Sea Otter Studies in Glacier Bay National Park and Preserve

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Summary

Following translocations to the outer coast of Southeast Alaska in 1965, sea otters have been expanding their range and increasing in abundance. We began conducting surveys for sea otters in Cross Sound, Icy Strait, and Glacier Bay, Alaska in 1994, following initial reports (in 1993) of their presence in Glacier Bay. Since 1995, the number of sea otters in Glacier Bay proper has increased from around 5 to more than 1500. Between 1993 and 1997 sea otters were apparently only occasional visitors to Glacier Bay, but in 1998 long-term residence was established as indicated by the presence of adult females and their dependent pups. Sea otter distribution is 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 (Figure 1).

We describe the diet of sea otters during 2001 in Glacier Bay based on visual observations of prey during 456 successful foraging dives. In Glacier Bay, diet consisted of 62% clam, 15% mussel, 9% crab, 7% unidentified, 4% urchins, and 4% other. Most prey recovered by sea otters are commercially, socially, or ecologically important species. Species of clam include *Saxidomus gigantea*, *Protothaca staminea*, and *Mya truncata*. Urchins are primarily *Strongylocentrotus droebachiensis* and the mussel is *Modiolus modiolus.* Crabs include species of three genera: *Cancer*, *Chionoecetes,* and *Telmessus.* Although we characterize diet at broad geographic scales, we 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 9 sites in lower Glacier Bay. All sites were selected based on the presence of abundant clam siphons. Sites were not selected to allow inference to any area larger than the sampling area (approx 400 m^2). 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. There was no direct evidence of otter foraging at any of our clam sampling sites. We sampled 11,568 bivalves representing 14 species of clam and 2 species of mussel. We sampled 4,981 urchins, all *Strongylocentrotus droebachiensis.* Only four species of clam (littleneck clams, *Protothaca staminea;* butter clams, *Saxidomus gigantea;* soft-shell clams, *Mya truncata*; and *Macoma* sp.) accounted for 91.6% of all clams sampled. Mean total clam density (#/0.25 m^2) across the 9 sites was 62.3. Densities (and se) of *P. staminea* averaged 22.6 (1.6) and ranged from 0 to 97. Densities of *S. gigantea* averaged 14.4 (1.0) and ranged from 0 to 63. Densities of *Macoma* sp. averaged 14.5 (1.2) and ranged from 0 to 78. Densities of S. *droebachiensis* averaged 27.3 (1.7) and ranged from 0 to 109. Mean S. *droebachiensis* sizes ranged from 16 to 30 mm by site. Mean *P. staminea* sizes ranged from 30 to 53 mm, mean *S. gigantea* sizes ranged from 51 to 85 mm, and mean *Macoma* sp. sizes ranged from 14 to 19 mm. Although not the most abundant clam, *S. gigantea* contributed the greatest proportion to total clam biomass (63%), followed by *P. staminea* (24%).

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 (*Strongylocentrotus droebachiensis*) that are commercially, culturally, or ecologically important. 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*) provide one of the best-documented examples of top-down forcing effects on the structure and functioning of nearshore marine ecosystems in the north Pacific Ocean (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 their habitat in the north Pacific since their near extirpation roughly 100 years ago. The role of sea otters as a source of community variation has resulted from spatial/temporal patterns of sea otter population recovery. During the absence of sea otters, many of their prey populations responded to reduced predation. Typical prey population responses included increasing mean size, density, and biomass. 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. 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 their associated habitat structure, 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 factors can influence urchin abundance (e.g. disease) and kelp forests can exist in the absence of sea otters. However, “urchin barrens” are unknown in the presence of equilibrium sea otter populations and the generality of the otter effect in nearshore communities is widely recognized (Estes and Duggins 1995).

Other species of sea otter prey respond similarly, at least in terms of density, size and biomass, to reduced sea otter predation. In some instances, humans eventually developed commercial extractions on species of marine invertebrates that would likely not have been possible had sea otters not been eliminated. Examples of fisheries that exist, 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 translocations. 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 for at least 30 years, only in the past few years could they be found in Icy Strait and Glacier Bay proper (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 2001 we estimated that nearly 1600 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 for the rigorous, before/after control/treatment design that has proven so powerful elsewhere, and will permit assigning cause to changes observed in Glacier Bay as a result of sea otter colonization.

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

Year	Number of sea otters observed
1994	0
1995	5
1996	39
1997	21
1998	209
1999	384*
2000	554*
2001	1590*

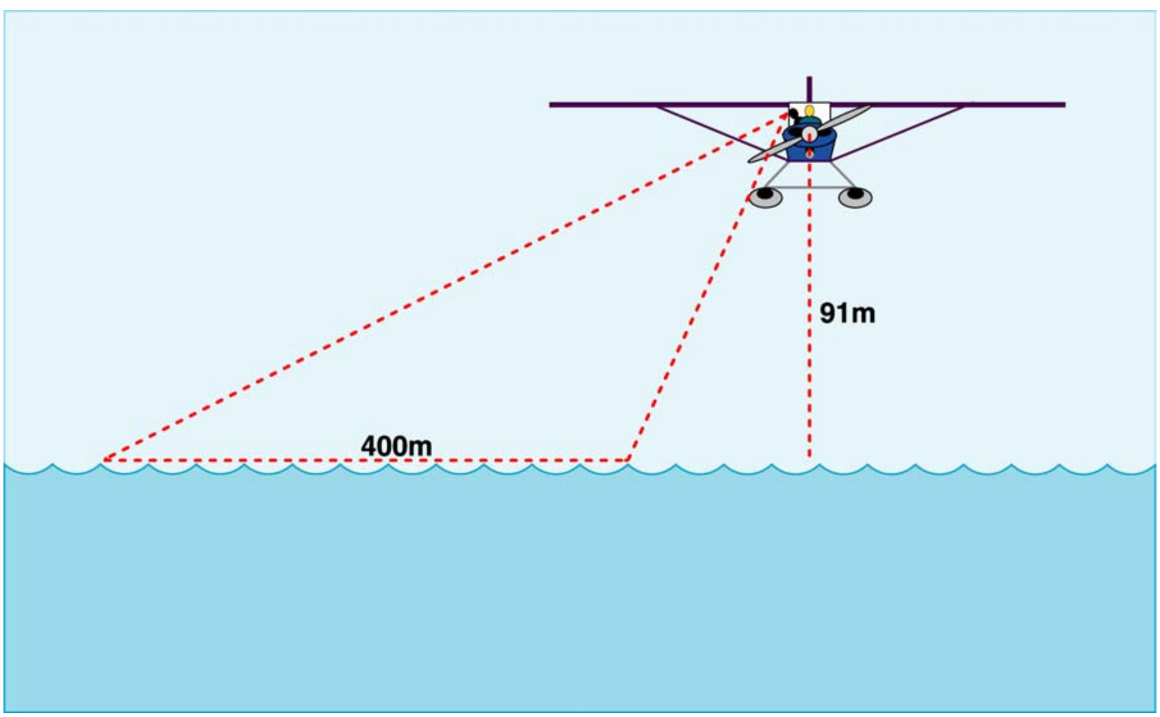
Fig. 1 Study areas in Glacier Bay National Park, Icy Strait and Cross Sound, Southeast Alaska.

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 to observed ecosystem changes. Infaunal bivalves constitute a major proportion of the biomass in benthic marine habitats of Glacier Bay and 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.

At least three elements are necessary to understand the effects of sea otters in Glacier Bay. First, describing the abundance and distribution of sea otters in the Bay, second, describing food habits of sea otters in Glacier Bay, and third, describing the structure and function of the coastal marine communities in the Bay that will be affected by sea otters. The Alaska Biological Science Center (ABSC) in conjunction with the Multi-Agency Dungeness (MADs) study originally undertook the first and second components. Currently, all three elements are being studied by ABSC with cooperation and support from the National Park Service. 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 to date 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) we include in this report results of foraging observations made in calendar year 2001 and also present a summary of forage results presented in the 2000 Annual Report. We include here preliminary results of our subtidal clam sampling in 2001. This report represents the cooperative efforts of the USGS, ABSC and the NPS, Glacier Bay National Park and Preserve.

Sea Otter Surveys



Sea Otter Surveys

We conduct two types of surveys of sea otters in Glacier Bay and surrounding waters. The first type, carried out since 1994, is designed to estimate the distribution and relative abundance of sea otters, 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 otter 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, the trade-off is that they require a much greater time investment and are therefore more costly to conduct than distribution surveys. Abundance surveys in Glacier Bay were completed in 1999, 2000, and 2001.

Methods

Distribution Surveys

All shoreline habitats out to at least the 40 m bathymetric contour are surveyed. Flight tracks are flown parallel to shore when water < 20 m extends > 1 km from the shoreline (e.g. Dundas and Berg bays). Surveys are flown at the slowest speed safe for the particular aircraft in use, and at the lowest safe altitude (e.g. 65 mph and 91 m in the Bellanca Scout and 90 mph and 152 m in the Cessna 185). In May 1999, 2000 and June 2001, distribution surveys were flown at 65 mph and 91 m in a Bellanca Scout.

Abundance Surveys

Aerial survey methods follow those described in detail by Bodkin and Udevitz (1999) and consist 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, a high and a low density, distinguished by distance from shore and bathymetry (Figure 2). Survey effort is allocated proportional to expected sea otter 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 group activity (diving or not diving). A group is defined as one or more otters separated by less than 4 m). Sea otter 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.

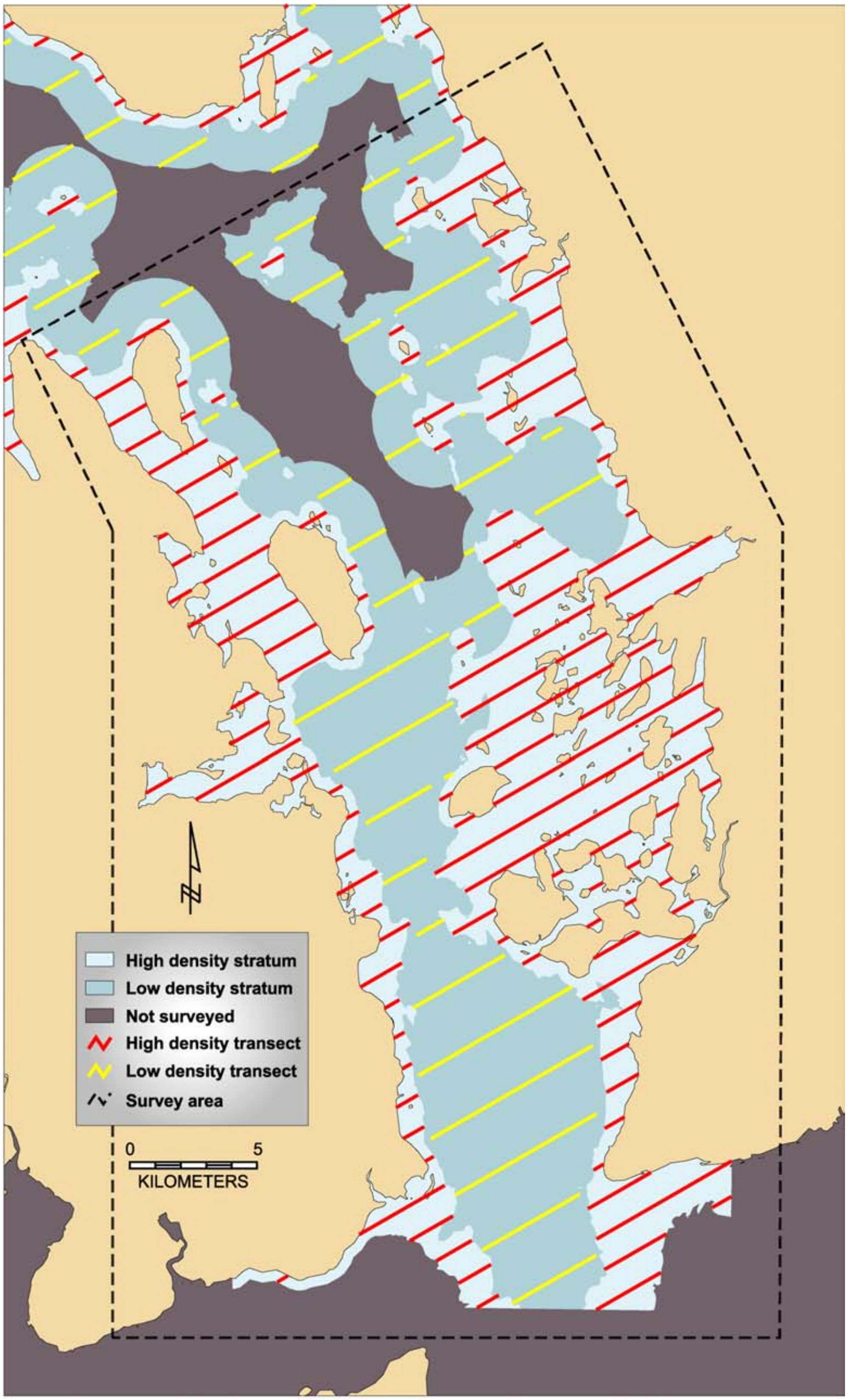


Fig. 2. One of four transect designs used during a sea otter abundance aerial survey in Glacier Bay National Park, June 2001.

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

The survey design consisted of 18 strip transect scenarios constructed in a GIS coverage (ARC/INFO) comprised of 3 possible sets of high density transects and 6 sets of low density transects. 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 2001 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 5 and 30 June 2001, a single observer surveyed four replicates from a Bellanca Scout. A single observer flew the 1999 and 2000 abundance surveys, while a new observer flew the survey in 2001. The same pilot flew all three Glacier Bay abundance surveys. See Appendix A for a detailed description of the survey methods used.

Results

Distribution Surveys

On 3 June 2001 we surveyed the shorelines of Cross Sound and Icy Strait, and from 5 - 30 June surveyed the shorelines of Glacier Bay (see abundance surveys) to estimate current sea otter distribution (Table 2). No major changes in distribution from prior surveys are evident. Pups were present for the first time in Dundas Bay, suggesting an increase in females from this previously male dominated area. In addition, we found for the first time sea otters present (6 adults/1 pup) in the west arm of upper Dundas Bay.

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 1590 (SE = 260). All group locations were digitized into ARC/INFO coverages (Figure 3).

The estimate of 1590 sea otters in 2001 represents an increase of 187% above the 2000 estimate. This rate of increase exceeds maximum growth rates observed in other recolonizing sea otter populations (Bodkin et al. 1999) and likely results from both production of sea otters within Glacier Bay and immigration of sea otters from outside the Bay.

Table 2. Results of Cross Sound/Icy Strait sea otter distribution surveys and abundance surveys in Glacier Bay proper in 1999, 2000 and 2001 (abundance estimates **bolded**). Counts are presented as # adults/# pups, while a period means 'no data'. Estimates adjusted by abundance survey methods include pups (Bodkin and Udevitz 1999).

Date	May 1994	May 1995	Mar 1996	Aug 1996	May 1997	Mar 1998	May 1999	May 2000	June 2001
Aircraft	Scout	Scout	172	172	Scout	185	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	1590
Excursion Inlet	.	.	.	.	.	7	1	0	0
Pt Couverdon	.	.	.	.	.	2	.	0	0
Pt Gustavus-Porpoise Is	29/0	94/1	73	2/1	161	8	18	57	129/1
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
Gull Pt-Pt Lavinia	77	81	48	141	94	3	90	139	95
Inian Is	31/9	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	2180/125

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 data suggest a major segment of the Icy Strait/Cross Sound sea otter population is moving into Glacier Bay. This has serious and immediate consequences to managers of marine resources in the Park.

The 2001 estimate indicates a population increase of 1036 sea otters over the 2000 estimate for Glacier Bay and an increase of 1267 adults above the total number observed and estimated throughout the area we survey (Table 2). This increase exceeds the maximum reproductive capacity of sea otters (about 25%) and therefore the majority of this growth must come from immigration. It is also possible that previous counts and estimates were low or the 2001 Glacier Bay point estimate was greater than the true population size. The largest concentrations of sea otters in Glacier Bay continue to inhabit the areas surrounding Boulder 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. One of the more significant observations this year, aside from the increase in overall numbers, is the occurrence of large numbers of dependent pups throughout the lower bay (Figure 3, green circles). Whereas in prior years, when abundance increases were mainly attributed to immigration, reproduction within Glacier Bay is now likely to be making a substantial contribution to sea otter population.

The number of sea otters occupying Glacier Bay is increasing rapidly, from a count of 5 in 1995 to an estimated 1590 in 2001 (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. 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.

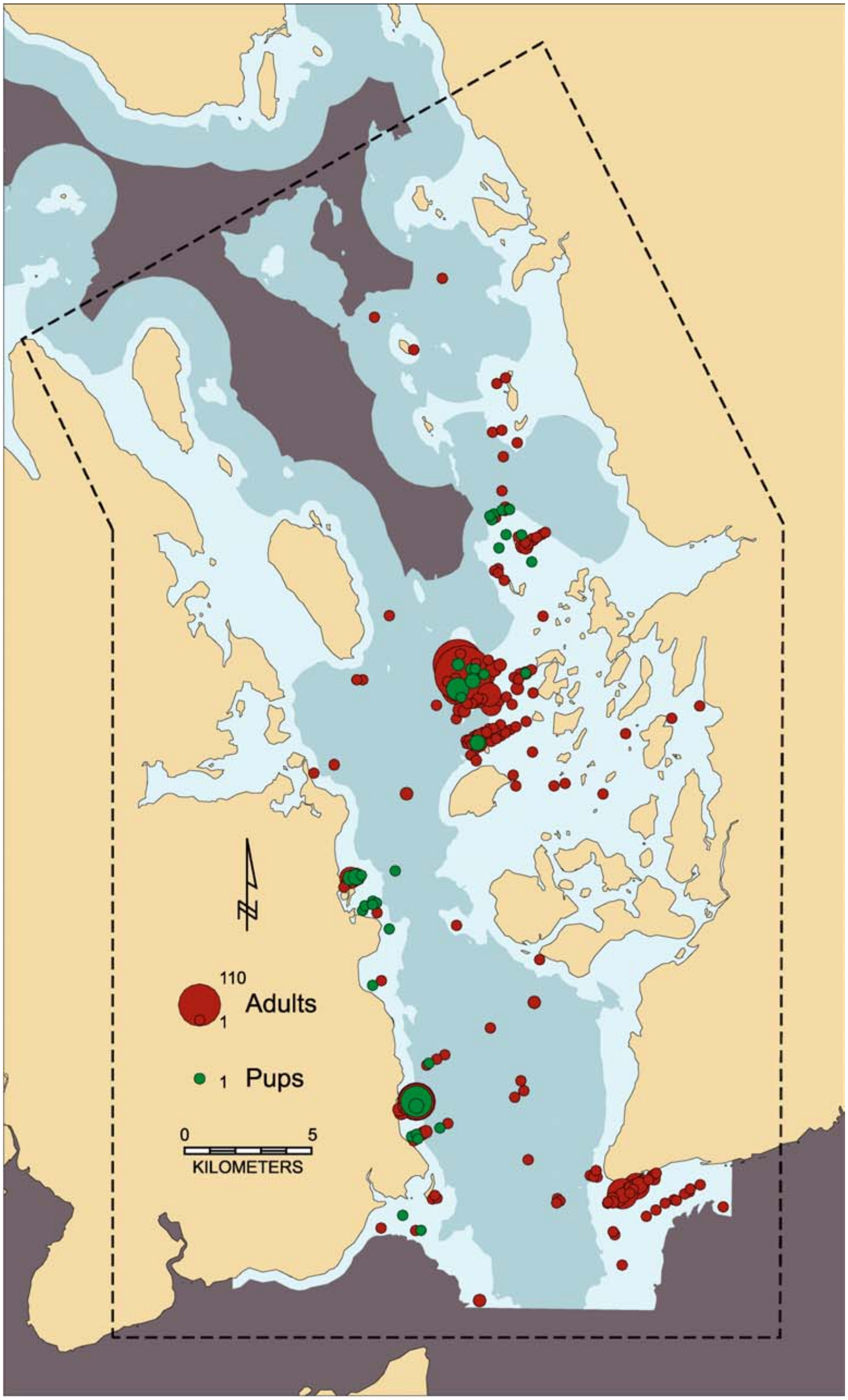


Fig. 3. Sea otter group locations from 4 replicate aerial surveys in Glacier Bay National Park, June 2001 (spot size proportional to group size).

Foraging Observations

Foraging Observations

Observations of sea otter foraging behavior in 2001were carried out in Glacier Bay to determine prey types, numbers, and sizes consumed by sea otters. Foraging data from nearly 5000 dives, collected from 1993 to 2000 are reported in the 2000 Annual Report (Bodkin et al. 2001). Here we summarize the prior work and report the 2001 data independently as they represent a relatively small proportion of the total foraging data set.

Foraging work consisted of shore and ship based observations at sites within Glacier Bay (Figure 1). Observations of foraging sea otters provide information on food habits, foraging success (proportion successful feeding dives), and efficiency (mean kcal/dive) 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. This 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 and ship 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. Otters feeding further than 1 km from shore are observed from a ship under calm sea conditions. 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. 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. In addition, some foraging areas are used more than others by individuals and by otters living in the area in general. 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 was collected from as many identified feeding locations as possible. If more than one foraging animal was available for observation at any particular observation site, then the first animal observed was randomly selected, and after completion of the bout the process repeated with the remaining animals. Observations continued at the site until each available animal was observed for a maximum of 30 dives, or otters had stopped foraging or left the area. Data were not collected on dependent pups.

Data collected

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

Analysis

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

Results

During 2001, we observed 456 successful sea otter foraging dives, 76 unsuccessful dives and 14 dives with unknown outcome. Our effort was allocated approximately proportional to sea otter abundance, with 135 dives observed in the vicinity of Boulder Island and Sita Reef and 356 dives observed in the vicinity of Hutchins Bay in the east Beardslee Islands (Figure 1). Sea otters successfully recovered prey on 84% of these dives. Mean dive time was 78 seconds (s) and mean surface interval was 66s. Mean dive and surface times varied by prey type. Mean dive and surface intervals (following dive) averaged 105 and 197s for crabs, 71 and 55s for clams, 81 and 103s for mussels and 44 and 59s for urchins. 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 was observed in 2001. In April, we observed one sea otter recover and consume 5 shrimp (*Pandalus sp*.) on two consecutive dives in Hutchins Bay.

Prey Composition

Species composition of sea otter diet in Glacier Bay, Icy Strait and Cross Sound between 1993 and 2000 are presented in Table 4. In 2001 we identified 1000 prey items recovered in 456 successful foraging dives. Overall diet was composed of 61.7% clam, 8.5% crabs, 15.2% mussel, 4.0% urchin, 3.5% other and 6.7% unidentified (Figure 4). At the Boulder/Sita sites mussels (*M. modiolus*) comprised 46% of the diet followed by clams with 34% (Figure 5). At the Hutchins Bay site clams comprised 83% and crabs 10% (Figure 5). In Hutchins Bay, Dungeness crabs (*C. magister*) comprised 67% of the total crabs consumed, and Tanner crab (*C. bairdi*) 12%.

Table 3. List of prey items that sea otters were observed consuming in southeast Alaska, 1993-2000.

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*
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, years 1993 - 2000. '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 three main areas (**Dundas, S. Icy, 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
Dundas (621)	**59**	**20**	**0**	**0**	**0.2**	**6**	**1**	**14**
Site 1 (168)	17	58	0	0	0	0	0	26
Site 2 (226)	93	2	0	0	0	0	2	3
Site 3 (227)	57	9	0	0	0.4	17	0	17
S Icy (1101)	**57**	**3**	**3**	**3**	**2**	**17**	**2**	**13**
Pt Althorp (237)	49	3	13	4	2	19	4	8
Dad (125)	79	0	1	6	0	1	0	13
Inian Cove (246)	85	1	0	2	1	4	0	8
Lemesurier (267)	3	10	0.4	2	0	48	5	31
N Inian (226)	89	1	0	3	4	0.4	0	2
GLBA (2399)	**40**	**4**	**18**	**2**	**1**	**21**	**2**	**12**
Berg Bay (71)	42	3	3	6	3	3	4	37
Boulder 1 (49)	84	2	8	2	0	4	0	0
Boulder 2 (307)	40	0.3	23	2	1	21	2	11
Fingers Bay (10)	30	10	0	0	30	0	0	30
Flapjack (22)	95	0	5	0	0	0	0	0
Hutchins B (206)	72	12	9	1	0	2	1	3
Kidney Is (67)	72	9	0	3	0	0	13	3
Lester Is (73)	66	4	4	0	0	16	0	10
Marble Is (31)	90	0	0	0	6	0	3	0
N Beardslee (15)	60	7	0	13	0	0	0	20
Netland Is (22)	41	9	9	0	5	5	5	27
N Marble Is (28)	71	0	0	7	0	0	7	14
NW Beards. (406)	31	2	47	3	0	8	1	8
Pt Carolus (284)	21	4	27	0.4	1	15	1	30
Pt Gustavus (440)	13	4	0	2	0.5	68	4	8
Ripple Cove (39)	90	0	0	0	0	0	0	10
Rush Pt (75)	53	1	12	0	0	15	0	19
S. Fingers (43)	63	2	2	5	2	0	7	19
Sita Reef (88)	16	0	47	0	0	24	2	11
S. Marble Is (19)	26	63	0	5	0	0	5	0
Strawberry Is (37)	87	5	0	0	0	0	0	8
Young Is (67)	42	6	3	0	3	33	0	13

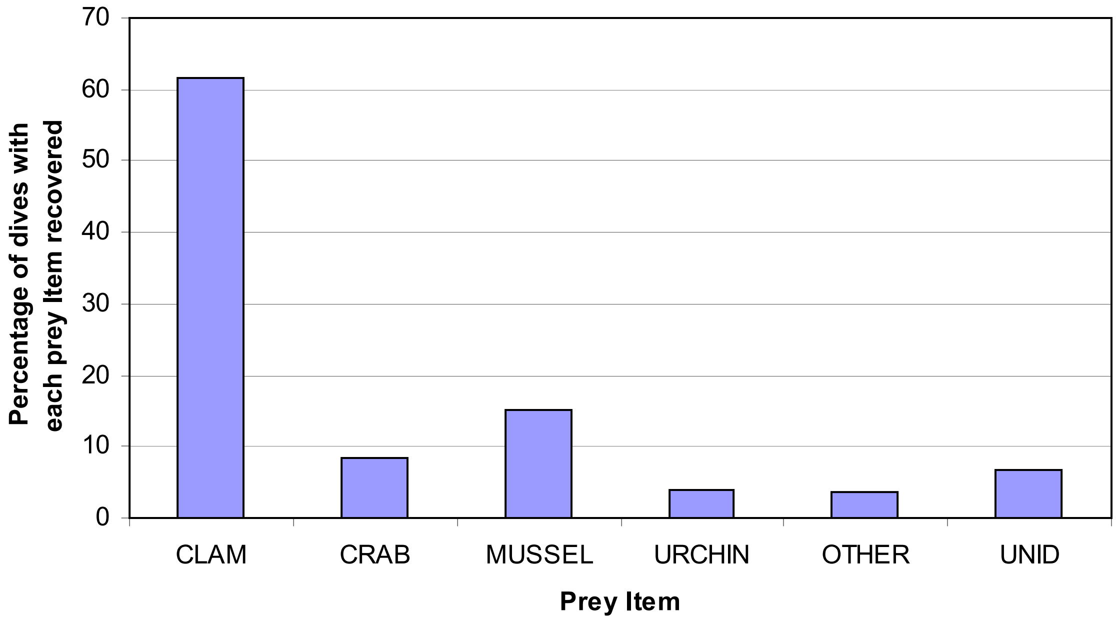


Figure 4. Prey composition of 456 sea otter successful foraging dives in Glacier Bay during 2001. The "Other" category consists of worms, sea cucumbers and non-clam /non-mussel bivalves. Sea otter ages and sexes are combined.

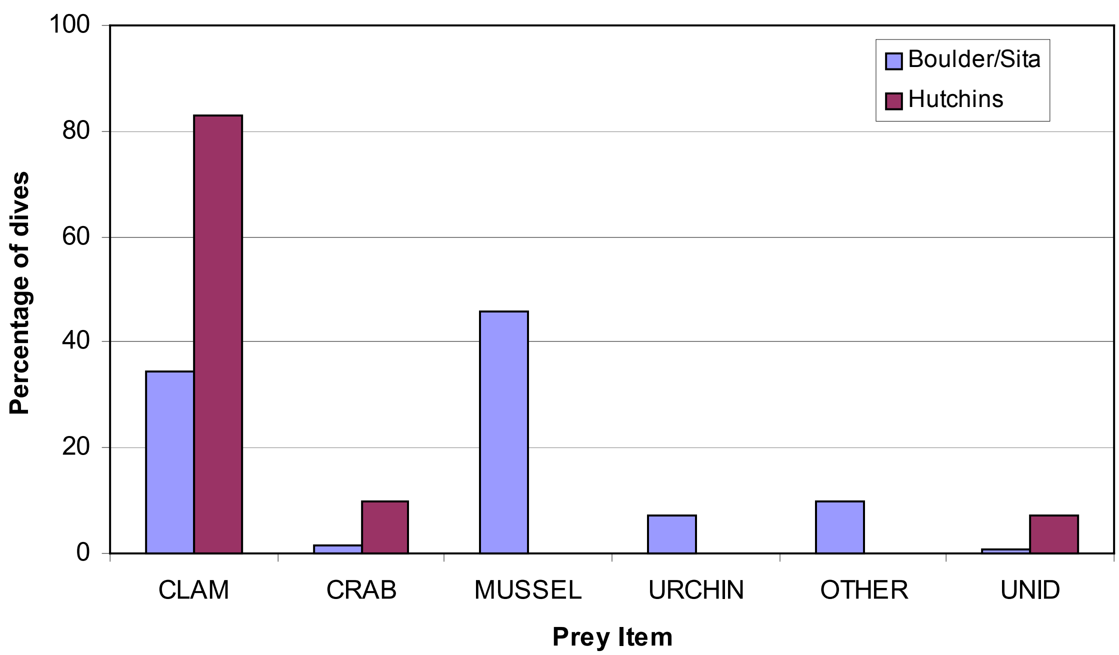


Figure 5. Sea otter prey composition in Glacier Bay, 2001, at Boulder/Sita Reef (128 successful dives) and Hutchins Bay (279 successful dives), in the Beardslee Islands. Sea otter ages and sexes are combined.

Prey Number and Size

On dives when specific prey types were recovered, we computed the mean number of individuals of that prey type and the sizes of those individuals (Figure 6). On average, sea otters recovered 2.6 prey items per successful dive in 2001. In Glacier Bay, sea otters retrieved an average (sd) of 1.9 clams (1.6), 1.6 crabs (0.5), 2.9 mussels (1.2), or 5.3 urchins (2.6) per dive. In Glacier Bay, the visually estimated mean size (sd) of clams recovered was 50.3mm (15), crabs: 75.8mm (23), mussels: 87.6mm (12), and urchins: 30.3mm (14).

Discussion

Sea otters are foraging with a high degree of success in Glacier Bay. Perhaps more importantly, 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 dominate the diet, although in some areas other prey can be important components of the diet. In 2001 we found crabs, particularly *C. magister*, to be relatively important in the Beardslee Islands. While at Boulder/Sita reef, mussels (*M. modiolus)* and urchins (*S. droebachiensis*) were relatively important. 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.

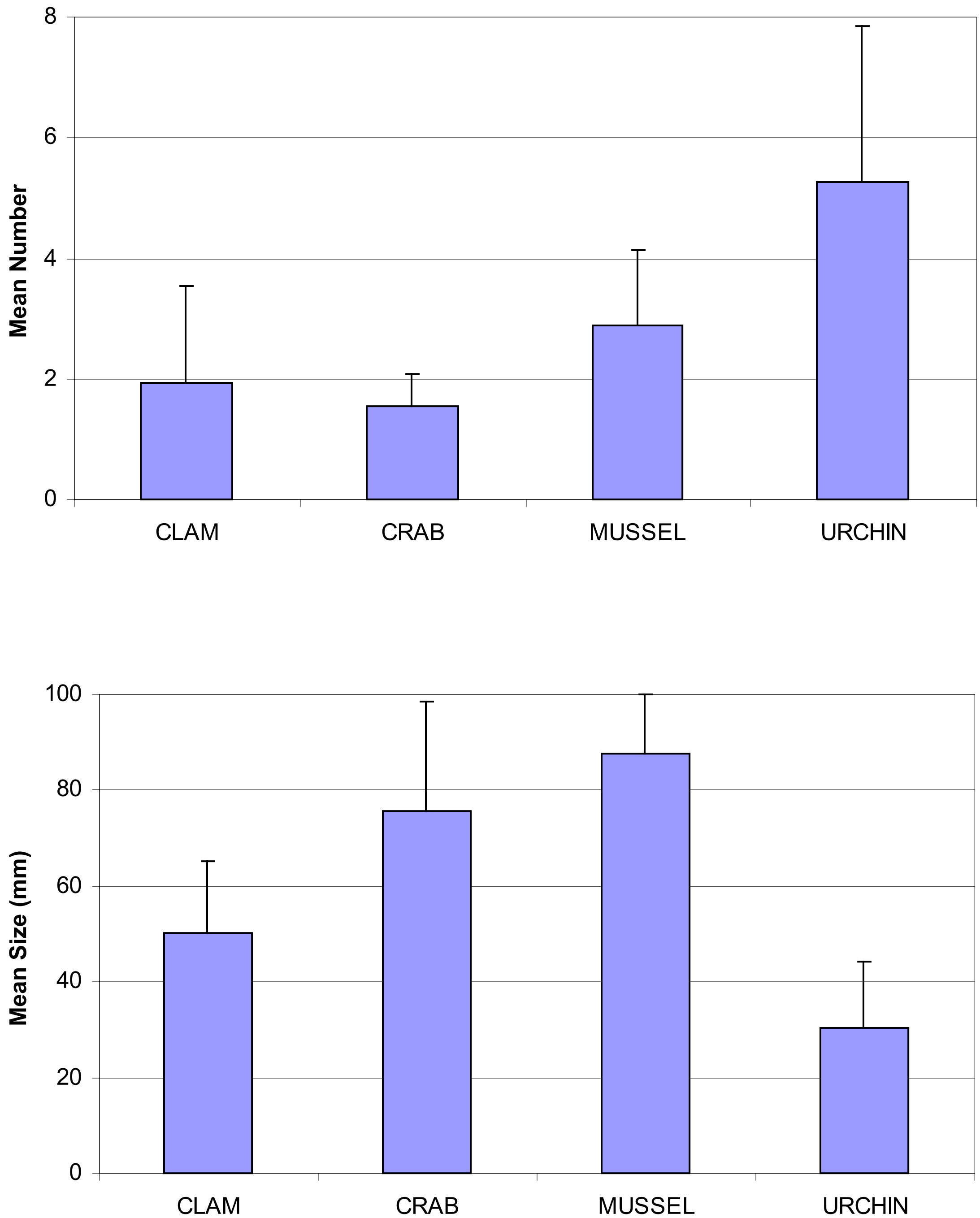


Figure 6. Mean number per dive (top graph) and mean size (bottom graph) and standard deviations of the primary prey items recovered by sea otters during observations of foraging behavior in Glacier Bay in 2001. The number of bouts for each prey type were: clam 21, crab 4, mussel 7, urchin 4.

Subtidal Clam Sampling

Subtidal Clam Sampling

Study of prey populations will allow documentation of species composition, abundance, and size distributions of 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 clam species composition, species diversity, size distribution, abundance, and biomass from our sampling of unconsolidated sediment habitats in Glacier Bay.

Methods

Site Selection

Our goal was to locate 8 to 10 subtidal clam beds in lower Glacier Bay that had not been depredated by sea otters so we could estimate subtidal clam species diversity, densities, and biomass in the absence of sea otters. Nine sites (Figure 7) were eventually identified and sampled based on the following criterion: 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. Because sites were not selected randomly or systematically, we do not make inference to areas beyond each site sampled.

Subtidal clam bed locations can be difficult to predict so we used a fisheye underwater drop camera or divers to locate the presence of clam siphons. 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. When abundant clam populations (identified by siphon densities) 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).

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 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 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, reduces variance among quadrats sampled and requires less time to sample. The field methodology employed to carry out this sampling design is described below.

On the first dive, divers prepared the site for sampling by installing a sand anchor to mark the center of the 20 meter diameter sampling circle. 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. The origin was moved when necessary to ensure that the sampling circle was located, as entirely as possible, on top of 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 used their compasses in conjunction with fiberglass measuring tapes to navigate to the predetermined quadrat location and position a 0.5 X 0.5 meter aluminum quadrat frame (0.25 m^2). After recording siphon count and substrate classification, urchins and crabs were placed into mesh bag #1. At this point, one diver signaled the surface tender to start the dredge while the other diver prepared to dredge. The dredge consists of an 8 horsepower gasoline fired engine outfitted with a centrifugal pump (Keene Engineering, Inc., Chatsworth, CA) that circulates sea water through a 2" diameter, 100' long fire hose at 350 gallons per minute. A vacuum created by movement of water through a suction nozzle attached to the other end of this fire hose sucks sediment into the exhaust stream that flows into mesh bag #2. The diver holding onto the dredge nozzle 'vacuums' the sediment out of the quadrat while the other diver grabs larger clams and deposits them into mesh bag #1. Smaller clams are sucked along with the sediment into mesh bag #2 on the exhaust hose. Quadrats were excavated to a depth of at least 25 cm or until no more clams were found. After dredging 3 or 4 quads, the divers are usually ready to return to the boat for fresh tanks, so they attach the samples to an inflatable lift bag and send the samples to the surface. Once divers return to the boat, the mesh bags are recovered and the sediments are sieved through 10mm mesh screens to locate smaller clams. All clams (as well as crabs and urchins) are identified to the lowest possible taxa, counted, and measured to the nearest millimeter using calipers. Sediments and fauna were returned to Glacier Bay following data collection.

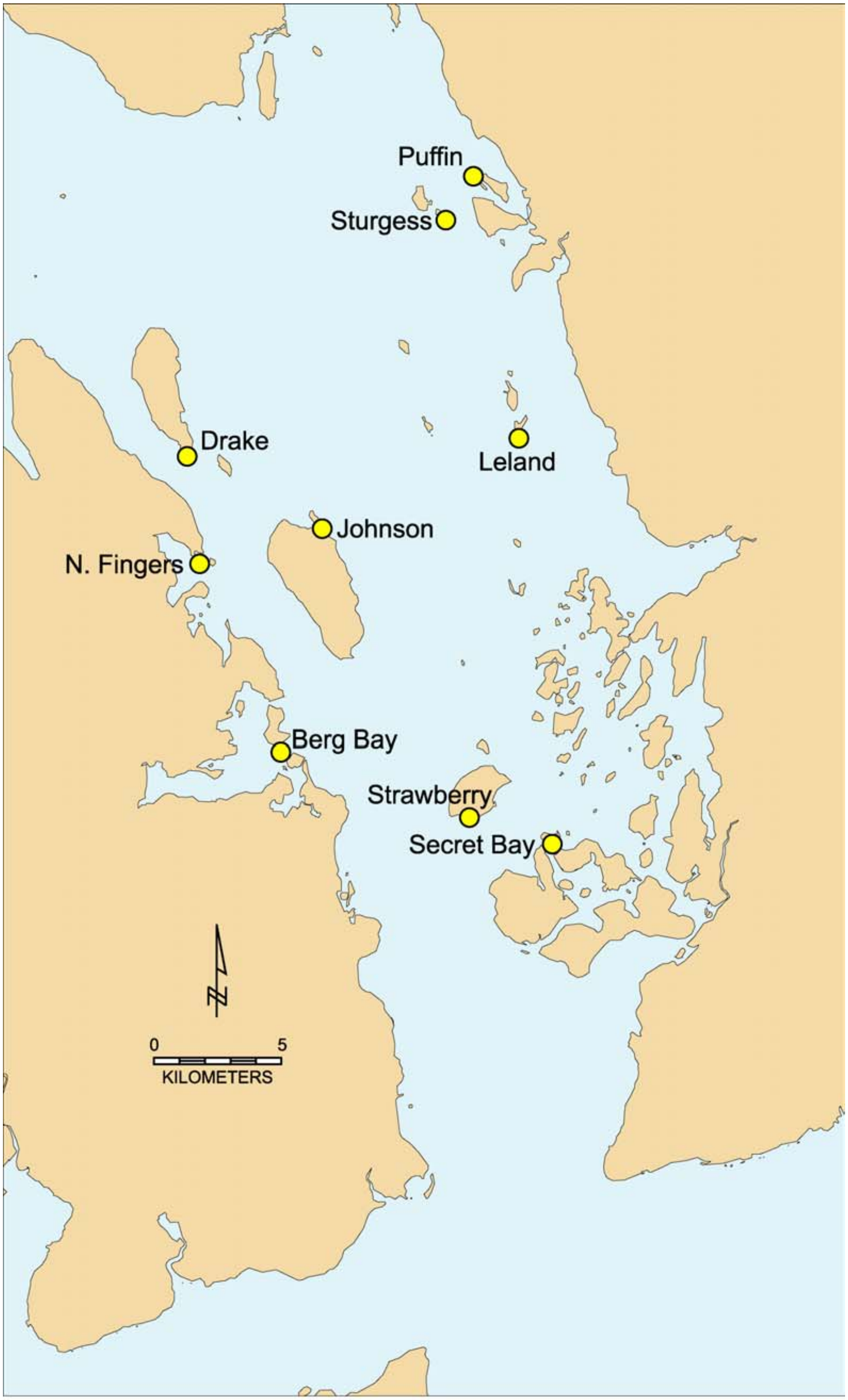


Fig. 7. Subtidal clam sites sampled in Glacier Bay National Park, 2001.

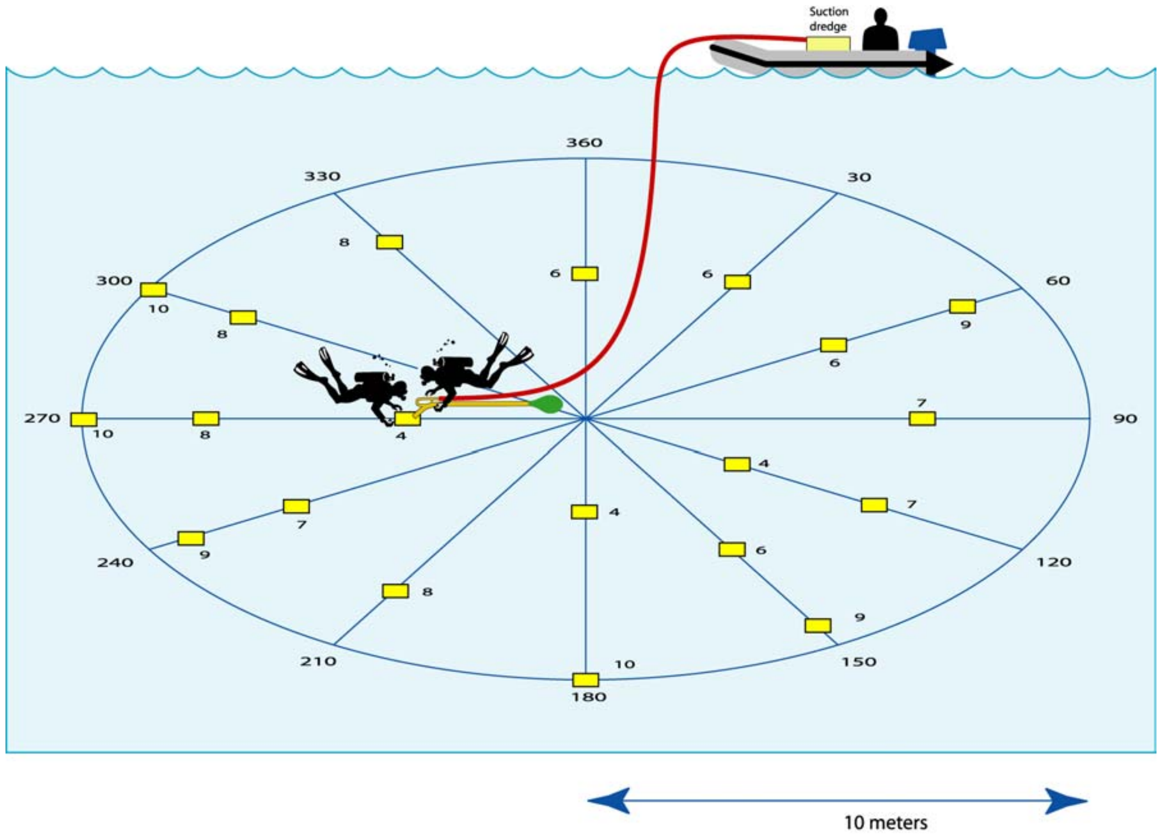


Fig. 8. Subtidal clam sampling design used in Glacier Bay National Park, 2001.

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. Because we intend to compare the data set collected to date against identical data collected from the same sites after occupation by sea otters, we do not perform or report statistical tests of significance in this report. Further, our sampling does not allow inference beyond the approximately 400 m^2 sampled at each site.

Results

We sampled subtidal clam and sea urchin populations at nine sites in Glacier Bay in 2001 (Figure 7). At each site we sampled 20 quadrats for a total 180 quadrats dredged. In our 2001 subtidal clam sampling we identified 14 clam species, two species of mussel, 1 scallop, and one species of urchin (Table 5). The species of clam and urchin we encountered and their frequencies of occurrence are presented in Table 5. The littleneck clam, *P. staminea*, was the most common clam, and several species were rarely found.

Bivalve Species Diversity

The Shannon-Wiener diversity index (H') was calculated for 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 nine sites we sampled are presented in Table 6. Mean species diversity among the sites we sampled was 1.75 (sd = 0.36). The theoretical maximum H', assuming we know the total number of species of bivalves possibly present, is 3.91.

Table 5. Species of bivalves and urchins and their frequency of occurrence in 180 pits dredged from 9 sites in Glacier Bay, Alaska, 2001.

Species	Frequency	Percent
Protothaca staminea (PRS)	4075	35.2
Saxidomus gigantea (SAG)	2742	23.7
Macoma sp. (MAS)	2643	22.8
Mya truncata (MYS)	1143	9.8
Serripes groenlandicus (SEG)	322	2.8
Mactromeris polynyma (MAP)	304	2.6
Yoldia sp. (YOS)	131	1.1
Modiolus modiolus (MOM)	77	0.7
Mya sp. (MYS)	41	0.3
Clinocardium nutalli (CLN)	38	0.3
Hiatella arctica (HIS)	19	0.2
Unidentified mussel (MUS)	13	0.1
Panomya ampla (PAA)	9	0.1
Tellina sp. (TES)	5	0.04
Humalaria kennerleyi (HUK)	3	0.03
Hiatella sp. (HIS)	1	0.01
Chlamys sp. (SCA)	1	0.01
Unidentified clam (CLA)	1	0.01
Strongylocentrotus droebachiensis (STD)	4981	100

Table 6. Shannon-Weiner diversity index values (H') for subtidal samples (Urchins not included).

Site	H'
Berg	1.40
Drake	2.05
Johnson	2.41
Leland	1.54
N. Fingers	1.89
Puffin	1.80
Secret	1.34
Strawberry	1.39
Sturgess	1.91

Density

The mean number of clams (including mussels) per quadrat over all sites sampled was 62.8 and ranged from 18.0 at Secret Bay to 151.4 at Johnson Cove on Willoughby Island (Figure 7, Table 7). Mean clam density varied by species within sites. *P. staminea* had the highest mean density (23 / 0.25 m^2), followed by *Macoma* sp. (15 / 0.25 m^2), *S. gigantea* (14 / 0.25m^2), and *Mya* sp. (7 / 0.25m^2). Maximum clam densities for *P. staminea*, *Macoma* sp and *S. gigantea* were 97 / 0.25 m^2, 78 / 0.25 m^2, and 63 / 0.25 m^2 respectively. Mean and standard errors of all clam species (and mussels and urchins) are presented by site in figures 9, 10 and 11. At Johnson Cove, we found the highest densities of five of the eight clam species encountered, *S. gigantea, Mya sp., M polynyma, S. groenlandicus* and *C. nutalli.* The highest *P. staminea* densities (41 / 0.25 m^2) were encountered at the Puffin Island site (North Sandy Cove). The highest *S. gigantea* densities (24 / 0.25 m^2) were found at two sites, Johnson Cove and North Fingers. The highest *Macoma* sp. densities (38 / 0.25 m^2) were found at Puffin Island. Subtidal clam density was positively and significantly correlated (adj. R^2= 0.68, p=0.05) with clam diversity.

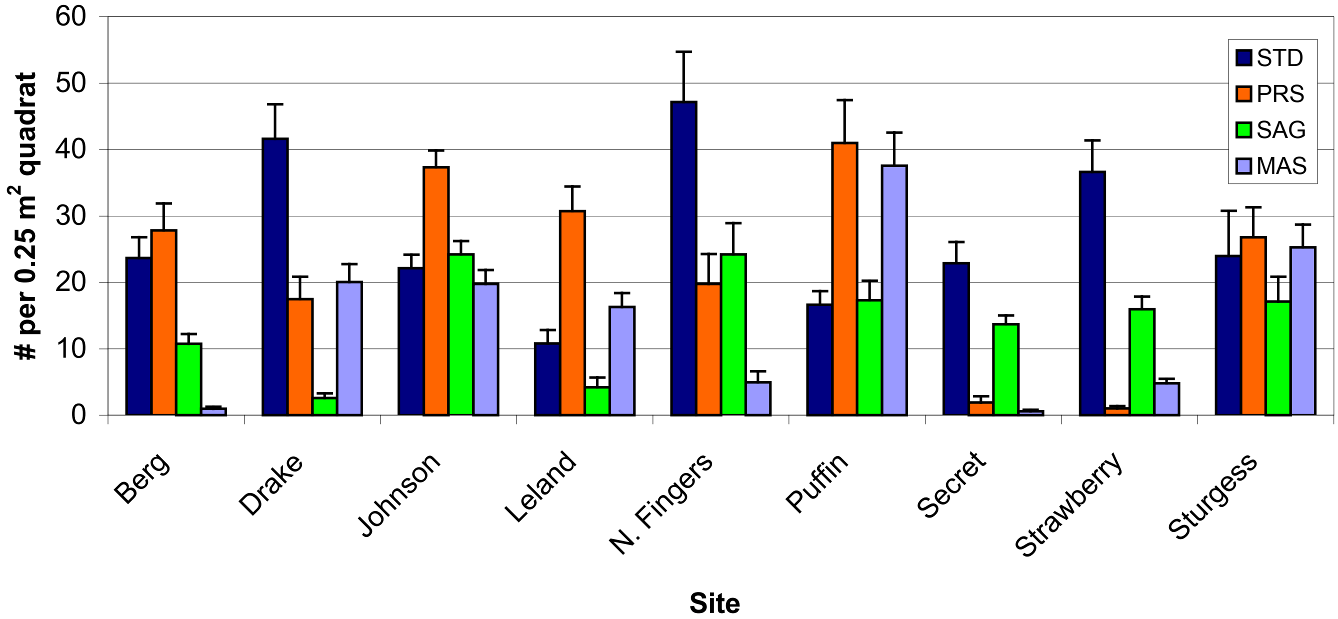


Figure 9. Mean density of clams *P. staminea,*(PRS) *S. gigantea* (SAG), *Macoma* sp.(MAS), and green urchins, S. *droebachiensis* (STD) at each of the 9 subtidal sites we sampled in 2001 in Glacier Bay (see Figure 7 for site locations).

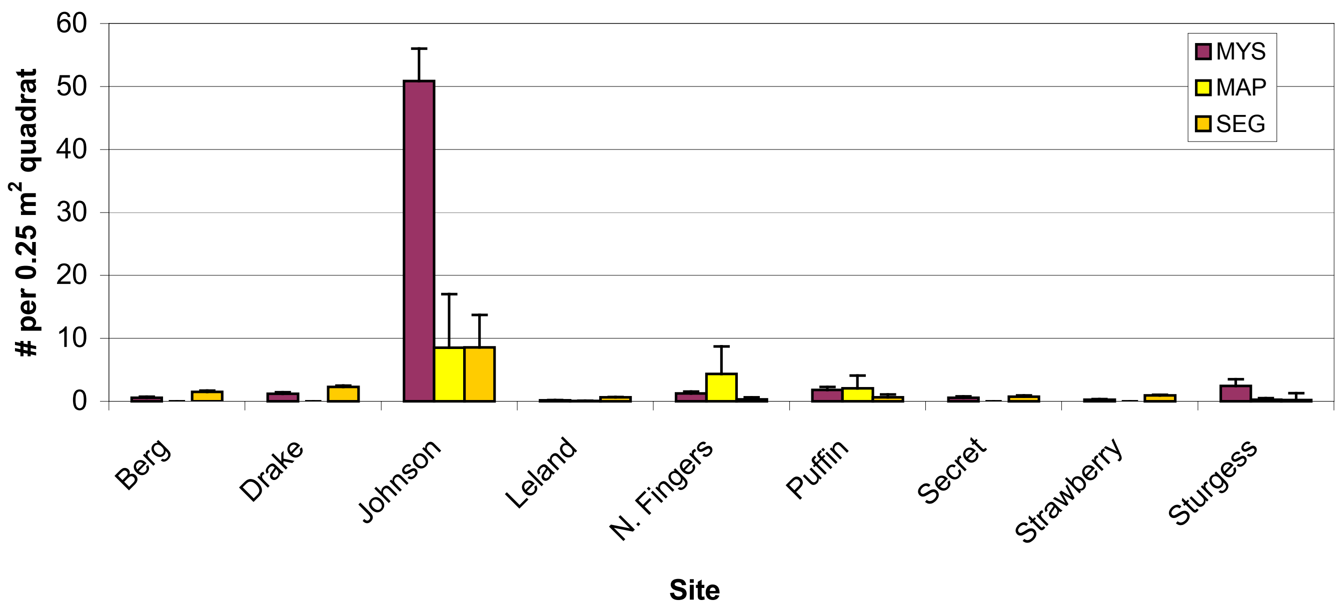


Figure 10. Mean density of clams *Mya* sp., (MYS), *M. polynyma* (MAP) and *S. groenlandicus* (SEG) at each of the 9 subtidal sites we sampled in 2001 in Glacier Bay (see Figure 7 for site locations).

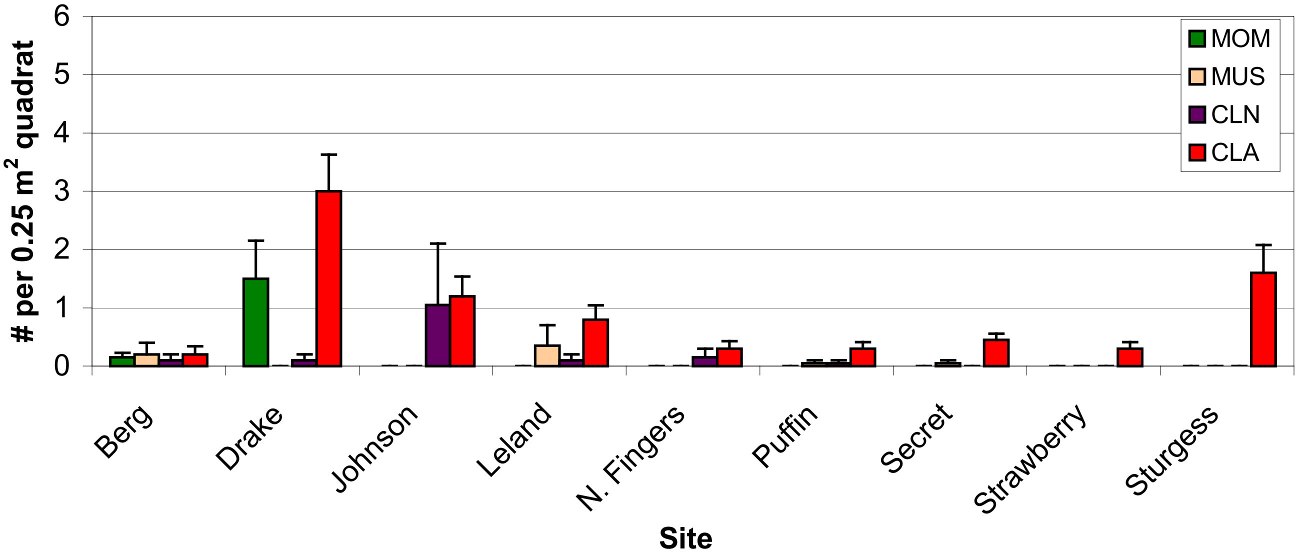


Figure 11. Mean density of clam *C. nutalli* (CLN) and unidentified clams (CLA) and mussels *M. modiolus* (MOM), and unidentified mussels (MUS) at each of the 9 subtidal sites we sampled in 2001 in Glacier Bay (see Figure 7 for site locations).

Biomass

The total biomass (grams ash free dry weight(AFDW)) of clams per site varied extensively among sites (Figures 12, 13, 14, Table 7). Mean biomass of clams per site ranged from 38.7 g at Leland Island to 313.2 g at Johnson Cove and averaged 121.0 g at the nine sites sampled. Total biomass, including clams, mussels, and urchins ranged from 62.6 g at Leland Island to 359.2 g at Johnson Cove, and averaged 177.1 g/ 0.25 m^2 at the nine sites sampled. Where *P. staminea* dominated numerically, in terms of biomass, *S. gigantea* was the dominant species. Maximum *S. gigantea* estimated biomass in a quadrat was 484 g at Sturgess Island. Maximum *P. staminea* estimated biomass in a quadrat was 93 g at Secret Bay. We also encountered a maximum estimated biomass of *M. polynyma*, of 252 g at Johnson Cove. Generally, sites with higher clam densities had higher clam biomass (Table 7), however some exceptions to this trend were noted. For example, the Leland Island site ranked 6th in terms of clam density but ranked 10th in biomass. Alternatively, North Fingers ranked 5th in clam density, but 2nd in biomass. These shifts in ranking likely result from differences in species composition and mean sizes within sites. Subtidal clam biomass was positively and significantly correlated (adj. R^2= 0.79, p=0.001) with clam diversity.

Table 7. Mean density (#/0.25 m^2), biomass (grams ash free dry weight per 0.25 m^2) of subtidal clams, and biomass of clams, mussels, and urchins in Glacier Bay.

Site	Density: clams	Biomass: clams	Biomass: clams, mussels and urchins
Berg	42.2	77.6	136.9
Drake	48.2	71.7	116.6
Johnson	151.4	313.3	359.2
Leland	53.2	38.7	62.6
N. Fingers	55.3	168.3	271.4
Puffin	100.7	145.0	209.1
Secret	17.9	71.7	101.8
Strawberry	23.3	51.0	151.7
Sturgess	73.7	151.7	184.6
Mean	**62.9**	**121.0**	**177.1**

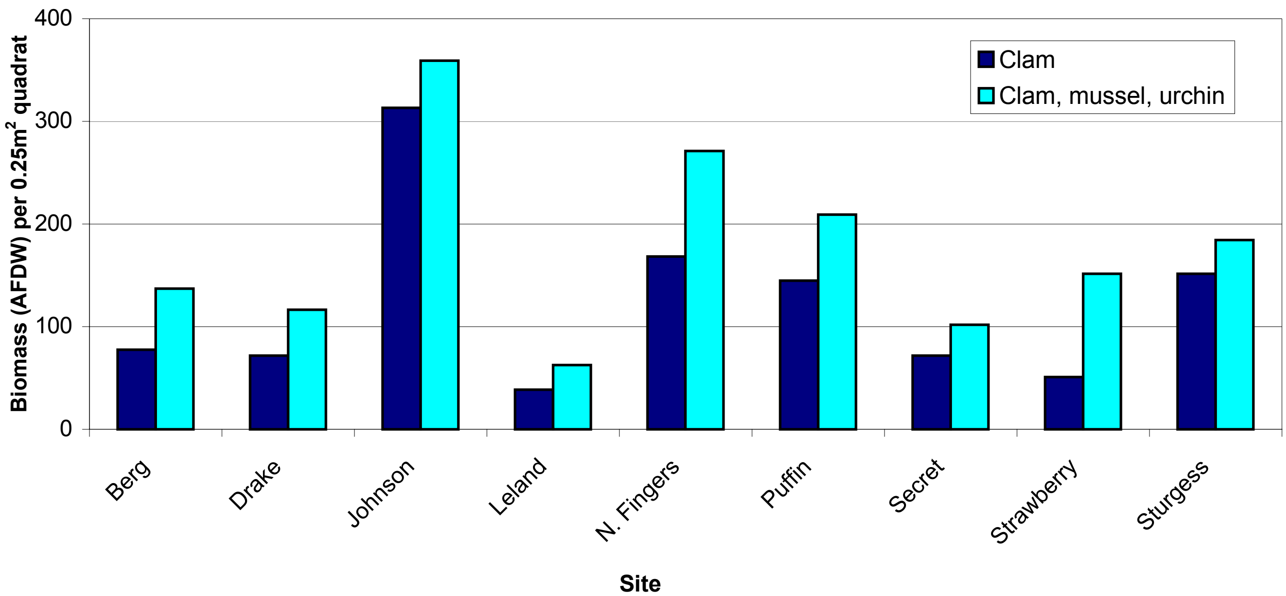


Figure 12. Estimated biomass (ash free dry weight (AFDW) in grams) of subtidal clams (species include all clams listed in the discussion, page 40). The "Clam, mussel, urchin" category includes mussels (*M. modiolus* and unidentified mussels) and green urchins (*S. droebachiensis*), as well as clams.

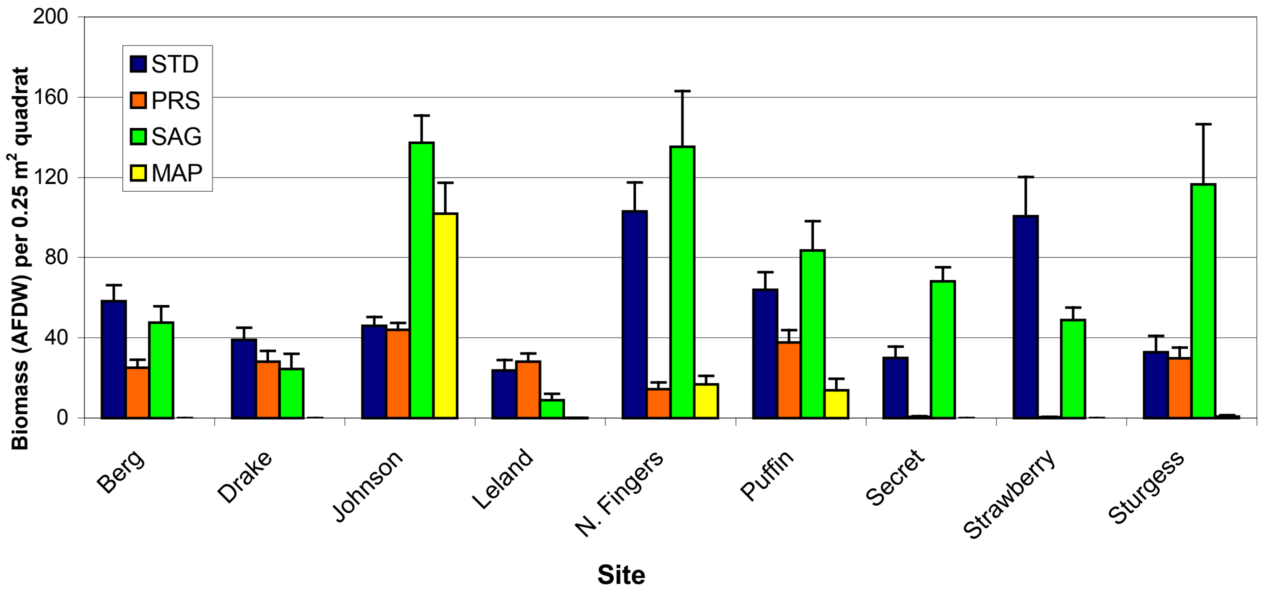


Figure 13. Estimated biomass (ash free dry weight (AFDW) in grams) of the subtidal clam species; *P. staminea* (PRS), *S. gigantea* (SAG), and *M. polynyma* (MAP), and the green urchin, *S. droebachiensis* (STD) at each of 9 subtidal sites we sampled in 2001 in Glacier Bay.

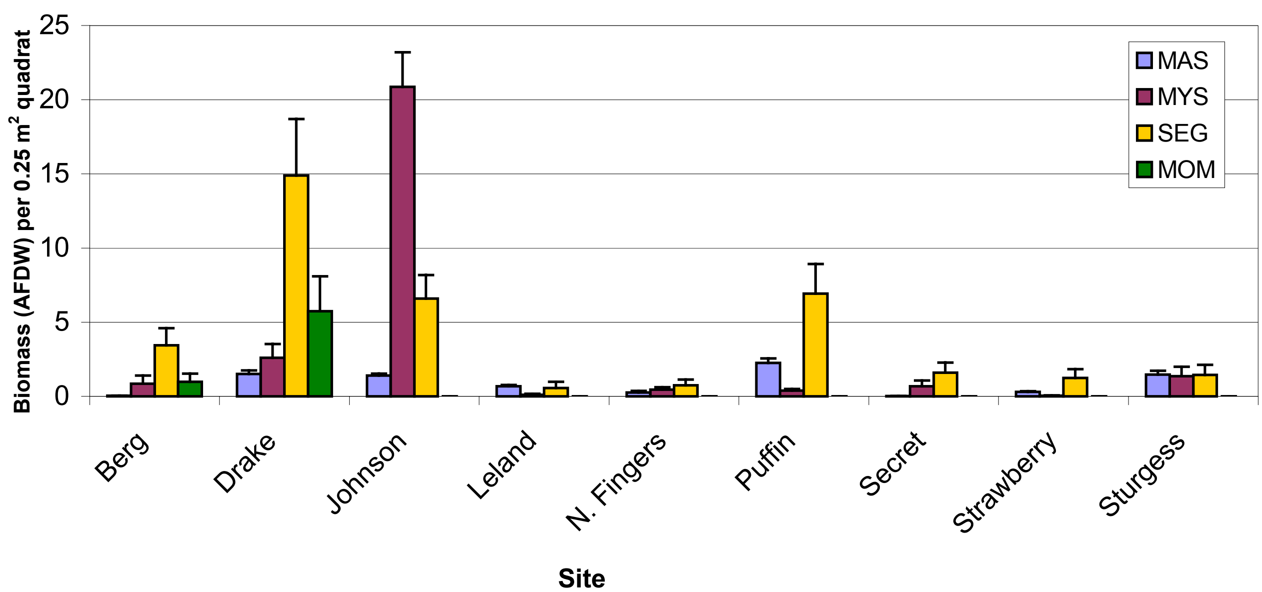


Figure 14. Estimated biomass (ash free dry weight (AFDW) in grams) of the subtidal clam species *Macoma* sp. (MAS), *Mya* sp.(MYS), *S. groenlandicus* (SEG), and the mussel, *M. Modiolus* (MOM) at each of 9 sites sampled in 2001 in Glacier Bay.

Size Distributions

Mean subtidal clam (and mussel and urchin) sizes and number measured by species are presented in Figure 15. Mean subtidal clam (and mussel and urchin) sizes varied by species and sites (Figures 16 and 17). Although we did not find large numbers of clams at Drake Island, we found the largest mean sizes of four species of clams there. Mean sizes (se) of *P. staminea* ranged from a maximum of 53.5 mm (0.5) at Drake Island to a minimum of 28.1 mm (2.0) at Secret Bay. Mean sizes of *S. gigantea* ranged from 85.5 mm (3.52) at Drake Island to 51.4 mm (1.2) at Strawberry Island. Mean sizes of *Macoma sp.* ranged from 19.5 mm (0.2) at Drake Island to 13.8 mm (0.8) at Secret Bay. Mean sizes of *M. polynyma* ranged from 94.3 mm (1.6) at Johnson Cove to 46.6 mm (12.6) at Sturgess Island. Mean sizes of *S. groenlandicus* ranged from 94.7 mm (11.3) at Puffin Island to 31.9 mm (1.2) at Johnson Cove. Mean sizes of *S. droebachiensis* ranged from 30.4 mm (0.4) at Drake Island to 16.4 mm (0.2) at Drake Island. Size class distributions varied among species sampled and among sites. Size class distributions for the numerically dominant species at all sites combined (*Macoma sp., Mya sp., P. staminea, S. gigantea,* and *S. droebachiensis*) are presented in Figures 18 and 19. Size class distributions of the numerically dominant subtidal clam species, *P. staminea, S. gigantea*, and the green urchin, *S. droebachiensis,* varied among sites and are presented in Figures 20-22. The differences in the size class distributions of clams and urchins we observed among sites are suggestive of spatial and temporal variation in recruitment of these species. For example, at Drake, Johnson, and Berg, size distributions of *P. staminea* were largely uni-modal, with maximum numbers of individuals > 50 mm (Figure 20), while at Leland, N. Fingers, and Puffin *P. staminea* were broadly distributed in sizes from 15 to 55 mm with few individuals > 60 mm. A similar pattern was observed in sizes of *S. gigantea* at Secret, Sturgess and Johnson, where distributions were skewed to the left and maximum numbers of individuals were between 80 and 100 mm. In contrast, at Berg, Puffin and Strawberry, sizes were broadly distributed between 40 and 110 mm (Figure 21).

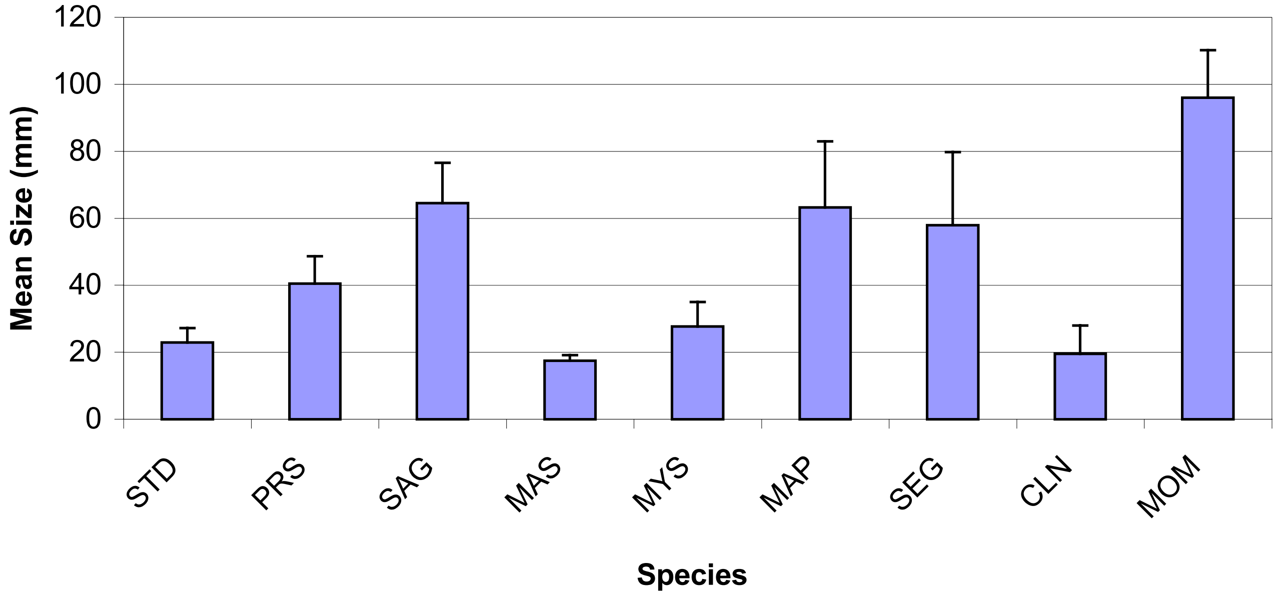


Figure 15. Mean sizes (sd) of subtidal green urchins: S. *droebachiensis,* (STD, n=4771); clams: *P. staminea* (PRS, n=3937)*, S. gigantea* (SAG, n=2703)*, Macoma* sp. (MAS, n=2572), *Mya* sp. (MYS, n=1065), *M. polynyma,* (MAP, n=299) *S. groenlandicus* (SEG, n=277) and *C. nutalli*. (CLN, n=38); and mussels *M. modiolus* (MOM, n=33) sampled at nine sites in Glacier Bay, Alaska, 2001.

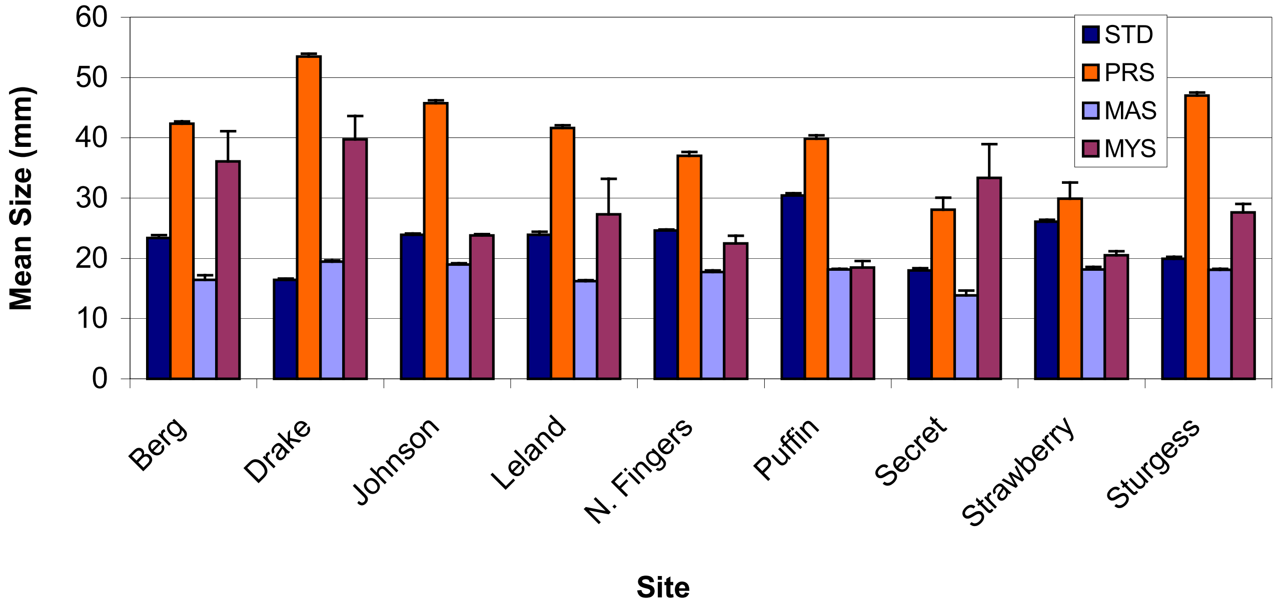


Figure 16. Mean sizes (sd) of subtidal clams: *P. staminea* (PRS), *Macoma* sp. (MAS), *Mya sp*. (MYS), and the green urchin, *S. droebachiensis* (STD) at each of the 9 subtidal sites sampled in 2001 in Glacier Bay (see Figure 7 for site locations).

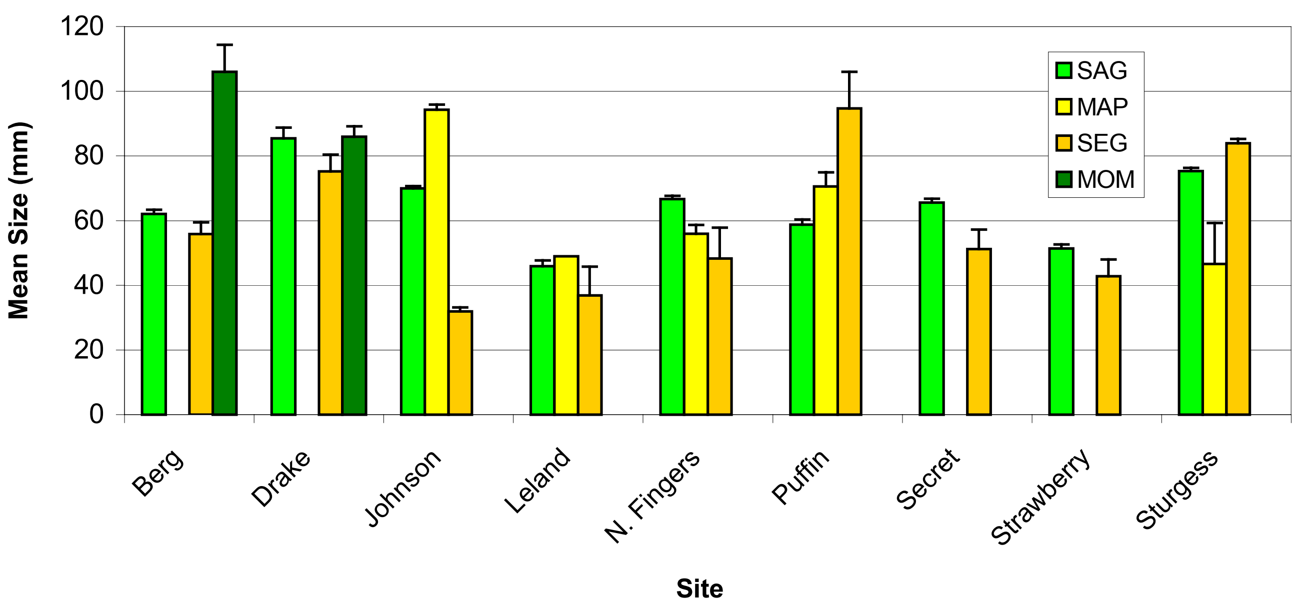


Figure 17. Mean sizes (sd) of subtidal clams: *S. gigantea* (SAG), *M. polynyma* (MAP), *S. groenlandicus* (SEG), and the mussel, *M. modiolus* (MOM) at each of the 9 subtidal sites sampled in 2001 in Glacier Bay (see Figure 7 for site locations).

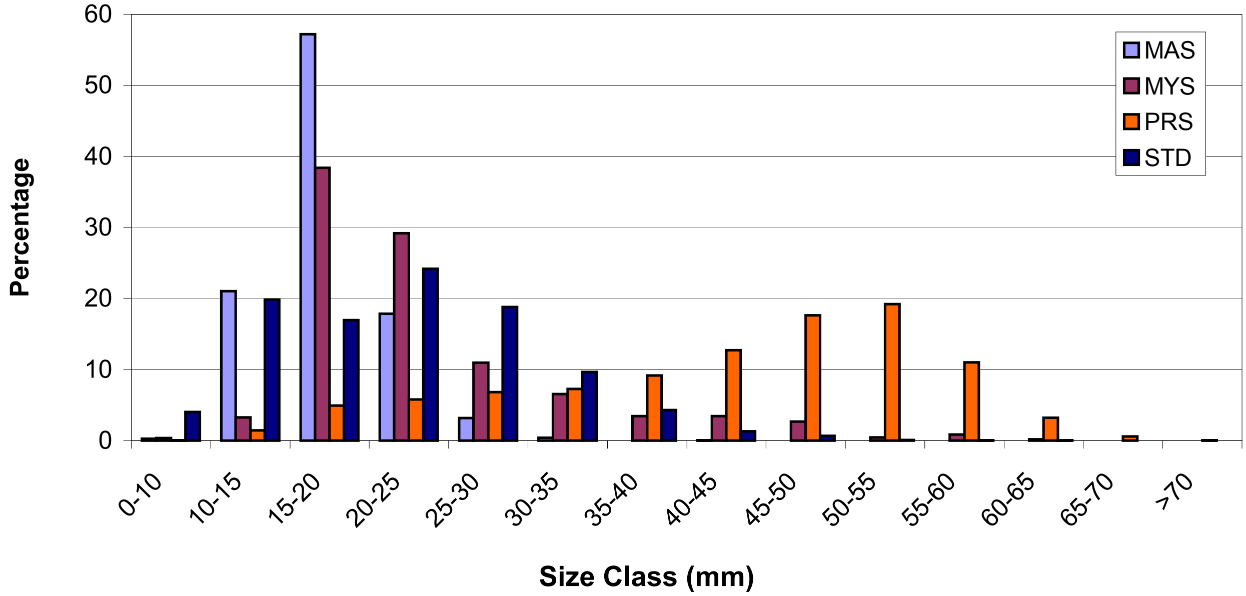
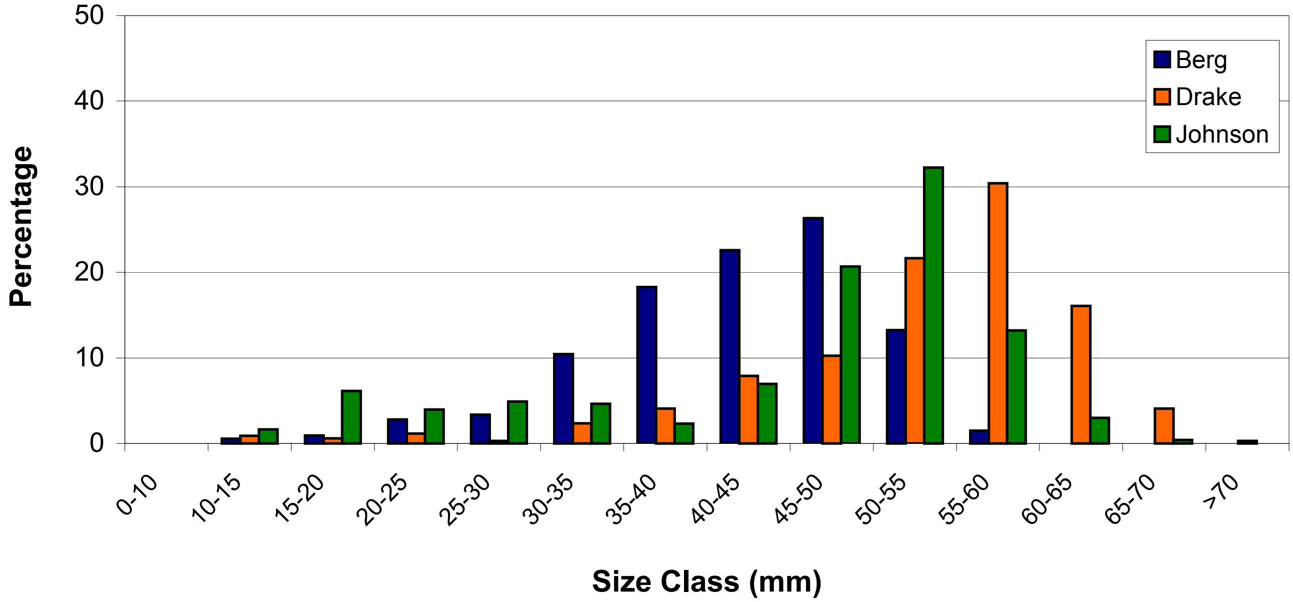


Figure 18. Size class distribution of subtidal clams: *Macoma sp*. (MAS, n = 2572), *Mya sp*. (MYS, n = 1065), *P. staminea* (PRS, n = 3937); and green urchins, *S. droebachiensis* (STD, n = 4771) at nine sites sampled in Glacier Bay, Alaska, 2001. This figure includes clams and urchins from all nine sites combined.

Figure 19. Size class distribution of the subtidal clam, *S. gigantea* (SAG) at nine sites sampled in Glacier Bay, Alaska, 2001. This figure includes SAG from all nine sites combined, n = 2703.



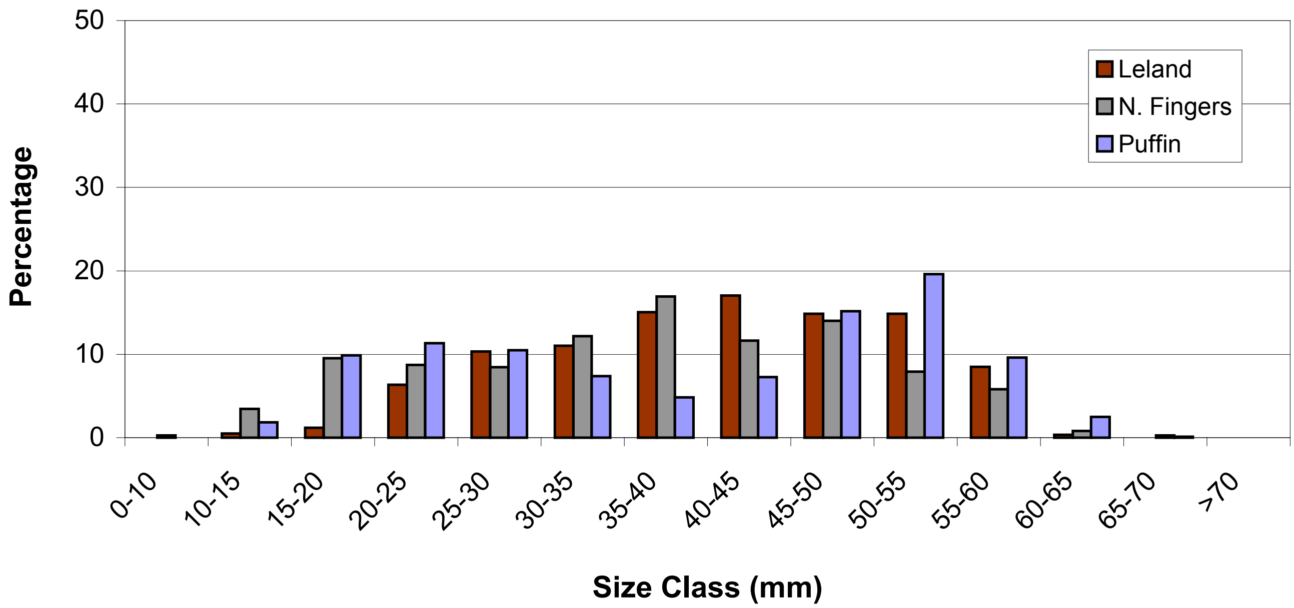
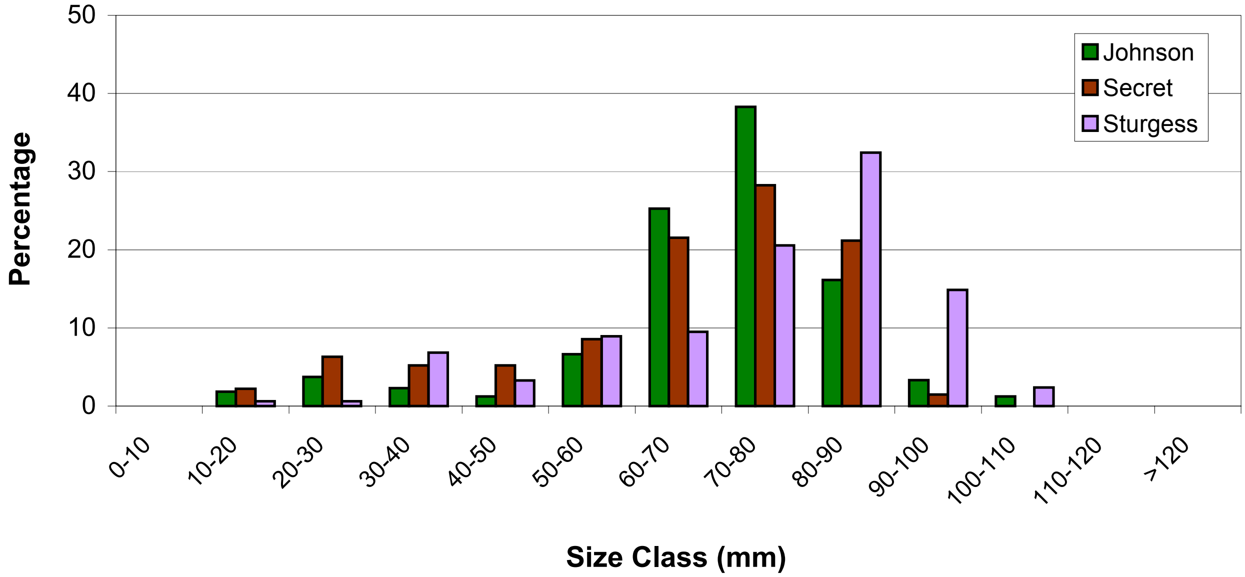


Figure 20. Size class distributions of subtidal *P. staminea* (PRS) at six sites in Glacier Bay sampled in 2001. See Figure 7 for site locations (Berg n = 536, Drake n = 342, Johnson n = 735, Leland n = 599, N. Fingers n = 378, Puffin n = 811).



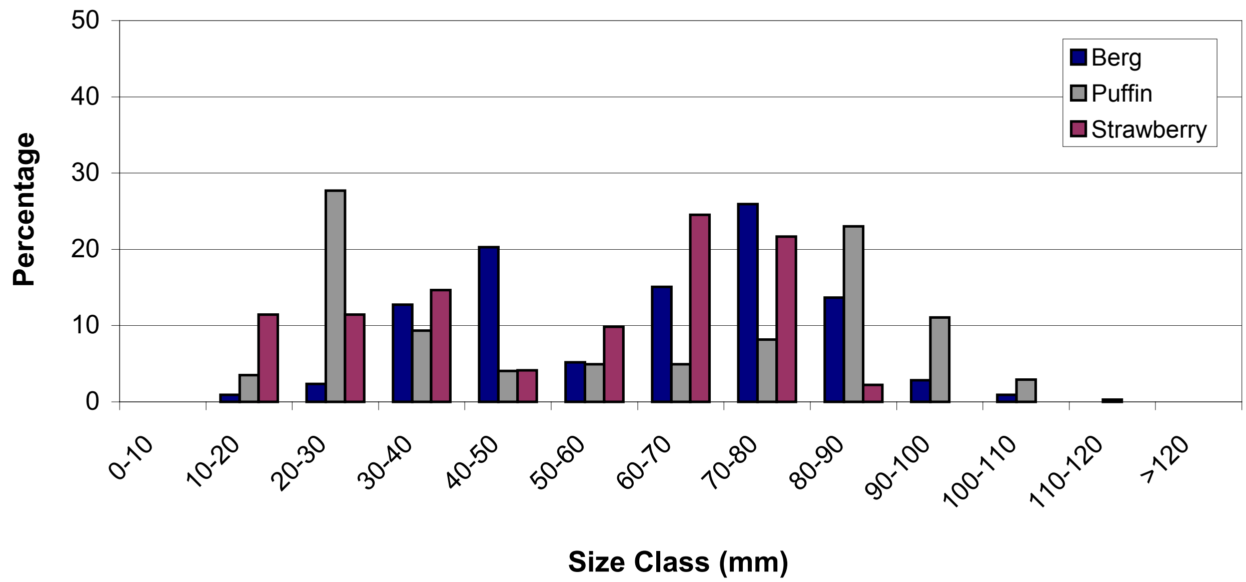
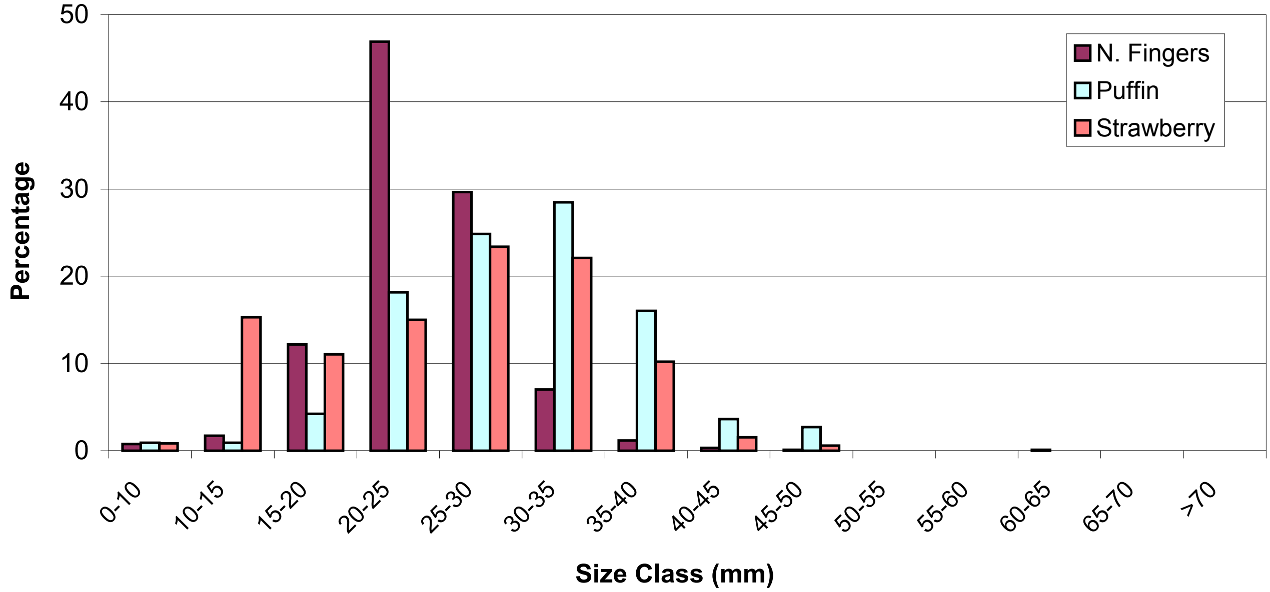


Figure 21. Size class distributions of subtidal *S. gigantea* (SAG) at six sites in Glacier Bay sampled in 2001. See Figure 7 for site locations (Johnson n = 483, Secret n = 269, Sturgess n = 336, Berg n = 212, Puffin n = 343, Strawberry n = 314).



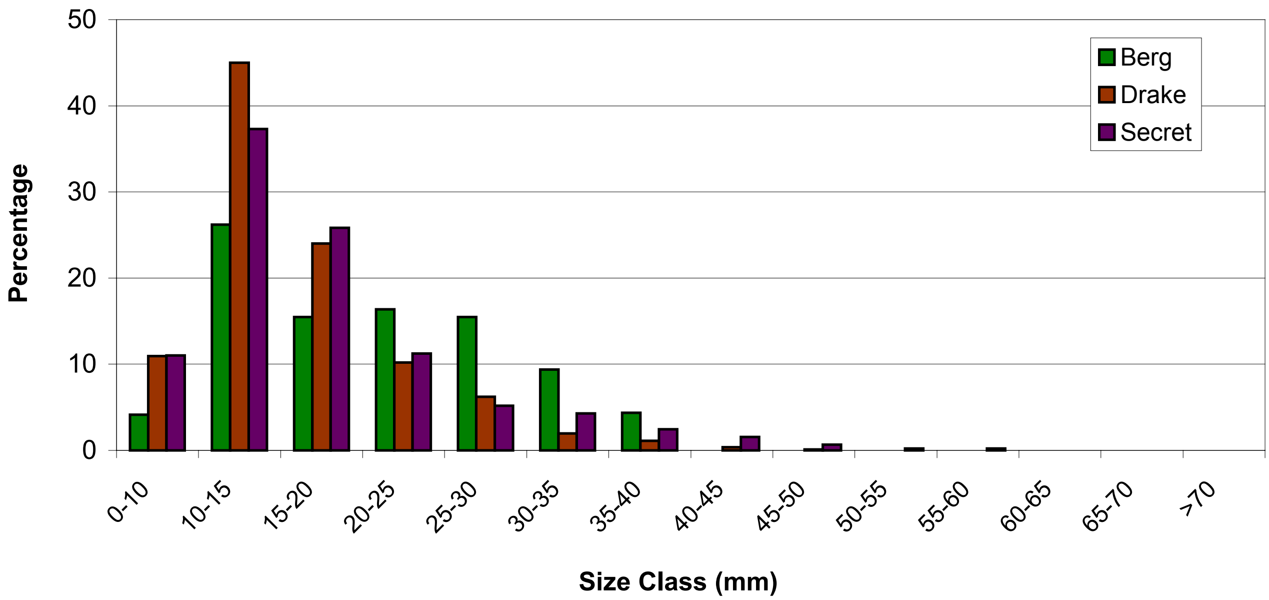


Figure 22. Size class distributions of subtidal *S. droebachiensis* (STD) at six sites in Glacier Bay sampled in 2001. See Figure 7 for site locations (N. Fingers n = 927, Puffin n = 330, Strawberry n = 706, Berg n = 458, Drake n = 804, Secret n = 445).

Discussion

Species diversity of subtidal clams (mean = 1.75) was similar to that measured previously among intertidal clam assemblages in preferred clam habitats in Glacier Bay (mean = 1.59) (Bodkin et al. 2001). Most of the clam 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: *Gari californica, Entodesma navicula,* and *Pseudopythina compressa*.

Subtidal clam densities over the nine sites sampled in 2001 averaged 62.9 / 0.25 m^2. This compares to the 96.7 clams / 0.25 m^2 we found in preferred intertidal clam habitats in Glacier Bay in 1999 and 2000 (Bodkin et al 2001). The mean subtidal clam biomass estimate of 121 g/ 0.25 m^2 is nearly twice the mean estimated intertidal clam biomass (73.4 g/ 0.25 m^2) we found in preferred intertidal clam habitats in Glacier Bay in 1999 and 2000 (Bodkin et al. 2001). The greater average biomass per quadrat in the subtidal, despite lower clam densities, results from differences in species composition between the subtidal and intertidal. In the subtidal, species composition is dominated by *P. staminea* and *S. gigantea*, which average 41 and 54 mm respectively and comprised 23% and 36% of the total number of subtidal clams. In the intertidal the numerically dominant clam was species of *Macoma* (58% of total clam numbers) and the average size of intertidal *Macoma sp*. was 22.6 mm.

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.

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 2001 far exceeds both theoretical and empirical growth rates for sea otter populations (Bodkin et al. 1999; Estes and Riedman 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-treatment 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 2001 we observed more than 4,000 successful foraging dives. Clams represented from about 40 to 60 % of the diet, depending on area (up to 95% at a specific site). Our work in 2001 is generally consistent with earlier work in terms of foraging success, dietary composition, number of prey per dive, and prey sizes (Bodkin et al 2001). 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 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, it is likely we will see large increases in the extent of under-story and canopy forming kelps in Glacier Bay. It is likely that effects on kelps will be most pronounced in areas of consolidated substrate that are capable of supporting kelps. We have observed a variety of crab species as sea otter prey in this study, some of which support commercial and subsistence fisheries. It is unlikely these fisheries will be able to persist coincident with an increasing sea otter population. An exception may be those crab species that achieve a refuge from predation by living beyond the foraging depths of sea otters (e.g. *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. The window of opportunity to acquire the needed information will close at a rate positively related to the rate of sea otter increase.

Acknowledgements

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Appendices

APPENDIX A. SAMPLING PROTOCOL FOR SEA OTTER AERIAL SURVEYS

Overview of survey design

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

1) Strip Transect Counts

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

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

2) Intensive Search Units

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

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

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

1) If the survey is not progressing rapidly enough because flying ISU's is too time intensive, *reduce* the minimum number of ISU's per hour slightly
2) If a running tally begins to show that, on average, less than 4 ISU's per hour are being flown, *increase* the targeted minimum number of ISU's per hour accordingly.

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

Preflight

Survey equipment:

binder: random map set selections

map sets (observer, pilot, & spare copies)

strip forms (30)

ISU forms (60)

survey protocol

Trimble GPS procedures

data entry formats

laptop computer for data entry

floppy disk with transect waypoints

Solidstate data drive with power adaptor & interface cable

RAM cards with transect waypoints

RAM card spare batteries

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

clipboards (2)

pencils

highlighter pen

stopwatch for timing ISU circles

35 mm camera with wide-angle lens

high-speed film

survival suits

Airplane windows must be cleaned each day prior to surveying.

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

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

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

Date - Recorded in the DDMMMYY format.

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

Start time - Military format.

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

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

Area - General area being surveyed.

Observation conditions

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

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

Observer fatigue

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

Vessel activity

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

Special rules regarding ISU's

1. Mistaken identity - When an ISU is mistakenly initiated by anything other than a sea otter (e.g. bird, rock, or floating debris), the flight path should continue for one full circle until back on transect. At this point the ISU is to be abandoned as if it was never initiated and the normal fight path is resumed.

2. Otters sighted outside an ISU - Otters sighted outside an ISU that are noticed during ISU circles are counted only when the ISU is completed, normal flight path has been resumed, and they are observed on the strip.

Unique habitat features

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

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

Example: Orca Inlet, PWS. Bring a camera, a good lens, and plenty of film. Timing is important when surveying Orca Inlet; the survey period should center around a positive high tide - plan on a morning high tide due to the high probability of afternoon winds and heavy glare. Survey the entire area from Hawkin's cutoff to Nelson Bay on the same high tide because sea otter distribution can shift dramatically with tidal ebb and flow in this region.

2. Cliffs - How transects near cliffs are flown depends on the pilot's capabilities and prevailing weather conditions. For transects which intersect with cliff areas, including tidewater glaciers, discuss the following options with the pilot prior to surveying.

In some circumstances, simply increasing airspeed for turning power near cliffs may be acceptable. However, in steep/cliff-walled narrow passages and inlets, it may be deemed too dangerous to fly perpendicular to the shoreline. In this case, as with large groups of sea otters, obtain complete counts of the area when possible.

In larger steep-walled bays, where it is too difficult or costly to obtain a complete count, first survey the entire bay shoreline 400 m out. Then survey the offshore transect sections, using the 400 m shoreline strip just surveyed as an approach. Because this is a survey design modification, these data will be analyzed separately.

<u>Example</u>: Herring Bay, PWS. Several high cliffs border this area.

<u>Example</u>: 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.

<u>Example</u>: 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.

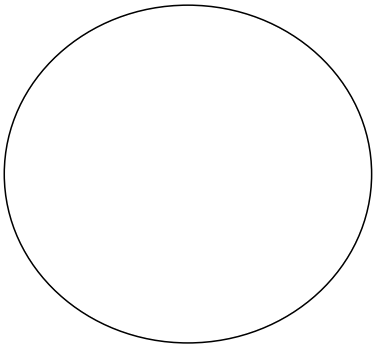
Data sheet for aerial survey strip transects

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:



Transcect #:		ISU #:
Group #	Strip Count	Circle Count
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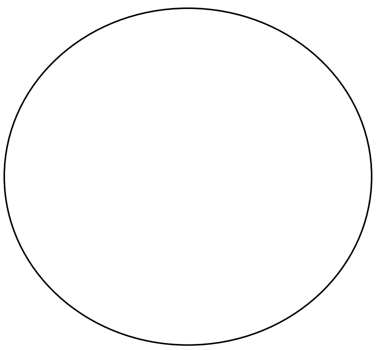

Transcect #:		ISU #:
Group #	Strip Count	Circle Count
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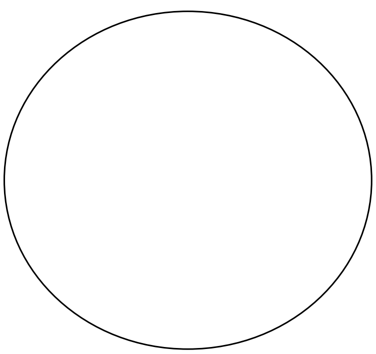

Transcect #:		ISU #:
Group #	Strip Count	Circle Count
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2		
3		
4		
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APPENDIX B. PROTOCOL FOR DETERMINING SEA OTTER DIET BASED ON VISUAL OBSERVATIONS.

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 seas 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. In addition, some foraging areas may be used more than others by individuals and by otters living in the area in general. 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 of 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 (small <4.5 cm, medium 4.5-9 cm, and large >9 cm) 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 form

Sea Otter Foraging Data

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

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

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	10
0 - 52	1B	20
26 - 52	1C	30
52 - 78	2A	50
52 - 104	2B	60
78 - 104	2C	70
104 - 130	3A	90
104 - 156	3B	100
130 - 156	3C	110
> 156	4Z	120

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 (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
Subtidal Clam Sampling

TITLE: Subtidal Clam Sampling Procedure

DATE: 12 February 1996

REV.: 1.0

1.0 Purpose:

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:

A 0.5-m by 0.5-m quadrat samples an area of 0.25 m^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
Corers are cylindrical sampling devices about 15 cm in diameter that sample an area of 0.009 m^2
Sampling area is the general area to be sampled, e.g. Herring Bay, Bay of Isles, or northwestern Montague Island.
Site is a sampling area (5-7 sites) within each area
Depth of sampling is a sampling area 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.