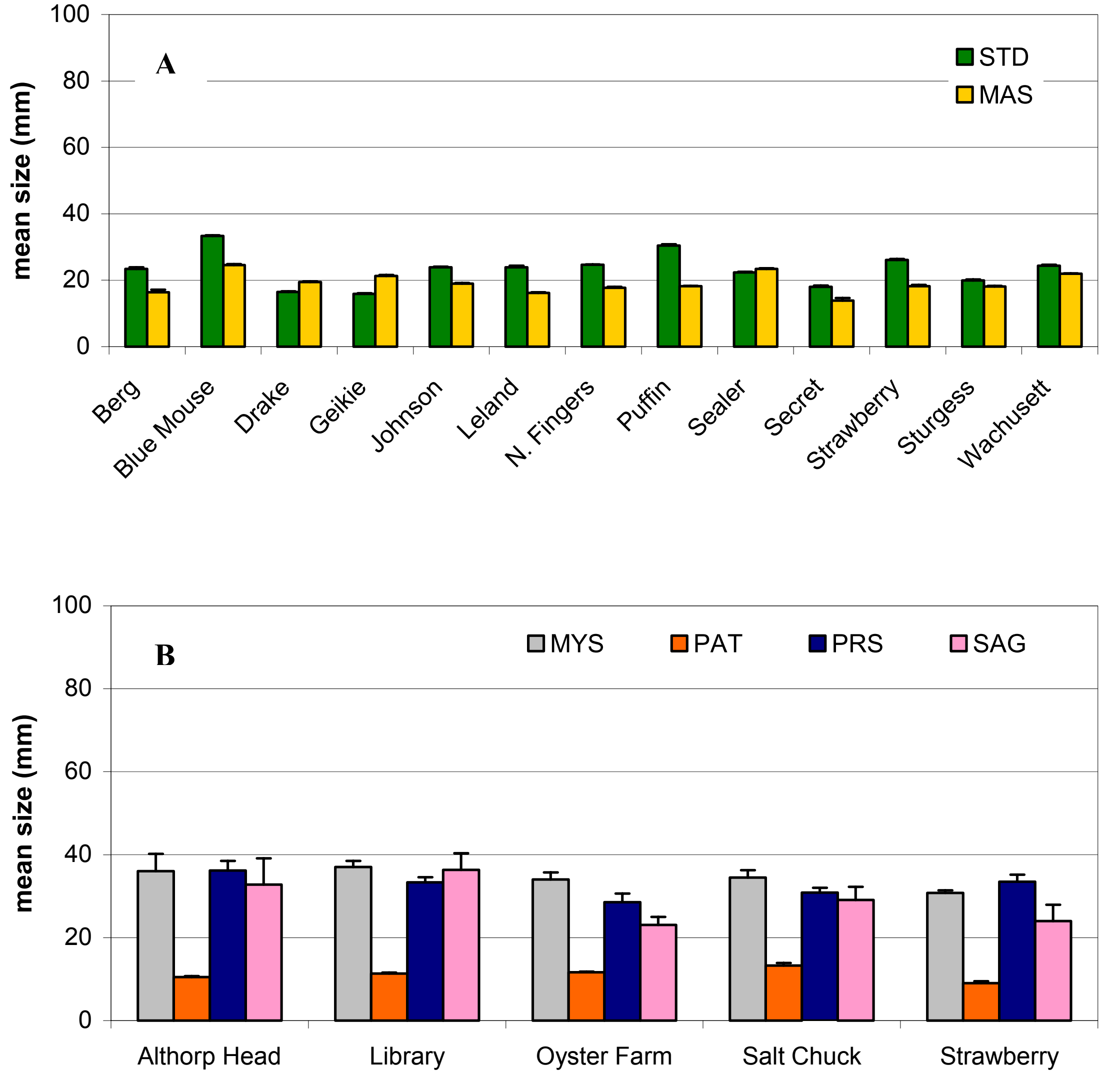


Figure 24. Mean size (mm) of S. *droebachiensis,* (STD), and *Macoma* sp. (MAS) in Glacier Bay (**A**) and species of *Mya sp*. (MYS), *P. tenuisculpta* (PAT), *P. staminea* (PRS), and *S. gigantea* (SAG) in Port Althorp (**B)**.

Size class distributions varied significantly between areas, sites within areas and by species. Size class distributions for the numerically dominant species at all sites combined (within each study area) are presented in Figure 25. Both *P. staminea* and *S. gigantea* size frequency distributions show curves skewed towards larger sizes for Glacier Bay sites than for Port Althorp sites (D_{calc}= 0.41 and 0.65, respectively, $p<0.001$ for both species, Figure 25 D, E). However, size frequency distributions for *Macoma* sp. and *Mya* sp. were skewed towards larger sizes for Port Althorp sites rather than for Glacier Bay sites (D_{calc}= 0.76 and 0.39 respectively, $p<0.001$ for both species) (Figure 25 A and B).

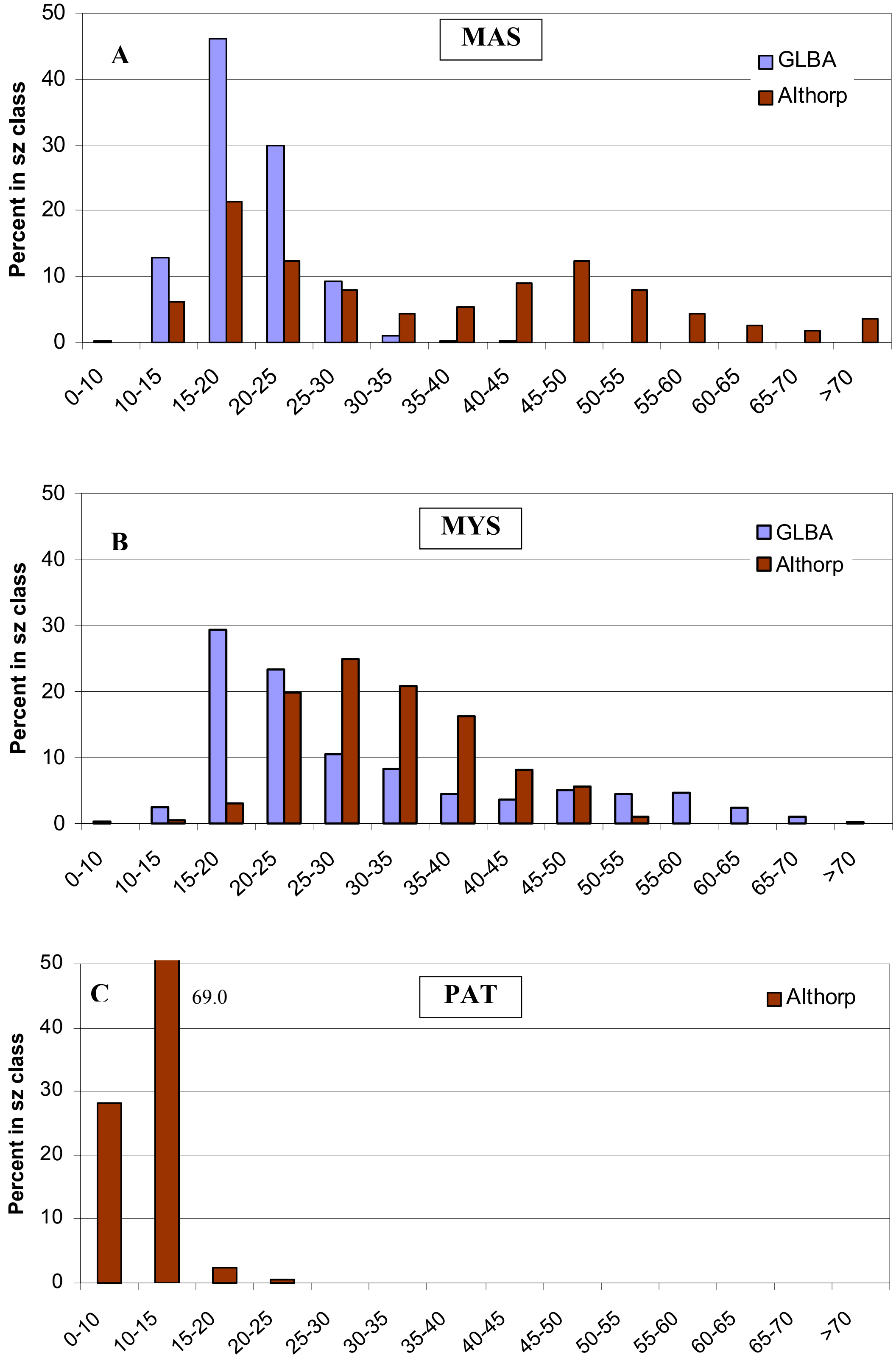


Figure 25. Size frequency distribution for subtidal clams and urchins from Glacier Bay (GLBA) and Pt. Althorp (Althorp). **A**. *Macoma* sp. (GLBA n=4394, Althorp n=112); **B**. *Mya* sp. (n=1466, 197); **C**. *P. tenuisculpta*. (Althorp n=171); **D**. *P. staminea* (n=4553, 289); **E**. *S. gigantea* (n=2613, 90); **F**. *S. droebachiensis* (GLBA n=6657).

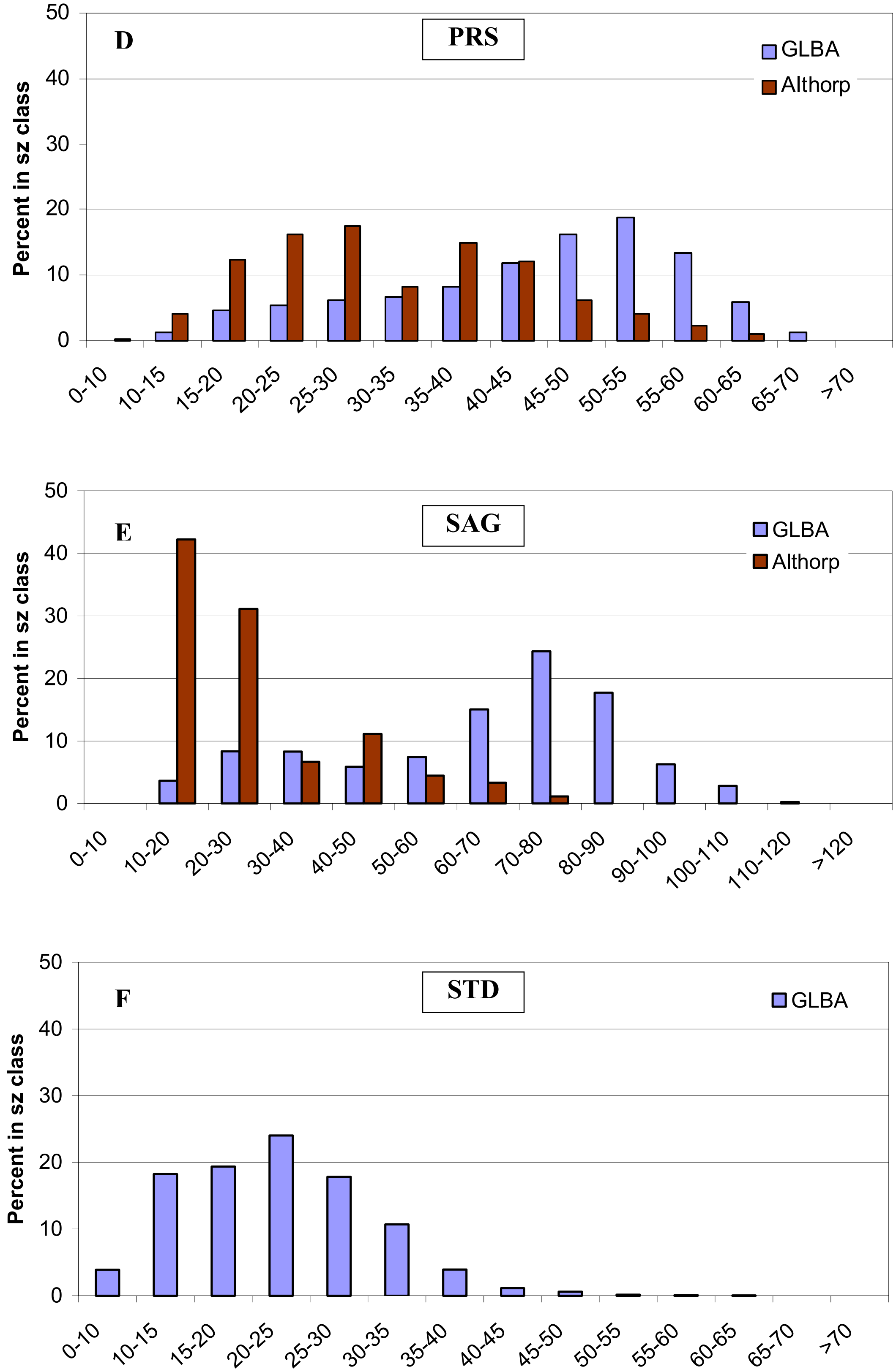


Figure 25. Size frequency distribution for subtidal clams and urchins from Glacier Bay (GLBA) and Pt. Althorp (Althorp). **A**. *Macoma* sp. (GLBA n=4394, Althorp n=112); **B**. *Mya* sp. (n=1466, 197); **C**. *P. tenuisculpta*. (Althorp n=171); **D**. *P. staminea* (n=4553, 289); **E**. *S. gigantea* (n=2613, 90); **F**. *S. droebachiensis* (GLBA n=6657, 5).

Size frequency distributions of numerically dominant taxa varied significantly among sites within areas (chi-square values = 1215, 1271, and 245 for *S. gigantea, P. staminea,* and *Macoma* sp, respectively). Size frequency distributions for *S. gigantea* had several patterns: unimodal with the peak in the smaller size classes, unimodal with the peak in the larger size classes, and bimodal with a higher peak in the larger size classes. Clams at the Port Althorp sites and Leland in Glacier Bay have the first type of distribution. Clams at Johnson, Drake, N. Fingers, and Sturgess in Glacier Bay have the second type of distribution. Berg, Secret, Strawberry, Geikie, and Puffin in Glacier Bay have the third pattern of distribution. Size frequency distributions from Oyster Farm, Johnson, and Puffin are graphed in Figure 26 to illustrate these patterns. Size frequency distributions for *P. staminea* showed the same patterns as for *S. gigantea*. The Port Althorp sites and N. Fingers in Glacier Bay have the first type of distribution. Leland, Berg, Blue Mouse, Drake, and Geikie in Glacier Bay have the second type of distribution. Johnson, Puffin, and Sturgess in Glacier Bay have the third pattern of distribution. Size frequency distributions from Library, Geikie, and Puffin are graphed in Figure 27 to illustrate these patterns. Size frequency distributions for *Macoma* sp. were unimodal with sharp peaks or broadly spread across all size classes. *Macoma* size distributions from Saltchuck and all of the Glacier Bay sites were unimodal, while the distribution from Oyster Farm was broad. Within Glacier Bay, the upper Bay sites (Sealer, Wachusett, Blue Mouse) had size distributions skewed slightly more towards larger size classes than did the mid bay sites, which in turn were skewed slightly larger than the lower bay sites. Oyster Farm had the largest *Macomas*, while other Port Althorp sites were similar to those in Glacier Bay. Figure 28 illustrates the *Macoma* sp. size frequency distributions from Saltchuck, Oyster Farm, Leland, Puffin, and Sealer. Size frequency distributions for *Mya* sp. in Glacier Bay and Port Althorp were unimodal. Upper Bay sites had distributions skewed towards larger size classes than mid- and lower Bay and Port Althorp sites. Figure 29 illustrates the *Mya* sp. size frequency distributions from Johnson, Strawberry (Althorp), and Sealer.

Size frequency distributions for *S. droebachiensis*, green urchins, were significantly different among sites within Glacier Bay (chi-square=2304, $p<0.001$). Size frequency distributions were generally unimodal with sharp peaks. Blue Mouse and Puffin had the largest urchins; Drake and Geikie had the smallest, with the other sites in between. There were no apparent patterns with respect to site location within the Bay. Figure 30 illustrates the range of urchin size frequency distributions by showing graphs from Drake, Johnson, and Puffin.

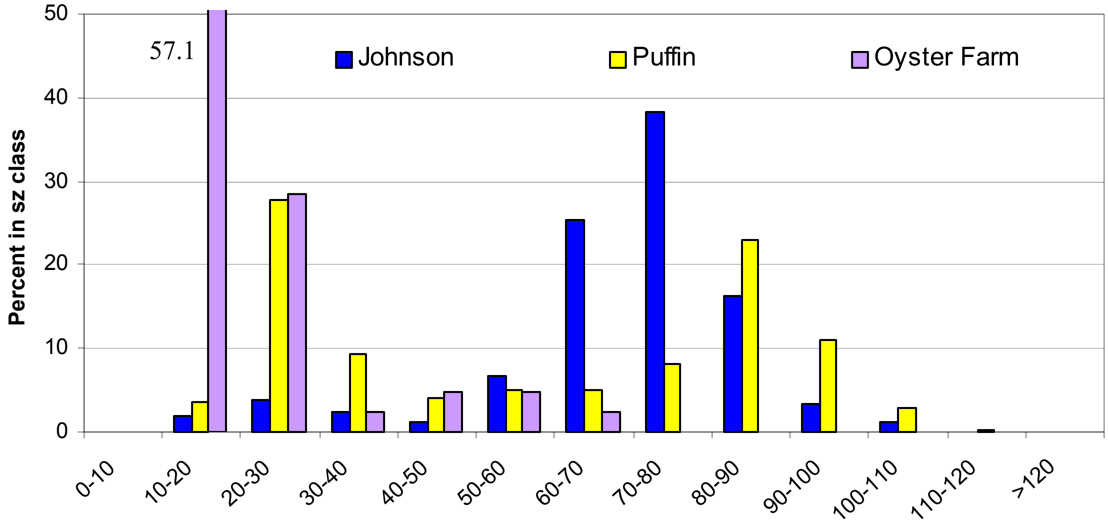


Figure 26. Size frequency distribution of *S. gigantea* (SAG) from representative sites from Glacier Bay and Port Althorp. Mean size (SE, N) for SAG from Johnson, Puffin, and Oyster Farm: 70.0 mm (0.73, 483), 58.8 (1.6, 343), and 23.1 (1.9, 42).

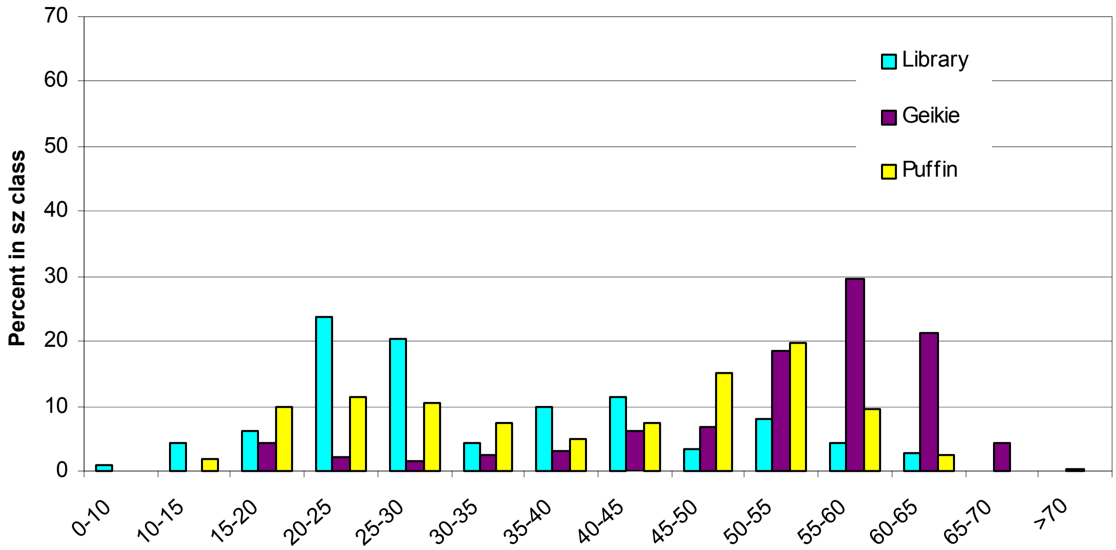


Figure 27. Size frequency distribution of *P.staminea* (PRS) from representative sites from Glacier Bay and Port Althorp. Mean size (SE, N) for PRS from Library, Geikie, and Puffin: 33.4mm (1.2, 113), 52.8 (0.6, 404), and 39.9 (0.5, 811).

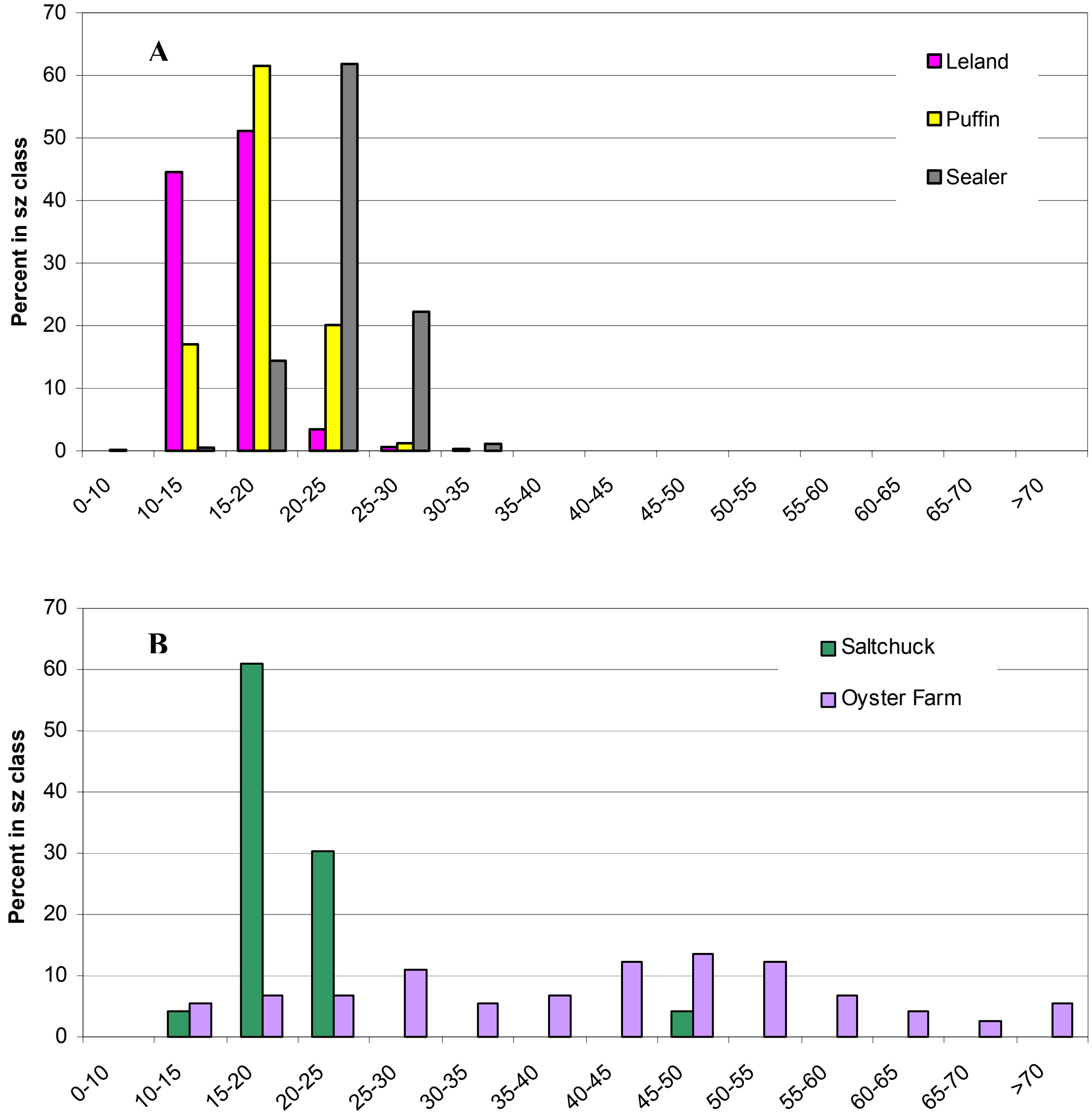


Figure 28. Size frequency distribution of *Macoma* sp. (MAS) from representative sites from **A**. Glacier Bay and **B**. Port Althorp. Mean size (SE, N) for MAS from Leland, Puffin, and Sealer: 16.2 mm (0.2, 321), 18.2 (0.1, 746), and 23.5 (0.1, 626). Mean size (SE, N) for MAS from Saltchuck and Oyster Farm: 20.4mm (1.4, 23) and 41.8 (1.9, 73).

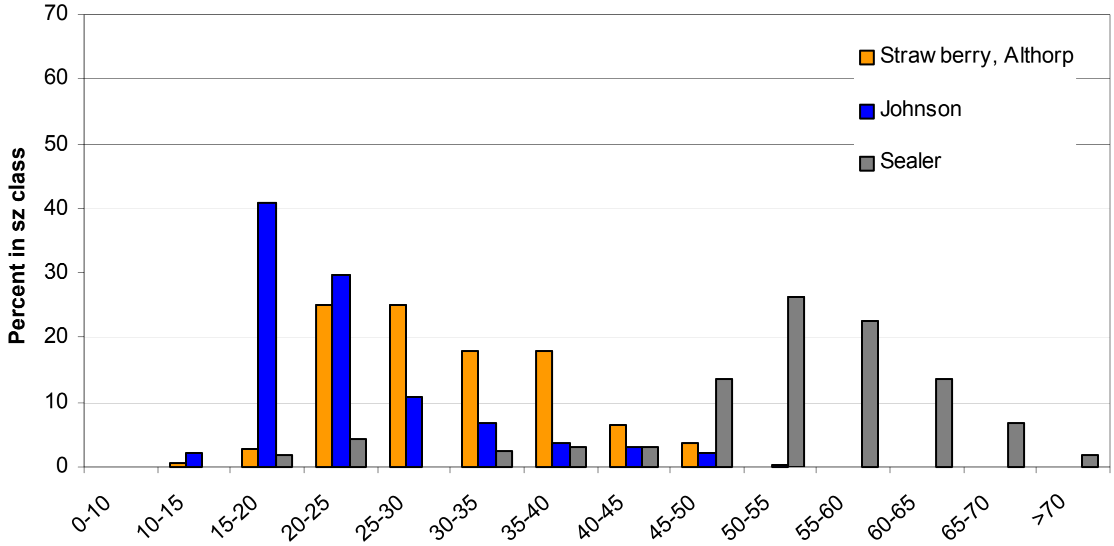


Figure 29. Size frequency distribution of *Mya* sp. (MYS) from representative sites from Glacier Bay and Port Althorp. Mean size (SE, N) for MYS from Strawberry (Althorp), Johnson, and Sealer: 30.8 mm (0.6, 139), 23.8 (0.3, 914), and 53.0 (0.9, 160).

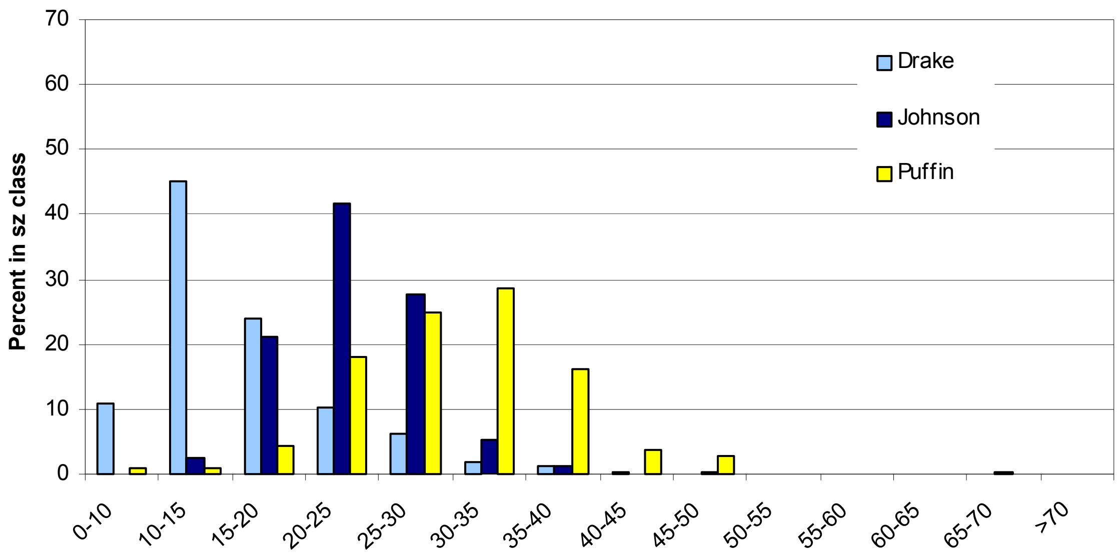


Figure 30. Size frequency distribution of *S. droebachiensis* (STD) from representative sites from Glacier Bay. Mean size (SE, N) for STD from Drake, Johnson, and Puffin: 16.4 mm (0.2, 804), 23.9 (0.2, 440), and 30.4 (0.4, 330).

Discussion

In spite of low densities of bivalves, the species diversity in Port Althorp was greater than in Glacier Bay (mean H' = 2.21). Species diversity from intertidal sites in Port Althorp was 1.4. Most of the bivalve species we identified in the subtidal were previously identified during intertidal sampling, including: *P. staminea, S. gigantea, Macoma sp., Mya sp*., and *C. nutalli*. Subtidal species not found in the intertidal included: *M. polynyma, S. groendalicus*, *Tellina sp*., *Chlamys sp., Yoldia sp*., and the mussel, *M. modiolus*. Clam species identified in the intertidal, but not the subtidal include: *Pseudopythina compressa*. Several species were only found in Glacier Bay while others were only found in Port Althorp (Table 5).

Species diversity of subtidal bivalves in Glacier Bay (mean H' = 1.73) was similar to that measured previously among intertidal bivalve assemblages in lower Glacier Bay (2000 mean H' = 1.47) (Bodkin et al. 2001). The upper east and west arms had lower intertidal than subtidal species diversities (Table 9).

In Glacier Bay, subtidal bivalve densities over the thirteen sites sampled in 2001-02 averaged 59.2 / 0.25 m^2. This is less than intertidal clam densities in preferred habitats, while greater than clam densities at randomly selected lower bay sites in Glacier Bay in 1999-00 (Bodkin et al 2001) (Table 9). The upper east arm subtidal sites had the highest mean density (72.7/0.25m^2), followed by the lower Bay sites (55.9/0.25m^2), and upper west arm sites (43.6/0.25m^2). In contrast, subtidal bivalve densities from the five Port Althorp sites sampled in 2002 averaged 10.3 / 0.25 m^2. These densities are similar to randomly selected intertidal sites in Port Althorp and upper east and west arms in Glacier Bay in 1999-00 (11.3 and 12.2, and 6.7/0.25m^2 respectively, Bodkin et al 2001).

Both the number of clams present and their respective sizes dictate biomass per unit area. This is why although species of *Macoma* may dominate clam assemblages numerically, because they are relatively small (Figure 25), they contribute relatively little to total biomass (Table 8). In addition, certain species have a greater biomass per given size than others. For example, to compute biomass for *S. gigantea*, the following formula is used: dry weight = $0.0001*(\text{size}^{2.555})$ versus *Macoma* sp., dry weight = $0.000006*(\text{size}^{3.147})$, thus for individuals of the same size, *S. gigantea* will contribute more in terms of biomass than *Macoma* sp.

In Glacier Bay, with the addition of upper Bay sites in 2002, the mean subtidal bivalve biomass estimate declined to 99.1 g/ 0.25 m^2 from a mean of 121.0 at the original nine sites. The lower Bay subtidal sites had the highest mean biomass, followed by the upper east arm sites, and upper west arm (Table 9). This is the same pattern as for intertidal biomass (lower Bay > upper east > upper west; Bodkin et. al 2001), although the subtidal biomass estimates are greater (5-49 times greater) than the intertidal. When looking at the intertidal preferred habitat sites, however, the biomass estimates are similar (73.4 and 99.1 g/0.25m^2 for preferred intertidal and all subtidal sites. The greater average biomass per quadrat in the subtidal results from higher densities and differences in species composition between the subtidal and intertidal. In the Glacier Bay subtidal, species composition is dominated by *P. staminea*, *Macoma* sp. and *S. gigantea*, which average 44.6, 20.1, and 65.0 mm respectively and comprised 30.3%, 29.8%, and 17.9% of the total number of subtidal clams. In the Glacier Bay intertidal the dominant clam was *Macoma* sp. (57% of total clam numbers). *P. staminea*, and *S. gigantea* were only 17 and 3% of the Glacier Bay intertidal bivalves. In Port Althorp, the mean subtidal bivalve biomass estimate was 5.8 g/ 0.25 m^2, an order of magnitude less than Glacier Bay. In the Port Althorp subtidal, densities are lower than in Glacier Bay and species composition is dominated by *P. staminea*, *Mya* sp. and *P. tenuisculpta*, which average 32.4, 31.9 and 11.4 mm respectively and comprised 29.1%, 21.7%, and 16.8% of the total number of subtidal clams.

Subtidal clam densities we measured in Glacier Bay were similar to those reported from other "otter free" soft sediment habitats in Alaska (mean number of clams = 48 / 0.25 m^2 range 31-63) (Kvitek et al. 1992). The densities we measured were about 10 times greater than the densities estimated at sites occupied by sea otters for more than 25 years (mean number of clams = 6.5 range 4-9) (Kvitek et al. 1992). Our observations of sea otters foraging predominately on bivalves provides evidence that sea otters will have a profound influence on the benthic invertebrate infaunal communities in Glacier Bay as they continue to colonize habitats. Anticipated direct effects of sea otter foraging will likely include reductions in the density and mean size of several preferred clam species, including *P. staminea, S. gigantea, M. polynyma*, and *S. groenlandicus,* and an increase in disturbance to benthic sediments where sea otters forage on infauna.

Table 9. Summary of intertidal and subtidal bivalve species diversity, density, and biomass from Glacier Bay, Port Althorp, and Idaho Inlet, 1999-2002. Intertidal clam data are from the 2000 and 2001 Annual Reports (Bodkin et. al. 2001, 2002).

	Intertidal			Subtidal		
Location	**Species Diversity**	**Mean Density**	**Mean Biomass**	**Species Diversity**	**Mean Density**	**Mean Biomass**
GB PCH	1.6	96.7	73.4	1.7	59.2	99.1
GB- Ran[1]		19.5	11.3			
GB LB	1.5	32.8	23.6	1.7	55.9	114.2
GB UW	0.5	6.7	0.9	1.6	43.6	45.1
GB UE	0.6	12.2	2.2	1.8	72.7	99.7
Althorp	1.4	11.3	5.2	2.2	10.3	5.8
Idaho	1.4	27.1	9.7	.	.	.

[1] Location notes: GB PCH refers to the preferred clam habitat sites from Bodkin et al. 2001. These sites were not chosen randomly and therefore inference to a larger area may not be made from these data. GB Ran refers to intertidal sites that were chosen randomly; LB, UW, and UE refer to subsets of the random sites (Lower Bay, Upper West Arm, Upper East Arm). The subtidal data were placed in the GB PCH row because they were collected from sites not chosen randomly. For comparison, summaries by region of Glacier Bay were also made.

Conclusions

Sea otter populations in the vicinity of Glacier Bay continue to increase following the successful translocation of sea otters to southeast Alaska nearly 35 years ago. The rate of growth observed in Glacier Bay between 1995 and 2002 exceeds both theoretical and empirical growth rates for sea otter populations (Bodkin et al. 1999; Riedman and Estes 1990). The explanation for this exaggerated growth is likely the combined contributions of pup production from within the Bay and immigration of juveniles and adults from outside the Bay. The rapid rate of growth of the Glacier Bay sea otter population requires an intensified effort to acquire pre-sea otter colonization data if we are to understand the range of effects sea otters will eventually have on the Glacier Bay marine ecosystem.

Sea otters are known to consume in excess of 100 species of prey (Riedman and Estes 1990), predominantly invertebrates, but also fishes and birds. 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). Prior to 2002 we observed more than 4,000 successful foraging dives (4,975 total dives) in Glacier Bay. Clams represented 40 to 60% of the diet, depending on area (up to 95% at a specific site). Our work in 2002 is generally consistent with earlier Glacier Bay work in terms of foraging success, dietary composition, number of prey per dive, and prey sizes (Bodkin et al 2001, 2002). As clams remain the largest component of the sea otters' diet in Glacier Bay, it is likely that the density and average size of clams will eventually decline as a result of sea otter predation. The effects of these changes on other predators that consume clams (e.g. sea ducks, sea stars and octopus), or in the recruitment of invertebrates that may be limited by filter feeders such as clams, are unknown. In Glacier Bay, mussels, (*Mytilus trossulus* and *Modiolus modiolus)* are also important prey for sea otters, as well as 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 prey item in Glacier Bay. If the patterns of reduced urchin populations and increased algal production observed elsewhere are observed in Glacier Bay, we will see large increases in the extent of under-story and canopy-forming kelps in Glacier Bay are likely. 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. *Chionocetes* and *Paralithodes*). However, if vertical movement is exhibited that brings prey within otters' foraging depth (maximum approximately 100m, J.Bodkin unpub. data) adverse effects of sea otter predation may still occur.

Glacier Bay currently supports a diverse and abundant assemblage of subtidal clams. Little evidence currently exists to identify effects of sea otter foraging on subtidal clams. This probably results from too few otters foraging over too large an area over too short a time period. However, given the rapid rate of increase in sea otter density in recent years, changes in the nearshore ecosystem of Glacier Bay can be expected in the near future. The ability of marine resource managers to detect change and implement appropriate management actions in Glacier Bay will be severely constrained unless the effects of sea otter colonization and foraging are well documented and understood. This will result because the effects of sea otters on the composition and function of nearshore marine communities will likely be strong. And the ability to detect other changes that are occurring in the Glacier Bay marine ecosystem will be difficult to detect 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 <u>level</u> 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.

5. 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.

<u>Example</u>: 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.

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

<u>Example</u>: 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.

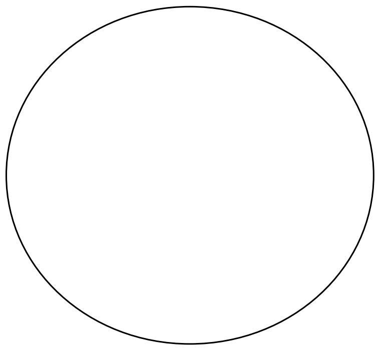
Data sheet for aerial survey strip transects

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

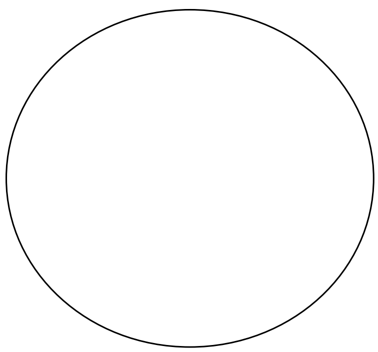
Transect Number	Side (N,S,E, or W)	Strip Count (Adults/Pups)	Chop (1-4)	Glare (1-4)	ISU Number(s)

Intensive Search Unit (ISU) data collection form

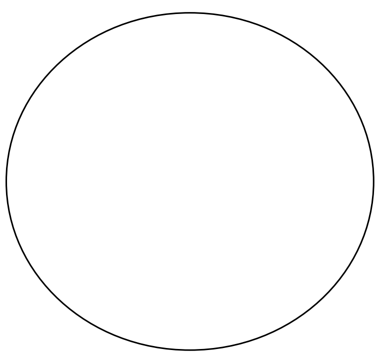
Date:	Observer:



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 OBSERVATIONS.

Sea Otter foraging success and diet – standard operating procedure

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.

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

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+

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 obser*

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

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APPENDIX C. PROTOCOL FOR ESTIMATING SUBTIDAL CLAM SPECIES, DENSITY, AND SIZES.

Protocol adapted from Prince William Sound, Exxon Valdez oil spill restoration project 96025-00025 Nearshore Vertebrate Predators Procedure 00x, Rev. 1.0
Prepared by Allan Fukuyama

TITLE: Subtidal Clam Sampling Procedure

DATE: 12 February 1996

REV.:

1.0 Purpose

1.0 This procedure consists of 2 sampling components: suction dredging to obtain deep-dwelling large bivalves and corer sampling to obtain smaller sizes of bivalves. The objective of this sampling procedure is to obtain subtidal macroinvertebrate samples to determine the abundance of bivalves and other macroinvertebrates from fixed 0.5-m by 0.5-m quadrats and from corers encompassing an area of about 0.009 m^2.

2.0 Definitions

1.A 0.5-m by 0.5-m quadrat samples an area of 0.25 m^2
2. A suction dredge is a sampling device that is gasoline powered and operated on the surface. A hose reaches the bottom connecting to a Venturi nozzle. Water is pumped through the hose from the surface, creating suction that draws sediment into mesh bags for sampling deep-burrowing organisms
3 Corers are cylindrical sampling devices about 15 cm in diameter that sample an area of 0.009 m^2
4. Sampling area is the general area to be sampled, e.g. Herring Bay, Bay of Isles, or northwestern Montague Island.
5. Site is a sampling area (5-7 sites) within each area
6. Depth of sampling is a sampling depth within a site (either 6 or 12 m)

3.0 Sampling Plan

List of field equipment:

Differential GPS positioning equipment and marine charts
Underwater data sheets and clipboards
Suction dredge
0.5-m by 0.5 m quadrats
Mesh bags labeled with sample numbers
cm ruler
Infaunal corers

List of laboratory equipment:

- Formalin and isopropanol preservatives
- Sampling jars
- Waterproof labels
- Forceps
- Vernier calipers
- Data sheets
- Mettler balance
- Binocular dissecting microscope
- Taxonomic references

Data forms

All samples collected in the field are marked with unique identification number. identification number, date of sampling, location (area, site, depth), time, sample type, and collectors are recorded on a data sheet.

4.0 Sampling Procedure

Core samples:

Core samples will be taken once per year in June-July.

Sample collection

Samples will be collected in the vicinity of suction dredge sampling. A temporary buoy will be dropped from a boat at each sampling site and will be used as a reference point underwater at the depth of interest. Random distances from the reference point will be pre-numbered on underwater data sheets for sampling and at least 5 replicate cores will be taken at each depth at each site. A total of 5-6 sites will be sampled at two different depths at each area of interest. Areas to be sampled will be at Herring Bay, Bay of Isles, and the Mooselips Bay/Port Chalmers/Stockdale Harbor region of Montague Island. The 0.25 m^2 quadrat will be placed down at each point of sampling and notes about the surface will be taken prior to sampling (number and type of clam siphons, substratum type, vegetation, etc.). Cores will be taken at one corner of the quadrat by pushing the corer as far as it will go into the sediment. The core will be gently removed from the sediment and placed into a mesh bag with openings less than 0.5-mm in size. The investigator will move to the next quadrat and sample again. When all replicate cores are taken, the diver will either take all samples back up to the surface and hand them to the boat driver or will attach an inflatable bag to the samples and send the samples to the surface where the boat driver will retrieve them.

Handling and preservation

Samples will be examined back on the main vessel. Each sample will have an unique identification number along with other information (date, location, time, samplers) on waterproof labels placed into the bag before sieving through a 0.5-mm sieve. All residues left on the 0.5-mm sieve will be placed into sample jars with the label information and preserved with 10% buffered formalin solution. The outside of each jar will be marked with the sampling number with a waterproof pen. Samples will remain in the formalin solution for at least 3-5 days before transfer to 70% isopropanol. Samples will be sorted and identified later in the laboratory.

Suction Dredge Sampling

Suction dredge samples will be collected on the same schedule as core samples.

Sample collection

Samples will be collected in the vicinity of core sampling. A temporary buoy will be dropped from a boat at each sampling site and will be used as a reference point underwater at the depth of interest. Random distances from the reference point will be pre-numbered on underwater data sheets for sampling and at least 5 replicate samples will be taken at each depth at each site. A total of 5-6 sites will be sampled at one depth (15-25 ft) at each area of interest. Areas to be sampled will be at Herring Bay, Bay of Isles, and Mooselips Bay/Port Chalmers/Stockdale Harbor region of Montague Island. The 0.25 m^2 quadrat will be placed down at each point of sampling and notes about the surface will be taken prior to sampling (number and type of clam siphons, substratum type, vegetation, etc.). The suction dredge will be turned on and will remove sediment from within the quadrat. Sediment will be sucked into a mesh bag with an opening of about 3-5 mm to retain all larger organisms. Quadrats will be removed down to about 15 cm and a ruler will be used to examine depth of sampling. Any floating clams removed by the suction dredge, but not sucked into the mesh bag will be placed inside the mesh bag. The investigator will move to the next quadrat and sample again. When all replicate samples are taken, the diver will either take all samples back up to the surface and hand them to the boat driver or will attach an inflatable bag to the samples and send the samples to the surface where the boat driver will retrieve them.

Handling and preservation

Samples will be examined back on the main vessel. Each sample will have an unique identification number along with other information (date, location, time, samplers) on waterproof paper placed into the bag before sieving through a 3.0-mm sieve. All residues left on the 3.0-mm sieve will be placed into sample jars with the sampling information and preserved with 10% buffered formalin solution. Residues of gravel, cobble, shell fragments, algae, wood debris, etc. will be discarded after careful examination. The outside of each jar will be marked with the sampling number with a waterproof pen. Samples will remain in the formalin solution for at least 3-5 days before transfer to 70% isopropanol. Samples will be sorted and identified later in the laboratory.

Data Processing

Field notes are recorded in field log books as soon as possible after completion of sampling. Data screening, data entry, and error analyses will be checked and cross-checked against field notes as soon as possible. The person responsible for the task personally transported all original data to the home office.. Photocopies of all data are made and given to the Principal Investigator and Data Manager. The original data will be stored in a separate file.

5.0 Quality Assurance

The cruise leader or his designee, will conduct all training sessions, and will approve or disapprove a person for use of this SOP. It is imperative that all data sheets are completed in full the day the work is done and that the cruise leader, or his designee, review all sheets daily. The cruise leader will complete a log of all activities daily.

APPENDIX D. RE-ANALYSIS OF SEA OTTER FORAGE DATA BASED ON UPDATED PREY SIZE CLASSES.

Collection of sea otter dietary information is done by observing foraging animals through a high powered spotting scope. While the number of prey items can be counted, and prey identity can be made visually; the size of prey items must be estimated. The least subjective way to do this is to compare the prey item to the size of the otter's paw (e.g. smaller than the paw, same size as the paw, larger than the paw). Then, using morphometric data collected during studies requiring sea otter capture, size categories can be assigned to prey items (e.g. mean paw size = 52mm; therefore prey smaller than ½ paw size are = 13 mm, prey = ½ paw size =26 mm, and prey items larger than ½ paw size, but < paw size are 39mm). With the collection of several hundred new sea otter paw size measurements during recent capture-related studies, we recognized the need to re-analyze our mean paw size value. We still categorize prey items in relation to paw size, however the numerical value of the size classes has been updated. This is reflected in Appendix B (Protocol for determining sea otter diet based on visual observations) in the 'Foraging data variables and codes'. The 2000 and 2001 Annual Reports contain the old size class (mm) and mid size values. This Annual Report (for field year 2002) contains the updated values.

In order that data analyzed using the updated values can be compared to older data, we have re-analyzed the foraging data from 1993-2000 (old analysis contained in the 2000 Annual Report, new analysis Figure D1) and 2001 (old analysis contained in the 2001 Annual Report, new analysis Figure D2). Of the variables calculated (prey composition, mean number of items captured per dive, mean size of prey captured per dive, and success rate), only mean size of prey captured changed under the new analysis. So these are the only data presented here. The relative sizes of prey from different sites remained the same, only the numerical values assigned changed.

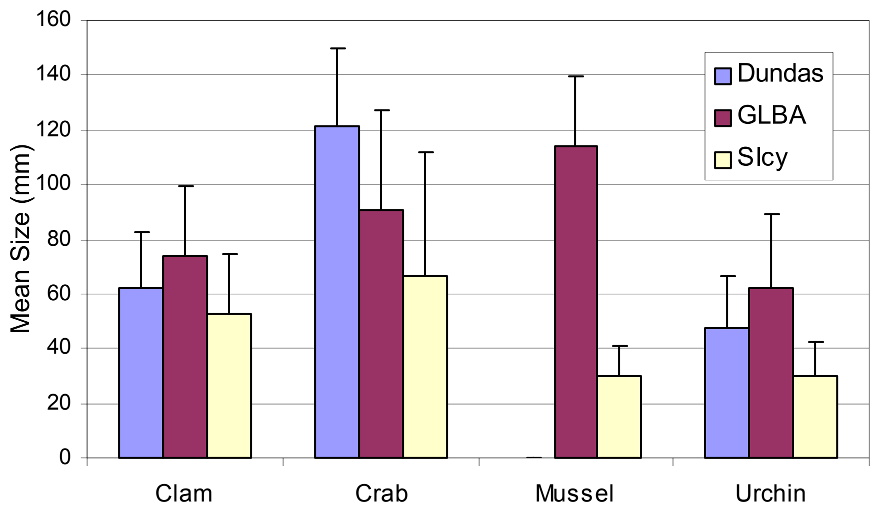

Figure D1. Mean size of clams, crabs, mussels, and urchins retrieved by sea otters foraging in Dundas Bay, Glacier Bay proper (GLBA), and south Icy Strait (SIcy) from 1993-2000. This figure replaces Figure 7 in the 2000 Annual Report (Bodkin et. al. 2001).

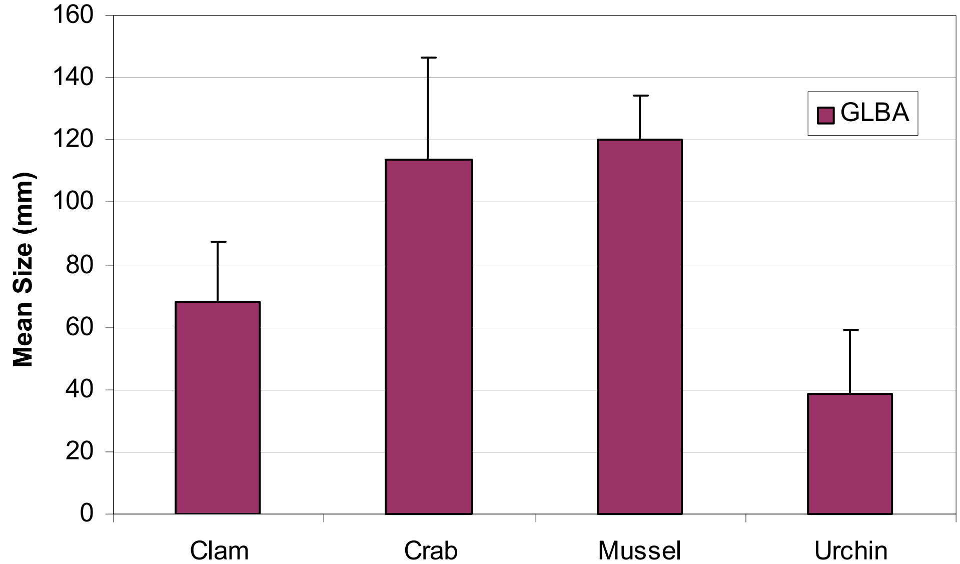

Figure D2. Mean size of clams, crabs, mussels, and urchins retrieved by sea otters foraging in Glacier Bay proper (GLBA) in 2001. This figure replaces Figure 6 in the 2001 Annual Report (Bodkin et. al. 2002).

APPENDIX E. SUBTIDAL CLAM STUDY SITE LOCATIONS IN GLACIER BAY.

Site Name	Date Sampled	Longitude	Latitude	Datum
Secret	23-Apr-2001	135.959	58.499	NAD83
Berg	10-May-2001	136.147	58.528	NAD83
Johnson	18-May-2001	136.115	58.607	NAD83
Strawberry	28-Jun-2001	136.013	58.505	NAD83
Sturgess	13-Jul-2001	136.036	58.716	NAD83
Drake	15-Jul-2001	136.208	58.632	NAD83
N Fingers	19-Jul-2001	136.194	58.595	NAD83
Puffin	11-Aug-2001	136.015	58.730	NAD83
Leland	14-Aug-2001	135.981	58.642	NAD83
Geike	16-Aug-2002	136.378	58.647	NAD83
Blue Mouse	17-Aug-2002	136.504	58.776	NAD83
Sealers	19-Aug-2002	136.119	58.959	NAD83
Wachusett	20-Aug-2002	136.168	58.934	NAD83