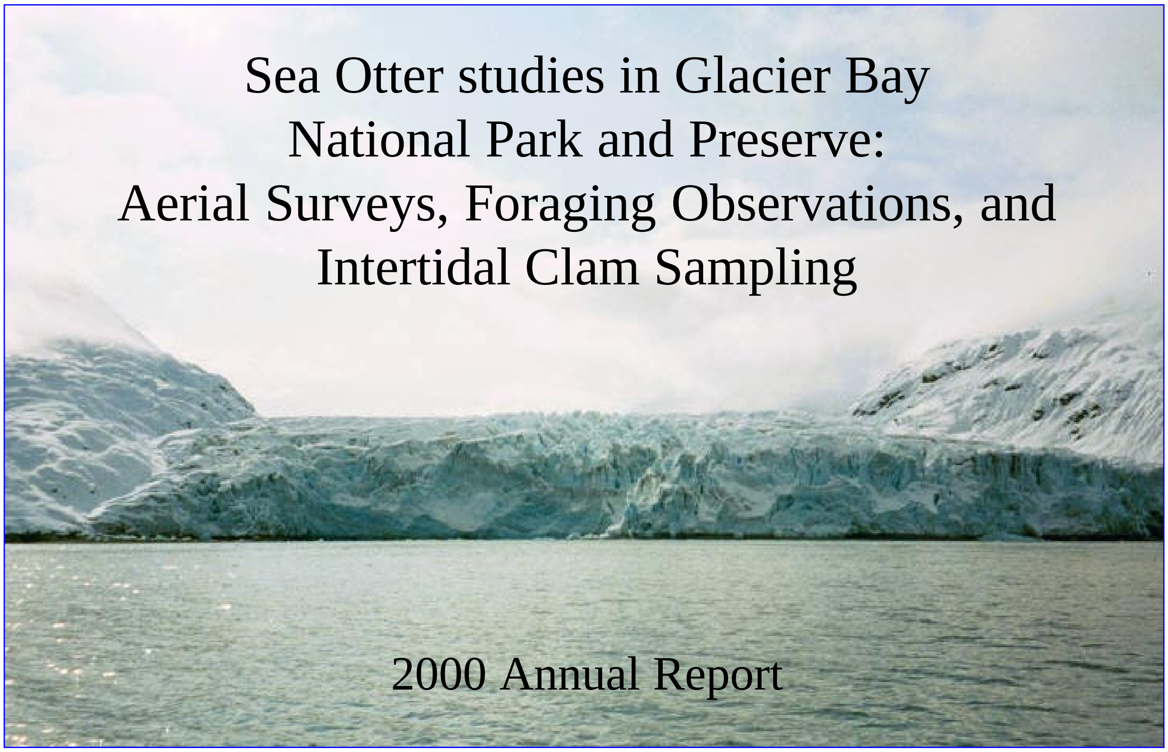
Sea Otter studies in Glacier Bay National Park and Preserve: Aerial Surveys, Foraging Observations, and Intertidal Clam Sampling



2000 Annual Report

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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 of their presence in Glacier Bay in 1993. Since 1995, the number of sea otters in Glacier Bay proper has increased from about 5 to more than 500. 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 in Glacier Bay and south Icy Strait through visual observations of prey during > 4,000 successful foraging dives. In 2,399 successful foraging dives observed in Glacier Bay proper, diet consisted of 40% clam, 21% urchins, 18% mussel, 4% crab, 5 % other and 12% unidentified. Most prey recovered by sea otters are commercially, socially, or ecological important species. Species of clam include *Saxidomus gigantea*, *Protothaca staminea*, and *Serripes groenlandicus*. Urchins are primarily *Strongylocentrotus droebachiensis* while both mussels, *Modiolus modiolus* and *Mytilus trossulus,* are taken. Crabs include species of *Cancer*, *Chionoecetes, Paralithodes*, 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 and individual choice.

We estimated species composition, density, biomass, and sizes of intertidal clams at 59 sites in Glacier Bay, 14 sites in Idaho Inlet, 12 sites in Port Althorp and 2 sites in Dundas Bay. There is no direct evidence of otter foraging at any of our clam sampling sites except at Port Althorp where sea otters have been present for > 20 years and regularly forage intertidally. There is some indication of intertidal foraging in Idaho Inlet, based on reduced mean size of preferred clam species. Sea otters have been present in Idaho Inlet for at least 12 years. We sampled 48 systematically selected sites to allow inference throughout Glacier Bay intertidal areas and 12 preferred habitat intertidal sites to estimate maximum clam densities in the Bay. We also sampled 14 and 12 random sites in Idaho Inlet and Port Althorp, respectively, to provide contrast between sites with and without sea otters. Densities and biomass of intertidal clams were greater in the Lower Bay than either the East or West Arms. Mean densities (#/0.25 m^2) of all species of clams > 10.0 mm total length were 96.5 at preferred sites, 32.8 in the Lower Bay, 12.2 in the East Arm, 6.6 in the West Arm, 11.32 at Port Althorp and 27.1 at Idaho Inlet. Clam densities were lower in the Upper Arms of Glacier Bay, compared to the Lower Bay and were similar to densities at Port Althorp. In the Lower Bay, clam densities were nearly twice as high at preferred clam sites compared to those systematically sampled. Species of *Macoma* were the numerically dominant intertidal clam at most sites in Glacier Bay, while

Protothaca staminea was dominant at Idaho Inlet and Port Althorp. Biomass (g/0.25 m^2) was higher in the Lower Bay (23.5) than either Arm (2.1 and .91) and higher at preferred sites (73.4) than systematically selected sites in Glacier Bay. Biomass estimates at Port Althorp were 5.2 and 9.7 at Idaho Inlet. Biomass estimates were dominated by species of *Saxidomus*, *Protothaca* and *Mya* in Glacier Bay and by *Protothaca* and *Saxidomus* at Idaho Inlet and Port Althorp. We suspect differences in density and biomass relate to habitat differences between areas within Glacier Bay, particularly sediment sizes. Differences in species composition, densities, and biomass between areas with and without sea otters likely result from predation, but also may reflect habitat differences as well. Size class distributions of clam species varied among species and areas. *Saxidomus*, *Protothaca*, and *Mya* were the largest clams in Glacier Bay and their mean sizes were larger in Glacier Bay than at Idaho Inlet or Port Althorp, suggesting sea otters may be foraging on these species in Idaho Inlet and Port Althorp. In Glacier Bay the size distributions of *Protothaca* and *Saxidomus* were skewed to the right of the distribution of these species at Idaho Inlet and Port Althorp while size distributions of *Macoma* were similar. This finding likely represents the relatively reduced biomass and energy content in intertidal *Macoma* clams and thus their relatively low value as a food item to sea otters.

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. Sea otter diet consists primarily of clams, mussels, urchins and crabs but varies on relatively small spatial scales. Glacier Bay supports large and diverse populations of intertidal clams that are largely unexploited by sea otters presently. It is predictable that the density and sizes of intertidal clam populations will decline in response to otter predation. This will result in fewer opportunities for human harvest, but will also result in 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, green sea urchins (*Strongylocentrotus droebachiensis*) and several clam species (*Saxidomus gigantea*. and *Protothaca staminea)* that are commercially, culturally, or ecologically important. As the recolonization of the Bay by sea otters continues, it is also likely that dramatic changes will occur in the species composition, abundance and size class composition of many components of the nearshore marine ecosystem. Many of the changes will occur as a direct result of predation by sea otters, other changes will result from indirect or cascading effects of sea otter foraging, such as increasing kelp production and modified prey availability for other nearshore predators. Without recognizing and quantifying the extent of change initiated by the recolonization 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 (Kenyon 1969, VanBlaricom and Estes 1988, Riedman and Estes 1990, Estes and Duggins 1995). Much of our knowledge of the role of sea otters as a source of community variation resulted from the spatial/temporal pattern of sea otter population recovery since their near extirpation nearly 100 years ago. During most of the early 20th century sea otters were absent from large portions of their habitat in the north Pacific. During the absence of sea otters, many of their prey populations responded to reduced predation. Typical prey population responses included increasing mean size, density and biomass. In one well documented example (the sea urchin, *Strongylocentrotus* spp), the removal of sea otters resulted in profound changes in community organization with cascading effects throughout the nearshore ecosystem (Estes and 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 primary production is dominated by attached macroalgae or kelps. This nearshore ecosystem, commonly referred to as a kelp-dominated system, is characterized by high diversity and biomass of red and brown kelps that provide structure in the water column and habitat for invertebrates and fishes that, in turn, support higher trophic levels, such as other fishes, birds and mammals. Once sea otters are removed from the kelp dominated system, sea urchin populations respond through increases in density, mean size and total biomass. Expanding urchin populations exert increasing grazing pressure eventually resulting in near complete removal of kelps. This system is characterized by abundant and large sea urchin populations, a lack of attached kelps and the associated habitat structure 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 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 (*Haliotis* spp), sea urchin (*Strongylocentrotus* spp., clams (*Tivela sultorum*, *Saxidomus spp.*, *Protothaca sp.*), crab (*Cancer* spp, *Chionoecetes* spp, *Paralithoides* spp), and spiny lobster (*Panuliris interruptus*).

Since the middle of the 20th century, sea otter populations have been rapidly reclaiming previous habitats, due to natural dispersal and 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, Kvitek et. al, 1992, Estes and Van Blaricom, 1988). 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. 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 2000 nearly 500 sea otters were observed in the Lower Bay (Figure 1 and Table 1). However, large areas of suitable sea otter habitat remain unoccupied in Glacier Bay, providing suitable 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*

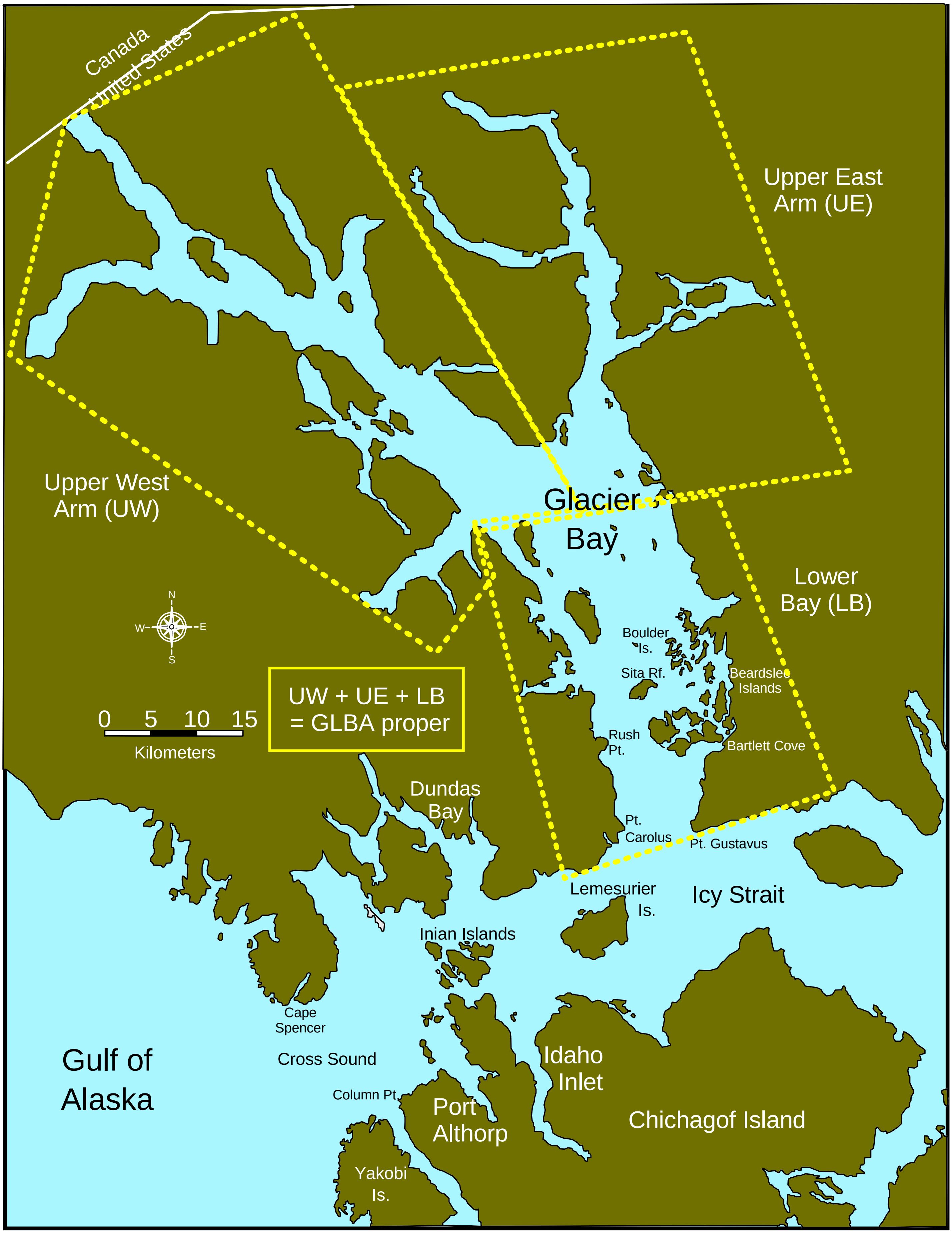


Figure 1. Study areas in Glacier Bay National Park, Icy Straits and Cross Sound, Southeast Alaska

Sea otters, a significant source of ecological change, are currently becoming established in the nearshore marine ecosystem of Glacier Bay National Park and Preserve. 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 wrongly assign cause to observed changes. Infaunal bivalves, including intertidal clams, 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, Kvitek et al. 1993). Understanding the effects of sea otter predation will be critical to appropriately managing the Parks 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 first and second components were originally undertaken by the Alaska Biological Science Center (ABSC) in conjunction with the Multi-Agency Dungeness (MADs) study. 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 intertidal clam populations. A secondary aim of this report is to identify expected changes in benthic marine communities in Glacier Bay that may result from sea otter colonization.

This annual report presents the result of work completed to date on surveys of sea otter abundance and distribution, sea otter food habits, and intertidal clam surveys. This report represents the cooperative efforts of the USGS, ABSC and the NPS, Glacier Bay National Park and Preserve.


Aerial 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 or counts of distribution surveys cannot be used as estimates of total sea otter abundance, as detection rates are not estimated and observers, aircraft, and pilots change between surveys. The other survey type is a systematic sampling of standardized transects within a specific area of interest and are referred to as abundance surveys. Survey conditions are closely controlled and detection of sea 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 in population change. Abundance surveys in Glacier Bay were completed in 1999 and 2000.

Methods

Distribution Surveys

All shoreline habitats out to at least the 40 m bathymetric contour are surveyed. Flight tracks parallel to shore are flown 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 300' in the Bellanca Scout and 90 mph and 500' in the Cessna 185). In May 1999 and 2000, distribution surveys were flown at 65 mph and 300' in a Bellanca Scout.

Abundance Surveys

Aerial survey methods follow those described in detail in 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. 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) (Figure 2). 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 (Fig. 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. Intensive searches are conducted systematically along strip transects to estimate the proportion of animals not detected during strip counts.

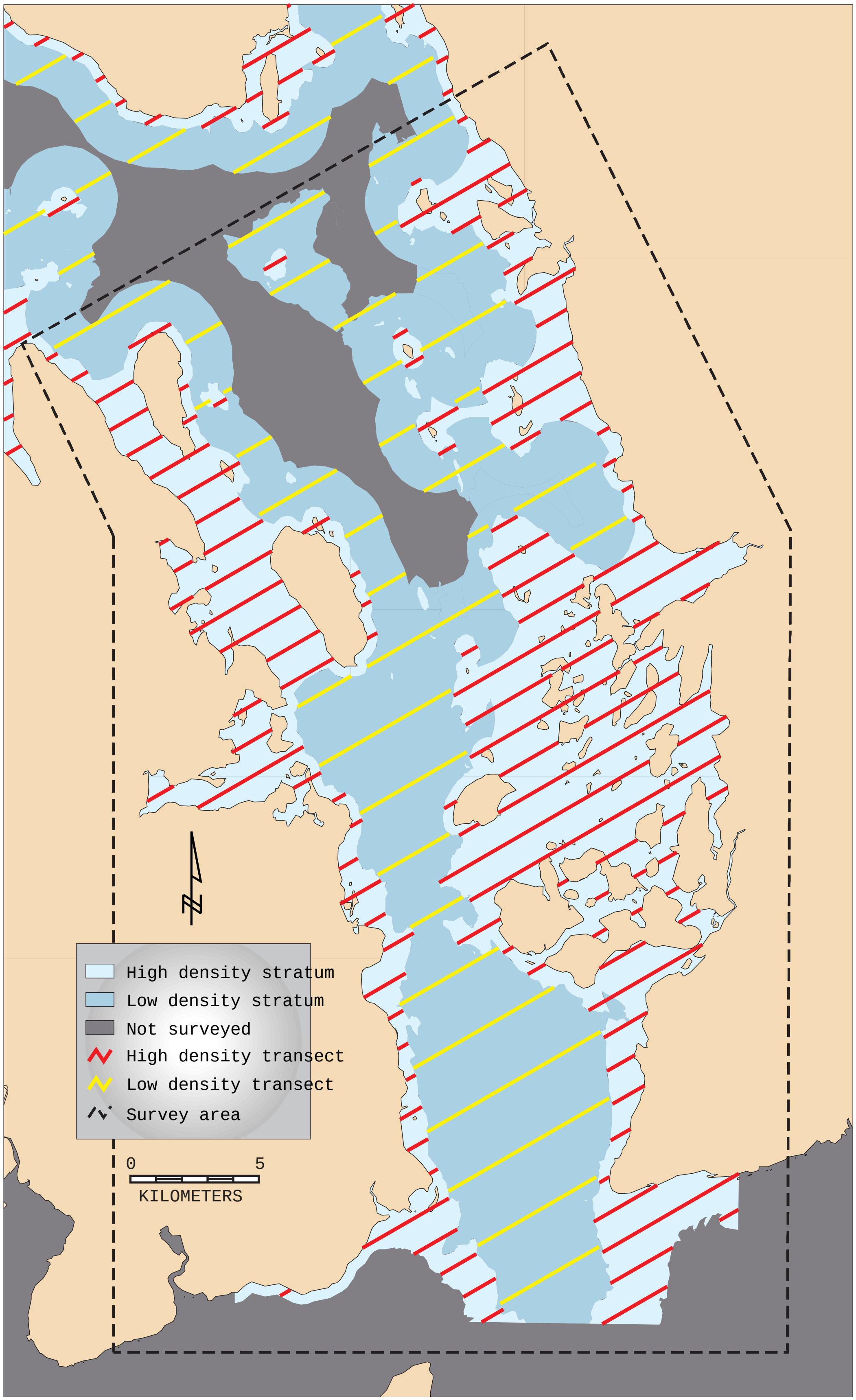


Figure 2. One of four transect designs used during a sea otter abundance aerial survey in Glacier Bay National Park, May 2000.

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 (Fig. 1) since sea otters do not yet occur in the upper bay. The 2000 lower bay survey area included 272 km^2 of high density stratum and 278 km^2 of low density stratum - 4 km^2 more low density than 1999. These four km^2 were added to the low density stratum to include an area identified last year as an exception to the original habitat classification scheme. Five replicates were randomly selected from the 18 possible combinations. Four replicates were surveyed by a single observer from a Bellanca Scout between 12 and 15 May 2000. This survey was conducted by the same pilot and observer who flew the May 1999 Glacier Bay sea otter survey. See Appendix A for a detailed description of the survey methods used.

Results

Distribution Surveys

On 10 May 2000 we surveyed the shorelines of Cross Sound and Icy Strait, and from 11-16 May 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. However, some trends are apparent based on the numbers and locations of otters observed. First, a trend toward increasing abundance in Glacier Bay proper is clear (see Figure 1 for area of Glacier Bay proper), and is supported by the abundance survey data (see below). Second, the numbers of sea otters in northern Icy Strait appear to be declining over time (Table 2). This finding likely reflects emigration of animals from Icy Strait into Glacier Bay and is at least in part responsible for the rapid increase in sea otter abundance in Glacier Bay in recent years.

Abundance Surveys

The four replicate surveys required 28 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 554 (SE = 97). Sea otter pups are combined with adults for population estimation because large pups are often indistinguishable from adults (Table 2). All group locations were digitized into ARC/INFO coverages (Figure 3).

The estimate of 554 sea otters in 2000 represents an increase of 44% above the 1999 estimate. This rate of increase is about twice the maximum rate of growth observed in other recolonizing sea otter populations (Bodkin et al. 1999) and likely results from 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 and 2000 (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
Aircraft	Scout	Scout	172	172	Scout	185	Scout	Scout
Survey Area								
Spencer-Pt Wimbledon	69/20	60/9	31/4	19/2	43/3	8	6	7
Pt Wimbledon-Pt Dundas	37/1	23	18	52	24	52	27	46
Pt Dundas-Pt Gustavus	0	12/1	41/1	178/4	10	1	17	0
Glacier Bay Proper	.	5	39	0	21	209	**384**	**554**
Excursion Inlet	.	.	.	.	.	7	1	0
Pt Couverdon	.	.	.	.	.	2	.	0
Pt Gustavus-Porpoise Is	29/0	94/1	73	2/1	161	8	18	57
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
Lemesurier Is	33/8	62/23	56/2	47/8	143/32	10	67/17	11
Gull Pt-Pt Lavina	77	81	48	141	94	3	90	139
Inian Is	31/9	36/16	11/1	30/12	31/8	10	18/4	9
Pt Lavina-Column Pt	100/31	159/73	42/3	94/21	148/25	31	21/7	88/11
Total	431/69	547/126	389/12	580/49	767/83	364	746/31	913/11

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 north in Icy Strait, toward Lynn Canal, or west into Glacier Bay (Fig. 1). Our data suggest they have elected to occupy Glacier Bay first. This has serious and immediate consequences to managers of marine resources in the Park.

The 2000 estimate indicates a population increase of 170 sea otters over the 1999 estimate for Glacier Bay. Boulder Island and Point Carolus continue to be sea otter strongholds (Fig. 3) whereas large groups were not observed around Leland Island as in prior years. The increase in abundance near Boulder Island indicates the possibility of movement of otters from Leland Island. This shift in abundance was also apparent to researchers doing other fieldwork during the summer 2000. Similar large scale movements have been, and will continue to be, expected to occur as long as prey resources are not limiting sea otter population growth.

Because lower Glacier Bay encompasses the forefront of an expanding sea otter population, immigration and emigration are likely to be the major factors driving abundance estimates. Previous aerial and boat surveys, covering Glacier Bay as well as

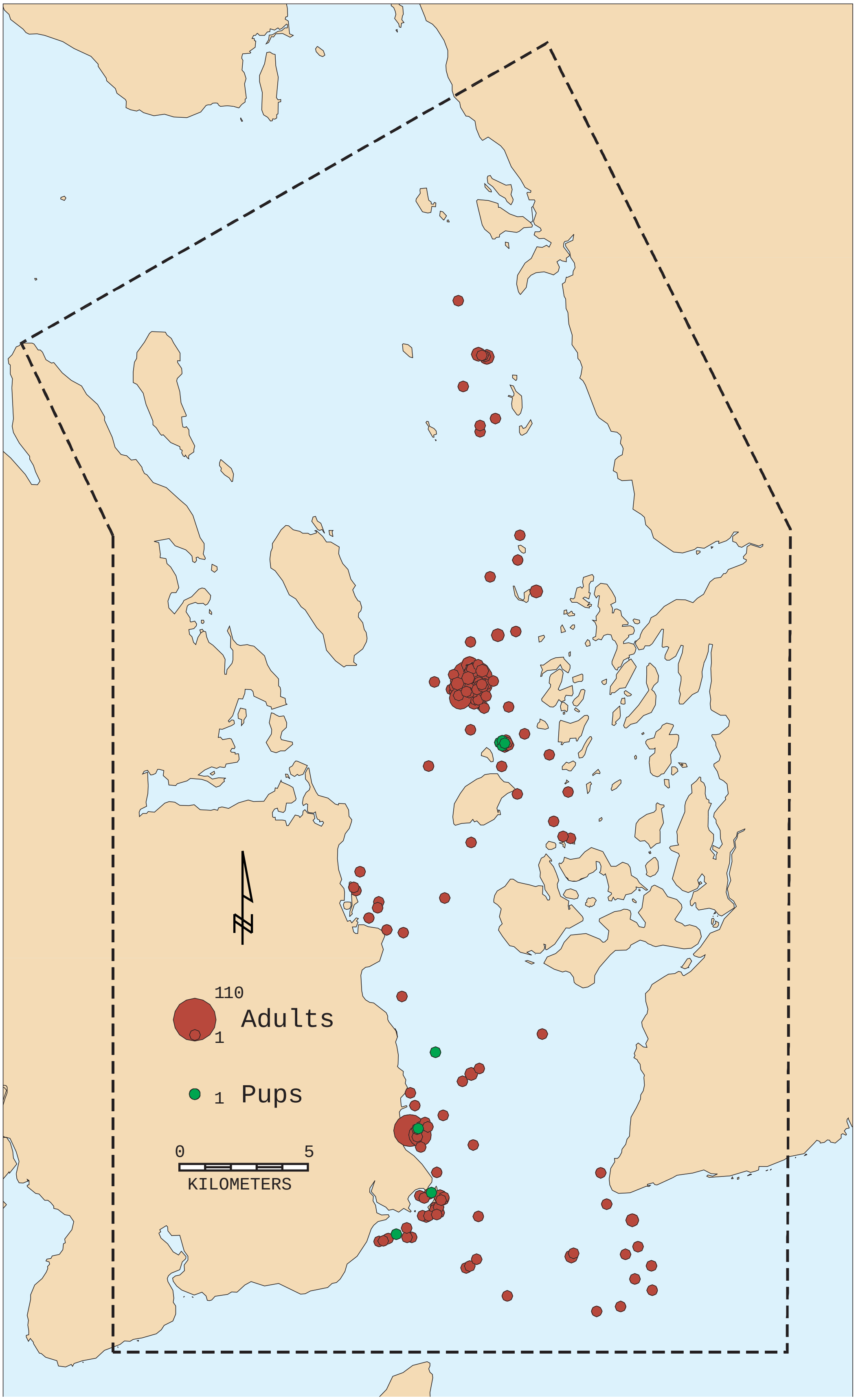


Figure 3. Sea otter group locations from 4 replicate surveys in Glacier Bay National park, May 2000.

surrounding areas in Icy Strait and Cross Sound, have shown evidence of seasonal movements (Table 2). For example, from March to August 1996, the number of otters increased at Pt. Dundas – Pt. Gustavus, Gull Pt. – Lavina Pt., and Lavina Pt. – Column Pt.; while the number of otters decreased in Glacier Bay proper and at Pt. Gustavus – Porpoise Island.

The number of sea otters occupying Glacier Bay is increasing rapidly, from a count of 5 in 1995 to 554 in 2000 (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 presence of dependent pups (Figure 3, green circles). One adult female tagged in Port Althorp in 1998 was observed near South Marble Island in July 1999 with a dependant pup. 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.

Foraging Observations

Foraging Observations

Observations of sea otter foraging behavior were carried out to determine prey types, numbers, and sizes utilized by sea otters. Foraging work consisted of shore and ship based observations at sites within Glacier Bay, Icy Strait, and Dundas Bay in Southeast Alaska (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 park 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). We assumed that each foraging bout records the feeding activity of a unique individual, therefore bouts were considered independent while dives within bouts were not.

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 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 was not collected on dependent pups.

Data collected

For each bout, the date, site, observer, otter's identification (if possible), estimated age (adult, juvenile, pup), sex, and reproductive status (independent or with pup) was recorded. Location of the focal otter was mapped. From the mapped location the foraging depth was determined or estimated from available GIS bathymetric data

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; (4) success rate; and (5) mean biomass captured per dive. We contrast diet among three sampling areas, Glacier Bay, south Icy Strait (including Idaho Inlet and Port Althorp), and Dundas Bay. We also contrast diet among sites within Glacier Bay. Because individuals are not marked, we cannot identify individual dietary differences.

Results

To date, we have collected data from three areas in southeast Alaska: Dundas Bay, south Icy Strait, and Glacier Bay proper. Within each area, observations have been collected from several sites. Information from 4975 dives, comprising 570 bouts, was recorded. Of those dives, 780 were observed at Dundas Bay, 1284 in south Icy Strait, and 2911 at sites within the Park. Numbers of dives with successful prey captures are lower. Sea otters were observed feeding on at least 30 different prey items including bivalves, decapod crustaceans, gastropods, and echinoderms (Table 3).

Prey Composition

To address the composition of sea otters' diets we looked for the presence of each prey type in each successful dive per sampling site as well as per area (Table 4). Overall, in areas of southeast Alaska sampled, clams are the prime prey choice by otters (Figure 4.). Sea otters recovered clams on 40 to 60% of the successful dives observed. Crabs were an important prey item for otters in Dundas (recovered on 20% of dives), urchins in S. Icy and Glacier Bay (recovered on 17% and 21% of dives), as were mussels (*Modiolus modiolus*) in Glacier Bay (recovered on 18% of dives). There was dietary variation at individual sites within an area. For example, recovery of clams ranged from 13 to 84%, mussels from 0 to 47%, and urchins from 0 to 68% at sites within Glacier Bay (Table 4, Figure 5). Variation among sites is obvious and it is interesting to note that even at sites in close proximity, otters are utilizing different prey resources. For example, at three sites separated by less than 1 km (Boulder 1, Boulder 2, Sita Reef), sea otters recovered different proportions of clams, mussels, and urchins (Table 4 and Figure 6).

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

Phylum (Subphylum)	**Class (Order)**	**Prey Item**
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 nuttallii*, *Serripes groenlandicus*, *Modiolus modiolus*, *Mytilus trossulus*, *Pododesmus macroschisma*, scallop
	Cephalopoda	*Octopus dofleini*
Echiura		*Echiurus* spp.
Arthropoda (Crustacea)		
	Cirripedia	
	(Decapoda)	*Cancer magister*, *Chionoecetes bairdi*, *Oregonia gracilis*, *Paralithodes camtschatica*, *Telmessus cheiragonus*
Echinodermata		
	Asteroidea	*Pycnopodia helianthoides*, *Solaster* spp.
	Ophiuroidea	*Ophiuroid* spp., *Gorgonocephalus caryi*
	Echinoidea	*Strongylocentrotus droebachiensis*, *S. franciscanus*
	Holothuroidea	*Cucumaria fallax*
Chordata		
	Osteichthyes	fish

Table 4. Percentage of dives with each prey type present. '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). 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

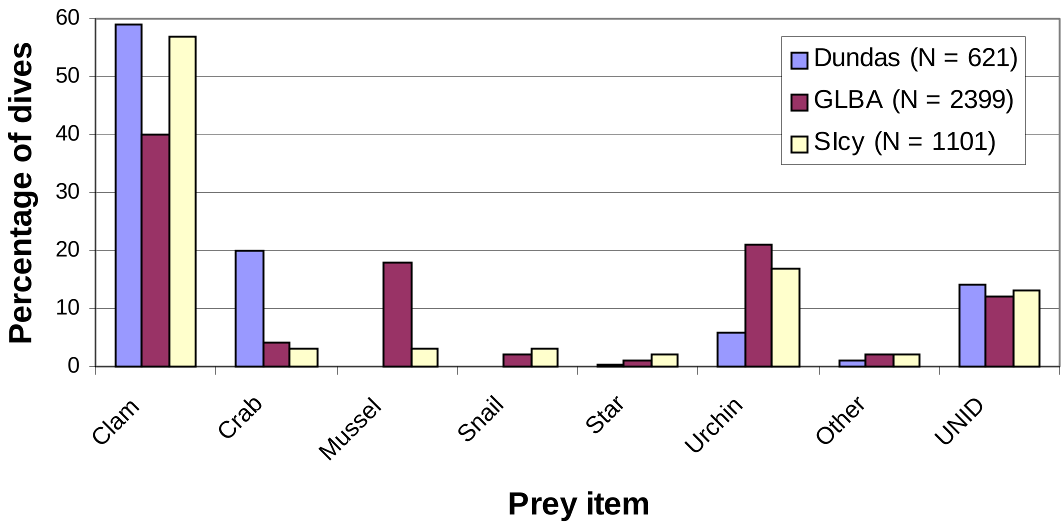


Figure 4. Prey composition of sea otter foraging dives in Dundas Bay, Glacier Bay proper (GLBA), and south Icy Strait (SIcy). This figure shows the percentage of all dives of known outcome that include each prey item. For example, sea otters retrieved at least one clam on 59% of their dives in Dundas Bay. N = number of dives with known outcome. 'Other' consists of worms, octopus, fish, sponges, sea cucumbers, shitons, non-clam/mussel bivalves, barnacles, and sea peaches. 'UNID' represents prey items not identified due to visual obstruction.

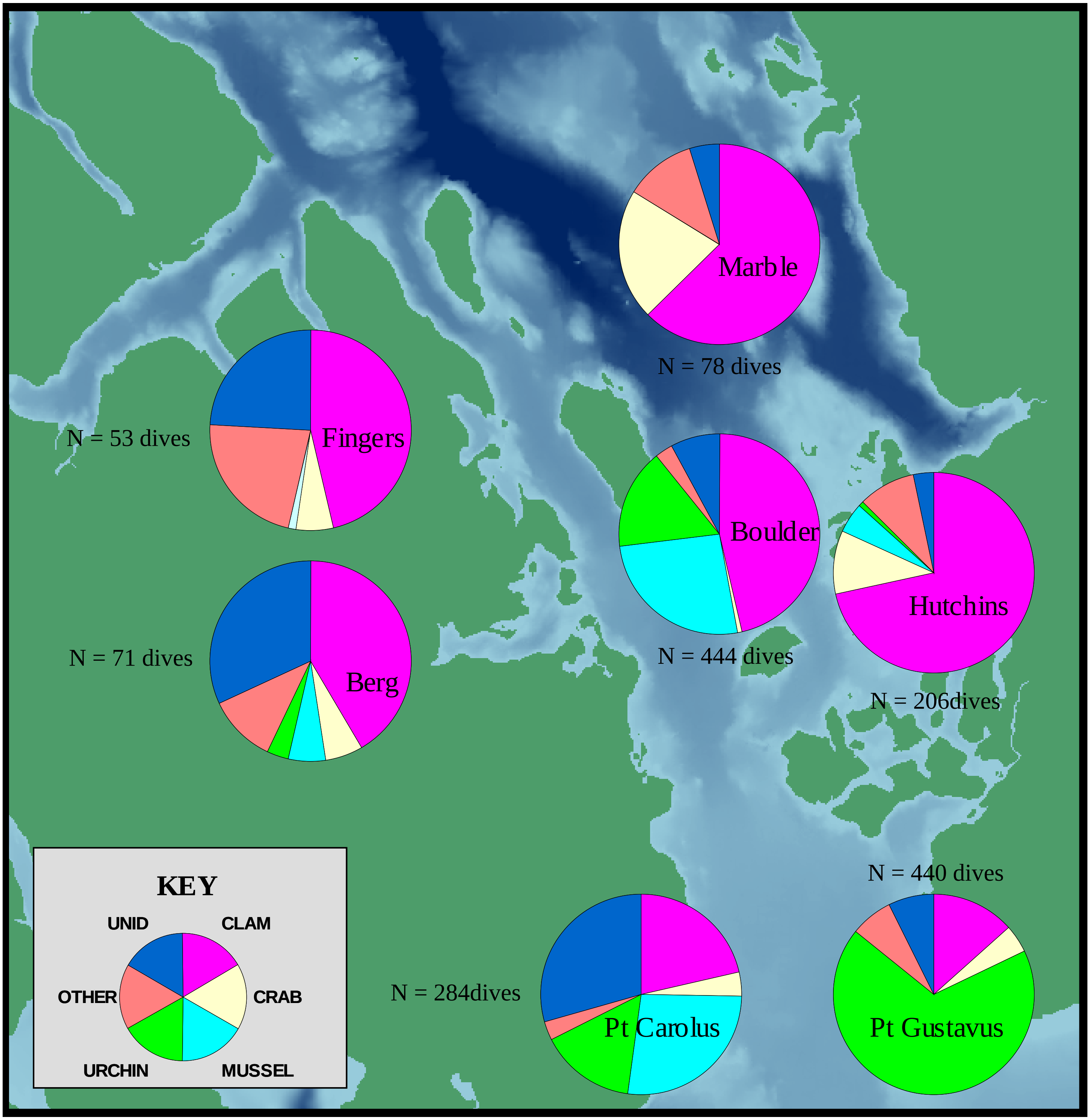


Figure 5. Percentage of prey types in successful sea otter foraging dives at various sites in Glacier Bay. This figure shows that prey utilization at sites within one study area can vary. This variation is due to differences in prey composition at individual sites as well as otter prey selection preferences.

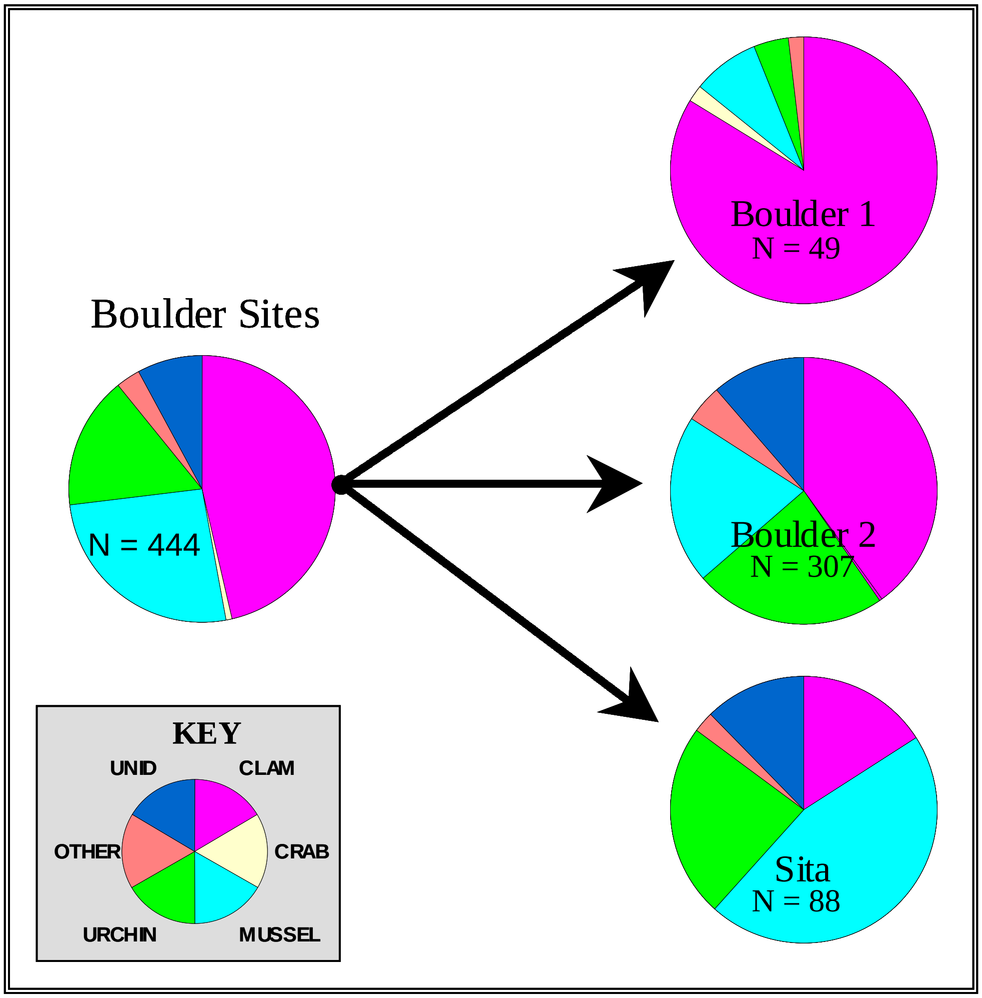


Figure 6. Percentage of each prey type in dives at the Boulder area and then individual sites within the Boulder area showing how variation in prey utilization occurs even on small geographic scales. See Figure 5 for prey composition of foraging dives at other areas within Glacier Bay.

Prey Number and Size

On dives when specific prey types were recovered, we averaged the number of individuals of that prey type and the sizes of those individuals, by sampling area and prey type (Figure 7). In south Icy Strait we consistently observed the highest average number of prey per dive across all prey types. We also observed mean prey size to be consistently smallest in south Icy Strait over all prey types, compared to either Dundas or Glacier Bay (Figure 7). In Glacier Bay sea otters retrieved an average of 2 clams, 1.1 crabs, 2.5 mussels or 3.7 urchins per dive. In Glacier Bay the mean size of clams recovered was 58 mm, crabs 73 mm, mussels 85 mm, and urchins 45 mm. Mean clam sizes were uniform among areas (40 to 55 mm), crabs were largest in Dundas, averaging 85 mm, mussels were smallest in south Icy, averaging 20 mm. Mussels consumed in south Icy were *Mytilus trossulus,* and in Glacier Bay were *Modiolus modiolus*.

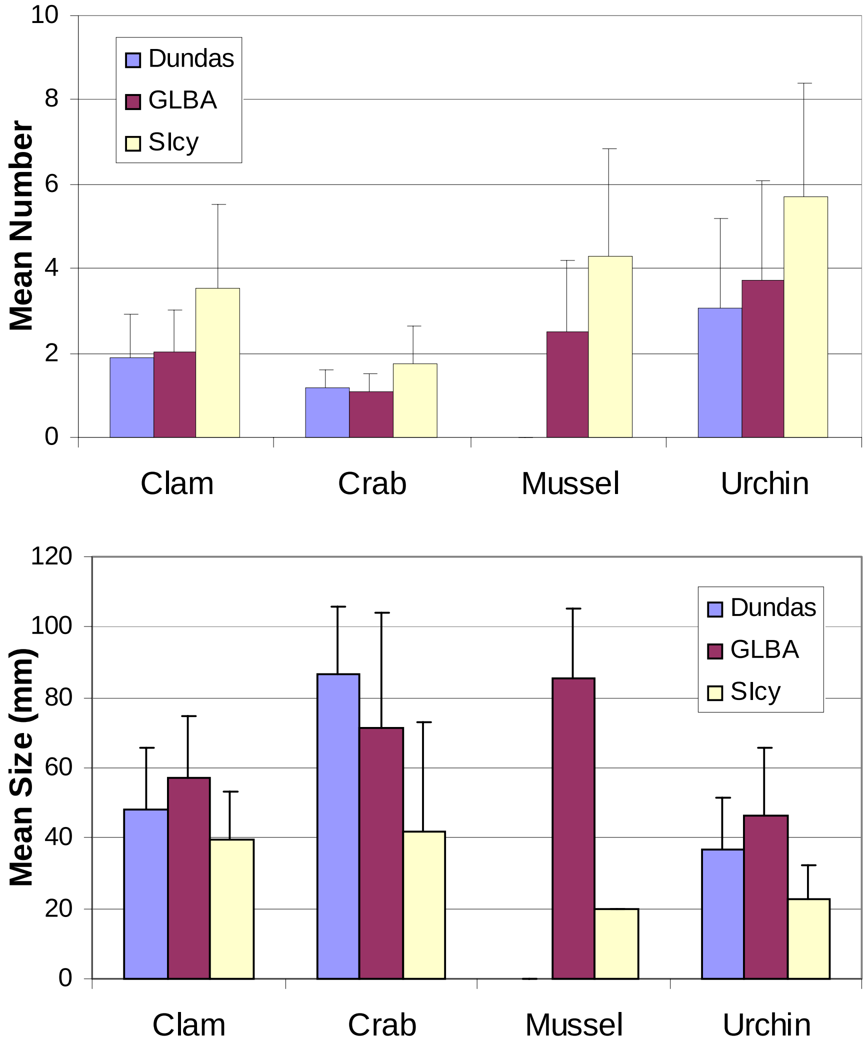
Discussion

Although differences in diet composition were detected among sampling areas, 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 in all three areas (Figure 4). In Dundas Bay crabs were important, in Glacier Bay mussels were important, and in South Icy Strait and Glacier Bay, urchins were important (Figure 4). These differences likely reflect habitat differences among areas.

Within the Glacier Bay sampling area, we found high variation in the species composition of the sea otters' diet (Figure 5, Table 3). For example, the green sea urchin was present in 68% of the foraging dives at Pt. Gustavus, 15% at Pt. Carolus, and 0% at Marble, Hutchins and Fingers. While clams were predominant at most sites, their proportion varied from between 10 to 20 % to 90% depending on location. Crab were present in the diet at most sites, but in relatively small proportions, usually < 10% but at S. Marble were recovered in 63% of the dives (Figure 5, Table 4). We also detected striking differences in diet within sampling sites. At the Boulder site we collected foraging data at three locations that were separated by < 1 km. We found clams present from 16 to 84%, mussels from 8 to 47% and urchin from 4 to 24% of the observed dives (Table 4, Figure 6).

The pattern of increasing average number of prey while the average prey size declines suggests a functional predation response to the reduction in average prey size. This finding is consistent with the premise that sea otters select the largest, most energetically valuable prey first, eventually switching to the smaller but more numerous prey, as the larger sizes are removed (Kvitek et al. 1992).

The observed differences in diet likely reflect differences in the abundance and availability of different prey types. For example, urchins generally occur in highest densities over rocky bottoms and their preponderance in the diet at certain sites probably



		Clam	Crab	Mussel	Urchin
#dives:	Dundas	272	78	.	19
	GLBA	686	31	314	397
	SIcy	471	25	26	145
#bouts:	Dundas	23	19	.	3
	GLBA	88	21	43	60
	SIcy	45	10	5	21

Figure 7. Mean number (top graph) and size (bottom graph) of clams, crabs, mussels, and urchins retrieved by sea otters foraging in Dundas Bay, Glacier Bay proper (GLBA), and south Icy Strait (SIcy). In general, the larger the prey item, the fewer an otter retrieved. For example, mussels retrieved in GLBA are large *Modiolus*, therefore only a few are retrieved per dive, whereas smaller *Mytilus* are retrieved at SIcy sites, thus the number retrieved per dive is higher.

indicates rocky habitats. Conversely, most clams reside in soft sediment habitats and their preponderance in the diet likely indicates soft sediment habitats. If the differences we observed in diet reflect differences in prey populations, rather than dietary differences among individual sea otters, it suggests sea otter effects may occur initially on rather small scales, and may be dependent on habitat types. An example of a small scale potential sea otter effect is depletion of *Modiolus modiolus* beds in the Beardslee Islands and Pt. Carolus.

Mapping observed foraging locations, characterizing habitat type, and describing the types of prey recovered will allow definition of ecologically important areas and prey species.


Intertidal Clam Sampling

Intertidal Clam Sampling

Study of prey populations will allow documentation of species composition, abundance, and size distributions in Glacier Bay. Proper documentation will allow description of changes resulting from sea otter foraging, will provide discrimination among other potential factors affecting intertidal communities, and will allow inference to all of Glacier Bay. In this annual report, we describe clam species composition, species diversity, size distribution, abundance, and biomass from our intertidal soft sediment sampling of Glacier Bay, Idaho Inlet, and Port Althorp.

Methods

Site Selection

For site selection, this study utilized the results of the aerial portion of the Glacier Bay Inventory and Monitoring Protocol (Irvine 1998). In that protocol 241 sites were sampled via fixed-wing aircraft for coverage by mussels, barnacles, and fucus, substrate category, and slope estimation. We eliminated any sites that were too steep or were part of the monitoring protocol development study and then using a random start, systematically chose sites to sample for intertidal clams. Ultimately we sampled 48 sites throughout Glacier Bay proper (Figure 8), several selected sites were eliminated due to snow avalanche danger, consolidated substrate, or excessive mud. In addition to the systematically chosen sites, we sampled 12 sites in preferred clam habitats (PCH) within the Park (Figure 8). These sites were chosen based on the prevalence of shell litter and/or siphon squirts observed at low tides. One of the primary focuses of this project is to examine the impacts of sea otters on the nearshore environment. To better understand the potential impacts we expanded our sampling efforts to include areas where sea otter populations are already established. Sea otters have been observed in Idaho Inlet and Port Althorp for 12 and > 20 years, respectively (Pitcher 1989). We divided the coastline of each area into 200m segments, estimated the number of sites we could sample during a minus-tide cycle, and beginning from a random start, systematically chose sites to sample. We sampled 14 sites in Idaho Inlet and 12 in Port Althorp (Fig. 9). Throughout this section of the report we differentiate among Glacier Bay systematically chosen sites (GLBA Random, including Lower Bay, Upper East and Upper West Arms), preferred habitat sites (GLBA PCH), Idaho Inlet sites (Idaho), and Port Althorp sites (Althorp).

Sampling Protocol

The sampling protocol was similar to that detailed in the 1999 Annual Report (Bodkin and Kloecker 1999) and was adapted from an intertidal clam sampling protocol we used in Prince William Sound, Alaska (Appendix C). A handheld GPS was used to navigate to the segment. At each site a 200m transect was positioned horizontally along the beach at the 0MLLW tide level. A random starting meter was chosen and ten $0.25m^2$ quadrats placed 20m apart were excavated to a depth of 25cm (Figure 10). All sediments were sieved through a 10mm mesh screen and all clams (as well as crabs and urchins at most

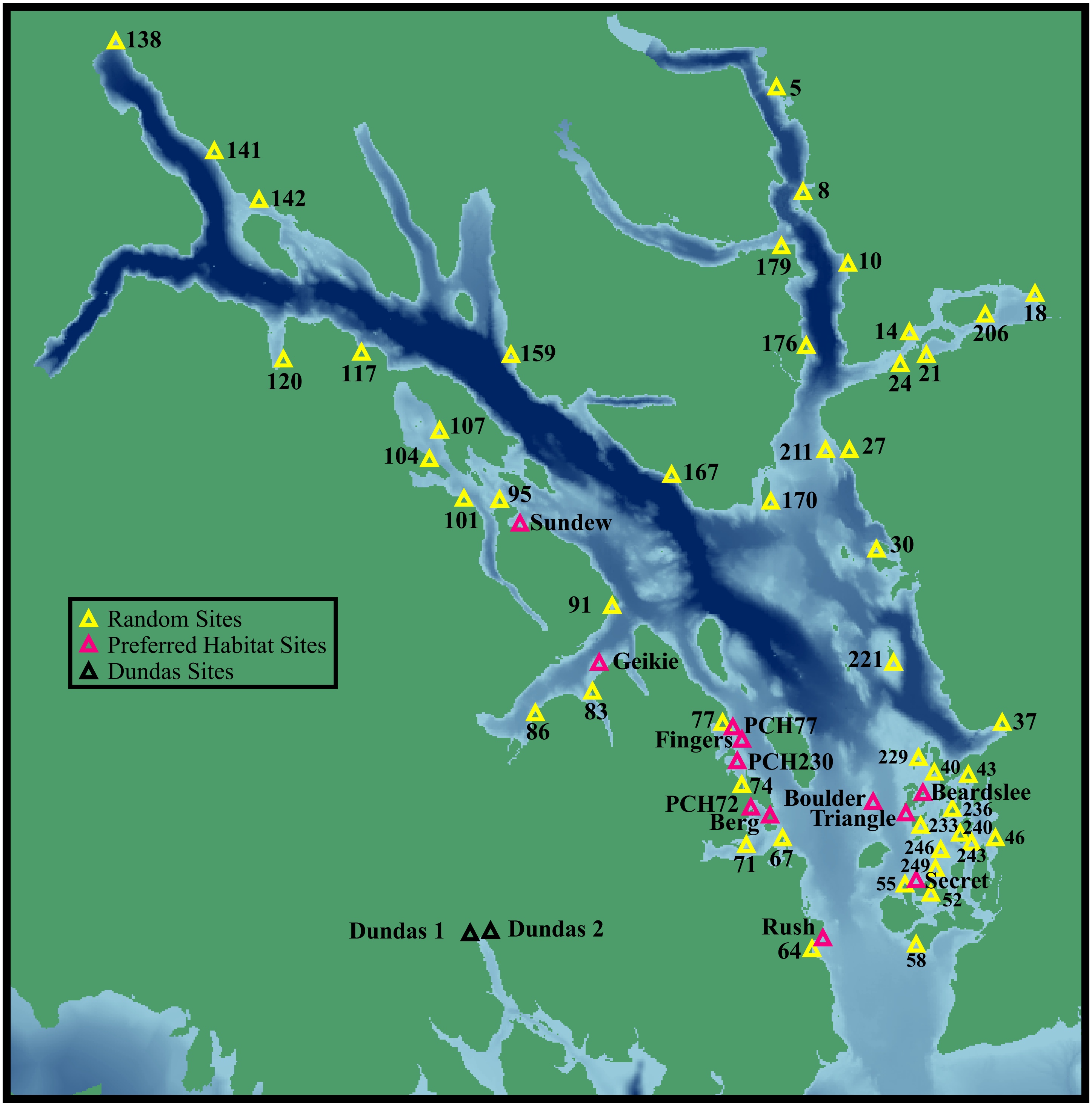


Figure 8. Map of Glacier Bay National Park and Preserve showing intertidal sampling sites. Yellow symbols represent sites chosen with a random start and systematic sampling thereafter. Pink symbols represent sites chosen for the likliehood of high clam abundance (e.g. shell litter or squirts observed). Black symbols represent two sites sampled as part of a baseline data set in response to ship grounding. The background map shows the bathymetry of Glacier Bay, lighter colors = shallower waters.

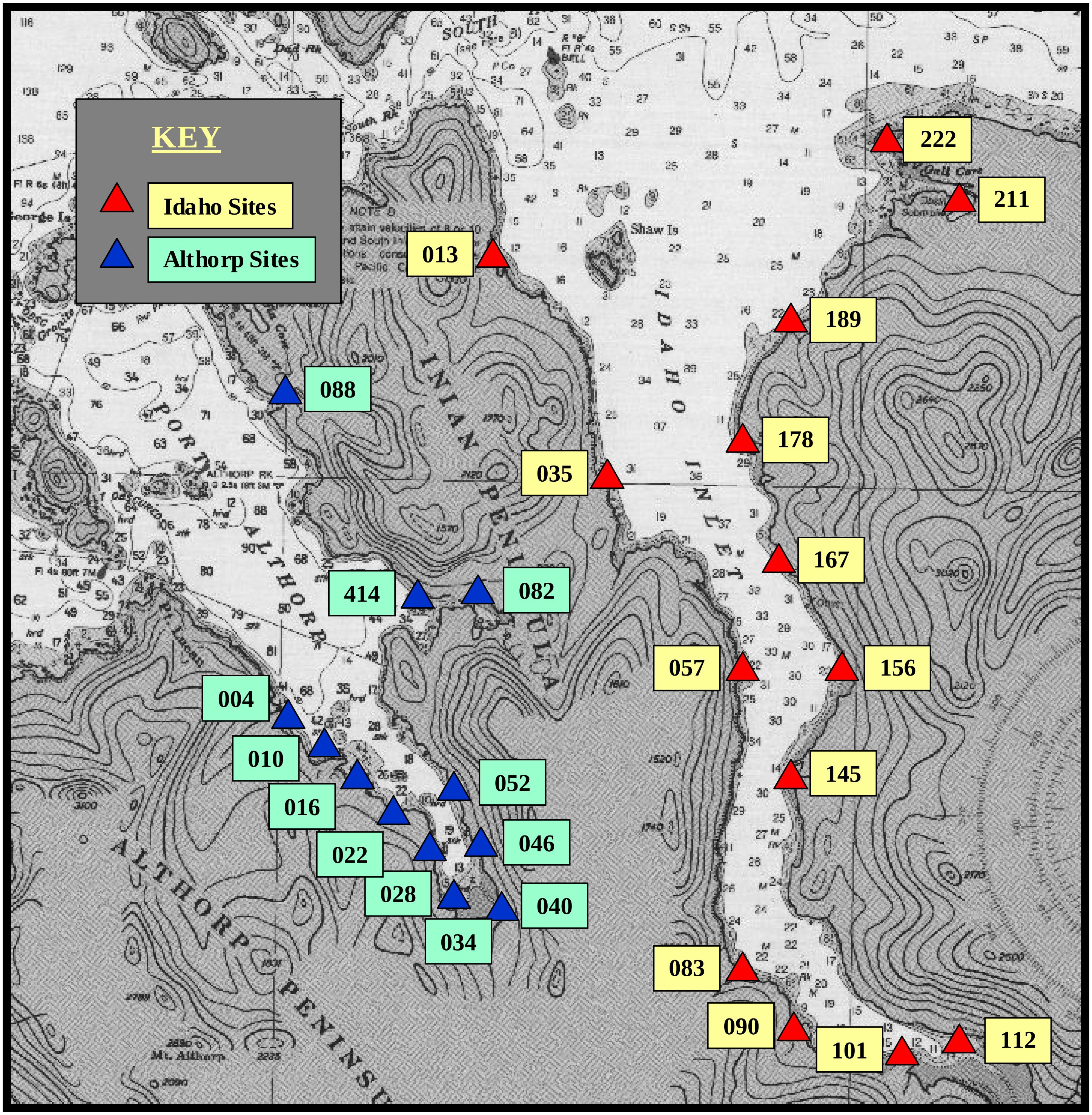


Figure 9. Map showing intertidal sampling sites in Idaho Inlet and Port Althorp. Sites were chosen systematically with a random start point. Some chosen sites were dropped from the sampling after visiting the site and finding the slope to be too steep or the substrate unsuitable for digging.

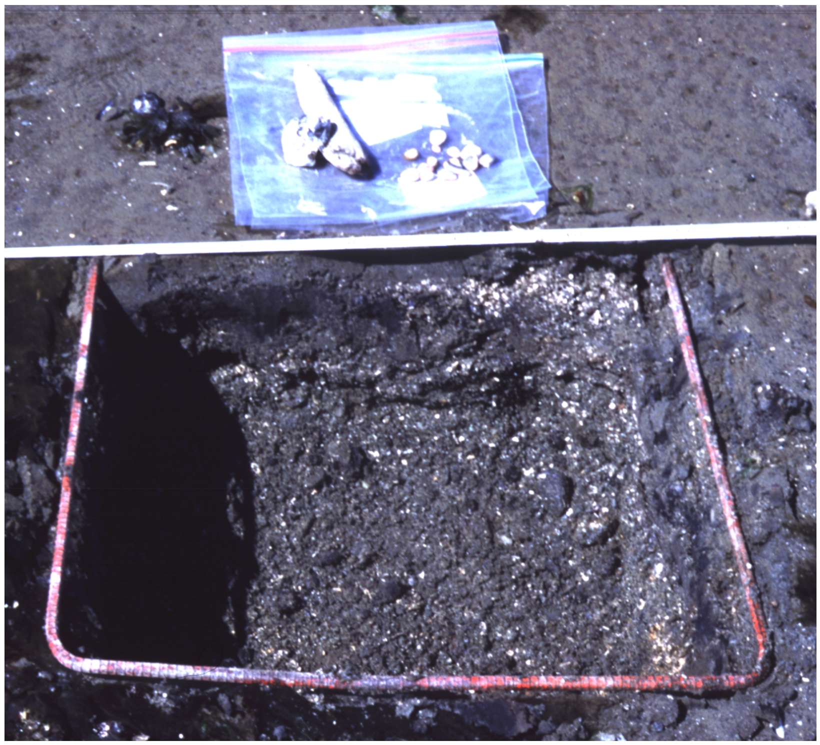


Figure 10. An excavated quadrat. Clams found in the sediments from this quadrat are on the ziploc bag behind the transect tape.

sites) were identified to the lowest possible taxa, counted, and measured to the nearest millimeter using dial calipers. Sediments were returned to the quadrat during the sieving process, while biota was returned following measurements.

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 the data set collected to date is intended to be compared 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.

Results

Clam 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'. The theoretical maximum for H' equals $\log_2$ (total number of species), in our study H'_{max} equals 3.60. Mean, minimum, and maximum diversity values for sampling regions (East Arm, West Arm, Lower Bay, Idaho Inlet, and Pt. Althorp) are presented in Table 5. Generally, intertidal clam diversity was greater in the lower Bay than in either Arm and higher in Idaho and Althorp than in either Arm (Table 5). Maximum species diversity values were generally similar among all areas sampled ranging from 1.54 at Glacier Bay West Arm to 2.19 at Lower Bay.

Table 5. Shannon-Weiner diversity index values (H') for intertidal clam sampling areas. H' = 0 when only 1 species is present, H'_{max} = 3.60.

Area	N	Mean H' (sd)	Minimum	Maximum
GB PCH	12	1.59 (0.40)	0.80	2.07
Lower Bay	19*	1.47 (0.66)	0.00	2.19
West Arm	12*	0.47 (0.61)	0.00	1.54
East Arm	14	0.56 (0.68)	0.00	1.92
Idaho Inlet	14	1.37 (0.47)	0.38	2.11
Port Althorp	10*	1.39 (0.41)	0.57	1.93

*N is less than total number of sites in an area because some sites had no clams and therefore the diversity index was null.

In our 1999 sampling we found 8 different intertidal clam species: *Clinocardium nuttallii* (CLN), *Gari californica* (GAC), *Hiatella arcticus* (HIA, now HIS for *Hiatella* spp.), *Macoma* spp. (MAS), *Mya* spp.(MYS), *Protothaca staminea* (PRS), *Pseudopythina compressa* (PSC), and *Saxidomus gigantea* (SAG). We also found a few unidentifiable clams that were lumped under the category other clam (CLA). In 2000 we again found all the species listed in 1999 as well as *Entodesma navicula* (ENN), *Humilaria kennerleyi* (HUK), and *Panomya ampla* (PAA). We lumped *Mya arenaria* and *M. truncata* because there were so few *M. arenaria*. We lumped all *Macoma* species because many are unidentifiable without dissection of the clam. However, we were able to identify *M. balthica* and *M. nasuta* in our samples and *M. inquinata, M. Macoma cf. calcarea,* and *M. obliqua* were found in core samples sieved through a 500 µm screen.

Clam Density

The number of clams per quadrat varied extensively within sites as well as among sites and areas. Mean densities of all clams per quadrat ranged between 0 – 137, 39 – 161, 2 – 120, and 0 – 30 for GLBA Random, GLBA PCH, Idaho Inlet, and Pt. Althorp, respectively (Figures 11 and 12). For each species, the minimum number per quadrat was zero in at least one quadrat per area. At GLBA Random sites, the maximum number per quadrat was 149 *Macoma*, 102 *Protothaca*, 114 *Hiatella*, 18 *Saxidomus*, 45 *Mya*, 18 *Pseudopythina*, and 12 *Clinocardium*. At GLBA PCH sites the maximum numbers were 161 *Macoma*, 50 *Protothaca*, 143 *Hiatella*, 46 *Saxidomus*, 33 *Mya*, 14 *Pseudopythina*, and 1 *Clinocardium*. In Port Althorp the maximum numbers were 24 *Macoma* , 53 *Protothaca* , 5 *Hiatella*, 29 *Saxidomus*, 11 *Mya*, and 2 *Clinocardium*. In Idaho Inlet the maximum numbers were 217 *Macoma* , 178 *Protothaca*, 36 *Hiatella* , 33 *Saxidomus*, 7 *Mya*, and 6 *Clinocardium*. Figures 11 and 12 show the mean numbers per quadrat of each clam species at every site. The presence of *Entodesma*, *Gari*, *Humilaria*, *Panomya*, unidentified clam was rare; therefore summary statistics were not calculated for these species.

In analyzing clam densities, *Macoma* was the predominant clam, followed by *Protothaca*, at most sites, both random and PCH, within Glacier Bay. A few exceptions were the prevalence of *Hiatella* at site 170 on Seabree Island, 211 on Garforth Island, and 77 and PCH230 in Fingers Bay; the incidence of *Protothaca* at site 43 in the Beardslee Islands; and the even distribution of several clam species at sites 221 on Leland Island, 229 in the Beardslee Islands, and the preferred habitat site at Rush Point. At Idaho Inlet and Port Althorp, *Protothaca* was the predominant species, followed by *Macoma*, and *Saxidomus* (only at Pt. Althorp).

Mean clam densities in lower GLBA were 2.5 - 5 times greater than in the upper Arms and were about 3 times less than the preferred clam habitat (PCH) sites (Table 6 and Figure 15). Densities at PCH sites were 8 – 14 times higher than random sites in the upper Arms. Clam densities at Idaho Inlet were similar to lower Bay sites, and at Port Althorp were similar to densities in the upper Arms of Glacier Bay (Figures 11, 12, and 15).

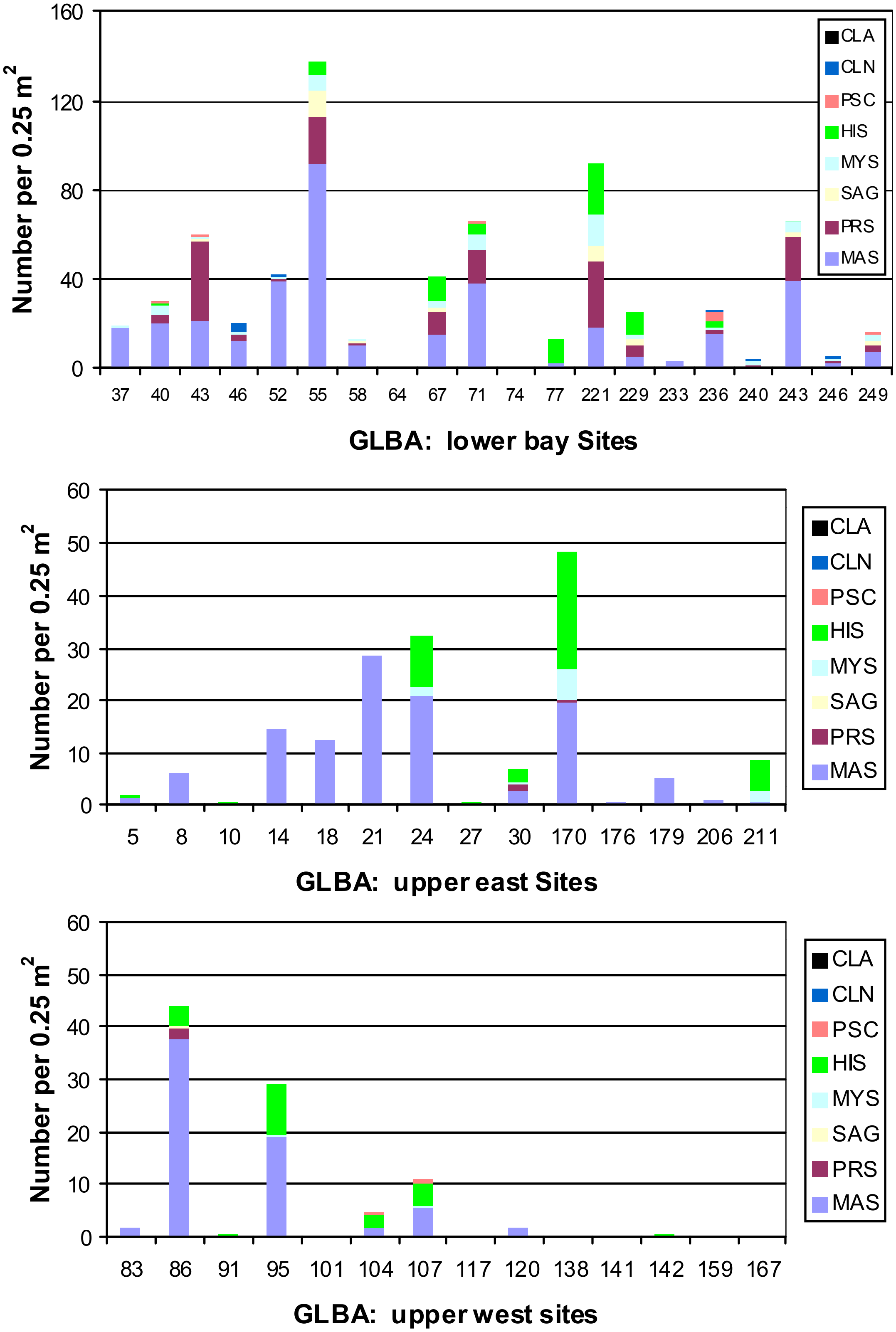


Figure 11a. Mean number of clams per 0.25 m^2 for randomly selected sites in Glacier Bay. Note the scale ranges from 0 - 160 clams per 0.25 m^2 at the lower bay sites while at the upper bay sites it ranges from 0 - 60 clams per 0.25 m^2. See Figure 8 for locations of the sites. Species abbreviation key: CLA = unknown and other clam species, CLN = *Clinocardium nuttallii*, PSC = *Pseudopythina compressa*, HIS = *Hiatella* species, MYS = *Mya* species, SAG = *Saxidomus gigantea*, PRS = *Protothaca staminea*, and MAS =

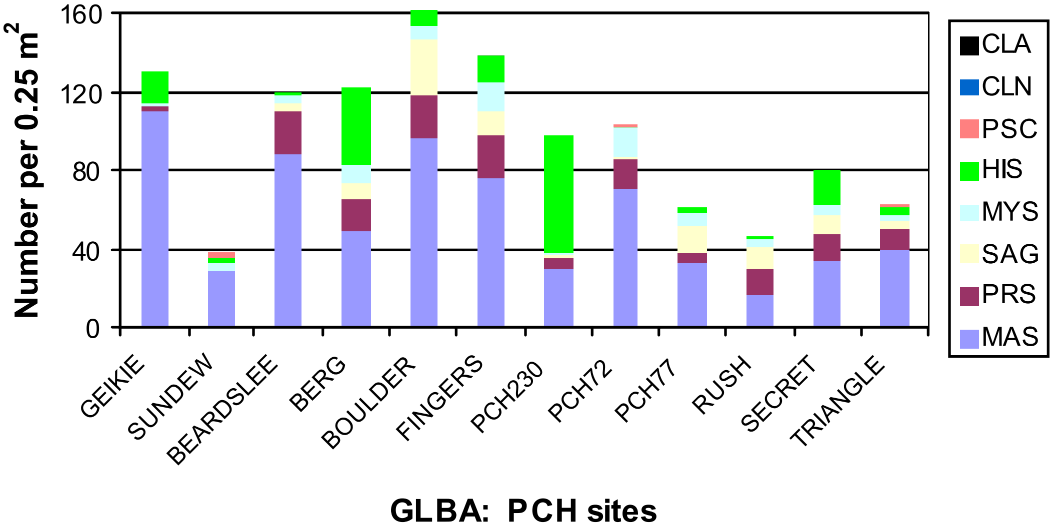


Figure 11b. Mean number of clams per 0.25 m^2 at preferred habitat (PCH) sites in Glacier Bay. See Figure 8 for locations of the sites. Species abbreviation key: CLA = unknown and other clam species, CLN = *Clinocardium nuttallii*, PSC = *Pseudopythina compressa*, HIS = *Hiatella* species, MYS = *Mya* species, SAG = *Saxidomus gigantea*, PRS = *Protothaca staminea*, and MAS = *Macoma* species.

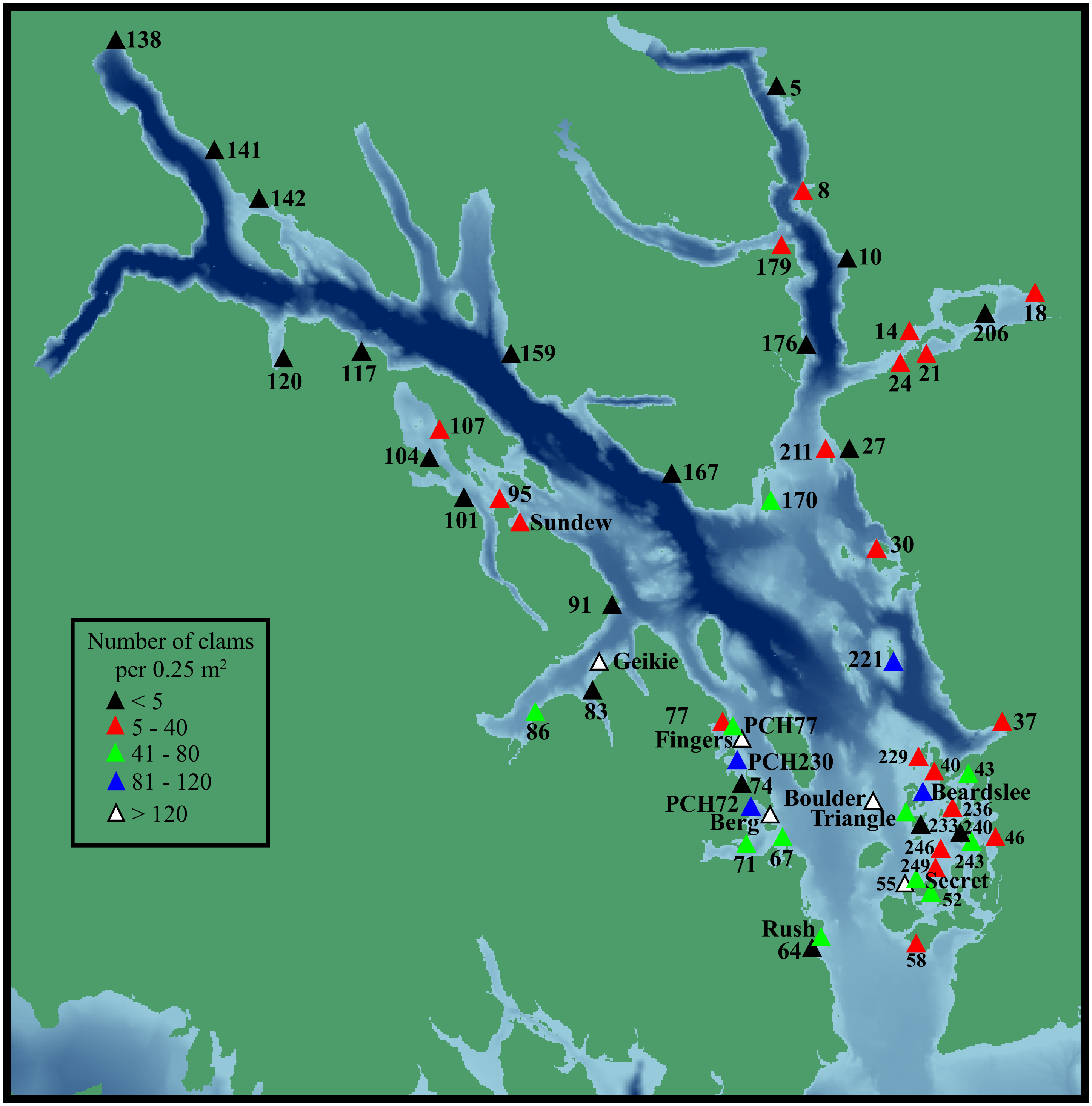
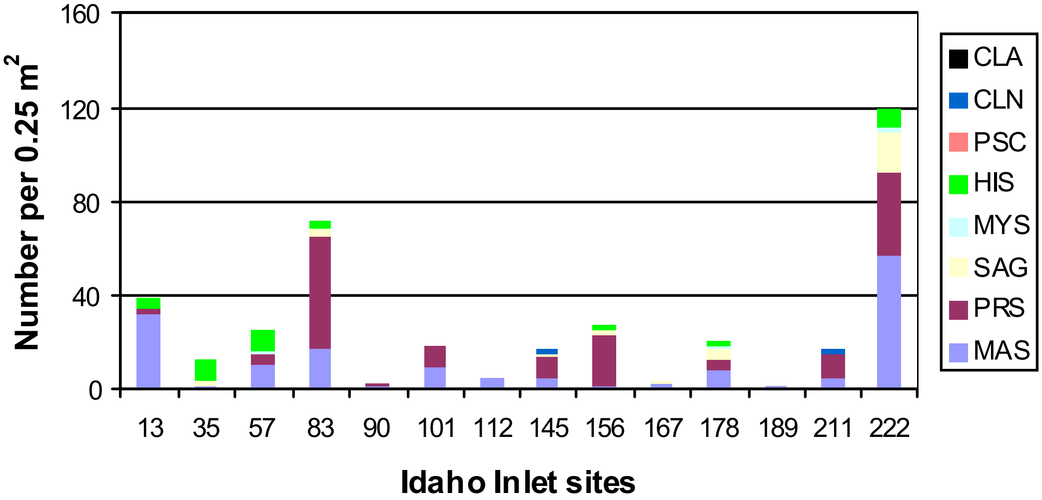


Figure 11c. Number of clams (all species combined) per 0.25 m^2 at all sites in GLBA. This figure summarizes data found in Figures 11a and 11b.



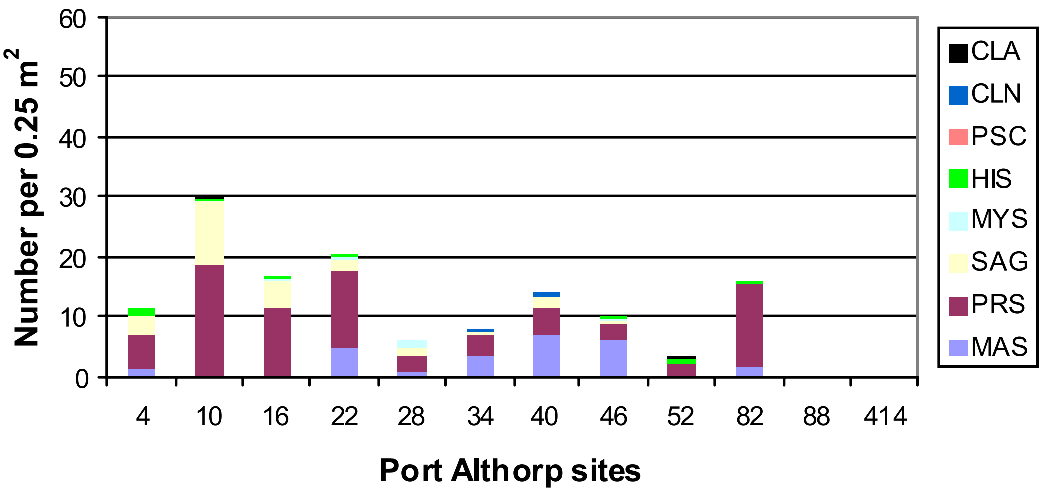


Figure 12a. Mean number of clams per 0.25 m^2 at sites in Idaho Inlet and Port Althorp. Note the scale ranges from 0 to 160 clams per 0.25 m^2 in Idaho Inlet while it ranges from 0 to 60 in Port Althorp. See Figure 9 for locations of the sites. Species abbreviation key: CLA = unknown and other clam species, CLN = *Clinocardium nuttallii*, PSC = *Pseudopythina compressa*, HIS = *Hiatella* species, MYS = *Mya* species, SAG = *Saxidomus gigantea*, PRS = *Protothaca staminea*, and MAS = *Macoma* species.

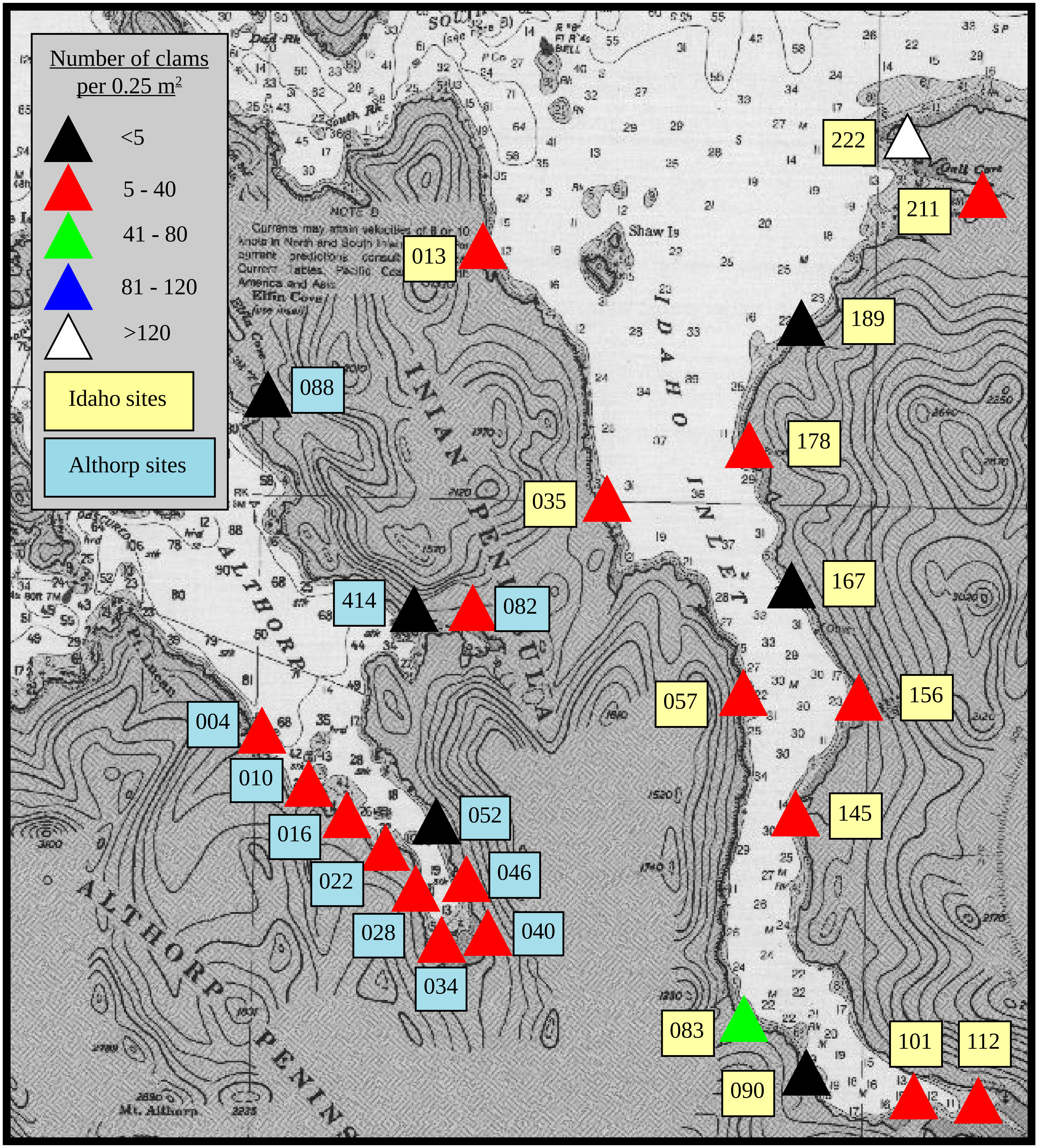


Figure 12b. Number of clams (all species combined) per 0.25 m^2 at sites in Port Althorp anad Idaho Inlet. This figure summarizes data from Figure 12a.

Clam Biomass

The biomass of clams per quadrat varied extensively within sites as well as among sites and areas (Figures 13, 14, 15, Table 6). Mean biomass of all clams per quadrat ranged between 0 - 101.7, 10.1 - 201.2, 1.8 - 37.9, and 0 - 14.8 for GLBA Random, GLBA PCH, Idaho Inlet, and Pt. Althorp, respectively (Figures 13 and 14).

Table 6. Mean total density (#/0.25 m^2) and total biomass (grams dry wt./0.25 m^2) of intertidal clams by area in Glacier Bay and Icy Strait, Southeast Alaska.

Area	Density all clams (#/0.25 m^2)	Biomass all clams (g/0.25 m^2)
GB PCH	96.7	73.4
Lower Bay	32.8	23.6
West Arm	6.7	0.91
East Arm	12.2	2.2
All GB Random	19.5	11.3
Idaho Inlet	27.1	9.7
Port Althorp	11.3	5.2

For each species, the minimum biomass was zero in at least one quadrat per area. Maximum biomass estimates by species and area are 22, 26, 28, and 7 for MAS at GLBA-Random, GLBA-PCH, Idaho Inlet, and Pt. Althorp, respectively. For *Protothaca*, keeping the order of areas the same, maximum biomass was 65, 57, 54, and 20, for *Saxidomus*, maximum biomass was 119, 265, 35, and 20, for *Mya*; 95, 87, 9, and 22, for *Hiatella*; 44, 24, 5, and 0.5 for *Pseudopythina* ; 0.6, 0.4, 0, and 0 and for *Clinocardium*; 65, 5, 4, and 4.

Although *Macoma* dominated intertidal clam densities, biomass estimates are influenced by the size of the different species of clams. In GLBA-Random lower Bay, GLBA-PCH, Idaho Inlet, and Pt. Althorp, mean biomass per quad of *Protothaca* was 1.3 – 3 times the biomass of *Macoma*. *Saxidomus* biomass was 2.5 – 5.6 times that of *Macoma*, with the exception of Idaho Inlet where *Saxidomus* *Macoma*. In GLBA Random lower Bay and PCH sites, *Mya* biomass was 1.3 – 1.6 times that of *Macoma*; while in Pt. Althorp, *Mya* and *Macoma* biomass were approximately equal; and in Idaho Inlet, *Mya* biomass was 5 times less than *Macoma* biomass. In GLBA upper East Arm, *Macoma* *Hiatella*; was 3.5 times greater than *Protothaca*, and 1.4 times less than *Mya* biomass. In the upper West Arm, *Macoma* was 3 – 3.8 times greater than *Protothaca*, *Saxidomus*, and *Hiatella*. *Mya* biomass in the upper West Arm was zero.

Total mean biomass per quad in lower GLBA was 11 – 26 times greater than in the upper Arms (Table 6 and Figure 15). PCH biomass was 2.4 times greater than the lower Bay and 34 – 81 times greater than the upper Arms. GLBA lower Bay biomass was 2.4 and 4.5 times greater than Idaho Inlet and Pt. Althorp. Biomass estimated for the upper Arms was 5 – 11 times less than in Idaho Inlet and 2 – 6 times lower than Pt. Althorp. PCH biomass was 7.5 and 14 times greater than in Idaho Inlet and Pt. Althorp (Table 6 and Figure 15).

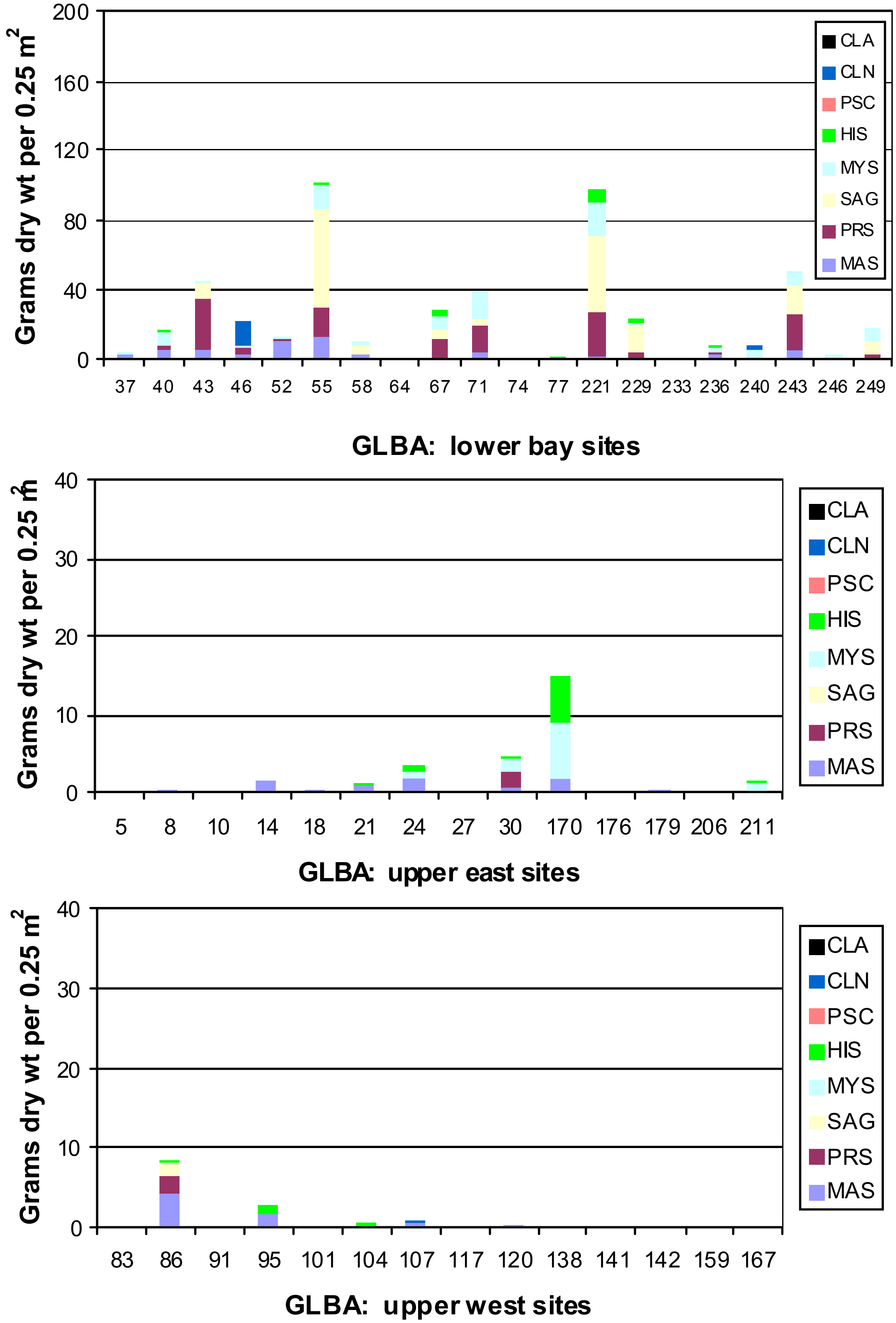


Figure 13a. Mean biomass in grams dry weight per 0.25 m^2 at randomly selected sites in Glacier Bay. Note the scales are different on the 3 figures: The scale on the GLBA upper figures ranges from 0 to 40 grams per 0.25 m^2 while the scale on the GLBA lower figure ranges from 0 to 200 grams per 0.25 m^2. See Figure 8 for site locations. Species abbreviation key: CLA = unknown and other clam species, CLN = *Clinocardium nuttallii*, PSC = *Pseudopythina compressa*, HIS = *Hiatella* species, MYS = *Mya* species, SAG = *Saxidomus gigantea*, PRS = *Protothaca staminea*, and MAS = *Macoma* species.

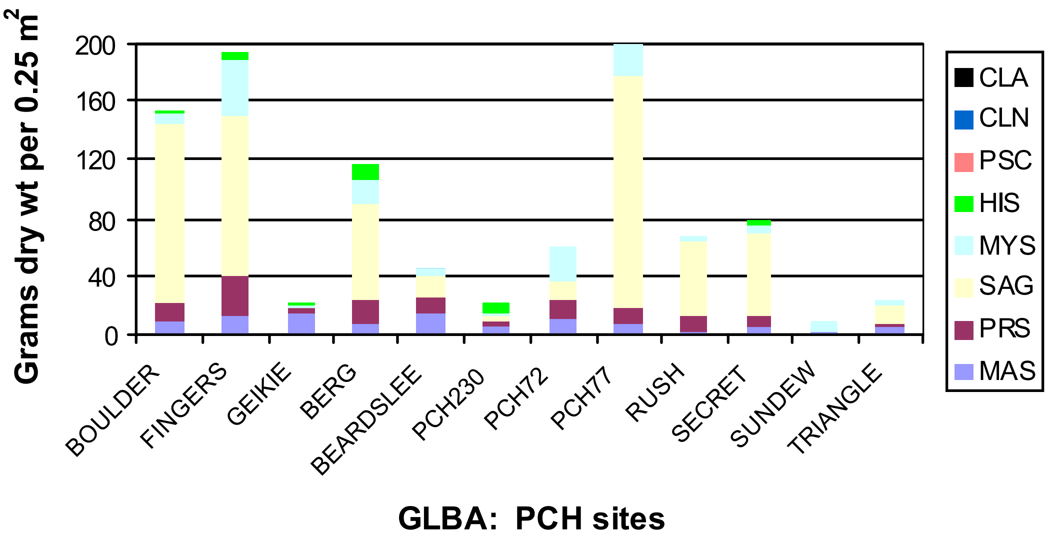


Figure 13b. Mean biomass per 0.25 m^2 at preferred habitat (PCH) sites in Glacier Bay. Note the scale on this figure ranges from 0 to 200 grams per 0.25 m^2. See Figure 8 for site locations. Species abbreviation key: CLA = unknown and other clam species, CLN = *Clinocardium nuttallii*, PSC = *Pseudopythina compressa*, HIS = *Hiatella* species, MYS = *Mya* species, SAG = *Saxidomus gigantea*, PRS = *Protothaca staminea*, and MAS = *Macoma* species.

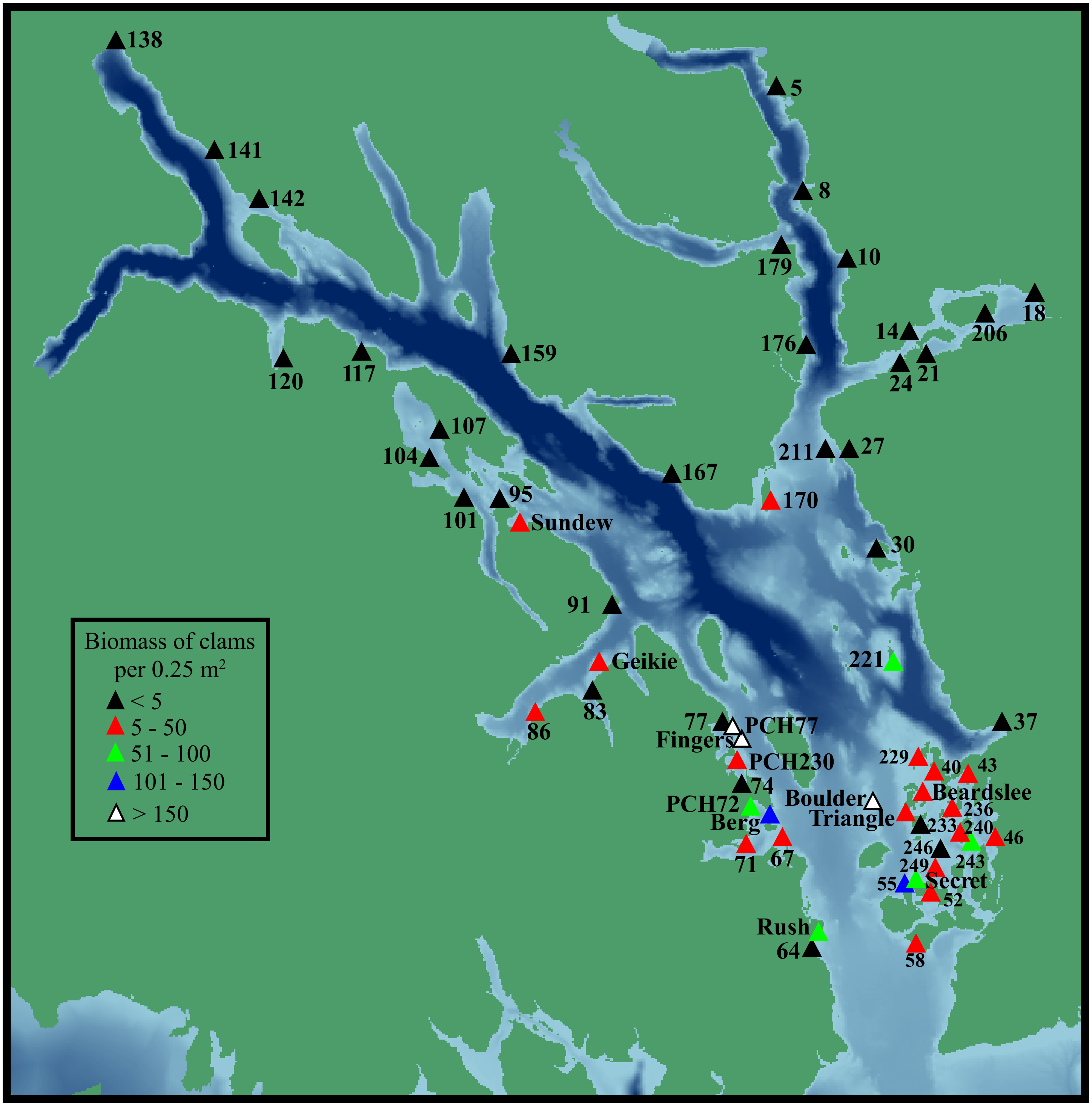
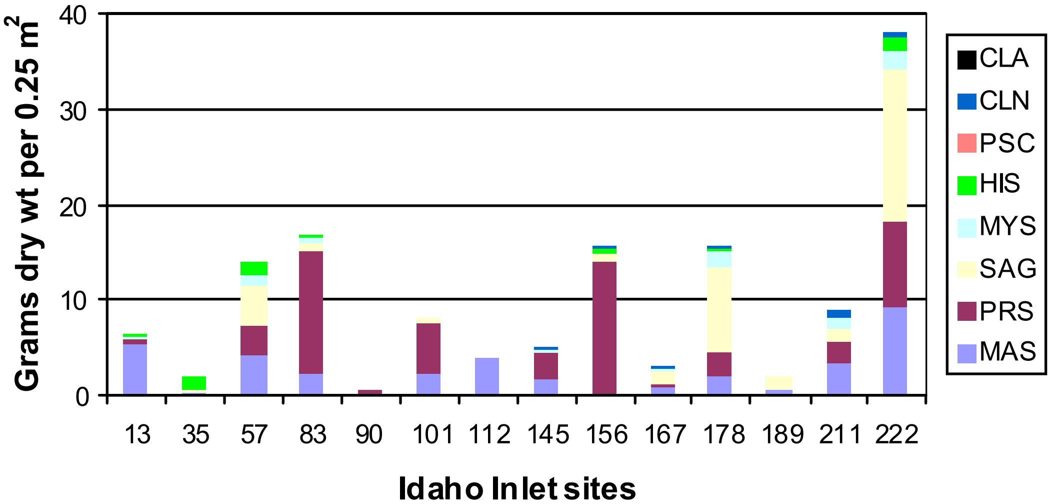


Figure 13c. Biomass (grams dry weight) of clams per 0.25 m² at sites in GLBA. This figure summarizes data from Figures 13a and 13b.



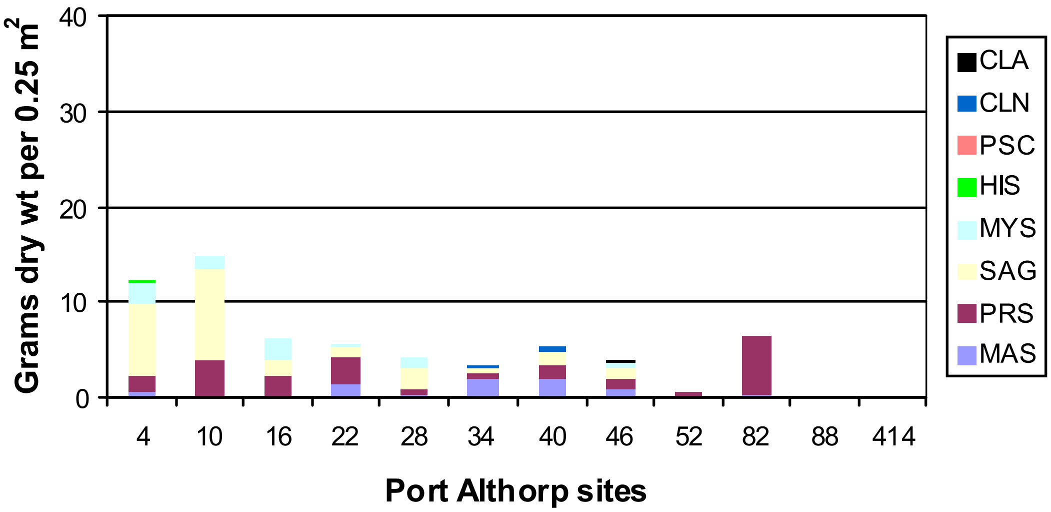


Figure 14a. Mean biomass in grams dry weight per 0.25 m^2 at sites in Idaho Inlet and Port Althorp. See Figure 9 for site locations. Species abbreviation key: CLA = unknown and other clam species, CLN = *Clinocardium nuttallii*, PSC = *Pseudopythina compressa*, HIS = *Hiatella* species, MYS = *Mya* species, SAG = *Saxidomus gigantea*, PRS = *Protothaca staminea*, and MAS = *Macoma* species.

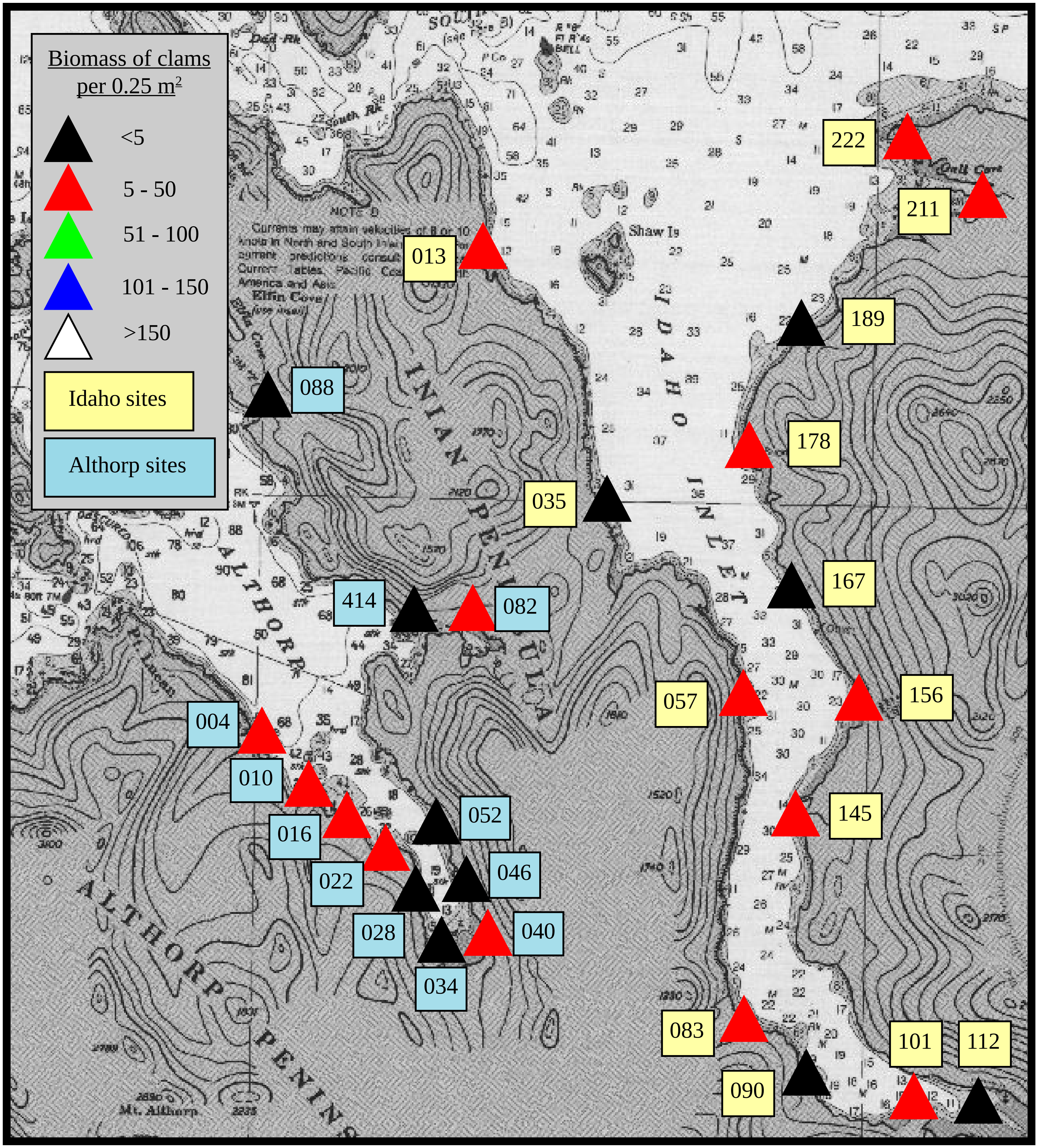
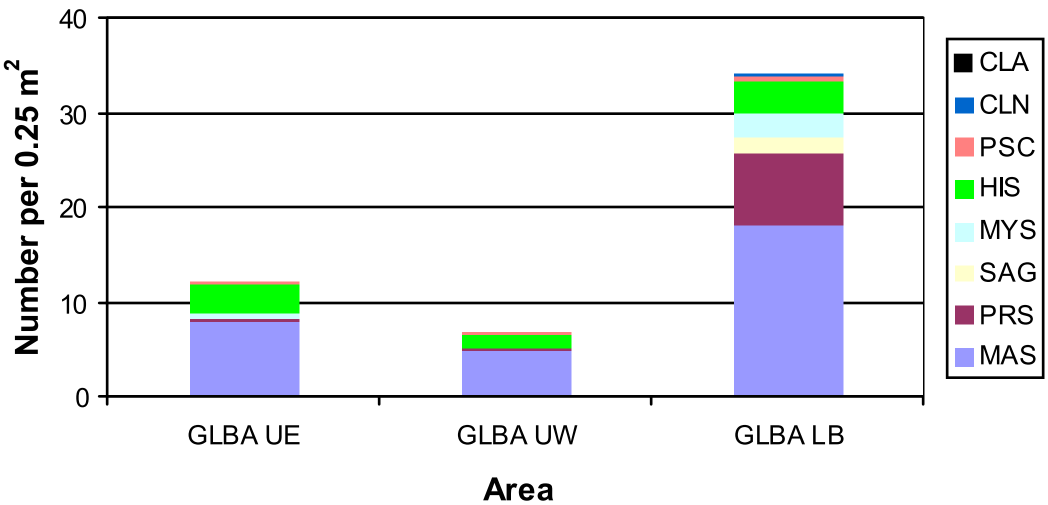


Figure 14b. Biomass (grams dry weight) of clams per 0.25 m^2 at sites in Port Althorp and Idaho Inlet. This figure summarizes data from Figure 14a.



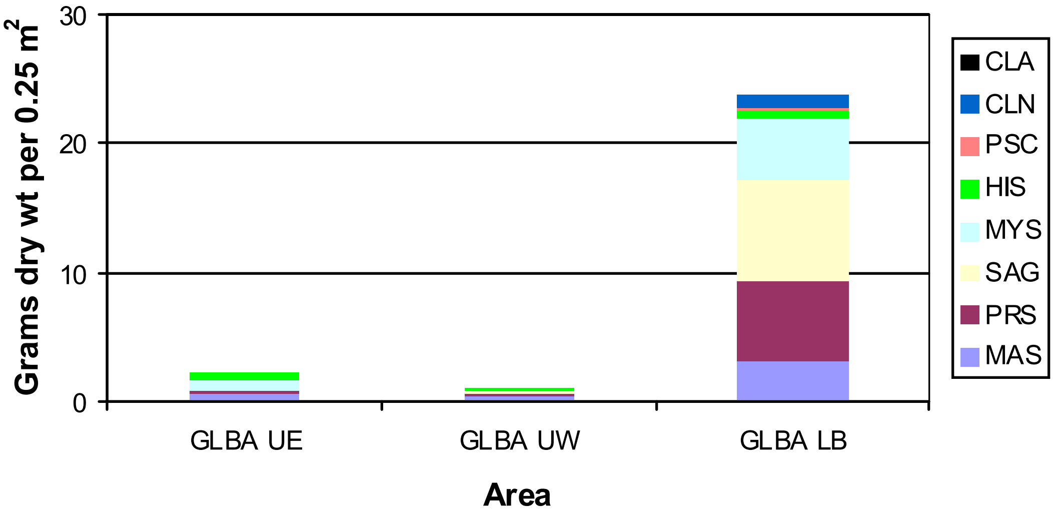
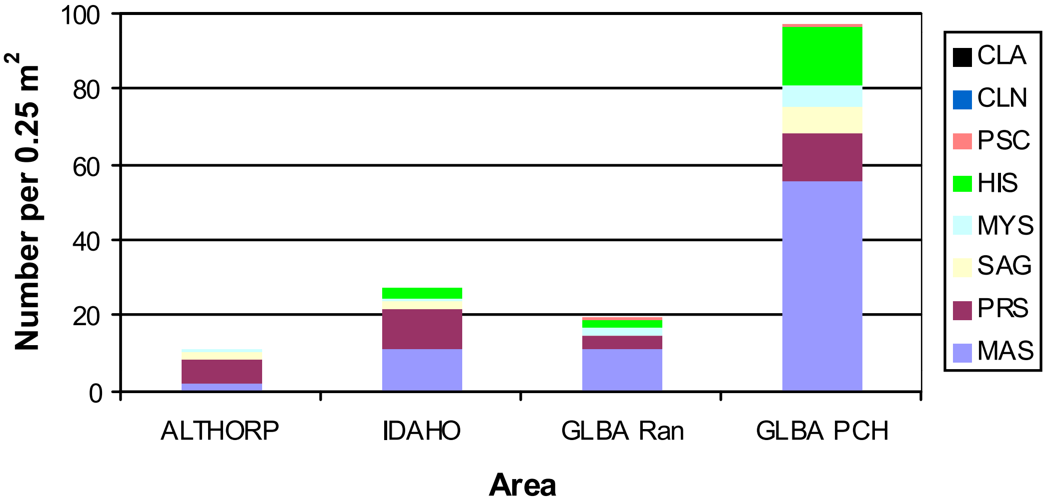


Figure 15a. Intertidal clam density and biomass at sites within Glacier Bay, subdivided into upper east (UE) , upper west (UW), and lower bay (LB). See Figure 1 for the locations of the study areas, including the divisions in Glacier Bay. Figure 15b shows this same data lumped for all Glacier Bay randomly selected sites, for comparison to Idaho Inlet and Port Althorp. Species abbreviation key: CLA = unknown and other clam species, CLN = *Clinocardium nuttallii*, PSC = *Pseudopythina compressa*, HIS = *Hiatella* species, MYS = *Mya* species, SAG = *Saxidomus gigantea*, PRS = *Protothaca staminea*, and MAS =



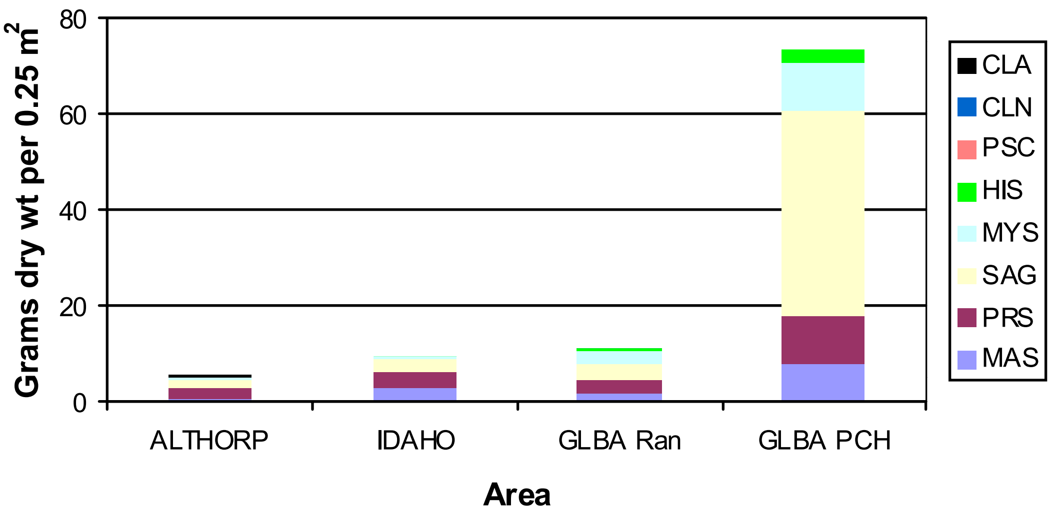


Figure 15b. Top graph shows intertidal clam density in our 4 study areas: Port Althorp, Idaho Inlet, Glacier Bay-randomly selected sites (GLBA-Ran), and Glacier Bay-preferred clam habitat sites (GLBA-PCH). Lower graph shows intertidal clam biomass for the same areas. Note that MAS (*Macoma* species) are the most abundant clam in both GLBA areas, yet account for very little of the actual biomass of intertidal clams. See Figure 1 for locations of study areas. Species abbreviation key: CLA = unknown and other clam species, CLN = *Clinocardium nuttallii*, PSC = *Pseudopythina compressa*, HIS = *Hiatella* species, MYS = *Mya* species, SAG = *Saxidomus gigantea*, PRS = *Protothaca staminea*, and MAS =

Size Distributions

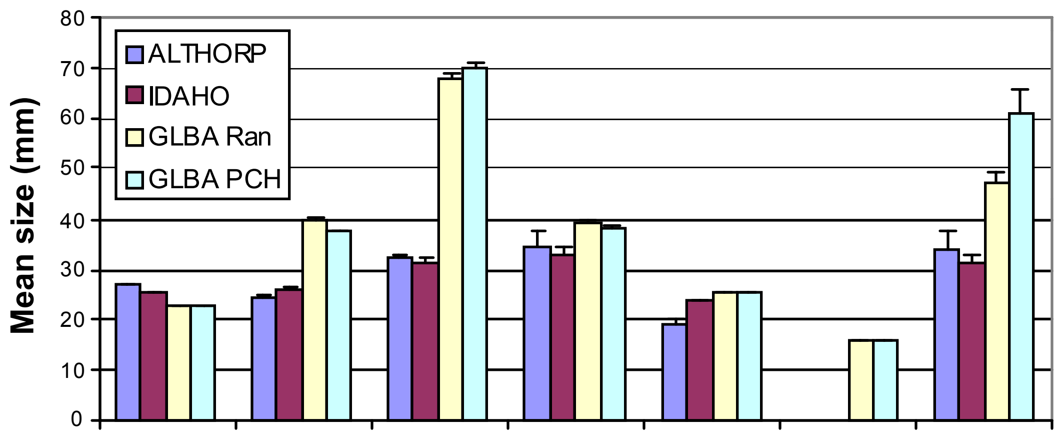
Mean clam sizes and number of clams measured by species are presented in Figure 16. Mean size of *Macoma, Mya, and Hiatella* were similar among areas. Mean sizes of *Protothaca, Saxidomus and Clinocardium* were apparently larger in both Glacier Bay random and preferred, compared to Idaho Inlet and Port Althorp (Figure 16). Mean size from GLBA sites was 1.5, 2, and 1.5 – 2 times larger for *Protothaca, Saxidomus and Clinocardium*. Size class distributions of Macoma were similar among areas (Figure 17) while size class distributions of *Protothaca* and *Saxidomus* were skewed toward larger sizes at GLBA sites when compared to Idaho or Althorp (Figure 17).

Discussion

Species diversity of intertidal clams was 2.5 to 3 times less in the upper arms of Glacier Bay compared to the lower Bay and PCH sites. Most (71%) of the sites in the upper Arms had 2 or fewer species present. In the lower Bay 17 of 20 sites had four or more different species present. Eight of 12 sites in Pt. Althorp, 12 of 14 sites in Idaho Inlet, and all PCH sites had 4 or more species present. Causes of observed differences in species diversity between the upper Arms and lower Bay are unknown; but may be related to size structure of the sediments, primary productivity, circulation, or may be an artifact of time since last glaciation and distance from glaciers as well as potential parent populations.

Intertidal clam densities were greatest at preferred sampling sites, followed by the lower Bay, Idaho the upper East Arm, Althorp, and were lowest in the upper West Arm. The spatial pattern observed in declining species diversity as one goes up Bay is similar for clam density. Clam densities in Althorp are about $1/10^{th}$ those at preferred sites and about $1/3^{rd}$ the densities in Lower GLBA. It is likely the reduced densities of intertidal clams at Althorp results from prolonged and persistent predation by sea otters. Clam densities in Althorp may be a reasonable approximation of th expected future in Glacier Bay. Densities in Idaho Inlet are similar to the lower Bay, each approximately $1/3^{rd}$ the densities found at PCH sites.

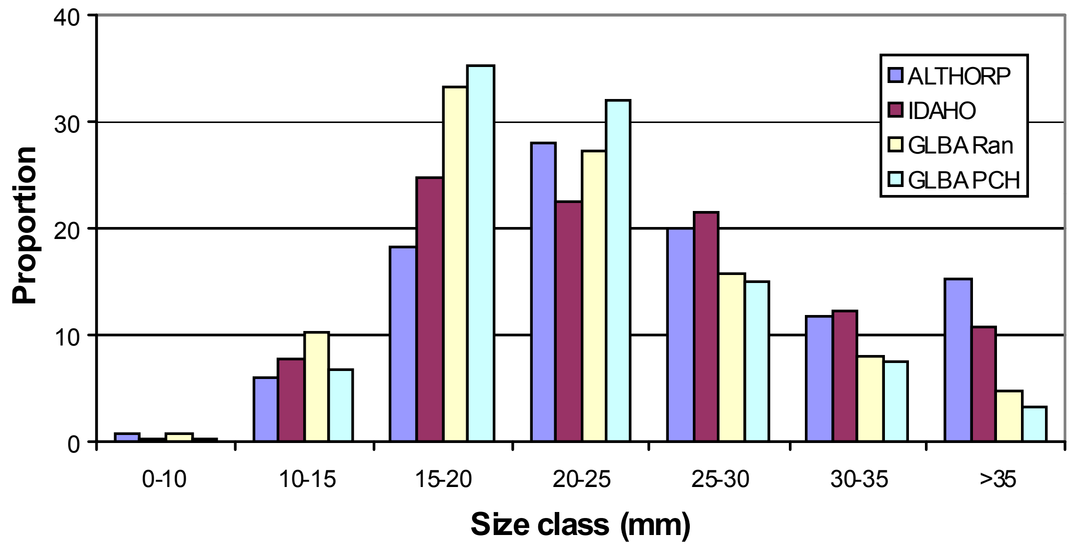
Patterns of differences in clam biomass were similar to the patterns observed in clam densities. Biomass estimates were 10 to 20 times lower in the upper Bay compared to the lower Bay and 30 to 80 times lower than PCH sites. Upper Arm sites have low biomass estimates due to low densities and a species composition of naturally small clams. At Pt. Althorp, biomass was $1/12^{th}$ that of PCH sites and $1/5^{th}$ the random lower Bay sites. It is likely that the reduced biomass estimates at Pt. Althorp are a result of sea otter predation, particularly on those species such as *Saxidomus* and *Protothaca*, which attain the largest sizes of the species commonly sampled and are thus the most energetically valuable to a large predator such as a sea otter. Biomass at Idaho Inlet sites was 7.5 times lower than PCH sites and 2.5 times lower than GLBA Lower Bay sites. The density similar to lower Bay sites with lower biomass estimates from Idaho suggest some degree of foraging may have reduced the larger size classes of clams during the 12 years of sea otter occupation.



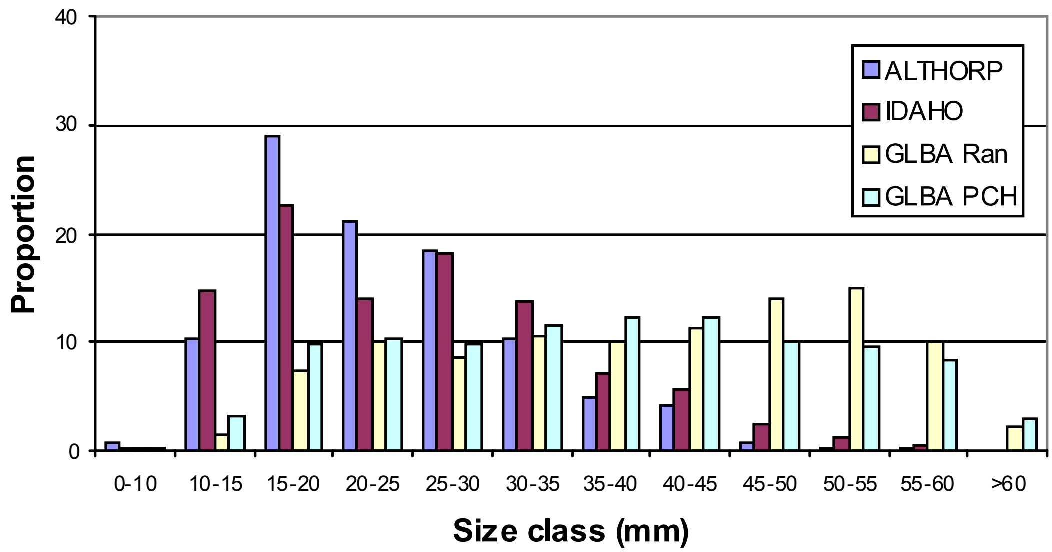
N	MAS	PRS	SAG	MYS	HIS	PSC	CLN
Althorp:	254	759	239	30	31	0	13
Idaho:	1531	1428	294	49	370	0	40
GLBA Ran:	5180	1494	281	566	1307	119	72
GLBA PCH:	5564	1250	723	576	1545	45	3

Figure 16. Mean size in mm (+ 1 SD) of clam species in 4 study areas. See Figure 1 for locations of study areas. Species abbreviation key: CLA = unknown and other clam species, CLN = *Clinocardium nuttallii*, PSC = *Pseudopythina compressa*, HIS = *Hiatella* species, MYS = *Mya* species, SAG = *Saxidomus gigantea*, PRS = *Protothaca staminea*, and MAS = *Macoma* species.

Macoma species (MAS)



Protothaca staminea (PRS)



Saxidomus gigantea (SAG)

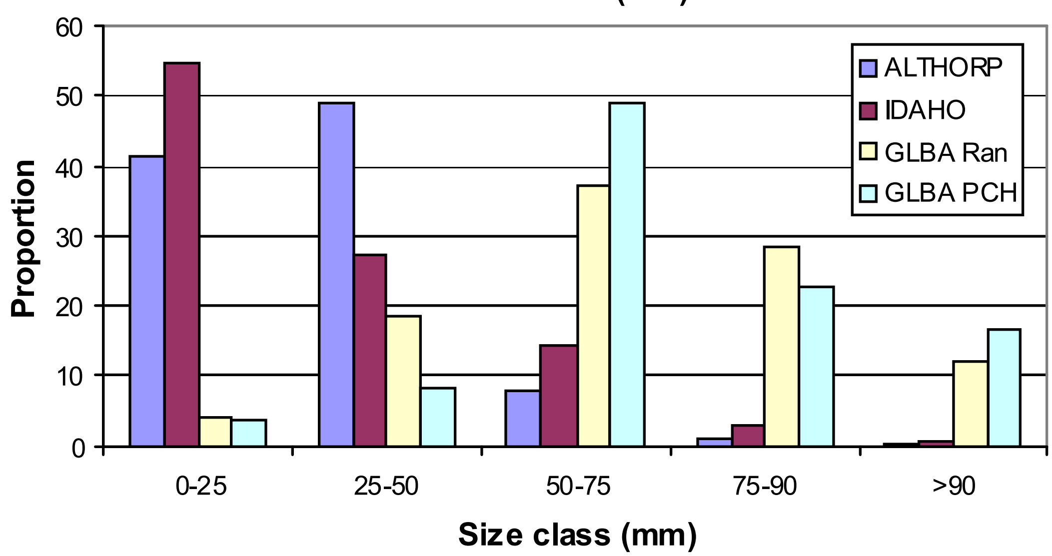


Figure 17. Size class distributions for *Macoma* species, *Protothaca staminea*, and *Saxidomus gigantea* at 4 study areas. See Figure 1 for locations of study areas. Note that the graphs use different scales, this is for comparisons with existing data in other areas.

Mean clam sizes and the distribution of clam sizes by species provide some of our best evidence of a possible sea otter foraging effect at Althorp and Idaho. At Idaho and Althorp mean sizes of *Protothaca* and *Saxidomus* are about 25 mm and 30 mm, respectively. In Glacier Bay, at random and PCH sites, respective mean sizes of *Protothaca* and *Saxidomus* are about 40 and 70 mm. *Saxidomus* and *Protothaca* are preferred clam prey of sea otters in Southeast Alaska (Kvitek and Oliver 1992, JLB unpub. data) and larger clams are preferentially selected by foraging sea otters (Kvitek and Oliver 1992, Kvitek et.al. 1993). The clam populations that persist in areas with prolonged sea otter foraging are characterized by reduced densities and size distributions that are truncated near the minimum size clams that are regularly consumed. Clam populations at Althorp, where otters have been present for > 20 years, and to a lesser degree, those at Idaho where otters have been present for about 12 years appear to demonstrate the expected reductions in density and average size resulting from prolonged sea otter predation. The clam populations at Althorp provide a reasonable expectation of how Glacier Bay intertidal clam populations may change in the future as sea otters continue to colonize the area.

Conclusions

Sea otter populations in the vicinity of Glacier Bay continue to increase following the successful translocation of seas otters to Southeast Alaska nearly 35 years ago. The growth increment of 44% observed in Glacier Bay between 1999 and 2000 likely represents the combined contributions of pup production from within the Bay and immigration of individuals 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 including fishes and birds. In most studies of diet, sea otter prey typically reflect the habitat characteristics of the study area (e.g., burrowing infauna in soft sediment habitats). In this study we observed more than 4,000 successful foraging dives and clams represent from about 40 to 60 % of the diet, depending on area (up to 95% at a specific site). It is likely that the density and average size of clams will decline as a result of sea otter predation. The effects of these changes on other predators that consume clams, 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. A variety of crab species were consumed by sea otters in this study, many 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 to those crab species that exist beyond the foraging depths of sea otters that may attain a refuge from predation (e.g. *Chionecetes* and *Paralithoides*). However, if vertical movement is exhibited that brings the prey within the otter's maximum foraging depth (about 100m, J.Bodkin unpub. data) adverse effects of sea otter predation may still occur.

Glacier Bay currently supports a diverse and abundant assemblage of intertidal clams. Differences in species diversity, density, and biomass are apparent, with more diverse and abundant populations in the Lower Bay. Little evidence currently exists to identify effects of sea otter foraging on intertidal 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. The side with less glare will be surveyed by a single observer in a fixed-wing aircraft. 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 (eg. 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 which 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 airspeed 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 which 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 which 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.

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

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

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

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

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

Example: Barry Glacier, PWS. Winds coming off this and other tidewater glaciers may create a downdraft across the face. The pilot should be aware of such unsafe flying conditions and abort a transect if necessary.

3. Seabird colonies - Transects which intersect with seabird colonies should be shortened accordingly. These areas can be buffered for a certain distance in ARC dependant on factors such as colony size, species composition, and breeding status.

Example: Kodiak Island. Colonies located within 500 m of a transect AND Black-legged Kittiwakes > 100 OR total murres > 100 OR total birds > 1,000 were selected from the seabird colony catalog as being important to avoid.

5. Drifters - During calm seas, for whatever reason - possibly a combination of ocean current patterns and geography - large numbers of sea otters can be found resting relatively far offshore, over extremely deep water, miles (up to 4 miles is not uncommon) from the nearest possible foraging area.

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

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

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

Planning an aerial survey

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

1) Unless current sea otter distribution is already well known, it is well worth the effort to do some reconnaissance. This will help define the survey area and determine the number of observers needed, spacing of ISU's, etc.

2) Plan on using 1 observer per 5,000 otters.

3) Having an experienced technical pilot is extremely important. Low level flying is, by nature, a hazardous proposition with little room for error; many biologists are killed this way. While safety is the foremost consideration, a pilot must also be skilled at highly technical flying. Survey methodology not only involves low-level flying, but also requires intimate familiarity with a GPS and the ability to fly in a straight line at a fixed heading with a fixed altitude, fixed speed, level wings, from and to

fixed points in the sky. Consider the added challenge of flying concentric 400 meter circles, spotting other air traffic, managing fuel, dealing with wind and glare, traveling around fog banks, listening to radio traffic, looking at a survey map, and other distractions as well. Choose the best pilot available.

Data sheet for aerial survey strip transects

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

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

Intensive Search Unit (ISU) data collection form

Date:	Observer:

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

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

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

APPENDIX B. PROTOCOL FOR DETERMINING SEA OTTER DIET BASED ON VISUAL OBSERVATIONS.

Sea Otter foraging success and diet – standard operating procedure

General Description

Sea otter foraging success and intensity will be measured using focal animal foraging observations, and activity scan sampling techniques (Altmann, 1974) adapted for sea otter work in past studies (Calkins 1978, Estes et al. 1981, Doroff and Bodkin 1994). Both will consist of shore based, near shore observations at selected sites within major study areas: One area will be within Glacier Bay proper, one in South Icy Strait, one in Althorp. Site selection will be based on the presence of 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 - 20	1A	10
0 - 40	1B	20
20 - 40	1C	30
40 - 60	2A	50
40 - 80	2B	60
60 - 80	2C	70
80 - 100	3A	90
80 - 120	3B	100
100 - 120	3C	110
> 120	4Z	120 +

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

Alaska Sea Otter Prey Data Codes

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

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

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

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Appendix C. Protocol for estimating intertidal clam species, density and sizes (adapted from Prince William Sound, Exxon Valdez oil spill restoration project 96025-00025)

SOP IC-1-2
Estimation of the Abundance and Size Structure of Intertidal Littleneck Clams as Food for Sea Otters
4/24/97

1.0 Introduction

Among the intertidal clams, littleneck clams (*Protothaca staminea*) are the dominant ones taken by sea otters. The purpose of this sampling effort is to determine the relative abundance and size distribution of intertidal littleneck clams in each of two regions in western Prince William Sound (PWS): along 50 km of unoiled coastline off western Montague Island between Mooselips Bay and Stockdale Harbor, and 50 km of oiled coastline around Knight Island, in Herring Bay (25 km) and Bay of Isles (25 km). This information is required to determine the availability of this clam as food for sea otters.

2.0 Background

Sampling was conducted in summer 1996 to estimate the abundance and size distribution of intertidal clams. We sampled at a series of systematically selected sites and at sites that were systematically selected from preferred clam habitat. Results indicate that littleneck clams (*Protothaca*) were more abundant and larger at Knight Island sites. The data for *Macoma* were less conclusive. Clams appeared larger at Knight, but *Macoma* were more abundant at Montague. This year, we will concentrate on sampling *Protothaca* and *Macoma* at new random (systematically selected with a random start point) sites, and resampling some preferred habitats where there were high densities of clams in 1996.

3.0 Methods

3.1 Initial stage stratified random sampling

Thirty sampling sites were selected from within each of two areas (Montague and Knight Island). The sites were 200 m long stretches of coastline. The following steps were used in selecting sampling sites that are systematically placed along the shoreline, with a randomly selected start point.

- Divide the coastline within each area (Montague or Knight) into segments of 200 m in length. Include the shorelines of major island which are included within existing GIS shoreline coverages.

- Note that a segment may include shorelines from several adjacent islands.

- Label each 200-m long segment with a number.

- Divide the total number of segments (xx) by the number of segments to be surveyed (30). Multiply a random proportion by the product (x) to indicate the first segment to be sampled. Select the remaining sampling segments by selecting every xth segment from the first.

Note that these are the same segments that are being sampled for sea urchins, and are a subset of those sampled for mussels.

We will sample along a randomly placed 50-m long transect at each site between + 0.5 and - 0.5 m. Transects will run roughly parallel to shore, along a selected depth contour (Fig. 5). The starting points for transects will be selected as follows:

- Start at a randomly selected location along the shore. Find the site using differential (or P-code) GPS. We know that the coordinates selected are not particularly accurate, and that some may be as much as 50 to 100 inshore of the waters' edge, or offshore of land. Do not get hung up on finding the “exact” location. Get to the location as best as possible and select the start point with as little bias as possible. Actual GPS locations of the beginnings and endings of all clam beaches will be recorded.

- Drop buoys at randomly selected depths within each depth stratum. Determine the tidally adjusted depths by noting the tidal height at a specific time and location using TIDE1 software. (ALT F2 allows one to obtain a specific tidal height for a given time and location.) Use Stockdale Harbor as the software location for determining tides at Montague sites, Knight Island Passage as the location for determining tidal heights in Herring Bay, and Snug Harbor for determining tidal heights in Bay of Isles.

- In some cases it may be necessary to set the intertidal station on foot. In these cases, place a 2 m stick (marked in 10 cm increments) at the waters edge and hold vertically. Place a hand site level at the appropriate height above the water. For example, if the tidal height is -0.4 m, and the desired station location is +0.4 m, hold the site level at the 0.8 m mark on the meter stick. Point at the site perpendicular to shore. Have a second person place a buoy at the place where the line-of-site meets the substrate.

Distances between the +0.5, 0, -0.5, -5 and -10 m depths will be noted in urchin surveys.

At each buoy, a 50 m tape will be stretched from the buoy along a given depth contour. The tape will be connected to the buoy and stretched to the right of the buoy, while facing shore. On each transect, we collect a sediment sample from 5 randomly selected 0.25 m^2

quadrats. The quadrat position will be at a random point between 0 and 0.95 m along the tape, and at 10 m intervals thereafter. The quadrats will be placed on the offshore side of the tape, and will be placed so that the right hand leg of the quadrat, while facing offshore, is to the randomly selected distance on the tape. In cases where the substrate is too coarse to collect a sample, no sample will be collected and we will note that the quadrat was unsuitable clam habitat.

All sediment samples collected from transects will be returned to the boat and sieved through a series of 3 nested screens. Mesh size for these screens are 2.5, 1.25 and 1.0 cm. Remove and measure all clams to the nearest mm using a vernier caliper. After being measured, clams will be frozen in labeled bags for further analysis.

This sampling will be conducted during the period May 19 through June 26, 1997, using 3 teams of two to three persons. On each day, each team will mark out 3 to 4 sites to be sampled during that or the following day. During the low tide, the team will sample over a 50-m stretch of intertidal area and collect sediments.

3.2 Sampling of preferred habitat

Sampling will be conducted at 12 sites (6 at Montague and 6 at Knight Island) where we observed relatively high densities of clams in 1996. These are ICMI006, ICMI007, ICMI008, ICMI011, ICMI012, ICMI013, ICBI002, ICBI003, ICBI005, ICBI007, ICHB001, and ICHB002.

Sampling will occur during a low-tide series between May 19 and June 26. Sampling will be conducted by two, two-person crews.

The starting points for transects will be the same as used in 1996. Find the site using differential (or P-code) GPS. We know that the coordinates selected are not particularly accurate, and that some may be as much as 50 to 100 m inshore or offshore. Do not get hung up on finding the exact location. Get to the location as best as possible and select the start point with as little bias as possible. Record on Intertidal Clam Sampling Sites Preferred Habitats form IC-97-FD-01.

At each site measure a random distance (the same as used in 1996) from the left hand site boundary. Find the 0 m tide level (MLLW) at this location. This is the left or the beginning end (facing shore) of the 100 m site transect at 0 m MLLW. A surveyors measuring stick, pop level, local tide table and watch will be needed to obtain the 0 m tidal height. Stretch a 100-m tape along the 0 m contour to the right of the start point. Randomly select the first quadrat between 0 and 13.8 m and place a 0.25 m^2 sampling frame down there. (These are different random numbers than used in 1996). Quadrats 2-7 are sequentially and equally spaced at 14.3 m intervals to the right along the transect line at 0 m tidal height.

The quadrat should be positioned so that the prescribed random distance is at the lower left corner of the frame. Excavate the substrate within the frame to a depth of 10 cm and place in a labeled 19 L bucket. Collect a core for sediment grain size analysis one meter to the left of the quadrat. Insert a core with a 5 cm inside diameter 10 cm deep into the substrate. Place the contents into a labeled 1 gallon zip-loc bag. Fill out the Intertidal Clam Sediment/HC Collection form (IC-97-FD-02). Repeat the sampling procedures from quadrat 1 for quadrats 2-7.

Later in the day, after all samples have been collected the samples are to be sieved to remove clams. Wash sediment through a series of three nested screens and measure all clams. Record data on a lab data form IC-97-LD-01.

In the laboratory, select 60 clams from the two study areas (Montague vs. Knight) for analysis. Measure shell length to the nearest 0.1 mm using vernier calipers. Blot each clam dry with a paper towel. Open the clam and remove tissue from the shell using forceps or a scalpel. Place tissue in a preweighed aluminum weigh boat and weigh to the nearest 0.001 g on a Mettler PM200 balance. Determinet wet weights of both the tissue and shell and record these on the laboratory data sheet (IC-97-LD-02). Place the clams in an 80^{O} C oven for 48 hours, cool in a dessicator and weigh to determine dry weight. Ash the clams in a 500^{o} C muffle furnace for 4 hours, cool in a dessicator and weigh to determine ash weight. Ash-free dry weight is calculated by subtracting the ash weight from dry weight.

4.0 Equipment and supplies

The sampling equipment and supplies needed by each field crew for each sampling site are as follows:

1	Differential GPS
1	Intertidal Clam Sampling Sites - Preferred Habitats form (IC-97-FD-01)
1	Intertidal Clam Sediment/HC Collection form (IC-97-FD-02)
1	meter stick, pop level, tide table, watch
7	0.25 m^2 PVC frames
2	shovels
8	19 L (5 gal) plastic buckets
1	set of nested screens and washstand
1	portable water pump w/2 hoses & nozzles
10	1 gal zip-loc bags w/plastic labels
2	sediment corers

5.0 Data analysis

6.1 The average density of intertidal littleneck and *Macoma* clams on random transects

We will compute the average density of each clam species within each site and area, as sampled from randomly selected site transects. We will test for differences between areas using a 1-way ANOVA.

6.2 The extent of habitat within each area

The extent of area within each area will be determined by multiplying the average distances between boundaries (measures by tape between -0.5 to +0.5 m) within an area, times the extent of shoreline with the area. We will test for differences between areas using a 1-way ANOVA.

6.3 The total abundance of intertidal littleneck clams within each area based on random sampling

The total abundance of littleneck clams within each area will be determined as the sum of the quantities (average densities x extent of area) within each area. We may also want to consider computing this value for specified size classes (e.g., 5-10 mm long). We will test for differences between areas using a 1-way ANOVA.

6.0 Training

The training for those conducting the field sampling is as follows:

- Read and comprehend the SOP prior to the time of the field cruise.
- Attend a briefing and review session to discuss the SOP just after mobilization for the cruise.
- Take part in the initial sampling of one designated site.

7.0 Quality Assurance

The cruise leader, or his/her 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. All data sheets will be reviewed by the cruise leader, or his/her designee, daily.

The cruise leader will complete a log of all activities daily.

Intertidal Clam Sampling Sites - Preferred Habitats
IC-97-FD-01

Samplers:___________________________ Date:________________________

Area:_____________Site Number:_____________0 m Tidal Height:_____________

Time:____________ ___________________ _________________ _____________

Tide:_____________ __________________ _________________ _____________

Target UTME:________________________ UTMN:________________________

Start Pt. UTME:_______________________ UTMN:________________________

Quadrat Positions: (RN)________________* 13.8m = _________________Q_1

Q_1 ______________+ 14.3m = ___________________Q_2

Q_2________________+ 14.3m = ___________________Q_3

Q_3 ________________+ 14.3m = ___________________Q_4

Q_4 ________________+ 14.3m = ___________________Q_5

Q_5________________+ 14.3m = ____________________Q_6

Q_6 ________________+ 14.3m = ___________________Q_7

Comments:____
____
____
____

Distance between -0.5 m to +0.5 m	Method
Q_1	
Q_2	
Q_3	
Q_4	
Q_5	
Q_6	
Q_7	

Comments:____
____
____
____

INTERTIDAL CLAM SEDIMENT/HYDROCARBON COLLECTION SHEET
Form IC-97-FD-02

Samplers :________________________________ Date:______________

Area.:______________Start: UTME:___________________ UTMN:________________________

Positioning Method:_______________

Site #	Transect #	Quad #	Sample ID #	Actual Depth	Sed Gsz Collected	HC Tissue Collected

INTERTIDAL CLAM DENSITIES ON TRANSECTS LAB SHEET
Form IC-97-LD-01

Observer:_________________________ Date:______________________

Site #	Quad #	Taxa	Shell Length (mm)	Site #	Quad #	Taxa	Shell Length (mm)

INTERTIDAL CLAM WEIGHTS LAB SHEET
Form IC-97-LD-02

Observer:_______________________ Date:__________________

Site #	Sample ID#	Taxa	Wet Wgt (g)	Shell Wgt	Tissue Wgt	Shell Lnth (mm)	Weight Boat	Weight Boat + DW	Dr W

INTERTIDAL CLAM SEDIMENT GRAIN SIZE LAB SHEET
Form IC-97-LD-03

Observer:_________________________ Date:______________________

Site #	Date Collected	Quad #	Sedgsz #	Replicate	Depth	% Gravel	% Sand	% Mud

APPENDIX D. INTERTIDAL CLAM SPECIES IN GLACIER BAY NATIONAL PARK AND PRESERVE

Following are brief descriptions of the clam species found during 1999-2000 intertidal sampling. This is not intended to be a complete listing of the species found in Glacier Bay National Park and Preserve.

Clinocardium nuttallii (CLN), heart cockle. This clam can grow to 140 mm and is found intertidally to 30 m in sand/gravel substrates (One source states 200 m). The heart cockle can live 15 years although some estimates are as high as 19 years. It is found in sheltered waters from the southern Bering Sea to San Diego, California.

Entodesma navicula (ENN), ugly clam. This clam can grow to lengths over 100 mm. It is found in crevices or under rocks intertidally to depths of 20 m. Its range is from the southern Bering Sea to Point Conception, California. The ugly clam cannot completely retract its siphon therefore there is a gape in the shell.

Gari californica (GAC), California sunset clam. This clam can grow to 149 mm and is found intertidally to 170 m in gravel substrates. *G. californica* is rare in the intertidal zone of Glacier Bay. Its range extends from the northern Gulf of Alaska to Baja California Sur.

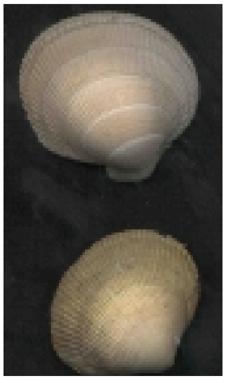
Hiatella arctica (HIA) Arctic hiatella clam. The Arctic hiatella can grow to 33 mm and is found intertidally to 800 m. This clam attaches itself with a byssus to rocks, mussels, shell litter, and even alga. It is often found in areas of unconsolidated rocky substrates from Point Barrow, Alaska to Chile. *Hiatella pholadis* grows to 50 mm and is found intertidally to 10 m, from the Bering Sea to Puget Sound. It attaches itself with byssus threads to kelp holdfasts, mussel mats, and pholad (piddock) burrows. *H. arctica* and *H. pholadis* were grouped as *Hiatella* species (HIS) in this study.

Humilaria kennerleyi (HUK), Kennerley's venus. This clam is found intertidally to 40 m in sand/gravel substrates. It grows to 100 mm and its range is from Cook Inlet, Alaska to Santa Rosa Island, California. *Humilaria* was rare in our intertidal sampling in Glacier Bay.

Numerically, *Macoma* is the predominate intertidal clam in Glacier Bay. Several species have been identified during our sampling: *Macoma nasuta* (MAN), *M. balthica* (MAB), *M. calcarea* (MAC), *M. inquinata* (MAI), and *M. obliqua* (MAO). *M. nasuta* is referred to as the bent-nosed macoma and is found intertidally to 50 m in sandy or silty substrates. It can grow to 110 mm and ranges from Cook Inlet, Alaska to Baja California Sur. *M. balthica* is found intertidally to 40 m. and only grows to 38 mm. Its range is from the Beaufort Sea to San Diego, California. *M. balthica* is often found in bays and estuaries in fine sediments, occasionally at high densities. The other species of *Macoma* have not been identified in the field, but in core samples sent to a bivalve taxonomic specialist.

Mya truncata (MYT) and *Mya arenaria* (MYA), softshell clams; grouped as *Mya* species (MYS). *M. truncata* grows to 80 mm while *M. arenaria* grows to 100 mm. MYT is found intertidally to 100 m, ranging from the Beaufort Sea to Neah Bay, Washington. MYA is found intertidally (subtidal depths were not given for MYA) from Icy Cape, Alaska to central California. They are found in substrates with sand/mud (e.g. in the interstitial sediments at an unconsolidated rocky site).

Panomya ampla (PAA), ample roughmya. This clam is sometimes mistaken for a juvenile geoduck. It is found intertidally to 100 m from Point Barrow, Alaska to Puget Sound in mud/sand/gravel substrates. It can grow to 70 mm. We found these clams near the entrance to Secret Bay in Glacier Bay.

Protothaca staminea (PRS), littleneck clam. This clam is found intertidally to 10 m and grows to 75 mm. *Protothaca* are usually found within the top 10 cm of rock/coarse gravel /sand/mud substrates. It occurs intertidally to 10 m from the Aleutian Islands to Baja California Sur. *Protothaca* can live 8 to 14 years. Growth rates can be 38 mm in 3-4 years.

Pseudopythina compressa (PSC), fuzzy clam. This clam is found intertidally to 100 m and grows to 20 mm. It is found from Point Barrow to Baja, California, usually in mud substrates.

Saxidomus gigantea (SAG), butterclam. The butterclam is found intertidally to 40 m. It can grow to 136 mm and is found in mixed substrates (sand/mud/gravel) from the southern Bering Sea to central California. These clams dominate the biomass of intertidal clams in Glacier Bay. *Saxidomus* can live for 20 years. Growth rates vary within its range. In the northern part of the range, SAG can grow 63 mm in 8-9 years; while in the southern areas, similar sizes are reached after only 4-5 years.

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