

**The Ecological Effects of Sea Otters on Shallow Benthic
Communities in Glacier Bay National Park
and
Inventory and Monitoring of Shallow Subtidal Communities in
Lower/Mid-Glacier Bay
Annual Report 2002**



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Executive Summary

Still rebounding from the brink of extinction, sea otters presently are re-colonizing former habitat in Southeast Alaska, including Glacier Bay National Park and Preserve. About seven years ago, sea otters re-discovered Glacier Bay and have since begun to rapidly re-colonize the Bay in order to exploit vast, essentially untapped food reserves. Based on research elsewhere in Alaska and California, sea otters are recognized to be highly important structuring agents of nearshore marine communities throughout the Northeast Pacific. Recognizing the potential for imminent, large-scale ecological change in Glacier Bay and the rapidly closing window of opportunity to characterize existing natural resources, National Park Service resource managers (in partnership with USGS Alaska Science Center) initiated a program to collect information about the nearshore zone prior to full-scale colonization by sea otters. The primary goals set out for this program were to 1) conduct a preliminary inventory of the benthic biota in the nearshore zone, 2) monitor a select group of indicator species over time for the purpose of detecting natural and unnatural change in the system, and 3) use this information to assess the impacts of sea otters as they colonize Glacier Bay. This annual report is a brief summary of the results obtained from the first three seasons of this effort.

Prior to the inception of this study, few researchers have had the tools (i.e. SCUBA), initiative, or logistical support to undertake a synoptic investigation of the biological communities occurring within the highly dynamic nearshore marine environment in Glacier Bay. Therefore much of the underwater realm within the Bay is still undescribed. Beginning in 2000, nearshore marine communities at various locations throughout lower/mid Glacier Bay were surveyed using SCUBA, and permanent stations were established. To date, we have established 30 “permanent” study sites at which we re-survey the biota on an annual basis. Taxa that are

studied represent different trophic levels, including primary producers (macroalgae), primary consumers (e.g., sea urchins), and secondary/tertiary consumers (e.g., sea stars, crabs). At each of the 30 study sites, we quantified the density of these organisms within a total of 1,341 one meter x one meter square “quadrats” and 1,354 “swaths” (one large 5 m² quadrat), for a total of 6,800 m² of seafloor. Sea urchins formed “urchin barrens” at many sites, and occurred at average densities of 6.9 / 0.25 across all sites and ranged from 0 to 180 / m². Conversely, kelp densities were relatively low, with an average density of 1.6 plants / m² across all sites and ranged from 0 to 44 plants / m². We have also assessed the population size structure for a subset of the species we study, and as of December 2002, we have measured 778 sea stars, 2,674 whelks (predatory snails), and 11,085 sea urchins. No truncations of large size classes of sea urchins or whelks were observed in the frequency histograms – indicating that otters have not yet had a pervasive effect on these populations. This project’s inventorying and monitoring efforts are ongoing, and the first phase (of three planned) is scheduled to continue through 2003.

Sea otters are rapidly increasing in the Bay, and major ramifications to the nearshore zone are expected in the near future. Given our current predictive capabilities concerning ecological systems, the long-term, cascading effects of this large-scale perturbation are largely unpredictable, but will likely be far-reaching. In order to protect and preserve Park resources for future generations, managers need to be able to distinguish human-induced change from the “background” natural variability inherent to ecological systems. If this goal is to be achieved for the nearshore zone of Glacier Bay, the effects of sea otters must be detected and quantified to prevent impairment of natural resource management for decades to come.

Introduction

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, they have not been found in Icy Straits and Glacier Bay proper until recently (Table 1; Bodkin, 2001 and unpublished data). As shown in Table 1, the number of sea otters inhabiting Glacier Bay has increased rapidly - from 5 individuals in 1995 to approximately 1238 in 2001, with an astounding increase of 108% from 2000 to 2001. Based on the number of otters currently occupying Glacier Bay and the results of studies in the North Pacific, it is a reasonably safe prediction that profound changes can be anticipated in the abundance, size, and species composition of the nearshore benthic communities (including economically, ecologically and culturally valuable taxa such as urchins, clams, mussels and crabs). Furthermore, it is likely that cascading changes in the invertebrate and vertebrate fauna such as sea stars, fishes, sea birds and possibly other mammals, of Glacier Bay can be expected over the next decade. It is also apparent that those changes are beginning now. For example, the spatial extent of kelp surface canopy has apparently increased between 1997 and 2001 in one location in mid-Glacier Bay frequented by large groups of sea otters (Bodkin, pers. obs.). Based on the anecdotal and quantitative evidence from other areas, this phenomenon is indicative of a large-scale removal of herbivorous sea urchins by otters.

The current distribution of sea otters in Icy Straits and Glacier Bay is ideally suited for a before/after control/treatment study, which may provide convincing evidence for changes observed in Glacier Bay resulting from sea otter colonization. If not quantified, the ecological effects of sea otter re-colonization will likely preclude or severely limit the ability of Park management to identify changes or causes of variation in nearshore subtidal communities. At

worst, Park management could wrongly assign cause to observed changes or be caught unaware of impending ecological change due to a lack of early detection.

At least three elements are requisite to understanding the effects of sea otters in Glacier Bay - first, describing the abundance and distribution of sea otters in the Bay, second, describing their food habits, and third, describing the structure and function of the coastal marine communities in the Bay before and after occupation by sea otters. The first and second elements have been undertaken by the USGS Alaska Science Center (ASC). In partial fulfillment of the third element, the ASC has collected data on bivalve density, species composition, and size class distribution in the intertidal and subtidal zones (Bodkin et al. 1999, 2000, and 2001). This information will serve as a baseline for future investigation of population- and community-level effects of sea otters on bivalves in Glacier Bay. In conjunction with the ASC, the National Park Service initiated this study in 2000 to complement the ASC's investigation of subtidal bivalves. Whereas the emphasis of ASC's study is primarily on bivalve infauna, the NPS study collects baseline data on the spatio-temporal distribution, abundance, and population size structure of conspicuous epibenthic biota occurring in shallow water within Glacier Bay, with emphasis on macroinvertebrates and macroalgae.

The information collected by this study (NPS) will be used first to describe the shallow marine communities of Glacier Bay proper, which has not been attempted by any researchers to date. This baseline information will then be used, in concert with data from repeated surveys over time (i.e. monitoring), to investigate the population- and community-level effects of sea otters using a Before-After-Control-Impact (BACI) approach. The sampling methodology and protocol development associated with this study will also serve as a preliminary pilot project for a more comprehensive program of inventory and monitoring of the subtidal resources within Glacier Bay.

In brief, this study was designed primarily to address the following hypotheses:

H₀. The species diversity of shallow benthic marine communities (as measured by diversity indices) do not differ between control sites (areas without the sea otter “treatment”) and impact sites (areas with the sea otter treatment) before or after the treatment of sea otter foraging has been imposed.

H₀. Neither the mean density/percent cover nor the temporal variance of various taxa differs between control and impact sites before or after the treatment of sea otter foraging has been imposed.

Taxa of interest include:

1. sea urchins (*Strongylocentrotus droebachiensis* and *S. pallidus*)
2. sea stars (e.g., *Solaster spp.*, *Evasterias troschelli*, *Leptasterias spp.*)
3. whelks (e.g., *Fusitriton oregonensis*, *Neptunea lyrata*)
4. hermit crabs (e.g. *Elassochirus spp.*)
5. mussels (i.e. *Modiolus modiolus*)
6. anemones (e.g. *Metridium giganteum*, *Urticina spp.*)
7. benthic diatoms
8. algae, especially kelps (e.g. *Nereocystis luetkeana*, *Laminaria spp.*)

H₀. Neither the mean size class distribution nor the temporal variance of various taxa (i.e. sea stars, whelks, and urchins) differs between control and impact sites before or after the treatment of sea otter foraging has been imposed (taxa of interest include sea urchins, sea stars, and whelks).

This study may be divided conceptually into three temporal components – a “pre-otter” period (i.e. before sea otters permanently re-colonize any of the study sites), a transitional period (i.e. the period during which sea otters begin re-colonizing study sites until 50% of sites are colonized), and a “post-otter” period (i.e. the period beginning when sea otters re-colonize 50% of the sites). We are presently in the “pre-otter” period, and this report summarizes results of the first three years [of the four years planned] of the pre-otter period. A detailed description of the study plan (including background, goals, objectives, and analysis) can be found in Appendix A

Methods

Permanent transects were established at –30’ Mean Lower Low Water (MLLW) at study sites throughout lower/mid Glacier Bay (see Appendix A for rationale behind site selection and permanent transect establishment). At each permanent site/transect, various methods were employed to sample the subtidal biota (Table 3). In brief, twenty 0.25m² and 1m² quadrats were sampled along each 50-m transect to quantify the densities of urchins, mussels, clam siphons, and the percent cover of algae. The densities of whelks, sea stars, sea cucumbers, crabs, and anemones were quantified using ten “swaths” (10m² quadrats). Size frequency measurements were taken for urchins, whelks, and sea stars to assess the population size structure and to facilitate calculations of biomass. Video footage was taken at each site to permanently record the habitat and species present. Immediately after completing these tasks for a given site, observers convened and recorded the presence/absence and approximate abundance of over 100 species representative of the benthic community. Field datasheets for the methods

described above are included in Appendix C. Underwater temperature loggers deployed at each of the –30' MLLW sites in 2001 were retrieved, downloaded, and re-deployed for a duration of approximately one year (72 minute sampling interval). Detailed procedures and a list of the species sampled (including common names) can be found in Appendix B.

Analysis

Power analyses performed after the 2001 field season indicated that 2-4 temporal replicates (e.g., the annual mean abundance of urchin density for each site) would be required to obtain 80% power to detect a 50-90% change in mean densities of high-priority taxa (e.g., urchins, sea stars, kelps) *at sites where these taxa occur at moderate-high densities* (see Appendix D for detailed analyses and discussion). Because some data were collected inconsistently during the project development stage (in 2000, primarily), the data collected during the 2002 field season represent, for all intents and purposes, the second of three projected temporal replicates planned for the “pre-otter” component of the study.

Although data were collected at the resolution of species (in most cases), species were grouped into higher-order taxonomic groups for ease and clarity of summary analyses. For each site for each year, we calculated the following: 1) mean density by broad taxonomic group (e.g., urchins, sea cucumbers, large sea stars, small sea stars, whelks, kelps, etc.); 2) mean percent cover of algae by functional/taxonomic group (e.g., kelps, foliose reds, crustose reds); 3) size class distribution by species (for sea stars, whelks, and sea urchins). No statistical hypothesis testing will be performed until identical data have been collected following the permanent colonization by otters at approximately 50% of the study sites.

Results and Discussion

During the 2000 field season, seventeen study sites (one transect at $-30'$ MLLW per site) were established and surveyed. In 2001, these sites were resampled and three additional sites were established ($n=20$ sites). In 2002, the original twenty sites were resampled, and ten new sites were established at $-15'$ MLLW immediately adjacent to ten of the existing sites. (Logistical statistics for the 2002 season are summarized in Appendix E.) Site names and coordinates are listed in Table 2 and displayed in Figure 1. The ten new sites in 2002 were established to increase the inference space from the $-30'$ contour [only] to the $-30'$ to $-15'$ depth range. One of the sites at $-15'$ MLLW had obviously been impacted by otters immediately prior to our visit (e.g., freshly excavated pits were observed), but was sampled nevertheless to practice quantifying an otter-impacted site.

Contrary to our pre-conceived notions of a general dichotomy between soft bottom and hard bottom habitats (based on experience in open coast, high energy wave environments), habitats in the shallow nearshore zone of Glacier Bay that occur on relatively flat/moderate slopes would best be described as being distributed along a continuum of soft to hard bottom. Our original plan to stratify subtidal sites between these two different habitats did not turn out to be strictly applicable, and the data may be combined in the final analysis. Therefore, data from all sites will be addressed and graphically depicted together for the purpose of this report.

The initial year of the study (2000) was essentially a “pilot study” because many techniques were being field-tested and modified for use in Glacier Bay. Furthermore, sampling began in September of that year and continued through October (i.e. well

outside of the standard Alaskan field season from May/June - August); as a result, data that were collected for organisms that exhibit seasonal changes in distribution or abundance (e.g. algae) are not directly comparable with data standardized to spring or summer of other years. Nevertheless, some taxa were sampled consistently since the inception of the study, and most of the data that have been collected thus far are summarized in this report. All ecological data that have been collected are included in a Microsoft ACCESS 97 database, which is available from the author/NPS to interested parties.

With some exceptions, within-site temporal variation of organism densities [at – 30' sites] and size frequencies was relatively minimal when organisms were present at levels greater than trace (and sampling techniques and seasonality of data collection were held constant). However, significant annual variability in mean density was evident for some taxa between 2000 and 2002. These trends generally were not consistent among sites, even among those within close spatial proximity. For example, from 2000 to 2002, urchins increased 50—400% at 3 sites (Sturgess Island, Willoughby Island, and Berg Bay), sea cucumbers increased from trace levels to 6 individuals / 10m² at a site in the western Beardslee Islands, and *Metridium* spp. increased from an average of 10 individuals / 10m² to 30 / 10m² at Willoughby Island. Although these trends and the within-site temporal variability are interesting, important, and have implications for the number of temporal replicates required for adequate characterization of populations and communities during the “pre-otter” period, we have chosen to omit detailed analysis within this report because of the large number of possible summaries (20 sites with temporal data x 18 summarizations per site = 360). Instead, we will present summaries

for each taxa at the site level, and within-site temporal variability will be apparent in the standard error calculations for the -30' sites. Sites established at -15' MLLW in 2002 have no estimate of error because only one temporal replicate was available.

Sea Urchins

Sea urchins were present at 26 of the 31 sites, albeit at very low densities ($< 0.2 / 0.25\text{m}^2$) at 6 of these 26 sites (Figure 2). Urchin densities exceeded 5 individuals / 0.25m^2 at 10 sites, and were abundant ($> 20 / 0.25\text{m}^2$) at 3 sites. Sea urchins were generally more abundant at the shallow sites, exceeding over 70 individuals / 0.25m^2 (on average) at one site off Willoughby Island. For comparison, the nearby -30' site (approximately 10 meters away) had an average density of 13 urchins/ 0.25m^2 . The maximum density that we observed in a single quadrat at the shallow site was 180 / 0.25m^2 , although most of these individuals were quite small. Figure 23 illustrates the density of sea urchins at the Willoughby Island shallow site. At this site, we observed sea urchin densities exceeding the maximum densities reported by Bodkin et al (2001) for any of their study sites in Glacier Bay proper and Duggins' (1981) at Torch Bay (i.e. outer coast of Glacier Bay National Park). These density estimates are all the more remarkable considering that we are not sampling the depth at which urchins typically occur at maximum densities (-2 to -3 m MLLW). Furthermore, the density information presented here are minimum estimates because urchin counts are standardized to only include individuals exceeding 10mm test diameter.

During 2002 only, urchins were also sampled invasively at 27 of the 31 sites. On average, urchin densities were 23% greater when sampling was invasive compared to non-invasive (Figure 3). Generally, the greatest increase in invasive/non-invasive

proportions was evident at sites with pebble and cobble substrates having an abundance of interstitial spaces. This type of habitat appeared to serve as a nursery area/refuge for small sea urchins. At these sites, invasive counts are probably underestimated because: 1) urchins occurring in these habitats were usually small and tended to burrow into the substrate; 2) divers had limited dexterity to move small pebbles and shells in search of urchins; and 3) limited dexterity made it difficult to handle small urchins. Also, the proportion of white urchins to green urchins increased slightly in these types of habitats because white urchins tend to burrow into the substrate more often than green urchins.

The average size of urchins (measured using test diameter) was also spatially variable among sites, although not nearly as variable as density estimates (Figure 18). The average sea urchin size among 27 of the 31 sites where urchins were present was 33 mm, and the within-site averages ranged from 19mm to 54mm. Urchin size frequency measurements approximated a normal distribution at many sites, but bimodal distributions and significant kurtosis were also evident. Cohort size classes were also obvious at many sites, and could be followed through time.

Figure 20 illustrates size class distributions at one site for each year of the study. At the site depicted in Figure 20, the mean size of urchins significantly increased each year at an average rate of 1.7mm per year. However, this site is not representative of all sites; the average size of urchins in 2002 was less than the average size in 2001. During this period, average size decreased by 1.1mm (for comparison, urchin size increased by an average of 1.7mm from 2000 to 2001). In part, this trend may have been exaggerated because urchins were collected for size frequency measurements during invasive quadrat sampling for the first time in 2002. Because the urchins living in and amongst the

substrate were generally smaller than their epibenthic counterparts, we sampled a different statistical “population” at some sites, essentially. This does not explain the trend entirely, however. From 2001 to 2002, the mean urchin size also declined by 0.7mm at sites where there was < 15% difference in the counts of invasively sampled urchins to non-invasively sampled urchins (n=6 sites). At sites where there was a difference between the counts greater than 15%, urchin size declined by 1.4 mm, on average (n=10 sites). For comparison, these two groups of sites also differed from 2000 to 2001: mean size increased by 1.9mm at the <15% sites, but by only 1.3mm at the >15% sites (a difference of -0.6mm). Therefore, the magnitude of the decline in mean urchin size is unclear, and cannot be entirely attributed to a change in sampling methods.

The cause of the observed decline in average size of sea urchins is not apparent. No truncations of large size classes of sea urchins were observed in the frequency histograms that would be indicative of size-selective sea otter foraging. We did observe a decrease in average water temperature throughout the study area during the 2001/2002 winter. Minimum water temperatures during this time period were approximately 1°C Celsius lower than the winter of 2000/2001 (Figure 21). Although speculative, perhaps colder water temperatures slowed the growth rate of larger individuals relative to smaller individuals in concordance with the laws of scaling (i.e. surface area increases in proportion to the square of its’ dimensions and volume increases in proportion to the cube). This trend would be exacerbated if urchin recruitment remained constant, or increased.

The estimated biomass of sea urchins was calculated for each site using measures of mean density and size (Figure 19). Estimated biomass was less variable among sites

than urchin density (Figure 2); simultaneous inspection of Figure 2 and 18 illustrates that mean size and density at a given site tended to be inversely proportional. Mean urchin biomass (15 grams AFDW per 0.25m²; n=31 sites) was substantially lower than the mean biomass of clams (approximately 150 g AFDW per 0.25m²) reported by Bodkin et al. (2001). However, this comparison is not entirely appropriate because Bodkin et al. sampled subtidal clam beds that were chosen non-randomly and biased to areas of high clam densities. While bivalves are undoubtedly a major proportion of the animal biomass in the nearshore zone (and the primary prey item of the sea otter in Glacier Bay, presently), urchins nevertheless represent a significant portion of the total biomass in the shallow areas of the Bay.

It became apparent during the 2002 season that two similar-looking species of sea urchins were being confused and reported as one species - the green sea urchin *Strongylocentrotus droebachiensis* and the white sea urchin *S. pallidus*. White urchins look similar to pale *S. droebachiensis* specimens, and they occur at such low densities that we assumed they were the same species. To our knowledge, the white urchin has not been documented in Glacier Bay previously. This species is usually found at depths of 50 meters or greater, and is rarely found at depths shallower than 20-30 meters (Kozloff, 1987 and Barr, 1983). Although this species was much less common than the green urchin (approximately 2% of the total number of urchins observed), it was encountered regularly at many sites as shallow as -15' MLLW.

Horse Mussels

The northern horse mussel *Modiolus modiolus* was present at 10 of the 31 sites, although at low densities (> 0.2 / 0.25m²) at 7 of these 10 sites (Figure 4). *Modiolus* was

only abundant at one site (E5 Hard_30 Lester Point), with a mean density of 35 individuals / 0.25m²). Mussels are so abundant at this site that understory kelps (primarily *Laminaria bongardiana*) recruit to the mussels and form a dense forest on top of the bed. This is the only location where we have observed this phenomenon. Ironically, sea otters may decimate this understory kelp canopy forest when they eventually find and consume the mussels upon which these kelps are growing.

Clam Siphons

Clam siphons were present at 28 of the 31 sites sampled, albeit at low densities (<1 / 0.25m²) at 21 of these 28 sites (Figure 5). Generally, siphons were more abundant at the -15' sites than the -30' sites. Siphons were not identified to species (see Bodkin et al. 2000 and 2001 for species present in Glacier Bay proper). Because the density of clam siphons is only weakly correlated with the actual density of clams present (Bodkin, pers. comm), the data presented here should be viewed as a measure of relative abundance. While suction dredging of the sediment is by far the most effective and reliable way to sample infaunal bivalves, obtaining an estimate of clam relative abundance via observation of siphons is a quick, non-destructive method that should be useful for detecting gross changes in density.

Large Sea Stars

Large sea stars were present at all of the 31 sites except one (Figure 6). Sea stars were more abundant on the West Side of the Bay than in the east; ten of the top eleven most densely populated sites (> 1.5 individuals / 10m²) were in the west Bay. Densities were highest at W5 Hard_30 and W5 Hard_15, although the individuals at these sites

were smaller (on average) than sea stars elsewhere. Size frequency data by species are listed in Table 3; however, data are not summarized by species for each site for brevity and sample size limitations. Biomass calculations are planned for this species group pending a literature search for length/weight regressions. Distributions of individual species within this grouping exhibited some spatial patterns. For example, *Orthasterias koehleri* was present at low densities at only three sites, two at Lester Point (E5 Hard_30 and E5Hard_15) and one at Willoughby Island (W3 Hard_30). These are the only two study sites with substantial mussel beds, indicating that *Orthasterias* probably has a strong dietary preference.

Small Sea Stars

Small sea stars occurred at 19 of the 31 study sites (Figure 6), but were present at moderate/high densities (i.e. $>1 / 10\text{m}^2$) at only 3 sites, 2 sites of which were separated by only 10 meters (W5 Hard_30 and W5 Hard_15). As with large sea stars, the small sea stars at these sites were smaller, on average, than at other locations throughout the lower/mid-Bay. These sites appeared to be a nursery area for small and large sea stars alike. Biomass calculations will be performed in the future for these species also. It is interesting to note that *Mediaster aequalis* was observed only in the western Bay (mostly at Willoughby Island).

Metridium spp.

Metridium occurred at 16 of the 31 study sites, but were present at densities greater than 1 individual / 10m^2 only at 6 of these 16 sites (Figure 8). Maximum densities (13-20 individuals / 10m^2) were observed at two of the three Willoughby Island sites. When present, *Metridium spp.* were usually highly aggregated if adequate substrate (e.g.,

cobbles, clamshells) was available. *Metridium giganteum* are surprisingly mobile organisms, and we observed rapid colonization of new substrate by *Metridium giganteum* within 2-3 months of deposition of a large piece of driftwood. This motility may explain some of the temporal variability that we have observed at particular sites over time. For example, mean density increased incrementally from 10 to 30 individuals / 10m² at W3 Soft_30 (Willoughby Island) from 2000 to 2002. Because of its apparent capacity for rapid colonization, *Metridium* may be one of the first species to colonize new “beds” of bivalve shells that have been discarded by sea otters.

Sea Anemones (not including *Metridium* spp.)

Sea anemones were present at 22 of the 31 study sites. Densities were greater than 1 / 10m² at 6 of these sites (Figure 9). Methods were standardized for counting sea anemones (using size class restrictions) in 2001, which probably explains much of the annual variability (short-term temporal variability is not expected for anemones given their sessile nature). Because two species of unidentified sea anemones were regularly encountered, taxonomic work for this group should be a priority in 2003.

Large Hermit Crabs

With the exception of one site, large hermit crabs were omnipresent (Figure 10). Densities were generally at low levels (<1 / 10m²) at most sites, however. Hermit crabs are a difficult group with which to standardize survey counts, as there is not a superb method to measure them in the field. When handled, they quickly retract into their shell. We eventually settled upon using a measure of the larger of the 2 chelae (>1.5cm diameter), but non-standardized count data prior to this standardization remain – hence

the substantial standard errors in Figure 10. These counts should be omitted from the next analysis after the 2003 season.

Crabs (excluding hermit crabs)

This group includes recreationally and commercially important species including Dungeness crab, Tanner crab, and Red king crab. The species included within this group were observed at 21 of the 31 study sites, although they never exceeded densities greater than 3 individuals / 10m² (Figure 11). The lyre crab *Hyas lyratus* was the most abundant member of this group (69% of total counts), but juvenile Dungeness crab, Tanner crab, and Red king crab were also observed on occasion. Inconsistent size class distinctions during 2000 were responsible for some of the inter-annual variability, most notably at W2 Hard_30. It is noteworthy that we observed and collected video footage of a large aggregation (> 200 individuals) of juvenile king crabs in -15' MLLW at Drake Island in 2001. Haphazard sampling indicated that the aggregation was composed primarily, if not exclusively, of females.

Sea Cucumbers

Sea cucumbers were observed at least once at 16 of the 31 permanent sites, but occurred at mean densities >1 / 10m² at only one site (Figure 12). At this site in the NW Beardslee Islands, sea cucumbers (both *Cucumaria miniata* and *C. frondosa*) rapidly increased in density from 0.2 / 10m² (0.1) in 2000 to 2.0 / 10m² (0.60) in 2001 to 5.9 / 10m² (0.97) in 2002.

Large Whelks

Large whelks (standardized to individuals > 6 cm) were present at 28 of the 31 sites at a mean density (standard error) of 4.4 / 10m² (0.9). Whelk densities were greater

than 5 / 10m² at 9 of these sites, with a maximum density of > 20 / 10m² (Figure 13). An unidentified whelk species made up 16% of the total counts; although relatively common in Glacier Bay (and abundant at some sites), this species has perplexed experts in gastropod taxonomy, but they have preliminarily identified this specimen as *Volutopsius castaneum*. Standard error was large at one site (E3 Soft_30) due to inconsistency in size class distinctions during the 2000 season. Size frequency histograms for the three most abundant whelks are presented in Figure 22. No truncation of larger size classes was evident, as would be expected if sea otters were foraging selectively on large individuals.

Kelps

Kelps were present at 23 of the 31 study sites during the 2000-2002 period, albeit at low density (<1 / m²) at all but seven of these sites (Figure 14). Maximum kelp densities occurred at E4 Hard_30 (Young Island/Sitakaday Narrows; 13 plants / m² [0.9]) and E5 Hard_30 (Lester Point; 20 plants / m² [0.2]) – sites which experience very strong tidal currents (especially relative to other study sites). At one of the study sites (W1 Hard_30), kelp density (nearly all of which was *Nereocystis*) increased from zero in 2000 to 4.5 / m² (0.8) in 2001, then to 7 / m² (2.0) in 2002. At E5 Hard_30, plant density was remarkably similar between the 2 years that this site was sampled: 19.6 plants / m² (0.9) in 2001 and 20 plants / m² (0.9) in 2002. The relative abundance of the kelps present was also quite constant (64-68% *Laminaria* spp., 36-31% *Agarum clathratum* during 2000 and 2001, respectively). Conversely, plant density at E4 Hard_30 remained nearly constant at 11-14 individuals / m² over the course of the study, but species relative abundance changed from 100% : 0% : 0% *Laminaria* spp./*Pleurophyucus gardneri* : *Nereocystis luetkeana* : *Alaria fistulosa*, respectively, in 2000 to 81% : 3% : 0% in 2001

to 52% : 25% : 19% in 2002. At this site only, *Laminaria spp.* and *Pleurophycus* were lumped together into one group during 2000 and 2001 because of difficulties in field identification and taxonomic confusion; species distinctions were made for large, mature plants in 2002, but uncertainty remained with respect to immature/sub-adult individuals.

In addition to plant density, kelps were also measured in terms of percent cover. Percent cover estimates did not include surface canopy coverage; underwater visibility was often limited to <10', therefore it was rarely possible to estimate canopy cover. Overall, plant density was the most reliable and informative measurement over time; most of the kelps occurring at our study sites have perennial life histories (except *Nereocystis luetkeana*) and therefore retain their holdfasts and stipes when the blade senesces at the end of the growing season. This condition was apparent especially at E4 Hard_30, because sampling took place during autumn 2000 and spring 2001 and 2002.).

Percent cover estimates were more variable than plant density due to the effects of seasonality, but nevertheless provide an important measure of the spatial coverage that is not obtainable with density estimates alone. As shown in Figure 15, mean percent cover was greater than 5% at 8 of the 31 sites, >10% at 5 sites, > 20% at 3 sites, and >80% at one site (E5 Hard_30 [Lester Point], which is growing primarily on *Modiolus*, as described in the Horse mussel section above). At E5 Hard_30, estimated percent cover of kelps increased substantially from 69% (4.4) in 2001 to 104% (4.1) in 2002. This does not reflect a true increase in percent cover, however. This reported increase apparently resulted primarily, if not entirely, from a change in methodology for estimating percent cover of kelps that was instituted at the beginning of the 2002 field season. This new method required distinguishing between and sub-adult and adult plants of the same

species and assessing percent cover for each, rather than the previous method of estimating cover for sub-adults and adults combined. Because sub-adults and adult kelps form multiple canopy layers, total percent cover for a species is overestimated using this method. This overestimation would predictably be more pronounced as kelp density increases, as is the case for E5 Hard_30. This sampling artifact does not appear to be significant at any other sites, even the site with the next highest abundance of kelp (E4 Hard_30). At this site, mean percent cover actually decreased from 2001 to 2002, although not [statistically] significantly. While this result may have masked a true decline in kelp percent cover at this site, this is unlikely because kelp density (based on stipe counts) exhibited a trend similar to that of percent cover.

At all sites where hard substrate was not a limiting factor, kelps were either not present or did not occur at or near carrying capacity (except at E4 Hard_30 and E5 Hard_30). Kelp usually did not occur at high densities/percent cover at any sites where urchin densities were moderate to high, probably due to intensive grazing of gametophytes and small sporophytes. However, kelps were present at the site with the highest density of urchins measured [W3 Hard_15], ironically. We have no explanation for this occurrence, and it will be very interesting to revisit this site in 2003. At many of the sites in which kelp was present, we observed signs of herbivory on kelp thalli, including complete severance of some *Nereocystis* stipes. At some of these sites, adult kelps were observed being actively fed upon by sea urchins (e.g., Figure 24), contrary to notions of a “size refuge” from urchin grazing once a plant becomes large.

Foliose Red Algae

The percent cover of foliose red algae was generally low (i.e. < 5%) at 25 of the 31 sites, except for two sites at which cover ranged between 16-26% (E2 Hard_15 and W5 Hard_15; see Figure 16). The most abundant foliose red algae at these two sites was *Constantinea spp.*, which appears to exhibit some resistance and/or resilience to grazing by sea urchins. Average percent cover was < 1% at 13 of these 25 sites. Foliose red coverage was especially variable at one site (E3 hard_30); mean percent cover [of *Constantinea*, primarily] increased incrementally from 1% in 2000 to 9% in 2002.

Encrusting Red Algae

The “red algal crust” group contains at least two species – an unidentified pinkish coralline crust (probably *Lithothamnion sp.*) and a dark maroon fleshy crust that tends to be more abundant in the western mid-bay. These two forms of encrusting red algae were present at 22 of the 31 study sites. Of these 22 sites, nine sites had cover between 1-5%, eight sites had percent cover between 5-20%, and five sites had coverage between 20-45%. The 14 sites with the highest percent cover were all hard bottom sites except one (W1 Soft_30). Substantial increases in percent cover were evident between 2000 and 2001 for some sites, and it is not clear whether this increase is real or is a result of inconsistent estimation by personnel during the study development stage. In any case, this species group should be re-assessed after the 2003 season. Taxonomic work must be performed in 2003 to identify these algal crusts.

Species Checklist

Species checklist data have not been entered into the database at this time. Copies of original hardcopy datasheets are used for reference and crosschecking other data, but analysis will be postponed until after the 2003 season.

Temperature

In 2002, we successfully retrieved 16 of the 20 water temperature data loggers that were deployed in 2001 at each of the 20 original sites. One logger was destroyed when the housing failed, and three were removed from the sites over the winter (probably due to a combination of strong water currents and drift kelp). Temperature data were quality controlled for outliers and pre-/post- deployment values and then archived. Data for each site were appended to the existing temperature time series (when available), then entered into an ACCESS database. Data were then summarized and graphically displayed (e.g., Figure 21).

Products & Accomplishments

A full list of products resulting from this project and accomplishments to date can be found in Appendix F.

Conclusions

Taxonomic/functional group densities and size frequencies exhibited considerable spatial variability among the 31 sites sampled, often among nearby locations. This time-averaged spatial variability, in all probability, is mostly attributable to among-site habitat differences (e.g., combinations of substrate type, oceanography, current speeds, sedimentation rates). Explanatory factors of lesser influence may include historical events

(e.g., differences in population trajectories of a species in different locations, community evolution along the glacial chronosequence), and stochastic processes at the scale of our 50 m transects (e.g. larval supply, recruitment patterns, disturbance rates, predation, and competition). Although few consistent patterns were immediately evident among study sites, some patterns were apparent to varying degrees (e.g., hard bottom vs. soft bottom, -15' sites vs. -30' sites, sites in very close proximity). Apparently, broad-scale spatial correlation was largely absent, with the exception of the pattern in which large sea stars were more abundant in the western Bay. Nevertheless, the apparent lack of ecological similarity among sites may present challenges in the future when considering spatial replicates of different community types for the BACI analysis. Quantitative analysis of community similarity and spatial pattern should be performed with these data in 2003.

The most striking ecological feature common to many of the study sites is the high average density of sea urchins in the lower-mid Bay. The sheer numbers and biomass of these herbivores are certainly limiting the diversity, distribution, and abundance of algal communities in the shallow nearshore zone. Once sea otters deplete highly nutritious, easily accessible bivalve resources in Glacier Bay, urchins will increasingly become a more important food source, and urchin biomass will decrease dramatically. When algae are thus released from intensive grazing pressure, we will likely see a dramatic increase of macroalgae in the Bay, including canopy forming kelp communities and understory Laminarians. This is the point where our relative certainty diminishes. Based on results from other studies, the direct and first order indirect effects of sea otter colonization are fairly well understood,. What the cascading effects of this large-scale perturbation will be are largely unknown and unpredictable, given our current

predictive capabilities for ecological systems. The importance of this looming ecological change should be clear to resource managers: natural systems occurring within the Park must be understood to protect and preserve them for future generations. Park managers can not understand how humans impact the landscape and natural systems/processes without knowing what natural resources exist, the approximate distribution and abundance of these resources, and how they vary over time and space. On a historical time scale, Glacier Bay is one of the most rapidly changing marine environments on earth. The ability to detect anthropogenic changes superimposed upon the natural changes occurring in this dynamic environment is a supreme challenge.

Table 1. Counts or sea otter population size estimates (*) for Glacier Bay, AK (J.L. Bodkin, 2001 and unpublished data)

Year	Number of sea otters observed
1994	0
1995	5
1996	39
1997	21
1998	209
1999	384*
2000	594*
2001	1238*
2002	1266*

Table 2. Permanent site information (Latitude and Longitude are in decimal degree format, NAD 83 datum). Depth of site is incorporated into suffix of site name.

Site Name	Site Description	Year Established	Latitude	Longitude	GPS Error (feet)
E1Hard_30	Sturgess Island	2000	58.71632	-136.04537	20
E1Soft_15	N. Sandy Cove	2002	58.72406	-136.00774	?
E1Soft_30	N. Sandy Cove	2000	58.72473	-136.00697	24
E2Hard_15	N. Beardslees	2002	58.53723	-135.96281	19
E2Hard_30	N. Beardslees	2000	58.53752	-135.96532	?
E2Soft_30	South of Flapjack Island	2000	58.56032	-135.97406	?
E3Hard_15	Beardslees	2002	58.53318	-135.94476	20
E3Hard_30	Beardslees	2000	58.53363	-135.94582	?
E3Soft_30	E. Kidney Island	2000	58.53437	-135.90280	32
E4Hard_30	W. Young Island / Sitakaday	2000	58.46868	-135.99905	27
E4Soft_15	W of N entrance to Secret Bay	2002	58.49262	-135.97333	17
E4Soft_30	W of N entrance to Secret Bay	2000	58.49242	-135.97368	?
E5Hard_15	Lester Point, Bartlett Cove	2002	58.44870	-135.93561	?
E5Hard_30	Lester Point, Bartlett Cove	2001	58.44796	-135.93420	13
E5Soft_30	Halibut Point, Bartlett Cove	2001	58.44856	-135.90129	21
W1Hard_30	S Drake Island	2000	58.63178	-136.20917	16
W1Soft_15	E Drake Island	2002	58.64440	-136.20998	?
W1Soft_30	E Drake Island	2000	58.64455	-136.20958	?
W2Hard_15	S. Fingers Bay	2002	58.56425	-136.18298	14
W2Hard_30	S. Fingers Bay	2000	58.56425	-136.18298	14
W2Soft_30	N. Fingers Bay	2000	58.59542	-136.19693	20
W3Hard_15	E. Willoughby Island	2002	58.59467	-136.09956	21
W3Hard_30	E. Willoughby Island	2001	58.59480	-136.09945	?
W3Soft_30	Johnson Cove, Willoughby Isl	2000	58.59542	-136.19693	20
W4Hard_15	SE Berg Bay	2002	58.51856	-136.15141	?
W4Hard_30	SE Berg Bay	2000	58.51917	-136.15248	25
W4Soft_30	SE Berg Bay	2000	58.51403	-136.15885	22
W5Hard_15	N. of Rush Point (S of Berg)	2002	58.51504	-136.10440	18
W5Hard_30	N. of Rush Point (S of Berg)	2000	58.51512	-136.10460	27
W5Soft_15	N. of Rush Point	2002	58.48685	-136.10045	?
W5Soft_30	N. of Rush Point	2000	58.48702	-136.09993	25

Table 3. Descriptive statistics for R measurements of sea star species (2002 only). “R” is the measurement from the tip of an arm ray to the center of the central disk; the approximate arm span of a sea star can be estimated by multiplying R by 2.

Species	Minimum Size (cm)	Maximum Size (cm)	Mean Size (cm)	Standard Deviation	Standard Error	Sample Size
<i>Crossaster papposus</i>	1	11	3	1.63	0.15	121
<i>Evasterias troschelii</i>	2	36	19	6.31	0.54	134
<i>Henricia spp.</i>	1	11	4	2.32	0.47	24
<i>Leptasterias spp.</i>	2	21	11	3.20	0.22	204
<i>Mediaster aequalis</i>	2	4.5	3	0.97	0.31	10
<i>Orthasterias koehleri</i>	20	33	26	4.10	1.45	8
<i>Pteraster tessellatus</i>	1.5	10	5	2.79	1.14	6
<i>Pycnopodia helianthoides</i>	1	50	21	13.15	1.90	48
<i>Solaster spp.</i>	1	24	8	4.70	0.33	197
<i>Solaster stimpsoni</i>	6	24	13	6.25	2.21	8
<i>Stylasterias forreri</i>	26	26	26	n.a.	n.a.	1

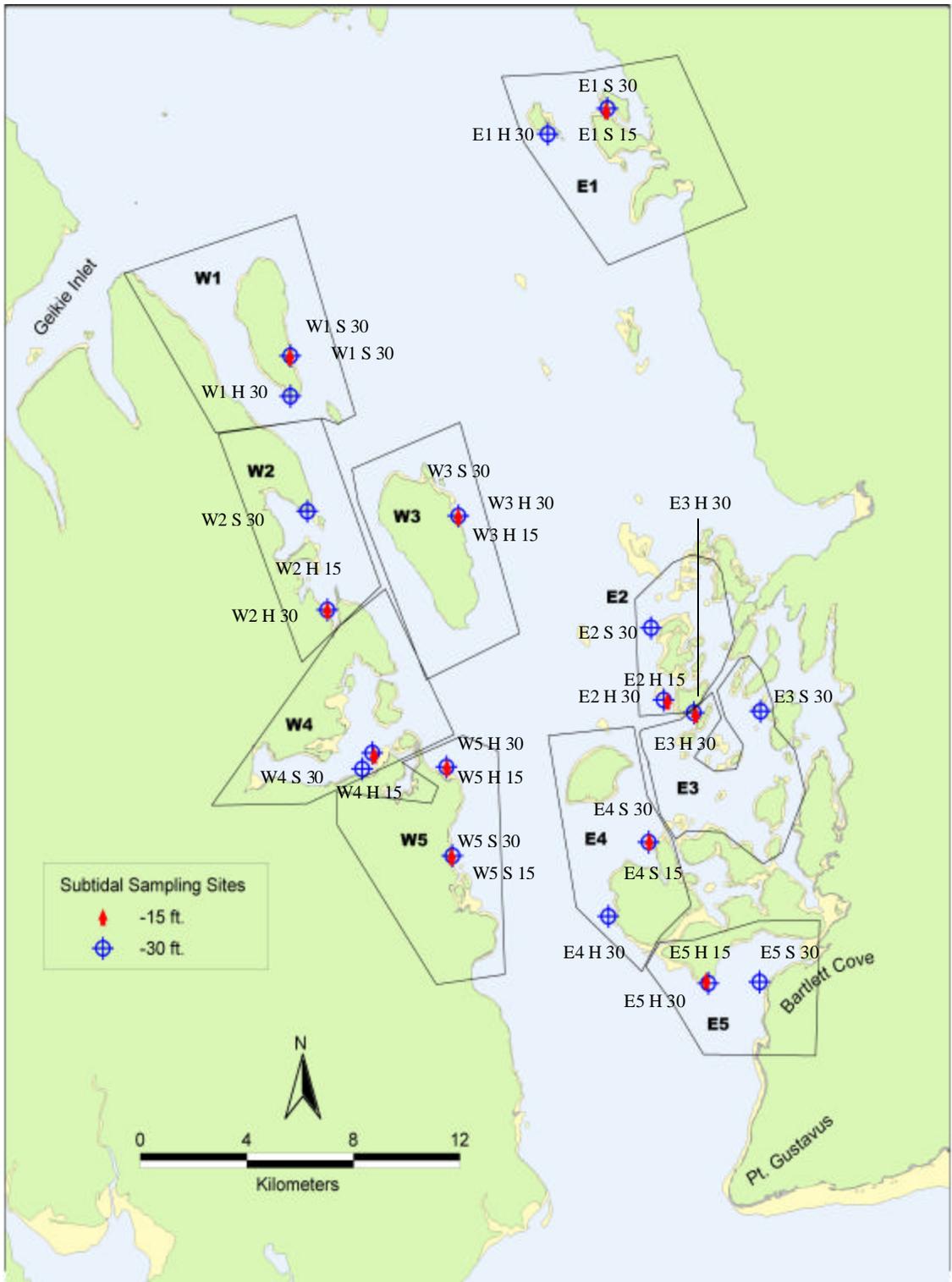


Figure 1. Location of study sites in Glacier Bay

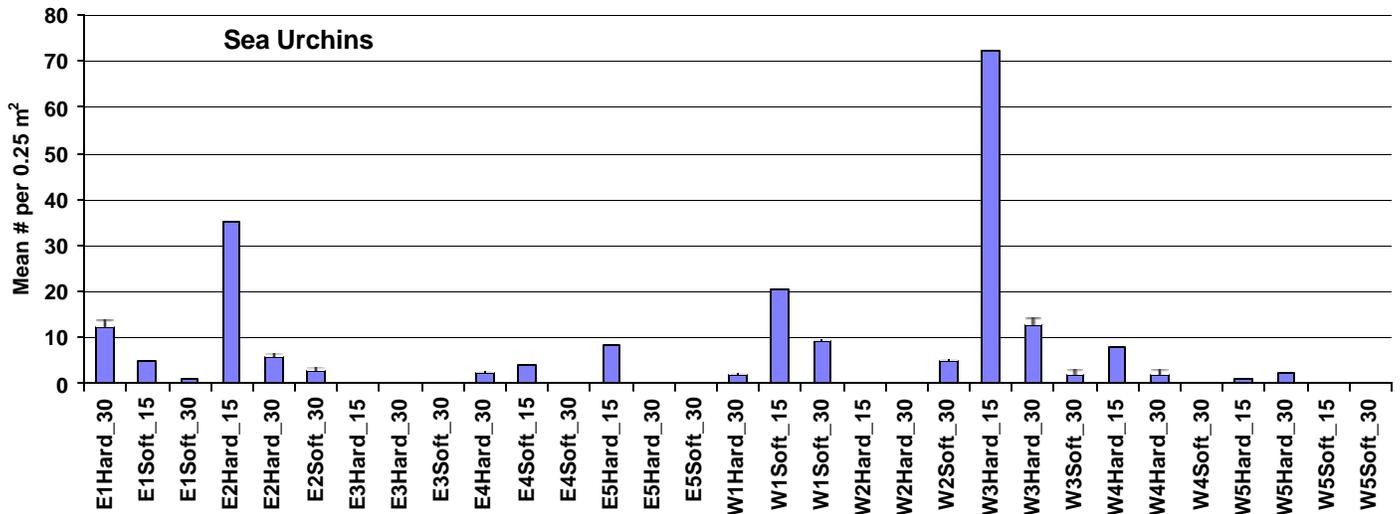


Figure 2. Mean density and standard error of sea urchins *S. droebachiensis* (98% of total) and *S. pallidus* (2%) at each of the 31 sites sampled as of 2002 (all years combined).

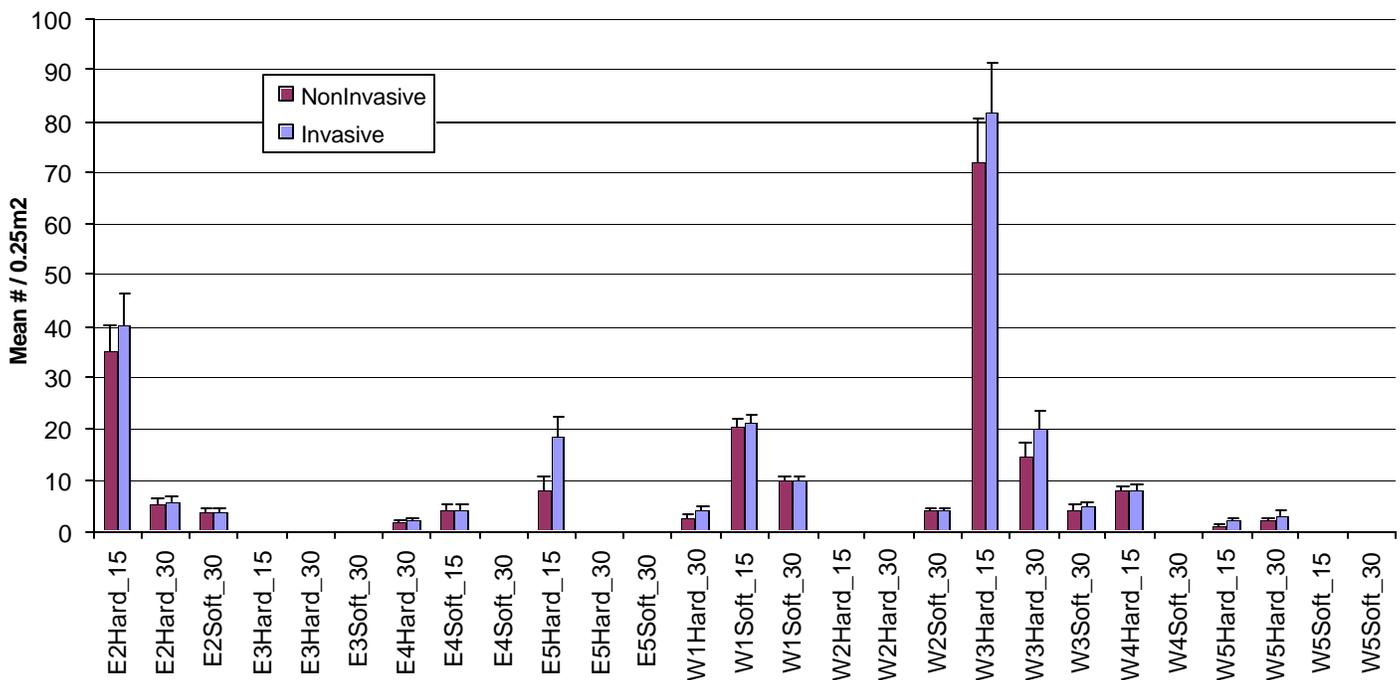


Figure 3. Mean density and standard error of sea urchins *S. droebachiensis* and *S. pallidus* sampled both invasively and non-invasively at 27 of the 31 sites sampled in 2002 (the only year in which invasive data was also collected). Invasive counts were not performed at E1 Hard_30, E1 Soft_30, E1 Soft_15, or W4 Hard_30.

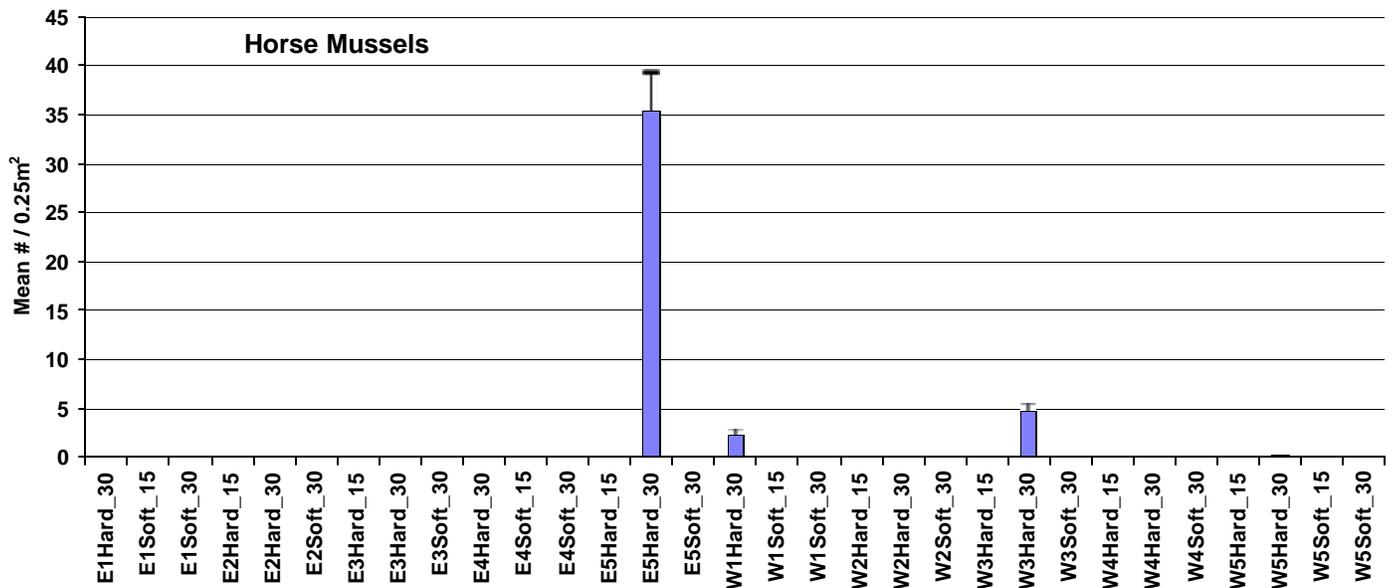


Figure 4. Mean density and standard error of the horse mussel *Modiolus modiolus* at each of the 31 sites sampled as of 2002 (all years combined).

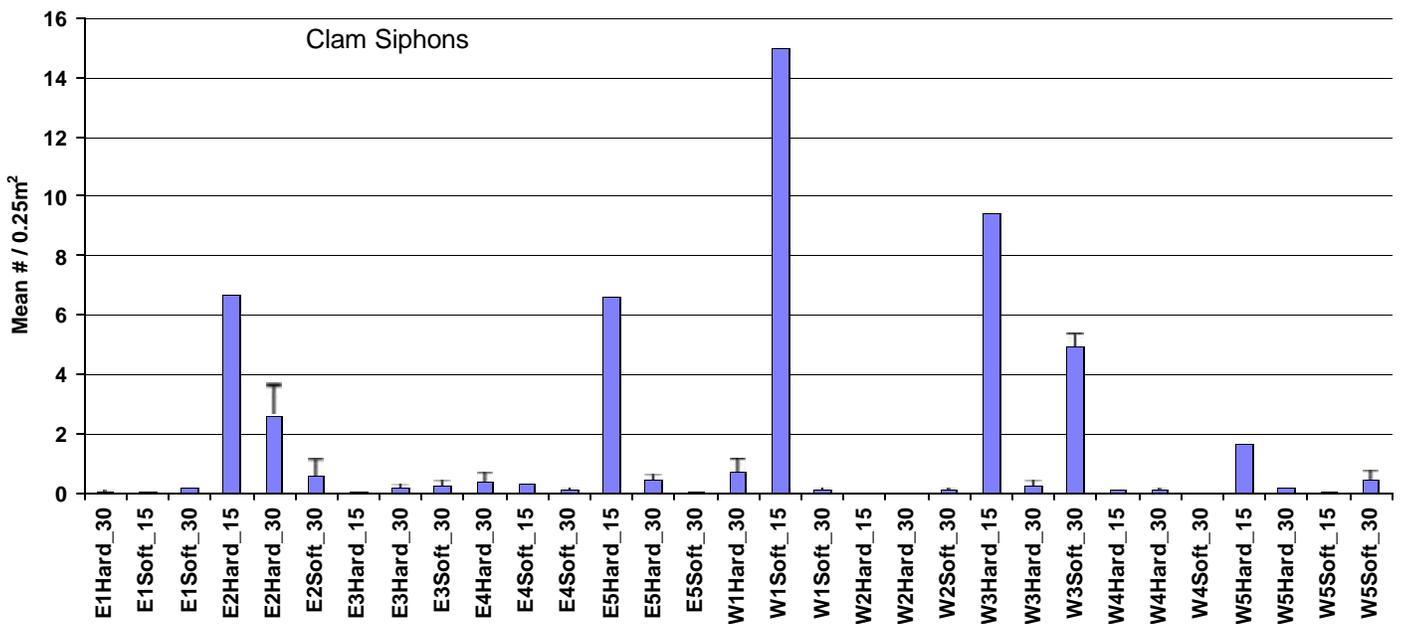


Figure 5. Mean density and standard error of clam siphons (not identified to species – see Bodkin et al. 2001 for species present in Glacier Bay) at each of the 31 sites sampled as of 2002 (all years combined).

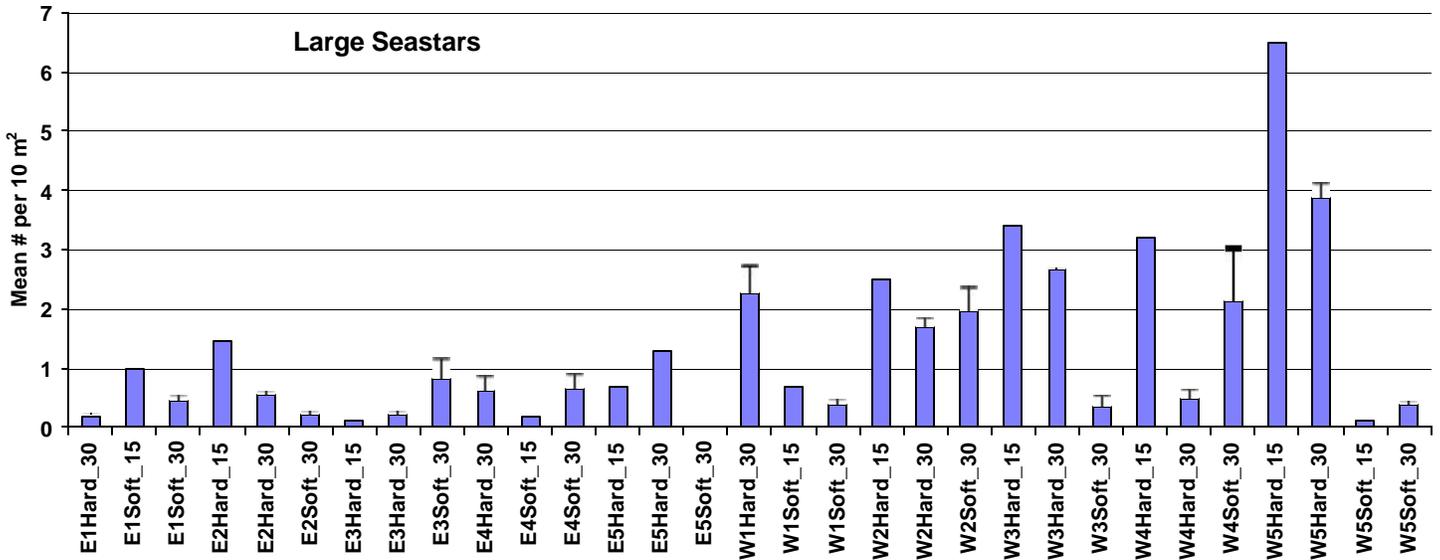


Figure 6. Mean density (+1 standard error) of large sea stars at each of the 31 sites sampled as of 2002 (all years combined). Taxa include *Leptasterias* sp. (36% of total), *Solaster* spp.(33%), *Evasterias troschelli* (26%), *Pycnopodia helianthoides* (5%), *Orthasterias koehleri* (0.5%), and *Stylasterias forreri* (0.1%).

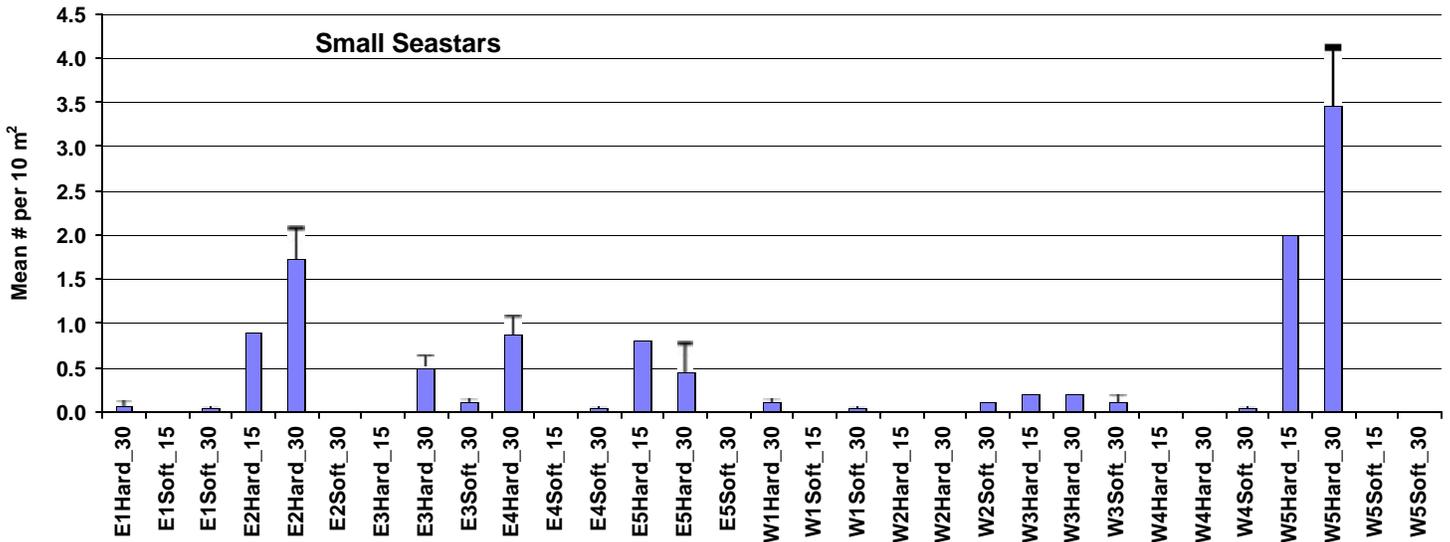


Figure 7. Mean density (+1 standard error) of small sea stars at each of the 31 sites sampled as of 2002 (all years combined). Taxa include *Crossaster papposus* (77%), *Henricia* spp. (17%), *Pteraster tessellatus* (3%), and *Mediaster aequalis* (3%).

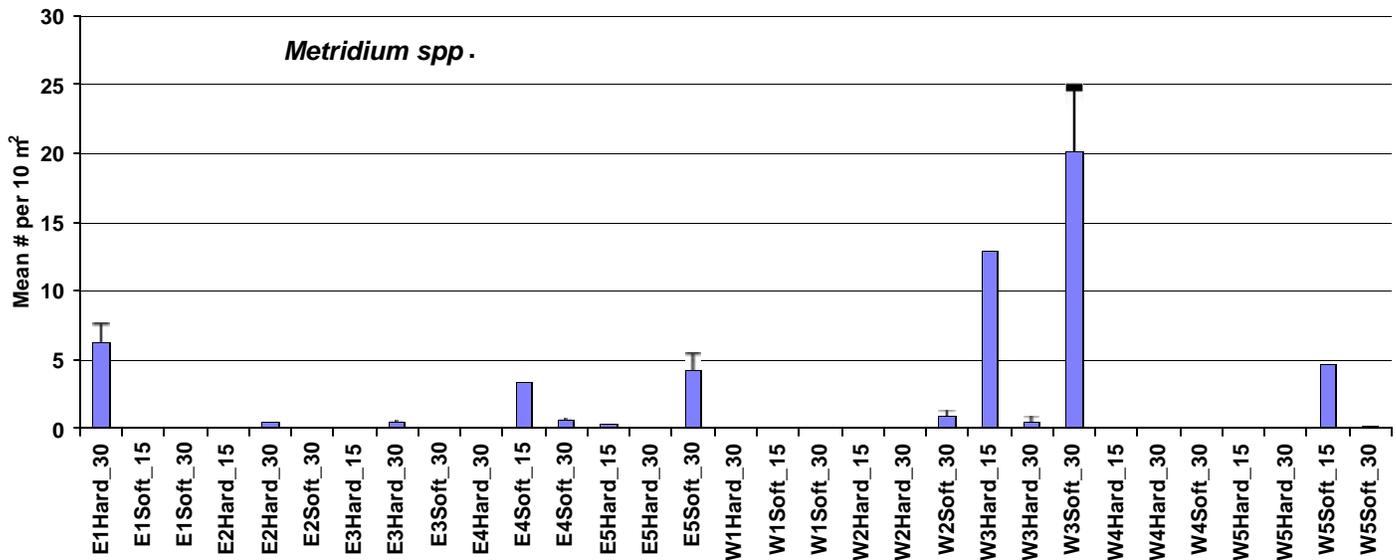


Figure 8. Mean density (+1 standard error) of *Metridium* spp. at each of the 31 sites sampled as of 2002 (all years combined). Taxa include *Metridium giganteum* (98%) and *Metridium senile* (2%).

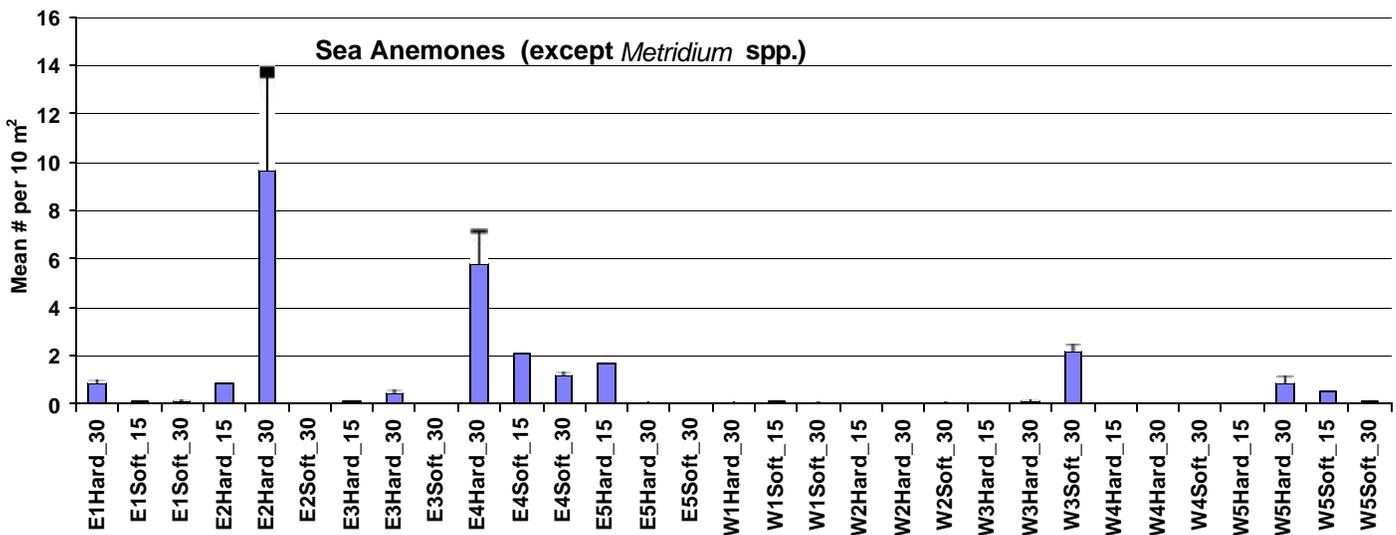


Figure 9. Mean density (+1 standard error) of sea anemones at each of the 31 sites sampled as of 2002 (all years combined). Taxa include unidentified anemone #1 (probably *Urticina crassicornis*; 35%), unidentified anemone #2 (22%), *Urticina crassicornis* (15%), *Cribrinopsis fernaldi* (12%), unidentified anemone #3 (7%), unidentified anemone #4 (possibly *Urticina lofotensis*; 4%), and *Urticina* spp. (3%).

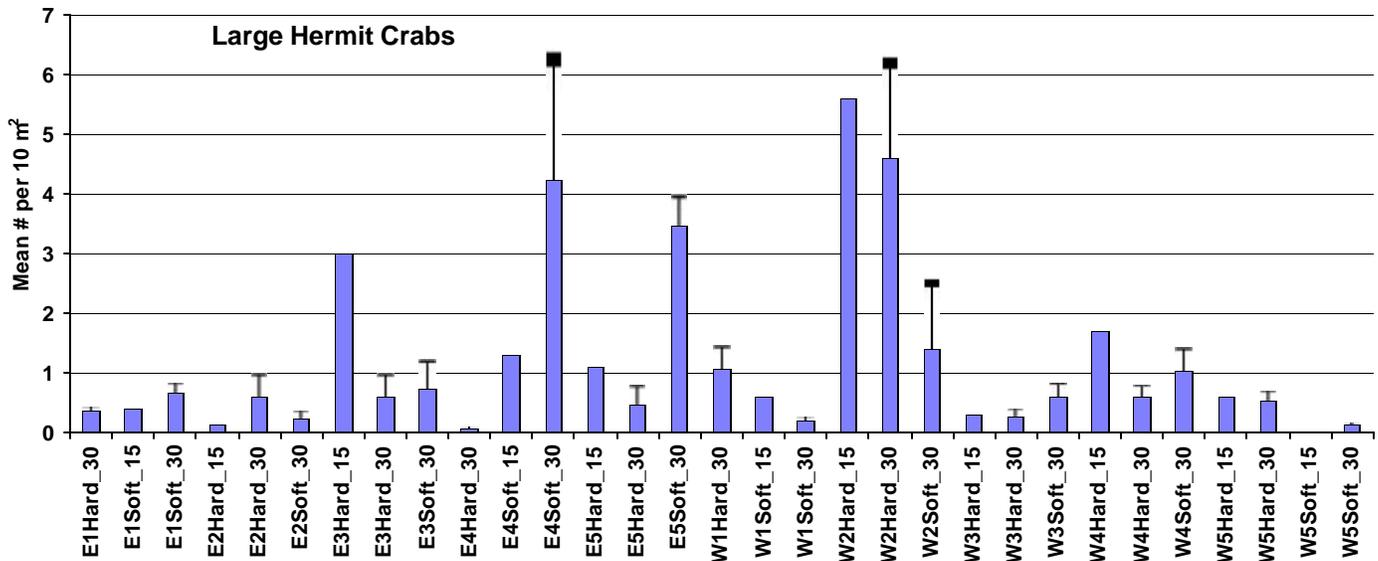


Figure 10. Mean density (+1 standard error) of large hermit crabs at each of the 31 sites sampled as of 2002 (all years combined). Taxa include *Elassochirus tenuimanus* (60%), *Elassochirus gilli* (15%), unidentified hermit crabs (12%), *Pagurus* spp.(9%), *Pagurus capillatus* (3%), and *Pagurus ochotensis* (0.5%).

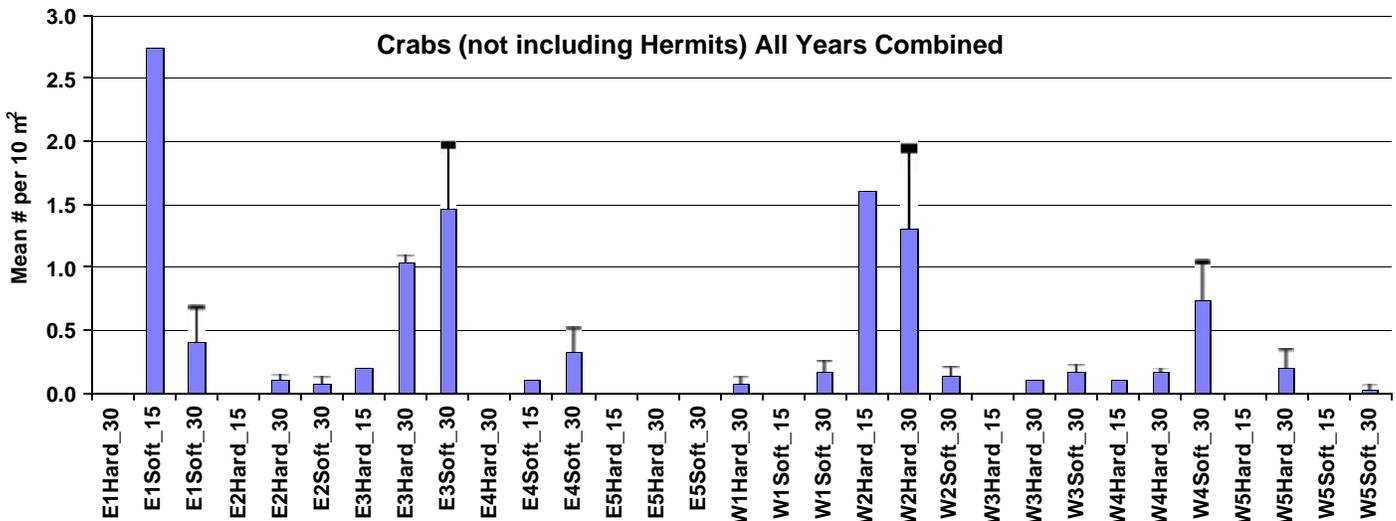


Figure 11. Mean density (+1 standard error) of crabs (not including hermits) at each of the 31 sites sampled as of 2002 (all years combined). Taxa include *Hyas lyratus* (69%), *Cancer oregonensis* (9%), *Telmessus cheiragonus* (7%), unidentified decorator crab (probably *Oregonia gracilis* (7%), *Rhinolithodes wosnessenskii* (2%), *Chionoecetes bairdi* (2%), *Cancer magister* (1%), *Paralithodes camtschaticus* (1%), *Oregonia gracilis* (1%), and *Cryptolithodes* spp. (0.5%).

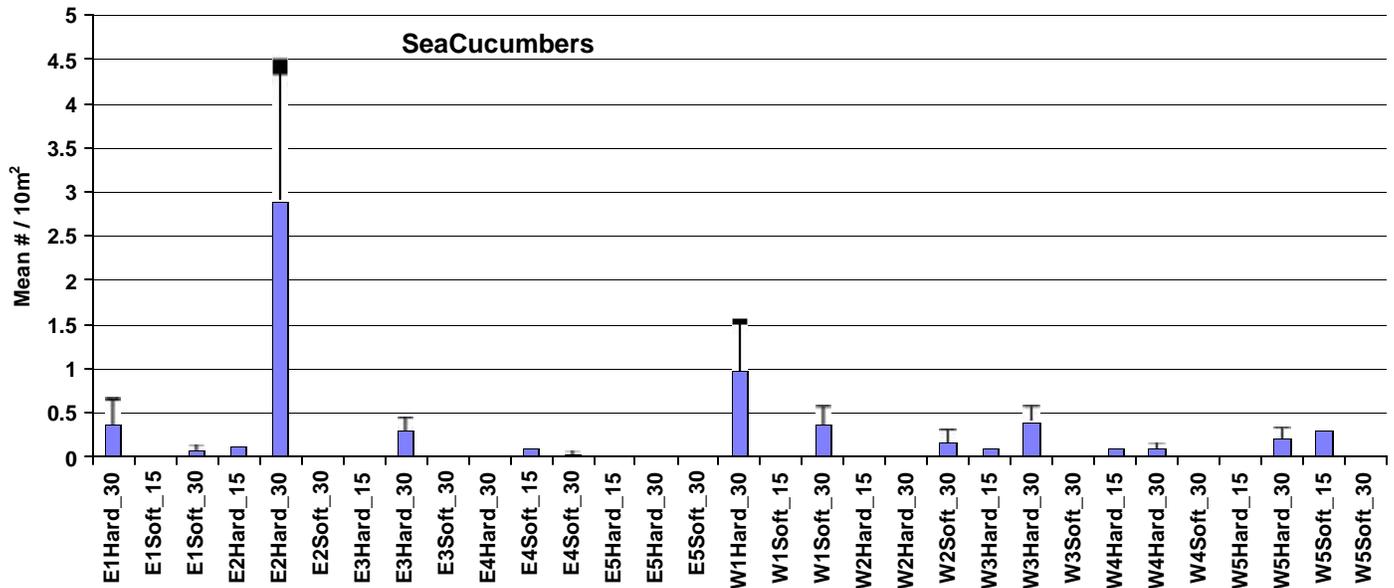


Figure 12. Mean density (+1 standard error) of sea cucumbers at each of the 31 sites sampled as of 2002 (all years combined). Taxa include *Cucumaria miniata* (84%), *Cucumaria frondosa* (9%), *Synallactes challengerii* (4%), unidentified cucumber (2%), and unidentified *Cucumaria* (2%).

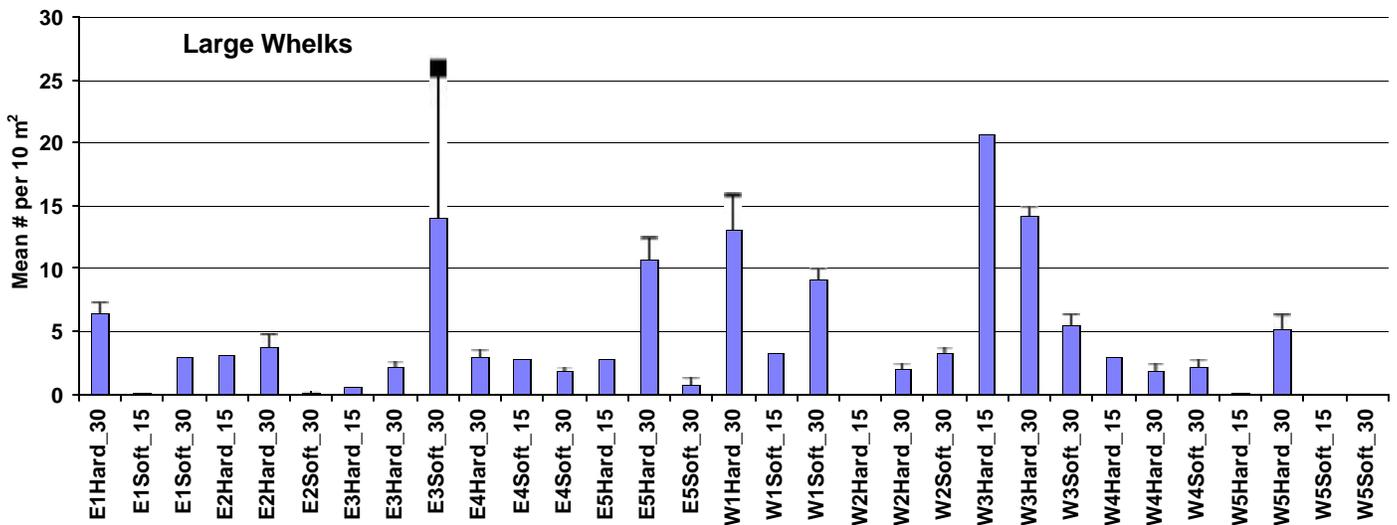


Figure 13. Mean density and standard error of whelks > 6cm (total length) at each of the 31 sites sampled as of 2002 (all years combined). Taxa include *Fusitriton oregonensis* (66%), an unidentified species (possibly *Volutopsius castaneum*; 15%), *Neptunea lyrata* (15%), *Beringius kennecotti* (3%), *Buccinum plectrum* (0.5%), and *Boreotrophon sp.* (0.05%).

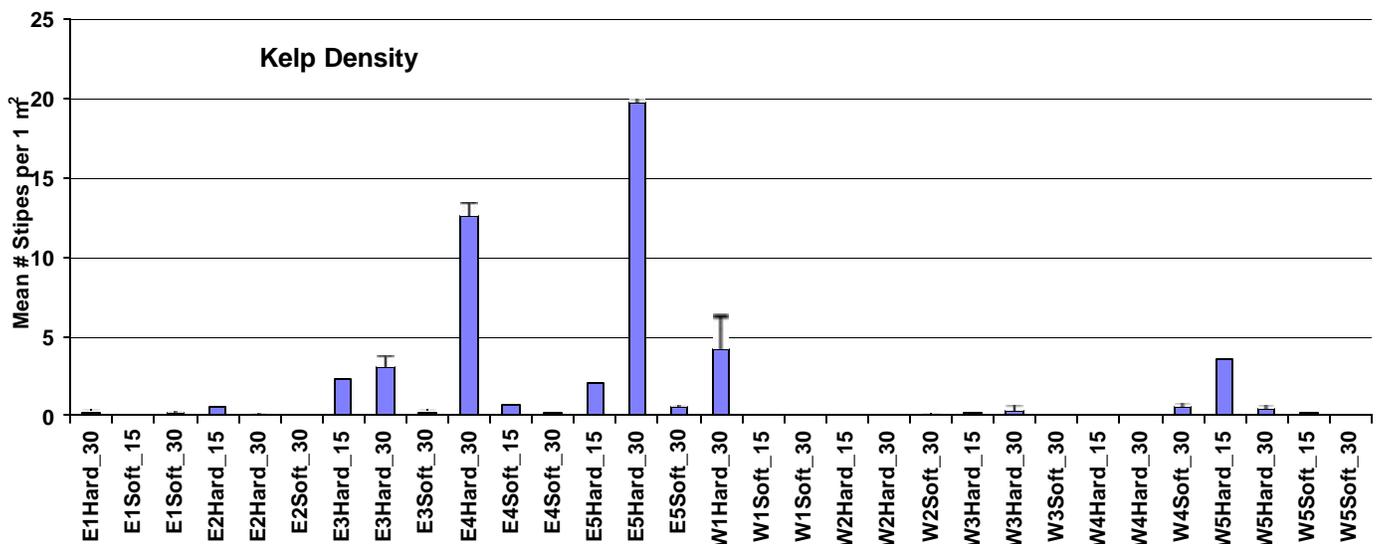


Figure 14. Mean density (+1 standard error) of kelp plants at each of the 31 sites sampled as of 2002 (all years combined). Taxa include *Laminaria spp.* (includes *L. saccharina* and *L. bongardiana*; 29%), *Laminaria spp./Pleurophycus gardneri* (24%), *Agarum clathratum* (20%), *Nereocystis luetkeana* (16%), *Alaria fistulosa* (5%), unidentified kelp (4%), *Costaria costata* (1%), and *Cymathere triplicata* (0.04%).

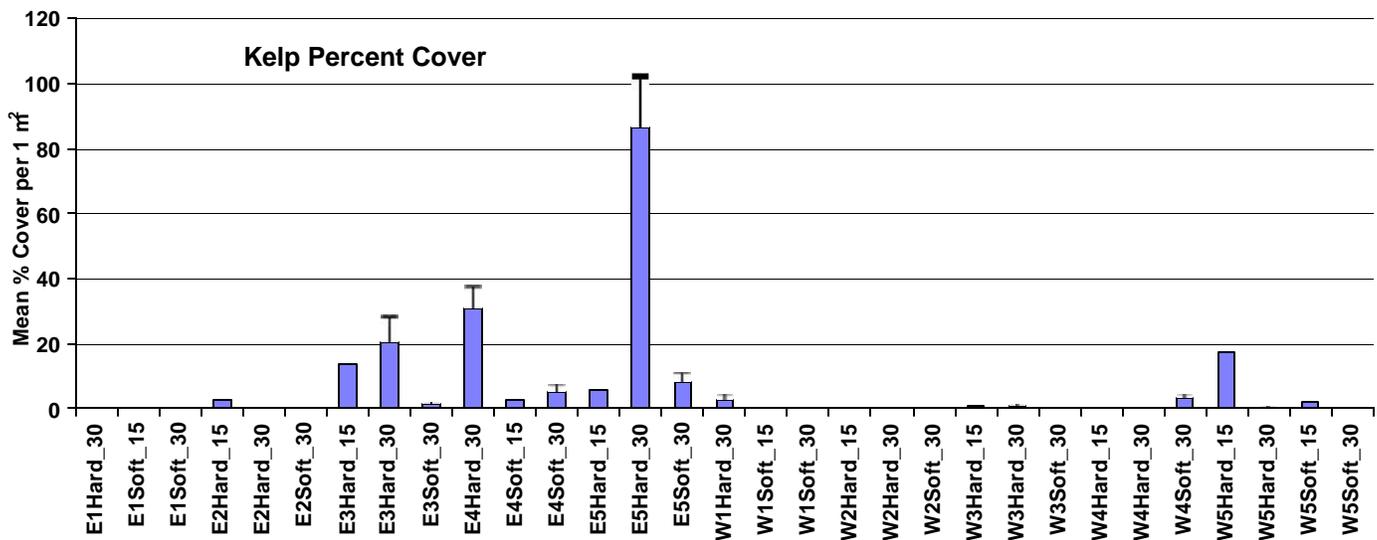


Figure 15. Mean percent cover (+1 standard error) of kelps at each of the 31 sites sampled as of 2002 (all years combined). Taxa include *Laminaria spp.* (includes *L. saccharina* and *L. bongardiana*; 41%), *Agarum clathratum* (28%), *Laminaria spp./Pleurophycus gardneri* (17%), *Alaria fistulosa* (6%), *Nereocystis luetkeana* (4%), *Cymathere triplicata* (2%), *Costaria costata* (1%), and unidentified kelp (1%).

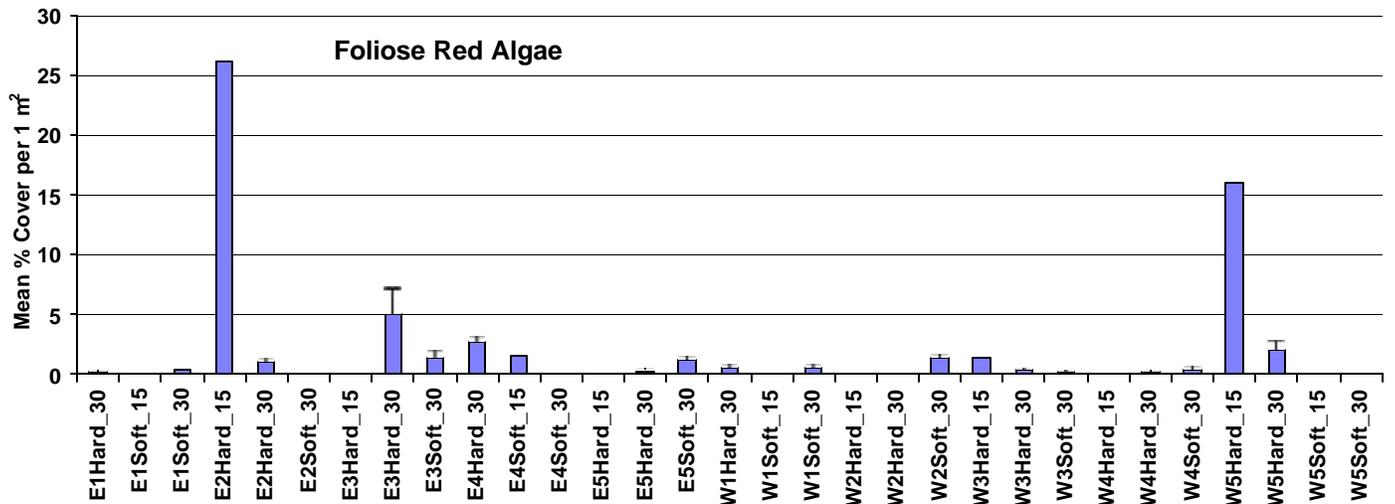


Figure 16. Mean percent cover (+1 standard error) of foliose red algae at each of the 31 sites sampled as of 2002 (all years combined). Taxa include *Constantinea spp.* (39%), unidentified red blade #1 (19%), unidentified red blade #2 (13%), *Sparlingia pertusa* (12%), *Turnerella mertensiana* (11%), and *Opuntiella californica* (6%).

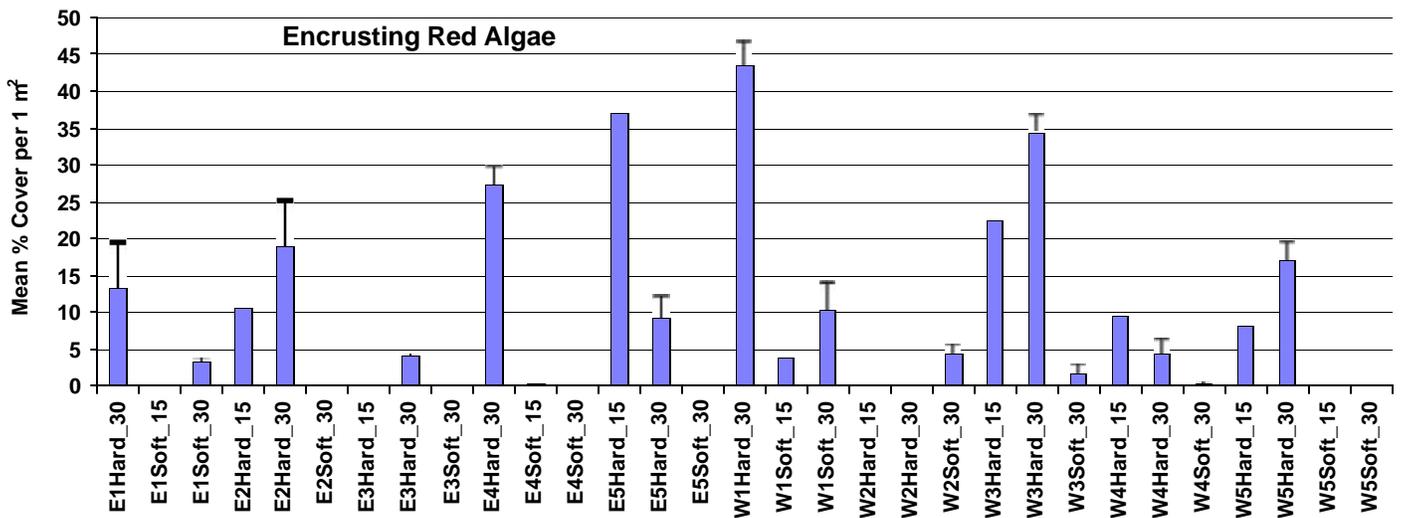


Figure 17. Mean percent cover (+1 standard error) of encrusting red algae at each of the 31 sites sampled as of 2002 (all years combined). Taxa include an unidentified coralline red algae (probably *Lithothamnion sp.*; 68%) and an unidentified fleshy maroon crust (32%).

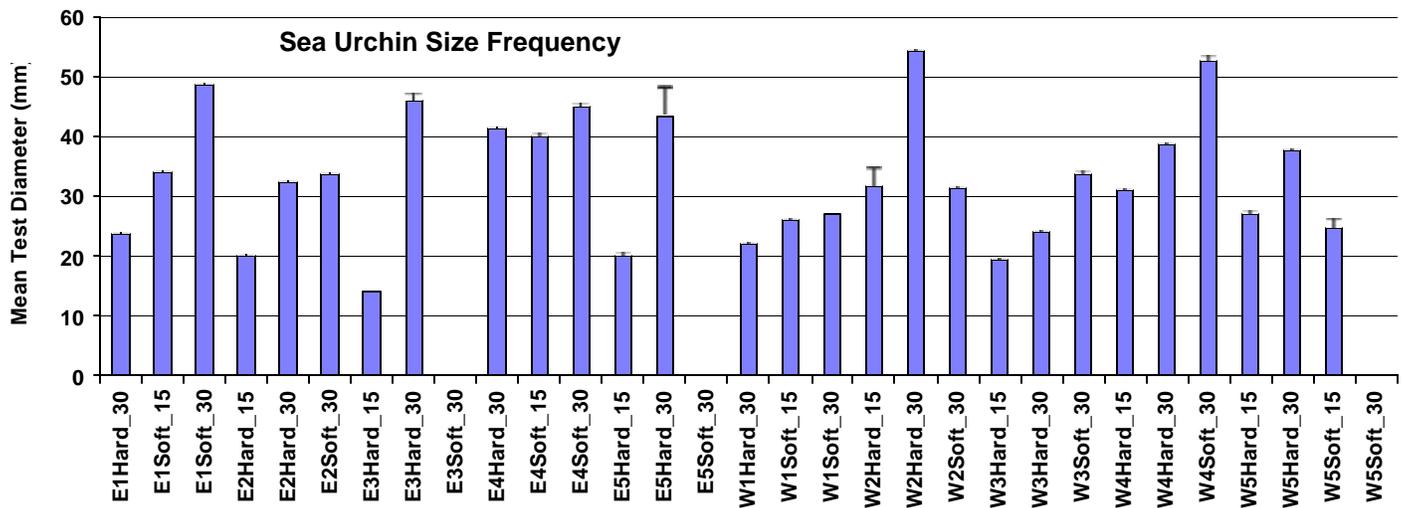


Figure 18. Mean test diameter (in mm) and standard error of sea urchins at each of the 31 sites sampled as of 2002 (all years combined). Note differences in the mean size of urchins between the -15' and -30' sites at the same location (e.g., E3 Hard, E5 Hard, W2 Hard).

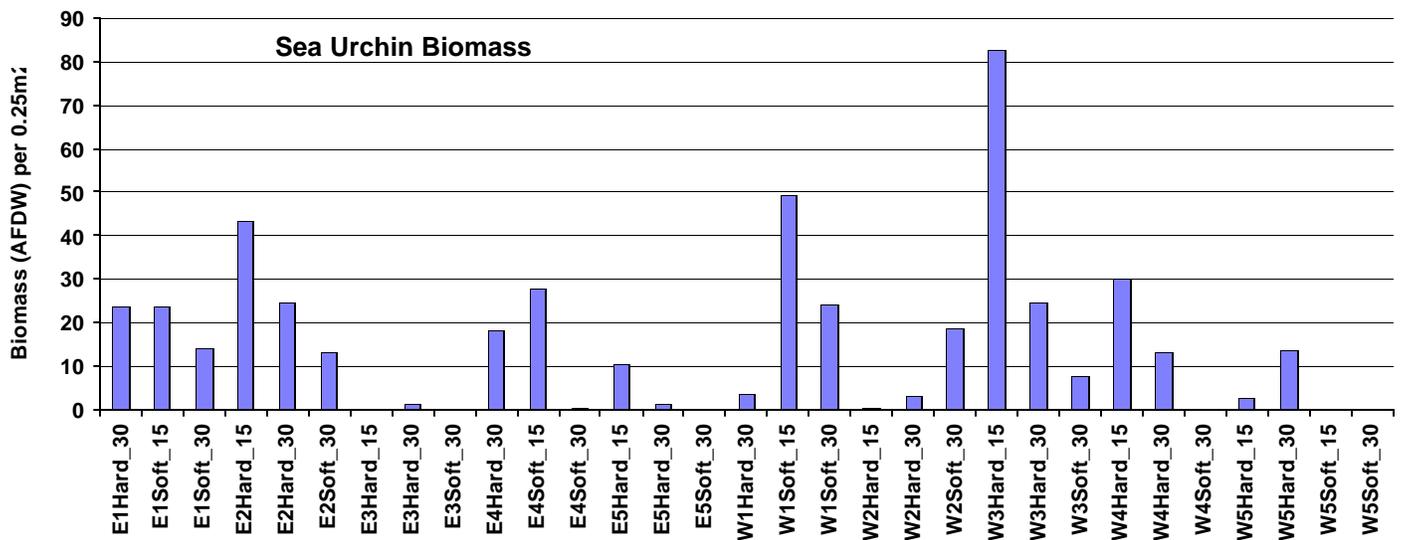
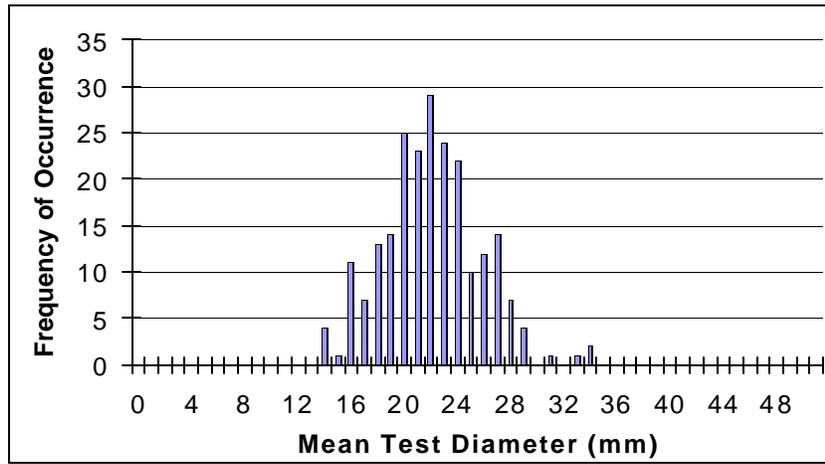
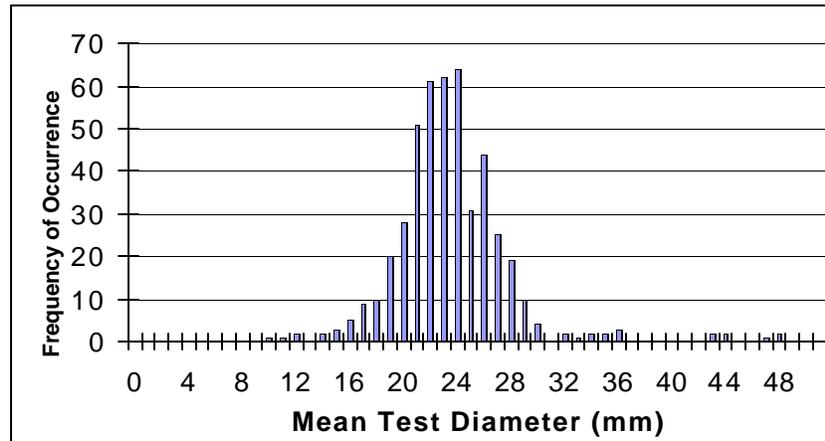


Figure 19. Estimated biomass (ash free dry weight [AFDW] in grams) of sea urchins. Biomass = (mean # urchins / 0.25m²) x [(0.000650) x (urchin test diameter [mm]^{2.5187})] Equation from Dean et al. (in press).

2000



2001



2002

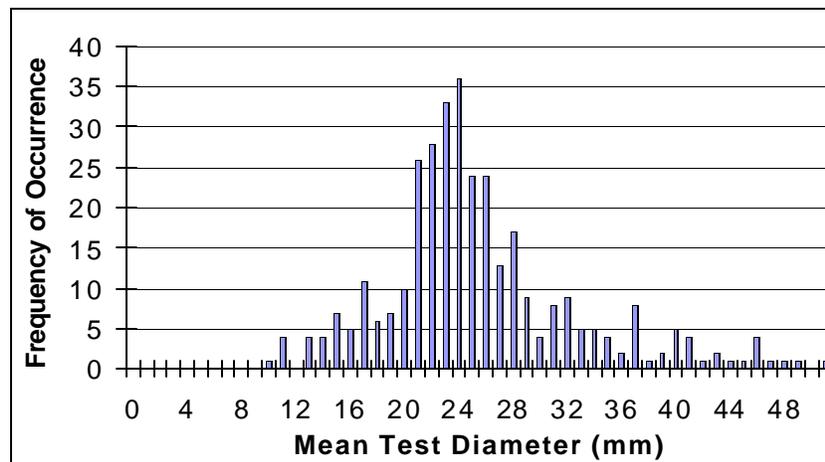


Figure 20. Size frequency histograms for non-invasively sampled sea urchins at E1 Hard_30 (Sturgess Island hard bottom site at -30' MLLW) for each year of the study. Mean test diameter (\pm 95% Confidence Interval) increased from 22.1 mm (0.48) in 2000 to 23.5 (0.40) in 2001 to 25.5 (0.77) in 2002. Sample size (i.e. number of individuals measured) for each year ranged from 224 – 469.

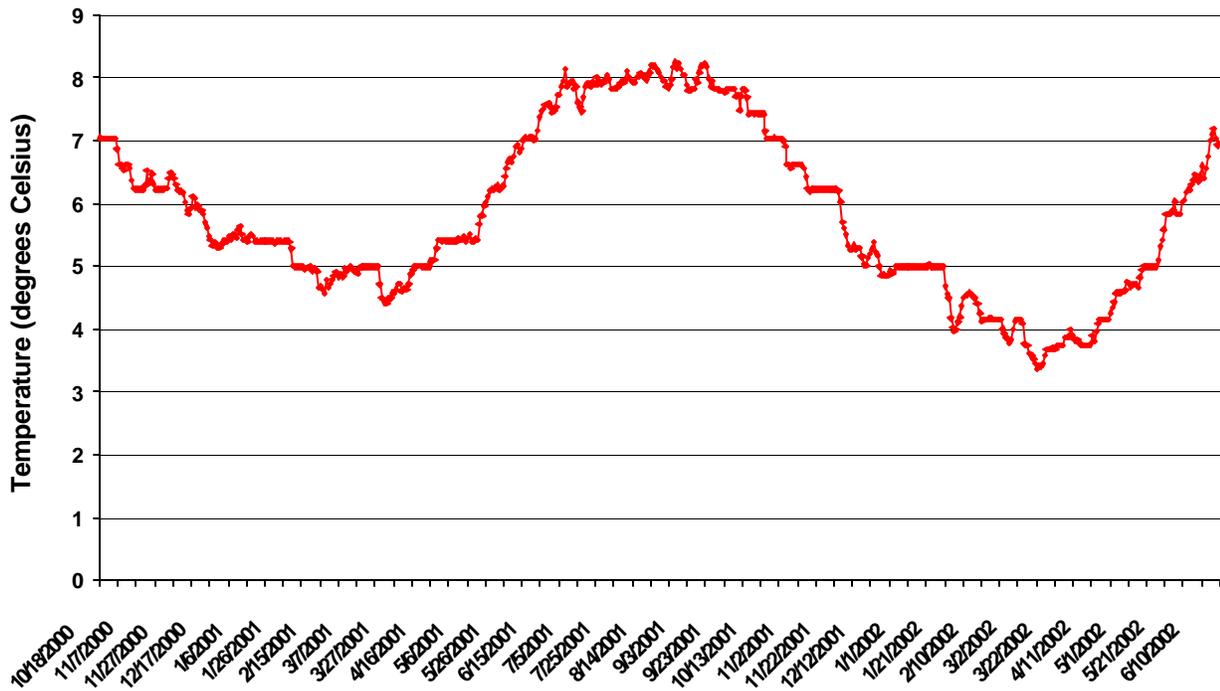


Figure 21. Average daily water temperature (°C) at E2 Hard_30 (NW Beardslee Islands at -30' MLLW) from October 2000 to June 2002.

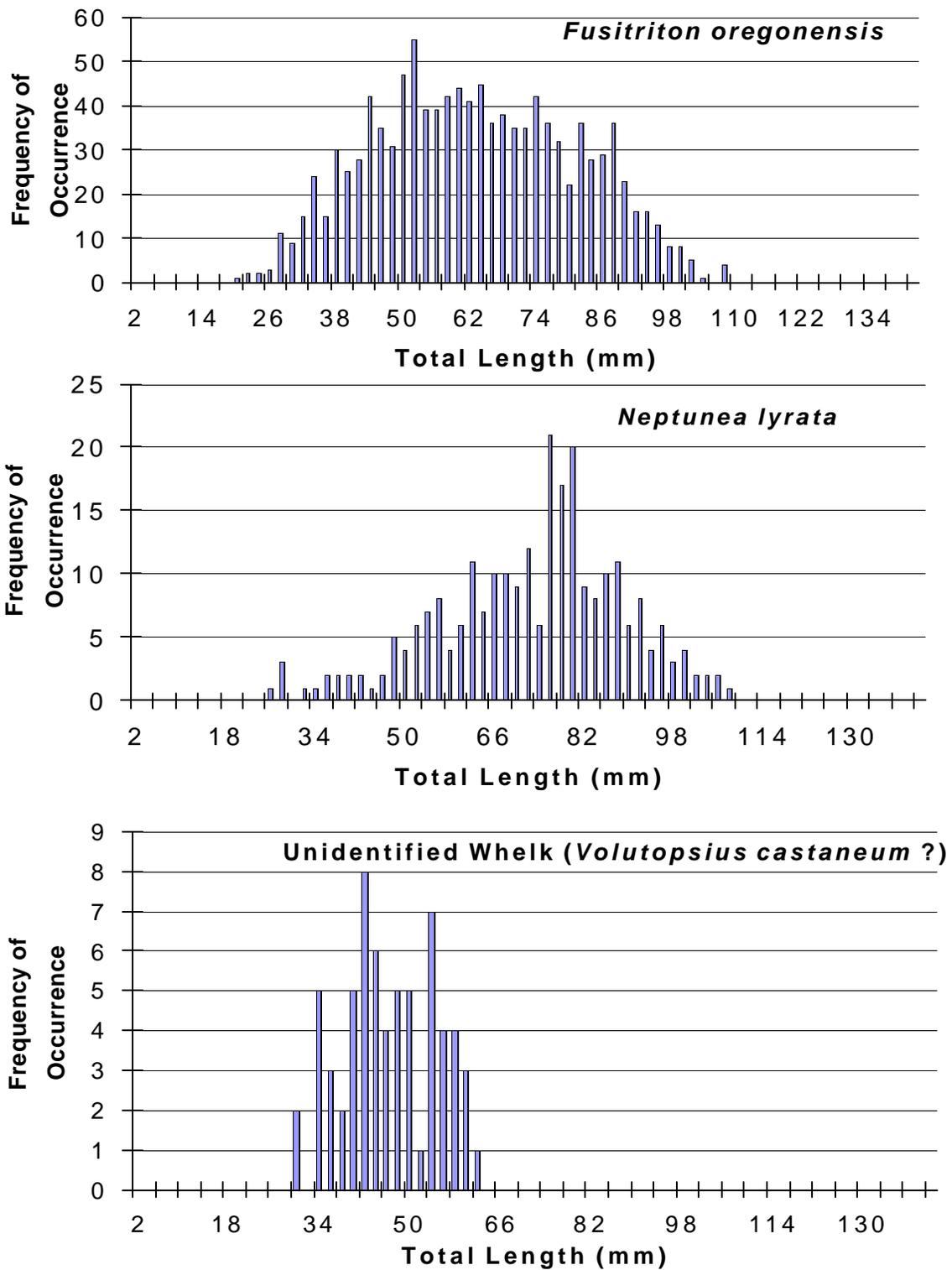


Figure 22. Size frequency histograms for the three most abundant species of whelks. Mean sizes (standard error): *Fusitriton oregonensis* 68.5 mm (0.5), n=1124; *Neptunea lyrata* 72.2 (1.03), n= 256; unidentified whelk 45.9 (1.0), n=65.

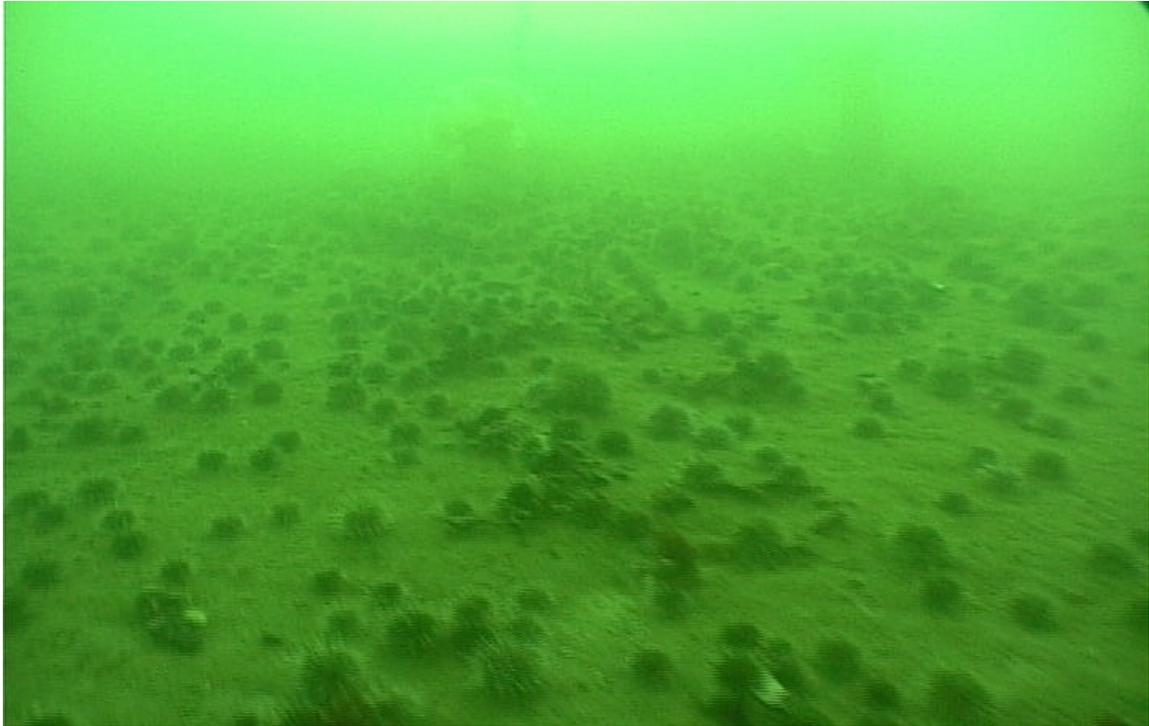


Figure 23. Sea urchin “barrens” at Willoughby Island (W3 Hard_15).



Figure 24. Urchins grazing on adult *Nereocystis luetkeana* stipes at W3 Hard_15.

Acknowledgments

This work has been supported by the National Park Service and the USGS Alaska Science Center. We would like to acknowledge the efforts and contributions of Larry Basch, Bethan Davis, Jed Davis, Captain Ken Grant of the M/V Nunatak, Jennifer DeGroot, Captain James Luthy, Mike Michalski, Bruce McDonough, Mary Beth Moss, Andy Rossi, Captain Justin Smith of the M/V Capelin, Joe Tiblus, Scott VanSant, and the numerous volunteers (especially Sue Hazlett) that have assisted with the project over the last 3 seasons.

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Appendix A. Sea Otter Effects / Subtidal Monitoring Study Plan

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1. STUDY PLAN TITLE: Ecological relations between sea otters and benthic marine communities in Southeast Alaska / Inventory and Monitoring of shallow benthic communities in Glacier Bay
2. ORGANIZATION: NPS & USGS/BRD Alaska Science Center (ASC)
3. PRINCIPAL INVESTIGATORS: Michael D. Donnellan and James L. Bodkin
4. PROJECT COSTS: FY02 \$ 110,000
FY03 \$ 120,000
5. SIGNATURES:

Project Leader: _____ Date: _____

Project Leader: _____ Date: _____

NPS Resources Management Division Chief: _____ Date: _____

NPS Superintendent: _____ Date: _____

Draft modified 12/10/02

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Summary:

Sea otters, extirpated from Southeast Alaska more than a century ago, are now in the process of re-colonizing prior habitat, including Glacier Bay National Park and Preserve. Based on observations elsewhere, we anticipate profound and long lasting effects (both direct and cascading) as this carnivore resumes its role in structuring nearshore marine communities. If not documented and quantified, these effects will hinder management of nearshore resources in Glacier Bay for decades to come. Ongoing studies supported by the USGS and NPS provide critical data on the numerical and distribution pattern of sea otter colonization and diet, and on intertidal and subtidal clam populations in Glacier Bay. The intent of this study plan is to identify specific hypotheses relative to the effects of sea otter predation (both direct and indirect) on epibenthic marine communities and to describe methods to provide the data required to test those hypotheses. In brief, a Before-After-Control-Impact (BACI) study design will be used (with foraging by sea otters defined as the “impact”) provided certain key assumptions are met. If the assumptions are not met, a less powerful Before-After approach will be used.

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1. Introduction

Sea otters (*Enhydra lutris*) provide one of the best-documented examples of top-down forcing effects on the structure and functioning of nearshore marine ecosystems in the North Pacific Ocean (Kenyon 1969, VanBlaricom and Estes 1988, Riedman and Estes 1990, Estes and Duggins 1995). Much of our knowledge of the role of sea otters as a source of community variation resulted from the spatial and 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 former habitat in the North Pacific. During this absence, populations of many of the sea otter's prey responded to reduced predation by increasing in mean size, density and biomass. In at least one well-documented example (the sea urchin, *Strongylocentrotus* spp), the removal of sea otters resulted in profound changes in community organization with cascading effects throughout the nearshore ecosystem (Estes and Palmisano 1974, Estes and Duggins 1995).

When sea otters are present in the nearshore system, the density and size class distribution of herbivorous sea urchin populations are reduced by sea otter predation, and attached macroalgae may flourish due to a release from grazing pressure. In this state, the nearshore ecosystem is characterized by relatively high diversity and biomass of red algae and brown algae (primarily “kelps” – members of the Order Laminariales that include conspicuous species such as *Laminaria* spp. and the surface canopy-forming *Nereocystis luetkeana*, *Alaria fistulosa*). These macroalgae - especially kelps - are highly productive and provide food and habitat for invertebrates and fishes that in turn support higher trophic levels, such as fishes, birds, and mammals. This system is commonly referred to as “kelp-dominated.”

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When sea otters are removed from a kelp-dominated system, sea urchin populations respond by increasing in density, mean size, and total biomass. Expanding urchin populations exert increasing grazing pressure, eventually resulting in near-complete removal of foliose algae. This system is characterized by large, abundant sea urchins and reduced algal productivity, diversity and biomass (and associated habitat structure). The reduction of algae in turn results in reduced abundance of organisms associated with or dependent upon foliose algae. The urchin-dominated community is commonly referred to as an “urchin barren”. Other factors such as disease influence urchin abundance, and kelp forests can and do exist in the absence of sea otters. However, “urchin barrens” are unknown in the presence of sea otter populations at equilibrium, and the generality of the otter effect in nearshore communities is widely recognized (Estes and Duggins 1995).

Other prey species have exhibited trends similar to those of sea urchins in response to reduction in sea otter predation (e.g., reductions in density, size and biomass). In some instances humans eventually developed commercial extractions that probably would not have been possible if sea otters were not eliminated from most of their historic range. Examples of fisheries that probably existed as a result, at least in part, because of sea otter removal include abalone (*Haliotis* spp), sea urchins, clams (e.g. *Tivela sultorum*, *Saxidomus* spp., *Protothaca* sp.), crabs (e.g. *Cancer* spp, *Chionoecetes* spp, *Paralithoides* spp), and lobster (*Panulirus interruptus*).

Since the middle of the 20th century, sea otters have been rapidly re-colonizing their former geographic range via natural dispersal and reintroduction by humans (Riedman and Estes 1990, Bodkin et al. 1999). At least three distinct approaches have been valuable to document the effects of sea otters on

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nearshore communities as they re-colonize former habitat. One approach is to contrast communities over time, both before and after sea otters re-colonize habitats. In concert with appropriate controls (i.e. communities in areas that are not inhabited by sea otters throughout the study period), this approach provides an experimentally rigorous and powerful study design to detect change in experimental areas. Another approach consists of contrasting different areas at the same time - those with, and those without the experimental treatment (sea otters, in this case). The problem with this approach is that interpretations may be confounded simply because of inherent differences between sites. A third approach entails experimentally manipulating community processes (e.g., sea urchin grazing by removal of individuals) and observing community response. All of these opportunities currently present themselves in Southeast Alaska, including Glacier Bay National Park and Preserve (Figure 1). 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, they have been found in Icy Straits and Glacier Bay proper only in the past few years (Table 1, J.L. Bodkin 2001). Based on data from other sites in the North Pacific, it is a reasonably safe prediction 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 invertebrate and vertebrate fauna such as sea stars, fishes, sea birds and possibly other mammals, of Glacier Bay can be expected over the next decade. It is also apparent that those changes are beginning now. Although no quantitative data exist, the spatial extent of kelp surface canopy has apparently increased between 1997 and 2001 in one location in

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mid-Glacier Bay frequented by large groups of sea otters (Bodkin, pers. obs.). During 1998, nearly 500 sea otters were observed in the lower Bay and in 2000 an estimated 1590 occurred in the lower Bay. However, large areas of Glacier Bay remain without sea otters, which may provide suitable controls. The current distribution of sea otters in Icy Straits and Glacier Bay is ideally suited for a before/after control/treatment design, which could provide convincing evidence for changes observed in Glacier Bay resulting from sea otter colonization.

At least three elements are requisite to understanding the effects of sea otters in Glacier Bay - first, describing the abundance and distribution of sea otters in the Bay, second, describing their food habits, and third, describing the structure and function of the coastal marine communities in the Bay before and after occupation by sea otters. The first and second elements have been undertaken by the ASC. In partial fulfillment of the third element, the ASC has collected data on bivalve density, species composition, and size class distribution in the intertidal and subtidal zones (Bodkin et al. 1999, 2000). This information will serve as a baseline for future investigation of population- and community-level effects of sea otters on bivalves in Glacier Bay. In conjunction with ASC, the National Park Service initiated a study in 2000, as described herein, to complement the ASC's investigation of subtidal bivalves. Whereas the emphasis of ASC's study is primarily on bivalve infauna, the NPS study will collect baseline data on the spatial and temporal distribution and abundance of conspicuous epibenthic biota occurring in shallow water within Glacier Bay, with emphasis on key macroinvertebrates and macroalgae. This information will be used first to describe the shallow benthic communities of Glacier Bay, which has not yet been rigorously attempted in a quantitative fashion. This baseline information will then be used, in concert with data from subsequent surveys, to investigate the

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population- and community-level effects of sea otters using a Before-After-Control-Impact (BACI) approach.

The sampling methodology and protocol development associated with this study will also serve as a preliminary pilot project for a more comprehensive program of inventory and monitoring of the subtidal resources within Glacier Bay.

2. Justification:

Sea otters are currently becoming established in the nearshore marine ecosystem of Glacier Bay National Park and Preserve. If not quantified, the ecological effects of sea otter re-colonization will likely preclude or severely limit the ability of Park management to identify changes or causes of variation in nearshore subtidal communities. At worst, Park management could wrongly assign cause to observed changes or be caught unaware of impending ecological change due to a lack of early detection.

Bivalves and sea urchins constitute a major proportion of the biomass in shallow benthic marine habitats of Glacier Bay, and in turn these species support large numbers of invertebrate and vertebrate predators and scavengers (e.g., sea stars, crabs, whelks, fishes, birds and mammals). It is likely that foraging by sea otters will drastically reduce the density and average size of their prey species, and also cause a corresponding significant increase in shell litter – a type of “hard” substrate that is an important, but limited, habitat on flat to moderate slopes within the nearshore zone of Glacier Bay. These direct effects of foraging by sea otters will subsequently drive changes in composition and abundance of plant and animal species occurring within the nearshore zone, thereby strongly influencing the structure and function of this important community. Therefore, understanding the effects of sea otter predation will be critical to appropriately

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managing the Parks marine resources.

3. Study Objectives:

1. Describe the subtidal epibenthic communities occurring within the shallow marine habitats of lower-mid Glacier Bay.
 - i. Inventory conspicuous macroinvertebrate and macroalgal species
 - ii. Quantify the distribution and abundance of key indicator species
2. Using the information acquired from objective 1 as baseline data, assess the cascading effects of sea otter foraging on marine community structure and function in Glacier Bay by measuring key population- and community-level parameters over time. Objectives include, but are not limited, to the following:
 - a. Assess the effects of sea otter foraging on the community structure of the shallow subtidal zone.
 - b. Assess changes in algal species composition and abundance associated with changes in sea urchin populations.
 - c. Assess the effects of shell deposition on algal and invertebrate assemblages.
 - d. Assess the effects of sea otter foraging on benthic invertebrate predators (e.g., sea stars and whelks)
3. Estimate the size class distribution and density of selected subtidal macroinvertebrate populations in

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Glacier Bay (e.g. sea urchins, whelks, sea stars) expected to be directly or indirectly affected by sea otters in areas currently unoccupied and in areas anticipated to be occupied by sea otters.

4. Obtain a GIS dataset of kelp forest canopy distribution from a quantitative aerial survey (or satellite imagery) prior to re-colonization of Glacier Bay by sea otters.
5. Develop sampling methodology and protocols to guide development and implementation of a comprehensive program for monitoring the shallow subtidal resources of Glacier Bay in a long-term, sustainable fashion.

To meet objectives 2 and 3, we propose the following specific hypotheses:

H₀. The species diversity of shallow benthic marine communities (as measured by diversity indices) do not differ between control sites (areas without the sea otter “treatment”) and impact sites (areas with the sea otter treatment) before or after the treatment of sea otter foraging has been imposed

H₀. Neither the mean density/percent cover nor the temporal variance of various taxa differs between control and impact sites before or after the treatment of sea otter foraging has been imposed

Taxa of interest include:

1. sea urchins (*Strongylocentrotus droebachiensis* and *S. pallidus*)
2. sea stars (e.g., *Solaster spp.*, *Evasterias troschelli*, *Leptasterias spp.*)
3. whelks (e.g., *Fusitriton oregonensis*, *Neptunea lyrata*)

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4. hermit crabs (e.g. *Elassochirus spp.*)
5. mussels (i.e. *Modiolus modiolus*)
6. anemones (e.g. *Metridium giganteum*, *Urticina spp.*)
7. benthic diatoms
8. algae, especially kelps (e.g. *Nereocystis luetkeana*, *Laminaria spp.*)

H₀. Neither the mean size class distribution nor the temporal variance of various taxa differs between control and impact sites before or after the treatment of sea otter foraging has been imposed (taxa of interest include sea urchins, sea stars, and whelks)

5. Methods:

Experimental Design & Data Analysis

As stated by Osenberg et al. (1994), the primary challenge of environmental impact assessment is to isolate the effect of interest from the background "noise" of temporal and spatial variability. Currently, the most rigorous types of experimental designs to detect and quantify anthropogenic environmental impacts are Before-After-Control-Impact (BACI) studies. The basic premise of this approach is that an environmental impact affecting the abundance of a sampled population at "impacted" locations must cause the temporal pattern of abundance in those locations to differ from the range of patterns in the set of control locations (Underwood, 1994). We propose to extend this type of approach developed for detecting human-caused impacts to assess the impacts of sea otters on members of the benthic subtidal

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community.

However, using an experimental approach to address this question poses a potentially major problem because the behavior of sea otters, unlike humans, is not possible to manipulate without inappropriate intervention. Therefore, it is impossible to predict *a priori* where sea otters will forage and where they will not. It may be considered by some to be inappropriate to *post-hoc* designate areas where sea otters have intensively foraged as "impact" sites and areas where they have not foraged as "controls." In other words, if we cannot manipulate our experimental treatment (i.e. otter foraging), it may be argued that we do not have any true "control." In this case, it would be theoretically illogical to proceed with a BACI-type experiment, because observed results may be attributable to factors other than the treatment. For example, the interpretation of results would be confounded if a statistically significant difference in the mean density of clams was detected between *post-hoc* designated control and impact sites if sea otters avoided "control" areas because of a particular physical factor (e.g. high levels of water turbidity associated with high sedimentation rates) that also affected clam densities. This is not a trivial concern, because physical oceanographic parameters and the distribution of sea otters vary substantially along a longitudinal gradient in Glacier Bay (e.g., sea otters, salinity, and temperature decrease toward the upper reaches of the bay and turbidity/sedimentation increases). One possible solution to this dilemma of a "true" control would be to establish control sites at nearby locations outside of Glacier Bay where sea otters have not yet colonized, such as Excursion Inlet. However, this approach was not taken due to logistical and financial constraints.

Although the rationale described above makes a case for not proceeding with an experimental

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approach, we make the argument that if a treatment is applied *randomly* among a pool of similar study sites (i.e. the treatment is not correlated with some external factor unbeknownst to us), then post-hoc designation of control and impact sites is valid, therefore an experimental approach is acceptable. Sea otter colonization of Glacier Bay has been rapid in recent years, and although they have been observed throughout the lower and mid-Bay (Figure 2), the largest persistent concentration of animals is located in the vicinity of the northwest Beardslee Islands (including Boulder Island, Sita Reef, and Flapjack Island), where it is likely that extensive food resources exist (e.g., mussels and clams). Outside of this primary area of occupation, groups of sea otters appear to be colonizing localized areas within the bay in a random fashion (Bodkin, personal communication). This observation is supported by evidence that sea otters are not behaving predictably in accordance with optimal foraging theory, probably because prey availability does not appear to be a limiting resource for sea otters in Glacier Bay (Bodkin, pers. Comm.) Because sea otters are highly gregarious, social interactions are probably more important than sources of optimal food supply in the short-term for influencing the location of permanent or semi-permanent colonization. Therefore, we argue that the treatment is essentially being applied randomly among locations at the spatial scale of interest. This critical assumption is the crux of our justification that, if untrue, compromises the BACI experimental design. If this assumption falls into question, a less rigorous approach will be taken by contrasting within-site variation for each site both before and after sea otters re-colonize. If results were to be consistent among sites and the effect size was large, this approach should provide convincing evidence for a generalized sea otter effect.

Because a BACI experimental design is flexible, we can employ either a symmetrical (i.e. equal

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number of control and impact sites) or asymmetrical experimental approach, depending on the outcome of sea otter colonization with respect to sampling sites. According to Underwood (1992), "this type of design can reliably detect a variety of environmental impacts, including those that do not affect long-run mean abundance, but do alter temporal variance." The ability to detect environmental impacts other than a change in the mean abundance of an organism is an important component of impact assessments, as comparisons of only the means are relatively simplistic. Differences in the mean abundance of populations are surely not the only type of relevant ecological impact, and furthermore, the inherent temporal variance common to the populations of many species makes comparisons of means even more difficult. Because our proposed study area encompasses a large portion of Glacier Bay, it is likely that the abundances of populations in different areas will display temporal interaction (i.e. populations in different areas have different population dynamics or trajectories) that will mask future analyses of mean differences between control and impact sites. This situation was problematic with earlier versions of BACI designs (e.g., Stewart-Oaten et al.), but is tractable with asymmetrical or symmetrical designs.

According to Underwood (1994), analyses of variance (ANOVA) tests using asymmetrical designs are statistically powerful for not only non-interactive sets of abundance, but also pulse (i.e. short-term) responses to disturbances, large alterations of temporal variance, and sustained, "press" responses in mean abundance coupled with altered temporal homogeneity. This is precisely the type of analysis applicable to the situation in Glacier Bay, in which we expect to observe press responses by highly variable populations (both temporally and spatially) of benthic prey species to predation by sea otters.

Because shallow benthic communities in Glacier Bay differ dramatically according to substrate

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type, we stratified sites by substrate type, and included "soft" (i.e. non-rock) and "hard" (i.e. mostly rock) substrate as an additional factor in the design (along with Before/After and Control/Impact) for dependent variables common to both substrate types (Figure 3).

In comparison to many BACI applications used to assess anthropogenic impacts, one important advantage of our study is that we can spatially replicate both Impact and Control sites. Sites will be replicated in time and space for each substrate type (Figure 3). An independent "replicate" of a particular dependent variable (e.g. urchin density) will be the average value of spatial sub-samples (e.g. quadrats placed along a transect) taken from a given site during a given year. Because replication is temporal, the question we have posed will take several years to answer effectively, and will be highly dependent upon the temporal variability of indicator species' populations, the accuracy and precision of the sampling methods, and the rate of colonization by sea otters.

A symmetrical or asymmetrical design can also accommodate sampling at hierarchical temporal scales (e.g., multiple visits to a study site within one year) if it is deemed desirable or necessary to do so in future years. This may be the prudent approach, because lack of knowledge about the short-term fluctuations of a given variable may lead to illogical, unwarranted interpretations of results. BACI designs ideally require Control and Impact sites to be sampled simultaneously, but this is logistically impossible for this study. However, use of asymmetrical or symmetrical analyses can partially overcome this problem (Underwood 1994).

Additional assumptions are required for applying a BACI design. For instance, study sites (both control and impact) must be chosen from a randomly selected pool of study sites, all of which must have

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similar features (e.g., habitat, substrate, physical oceanographic phenomena, species composition, abundance of target species). Underwood (1994) points out that all sites do not need to have identical characteristics or abundance of a given population (as indicated by Stewart-Oaten et al. 1986), as this is usually impractical and unnecessary - the control sites simply must be representative of the same range of habitats as the impact sites.

Another important assumption is that the treatment (i.e. sea otter foraging) is not applied to any site (either control or impact) during the "before" period. This requirement is usually straightforward when applying a BACI design to human impacts such as a power plant or shopping mall, but it is more nebulous in the case of sea otters in Glacier Bay. For example, should the recent colonization of the lower to mid-bay by a relatively small population of sea otters prevent the collection of valid "before" data to be used in a BACI experiment? We argue that it does not, so long as "before" data are collected very soon after colonization. . While it is true that we have lost the opportunity to indisputably collect bonafide "before" data in the lower/mid-bay because sea otters have rapidly colonized the bay since 1994, persistent occupation by otter groups has occurred in relatively few locations to date (see large graduated symbols in figure 2 for an indication of group size; Bodkin et al. 2001). As shown in figure 2, these locations include the west side of the lower-mid bay from Point Carolus to just south of the entrance to Berg Bay, the Point Gustavus area at the eastern entrance of Glacier Bay, and an area northwest of the Beardslee Islands (approximately encompassed by Flapjack Island, South Marble Island, and Leland Island). Because of a combination of the abundance of sea otters and their voracity, sea otters have probably affected prey populations, and perhaps entire communities, in these areas of persistent occupation.

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Therefore, these areas were eliminated from consideration as study sites.

Because we do not have bonafide “before” data, there is an element of uncertainty as to whether sea otters have had significant impacts to prey populations or marine communities outside the areas of persistent occupation. Because of this uncertainty, this study risks confounding if otters have indeed already impacted benthic marine communities in the lower/mid-bay prior to initiation of site establishment in 2000. Sea otters are highly mobile and may forage well outside of the groupings shown in figure 2. For example, during the 2000 field season we observed 25-30 otters near both Berg and Fingers Bay on several occasions. While sea otters have undoubtedly impacted these areas of persistent occupation, we suspect that they have probably had little to no population or community-level effect yet on other areas (based on expertise and experience observing marine communities within and outside the range of sea otters). .

It is not straightforward how to determine the onset of treatment at the impact sites. One approach may be to determine if the sea otter population is persistent within the local geographic area, which may be indicated by the presence of mother/pup pairs. Another approach may be to make the determination based upon the quantity of accumulated shell litter on the seafloor that is attributable to otter foraging. For this reason, we will collect data on the abundance of shell litter on the seafloor that is attributable to otters. Perhaps the best method to estimate the presence and magnitude of the sea otter treatment is to directly observe the distribution and abundance of the sea otters relative to our study locations. The ASC plans to undertake this project beginning in 2003 via radio telemetry of a subset of the otter population in the Bay (Bodkin, pers. Comm.). The resultant spatial analysis of the telemetry

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study, in combination with ongoing censuses of distribution and abundance, should provide relatively clear guidance as to the onset of sea otter treatment without the need for diver surveys of shell litter accumulation and/or monitoring prey population density and size structure.

Site Selection

Finite resources (both financial and personnel) require that a compromise be made among the spatial extent of the study area, the number of sites visited, the number of transects per site, the number of spatial subsamples per transect, sample unit size, and the number of species/taxa studied. Our goal is to collect community and population-level data at a fine resolution (in terms of space and number of community types and species sampled) at as many sites as possible within the nearshore zone of Glacier Bay. We expect that sea otter “treatment” will not be applied in an optimal manner (from our perspective), therefore the more sites in the “pool”, the greater the likelihood that the sea otter treatment will not impact all sites (or communities) simultaneously. To balance the desire for spatial coverage and sampling resolution with logistical capability, and to increase the likelihood of achieving similar numbers of impact sites and control sites in the future (which is based on the unpredictable behavior of sea otters), we decided to establish 20 sites at –30’ MLLW depth.

A BACI design requires that permanent study sites be established to eliminate or minimize the effect of spatial variability (i.e. only time is varied). We determined our desired inference space to be from the lowest possible reaches of the bay (defined by persistent presence of sea otters according to 1999 data collected by Bodkin and recollection of Bodkin and J. DeGroot) to mid-bay (Sandy Cove to Drake

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Island). The inference space was restricted to this area in part because pre-treatment data were needed for all study sites, and also to satisfy the assumption of a BACI design that all sites are environmentally similar. The study could be strengthened and more ecologically interesting by extending sampling into the upper portion of Glacier Bay. Not only are sea otters currently absent in that area (i.e. indisputable “before” data could still be collected), but the upper bay exhibits drastically different oceanography (Hooge, 2002) and a more simplified benthic community (Hooge, pers. Obs.). Logistic considerations and the need for environmentally similar sites prevented us from exploring this option during this phase of the study. The 20 study sites were stratified in a longitudinal (up-down bay) and latitudinal (cross-bay) fashion in order to maintain adequate distance between adjacent sites and reduce potential for spatial correlation (Figure 4). We achieved this by designating ten "sub-regions" within the desired inference space, 5 sub-regions on each side of the bay. We did not knowingly include areas of persistent sea otter occupation, except possibly for the southern sub-region on the west side of the bay. The Spider Island complex, a group of small islands adjacent to and including Spider Island, was eliminated from consideration because of proximity to sensitive seal habitat. Only the outer Beardslee Islands were considered because of navigational hazards within the island complex, a perceived lack of adequate rocky habitat within the inner cluster of islands, and otter occupation within the vicinity of Hutchins Bay (in the eastern region of the Beardslees).

These boundaries of these sub-regions were digitized using ArcView GIS software. We attempted to standardize the size of each sub-region by the amount of area suitable for sampling within each area - therefore, the Beardslee Islands were broken into two sub-regions. The Sandy/Spokane

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Cove sub-region was disjunct from the other four eastern sub-regions because very few areas between Sandy/Spokane cove and the northern Beardslee Islands appeared to be adequate for SCUBA sampling because of a steep submarine slope. As shown in Figure 1, each sub-region was conventionally named from north to south (1-5) following which side of the bay they are on (e.g. W1 through W5 for the west side and E1 through E5 for the east).

Site placement within sub-regions was an interactive process. Remote-sensing data were unavailable to aid discrimination between subtidal substrate types, and we attempted various methods to find appropriate substrates. Our initial assumption about subtidal substrate type in Glacier Bay was that offshore geology/substrate type could be extrapolated from onshore geology/substrate type. Under this assumption, we queried the Glacier Bay Coastal (intertidal) GIS database for primary and secondary substrate in the intertidal zone that consisted of cobble, boulder, or bedrock. The resulting GIS layer indicated that most of the intertidal substrate was cobble, boulder, bedrock, or some combination thereof. Because we observed mostly soft substrate during preliminary *in situ* diving observations, and had previously observed soft substrates within some of the areas indicated by the query to be hard bottom, we concluded that onshore substrate was probably not a suitable proxy of offshore substrate.

Under the assumption that aggregations of canopy-forming kelps (i.e. *Nereocystis luetkeana* and *Alaria fistulosa*) can only occur on hard substrate (because the algae must successfully recruit and adhere to sufficiently stable substrate so as not to be carried away by currents), we re-queried the Coastal database for primary and secondary substrate equal to cobbles, boulders, or bedrock AND “offshore kelp”. Again, the results of the query were of limited utility because most of our proposed study area

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within Glacier Bay fulfilled these conditions. This was probably due, at least in part, to the convention by intertidal surveyors for determining the presence or absence of offshore kelp. According to their field protocol, “offshore kelp,” was considered present if at least 12 stipes of *Alaria*, *Nereocystis*, or *Laminaria* occurred within a “segment” (which may be 30m to 1 km long). Because the number of kelp stipes considered to be offshore kelp were so few per unit area, and because *Laminaria* is not a canopy-forming kelp in this region (i.e. intertidal *Laminaria* plants that were emergent at very low tides may have been considered “offshore kelp”), we did not use the results of this query for site determination. Infrared aerial photos of the shoreline and adjacent offshore areas were available from the Coastal database, but photos were taken during the early portion of the growing season for canopy-forming kelps, and canopies had not yet developed.

Under the same premise, we created our own map of kelp canopy distribution in the study area via low-speed, low-altitude aerial reconnaissance above the study area during a low tide window on August 18, 2000. Two methods of data collection were used: 1) hand-shading of all “substantial” surface canopies (i.e. beds defined as larger than 50 meters along shore) onto a nautical chart, and 2) geographic positional data were collected as a GIS layer using a laptop computer and a fuselage-mounted Global Positioning System (GPS). The resultant GIS layer indicated that sparsely distributed points reflected sparse kelp beds, and densely spaced points indicated a dense kelp bed. Both data collection methods were subsequently evaluated and found to corroborate well. The hand-shaded kelp map was more aesthetically pleasing, but GPS point data were determined to be equally useful. We used the GPS data

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for site selection instead, however, because each point already had an associated geographical location (Figure 4).

Using a GIS, point data representing kelp canopy were overlaid with the hand-digitized sub-regions (or, “polygons”). Point data representing surface kelp canopy that occurred within the sub-regions were selected and extracted from each polygon, and then potential hard bottom site locations were chosen by randomly selecting 15 kelp data points from this extracted list. Assuming that we would need a pool of potential sites to choose from, and that some sites would not be adequate for our needs, we randomly assigned these sites a priority from 1-15. Because points that were more densely aggregated indicated a larger kelp bed, the selection of kelp sites was biased toward denser kelp beds. This inherent bias was useful, however, because subsequent observations indicated that sparse kelp beds often occurred on unstable substrate such as shells and small cobbles. Therefore, the denser beds were more indicative of hard substrate composed of cobbles and boulders.

Because much of the subtidal habitat occurring on flat to moderate slopes in our study area apparently is dominated by non-rocky, unconsolidated substrate (e.g., silt or mud, although often mixed with small rocks), we took a different approach for the site selection process for this type of substrate. We dovetailed our sampling program with the ongoing study of Bodkin et al. (1999, 2000), whose team has sampled bivalve populations within the same portion of Glacier Bay that we intended to study. Prior to the inception of our study, Bodkin et al. (2000) systematically designated Intertidal Clam (IC) sites throughout Glacier Bay to sample the density and size frequency of bivalve species. These sites were designated using the aerial portion of the Glacier Bay Inventory and Monitoring protocol for site selection

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(Irvine 1998). Using this protocol, the coastline of Glacier Bay was broken into 5,545 200-meter segments, of which every twenty-third segment was selected as an Intertidal Monitoring (IM) site, for a total of 241 IM sites. Within Glacier Bay proper, Bodkin et al. (2000) systematically sampled 48 of these IM sites for intertidal clams. In addition to these systematic IC sites, 12 additional segments were chosen as Preferred Clam Habitat sites, which were based on the abundance of shell litter and clam siphons in the intertidal zone (see Bodkin et al. 1999, 2000 for more details). To complement Bodkin et al.'s study, we incorporated their study sites into our site selection process whenever possible so that we could sample offshore of their intertidal study sites (both IC and PCH) in the lower Bay.

Using GIS, we selected and extracted all IC sites and IM sites that occurred within each of our designated sub-region polygons (Figure 5). Each of these segments was randomly assigned a sampling priority with higher priority given to IC sites than IM sites. In part, we did this to facilitate correlation between intertidal and subtidal sites with respect to the type and magnitude of effects of sea otter foraging. For example, if 5 IM sites existed within the perimeter of one of our designated sub-regions and 2 of those were IC sites, we would randomly choose one of these two IC sites to be priority #1, and the second IC site would be priority #2 by default. The remaining 3 sites would be randomly assigned priority 3-5. No instance existed in which at least one IM site or IC site was not present in any sub-region. Because the GPS coordinates of the IC sites were always onshore, we would navigate as close as possible to the coordinates when establishing a site. Although the IC sites that we used as a model for our site selection process were systematically selected, we retained an element of randomization and therefore have met the requirement of randomness for inferential statistics.

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The randomly chosen sites were then reconnoitered in the field and evaluated using the following list of criteria (listed in order of importance):

1. Safety/diveability - the overriding criterion for all sites was that they be safe to dive and work in; for example, we automatically eliminated sites that we deemed to be too exposed to strong currents (particularly in Sitakaday Narrows, Rush Point, some areas of Drake and Willoughby islands, and the entrance to Berg and Fingers Bays).
2. Correct substrate type - this was not usually apparent from surface-based observations, but toward the end of the 2000 field season we were able to distinguish hard versus soft substrate with the vessel fathometer using dual frequency output. Often, we had to do a quick SCUBA dive on a site to determine if a site was suitable. Also, we evaluated circumstantial evidence such as the rugosity of the seafloor and submarine slope using the fathometer output.
3. The need for a suitable submarine slope for working - because we elected to keep depth constant along the -30 foot MLLW isobath while collecting ecological data (for rationale, see below), we chose to disqualify sites with slopes greater than approximately 45 degrees. This was done in order to maintain similarity among habitats at different sites (because steep slopes tended to have unstable substrate that was colonized by different species assemblages, and thus could be considered a different type of habitat), and for logistical purposes (e.g., so our quadrats did not slide into the abyss whenever they were placed on the seafloor). This criterion was particularly hard to satisfy at Drake and Willoughby Islands.

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4. We needed a 50 m long linear isobath at the -30 foot MLLW contour to lay out our transect tape (for rationale see below).

If these criteria were not met in full for the highest priority site, we reconnoitered adjacent areas to satisfy our criteria, and if a suitable site was not found, we progressively searched up to a maximum distance of approximately 500 meters away. For one sub-region (Drake Island), we reconnoitered up to approx. 1000 meters away because of a paucity of suitable sites. If a suitable site was still not found, we eliminated the site and evaluated the next highest priority site. Because a number of sites were removed from consideration for the reasons described above, the inference space of this study was accordingly reduced.

Seventeen sites were established during the 2000 field season, three short of our goal; however, actual data collection did not begin until late in the field season. Three additional sites were established during the 2001 field season, for a total of 20 sites. In 2002, ten sites were established at -15' MLLW immediately adjacent to ten of the -30' sites in order to increase the inference space from the -30' contour only to the -30' to -15' depth range. Site names and coordinates are listed in Table 2 and displayed in Figure 6.

Since the inception of this study in 2000, sea otters have been observed foraging near some of our permanent sites. The otters have surely caused localized impacts in some of these locations - but the permanent stations we set up in 2000 do not appear to have been affected, with the possible exception of one (W5Soft_30, north of Rush Point). This postulation was generally supported by SCUBA observations during the 2000, 2001, and 2002 field seasons, although bivalve shells that may have been cracked open by otters

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were observed at approximately 4 study sites, and a broken urchin test was observed at one site (W5Soft_30). Although possible evidence of foraging was observed at these sites, the number of broken shells and tests was very limited relative to obviously impacted areas – indicating that the otters were probably foraging while in transit. Further evidence for this lack of impact is as follows:

- 1) The sea otter population in Glacier Bay did not begin to increase to substantial numbers until 1998 (209 animals censused - see Table 1 in study plan), and data collection at permanent stations began shortly thereafter (in 2000). In 1999, 2000, and 2001, census data indicated 384, 594, and 1590 animals, respectively. According to Bodkin (pers. Comm.), the otters that have come into the bay have so far been colonizing relatively discrete areas (as defined by the presence of mother/pup pairs), and foraging forays by large groups of otters into non-colonized areas have apparently been relatively restricted.
- 2) Since our data collection efforts began in 2000, we have not observed clear evidence for otter foraging (e.g., direct observation, foraging pits) on any of the transects at the study sites. However, we have occasionally observed sea otters foraging within the vicinity of approximately 5 of our sites (Fingers Bay, Berg Bay, Rush Point (2), northern Beardslees), and have also observed some circumstantial evidence for otters feeding within the immediate vicinity of our transects (e.g. broken sea urchin tests, *Saxidomus gigantea* shell litter with one fractured valve and the other valve and the hinge intact). The circumstantial evidence is not proof, however, as the litter may have also resulted from the foraging activities of giant pacific octopus and large seastars (e.g. *Pycnopodia*).
- 3) Inspection of our data suggests that otters have not impacted the permanent stations as of yet:

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- a) Sea urchins occurred at high densities (> 20 individuals / 1 m^2) at 5 of the 20 permanent sites during 2000 and 2001, and the lower densities at the other 15 sites appeared to be due to unsuitable habitat (e.g., mud substrate, extreme water currents) and/or food availability (i.e. lack of diatom film, drift or attached macroalgae). However, the possibility can not be discounted that the low urchin densities are a result of otter foraging (although broken tests would presumably be present, which they were not).
- b) At each site in which urchins were present in great enough abundance to collect an adequate sample size, the size frequency distribution of sea urchins exhibited “normal”, bell-shaped distributions. We would expect to see a truncated size frequency distribution if otters were foraging size-selectively on a local urchin population.
- c) One of the predicted (and historically observed) community-level effects of otters is an increase in the biomass and diversity of macroalgae (especially kelps) in response to reduced herbivory by sea urchins (effected as a result of otter predation). However, only 2 of the 20 study sites (E5 Hard_30 [Lester Point] and E4 Hard_30 [west Young Island/Sitakaday narrows]) exhibit a relatively high level of algal biomass and diversity. The reason for the well-developed kelp assemblage at these 2 sites is probably habitat-related, because these sites experience the strongest water motion of our 20 sites. These strong currents facilitate low siltation/deposition rates on the seafloor, thereby providing suitable habitat for recruitment of kelps. The currents may also hinder the ability of urchins to maintain their hold on the substrate (we have observed hundreds of urchins rolling like tumbleweeds on muddy bottoms). Furthermore, these currents

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may inhibit effective sea urchin foraging indirectly by subjecting them to intensive scouring by thick-bladed Laminarian algae. The presence of relatively large sea urchins at moderate density at the Young Island location suggest that otters have either not impacted this site yet, or they impacted it in the past very soon after they began colonizing the bay in 1996. The kelp understory at this site was well developed in 2001 and was most likely at least 2-3 years old on average (based on size class) at that time. This site was sampled in the fall of 2000, but many of the macroalgae were senescing at that point in the season, and it was unclear how developed the kelp assemblage was. Without detailed inspection, the Lester Point site is a clear example of what a marine community would be expected to be in the presence of sea otters – very few sea urchins, a well-developed kelp assemblage. However, the macroalgal assemblage at Lester Point is largely growing on a dense bed of *Modiolus modiolus*, which serves as a “hard” substrate to which kelps can recruit. Because *Modiolus* are one of the top prey choices of sea otters, the *Modiolus* bed at this site would probably not exist (nor would the kelp assemblage, by default) if a significant number of otters had foraged in this area previously.

- 4) Based on evidence from other studies on the effects of sea otters, the distribution of kelp canopy within the lower/mid-Bay during the 2000 survey (figure 4) reinforces the postulation that otters may have already influenced the lower/mid-Bay. However, a well-developed kelp canopy existed prior to colonization of Glacier Bay by sea otters (since at least 1984 when an aerial survey was completed; NPS, unpub. data). This suggests that oceanographic factors affecting light availability may be the most important factor determining the *distribution* of canopy-forming kelps in Glacier Bay.

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However, the *abundance* of canopy-forming kelp within the oceanographically-imposed distribution limits may well have increased since reoccupation of the Bay by otters – however, this comparison is impossible because no quantitative kelp surveys are available before and after 1995 (when sea otters first arrived).

Permanent transects

“Permanent” transects were established to reduce within-site variability due to space. Each permanent transect at a given site was established in -30 feet Mean Lower Low Water (MLLW) to minimize any variability of species composition, abundance, or size that may be associated with depth. The -30 feet MLLW isobath was chosen for study in part because of logistical constraints associated with SCUBA sampling at deeper depths, including limited sampling time due to a limited air supply and nitrogen accumulation.. Glacier Bay experiences tidal ranges of up to 25 feet, therefore during high tides diving is occasionally conducted in 55 feet of water while working at -30 feet MLLW. No constraints were imposed by establishing transects shallower than -30 feet MLLW, however, and 10 transects were established at -15’ MLLW in 2002. Because the lower depth limit for canopy forming kelps in Glacier Bay generally occurs between -20 and -30 feet MLLW, the transects established at -30’ MLLW will have limited ability to detect or quantify the possible effect of kelp forest proliferation and expansion due to sea otter foraging (e.g., by reduction of herbivorous grazers and increases in bivalve shell litter). However, these data may be used in the future to assess a predicted increase in the lower depth limit of

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canopy forming kelps due to decreasing turbidity and sedimentation rates associated with stabilization of terrestrial habitats following glacial recession.

Because of ecological and logistical constraints, the optimal transect length was determined to be 50 meters. In reality, the “optimal” transect length for adequately characterizing the density and spatial variability of the biota varies depending upon the density and fine-scale spatial variability of the species of interest, which in turn varies depending upon location in the Bay. In order to accurately represent fine-scale spatial variability of a species’ density, and to maximize comparability between habitats at different locations and at a single location over time, we attempted to establish transects entirely within a given habitat type. Reconnaissance in the nearshore zone of Glacier Bay indicated that the likelihood of encountering different habitat types (and therefore, community types) in the nearshore zone of Glacier Bay increased substantially at distances greater than 50 meters. We determined that a 50-meter transect was logistically optimal for SCUBA sampling because of time constraints imposed by working in cold water, short time-windows of minimal tidal current at some sites, and the efficiency of swimming long distances in cumbersome exposure suits with a limited air supply.

The 50-meter transects that have been established at each site are not truly permanent in that there is no fixed transect (e.g., lead line) on the seafloor. We did not deploy permanent lines on the seafloor because they would have quickly attracted invertebrate and algal settlers, and therefore influenced subsequent measurements. Instead, a permanent anchor was placed at both ends of a transect, and the transect tape was/is deployed and retrieved for each sampling session (Figure 7).

Despite the absence of a truly permanent transect, it is possible that repeated sampling may affect

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subsequent measurements of species composition, species density, or population size structure.

Mechanisms may include destructive sampling, habitat destruction/alteration, and removal sampling. We

have attempted to minimize such potentially confounding effects by the following mitigation procedures:

minimizing contact with the seafloor while working, minimizing destructive sampling to small numbers of

sea urchins, collecting voucher specimens off-transect whenever possible, collecting size frequency

distribution for sea stars *in situ*, avoiding collection of whelks that are guarding or laying eggs for size

frequency measurement, returning all urchins and whelks to the immediate vicinity of the transect as soon

as possible after collecting size frequency data topside, and not anchoring the support vessel in the

immediate vicinity of the transect. Organisms were not sampled invasively in 2000 or 2001, but sea

urchins were sampled invasively in 2002. These collections/ substrate disturbances were limited to

relatively small spatial areas (20 - 0.25m² quadrats along the length of the 50m transect), but only a few

sites had substrate types (e.g., pebbles/cobbles) that required invasive sampling. It was not our original

intent to disturb the seafloor by sampling invasively, but a systemic review of the Channel Islands National

Park subtidal inventory and monitoring program strongly suggested that invasive sampling should be

incorporated into their sampling protocol in order to adequately sample the true biological population of

cryptic epibenthic organisms.

Indicator Species Selection

Constraints imposed by funding, time, and personnel require that sampling effort focus on

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“indicator” organisms rather than sampling every species that is present in the benthic community. As outlined by Jones and Kaly (1996), criteria for choosing indicator species are often double-edged, and subjective arguments can be made for choosing species at each end of an ecological continuum ranging from stress-tolerant to susceptible, common to rare, cosmopolitan to localized, stable to unstable population dynamics, long-lived vs. short-lived, habitat specialist vs. generalist, and sessile vs. mobile. Obviously, the selection of indicator species is dependent upon study goals. In this study, we wish to first detect and then quantify the magnitude of a future ecosystem-level perturbation imposed by sea otters on an entire community of species. Because we seek to quantify ecological change, it follows that the species monitored should be ecologically “important” – meaning that they are either an important link in food webs/energy flow (e.g., bivalves) or affect the community structure disproportionately as agents of organization (e.g., sea otters), creators or modifiers of habitat (e.g., kelps and other algae), or act as regulators of these other important species (e.g., sea urchins, sea stars).

To these ends, the ASC is currently monitoring sea otters in Glacier Bay and has collected baseline information on intertidal and subtidal bivalves. The objective of this study is to “cover the other bases”, ecologically speaking. The highest priority organisms for this study to monitor are sea urchins, algae (with emphasis on kelps), and sea stars. Secondly are organisms that may be moderately important agents of community structure such as large predatory whelks and scavengers (hermit crabs / *Hyas lyratus*). Tertiary priority species include miscellaneous invertebrates that may potentially be indirectly affected by changes in community structure or are indicators of community types, including *Metridium* spp., other anemones, and sea cucumbers. A comprehensive list of the species that will be

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sampled can be found in Appendix SPECIES_LIST. We will collect species data at the highest taxonomic resolution possible, with the knowledge that taxa can be “lumped” subsequently for purposes of analysis. To ensure consistency and taxonomic integrity, a specimen voucher collection will be established that will include all taxa sampled (unless practically infeasible). When sufficient pilot data exist, power analyses will be performed for each species or species group to estimate the number of temporal replicates necessary to detect 50-90% levels of change in mean abundance. At that time, decisions will be made whether or not to continue sampling species that demonstrate low power to detect change, and whether or not to modify sampling strategies for species that are highly desirable to include in the study but exhibit low statistical power.

Sampling Methodology

The diversity of organisms and habitats sampled in Glacier Bay requires a diverse set of sampling techniques to adequately quantify the natural density and variability of selected species. Monitoring the impacts of sea otters on these organisms requires sampling that is accurate and precise while balancing the efficiency (i.e. measurement precision vs.cost-effectiveness) of subtidal sampling using SCUBA. Additionally, a successful monitoring program must also be repeatable by generations of samplers with minimal among-observer variation, and should not require highly trained personnel or complex procedures. Table 3 outlines nine sampling techniques to satisfy these criteria and the sample unit size used for each species (with consideration given to relative rarity and motility).

Sampling procedures for subtidal biota and substrate are detailed in the Appendix Sea Otter Effects

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Sampling Protocol.doc. The species included in the species checklist are included in Appendix SPECIES_LIST, and datasheets for each type of sampling technique are included in the Appendices subdirectory.

6. SCHEDULE

This study may be divided conceptually into three temporal components – a “pre-otter” period (i.e. before sea otters permanently re-colonize any of the study sites), a transitional period (i.e. the period during which sea otters begin re-colonizing study sites until 50% of sites are colonized), and a “post-otter” period (i.e. the period beginning when sea otters re-colonize 50% of the sites). Therefore, in part, the length of the study is dependent on the rate of re-colonization of Glacier Bay by sea otters, a factor over which we have no control. However, it is anticipated that effects of sea otter foraging may be observed within a few years if current population growth rates continue at a high level. The length of the study will also be dependent on the number of annual temporal replicates necessary to adequately characterize each population parameter of interest (e.g., mean density, mean individual size) for each species of interest – a factor over which we have much (but not total) control. The more precise an estimate is for a given population parameter during each period, the greater the statistical power will be to detect change over time.

Obtaining an accurate, precise estimate for a given population parameter in each sampling period is a function of both the inherent natural variability of that parameter and the ability of a sampling program to obtain an accurate annual estimate. Populations may be highly variable in time and space, and the greater the inherent annual variability, the more annual replicates will be necessary to precisely and accurately characterize

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the mean population density. Superimposed upon this natural variability is the variability of the estimate of a given parameter captured by the sampling methods. The better designed the sampling program is, the more accurate and precise annual estimates will be – which will reduce the number of annual temporal replicates needed per period. To answer the questions outlined in this study plan, population parameters must be adequately characterized in at least the pre-otter and post-otter periods, although sampling throughout the transitional period is highly desirable to both document the temporal sequence of change and minimize the chances of drawing erroneous conclusions. Furthermore, the population parameters of different species will require varying numbers of annual temporal replicates to adequately quantify, so it would be of great value to extend sampling in the pre-otter and transitional period as long as feasibly possible. A continuation of sampling throughout the transition period would also provide valuable pilot information for the monitoring component of this study, because lack of knowledge about the short-term fluctuations of population parameters may lead to illogical, unwarranted interpretations of long-term datasets.

Data collection efforts for this study began in 2000 and have continued through 2002. Sampling methods were being refined throughout much of 2000 and part of 2001; therefore some of the data collected during that time should be considered part of a pilot study and used with caution. Preliminary analyses of these data indicate that statistical power to detect change in the density and size of various indicator species is good for some species at some sites (1-2 more years of sampling during the pre-otter period). A better estimate of a timeline for the “pre-otter” portion of the study will be possible after another temporal replicate is available from the 2002 season.

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7. ANIMAL HEALTH AND WELFARE: We anticipate handling of live benthic invertebrates (e.g., sea urchins, sea stars, and snails) for purposes of species identification and measuring individuals. Some invertebrates and fishes will be taken for a reference specimen collection. Disturbance to animals in the wild will be minimized. Activities will be discontinued if large-scale influence on animal behavior is observed. Species collected under the prey abundance, density, and size class distribution portion will be returned to the ocean where they are collected.

8. SECTION 7 CONSIDERATIONS: I know of no listed species that may be impacted within the suggested areas of study.

9. STAFFING: Staffing requirements for this study will be met by NPS personnel, and additional staffing may be supplied by the ASC and /or through cooperative agreements with universities or through contractual agreements.

10. LOGISTICS: This study will be under the direction of the NPS sea otter project leader in collaboration with ASC scientists. Studies will be conducted out of Bartlett Cove and from onboard large research vessels.

11. RELATIONSHIP TO OTHER PROJECTS: The design of this study requires input from other studies in Glacier Bay, specifically studies documenting sea otter dietary composition, abundance and distribution surveys, and movement studies. These adjunct components are under the direction of J.L. Bodkin, ASC.

12. BUDGET

FY01 \$120,000 (?) Personnel: 1 GS-13 Project Coordinator, 3 biological technicians (1 GS-6, 2 GS-7)

FY02 \$110,000 Personnel: 1 GS-8 Project Crew Leader, 3 biological technicians (1 FT seasonal GS-7, 2 PT GS-7)

FY03 \$120,000 Personnel: 1 GS-8 Project Crew Leader, 3 biological technicians (3.5-4 full-time seasonal GS-5/6/7)

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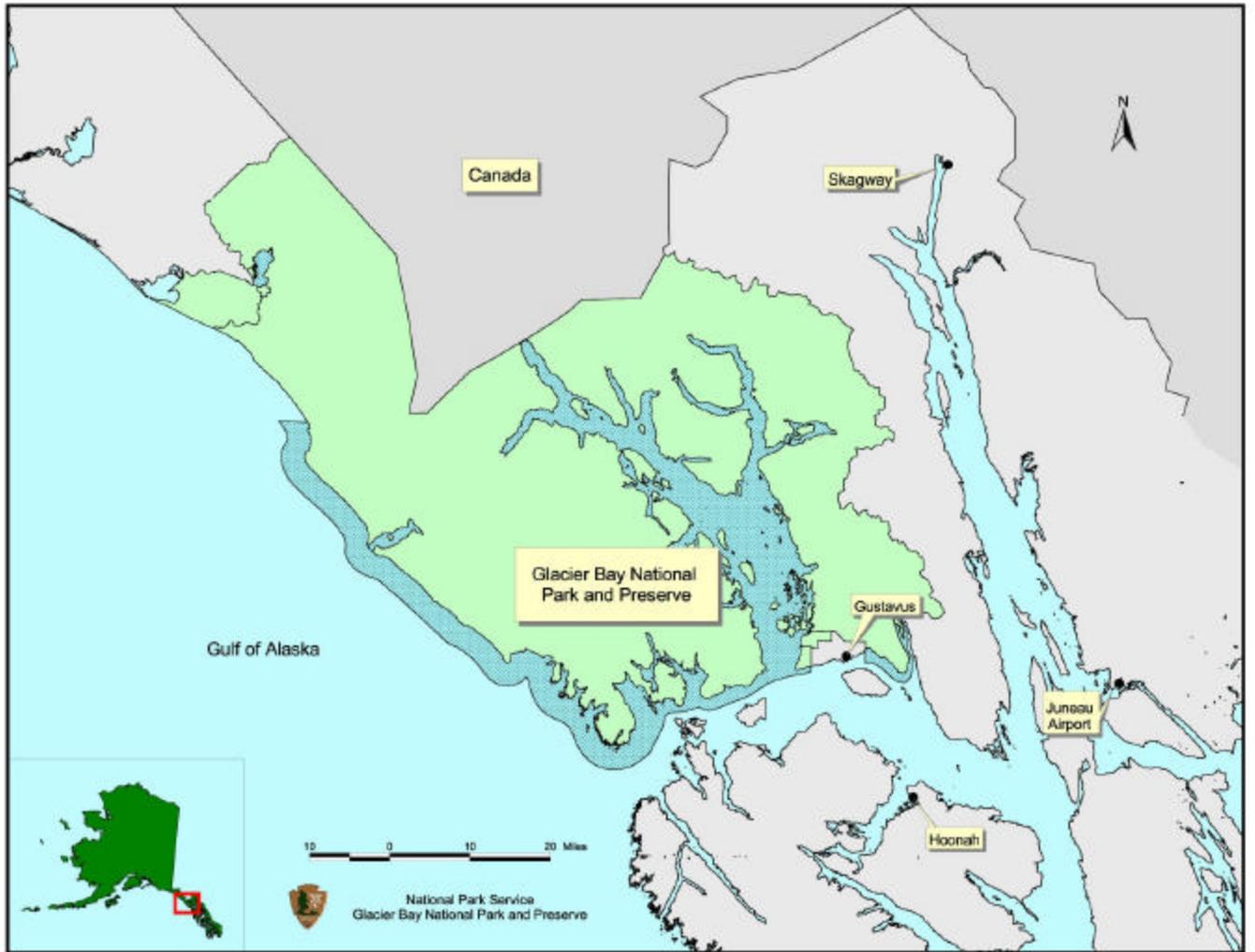


Figure 1. Glacier Bay National Park and Preserve and vicinity.

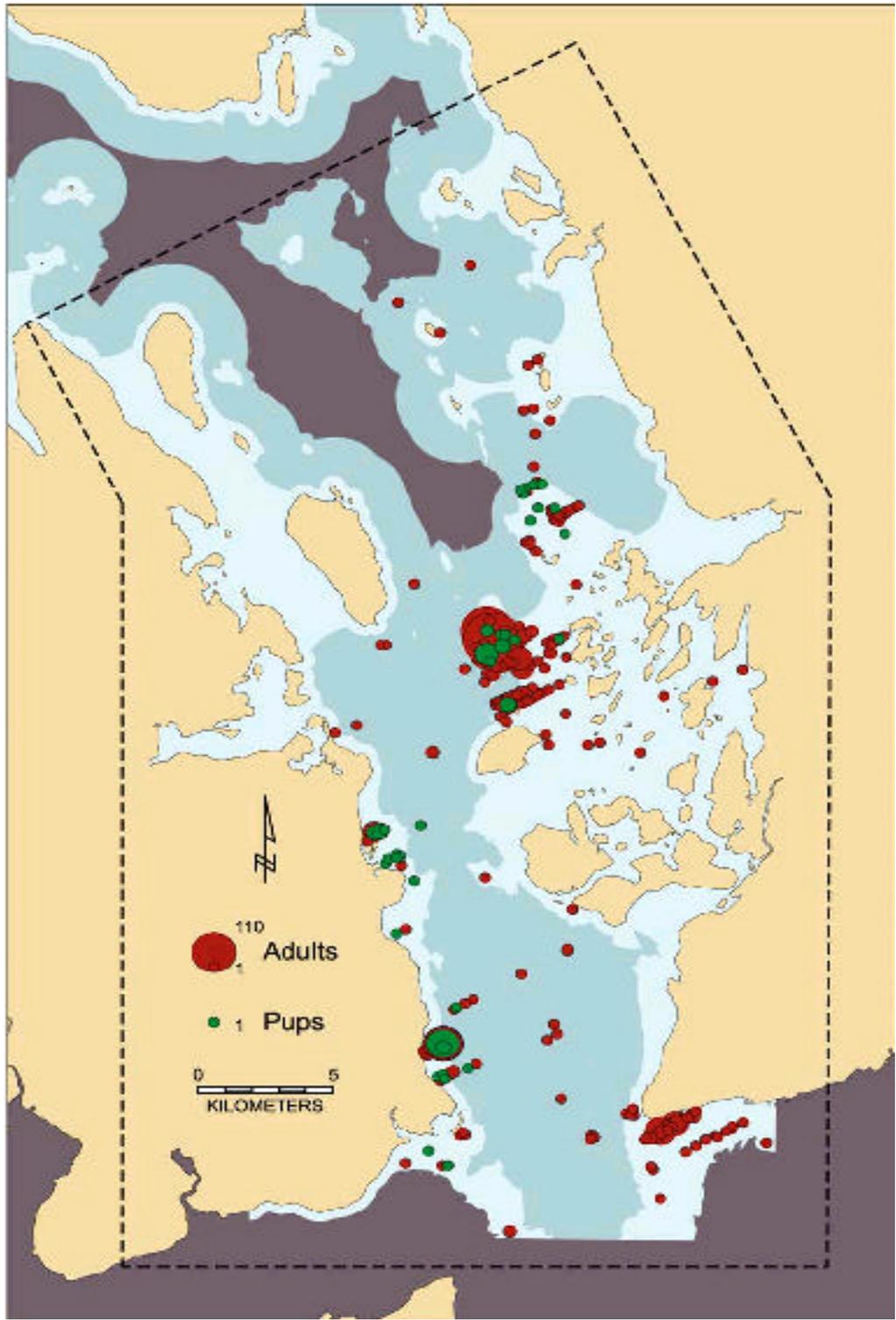


Figure 2. Sea otter group locations from 4 replicate aerial surveys in Glacier Bay National Park, June 2001 (dot size is proportional to group size; Bodkin et al. 2001).

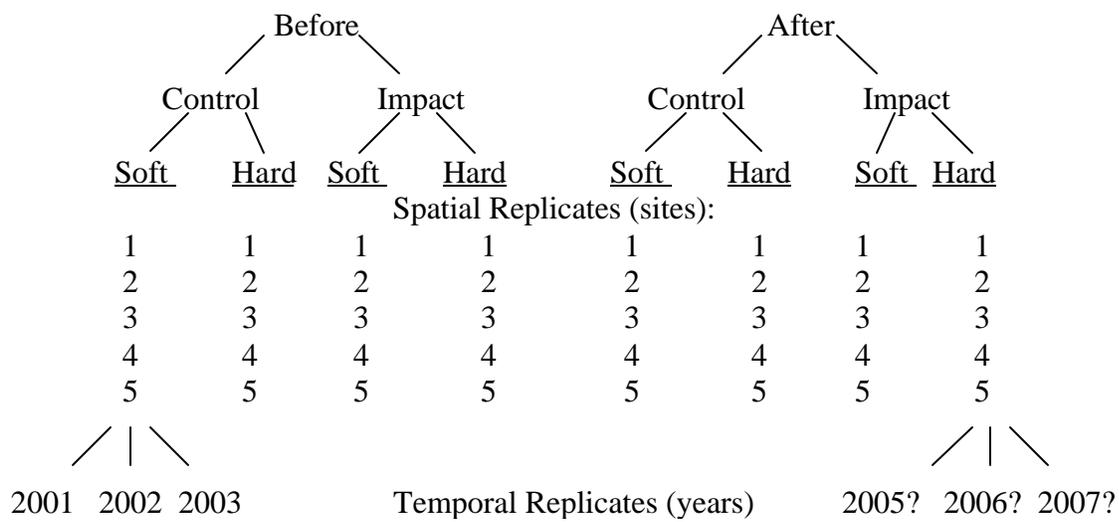


Figure 3. Schematic of 3-factor nested BACI experimental design

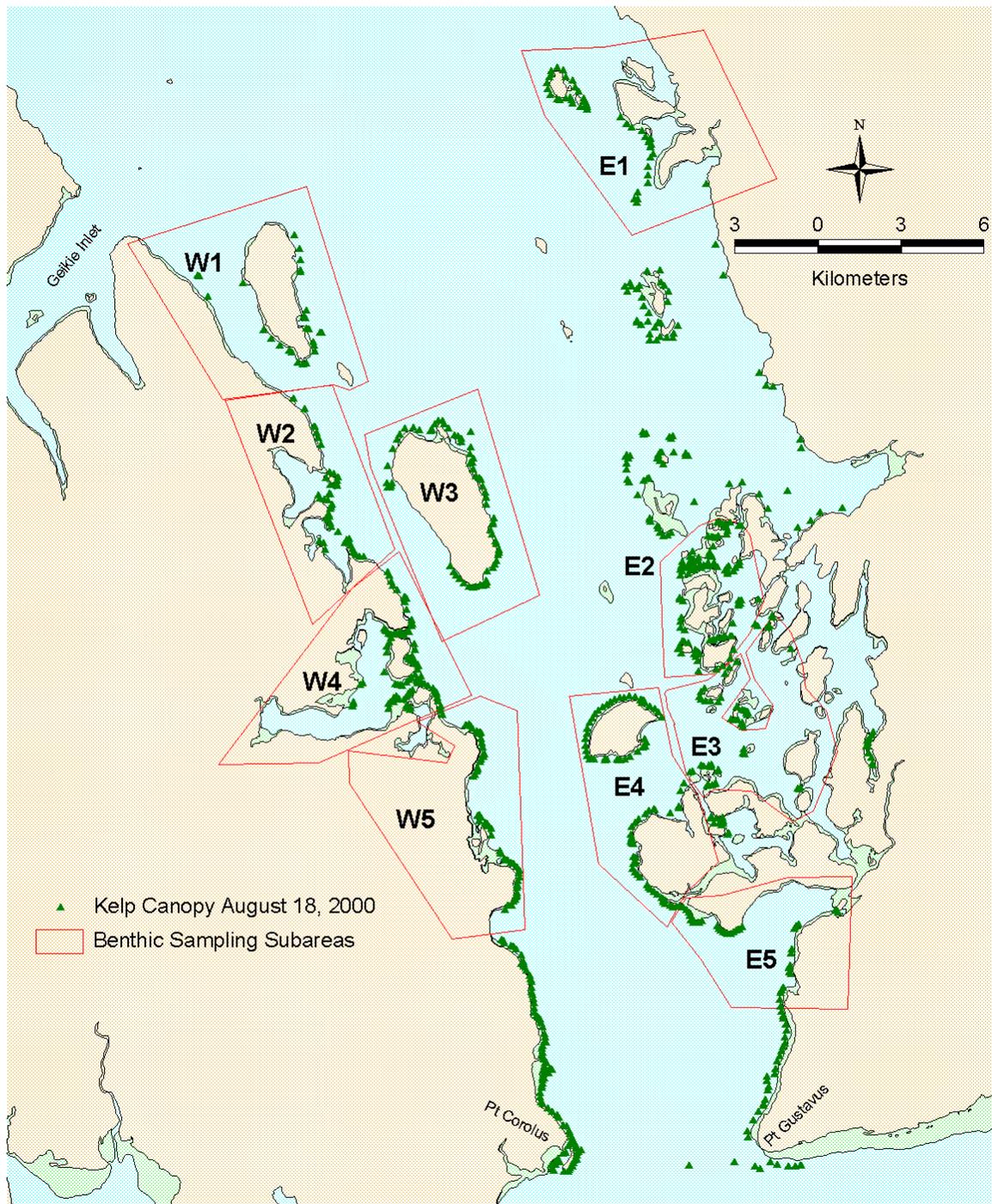


Figure 4. Kelp canopy from aerial survey, August 18, 2000. Each point was used as a potential hard bottom site for subtidal sampling within each subarea.

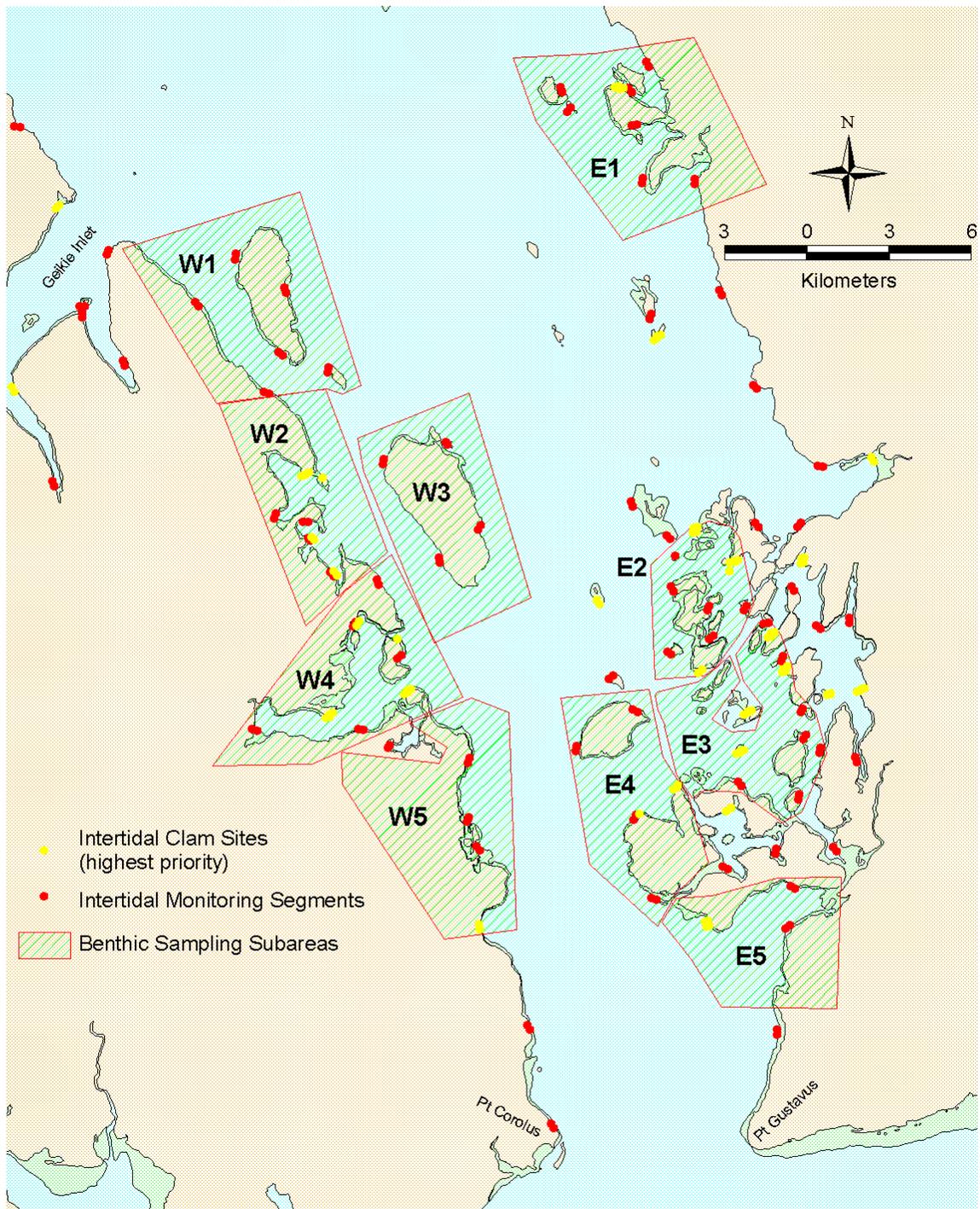


Figure 5. Pool of sites used to determine location of stratified (within each benthic sampling subarea) random subtidal sampling sites for soft bottom habitats. Intertidal Clam sites were allotted highest priority over Intertidal Monitoring segments.

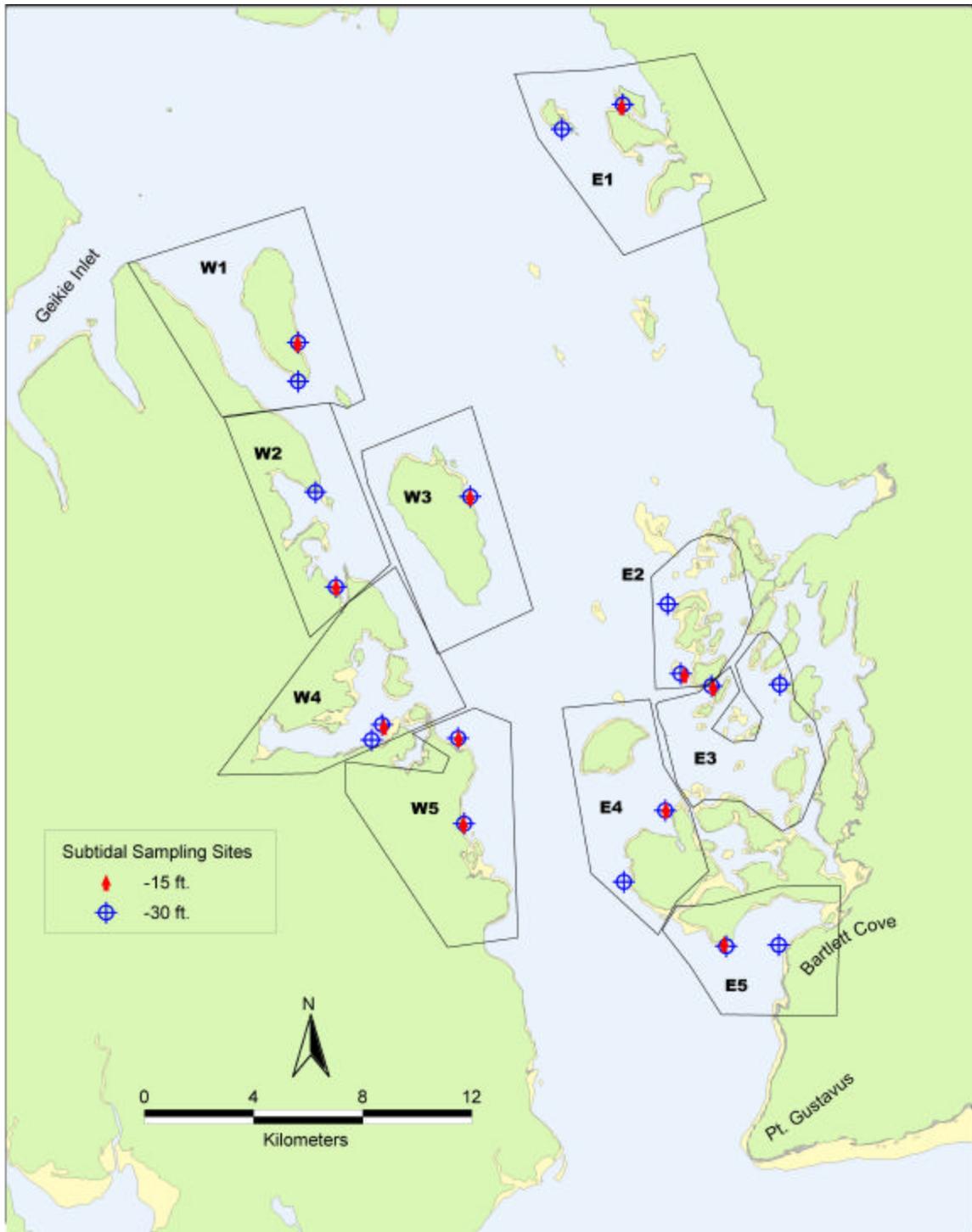


Figure 6. Subtidal monitoring sites within each geographical sub-region as of 2002 (30 total).

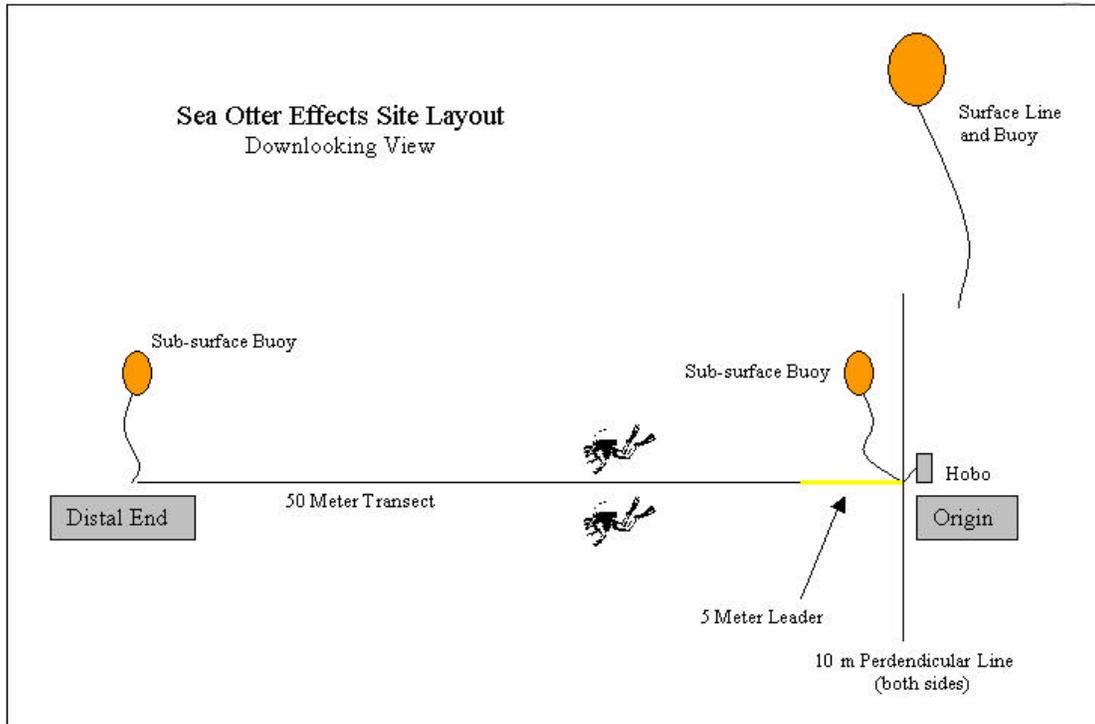


Figure 7. Gear arrangement at permanent site. Note that the 50-meter transect tape has a five meter leader line attached so that sampling begins away from the influence of the permanent station gear at the origin.

Appendix B. Field Datasheets

Sea Otter Effects Sampling Protocol



Glacier Bay National Park



Field Sampling Protocol

Glacier Bay National Park



Michael Donnellan
Jennifer Fisher
Julie Barber
Larry Basch

Document created 12/2001
Modified 11/2002

National Park Service
Glacier Bay National Park
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Permanent transects

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We used permanent transects in order to reduce within-site variability and to meet the requirements for a BACI design. Each transect is placed in -30 feet Mean Lower Low Water (MLLW) to minimize any variability of organism abundance or size that may be associated with depth. These transects are not truly permanent in that there is no fixed line on the seafloor (e.g. lead line). We didn't deploy permanent lines on the seafloor because they would quickly attract invertebrate and algal settlers, and therefore possibly influence our measurements. Instead, a permanent 'anchor' is placed at both ends of the transect, and the transect tape is deployed and retrieved for every sampling session. We determined that a 50-meter transect is optimal for SCUBA sampling because of cold water, variable weather conditions, the minimal slack tide window, narrow workable shelf, and the efficiency of swimming long distances in cumbersome exposure suits. Each 50-meter transect tape has a *five meter leader line* attached so that sampling begins away from the influence of the permanent station gear (Figure 1).

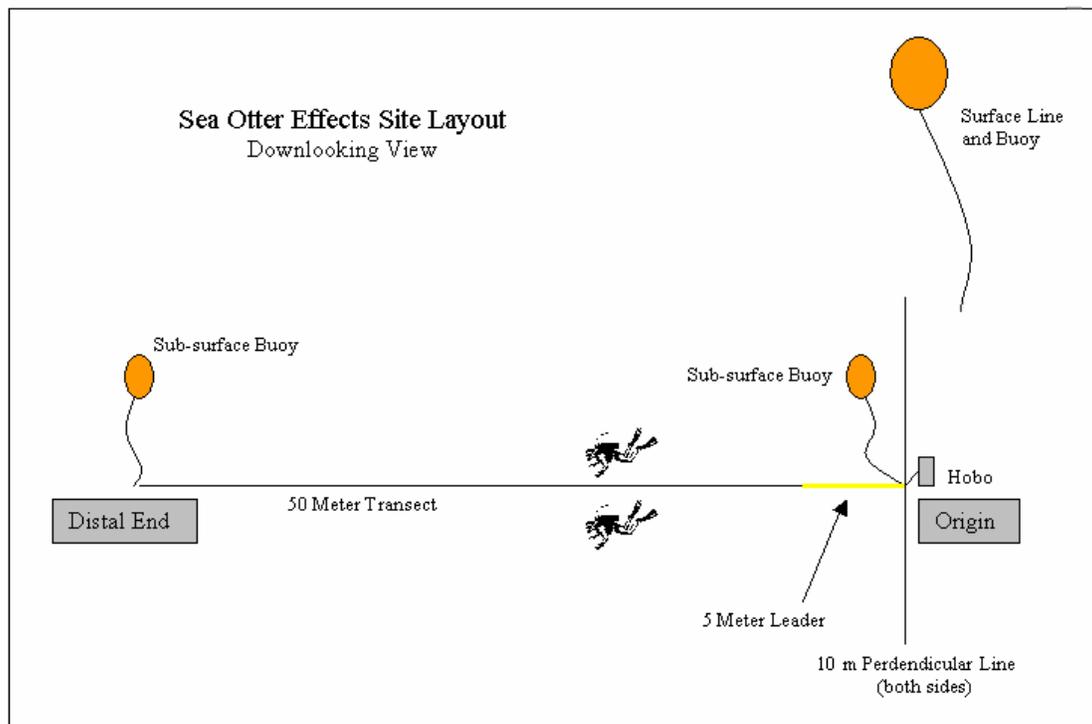


Figure 1. Gear arrangement at permanent site.

Permanent Transect Establishment and Re-establishment

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With the exception of sites within Wilderness Waters boundaries (Beardslee Islands), each site has a surface buoy at the origin for easy relocation. In addition, a differentially-corrected GPS position and line-of-site bearings are recorded to aid in relocating sites. For the 2000 field season, each transect was placed in 30 ft. MLLW. Tide curves were printed daily (for either Willoughby Island or Bartlett Cove) using Tides and Currents Version 2.0 from Nautical Software, and *in situ* tidal corrections were made (if it was a +12 ft. tide at that time, we would place the transect in 42 ft. which would equal 30 ft. at MLLW), prior to the establishment of a site.

Materials needed

Depending on the substrate (hard vs. soft) and if you are in Wilderness Waters or not (i.e. where no surface buoys are permitted), you will need the following materials. It is best to have the materials set-up prior to reaching the site.

- ? 50 meter transect tape with a clip on the handle and a 5 meter leader line.
- ? 1 surface line (25 m) with orange surface buoy attached (buoy should read 'NPS GLBA ongoing research, phone #697-2601')
- ? 1 surface line with a buoy attached to be used for hauling up the ingot once permanent gear has been placed and site is completed
- ? 2 sub-surface lines with buoys (lines ~2 m, white buoys best for relocating)

- ? 1 perpendicular line (20 m with an overhand knot to create a loop in the center of the line)
- ? 5 sand anchors
- ? 3 lead weights or ingots
- ? 1 Pelican float
- ? cane for screwing in sand anchors
- ? cable-ties
- ? Hobo configured for that particular site
- ? Gear bags
- ? Tide depth corrections

Personnel Required

At least 2 SCUBA-equipped divers with compasses

Time Required

Once the substrate is decided to be suitable, site assembly takes approximately 90 minutes, depending on conditions. If the substrate is hard and a sand anchor cannot be used, it may take longer.

Recommended Procedures for Transect Establishment

The most efficient way to set-up a site is to dovetail maintenance with data collection.

1. Navigate to the site using GPS. Reconnoiter the site using the Capelin's depth sounder along a compass bearing. Once you have traveled a distance of at least 100 meters (if soft bottom, in order to leave enough room for a dredge transect), along a - 30 ft. isobath, position the boat at exactly 30 ft. MLLW.
2. Drop an ingot (lead weight) at that exact position with 2 surface buoys (one to become permanent surface buoy and one to haul up ingot when the site has been finished) and a sub-surface buoy attached. DO NOT zip-tie any of the knots because they will be untied underwater.
3. 2 divers enter the water with a transect tape and a bag with Pelican float, sand anchor, sub-surface, metal cane for screwing in anchor (which can also be used as a sea lion poker), and zip-ties. They descend the surface buoy line and swim out 50 meters on the known compass bearing at the corrected depth. During this time one of the divers is usually recording the forward-looking section of the video transect, while the other diver is recording the point contact data.
4. If the transect looks good (proper depth and substrate) they deploy the Pelican float at the far end (to notify the next buddy team [if applicable] to enter the water).
5. Dive team screws in a sand anchor and attaches the sub-surface using a bowline with two half hitches followed by zip-tying the bitter end.
6. Attach the transect tape to the sand anchor, and attach the Pelican securely to the transect tape handle (to be later pulled up by data collectors). Keep in mind that at the end of the day the transect tape should be unclipped so it can be hauled up by the

- Pelican float from the surface. If you don't think divers will be back to unclip the tape, don't clip the tape to the sand anchor. Attach the Pelican float to the tape and place a rock or weight on the transect tape to hold it in place until necessary.
7. Team swims back to the origin. During this time one of the divers is usually recording the down-looking section of the video transect and the other diver is observing the fish species in the area.
 8. In the meantime, surface support has sent down the rest of the sampling gear on the origin line. It worked well to place the perpendicular line in one bag (to avoid tangling), sand anchors in another, and the Hobo in another. Clip all three bags together, using at least two clips (so as not to create havoc and undue stress on divers while trying to pry three bags off one clip with 7mm mitts). Place these bags on *another* clip, which you will clip to the surface line. Position the boat directly over the origin (if no divers are present) and send the bag down the line. You may need to pull up on the line to be certain it reached the bottom.
 9. At the origin screw in 1 sand anchor for the sub-surface buoy, transect tape and Hobo. Transfer the sub-surface buoy to the transect sand anchor.
 10. Near the origin sand anchor, but placed about a meter away screw in another sand anchor. The surface buoy line should then be attached to this separate anchor. The reasoning for placing this sand anchor further away is to keep the subsurface buoy from entangling itself in the surface buoy line.
 11. Loop the middle loop from the perpendicular lines through the transect sand anchor, and run the bitter ends through the loop
 12. Run each end of the perpendicular line out at a 90° angle to the transect tape and secure each end with a sand anchor (using the above technique).
 13. Deploy the Hobo (it is buoyant!) on the transect sand anchor. We found that 3+ cable ties work best to hold the Hobo on the sand anchor.
 14. Ascend...you are done!
 15. Pull up the ingot using the remaining surface buoy (never should have been untied) We found it worked best underwater to have two different colored lines to distinguish between the permanent buoy and the non-permanent buoy used for pulling the ingot back up to the boat. For example, most of our permanent surface buoys have yellow polypro line, whereas the buoy used for hauling the ingot had a grey crabpot line.

Note: This usually takes at least two dives.

If the substrate is too hard to screw in a sand anchor a lead ingot or weight will need to be substituted.

Transect Re-establishment

Materials needed

- ? 2 50-meter transect tapes, one with a clip on the handle (no leader line) and one with a **5 meter leader line**
- ? Site line-ups

- ? Pelican float
- ? Site coordinates
- ? Tide depth corrections

Personnel Required

At least 2 SCUBA-equipped divers with compasses.

Recommended Procedures for Transect Re-establishment

If the surface buoy is missing, the transect sites are designed to be best relocated by navigating as close to the point as possible with the boat, fathometer, GPS, and line-ups; then staging the boat off a short distance (in the opposite direction of the transect bearing), and taking a bearing to the site underwater. By offsetting the boat, you will only have one direction to swim instead of guessing which direction you may be erring, and you are aiming for the twenty meter (10m on each side of origin) perpendicular line. It is important to note that extra time spent in the vessel maneuvering as close to the point as possible is more efficient than time spend underwater looking, so give yourself plenty of time in relation to your slack tide window. In addition, with a patient captain on the boat, the subsurface buy can also be seen on the depth sounder of the boat. When you think you are close to the area, keep an eye on the depth sounder, the subsurface buoy looks like a piece of kelp floating off the bottom. This is one way to know that you are right on top of the site without ever going diving!

Note: When relocating sites, be sure to always be looking at the correct depth contour. If you are at the wrong contour, you are probably in the wrong place. Underwater communication systems would be helpful.

1. Navigate as close to the point as possible using the boat, then fall back away from the transect (in the direction *away* from the direction of the transect) and anchor the boat. The anchor acts as a good point of reference, so place *it* where you want to be, *not* the boat.
2. Descend the anchor line, attach the transect tape without the leader line to the anchor (for a reference point) and swim in the direction of the perceived transect origin at the corrected depth contour.
3. You are looking for the perpendicular line (20 meters).
4. Once you find the perpendicular line, follow it either way until you find the origin.
5. If you *do not* find the perpendicular line after a known distance, then travel back to the anchor and try another compass bearing.
6. Once you find the origin, attach the transect tape with the leader line to the origin and swim at the known bearing to the far end.
7. Once you reach the end of the tape, look in all directions for the buoy. Before swimming, look long and hard for the buoy, because once you start swimming you will lose your place of reference. Often, the buoy is just outside your visibility range, so it sometimes helps if you attach the Pelican float to the transect tape and use that as a guide and a reference back to where you started. Another tactic is to have one

buddy remain with the transect tape while the other swims off (but remains in sight at all times of the other buddy) to look for the buoy. In either case, it is important to leave the tape where you ended so that you always have a reference point of where you *think* the end of the transect should be.

8. If the buoy is still not found, try to find a landmark as a reference and make mental note. Then swim in one direction with the transect tape still in hand (or the Pelican line/float).
9. If the buoy is still not found, swim in the other direction (past your reference point).
10. Once you find the other end, attach the Pelican line to the sand anchor, if the tape does not reach.
11. Swim back along the transect tape, unsnagging the tape from rocks and kelp, and tighten the tape until it reaches the sand anchor. You may need to do this a few times and the tape may never reach.

Sampling Techniques

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The diversity of organisms and physical settings in Glacier Bay requires a diverse set of sampling techniques to adequately quantify the density of selected species. Monitoring the impacts of sea otters on these organisms requires sampling that is accurate and precise while balancing the efficiency (cost-effectiveness) of subtidal sampling using SCUBA. Additionally, a successful monitoring program must also be repeatable by generations of samplers with minimal among-observer variation, and should not require highly trained personnel or complex procedures. Table 2 outlines nine sampling techniques to satisfy these criteria, which incorporates estimates of ideal sampling unit size for each species (with consideration given to an organism's relative rarity, motility, etc.)

Technique	Area Sampled	Number of Spatial Replicates (per site)	Number of True Spatial Replicates (per site)
0.25 m Quadrats	0.5 m x 0.5 m	20	20
1.0 m Quadrats	1 m x 1 m	20	20
Swath	2 m x 2.5 m	20	10
Habitat Video	1 m x 50 m	1	1
Size Frequency	an individual	< 300	< 300
Species Checklist (Presence/Absence)	transect vicinity	1	1
Temperature	hourly	1	1

Datasheet Header Information

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Listed below are the general information required on every datasheet. In some instances, there is additional information particular to that sampling methodology which is listed last in the list below.

- ? DATE: Enter date in format yyyyymmdd; e.g. May 4, 2000 = 20000504 (this makes “date” easy to sort in a database)
- ? HOUR: Enter the military time for the nearest hour (e.g. 1300 for 1pm). Sir yes sir!
- ? LOCATION: Use naming convention with Polygon Number, Hard or Soft, and site number; e.g. E2 Soft 30 (the soft-bottom site within the E2 subarea established at –30 feet MLLW). Also include a brief description of the site location; e.g. south of Flapjack Island
- ? LEFT/RIGHT: Enter the side of the transect you will be working on (oriented from 0 m at the origin to 50m); This should be decided before the dive and is best decided upon by playing rock-paper-scissors, a.k.a. ro sham bo.
- ? LAT: Latitude of site (at origin) from differentially-corrected GPS (collect data in decimal degrees using NAD83 datum); if latitude data is reported for whatever reason in decimal minutes, the numbers occurring after the decimal point should be divided by 60 to convert to decimal degrees; e.g. 58°23.444’ = 58 + (23.444/60) = 58.39073°
- ? LONG: same as above but for longitude
- ? GPSError: positional error recorded from GPS at time of fix (in feet)
- ? VIS: Approximate underwater horizontal visibility, in feet
- ? SLOPE: approximate average slope across 50 m transect (measured across transect, usually perpendicular to shore, in degrees)
- ? TRANSNUM: number identifying the transect in the field (This will be “1” for the one existing transect at each site. Future transects with different origin, bearing, or depth will be transect 3 etc.)
- ? VISIT NUMBER: The nth visit to a permanent site within a calendar year. For example, if the same data are collected at a particular site twice in a year, VISIT NUMBER = 2. This does not include the instance when it takes multiple days to complete the collection of data at a site. E.g. if you accomplish 5 quadrats in day xxx and then return at day yyy to complete the remaining 5 quadrats, that would still be visit 1. If you have completed all 10 quadrats at a site and return later in the year to collect quadrat data from the *same* transect (e.g. to see if urchin distribution has changed) then that would be recorded as visit 2.
- ? DIVER: Observer name
- ? BUDDY: Your buddy’s name
- ? SAMPLING START MARK (Quadrats Only): Each year different points are sampled along the transect line, therefore new points must be selected. BEFORE the dive, each buddy should generate 2 random numbers, or quadrat starting points, per 10m segment, per side of the 50m transect, for a total of 10 quadrats (i.e. randomly choose 2 numbers between 0 and 9, 10 and 19, etc. for each side of the transect). A calculator with a random number generator works well for this. Enter these numbers above the underlined portion of the datasheet cell. Enter your buddies start marks

within the parentheses of the same cell (so you know where each other are). For example, you need to work at the 11 meter mark and your buddy will be at the 14m mark. The datasheet square for that section should look like this:

10 (14)

Quadrats

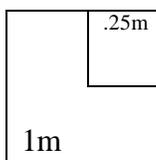
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Purpose

To 1) determine the density and/or percent cover of selected indicator species (animal and algae) and 2) to assess substrate and habitat characteristics.

Materials

- ? 2 underwater clipboards
- ? 2 underwater double-sided quadrat datasheets with random numbers coinciding with meter mark to be sampled
- ? 2- 1m² PVC quadrats with nested 0.25 m² quadrats



- ? game bag (for collecting sea urchins and unidentified algae and animals and shells)

Personnel

2 SCUBA-equipped observers

Time Required

Approximately 40 minutes of bottom time per buddy team. Areas of high species diversity and/or abundance or complex substrate types will take longer.

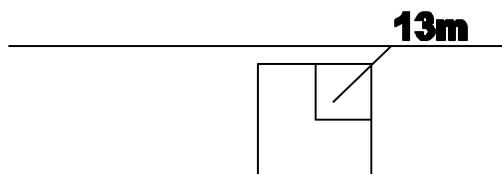
Datasheet Header Information

FILL OUT AS MUCH DATASHEET HEADER INFORMATION AS POSSIBLE BEFORE THE DIVE. [Quadrat Datasheet Hyperlink](#)

Methods

Each diver will sample 10 stratified random quadrats (2/ 10 m segment) on either the right or left side of the transect line. Each buddy team will descend to the transect

either by following the surface buoy line at the origin of the transect (to work from 0 to 50 m) or by descending the temporary pelican buoy deployed from the distal end of the transect (and working from 50m - 0m). (REMEMBER never to apply heavy force to a surface buoy line (e.g. pulling oneself down when in a relatively strong current), because the sand anchors securing the permanent transect may pull loose!!) The desired direction of travel depends upon the current direction and strength (it is ideal to have a slight current and work up-current, so silt clouds are carried away downstream), and transects may be worked one-way. Upon reaching the pre-designated quadrat starting point on the transect tape, lay the quadrat on the substrate so that the outside corner of the 0.25 m² quadrat is positioned closest to the origin and next to the quadrat starting number on the transect tape, and the side of the quadrat is directly adjacent and parallel to the transect tape.



As a general rule, collect data first in the 0.25 m² quadrat, then within the 1 m² quadrat. When algae are abundant, it is probably best to collect data on these species first before counting and collecting urchins (and thereby disturbing the sediment). Although each buddy collects quadrat data independently, each diver should never be more than 5-8 m away from each other at any point, and the diver in the lead should wait until the other has caught up before advancing.

Always remember the key to a good datasheet begins in the field (i.e. G²=garbage in equals garbage out!). Collect data that you are sure of, if there is ever a question, ask, never assume.

0.25 m Quadrats

Organisms sampled

Strongylocentrotus droebachiensis (green sea urchin)

Strongylocentrotus pallidus (white sea urchin)

Modiolus modiolus (horse mussel)

Clam siphons

New otter-cracked shells

New non-otter cracked shells

Strongylocentrotus droebachiensis (green sea urchin): Count and record all urchins with >10cm test diameter, which is about the smallest ones you can pick up with gloves, within the 0.25 m² quadrat and record. If sea urchins are NOT extremely abundant (this is a judgment call to be made by the project leader or lead technician), then count urchins within the 1 m² quadrat and record data – being sure to include in the count the urchins in the 0.25 m² quadrat. For example, if 3 urchins are counted within the 0.25 m² quadrat, and

5 urchins are counted within the 1 m² quadrat but *outside* the 0.25 m² quadrat, record the data as 3 green urchins in the 0.25 m² quadrat box and 8 in the 1 m² quadrat box.

Sometimes it's necessary to move algae stipes/blades around to see and count urchins (therefore it is best to record % cover of algae first), however, do not conduct any invasive sampling (i.e. don't turn over rocks).

After recording the number of green urchins in the 0.25 m² quadrat present on the surface of the substrate (i.e. non-invasively), invasively search for and count urchins occurring within this same 0.25 m² quadrat ONLY (i.e. do NOT invasively sample sea urchins within the 1 m² quadrat), turning over rocks and shells and carefully digging into the substrate, if necessary. After recording data, attempt to return substrate to its original condition and replace rocks right-side up.

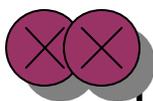
A quick and dirty comparison of urchin counts with and without invasive sampling yielded urchin densities up to 2-3 times higher when invasive sampling was conducted in complex pebbly habitat.

Using a mesh bag, collect all urchins within the 0.25 m² quadrat (when abundant) or 1 m² quadrat (when less abundant) for subsequent size measurements after the dive. **See detailed methodology** under the method heading "Size Frequency."

Strongylocentrotus pallidus (white sea urchin): Use same techniques as described above for green urchins, including invasive and non-invasive sampling.

Modiolus modiolus (Northern horse mussel): These mussels are usually partially buried in the substrate and can blend in with the seafloor quite easily, but many are readily visible and identifiable by their orangish mantle protruding from slightly open valves. Some mussels are inconspicuous (especially when the mussels are densely aggregated), so exhibit care to get an accurate count. When present, *Modiolus* are usually aggregated and generally occur only in certain habitat types. Record the number of individuals within the 0.25 m² quadrat.

Clam siphons: Count the number of clam siphons and holes that *obviously* contain siphons (very small holes are probably brittle stars or worms, not clams, while very large holes are potentially worm casings). Certain species of clams have siphons that are a deep red color with figure eight-shaped holes and frilly edges or a deep brown color with a flattened surface and wrinkly sides. *Mya* spp. have siphons that can protrude well above the surface of the substrate. The siphons tend to be quite visible when the clam is feeding, sticking up about an inch into the water column. However, if the area is disturbed and the clams pull their siphons in, you can still see the figure eight shaped hole, and sometimes the siphon within the hole. From site recon experience, the clam siphons tend to be the most abundant in areas of high current and cobble, pebble, fine sand substrate combinations. Not all clam species have readily visible siphons, and not all clams may have their siphons out to feed when you are counting. The siphons could also be poking out from underneath of a rock or covered by algae.



1 m Quadrats

Organisms sampled

Sea urchins (see description and methods in the 0.25m² quadrat section)

Algae

Agarum clathratum

Alaria marginata

Alaria fistulosa

Codium ritteri

Costaria costata

Cymathere triplicata

Desmarestia spp. – wiry (Acid weed complex of 3 possible species that are difficult to identify in the field: *D. kurilensis*, *D. aculeata*, and *D. viridis*)

Desmarestia munda

Diatom Film (only quantify film that is not on rocks)

Fucus gardneri (always drift from intertidal)

Kelp recruits

Nereocystis luetkeana

Opuntiella californica

Palmaria spp.

Pleurophycus gardneri

Sparlingia pertusa

Turnerella mertensiana

Constantinea spp.

Unidentified green blade (always drift from intertidal)

Unidentified brown algae (usually drift *Nereocystis* blades)

Unidentified coralline red crust (pinkish non-geniculate coralline crust on rocks and shell litter, probably *Lithothamnion* but unsure)

Unidentified fleshy algal crust (maroon non-coralline algal crust on rocks, seems to be more predominant in the northern sites)

Unidentified red blade (non-descript or immature red algal blades)

Unidentified fleshy red (includes filamentous and filamentous-looking algae)

Unidentified *Laminaria* spp. (thick blade/Sugar) – use this category if unsure of species identification (e.g., for immature individuals)

Substrate (sampled using the Wentworth scale, see below)

BEdrock

BOulder (>25cm) head size or greater

CObble (6-25cm) billiard ball to head size

PEbble (0.4-6cm) pea size to billiard ball

GRanule (0.2-0.4cm) bb size to pea size

Coarse Sand pinhead to bb size

Fine Sand salt/sugar-pinhead

Shell Debris (shell fragments)

Shell *Litter* (large enough for settlement)

Silt

Clay (clumpy, thick substrate, hard to dig through)

Substrate Categories

- ? PRIMARY – the single sediment particle size that encompasses the largest planar area within the quadrat (>50%).
- ? SECONDARY – the single sediment particle size that encompasses the next largest area within the quadrat (10-50%).
- ? MODIFIER – substrate types that are present, but are not primary or secondary substrates (<10%). Note: we have modified the definition of modifiers in the coastal database. Modifiers are defined in the coastal database as grain sizes that are larger than pebbles, but we defined a modifier to be any substrate type in the quadrat present, regardless of size.
- ? INTERSTITIAL – the single most abundant of the smallest particle sizes found between the primary and secondary substrate (i.e. granules or smaller). If the bottom is predominantly pebbles with silt between the pebbles, silt would be the interstitial substrate.
- ? UNDERLYING- the substrate type that dominates the underlying area beneath the surface layer of substrate. In most cases, it is difficult to determine accurately what the substrate is comprised of without a tool (i.e. sediment core), therefore it is an arbitrary measure used for qualitative purposes. For example, if you poke your finger beneath the sediment and you feel something hard, it is difficult to discern whether that something is a cobble, pebble, or boulder, in which case you may simply record Rock for underlying instead of trying to make a guess. Likewise, if you poke into the substrate in various places and find that the substrate is soft on a predominantly silty bottom, the underlying substrate is more than likely silt, and you would therefore record silt as the underlying substrate. **MAYBE WE SHOULD CHANGE THE POSSIBLE CHOICES IN THIS CATEGORY TO SOFT, HARD, UNKNOWN, AND MAYBE CLAY (B/C WE COULD DIG DOWN IF SUBSTRATE WAS SOFT ENOUGH?)**

A segment will always have a primary substrate, a secondary substrate, and usually one or two modifiers. Modifiers can be used to describe particles that are present and important but cover LESS THAN 10%. Two simple examples follow: A beach covered by 70% pebbles, 21% cobbles, 5% boulders, and 4% fine sand is reported as a primary = pebbles, secondary = cobbles, and modifiers = fine sand and boulders. A beach covered by 80% pebbles, 8% cobbles, 7% fine sand, and 5% boulders is reported as a primary = pebbles, secondary = pebbles, modifiers = fine sand, cobble, and boulder.

Algae

The percent cover of each species of algae present in the quadrat is estimated (see species list above), and for some species, the number of stipes present and whether it is a recruit, juvenile, or adult. To decrease underestimating or overestimating the percent cover of algae, which is highly dependent on the season sampled, both stipes and percent cover of ONLY brown algae are counted. For each species observed, record the number of stipes to the left of the slash (if a brown algae), and then the percent cover of that

species to the right. E.g. if you are sampling late in the season, it is conceivable that blades could be tattered and senescing. If you observe five *L. saccharina* stipes covering an area of only ten percent then you would record it 5/10. For red and green algae, and diatom film, only record percent cover. In addition, if an algal thallus or piece of thallus is drifting on the bottom, or not attached to any type of substrate (e.g., pebbles, cobbles, or shell litter) by the holdfast, then denote the percent cover of the species and put a “d” next to the count noting that it was drift (remember to include the number of stipes if the holdfast of brown algae are observed, even though they may not be attached to the substrate). The designation of "drift" does not encompass algae that are attached to small pebbles, shells, etc that may have possibly tumbled downslope from shallower water (e.g., generally shallower subtidal species like *Cymathere* and *Costaria*), but species of algae that are strictly intertidal observed on the transect should always be recorded as drift, even if the holdfast is still attached to a piece of substrate.

It is easy to overestimate percent cover. As a reference, determine whether the algae in the quadrat can fit into the nested 0.25 m² quadrat for a starting point. To minimize guesswork, and decrease among-observer error, we limited percent cover estimates to multiples of ten, with the exception of one and five percent (It is difficult to differentiate between 50% and 55%). If a species is present but covers less than one percent of quadrat area then record as 1% (e.g. individual filamentous red algae, *Desmarestia*, or small bits of *Ulvaria* drift often occur in this category). If a species is present and in greater quantity than about 2%, but less than 7%, it is recorded as 5% (5% encompasses 3-7%). Likewise, if a species is 7%, it is recorded as 10% and if a species is 55% then the observer needs to make a call as to whether the coverage is closer to 50% or 60%.

Back in the boat after each dive, read over your datasheet, make all corrections you need to, make it legible, circle all counts you make, and then hand it to your dive buddy *to be sure they too can read it*. Always make sure your fellow dive patron can read your datasheet, there should never be a question whether a scratch on the datasheet is really a scratch or an actual count for a species. Often, the person entering the data is not the person who collected the data, so NEVER assume your handwriting is legible. When you have completed this, rinse each datasheet in fresh water, let air dry (never wipe the datasheets clean or dry because this leads to smearing), and store the datasheets in a safe place. Before storing the datasheets, photocopy them. Place the photocopies in one place and the originals in another place. Only use the photocopied datasheets when going to enter data into the database.

2m x 2.5m Quadrats (“Swaths”)

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Purpose

To determine the density of selected sedentary macrofauna that are more rare or clumped than organisms sampled within 1m quadrats.

Materials

- 2 underwater clipboards

- ? 2 underwater swath datasheets
- ? 2- 2m PVC swath bars
- ? game bag (for collecting whelks and unidentified animals)

Personnel

2 SCUBA-equipped observers

Time Required

Approximately 40 minutes of bottom time. Areas of high species diversity and/or abundance or complex substrate types will take longer.

Datasheet Header Information

FILL OUT AS MUCH SWATH DATASHEET HEADER INFORMATION AS POSSIBLE BEFORE DIVE - [Swath Datasheet](#)

Methods

Each diver will sample ten 5m² “swaths” (each swath is 2m wide x 2.5m along-transect) on either the right or left side of the transect line. Choose random numbers at 2.5m intervals (including meter 0, ending at meter 47.5) before dive to determine which 10 swaths will be sampled out of the 20 possible (stratify sampling so that 2 swaths are chosen within every 10m section of the transect). Each buddy team will descend to the transect either by following the surface buoy line at the origin of the transect (to work from 0 to 50 m) or by descending the temporary pelican buoy deployed from the distal end of the transect (and working from 50m - 0m). The desired direction of travel depends upon the current direction and strength (it is ideal to have a slight current and work up-current, so silt clouds are carried away downstream).

Upon reaching the designated meter mark, orient the 2-meter swath bar perpendicular to the transect tape and swim with the swath bar in front of you along the tape, counting all swath species encountered along your bar until reaching the end of the 2.5m block (pay close attention, as it is easy to “overshoot” the ending point). When you reach the end of the 2.5 meter block on the transect tape, stop and record the species observed in the appropriate column for that segment (e.g. 5-7.5m, etc.). It may be necessary to make tick marks on your datasheet to keep track of species if they are abundant. In this case, after finishing a swath, tally your tick marks and record them as a value (?? = 3), and be sure to circle the value to avoid later confusion. Only those species that are larger than the minimum size class cutoff should be counted (see size class of organisms sampled below) . If organisms are smaller than the minimum size class cutoff, the number counted should be marked separately on the datasheet as juveniles (but in the

same cell as the adult count). Occasionally, relatively rare macrofaunal species will be encountered that do not have a dedicated row listed on the datasheet (e.g. king crabs, basket stars, *Halocynthia*). Familiarize yourself with the list of incidental species at the bottom of the swath datasheet before collecting data underwater. If an individual(s) is observed on the transect, then write that species name in on one of the blank rows provided and enter the count. Unknown species should be collected and brought to the surface for identification. Note that write-in species (i.e. those that are not on the datasheet printout) have not necessarily been recorded consistently at each site by different divers as of 6/19/2001, therefore among-site comparisons are not reliable prior to this date.

This sampling method is non-invasive, meaning that you should look on either sides of rocks and in crevices, but do *not* overturn rocks to look for critters. Although each buddy works independently, each diver should work abreast of the other to avoid potential decrease in visibility from kicking up silt, buddy awareness, etc. There is no reason for one buddy to be far ahead of the other.

****Always remember the key to a good datasheet begins in the field (i.e. G^2 =garbage in equals garbage out!). Collect data that you are sure of, if there is ever a question, ask, never assume.****

Organisms sampled:

Arthropoda

Cancer magister (Dungeness Crab)
Cancer oregonensis (Pygmy Rock Crab)
Chionoecetes bairdi (Tanner Crab)
Elassochirus tenuimanus.(wide-hand hermit)
Elassochirus gilli.(orange wide-hand hermit)
Hyas lyratus (Lyre crab) adult >3cm
Oregonia gracilis (decorator crab)
Pagurus spp. (includes *P. capillatus*, *P. ochotensis*, *P. beringanus*)
Pandalus spp.
Telmessus cheiragonus (Helmut Crab)
 Unidentified Decorator Crab

Holothuroidea

Cucumaria miniata (Orange Sea Cucumber)
Cucumaria frondosa (Black sea Cucumber)
Synallactes challengerii
 Unidentified *Cucumaria sp.*
 Unidentified sea cucumber

Cnidaria

Cribrinopsis fernaldi (Crimson anemone)
Metridium giganteum (White-plumed anemone)

Metridium senile

Urticina lofotensis (white-spotted rose anemone) – need to positively ID

Urticina crassicornis (red and green Christmas anemone)

Unidentified sea anemone

Asteroidea

Crossaster papposus (Rose star)

Evasterias troschelii (False Ochre Star)

Gorgonocephalus eucnemius (Basket Star)

Henricia spp. (Blood Stars)

Leptasterias sp. (Six-armed star complex)

Mediaster aequalis (Red Sea Star)

Orthasterias koehleri (Rainbow star)

Pteraster tesselatus (Cushion Star)

Pycnopodia helianthoides (Sunflower star)

Solaster spp. (Sun Star) – identified to species, if possible

Solaster dawsoni (Dawson's Sun Star)

Solaster endeca (Northern Sun Star)

Solaster stimpsoni (Stimpson's Sun Star)

Stylasterias forreri (Fish-eating star)

Mollusca

Beringius kennecotti (Kennecott's whelk)

Boreotrophon sp.

Buccinum plectrum

Cryptochiton stelleri (Gumboot chiton)

Fusitriton oregonensis (Oregon triton)

Neptunea lyrata (Lyre Whelk)

Unidentified whelk

Miscellaneous

Stylissa stipitata (vase sponge)

Halocynthia aurantia (Sea peach)

Size class determination for organisms sampled in swaths:

Because we are looking at changes in macrofaunal communities, and our emphasis is towards sea otter prey items, we made arbitrary size class cut-off distinctions for counting individuals of given species. While it is desirable to acquire a density estimate for an entire population of a species - not just the larger size classes - this is impractical for certain species because of non-linear increases in sampling effort associated with searching for very small individuals, particularly for cryptic or camouflaged species.

After a cursory collection of *Hyas lyratus*, we determined that only crabs >3cm would be counted. This decision was based on a size class difference (n=21) and the gravidity of females (females >3 cm were gravid). For anemones, the size class cutoff was set at 3cm column diameter, and the minimum length for sea cucumbers was also set at 3cm. Because the hermit crabs *Elassochirus spp.* and *Pagurus spp.* utilize shells of varying sizes, we decided to use a measure of their conspicuous large chelae for size class determination. During the initial portion of this study in 2000, we attempted to measure crab chelae to determine what could be considered otter-food, but we found that the crabs often retract quickly into their shell without permitting a good enough look at their chelae to determine an actual size. We therefore, took a more esoteric approach, and decided that if the enlarged chelae was clearly visible and of "sizeable", then we would count it. After collecting some crabs, we calibrated what divers thought to be 'sizeable'. We understand this is not as repeatable as others, but there does seem to be a distinct size class break between crabs with chelae that are quite small (<1 cm) and those that we would count with larger chelae (>1.5 cm). For whelks, we record all species that are >6cm in length, measured from the tip to the tip of the siphonal canal. We also collect all whelks (large and small) to get a size class distribution on the species (see information further in protocol on measuring whelks). For the sea stars, during 2000 we counted only individuals that weren't "recruits", leading to a degree of among-observer variability depending on the observer's size class cutoff. In 2001, only sea stars with a central disc greater than 3cm were recorded. In 2002, all seastars were recorded regardless of size, except for obvious "recruits" with an "R" measurement (middle of central disk to tip of ray) of less than 1.5 cm.

After each dive, read over your datasheet, make all corrections you need to, make it legible, circle all counts you make, and then hand it to your dive buddy to be sure they *too* can read it. Always make sure your fellow divers can read your datasheet - there should never be a question whether a scratch on the datasheet is really a scratch or an actual count for a species. Often, the person entering the data is not the person who collected the data, so NEVER assume your handwriting is legible. When you have completed this, rinse each datasheet in fresh water, let air dry (don't wipe the datasheets clean or dry because this leads to smearing), and store the datasheets in a safe place.

New otter-cracked shells: Sea otters break open bivalves with rocks and consume them while floating on the surface, subsequently disposing of the shells on the seafloor. The cracked shells of certain thick-valved species (e.g. *Saxidomus gigantea*, *Serripes groenlandica*) preyed upon by otters exhibit a fairly consistent fracture pattern in which one valve is split open, while the hinge and other valve are left intact. The seafloor in the vicinity of the foraging activity may be strewn with discarded shells, which in turn may be used as an indicator of otters foraging activity in the vicinity. However, other predators such as the giant Pacific octopus and large sea stars may also break bivalves open, and these broken shells can be mistaken for otter-cracked shells to an untrained observer. Therefore, a broken bivalve that appears to be cracked by an otter must be interpreted within the context of its surroundings. For example, the resulting valve fracture pattern due to octopus predation resembles that caused by a sea otter, but these broken shells are typically very densely aggregated in the localized area of the octopuses' garden. Predation by sea stars, on the other hand, may result in a similar spatial pattern

or density of broken bivalves on the seafloor, but sea stars are not known to crack open thick-valved bivalves that results in a similar fracture pattern to that caused by sea otters. Thin-shelled bivalves (e.g., *Modiolus*, *Mya*) that have been cracked can't be reliably attributed to sea otters. Furthermore, old shells may deteriorate rapidly and become brittle, making it susceptible to breakage. Therefore, ONLY record otter-cracked shells that appear like they recently died (i.e. no fouling growth), and NOTE the species of bivalve if possible. This data category was collected in quadrats only prior to 2002.

New cracked shells: It is not always obvious to determine the cause of bivalve shell breakage, and agents other than sea otters may facilitate increases in shell litter (e.g. octopus, sea stars). Record the number of fractured/broken shells of bivalves that appear to have died recently (i.e. no fouling growth).

Video

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Purpose

To 1) qualitatively document the general habitat at each site in the vicinity of the 50 meter transect tape; 2) document unidentified species.

Materials

- ? Digital video camera
- ? Underwater video housing
- ? 2 Light and Motion underwater lights with battery pods
- ? 1 digital video tape (pre-labeled with successive numbering system, i.e. no duplicate tape numbers)
- ? 1 digital camera battery, fully charged
- ? Light and Motion light batteries, fully charged
- ? O-ring kits and grease

Personnel

2 SCUBA-equipped observers

Time Required

Approximately 30 minutes of bottom time.

BE SURE TO THOROUGHLY READ THE CAMERA MAINTENANCE GUIDELINES PRIOR TO HANDLING THE CAMERA. IF NOT INTIMATELY FAMILIAR WITH THE WORKINGS OF THE CAMERA, LIGHTS, AND HOUSING, BE SURE TO CHECK THE QUICK REFERENCE CAMERA GUIDE EVERY TIME BEFORE ENTERING THE WATER THIS EQUIPMENT IS VERY EXPENSIVE!!!

[Quick Reference Guide](#)

[Video Camera Maintenance](#)
[Housing Maintenance](#)

Methods

- 2 Prior to entering the water, turn the camera on (see camera protocol for more details) and videotape the header information from a datasheet, making sure to record the date and site location. While recording this information, audibly state the date, tape number, dive number (number of dives you took video for that day), site location, and videographer clearly into the housing.
- 2 When you are completed, turn the dial to lock position.
- 2 Upon entering the water, have somebody hand the camera to you (NEVER roll into the water holding the camera; water pressure is the mechanism compressing the o-rings and preventing the housing from leaking. On the surface, the water pressure is minimal and thus **the camera is most susceptible to flooding**. The camera is NEGATIVELY buoyant, therefore, do not let go of the camera until you have a firm grip on it and the lanyard is secure around your wrist (or in some cases, you have it clipped to you).
- 2 Immediately check the moisture indicator viewer on the top right corner of the camera (while looking down onto it). If the indicator is a bright red, immediately remove the camera from the salt water and follow the procedures outlined in XXXX for a flooded camera.
- 2 If there is no light, proceed with the dive. If at any time during the dive you see the moisture indicator light on (red light), abort the dive immediately and surface with the camera.
- 2 Upon reaching the bottom, turn the dial to video, be sure the camera is in standby, not record, zoom all the way out (wide-angle), turn the auto focus on (button on lower left of housing), let the camera focus on something in the distance, i.e. the permanent transect tackle or your fin, but not the particles in the water column, and then turn off the auto focus. Now you have locked the focus for the distance you will be shooting at, which in this case is infinity. (See camera protocol for more details). With the camera in wide-angle mode and infinity focus (not auto focus), you are now ready to record the dive.

Forward-looking

When your buddy is ready to proceed, hit the record button and begin swimming the length of the transect. If the visibility is decent, turn on the lights and position them so the light is shining down on the substrate and a bit into the water column. You will see how to best light it up with practice underwater. You do not want the lights pointing directly out into the water column because this will create backscatter and you will not record anything but particles! If the visibility is too bad and all you get in the viewfinder is backscatter, then turn the lights off and proceed without them. If you decided you can use the lights, you can adjust their level of brightness by pushing the red button on the battery pods once, again, and again....until you have the desired brightness. I find that the

third level, the lowest brightness, is all you need for shooting in Glacier Bay. To turn lights off, push the red button down and hold it down until the lights turn off.

You want the video camera forward-looking to record the general substrate and surrounding area i.e. not the water column. You should be looking through the viewfinder of the camera periodically to be sure that you have the substrate in view, but you are not focusing solely on the substrate (i.e. not getting the general picture of the habitat) and that you are not looking ahead too much and recording mainly the water column, with little substrate in view. Depending on the visibility, it is a general rule of thumb to keep about two thirds of the view frame as substrate and one third water column. Swim at a constant speed approximately 1 meter off the bottom, but not so fast as to lose your buddy or to lose a good visual census of the habitat.

Down-looking

The camera should be in wide-angle mode and infinity focus. Turn on your lights, in this case the visibility does not matter as much because you are going to be close enough to the substrate (subject of focus), so you should always use the lights. Adjust the level of brightness for the lights, again, the third lower level is usually the best level to shoot film with. When your buddy is ready to proceed, swim at a constant rate, holding the camera directly over the transect tape, so that the fishing weight is just skimming the bottom. The transect tape should be in the center of the frame and the numbers on the tape should be visible. This is often a difficult task, because the transect tape is generally twisted and the numbers are difficult to read. In order for the data to be used in a quantifiable manner, it is important that the numbers are legible, therefore do your best to use one hand to flatten out the tape so that the numbers are visible, while holding the camera at the proper distance from the tape with the other hand. You also need to try to keep the transect tape in direct contact with the bottom, rather than lifted off the substrate.

- ? When you have reached the end of the transect tape turn the video to standby.
- ? If time allows, record species of interest with high priority on unidentified species.
- ? After leaving the water, immediately submerge the camera housing in a fresh water bath, or at least keep the housing wet with saltwater until you can reach a freshwater rinse off. NEVER let saltwater dry on the camera housing. When rinsing the camera never apply a lot of water pressure because you could flood the camera. Most camera floodings occur when the housing is being rinsed off! Simply immerse the housing and push all the buttons and move the levers and push all the buttons while the housing is in the freshwater rinse. If you cannot dunk the housing in freshwater....spray lightly keeping the water pressure light and continue to push all the buttons and work the levers to get the saltwater out.

Size Class Structure Of Population

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Sea Urchins :

Purpose

To monitor the direct effects of size-selective foraging by sea otters on sea urchins.

Materials

- ? Calipers
- ? See materials needed for quadrats (above)
- ? As many sea urchins as possible, up to approx. 300 individuals

Personnel

2 SCUBA-equipped observers (for collecting urchins), and 1-2 topside personnel for assistance with measuring and recording.

Time Required

Approximately 5-10 minutes of bottom time (coincident with quadrat sampling). Areas with abundant urchins, low visibility, high algal percent cover, or complex substrate types will take longer. Topside measurement usually requires from 1-30 minutes.

Organisms Sampled

Invertebrates

Strongylocentrotus droebachiensis (green sea urchin)

Strongylocentrotus pallidus (white sea urchin)

Datasheet Header Information

FILL OUT AS MUCH DATASHEET HEADER INFORMATION AS POSSIBLE BEFORE DIVE - [Urchin Datasheet](#)

Methods

It is very important when sampling for size frequency distributions that all individuals in the target population are represented in proportion to their abundance in the population. To eliminate or minimize size-selective bias during collection, all urchins with a minimum test diameter > 10 mm (i.e. *not* recruits) should be collected, in most cases, within fixed bounds (e.g. the 0.25 m² or 1 m² portion of the quadrat) along the length of the transect. Urchins were not collected via invasive means (i.e. turning over rocks/shells or digging into pebble/cobble substrate) in 2000 or 2001, but were collected

during the course of invasive quadrat counts in 2002. In retrospect, an essentially different “population” of small sea urchins was sampled in 2002 that wasn’t sampled in 2000 or 2001 as a result of this decision. This will confound among-year analysis of changes in population size structure at certain sites where a substantial number of urchins were buried in the substrate. If urchins are *abundant*, an adequate sample size may be achieved by collecting them within the 0.25 m² quadrat only, coincident with quadrat sampling. If they are *common* (not *rare* or *abundant*), an adequate sample size should be possible to obtain by collecting them from within the 1 m² quadrat, again coincident with quadrat sampling. However, if urchins are relatively rare, or even common but highly aggregated outside of the particular quadrats sampled, urchins may then be collected from outside of the quadrats to achieve adequate sample size. This is when size-selective bias may influence collections, so extreme care must be exercised to collect all urchins in a given sample area, not just the conspicuous larger individuals. **Note** that this decision must be made by the quadrat counters/urchin collectors prior to (ideally) or early in the dive, so collection effort is equally applied along the length of the transect and not concentrated at one end.

If it becomes apparent during the course of a dive that urchin collections only within quadrats will not be adequate to achieve desired sample size, the next best alternative is to continue quadrats and collections as planned (while still collecting urchins within the 1 m² quadrat), and resume collecting urchins on a subsequent dive. During the next dive(s), urchin collection effort may be distributed equally along the length of the transect by collecting within 1 or 2 m (situation and depth-dependent) of the transect tape. Ideally, resumed collection could be accomplished opportunistically during the course of other tasks (e.g. swath counts), but if that is not feasible, another dive may be necessary.

For each site, *DOCUMENT* which sample unit size was used to collect urchins on the urchin size frequency datasheet. After urchins are collected by divers and brought to the boat, 1-4 people will then measure urchins and one person will record measurements on the Urchin Size Frequency datasheet (filling out all header information, of course). Be sure to clearly write the species name under the appropriate column. Measure and record urchins while still on-site, then return them to the immediate vicinity of the transect. (Urchins were returned to the site only ~50% of the time during the 2000 field season.) **IMPORTANT:** If there are no urchins present to measure at a site, it is still important that a datasheet is filled out with the appropriate header information entered. Simply write the species name in the proper column and “NONE OBSERVED” in large lettering.

We progressively developed these relatively rigid guidelines during and after the 2000 field season, so size-selective bias *may* have occurred to some degree on rare occasions, and non-representative sampling along the length of the transect surely did occur on certain occasions when urchins were rare. However, these deviations were uncommon and most likely negligible in effect. Occasions when urchins were collected under these certain conditions were either noted on the datasheet or should be apparent when the data are queried (e.g. if no/few urchins were counted within quadrats but many urchins were measured).

Whelks:

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Purpose

To monitor the direct effects of size-selective foraging by sea otters on whelks within Glacier Bay.

Materials

- ? Calipers
- ? Collection bags
- ? As many whelks at a site as possible

Personnel

2 SCUBA-equipped observers (for collecting), and 3-5 topside personnel for measuring and recording. (Only 2 are really necessary for the measuring and recording, although it moves faster with more people)

Time Required

Approximately 5-10 minutes of bottom time (coincident with swath sampling). Areas with abundant whelks, low visibility, high algal percent cover, or complex substrate types will take longer. Topside measurement usually requires from 1-30 minutes.

Organisms Sampled

Beringius kennecotti (Kennecott's whelk)
Boreotrophon sp.
Buccinum plectrum
Cryptochiton stelleri (Gumboot chiton)
Fusitriton oregonensis (Oregon triton)
Neptunea lyrata (Lyre Whelk)
Unidentified whelk

Datasheet Header Information

FILL OUT DATASHEET HEADER INFORMATION AFTER DIVE -

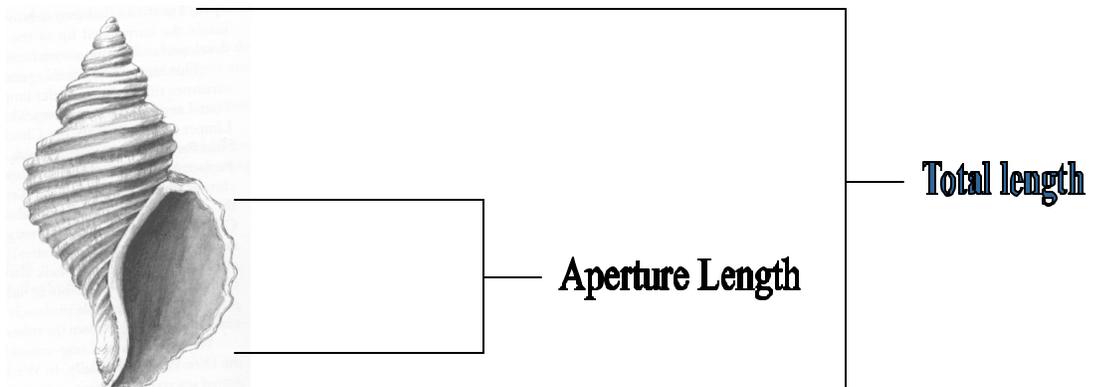
Methods

It is very important when sampling for size frequency distributions that all individuals in the target population are represented in proportion to their abundance in the population. To eliminate or minimize size-selective bias when collecting whelks, all whelks > 10 mm in maximum length (i.e. *not* recruits) should be collected **EXCEPT**

individuals laying/guarding eggs. In most cases, collecting should occur within fixed bounds (i.e. the 1m swath) along the length of the transect. If whelks are relatively rare, or even common but highly aggregated outside of the 1m swath area sampled, whelks may then be collected from outside swath bar limit to achieve adequate sample size. This is when size-selective bias may influence collections, so extreme care must be exercised to collect all whelks in a given sample area, not just the conspicuous larger individuals. Due to the fact that whelks are not abundant at most sites, most collections will be occurring along the length of the entire 50m transect while the divers are running the swaths. Once the divers have finished the swaths and do not have enough whelks, and they have enough air left, they can swim back on either side of the transect about 2m away from the line and collect more whelks all the way back to the origin. All macrofaunal whelk species present should be collected, as well as all sizes present.

For each site, *DOCUMENT* the method used to collect whelks on the whelk size frequency datasheet. It is best if whelks are collected from a known spatial area, as it may provide a more accurate estimate of whelk abundance at sites where whelks are highly aggregated and/or relatively rare. After whelks are collected by divers and brought to the boat, 1-4 people will then measure whelks and one person will record measurements on the Whelk Size Frequency datasheet (filling out all header information, of course). Be sure to clearly write the species name under the appropriate column, and next to the measurement note whether the tip of the shell was broken. Measure and record whelks while still on-site, then return them to the immediate vicinity of the transect. **IMPORTANT:** If there are no whelks present to measure at a site, it is still important that a datasheet is filled out with the appropriate header information entered!!! Simply write the species name in the proper column and “NONE OBSERVED” in large lettering.

Measuring a whelk:



The total length and aperture measurements were recorded for all whelks, even if the tip of the whelk had broken off. In order to obtain the most accurate aperture measurement, we created a system for measuring the whelks, where we drew a line across the beginning of the siphonal canal and measured from the top of the aperture to the bottom of this line (see diagram).

Presence-Absence

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Purpose

To semi-quantitatively characterize the benthic community at study sites by documenting the presence or absence and relative abundance of flora and fauna.

Materials

- ? 2 perceptive eyes (per person)
- ? 1 Presence/Absence datasheet (should not be printed on waterproof paper)
[Presence/Absence Datasheet](#)

Personnel

2-4 SCUBA-equipped observers

Time Required

Coincidental with other tasks

Organisms sampled

All that are present in the subtidal community (see datasheet)

Methods

Observe the presence, absence, and relative abundance of benthic community members to the greatest extent possible during the course of performing other tasks while diving. (Note: also include species that are counted on datasheets but which may occur outside of measured areas into account.) Take notes if necessary and collect organisms that are not readily identifiable. Keep a drybox full of ID books in the boat for this purpose when in the field. Underwater video works well for organisms which are not easily brought to the surface (e.g. anemones and nudibranchs). Upon completion of dives at a site, one datasheet recorder should read off each taxon on the list and all divers should reach consensus for the absence or presence and relative abundance for that entry. We tended to do this task on our way home from a dive site.

IMPORTANT:

- 1) Knowing a particular taxon is *not* present is just as important as knowing that it *is* present, so enter a minus sign for *every* taxon on the list that is not present.
- 2) If none of the observers are familiar with a particular taxon on the presence absence list, enter NA.
- 3) If you observe taxa not on the list, identify to lowest possible taxonomic level and record entry on datasheet. Back at the office, enter the new species into the MS

database (and the date when it was added) and to the presence/absence datasheet so it can be incorporated into the datasheet for the next site sampled.

- 4) Don't delay this task for too long after the dive, because short-term memory fades quickly!

Data Collection Suggestions

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Because the field season in Glacier Bay is limited (except in 2000), and the actual slack window which permits safe diving is so short, it is important to have the methods for each task ironed out and use your time as efficiently as possible. After numerous field tests, we believe we have devised an efficient sampling methodology which incorporated data collection with site set-up and maintenance.

We tried to always allot ourselves plenty of time before the slack tide window to transit to the site (whale water restrictions slow you down), reconnoiter the site with the boat, and suit in, so we were always ready to get into the water when the water looked slack. We generally followed the tide profiles from the Tides and Currents program to determine slack windows, but often the actual conditions at a site differed from the predicted model. Sometimes it seemed, the water would slacken prior to the prediction while other times it seemed later than the prediction, or sometimes there didn't seem to *ever* be a slack window. Bottom line, the current conditions in Glacier Bay are highly variable, and the topside current conditions should always be consulted and honored over the modeled predictions on paper. Through experience and trial and error, we were able to detect relative currents by looking at kelp stipes, looking at the anchor line, and by looking for offshore current lines. Often times, this was not enough. The current always has the potential to be stronger on the bottom than on the surface or vice versa, so always enter the water with caution. Some sites were more unpredictable than others, and we tried to keep diligent notes and enter this information into the database for that particular site.

Once you have deemed the site to be safe for diving and you have properly deployed an ingot with surface buoy (see above section for site establishment), we followed the general protocol below with minor revisions depending on currents, work needed to be done, etc.

- 1) Team 1 enters the water with camera gear, point contact datasheet, transect tape, Pelican float, and gear to establish the distal end of the transect.
- 2) They descend the surface line, swim out the known bearing while buddy 1 conducts forward-looking video, and buddy 2 pays out the transect tape.
- 3) If the transect looks good (good substrate, depth) they send up the Pelican float at the far end. This signals team 2 that is OK to enter the water.
- 4) Team 2 sends the rest of the site maintenance gear down the surface line and gets ready to enter the water.
- 5) Team 1 installs a sand anchor and sub-surface buoy at the distal end. They attach the Pelican float to the handle of the transect tape but *not attached or through* the sand anchor.
- 6) Team 1 swims back while buddy 1 does down-looking video and buddy 2 does Point Contact.
- 7) Team 2 enters the water at the Pelican float (distal end) and conducts Swath counts from 50 meters toward 0 meter.
- 8) At the origin, team 2 conducts as much maintenance as possible (perpendicular, Hobo, etc.)

- 9) Team 1 does second dive conducting Quadrats. When finished, they do as much maintenance as possible.
- 10) Team 2 does second dive to finish up all maintenance required for permanent station set-up.
- 11) All persons collect site line-ups and DGPS coordinates for sites and record in site notebook.
- 12) All persons measure urchins and identify organisms so they can be placed back where they came from *before* leaving site.
- 13) On the transit back to BARCO, all persons go over their own datasheet to make sure they are legible and make sure your buddy can also read them.
- 14) Fill in Presence Absence on the way back to BARCO and complete it *before* you leave the boat.
- 15) And you are done! Have a good night, because you'll get up the next morning and do it all over again.

Appendix C. Field Datasheets

Glacier Bay Information Datasheet

Site Name _____

Site Description _____

Year _____

Date(s) visited _____

Divers _____

LAT (NAD83dd) _____

LON (NAD83dd) _____

GPS Error (ft) _____

Bearing _____

Origin Depth _____

50m Depth _____

Slope _____

Transect Length (m) _____

Transect Purpose _____

Transect # _____

Otter Sightings:

Number of otters sighted in site area _____

Mother/pup pairs _____

Observation Notes: _____

Site Notes:	
-------------	--

Gear Notes:	
-------------	--

Glacier Bay Subtidal Project

BIOLOGICAL NOTES

Site Name _____

Site Description _____

Date(yyyymmdd) _____

LAT (NAD83dd) _____ LON (NAD83dd) _____

Biological Notes

Glacier Bay Presence Absence and Relative Abundance Datasheet										P. 1 of 4	
Transect # _____ Visit # _____		Observers: _____									
Location _____											
Date (YYYYMMDD)		Lat NAD83				Lon NAD83					
Species		Pres/Abs +/-/?	Percent Cover (circle appropriate range)								
			? = Don't know/not observed carefully								
ALGAE			Trace = 0<x<1% (e.g. 1 plant)								
Bacillariophyta											
diatom film			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Chlorophyta (Greens)											
Unid. green blade			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Codium ritteri			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Phaeophyta (Browns)											
Unid Brown Algae			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Unid Brown Algae recruits (<10cm)			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Agarum clathratum (Sieve Kelp)			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Alaria fistulosa (Dragon Kelp)			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Alaria marginata (Ribbon Kelp)			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Costaria costata (Seersucker)			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Cymathere triplicata (Three-ribbed Kelp)			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Desmarestia sp.1 (Wiry Acid Kelp)			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Desmarestia sp.2 (Ligulate Acid Kelp)			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Laminaria saccharina (sugar kelp)			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Laminaria bongardiana			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Laminaria spp.(unidentified)			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Nereocystis luetkeana(Bull Kelp)			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Fucus gardneri (rockweed)			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Rhodophyta (Reds)											
Unid filamentous red			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Unid Fleshy maroon crust			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Unid. Pink coralline crust			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Foliose/bladed Reds (all species combined)			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Unid Red Blade			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Constantinea spp.(Cup and Saucer)			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Opuntiella californica			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Neodilsea borealis (Northern Red Blade)			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Palmaria spp.(Red Ribbon)			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Turnerella mertensiana(Red Sea-Cabbage)			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
Sparlingia pertusa			? Trace	1	1-5	5-10	10-25	25-50	50-75	75-100	
ARTHROPODS			Abundance (circle appropriate range)								
Cancer magister(Dungeness Crab)			? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000	
Cancer oregonensis(Pygmy Rock Crab)			? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000	
Chionoecetes bairdi(Tanner Crab)			? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000	
Elassochirus gilli(Red/Orange Hermit Crab)			? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000	
Elassochirus tenuimanus(Widehand Hermit)			? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000	
Heptacarpus spp.(Broken-back Shrimp)			? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000	
Heptacarpus stylus			? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000	
Hyas lyratus(Pacific Lyre Crab)			? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000	
Telmessus cheiragonus(Helmut Crab)			? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000	
Unid decorator crab			? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000	
Oregonia gracilis(Graceful decorator Crab)			? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000	

Glacier Bay Presence Absence and Relative Abundance Datasheet

Transect #	Visit #	Observers:								
Location										
Date (YYYYMMDD)	Lat NAD83				Lon NAD83					
Solaster stimpsoni(Northern Sun Star)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Pteraster tesselatus		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Gorgonocephalus eucnemius (Basket star)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Unid brittle star		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Ophiopholis aculeata(Daisy Brittle Star)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Strongylocentrotus droebachiensis		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
FISH		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Clupea pallasii(Pacific Herring)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Family Agonidae(Unid Poachers)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Hemilepidotus spp. (Irish Lords)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Leptocottus armatus (Pacific Staghorn Sculpin)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Myoxocephalus polyacanthocephalus (Great Sculpin)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Hemitripteris bolini (Bigmouth Sculpin)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Enophrys bison (Buffalo Sculpin)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Family Hexagrammidae (Unid. Greenling)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Hexagrammos stelleri (Whitespotted Greenling)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
H. decagrammos (Kelp greenling)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
H. octogrammus (masked greenling)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Ophiodon elongatus (Lingcod)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Family Pholidae (Unid Gunnel)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Pholis laeta (Crescent Gunnel)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Unid Prickleback		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Lumpenus sagitta (Snake Prickleback)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Platichthys stellatus (Starry Flounder)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Unid. Right eye Flatfish		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Unid. Left eye Flatfish		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Family Gadidae (cod, etc)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Sebastes YOY/Unid. YOY Rockfish		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Unid. YOY		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Pacific Cod YOY		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Searcher		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Sebastes. Spp (rockfish)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Unid. Large Sculpin (>4")		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Unid. Small Sculpin (<4")		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Eumicrotremus orbis (Pacific Spiny Lump sucker)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Aptocyclus ventricosus (smooth lump sucker)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Bathymaster signatus		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Ronquilus jordani (Northern Ronquil)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
MOLLUSCS		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Placiphoralla rufa (Predatory chiton)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Cryptochiton stelleri(Giant Pacific Chiton)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Tonicella lineata(Lined Chiton)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Octopus doffeini		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Acmaea mitra(Whitecap Limpet)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Calliostoma annulatum		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Calliostoma sp.		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Cryptonatica affinis(Arctic Moon snail)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000
Fusitriton oregonensis(Oregon triton)		?	1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000

Glacier Bay Presence Absence and Relative Abundance Datasheet											P. 4 of 4
Transect #	Visit #	Observers:									
Location											
Date (YYYYMMDD)	Lat NAD83	Lon NAD83									
Neptunea lyrata	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Buccinum sp.	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Boreotrophon spp.	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Beringius kennicottii	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Trichotropis cancellata (Checked Hairysnail)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Unid whelk	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Unid moon snail	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Pododesmus macroschisma (Falsejingle)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Suborder Aeolidacea(Aeolid Nudibranchs)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Suborder Dorid(Dorid Nudibranchs)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Triopha catalinae (Catalina triopha)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Diaulula sandiegensis (Ringed Doris)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Melibe leonina (Lion Nudibranch)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Dendronotus rufus (Red Dendronotid)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
D. albus (White spotted dendronotid)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Tochuina tetraquetra (Tochni)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Mytilus spp. - LITTER	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Modiolus modiolus(Horse mussel) - LIVE	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Modiolus modiolus(Horse mussel) - LITTER	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Mya spp. (truncata or arenaria) - LIVE	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Mya spp. (truncata or arenaria) - LITTER	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Clamys spp.(Scallop spp.) - LIVE	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Clamys spp.(Scallop spp.) - LITTER	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Clinocardium nuttalli(Nuttall Clam) -LITTER	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Serripes groenlandicus - LIVE	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Serripes groenlandicus - LITTER	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Prototheca staminea - LITTER	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Saxidomas gigantea - LITTER	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Mactromeris polynyma - LIVE	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Mactromeris polynyma - LITTER	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Macoma spp. - LITTER	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Clam siphons	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
OTHER											
Halocynthia aurantia (Sea Peach)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Unid barnacle spp.	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Unid hydroids	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Unid worm	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Family Spirorbidae (Dwarf tubeworm)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Family Serpulidae (Calcareous tube worm)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Unid sponges	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Stylissa stipita (Vase Sponge)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Neoesperiopsis digitata	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Hippodiplosia insculpta (Fluted Bryozoan)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Microporina borealis (Orange-stalked Bryozoan)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Membranipora membranacea (Kelp Lace)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Terebratalia transversa (Lampshell)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Sea Lion	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			
Humanus idioticus (Glacier Bay diver)	? 1	2-5	5-10	10-25	25-50	50-100	100-500	500-1000			

Glacier Bay Subtidal Quadrat Datasheet

Transect # _____ Visit# _____

Date (yyyymmdd) _____

Location _____

Diver _____

Hour _____

Left / Right

Buddy _____

	Q1	Q2	Q3	Q4	Q5
Start Mark	()	()	()	()	()
clam siphons 1/4m					
<i>Modiolus</i> 1/4m					
sea urchin 1/4m					
sea urchin 1m					
sea urchin 1/4m <i>Invasive</i>					

Substrate (1m quadrat)					
	Q1	Q2	Q3	Q4	Q5
Primary (>50%)					
2ndary (10-50%)					
Modifier 1 <10%					
Modifier 2 <10%					
Modifier 3 <10%					
Modifier 4 <10%					
Interstitial					
Underlying					

	Q1		Q2		Q3		Q4		Q5	
	Juv. (10-40cm)	Adult (>40cm)								
Quadrat (1 meter²)										
Brown#(Stripes/%Cover)										
Unid Brown algae										
Kelp recruits (% cov)										
<i>Alaria fistulosa</i> (floats)	/	/	/	/	/	/	/	/	/	/
<i>Nereocystis luetkeana</i>	/	/	/	/	/	/	/	/	/	/
<i>Agarum</i> cl. (perforated)	/	/	/	/	/	/	/	/	/	/
<i>Laminaria bong.</i> (big)	/	/	/	/	/	/	/	/	/	/
<i>Laminaria</i> sacc. (sugar)	/	/	/	/	/	/	/	/	/	/
Unid. <i>Laminaria</i> spp.	/	/	/	/	/	/	/	/	/	/
<i>Costaria</i> co. (5-ribbed)	/	/	/	/	/	/	/	/	/	/
<i>Cymathere</i> tr. (3-ribbed)	/	/	/	/	/	/	/	/	/	/
<i>Desmarestia</i> spp. (wiry)										
<i>Desmarestia munda</i>										
<i>Fucus gardneri</i>										
Reds (# Stripes / % Cover)										
Unid coralline red crust										
Unid maroon crust										
Unid filamentous red										
<i>Sparlingia pertusa</i>	/	/	/	/	/	/	/	/	/	/
Unid red blade	/	/	/	/	/	/	/	/	/	/
<i>Palmaria</i> spp.	/	/	/	/	/	/	/	/	/	/
<i>Constantinea</i> sp.	/	/	/	/	/	/	/	/	/	/
<i>Turrerella mertensiana</i>	/	/	/	/	/	/	/	/	/	/
<i>Opuntella californica</i>	/	/	/	/	/	/	/	/	/	/
Unid. green blade										
Diatom Film										

BO under (>25cm) head size or greater **BE** drock

CO bble (6-25cm) billiard ball to head size **S/it**

PE bble (0.4-6cm) pea size to billiard ball **CL ay**

GRanule (0.2-0.4cm) bb to pea size

Coarse **S**and pinhead to bb size

Fine **S**and salt/sugar-pinhead

Shell **D**ebris (shell fragments)

Shell **L**iter (large enough for settlement)

Count all algal species, including *Alaria marginata*,

Neodilsea borealis, *Codium Ritteri*

% Cover: 0, <1, 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100

Glacier Bay Subtidal Urchin Size Frequency Datasheet

Date _____
 Hour _____
 Diver/s _____
 Recorders _____
 Species _____

Visibility _____
 Location _____
 Transect # _____ Visit # _____
 Lat.NAD83 _____
 Long.NAD83 _____
 Collection Method _____

	Length (mm)							
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								

Glacier Bay Subtidal Whelk Size Frequency Datasheet

Date _____
 Hour _____
 Diver/s _____
 Recorders _____
 Collection Method _____

Visibility _____
 Location _____
 Transect # _____ Visit # _____
 Lat.NAD83 _____
 Long.NAD83 _____

	Species	Length (mm)	Aperture	Species	Length (mm)	Aperture	Species	Length (mm)	Aperture
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									

Glacier Bay Subtidal Whelk Size Frequency Datasheet

Date _____
 Hour _____
 Diver/s _____
 Recorders _____
 Collection Method _____

Visibility _____
 Location _____
 Transect # _____ Visit # _____
 Lat.NAD83 _____
 Long.NAD83 _____

	Species	Length (mm)	Aperture	Species	Length (mm)	Aperture	Species	Length (mm)	Aperture
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									



Appendix D. 2001 Preliminary Analysis

Preliminary Analysis and Evaluation of Sea Otter Effects / Subtidal Monitoring Study

Glacier Bay National Park

DRAFT

Prepared by
Michael Donnellan
Fall 2001



National Park Service
Glacier Bay National Park
One Park Rd.

Summary and General Considerations:

The sampling program appears to be on the right track, but will need to be re-analyzed after more data have been collected during the 2002 field season. Preliminary analyses indicate that the most important species sampled (i.e., urchins, sea stars, kelps) are well characterized at sites where densities are moderate to abundant. Not surprisingly, relatively rare species that are counted in swaths have highly variable counts between years, and implementation of an improved sampling method in lieu of swaths should increase precision of data.

The 2000 season should essentially be considered a “pilot study”, as many of the techniques were being worked out during that time. (To put the amount of time for this pilot study into perspective, the Channel Islands Subtidal Monitoring Program pilot study took 5 years to accomplish.) Much of the data from 2000 are still usable, but inconsistencies in collection techniques for some species preclude critical evaluation of this study to detect temporal changes in abundance of targeted organisms. Furthermore, the inconsistencies in sampling conventions for some species prevent meaningful evaluation of what species have the greatest likelihood of detecting change and should continue to be monitored.

Several issues are not addressed in these preliminary analyses, including evaluations of substrate measurement, size frequency data for urchins, sea stars, and whelks, video footage, and species presence/absence data. Species diversity indices for each site should be calculated, and multivariate analysis of community similarity (e.g., nMDS) should be explored.

INTRODUCTION

In conjunction with the Alaska Biological Science Center (ABSC), the National Park Service (NPS) initiated an ecological study in Glacier Bay National Park (GLBA) to assess the effects of re-colonization by sea otters on the benthic marine community, and also to provide pilot data for an inventory and monitoring program of subtidal resources within the park.

Ecological data have been collected for a variety of organisms in 2000 and 2001, and preliminary analyses of these data have been performed. The objectives of this report are to: 1) summarize preliminary results from the 2000 and 2001 field seasons, 2) evaluate the performance of the sampling protocol with respect to precision and accuracy of population parameter measurements for the purpose of detecting change, 3) assess the applicability of the data being collected to the study goals, and 4) to provide recommendations for improvement to meet these goals.

METHODS

An important objective of the GLBA study is to describe the benthic marine communities occurring within the shallow marine habitats of lower-mid Glacier Bay. To accomplish this goal, we initiated a preliminary inventory of conspicuous macro-invertebrates and macro-algal species, and have begun the process of quantifying the spatio-temporal distribution, abundance, and the natural limits of variation for population parameters of key indicator species. Four techniques have been used to these ends, including data collection using 20 stratified random 1mx1m quadrats placed along a 50-meter transect, 20 contiguous 1mx5m

quadrats, a post-dive species checklist to document the presence/absence and relative abundance of 178 taxa opportunistically observed in the field, and underwater video footage.

Swaths

In 2000 and 2001, individuals of specified indicator species were sampled by 2 divers, each collecting data in ten contiguous 1m x 5m quadrats (hereafter called “swaths”) on opposite sides of a 50m transect tape. A consequence of this sampling strategy was that the spatial replicates were not statistically independent (i.e. “pseudoreplicates”) - therefore it was not possible to assess the precision of density estimates at a study site within a given year.

Therefore, the counts for each species within each swath were summed for the entire site in a given year and presented as a single number without an estimate of variability. Instead of summarizing results and performing power analyses for each of the approximately 30 species for which swath data have been collected (this would require 20 sites x 30 species = 600 analyses!), I combined counts of similar functional groups for comparison. When standards for counting individuals of a particular species were not different between 2000 and 2001, and a species was present with moderate to high abundance, I used the two temporal replicates per site (one from each year) to calculate the predicted sample size necessary for a 2-sample t-test to detect a 50% and 90% change with 80% power and $\alpha = 0.05$. Power analyses for each group are summarized below, and detailed versions are included in Appendix

SWATH_POWER_ANALYSES.

Small Sea Stars (*Henricia* spp., *Crossaster papposus*, *Mediaster aequalis*, and *Pteraster tesselatus*)

To avoid equating large sea stars such as *Pycnopodia* with small sea stars like *Henricia*, I grouped sea stars into large and small categories for analysis. Methods for data collection were slightly inconsistent in 2000 and 2001 because the size class cutoff for enumeration of “recruits” vs. “non-recruits” was imprecise and open to observer interpretation. It was expected that a clear size difference would be evident between newly recruited individuals and juveniles, but this was not the case, and no obvious distinction among size classes was apparent.

Counts of small sea stars by site and year are shown in Figure 1. Power analyses for E2 Hard, E3 Hard, E4 Hard, and W5 Hard estimate that 80% power to detect a 50% change in mean abundance would be achieved with 2, 4, 10, and 7 temporal replicates (i.e. years) per period (i.e. pre-otter and post-otter), respectively. To detect a 90% change in abundance would probably take 2, 3, 4, and 3 temporal replicates per period, respectively. I suspect statistical power could be bolstered for small sea stars by increasing the precision of the density estimates at each site (e.g., by collecting density data in at least 5-10 large quadrats instead of one large 2m x 50m quadrat) and eliminating the size class distinction and counting all individuals. Sea stars are rarely very abundant, and it would not increase the workload substantially to count each individual. Size frequency data collected topside should complement these data well because large individuals would not be equated with smaller juveniles or recruits.

Large Sea Stars (*Solaster* spp., *Pycnopodia helianthoides*, *Orthasterias koehlerii*, *Stylasterias forreri*, *Evasterias troschelii*, and *Leptasterias polaris*)

As with small sea stars, the size class distinction between recruits and non-recruits was imprecise and somewhat subjective, and among-observer interpretation was probably an important source of variability for count data during 2000 and 2001. Nevertheless, power analyses were performed for the nine sites in which the mean number of sea stars (between the two years) per site exceeded five (Figure 2). For the sites tested, 80% power to detect a 50% change in mean abundance would probably require 2 years (i.e. temporal replicates) of sampling per period at 3 sites, 3-4 years of sampling at 2 sites, 7-13 years at 2 sites, and 20-25 years at 2 sites. To detect a 90% change in mean abundance with 80% power would require 2 years at 4 sites, 3 years at 2 sites, and 5-9 years for 3 sites. I recommend the same measures as described for small sea stars to increase the precision of count data and boost statistical power to detect changes.

Large Whelks: (*Fusitriton oregonensis*, *Neptunea lyrata*, *Buccinum* spp., *Boreotrophon* spp., *Beringius kennicotti*, and miscellaneous unidentified whelks)

Unfortunately, these species were counted inconsistently until June 2001 (e.g., E3 Soft 2000 vs. 2001), and the data were therefore not analyzed. The size class distinction made by observers prior to the establishment date of the 6 cm size class cutoff was subjective, and among-observer variability may have been high. Although counts between most sites except E3 Hard appear similar visually (see Figure 3), I suggest that pilot data from 2000 season be used cautiously, if at all. As of June 2001, the size class cutoff for large whelks was set at 6 cm (total

length). This cutoff was chosen because small whelks may be very abundant, time consuming to enumerate, and relatively cryptic and difficult to observe in complex habitats.

Large Sea Cucumbers (primarily *Cucumaria miniata* and *C. frondosa*, but also trace numbers of *Synallactes challengerii*)

Counts of sea cucumbers were extremely different between 2000 and 2001. This trend was probably real and not due to a sampling artifact - sea cucumbers are relatively large and easily enumerated, but may be inconspicuous if they have been disturbed immediately prior to sampling, whereupon they can contract into crevices. If variability was high among sites and between years, I would probably come to the conclusion that the animals were probably disturbed by the process of laying the transect tape out and subsequently contracted out of site into crevices, but I think that this is highly unlikely given the consistent trend of higher counts in 2001. Perhaps the variation in counts may be due to seasonal migrations along a depth gradient, or possibly complete contraction by the cucumbers into crevices when feeding conditions are not ideal (e.g., in the Fall, when sites were sampled in 2000). It will be interesting to calculate the mean density of cucumbers when they are surveyed again in the summer of 2002.

Metridium spp. (*M. giganteum* and *M. senile*)

As shown in the Figure 5, counts of *Metridium giganteum* and *M. senile* were generally low on average for most sites, except for E1 Hard, E5 Soft, and W3 Soft. The variability between years of counts at E1 Hard and W3 Soft was possibly a real change in density, as *Metridium* spp. are not easily mistaken for any other anemone, and they are

reported to be fairly mobile. However, some of the variability at E1 Hard may be spatial, because one end of the transect could not be found and had to be re-established in a slightly different location. This could explain the variation if the original transect location included a large boulder with a large *Metridium* aggregation. The video footage should be referenced. Because *Metridium* are often highly aggregated, the difference may be solely due to the inadequacy of the sample unit size, configuration, or number for sampling highly aggregated organisms. Power analyses were performed for the two sites in which the mean number of *Metridium* spp. per site was relatively high. At the sites tested, 80% power to detect a 50% change in mean abundance would require 18 temporal replicates at E1 Hard and 9 replicates at W3 Soft; to detect a 90% change would require 9 and 4 replicates, respectively.

Anemones not including *Metridium* spp (*Urticina* spp., *Cribrinopsis fernaldi*, *Stomphia coccinea* (trace), and miscellaneous smaller anemones that are difficult to identify in the field)

A size class cutoff of 3 cm was established at some point during the 2000 season (date unknown), and among-observer interpretation prior to this date was probably inconsistent. Extremely high counts of an unidentified anemone are largely responsible for the large difference between years at E2 Hard and E4 Hard (see Figure 6). From personal experience, I recall that this unidentified anemone frequently measures approximately 3 cm diameter across the column, so it is likely that inconsistent counts of this species are the reason for such strong differences between years at these sites. I suggest that the protocol be modified so as not to include these small, cryptic, unidentified anemones in the future, possibly by increasing the size class distinction to 5-6 cm.

With the exception of one of the unidentified anemones, these anemones are usually found on rocky substrate, so it is unlikely that mean density would fluctuate widely if the rocky habitat on which they attached remained constant. Again, some of the variability at E4 Hard may be spatial, because one end of the transect could not be found in 2001 and had to be re-established in a slightly different location. Power analyses were performed for the five sites in which the mean number of anemones per site exceeded ten individuals. Two of the sites required only 2 temporal replicates per period to detect a 50% change in abundance, one site required 5 replicates, and 2 sites needed 28 replicates per period. To detect a 90% change in abundance, 3 sites needed between 2-3 replicates per period, and 2 sites required 10 replicates per period.

Non-hermit Crabs (*Hyas lyratus*, *Cancer magister*, *Chionoecetes bairdi*, unidentified Decorator crabs, *Paralithodes camtschaticus*, and *Telmessus cheiragonus*)

Where crabs were present, counts were highly variable between years at all sites except one (Figure 7). The crab species counted most often was the lyre crab *Hyas lyratus*, *Telmessus* was an occasional visitor from the shallower subtidal zone, very small *Paralithodes* were occasionally encountered, *Chionoecetes bairdi* juveniles were occasionally observed, and *Cancer magister* was very rarely observed. Sample unit size was much too small to adequately sample the larger crabs *Cancer magister* and *Chionoecetes bairdi*, but I think that sampling these species is outside of the scope of study and should be left to the MADS project. The observed variability between years may or may not be real, as *Hyas* were counted

inconsistently because of size class inconsistency until October 10, 2000 (after which 12 sites were sampled). These data will not be analyzed until after the 2002 season.

Elassochirus spp. (*E. tenuimanus* and *E. gilli*)

As with the crabs described above, counts of *Elassochirus* spp. were inconsistent until mid-season in 2000 (see Figure 8) because of a subjective size class distinction, so I will not analyze these data until after the 2002 season. Various factors conspire to make *Elassochirus* sp. occasionally difficult to sample adequately: 1) they may be cryptic, depending on individual size, habitat complexity, and whether they have been disturbed or not (because they can contract their entire body into a shell); 2) *E. tenuimanus* may be confused with certain *Pagurus* spp. if not inspected carefully; and 3) because of their propensity to contract, it's difficult to measure individuals to determine whether or not to count them. Despite these problems, it is desirable to quantify the density of large hermits such as *Elassochirus*, as they are an occasional source of food for sea otters (Bodkin, pers. comm.), and may play an important role in the community. I suggest that we continue to count *Elassochirus* during the 2002 field season and re-visit this issue thereafter.

Large Hermits (*Elassochirus* spp., *Pagurus* spp.)

For similar reasons as described for *Elassochirus* spp., counts of large hermits (*Pagurus* spp. and *Elassochirus* spp.) were quite variable (Figure 9), and will not be analyzed until after the 2002 field season.

Swath Summary

The original rationale for counting organisms in consecutive swaths was that the organisms targeted were sufficiently rare and “clumped” in distribution that a much larger sample unit size was necessary (relative to 1m x 1m quadrats) to adequately sample them. As a result, counts of individuals in contiguous swaths had to be summed for a particular year at a particular site, and that value was considered the temporal replicate. While this sampling strategy was/is adequate to meet the goals of this study, it was/is not ideal because: 1) no estimate of spatial variability, and 2) in general, large quadrats in which many organisms are counted have lower statistical precision than a larger number of smaller quadrats comprising the same total spatial area.

Given these two points, I strongly recommend that the swath technique be reconfigured in 2002 to provide an estimate of spatial variability and measure of precision. For example, each diver could sample organisms that are currently counted in swaths within ten randomly spaced quadrats 2.5m long (along-transect) x 2m wide (perpendicular to transect) on each side of a 50m transect tape. The ten quadrats sampled by each diver could be contiguous with the quadrats sampled by the other diver and the counts combined, resulting in a total of ten independent 10m² quadrats. According to this scenario, a total of 100m² would be sampled – equal to the spatial area currently sampled, which has been found to be ideal logistically at most sites for one tank of air. Using this technique, spatial replication could be achieved without sacrificing spatial coverage. Although this proposed quadrat size surely will not be large enough for rare species or groups of species (of which there are many), the counts for each quadrat could be summed to provide one value that could be used as a temporal replicate (as is

presently done with swath data). The relatively low numbers of most species at most sites, as shown in the graphs above, would probably necessitate lumping counts from the 10 quadrats together for many comparisons - but the extra precision gained from increasing sample size from 1 to 10 will be invaluable for some comparisons.

Other quadrat configurations could possibly be employed to serve the same ends of spatial replication, but the potential for confounding sampling is great because of the strong gradient in species composition and abundance with depth, coupled with the steep slope present at some study sites. Sites are located in -30 feet MLLW, which is also the average depth of the lower edge of the canopy-forming kelp community, and if long, thin band transects were oriented perpendicular to the transect (which runs along the -30 ft contour), very different habitats would be sampled. This would result in a great deal of within-site variability that would probably swamp the ability to detect change. Although previous ecological research has shown that long, thin quadrats are generally better for sampling than other shapes that have identical spatial area (because of sampling across habitat heterogeneity), the problems associated with this configuration would probably outweigh the benefits in this case

As summarized above and detailed in Appendix SWATH_POWER_ANALYSES, statistical power to detect a 50% change in mean temporal abundance was generally low for most species groups at most sites. However, power to detect 50% change in 4 years or less per period (i.e. pre-otter or post-otter) was good for large sea stars at 5 sites out of 9 sites analyzed, as well as small sea stars at 1 site of the 4 analyzed, and anemones at 2 sites out of 5. Power to detect 90% change in abundance for these species groups at the same sites was generally attainable in 2-3 years. Overall, statistical power was generally low because of small

sample size (n=2 temporal replicates), inconsistent counts between years of some species, and the likelihood of low precision of abundance estimates as a result of the sampling design (i.e. sampling 1 large quadrat instead of several smaller ones). More informative analyses will be possible after the 2002 field season, when 2-3 temporal replicates will have been sampled in a consistent fashion with respect to season and size class distinction (although sample unit size will be different in future sampling – but counts from individual quadrats may be summed for comparability).

As referenced in the NPS study plan, sea otters will probably cause a decrease in the density/abundance of prey populations in Glacier Bay on the order of 50-90%. However, it is unknown what the magnitude of their indirect effect will be on benthic invertebrates that are not food items. Given unlimited time and resources, we could design a sampling program to detect very small changes in abundance for many species – but financial and logistical constraints require us to determine what level of change we think is biologically meaningful and desire (and afford) to be able to detect. Obviously, the smaller the change we desire to detect, the greater the cost of the study or the greater the compromise for measurement of some other parameter. This should be resolved after analyses and evaluation of 2002 field season data. It's generally accepted that most ecological studies have done pretty well if a difference in abundance of 50% can be detected, so I think that is a realistic goal to strive for.

Quadrats

In 2000 and 2001, indicator species of algae and animals were sampled by 2 divers collecting data in ten stratified random quadrats (2 per 10m segment) on opposite sides of a

50m transect tape. Algae and sea urchins were sampled in a 1m x 1m quadrat, and sea urchins, *Modiolus modiolus*, clam siphons, and shell litter (otter-cracked and non-otter cracked) were sampled in a 0.25m X 0.25m quadrat. Unlike the swath method, each of the 10 quadrats was an independent spatial replicate, therefore were averaged for a more precise estimate of the actual population density. As was the case with swaths, the number of possible comparisons among different species, sites, and years was extremely large, so I've summarized algal species by group (e.g., red foliose algae, kelps, red crustose algae), but did analyze urchins and *Modiolus* individually. Detailed summary statistics for each group are presented in the appendices and are summarized below.

Sea Urchins:

The sea urchin *Strongylocentrotus droebachiensis* is one of the most important organisms sampled by this study because of its importance as a prey item for sea otters, numerical abundance throughout the bay, and because of its role as a structuring agent of algal communities. Therefore it is imperative that we monitor this species well. Urchins were counted in 0.25 m² quadrats during 2000 and 2001 (Figure 11), *and* in 1m² quadrats for 2001 and part of 2000 (Figure 10). Summary statistics and analyses are detailed in Appendix URCHIN-DENSITY.

To test whether urchin densities were different at a given site between years, I ran a series of 2-sample t-tests for all but seven sites in which urchins were either not present, at very low densities, or data were not available for both years. When data from 1m² quadrats were available for both years, I used those data for testing – otherwise data from 0.25m quadrats

were used. Of the 13 sites tested, three sites – E1 Soft, E2 Soft, and W3 Soft – were significantly different between years. The consistency of density estimates between years at all other sites suggest that these differences are not the result of a sampling artifact, and given the simplicity of counting urchins in habitats without complex substrate, I doubt that these differences are due to observer error. While the difference between years at E1 Soft is probably due to random spatial variability of urchins occurring at low densities, the substantial decrease in density at E2 Soft and increase from 0 to an average of 4 urchins per 1 m² at W4 Soft is interesting, and perhaps due to seasonality of movement patterns.

Assumptions for parametric statistical testing (i.e. normality and equal variance; independence was assumed) were tested when data from 1m² quadrats were used in the analysis. Assumptions were met for approximately 50% of the tests, and it is likely that the failure rate was greater when data from 0.25m² quadrats were used (assumptions were not tested for 0.25m² data).

To get an indication of how well urchins were being sampled in 0.25m² quadrats relative to 1m² quadrats, Figure 12 shows extrapolated urchin density estimates per 1m² derived from counts in 0.25m² quadrats versus actual data from 1m² quadrats. No significant difference is evident between predicted and actual counts, which indicates that sampling sea urchins can be improved logistically without sacrificing accuracy by counting individuals in 0.25m² quadrats only. However, inspection of count frequency histograms for 0.25m² quadrats versus 1m² quadrats in Appendix URCHIN reveal “normal” Poisson frequency distributions at many sites for urchin counts in 1m² quadrats, but less-desirable negative binomial distributions for counts in 0.25m² quadrats. The negative binomial distributions are not problematic for the primary study

goal of detecting temporal change at sites before and after sea otters. This is because *temporal* replicates will be used – therefore the annual mean values of urchin density at a site should exhibit a “normal” Poisson distribution to meet the assumptions of statistical testing, not necessarily the actual count values used to calculate the annual mean.

Using the data from 0.25m² quadrats, I used two temporal replicates (one from each year) at all sites where urchins were present to calculate the sample size necessary for a 2-sample t-test to detect a 50% and 90% change with 80% power and alpha = 0.05. Detailed results are shown in the table below:

Site	# temporal replicates estimated necessary to achieve power of:	
	50%	90%
E1Hard	3	2
E1Soft1	19	7
E2Hard1	3	2
E2Soft1	24	9
E3Hard1	15	6
E3Soft1	n.a.	n.a.
E4Hard1	10	4
E4Soft1	n.a.	n.a.
E5Hard1	n.a.	n.a.
E5Soft1	n.a.	n.a.
W1Hard1	5	3
W1Soft1	2	2
W2Hard1	54	17
W2Soft1	3	2
W3Hard1	n.a.	n.a.
W3Soft1	n.a.	n.a.
W4Hard1	19	7
W4Soft1	n.a.	n.a.
W5Hard1	3	2
W5Soft1	n.a.	n.a.

Statistical power to detect a 50% change in mean density was very good for each of the four sites in which urchin densities were greater than 4/ 0.25m², with change being detectable in

2-3 years per period. However, power was low at most of the other sites with lower densities except W5 Hard, and the number of replicates needed was highly variable. Power to detect a 90% change with 4 or less temporal replicates per period was achievable for seven sites of the twelve sites tested.

Overall, power was good for five of the eight sites with an average of two or more urchins per 0.25m² quadrat, indicating that the sampling methods are generally well suited for sampling sea urchins at moderate to high densities. Furthermore, power may increase when data from 2002 are included because data will have been collected during the same time of year in 2001 and 2002.

The evaluation of the Channel Islands National Park subtidal monitoring program by Ecometrics in 1996 strongly suggested that invasive sampling methods should be used to enumerate cryptic sea urchins occurring within complex habitat. I recommend that this study follow that advice as well. A quick and dirty comparison of urchin densities at one of our study sites characterized by a complex substrate of pebbles and cobbles revealed a two- threefold difference in the density of urchins. Assuming that urchins are not sampled in 1m² quadrats in 2002, extra time would be available for conducting invasive sampling, perhaps in the 0.25m² quadrat after surface-dwelling urchins have been counted and recorded.

Modiolus modiolus

The Northern horse mussel *Modiolus modiolus* is an epibenthic bivalve that may form dense aggregations, which may in turn be a locally important food supply for sea otters.

Modiolus is very patchy in space, and apparently prefers habitats exposed to strong currents –

which is a habitat our original site selection process was biased against. Therefore, it is not surprising that *Modiolus* is absent from most of the 20 study sites (Figure 13).

Because no data were collected during 2000 for two sites at which *Modiolus* was present in moderate to high abundance (E5 Hard and W3 Hard), analyses were performed solely for W1 Hard (Appendix MODIOLUS). Results of a 2-sample t-test indicated that the mean density was not significantly different ($P=0.054$) at W1 Hard between surveys. Power to detect change at this site was low - approximately 26 and 9 temporal replicates would be necessary to detect a 50% and 90% change in density, respectively. Assuming spatial variability of *Modiolus* is not excessive at E5 Hard and W3 Hard in 2002, we will only have two sites where *Modiolus* is monitored effectively. Time permitting in 2002, I suggest we consider sampling *Modiolus* at another location where they are known to be (perhaps Francis Island?)

Clam Siphons:

Inconsistencies between conventions for counting clam siphons between 2000 and 2001 prevent meaningful comparisons at this time. During field data collection in 2000, miscellaneous holes thought to *possibly* be contracted clam siphons were counted, hence the great differences in density between many sites between years (Figure 14). This convention was changed in 2001 to only count visible siphons, so data from 2001 will not be analyzed until after the 2002 season. Assuming clam siphons are correctly identified, another major source of variability in siphon counts is due to underestimation of density due to contraction of the siphon by the clam when disturbed. Regardless, the utility of these data have been questioned because

the density of clam siphons have not been shown to correlate well with actual clam densities according to a preliminary study by Bodkin et al (pers. comm.). However, these counts could be used as a measure of relative clam density over time if care is taken to not disturb the animals immediately prior to sampling, and siphons are correctly identified.

Non-Otter-cracked Shells and Otter-cracked shells:

Data have been collected on the density of apparently otter-cracked shells primarily as a proxy for inferring the onset of sea otter foraging in the vicinity of existing study sites. These data by themselves shouldn't be used for making the judgment about whether an area has been "impacted" or not, but should be used in conjunction with information on sea otter distribution and the presence of mother/pup pairs. To date, four pieces of shell litter that had apparently been cracked open by sea otters have been observed within quadrats at only one site, W5 Hard (a site that also has the highest density of sea stars, and in the vicinity of sea otters that have been observed foraging). These data should continue to be collected in the future, but the litter should be searched for and counted in a much larger quadrat (i.e. swaths or the technique that replaces swaths) than the 0.25m² quadrat currently sampled. I also suggest that in the future the species of bivalve that has been cracked open be noted.

Changes in the density of shell litter, whether caused by otters or not, may have important ecological consequences. For example, sea stars may prey heavily on bivalves, and the resulting shell litter may provide hard substrate suitable for recruitment of algae. If an event like this occurred coincident with sea otter colonization of an area, interpretations could be confounded if shell litter other than that obviously caused by sea otters was not considered.

Therefore, it may be important to monitor this variable. Presently, recent shell litter that hasn't obviously been cracked open by sea otters is counted within 0.25m² quadrats. However, the data collected to date are highly variable among sites and between years within a site, so I suggest that in the future this parameter should be incorporated into substrate assessment and not explicitly counted within quadrats.

Kelps:

The “kelps” are a group of large brown algae that for our purposes primarily includes the surface canopy-forming *Nereocystis luetkeana* and *Alaria fistulosa*, and the understory kelps *Costaria costata*, *Cymathere triplicata*, *Laminaria* spp., and *Agarum clathratum*. In Glacier Bay, *Nereocystis* and *Alaria* form surface canopies in shallow water (i.e. –30 feet MLLW) with suitable hard substrate, and are generally found in areas of moderate to strong currents. In the limited amount of time I have personally spent in the shallow kelp forests, I've observed an understory kelp assemblage that includes *Costaria costata*, *Cymathere triplicata*, *Laminaria* spp., and *Agarum clathratum*. *Laminaria* and *Agarum* are the species that are encountered most frequently at the study sites, and these species tend to occur in both high- and low- current areas, although stipe density and percent cover are much higher in areas of strong current flow (e.g., E4 Hard in the Sitakaday narrows, and E5 Hard at Lester Point). As shown in Figures 15 and 16, and detailed in Appendix KELP, kelps presently occur at only 3-4 sites above trace levels. At one of these sites, E5 Hard, *Laminaria* spp. are the dominant kelps, and these plants are anchored by their holdfasts to dense aggregations of *Modiolus*. In contrast to expected general trends, kelps would probably decrease substantially

at this site if sea otters decimate the *Modiolus* bed. However, foraging by otters is generally expected to result in increased kelp abundance at most sites via reduction of grazer populations and increases in shell litter deposits that may facilitate recruitment. Therefore, the precise and accurate estimation of the present and future abundance of kelps is a very important objective for this study. The conservative approach is to ensure that kelps are measured adequately at present levels of abundance (where they occur at more than trace levels) to maximize the likelihood that they will be sampled satisfactorily at the expected levels of greater abundance in the future.

Percent cover dramatically increased at E4 Hard during 2001 (Figure 16), but Figure 15 reveals that the stipe density at that site was similar between 2000 and 2001. This is clear evidence of seasonal variability in the percent cover of kelp blades but not the number of adult individuals. *Laminaria* spp., kelps with a perennial life history that are the dominant algae at this site, exhibited blade senescence and abscission during the waning phase of the growing season in 2000, and the same individuals re-sprouted blades that were measured in 2001. This case emphasizes the need to consistently sample kelp (and algae in general) during the same time of the year to reduce the “noise” of environmental variability. No seasonal effect was apparent at E3 Hard, but inspection of raw data indicate that the percent cover of *Agarum*, which was the dominant species with respect to percent cover during the 2000 survey, was reduced in 2001 with a corresponding increase in *Laminaria* spp., thereby in part masking the seasonal effect. The relatively largest increase in stipe counts occurred at W1 Hard, where inspection of raw data reveals *Nereocystis* increasing substantially in density. Although this trend seems to be even more pronounced at E4 Soft in 2001, a large portion of the increase in percent cover was

because of a large piece of drift kelp lying directly on the transect lengthwise (future analyses should not include drift kelp).

Because of the seasonal effect on the percent cover of kelp, the data from 2000 and 2001 are inconsistent and I won't analyze percent cover data until after the 2002 season. Power analyses of stipe counts estimate that approximately 11 and 5 temporal replicates are required to detect a 50% and 90% change, respectively, in mean stipe density at E3 Hard, and 4 and 3 replicates are needed to detect a 50% and 90% difference at E4 Hard.

In addition to my recommendation that sampling occurs consistently among years within the same season, I suggest that juvenile kelps should be distinguished from adult kelps when recording stipe counts and percent cover estimates. Many young kelps are present early in the growing season, and counting the stipes of individual kelp recruits adds substantial variability to the average stipe density. I did not perform separate analyses for canopy-forming kelps, but this can be considered a different type of functional group and should be analyzed prior to the 2002 season for possible inclusion in swath or "large quadrat" counts.

Red foliose and filamentous algae:

Red algae included in this category are *Constantinea* spp., *Opuntiella californica*, *Palmaria* spp. (need confirmation of this identification), *Sparlingia pertusa*, *Turnerella mertensiana*, unidentified red blades (which are usually tattered and unrecognizable), and filamentous red algae that are too difficult to identify in the field. As shown in Figure 17, these algae are found at many sites, albeit at low percent cover. Because of the problem with comparing percent cover between years due to seasonality of data collection, I will not make

within-site comparisons between years or conduct power analyses for temporal trends until after the 2002 season. Inspection of frequency histograms for percent cover estimates at each site during each survey (Appendix RED_ALGAE) reveal that the statistical distribution approximates the negative binomial rather than the Poisson. This type of distribution is not ideal for making among-site or between-survey comparisons, but analyses of temporal trends should be relatively unaffected because only the mean percent cover value for a given site during a given year is used. Ideally, the sample unit size in which percent cover is estimated could be increased, but this is not logistically practical and would probably introduce a large amount of measurement error by the observer.

Desmarestia spp.

Desmarestia spp. are generally opportunistic, weedy species that exhibit strong seasonal changes in abundance. I included this group to demonstrate the drastic seasonal differences in % cover for some species of algae – note that virtually no *Desmarestia* was observed in 2000 relative to 2001 (Figure 18). The ephemeral nature of *Desmarestia* and the associated large fluctuations in abundance of these species make detection of change difficult, but it will nevertheless be interesting to compare the data from 2001-2002.

Red Algal Crusts:

The “red algal crusts” group contains at least two species – an unidentified pink coralline crust and a dark maroon fleshy crust that tends to be more abundant in the western mid-bay.

These data presented in Figure 19 should be interpreted with caution because of inconsistent sampling conventions from 2000 to 2001, namely that the percent cover of the fleshy red algal crust was not recorded for the first sites that were sampled in 2000 (e.g., E1 Hard, E2 Hard, W1 Hard, and W1 Soft). Note in the figure that the standard error bars are very small – this is surprising in that I expected more among-observer error. However, the percent cover of red crusts shouldn't be changing much from year to year given its slow growth rate, so theoretically our estimates of cover shouldn't change much from year to year. Some variability should be expected due to space, because the same quadrats aren't sampled each year, but it will be revealing to compare consistently collected data from 2001 and 2002. I will analyze these data in full after the 2002 season. Also, samples of these species should be sent out to specialists for positive identification in 2002.

Drift Algae

I included this group to explore the idea that persistently occurring drift algae may possibly be an indication of disturbance regime at a given location. Some sites, for example, had an abundance of green algae and *Fucus* tumbling down slope from the intertidal zone. Figure 20 reveals very high variability between years at most sites, but this may be a function of seasonality.

Substrate

Because substrate type can strongly influence benthic community structure, we explored two methods for quantification of this parameter. The primary method involves assessing substrate in each of the 20 randomly spaced 1m quadrats per site using a modified Wentworth

scale of relative abundance. At each site, we also used a “point contact” method in which an observer records substrate type at a single point at a systematic interval (2m) over the length of the 50m transect. Obviously, the spatial area sampled is vastly different between methods – 20m² of substrate are surveyed using the quadrat method versus approximately 26cm² of substrate using the point contact method. Despite this large disadvantage, the main advantage of the point contact method is an easily interpretable record of substrate over distance, which may reveal obvious patterns of habitat gradation or heterogeneity. However, there are two major problems apart from spatial coverage with these methods: 1) the Wentworth scale is semi-quantitative, while quantitative data are desirable; and 2) among-observer error is unacceptably large and thus unrepeatable for sediment grain sizes smaller than pebbles. For example, some observers interpret a silt/shell debris matrix as coarse sand while others may consider it fine sand, and others may consider it silt with shell debris as a modifier. Therefore, a better system must be devised and implemented.

Most of our study sites in Glacier Bay probably do not receive wave action that is strong enough to redistribute substrate larger than pebbles at a depth of –30 feet MLLW. Therefore, “permanent” transects should theoretically exhibit consistent substrate measurements over time, at least over relatively short time periods on the order of years. So, the first step toward standardizing the measurement of this parameter is to ensure transects are indeed permanent. This will be discussed subsequently in greater depth in the “transect” section below. Assuming the goal of an effectively “permanent” transect is met, the second step is to collect repeatable data for substrate type and quantity. The most effective way of achieving this goal rigorously may be to obtain a photographic or video record (with a calibrated scale) for each

square meter of substrate along the transect, complemented by analytically testable grab samples of grain sizes smaller than pebbles. This method would be relatively costly timewise in the short-term, as it would probably take two dives per site to collect the information (depending on water visibility). However, time may be saved in the long run by elimination of annual substrate assessment by divers collecting quadrat data. Furthermore, rigorous photo- or video-quadrats would probably only need to be repeated every 5 years or so, as sedimentation rates are not constant. A realistic, logistically feasible approach could be taken in which initially this technique is used to quantify substrate for only a subset of sites in which substrate is complex and among-observer error has been demonstrated to be greatest.

Substrate data collected in 2000 and 2001 have not been evaluated statistically to date, but should be prior to the 2002 season. My general impression is that among-observer variability is substantial for smaller grain sizes, but this imprecision may not be relevant enough to this study to warrant the additional cost and effort of its precise quantification. However, it is clear that differences in sediment grain size that are subtle to the human observer strongly influences the suitability of habitat for various organisms (e.g., clams, tubeworms, etc.) – the question is whether these differences affect any of the organisms targeted by this study. I suspect that it does for organisms such as *Leptasterias* and sea urchins that feed upon diatom films, and I recommend that at least grain sizes be examined on a preliminary basis for a small subset of study sites.

Species Presence/Absence/Relative Abundance

At this time, data entry is not complete for the species checklists recorded in 2001, and no summarization or analyses have been performed. However, because of my involvement and experience with the development of this procedure, I can provide a generalized assessment of its applicability to the study objectives, an evaluation of the technique, and provide recommendations for changes to the protocol. First and foremost, I think that this method is an important inclusion in the study because the number of taxa sampled (178) using this technique far exceeds the number of taxa sampled using more quantitative methods (i.e. quadrats and swaths), and the cost per unit effort relative to the information gained is very low (data are recorded on the return trip home from a sampling outing). Many of the species included on this checklist are not widespread or abundant enough among most sites to warrant dedicated quantitative measurement, but are representative indicators of entire community types (e.g., vase sponges and octocorals that are indicative of high current, low sedimentation communities). The accurate designation of “community type” at a particular study site will be important for future analyses and interpretations of quantitative data collected at different study sites (i.e. decisions about which sites can validly be compared). Furthermore, species that we currently do not sample quantitatively may indeed show large changes over time, either as a result of otters or for some other reason, and it would be wise to have data to assess those changes, even if it is semi-quantitative (which is readily analyzable using non-parametric statistics). Finally, the inclusion of this technique in the sampling repertoire also satisfies one of the primary objectives of this study – to provide pilot data for a large number of potential candidate species in anticipation of a

park-wide subtidal monitoring program included as part of a comprehensive GLBA science plan.

Long-term repeatability is a major issue with this technique. Firstly, opportunistic species identification in the field is a function of observer perception, skill at rapid field identification of a wide array of taxa, and memory recall ability (these data are recorded topside after sampling has concluded at a particular study site). Obviously, these skills are highly variable among observers. For example, I have observed algae specialists completely overlook small invertebrates considered to be common to abundant by invertebrate specialists, and vice versa. Variation of data due to perception ability and memory recall can be minimized to some extent with training and by immediately recording data after dives. With respect to rapid, accurate species identification, however, the learning curve is steep - there are a large number of different types of organisms that occur within subtidal communities, and it is highly unlikely that all observers are/ will be skilled at identifying all of them. Therefore, it may take a significant amount of time – on the order of 1-2 months - to become familiar with the majority of taxa sampled. Because it takes such a long time to acquire this knowledge and skill, a field season can be well underway before new observers have achieved sufficient skill to collect high quality data. A high rate of employee turnover would be detrimental to this endeavor, and every effort should be made to maximize employee re-employment once an individual has mastered these skills. This strategy will improve data quality, consistency, and reduce training costs, which are significant (depending on the prior knowledge of a new employee).

Other measures can be taken to improve data quality and maximize repeatability of the species checklist. For instance, a video and/or photo library should be created that contains all

species on the checklist. An online photo database is presently being developed as a training aid for species recognition and identification. Video footage has the added benefit of being more interactive and depicting the organism in the three-dimensional context of its natural habitat. For species that are not readily identifiable in a photo or video catalog, a specimen voucher collection program should be initiated. When training new employees, priorities for species identification should be set according to 1) whether a particular species is quantified using swaths or quadrats, and 2) rates of encounter and “importance” for distinguishing among community types. Species are presently identified to the lowest taxonomic level possible, but there is much room for improvement - many taxa are not currently identified to the species level, and many not to the genus (or higher) level. Some species are either difficult or impractical to identify in the field (e.g., crustose red algae, filamentous red algae, small hermit crabs, sea stars in the genus *Henricia* and *Solaster*, *Laminaria* spp.). While it will possibly never be practical to identify and distinguish among several identical-looking species in the field, if these species “groups” that we are observing are indeed only one species, or two different species that are readily distinguishable by a key feature, then it would be worthwhile to collect data at the maximum species resolution possible. Primarily due to time/personnel constraints, we have to date not vigorously pursued taxonomic identification of difficult species. Beginning in 2002, more effort should be expended toward this goal after more important priorities have been satisfied. Furthermore, specimens for which identification is questionable should be sent out for independent verification and/or identification by expert specialists.

The second major issue that hinders repeatability of the species checklist is the lack of a standardized system for designating relative abundance of species that are present at a study

site. Currently, relative abundance is assigned a value of either Rare (1), Rare (2-4), Common, or Abundant, and is recorded for a particular taxa after consensus has been reached among the group of observer/samplers. The problem is that the relative abundance scale is highly subjective with the exception of rare (1) or rare (2-4). Furthermore, the current protocol for evaluating relative abundance is very relative itself – species are assigned a relative abundance at a given site “relative to other sites within Glacier Bay.” This valuation technique was used to discourage an observer from assigning relative abundance based on observations from subtidal communities in different geographic locations. For example, much of my diving has been in central California where the density of sea urchins is low (because of otters), and nearly every place in Glacier Bay would therefore have “Abundant” relative urchin densities by comparison. However, this system of assigning relative abundance values is clearly not adequate because, firstly, one can’t have an idea of the relative abundance of a species at different locations in Glacier Bay without having done a fair amount of diving in the bay. Therefore a new employee would not be able to contribute meaningful relative abundance data for most of a diving season. If turnover among divers is high, the quality of the relative abundance data is severely compromised, or it is unduly influenced/biased by one or two individuals who have more diving experience in the bay. Secondly, the relative abundance of a given species may change on a bay-wide scale over time, and therefore the relative abundance scalar would be a moving target. In light of these criticisms, I think that relative abundance should be assigned using a new method in 2002. Instead of the highly subjective method of assigning relative abundance, standards that are repeatable and quantitative should be outlined for each species on the checklist. For example, a scale of 0, 1-3, 3-10, 10-20, 20-50, 50-100, 100-1000, >1000 may

be used for species that can be counted as discrete individuals. For organisms that are best measured using percent cover (e.g. algae, invertebrate mats, or sponges), a scale of 0, 1 (trace), 1-10, 10-50, 50-100 can be used.

Video Footage

Video footage is recorded for each site to serve three purposes: firstly, it is used to qualitatively document the general habitat and conspicuous biota at each site; secondly, it is used to document unidentified species - some of which are impractical or destructive to identify outside of their natural habitat - for future identification; thirdly, it is used to document substrate type and percent cover of organisms for future analysis by the NPS team or others who may wish to independently assess the biota on the seafloor. I strongly feel that it's worthwhile to collect video footage for the purpose of documenting habitat and unidentified species (at least in the near term). This qualitative footage is recorded by one diver while his/her dive buddy pays out the transect tape to re-establish a study site for sampling. Therefore, no time is "lost" for the performance of this task, as there is not much else this diver can accomplish while the transect is being paid out. Furthermore, this footage is occasionally quite captivating (e.g., when a writhing mound of baby king crabs was recorded on tape) and can be used to introduce interested parties to our study.

On the other hand, "quantitative" video footage is of questionable utility in its current incarnation. In theory, it should provide a permanent record of the substrate and biota on the transect that may be accessed by any interested party in the future. For example, if future researchers with their space-age statistics decide we counted things incorrectly in our quadrats,

they could go back to the video record and analyze whatever parameter they were interested in themselves. With appropriate frame-grabbing software and an image analysis program, members of our team could independently calculate percent cover of substrate type or algae, for example. A lack of “scale” is the proximate problem with the quantitative video. Scale is required to calibrate measurements of anything that is recorded on video. We’ve attempted to provide scale by holding the camera in position approximately one half meter above the substrate (oriented downward) while swimming along the transect and keeping the transect tape meter increments in focus and in the center of the field of view. In practice, this is quite difficult however. If quantitative video footage is to ever be used in a quantitative way, a scalar is imperative. Paired laser systems are a very effective tool for this purpose, and has been used effectively to precisely measure length-frequencies of rockfish in California (CDFG, unpub. Data). The value of this procedure should be discussed and critically evaluated prior to the 2002 field season.

Size Class Distributions :

The size class distributions of three functional groups of organisms (sea stars, large whelks, and sea urchins) were sampled in 2000-2001 in order to monitor the size structure of populations of organisms likely to be directly or indirectly effected by sea otters. The size frequency distribution of a population is a function of recruitment success and size specific rates of individual growth and mortality, and may be an early indicator of ecological change or perturbation (e.g., size class truncation of large individuals due to size-specific otter foraging). Because of differences in these variables and the likelihood of stochastic population trajectories

among different areas within Glacier Bay, size frequency information is a valuable dataset, especially when complemented with information about organism density

Sea urchins have been consistently measured at each site since the inception of this study, whelks have been measured since early 2001, and sea stars have been measured only since very late in the 2001 season. As shown in Appendix URCHIN_SIZE, size frequency distributions at each site are often mirror images between years, but the overall trend and assessment of some individual sites reveal noticeable, albeit subtle, increases in mean individual size. It should be possible with this method to follow cohorts through time by examining successive size frequency distributions. The usual assumptions for this method are met with the current sampling program, and include frequent sampling, large sample sizes, and relatively little movement among different populations. Furthermore, these data can be acquired at relatively low cost per unit of information gained. After individuals have been enumerated by divers surveying the transect, they are placed in a game bag and brought to the surface for measurement. Typically, approximately 300 urchins can be measured in about 15 minutes with 3 measurers while one person records data.

A vast body of knowledge has been amassed that addresses the uses and methods of analyses of size frequency distribution data, and a thorough treatment is outside the scope of this preliminary report. However, these data should be explored in depth after the 2002 season. Size frequency data for sea urchins are very informative and should be continued in the future.

Large species of whelks were also targeted for size frequency enumeration, initially to detect whether a natural discontinuity was evident for purposes of establishing a size class cutoff for density measurements. These data are detailed and size frequencies are graphed in

Appendix WHELK_SIZE. These data have not been analyzed and it should be determined prior to 2002 whether the original goal has been met, and if sampling should continue into the future.

After debating what size class cutoff should be used when collecting data on the density of sea stars, it was determined that size frequency data would be valuable for these species, since they can be important agents of community structuring in the marine environment. It wasn't logical to equate a *Pycnopodia* 10 cm in diameter with an individual 60 cm in diameter, so it was decided that all sea stars would be enumerated during surveys, and size frequency data would also be collected in conjunction for the estimation of biomass. Sea stars have been collected and measured for only 2 sites (see appendix SEASTAR_SIZE), but the information can be useful and the very low cost per unit information associated with its collection warrants future sampling.

General Considerations of Sampling Design

Site Selection

Sites were originally stratified geographically by latitude and longitude in order to maximize the inference space of the study and increase the likelihood that sea otters would not impact all sites simultaneously. Sites were also grouped by substrate type to investigate the impact of otters on both soft and hard substrate (with 5 of each type placed on each side of the bay), and to minimize variability of measured population parameters due to extrinsic physical factors such as habitat associated with substrate type. Because the pattern of re-colonization by sea otters is unpredictable, however, it is impossible to know at this time which sites will be

compared as “control” and “impact” sites in the final analysis. Therefore, we attempted to establish a pool of ten replicate sites with similar habitat for each substrate factor that could be potentially compared in the future. Of course, high variability among sites of similar substrate type would limit the ability to make relevant comparisons when the time comes for analysis.

To explore the degree to which geographic stratification and the designation of substrate types is reflected in the biotic community data we’ve collected, I performed a cluster analysis to “classify” the ecological data into naturally occurring groups. While this type of analysis is not a formal statistical test for differences, it can be used to evaluate general patterns in the data. In particular, I wanted to explore whether and to what degree sites did indeed group by *a priori*-defined substrate type, latitude and longitude, and spatial proximity. I conducted two separate cluster analyses – one for key invertebrate groups (including large sea stars, small sea stars, large whelks, sea urchins, *Metridium spp.*, *Elassochirus spp.*, other large hermits, other crabs, *Cryptochiton*, sea cucumbers, and sea anemones) and one for algae (including kelps, foliose/filamentous red algae, crustose red algae, *Desmarestia spp.*, and drift algae). Details of the analysis are presented in Figure 21 and in Appendix CLUSTER_ANALYSIS.

At approximately the 20% dissimilarity level, animal assemblages cluster into 3 distinct groups: one “oddball” pair of sites (E2 Soft and W5 Soft) characterized by silt substrate and few animals, one cluster of sites primarily consisting of hard bottom sites (7 of 9 sites), and one cluster of primarily soft bottom sites (6 of 9 sites). At the 21 % dissimilarity level, sites also appear to cluster according to the side of the bay in which they occur (6 of 9 sites in each cluster). It also appears that sites in close spatial proximity tend to group together on average.

As shown in Figure 22, the groups of algae segregate by substrate type even more so than the animals – at the 35-40% dissimilarity level, 9 of 12 sites in one cluster are hard substrate, and 7 of 8 sites in the other cluster are soft bottom. At this same level of dissimilarity, equitability is greater within clusters between sides of the bay in which sites occur (4 East and 4 West in one cluster, and 6 East and 6 West in the other cluster). Some groups occurring at greater levels of similarity also apparently cluster according to spatial proximity.

Despite the problems with subjectivity and lack of statistical rigor characteristic of cluster analyses, these results provide an indication of patterns inherent in the ecological data collected in this study. Furthermore, the grouping results are intuitively similar to my personal recollections of habitats at each site. As expected, sites clustered primarily according to substrate type, and to a lesser extent, side of the bay (for animals but not algae), and spatial proximity/latitude. These results largely support the original goal of stratification by substrate and geography, and are satisfying in the sense that “communities” were identified fairly accurately without remote sensing data of the seafloor to guide site selection.

Permanent Transects

Permanent transects are desirable for this study in order to minimize the “noise” of environmental/biological variability due to space. The advantage of the “permanent” transect method that we currently employ, in which the transect is deployed and retrieved for each sampling visit from anchors that are semi-permanently affixed to the seafloor, is that no sampling artifacts are present that may affect measurements of the biota (e.g., lead line permanently deployed on the seafloor readily attracts algal and invertebrate settlers). The disadvantages are:

1) time must be spent searching for the permanent transect anchors on the seafloor each time the transect is to be deployed for sampling; 2) occasionally a transect anchors are carried away by currents (e.g., if a raft of kelp tangles in the subsurface buoy line); and 3) “slop” in the transect tape is nearly impossible to avoid, which decreases the probability for highly accurate, repeatable relocation of a given square meter of seafloor. While the first point is merely a logistical necessity, the second and third disadvantages may actually affect the data collected for certain species. Most of the animal species sampled are mobile, and variability of annual mean densities due to space is probably inconsequential. However, estimates of abundance for algae and sessile invertebrates such as anemones may be affected by relatively small changes in the location of the transect (e.g., if a large boulder is included or excluded from sampling). In one sense this could be an indication that the spatial extent of sampling (i.e. the transect) isn’t large enough if mean abundance estimates are dramatically affected by the inclusion or exclusion of one boulder. This may be a valid criticism, but I doubt that it is an important factor in reality. Nevertheless, steps can be taken to improve the spatial precision, and thus repeatability, of sampling by minimizing the spatial variability of transect placement. Currently, the transect tape is only anchored at either end. In the future, small sand anchors could be installed at fixed locations along the transect (e.g., every 10 meters) to which the transect tape may be fastened. This is a small measure that could dramatically improve spatial precision, and I recommend that this be done in 2002.

Personnel

BRD and NPS personnel successfully accomplished sampling of 20 permanent subtidal study sites and 7-9 (?) subtidal clam study sites in 2001. However, all employees were exhibiting signs of stress due to the volume of work to do in the time allotted. Work statistics (including boat use) are detailed in Appendix WORK_STATS, and personnel wages, including overtime costs, are detailed in Appendix PERSONNEL_HOURS.

Three NPS personnel logged 84 person-days of diving during the 2001 season, almost exactly the required number of person-days needed to complete fieldwork for permanent study sites. Permanent sites were accomplished in 21 field days (not including weather days) by an average of 4 divers/ day. Note that this number alone does not factor in the difference in efficiency of having varying numbers of divers available for diving on a given day. An even numbers of divers are most efficient, with 4-6 being optimal; a third diver is like a third wheel - one of the other 2 buddies must still take a surface interval before diving again with the third diver. Therefore, 4 divers will be necessary for the 2002 field season to complete 20 sites, and allow time for office-related tasks. Furthermore, a great deal of work remained to do when seasonal personnel departed for the season, including data entry, verification, equipment maintenance, data entry and verification, data analysis, report writing, and miscellaneous other duties, so it would be highly desirable to have a technician working throughout the Fall of 2002.

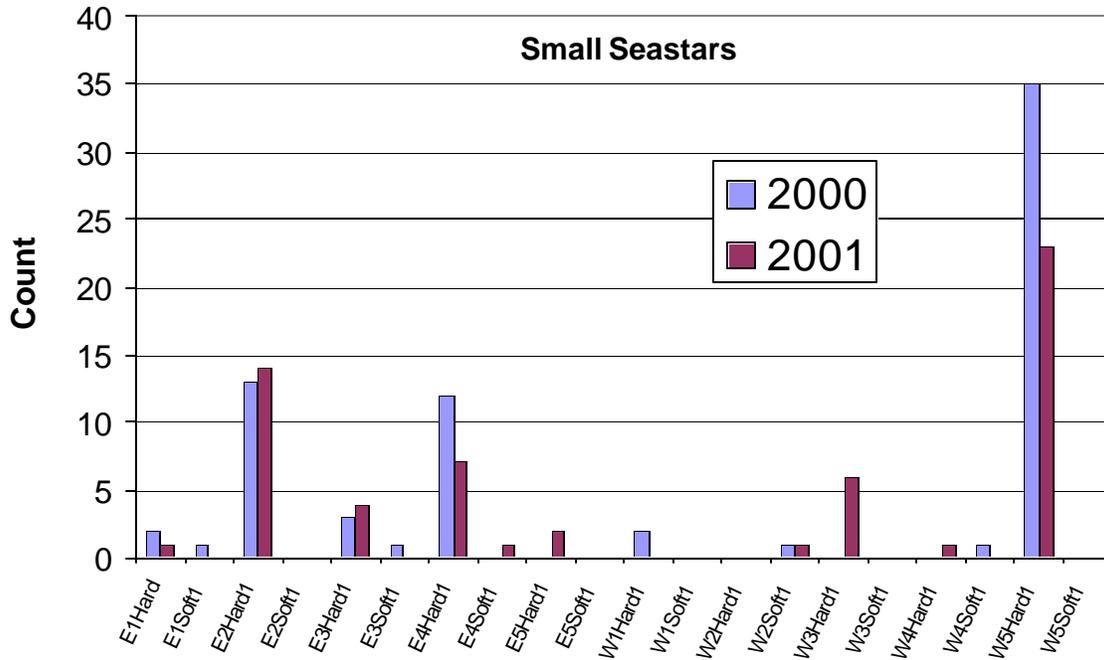


Figure 1. 2000-2001 summary of count data for small sea stars (includes *Crossaster papposus*, *Henricia* spp., *Pteraster tessellatus*, *Mediaster aequalis*). E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available.

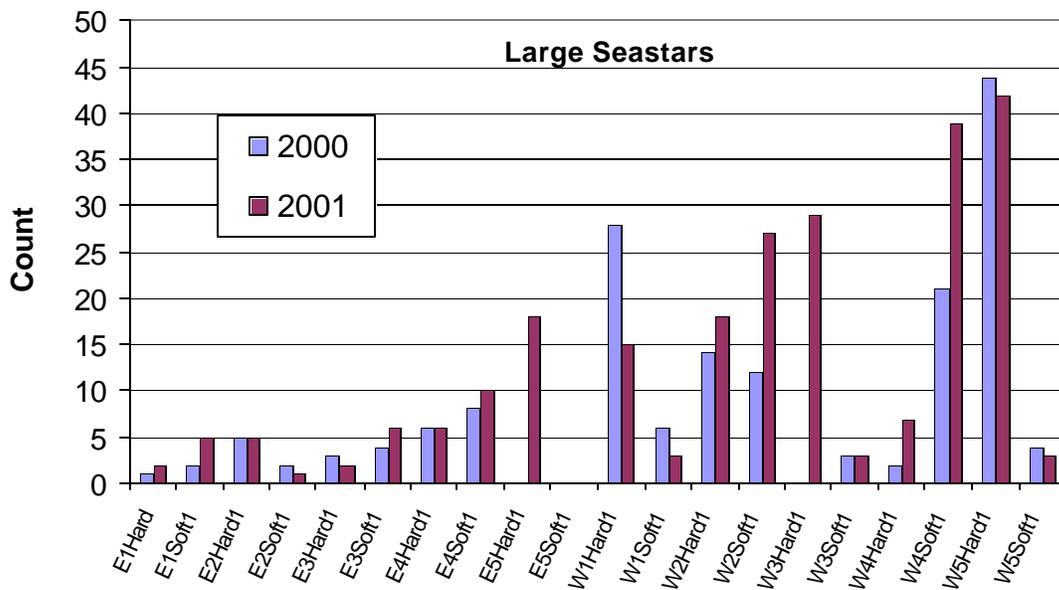


Figure 2. 2000-2001 summary of count data for large sea stars. E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available.

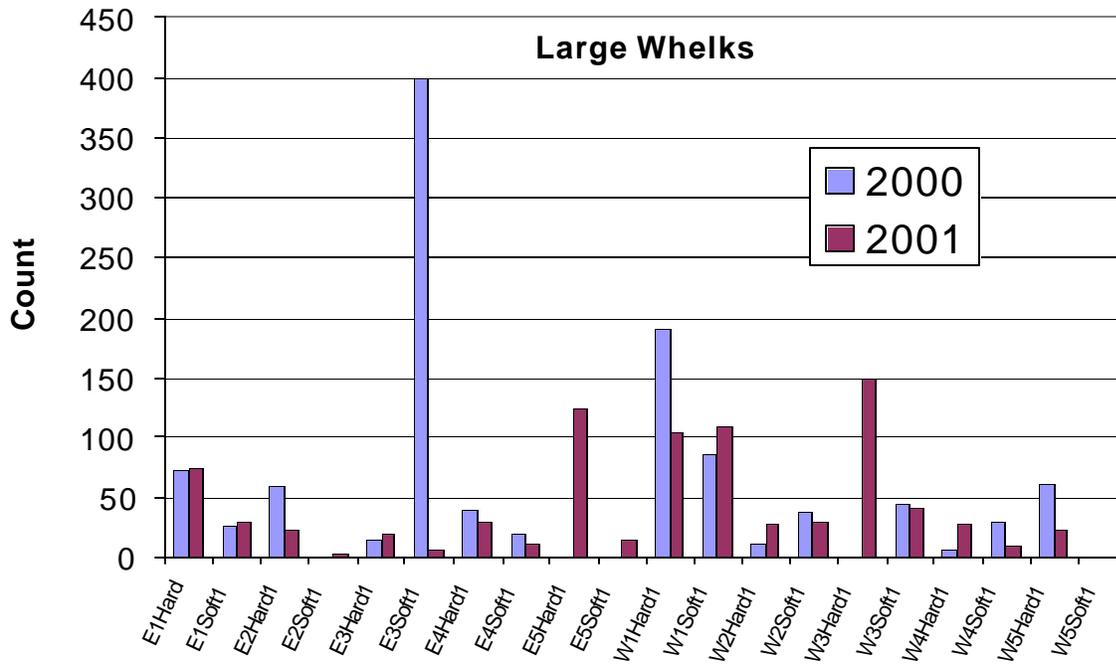


Figure 3. 2000-2001 summary of count data for large predatory whelks. E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available. The extreme outlier count at E3 Soft in 2000 was recorded prior to size class distinction.

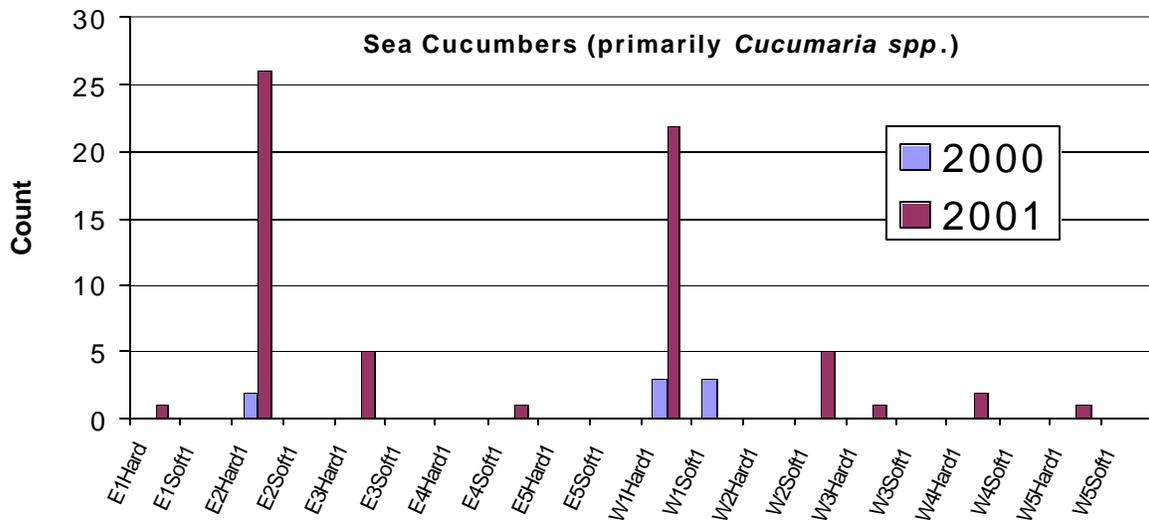


Figure 4. 2000-2001 summary of count data for sea cucumbers. Note extremely different abundance between years.

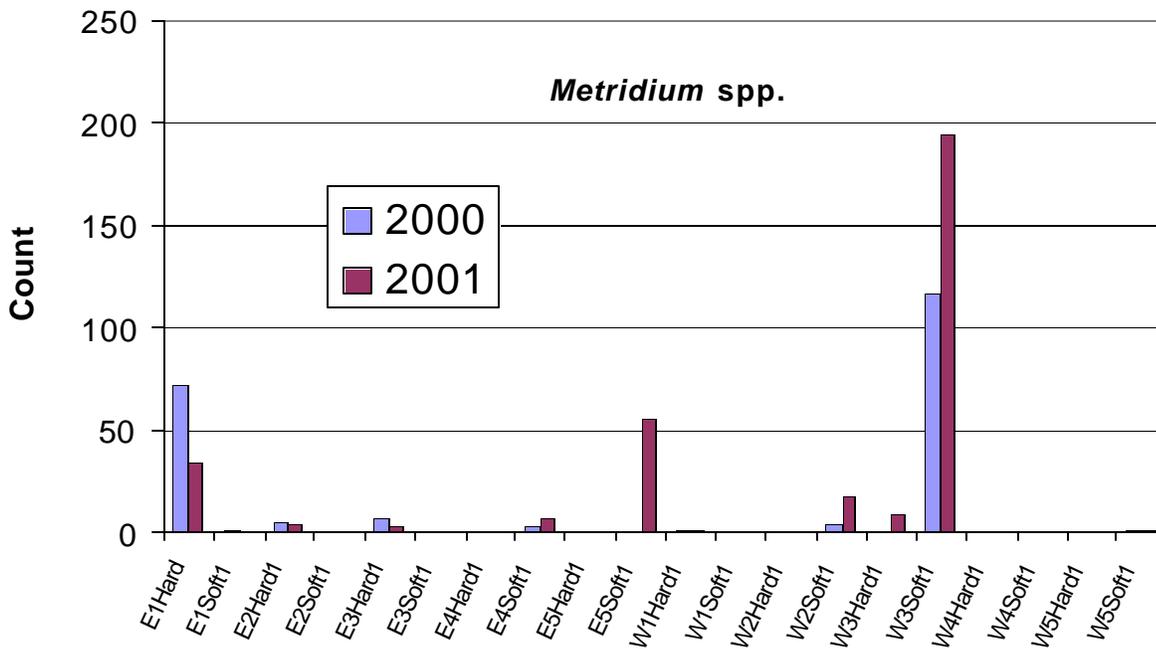


Figure 5. 2000-2001 summary of count data for *Metridium* spp. E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available.

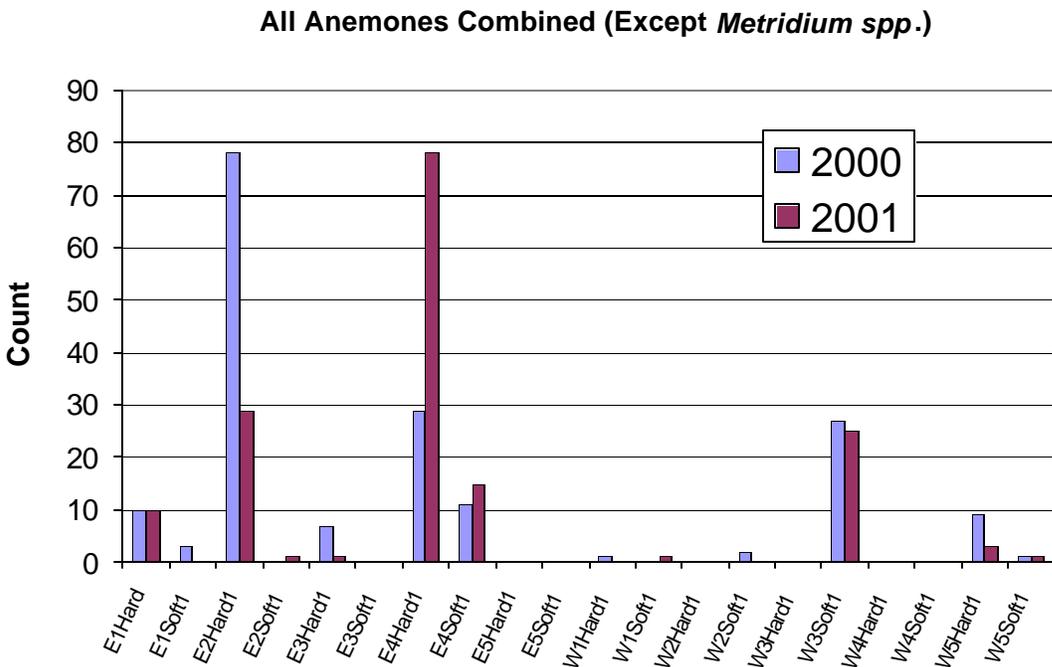


Figure 6. 2000-2001 summary of count data for all anemones combined (except *Metridium* spp.) E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available.

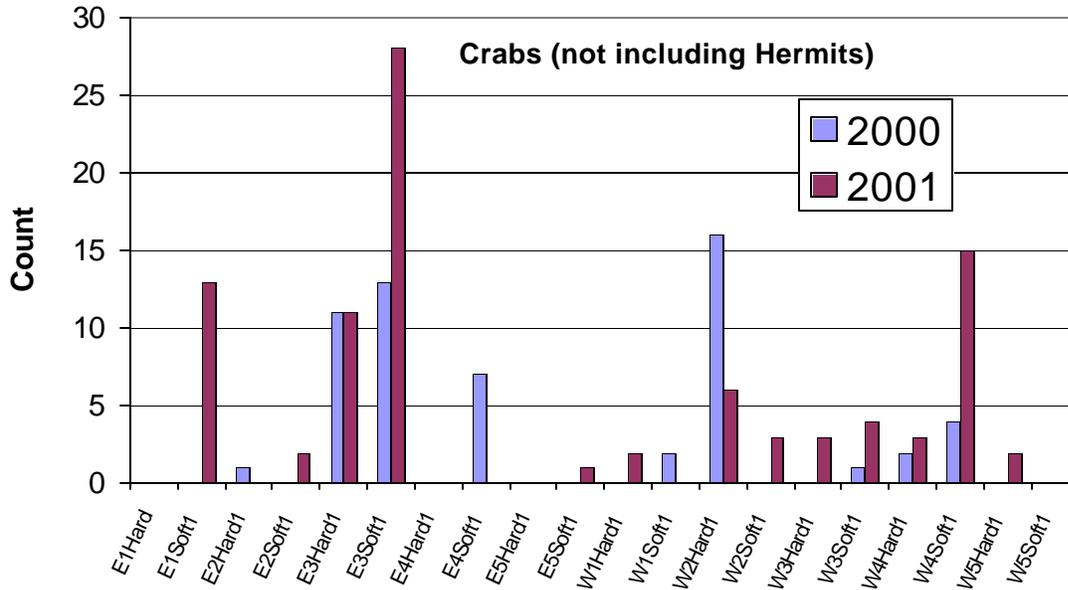


Figure 7. 2000-2001 summary of count data for crabs (not including hermit crabs). E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available.

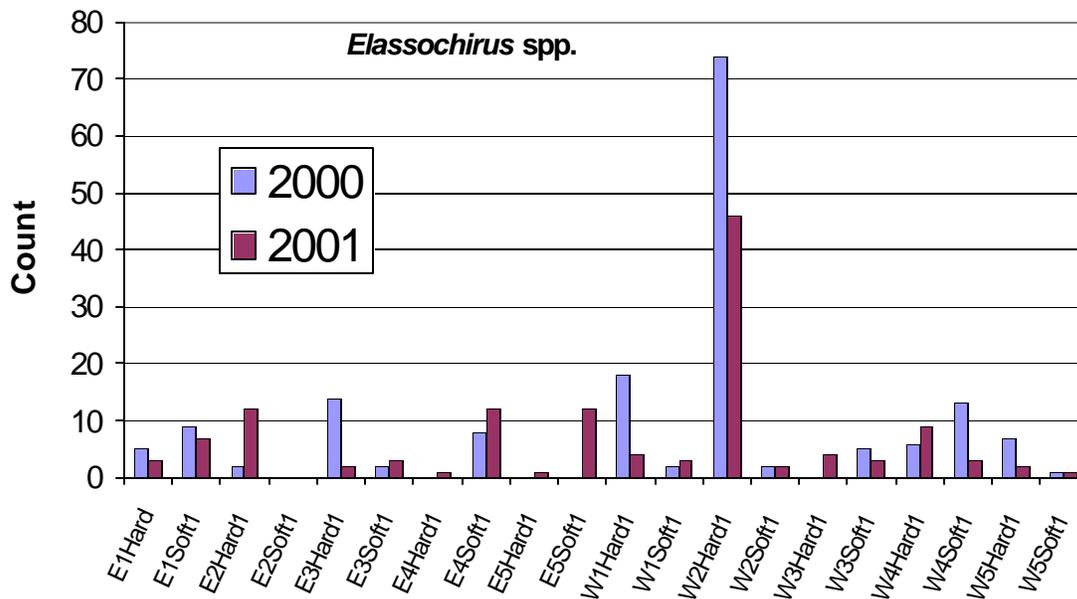


Figure 8. 2000-2001 summary of count data for crabs (not including hermit crabs). E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available.

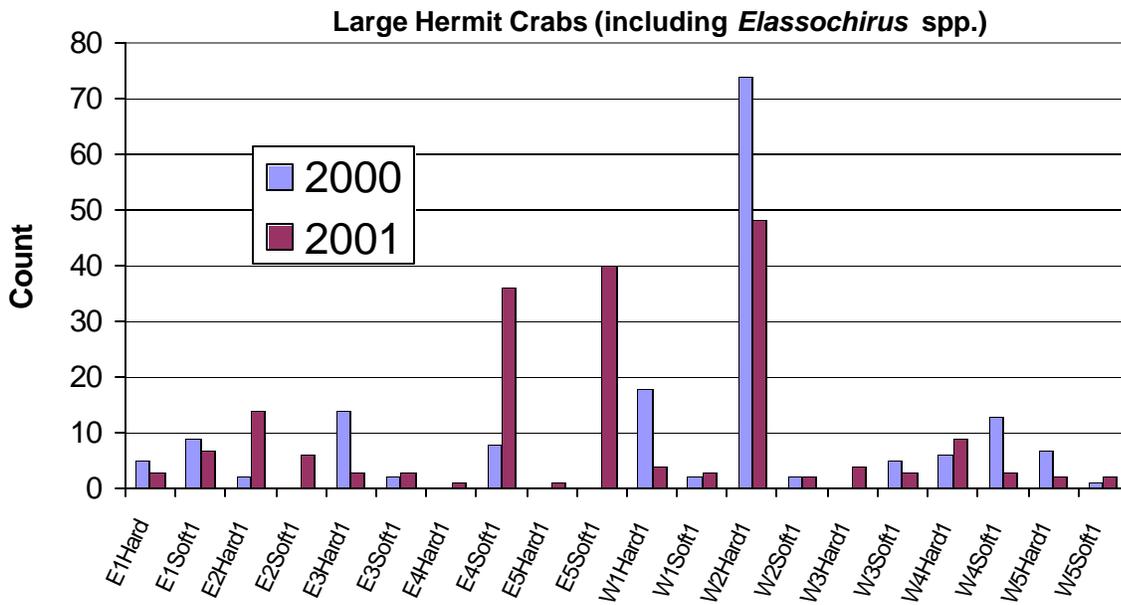


Figure 9. 2000-2001 summary of count data for all large hermit crabs. E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available.

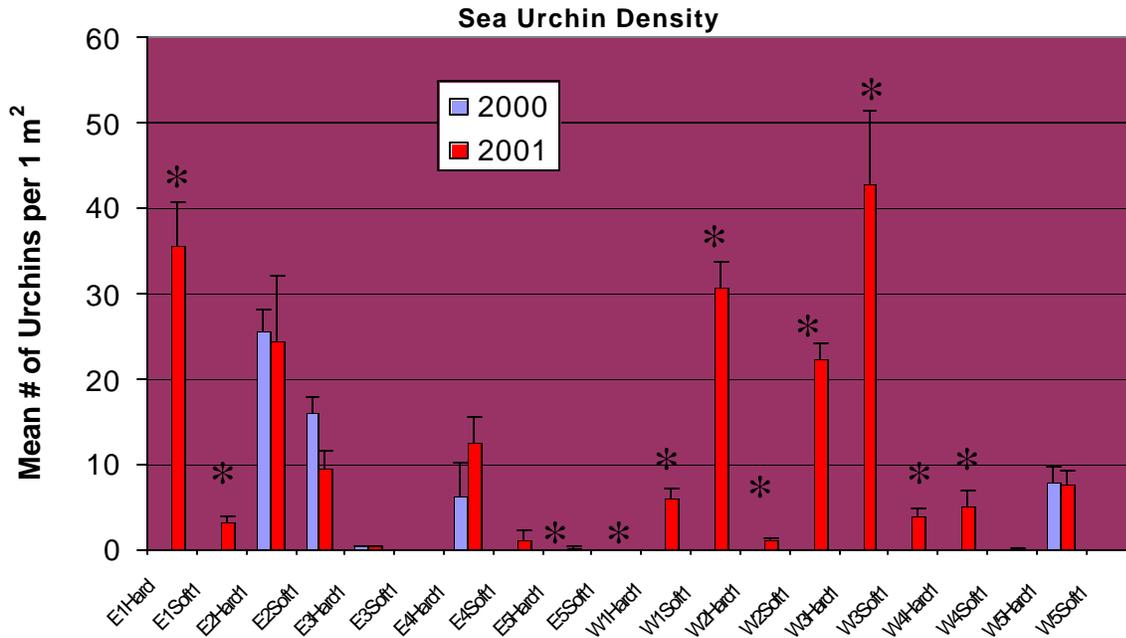


Figure 10. Summary of sea urchin density by site for 2000-2001 as estimated by 1m² quadrats (+/- 1 Standard Error). E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available. (asterisks denote sites in which urchins were counted within 1m² quadrats only in 2001).

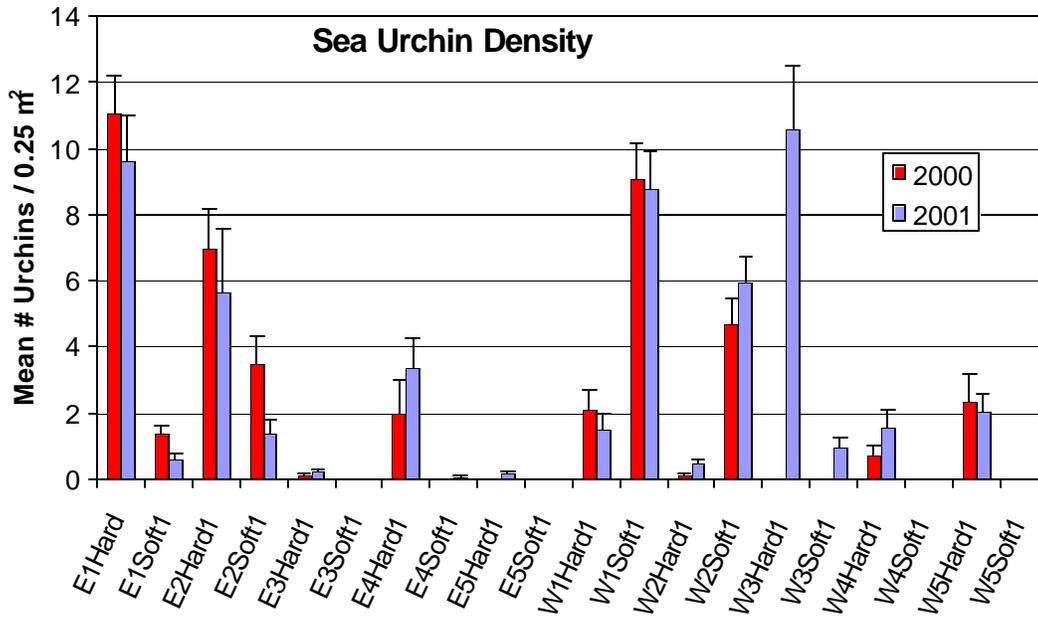


Figure 11. Summary of sea urchin density by site for 2000-2001 as estimated by 0.25m² quadrats (+/- 1 Standard Error). E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available.

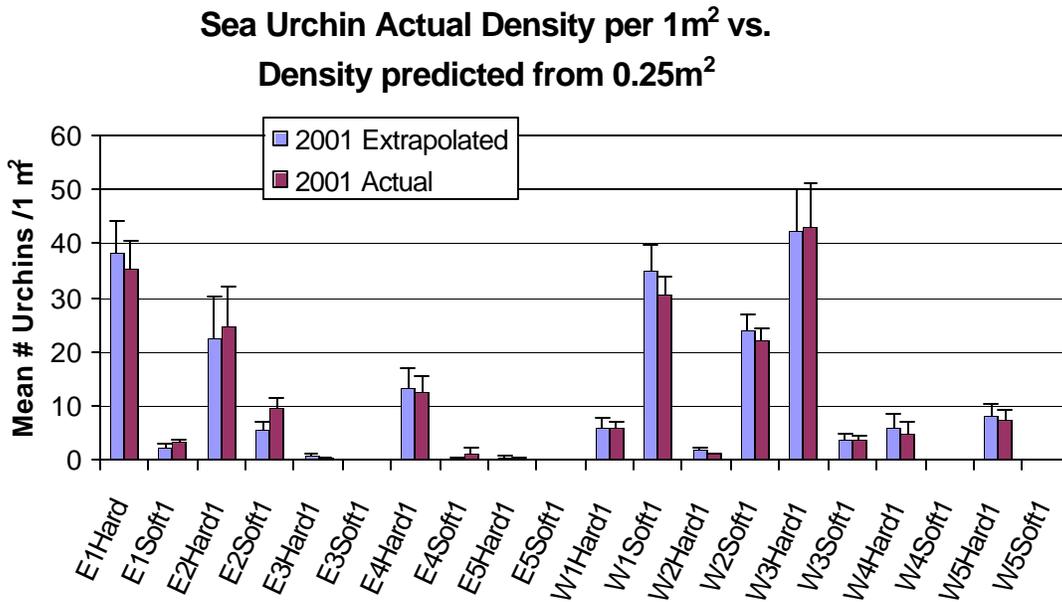


Figure 12. To get an indication of comparability between urchins sampled using 0.25m² quadrats relative to 1m² quadrats, this graph plots extrapolated urchin density estimates per 1m² derived from counts in 0.25m² quadrats vs. actual data from for 1m² quadrats in 2001 (+/- 1 S.E.).

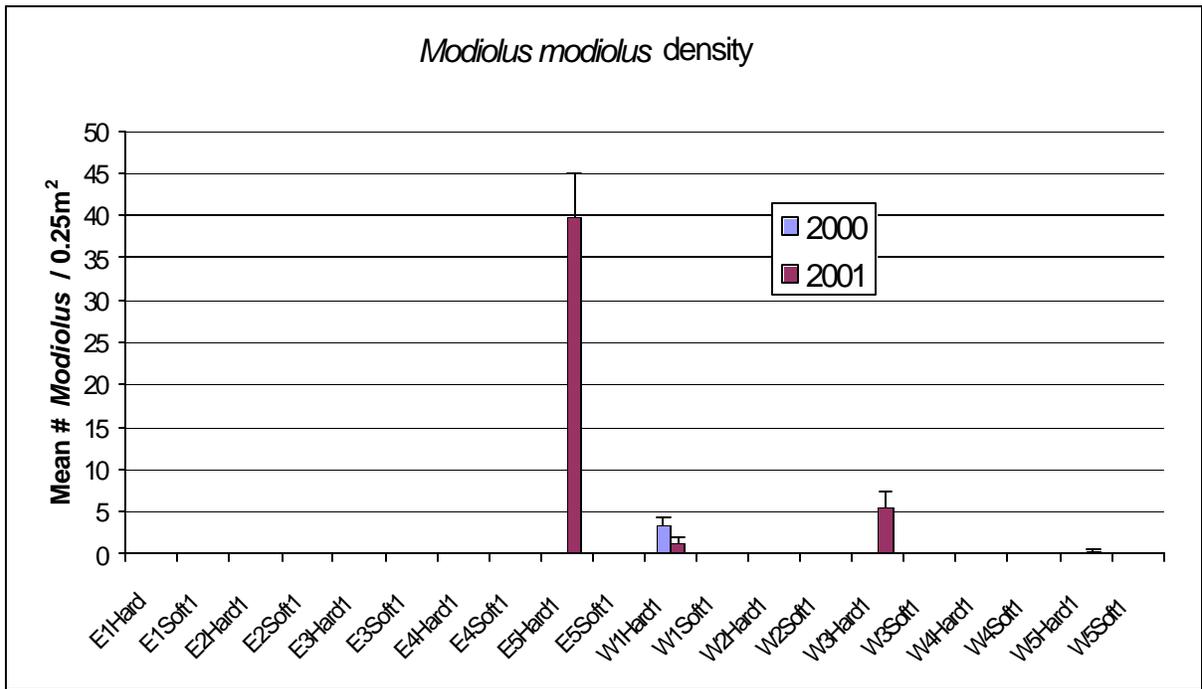


Figure 13. Summary of *Modiolus* density by site for 2000-2001 (+/- 1 Standard Error). E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available.

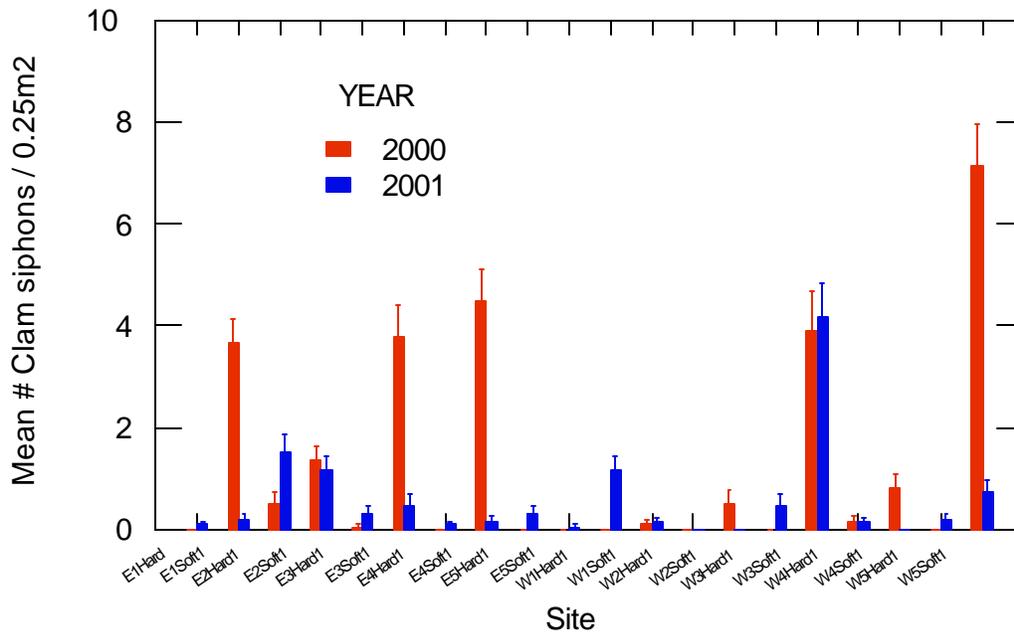


Figure 14. Summary of clam siphon density by site for 2000-2001 (+/- 1 Standard Error). E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available.

Kelp Stipe Density

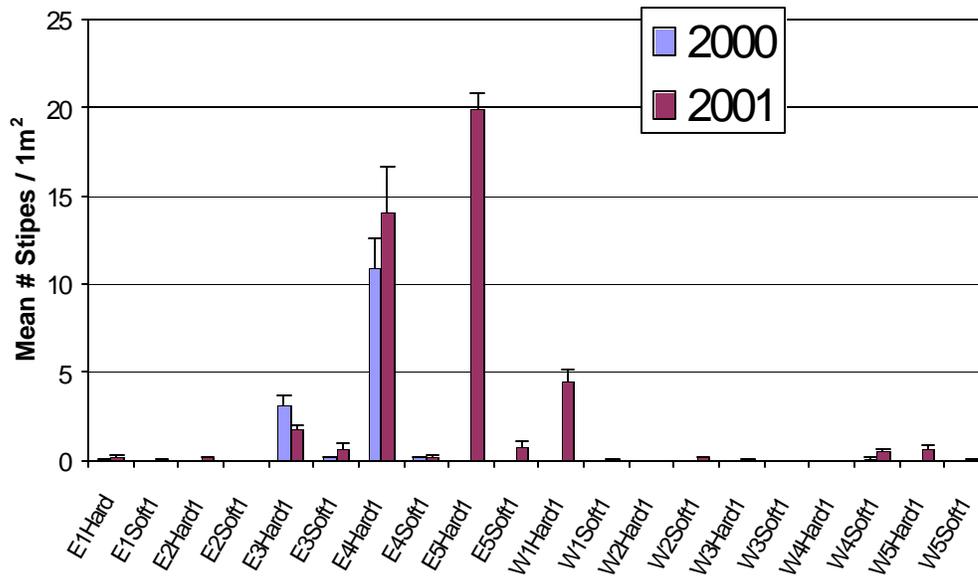


Figure 15. Summary of kelp stipe density by site for 2000-2001 (+/- 1 Standard Error). E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available.

Kelp Percent Cover

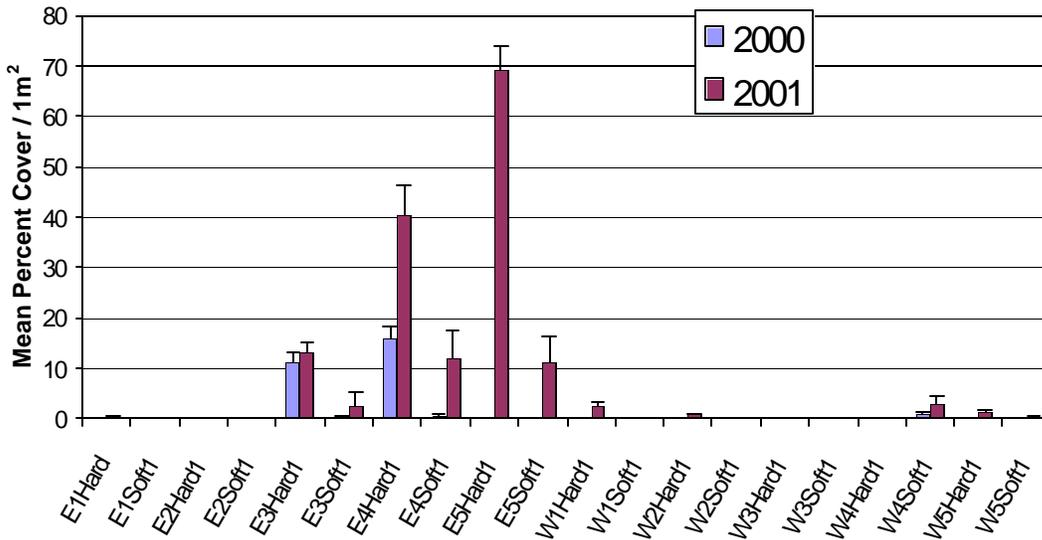


Figure 16. Summary of kelp percent cover by site for 2000-2001 (+/- 1 Standard Error). E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available.

Red Foliose and Filamentous Algae

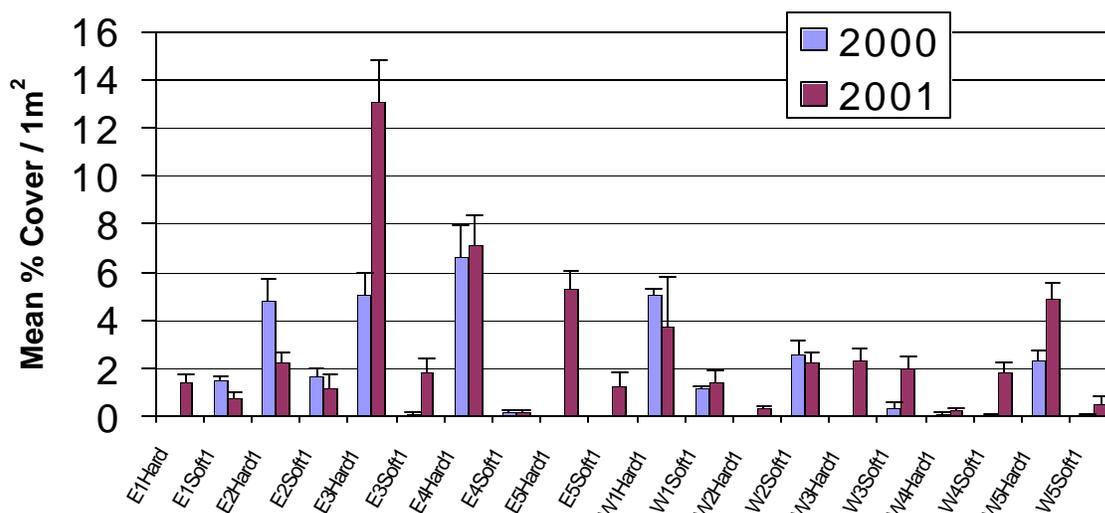


Figure 17. Summary of percent cover for filamentous and foliose red algae by site for 2000-2001 (+/- 1 Standard Error). E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available.

Desmarestia spp. Percent Cover

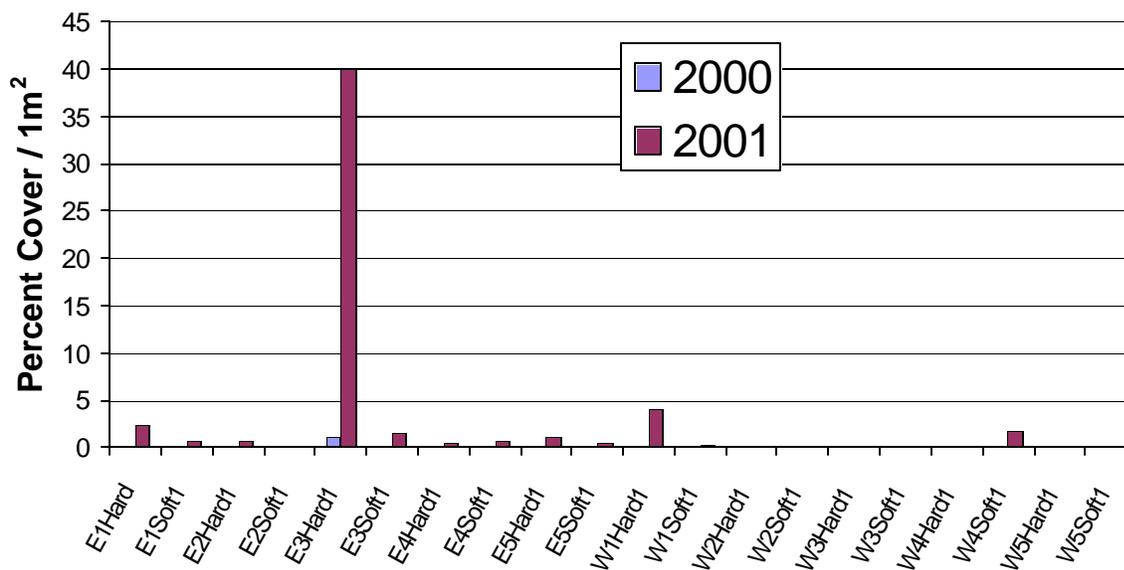


Figure 18. Summary of percent cover for *Desmarestia* spp. by site for 2000-2001 (+/- 1 Standard Error). E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available.

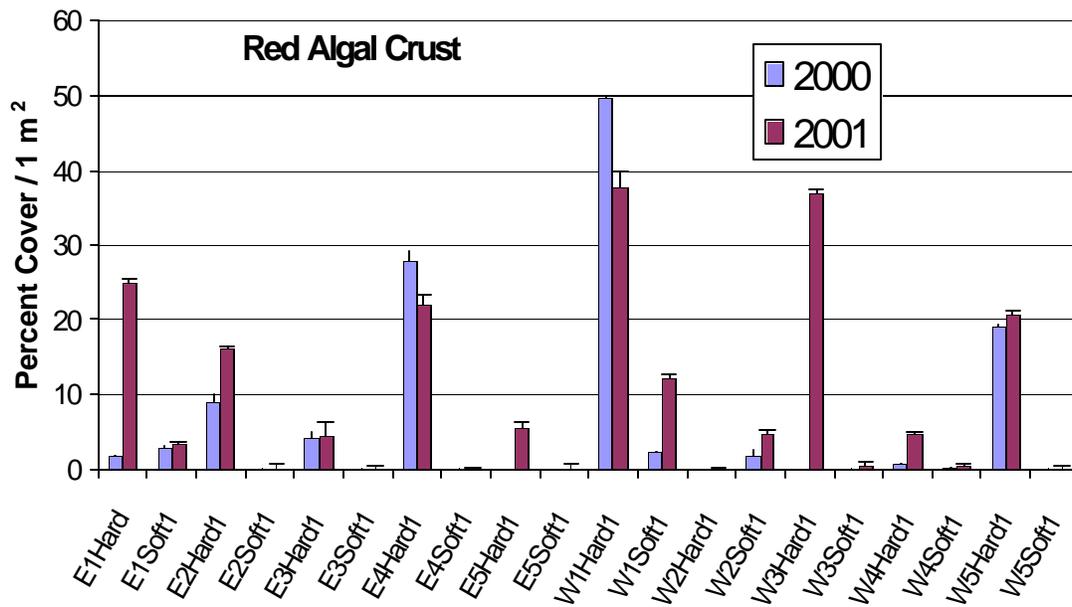


Figure 19. Summary of percent cover for red algal crusts by site for 2000-2001 (+/- 1 Standard Error). E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available.

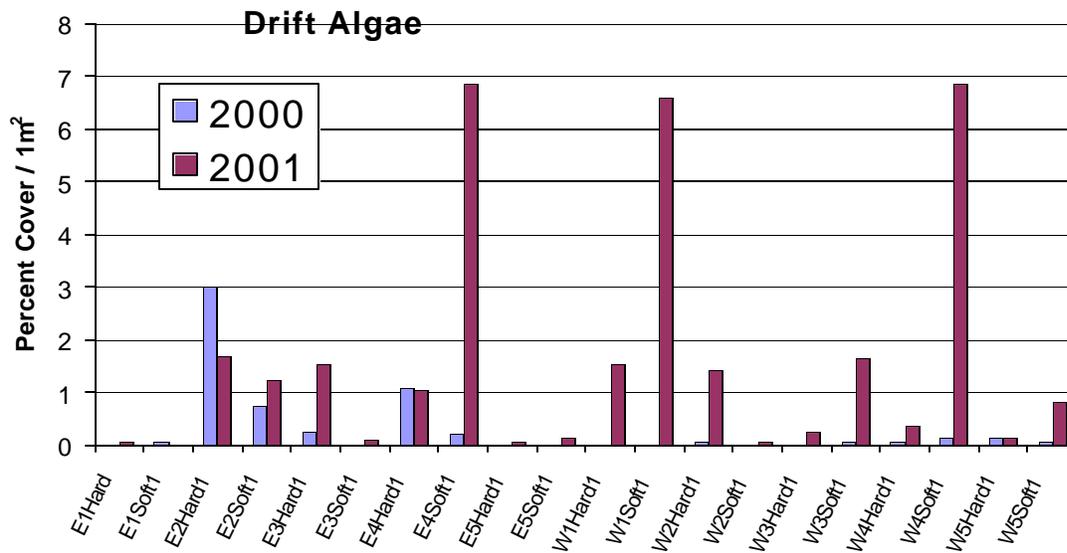


Figure 20. Summary of percent cover for drift algae by site for 2000-2001 (+/- 1 Standard Error). E5 Hard, E5 Soft, and W3 Hard were established in 2001, therefore no data from 2000 were available.

Animals

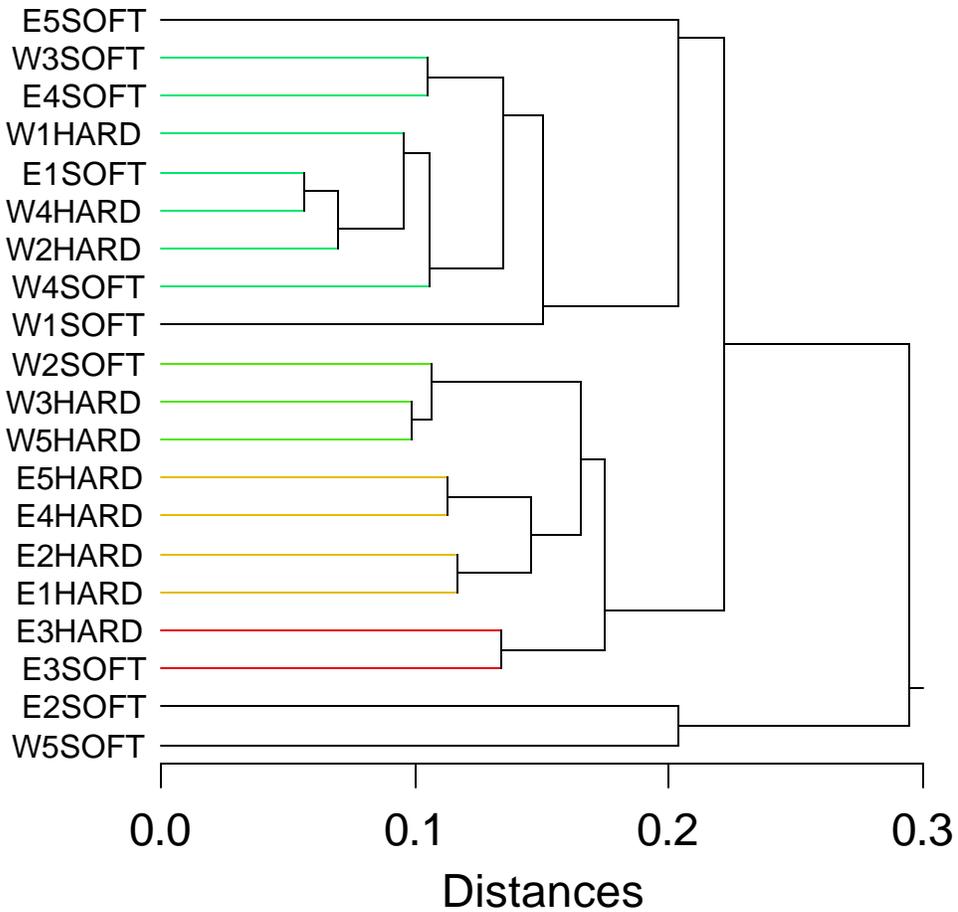


Figure 21. Cluster analysis of key invertebrate species groups by classified by site. Note that the “distance” axis is a measure of % dissimilarity – the closer a linkage value is to 0, the more similar the sites are, and the closer a value is to 1.0, the more dissimilar.

Algae

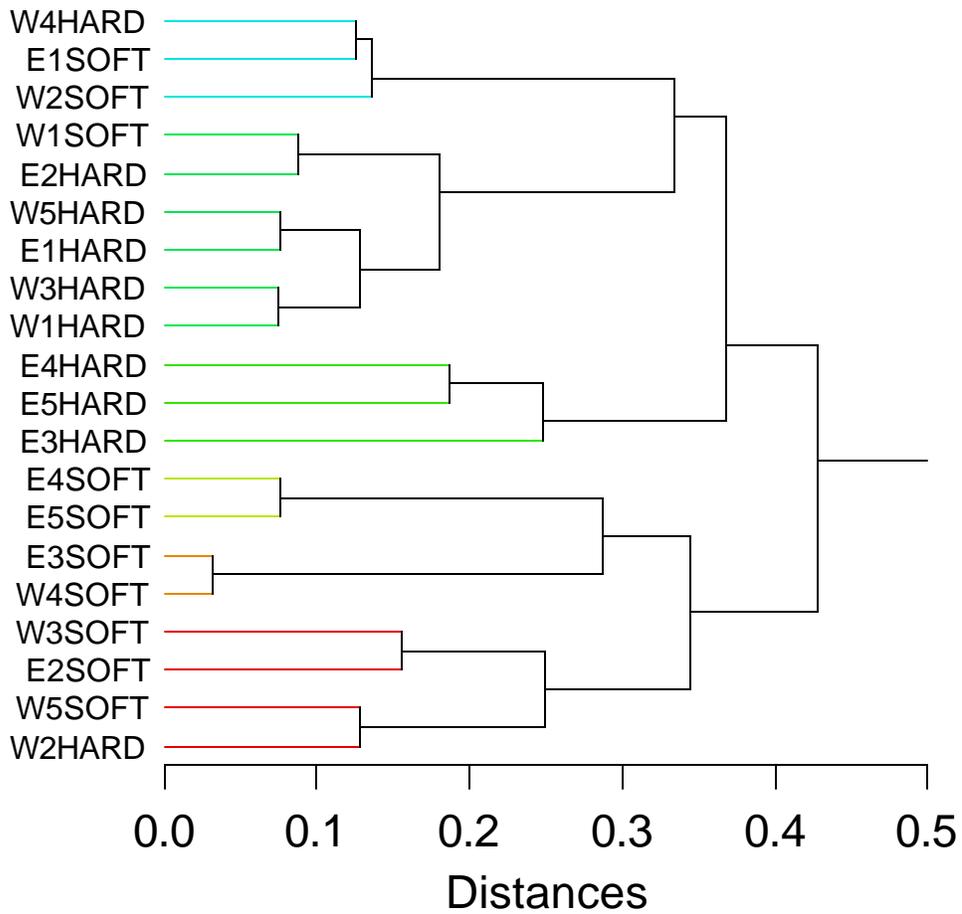


Figure 22. Cluster analysis of key algal species groups by classified by site. Note that the “distance” axis is a measure of % dissimilarity – the closer a linkage value is to 0, the more similar the sites are, and the closer a value is to 1.0, the more dissimilar.

Appendix E. 2002 Logistical Statistics

Personnel: Julie Barber (GS-7 Biotech student hire, ½ time), Jennifer Fisher (GS-7 Biotech, ½ time student hire), Mike Donnellan (GS-8 Biotech full time Term/ Project Manager, 2/3 year), Scott VanSant (GS-7 Biotech full-time seasonal)

Volunteer Hours (approximately): 400

Volunteer Personnel: Erica Kean, Katie Lotterhos, Bethan Davis, Sue Hazlett, Kyna Mallery, Kate Koschmann, Jeremy _____

Beginning of field season: 5/22/02

End of field season: 9/30/02

Field Days (total): 42

Vessel Days: M/V Capelin 24; M/V Nunatak 18 (3 cruises)

Dives Logged (person-dives): 314 (205 in 2001)

Hours Underwater: 235 (151 in 2001)

Air Compressor Hours: 90 (2+ work weeks)

Sites Re-sampled: 20

New sites established: 10

Total # Sites sampled: 31 (one additional site not to be used in analysis – otter impacted)

Outreach Presentations: 4 (USGS Science Symposium, Gustavus school [3 grades])

FY 02 Budget: \$110,000 (approximately; \$90k salary, \$7500 equipment, \$2900 services; \$2200 travel)

Appendix F. Project Products (as of 12/2002)

- 3 Seasons of ecological data from 20 permanent sites at –30' MLLW
- 1 Season of ecological data from 10 permanent sites at –15' MLLW
- User-friendly ecological database
- Biological specimen collection (250+ fish, marine invertebrates, algae)
- User-friendly Specimen/Image database
- Metadata for all databases
- Comprehensive species inventory list for GLBA proper
- Archived digital video footage for all sites
- Preliminary kelp canopy aerial survey
- Project study plan (under review by USGS ASC / Eric Knudsen as of 12/02)
- Preliminary Analysis of 2000/2001 data
- 2001 Annual Report
- 2002 Annual Report
- Protocols (Field Sampling, Data Processing, Equipment, Specimen Collection, GLBA Diving)
- Continuous water temperature record for 20 locations in Bay
- 2 Master's theses (in progress)
 - Larval crab dispersal to/from GLBA (Marine Reserves)
 - Dungeness crab injury rates in BARCO recreational fishery

Appendix G. Comprehensive Species List (as of 12/10/2002)

Glacier Bay Species List, Field Season 2000

Taxon (O'Clair and O'Clair 1998, Brusca and Brus updated 12/10/02 MD)	CommonName	A Depth	Zo Notes
Phylum Bacillariophyta			
?	unidentified benthic diatoms		
Phylum Chlorophyta			
<i>Codium ritteri</i>	Coarse Spongy Cushion		
unidentified green blade (probably <i>Ulva/L</i>)	Sea Lettuce		
Phylum Phaeophyta			
<i>Agarum clathratum</i>	Sieve Kelp		add algal orders to list
<i>Alaria fistulosa</i>	Dragon Kelp		
<i>Alaria marginata</i>	Ribbon Kelp		
<i>Costaria costata</i>	Seersucker (5-ribbed)		
<i>Cymathere triplicata</i>	Three-ribbed Kelp		
<i>Desmarestia</i> spp. (including species compi)	Acid Kelp		
<i>Laminaria bongardiana</i>	Split Kelp		
<i>Laminaria saccharina</i>	Sugar Kelp		
<i>Nereocystis luetkeana</i>	Bull Kelp		
<i>Fucus gardneri</i>	Rockweed		
<i>Pleurophycus gardneri</i>	Sea Spatula		
<i>Desmarestia munda</i>	Acid Kelp		
<i>Hedophyllum sessile</i>	Sea cabbage		intertidal
Phylum Rhodophyta			
<i>Halosaccion glandiformis</i>	Sea Sac		intertidal
<i>Constantinea</i> sp.	Cup and Saucer		
unidentified coralline crust (possibly <i>Litho</i>)	Rock Crust		
Unidentified fleshy algal maroon crust			
<i>Neoptilota asplenioides</i>	Sea Fern		must be positively identifi
<i>Opuntiella californica</i>	Red Opuntia		
<i>Palmaria</i> spp.	Red Ribbon		must be positively identifi
<i>Polysiphonia pacifica</i>	Polly Pacific		must be positively identifi
<i>Pterosiphonia bipinnata</i>	Black Tassel		must be positively identifi
<i>Turnerella mertensiana</i>	Red Sea-Cabbage		
<i>Sparlingia pertusa</i>	Red eyelet silk		
unidentified reds (possibly <i>Callophyllis</i> , etc)			
Phylum Porifera			
<i>Stylissa stipita</i>	Vase Sponge		
many unidentified sponges			
Phylum Cnidaria			
Class Hydrozoa			
Order Hydrioda			
Suborder Leptomedusae			
<i>Abietenaria</i> sp.	Hydroid		
Class Scyphozoa			
Order Stauromedusae			
<i>Haliclystus stejnegeri</i>	Stalked Jellyfish		
Class Anthozoa			
Sub-class Octocorallia			
Order Pennatulacea			
<i>Ptilosarcus gurneyi</i>	Orange Sea Pen		
???	unidentified very large sea pen observed in 2002 Boulder Isl.		
Order Alcyonacea	Soft Corals		

Glacier Bay Species List, Field Season 2000

<i>Gersemia rubiformis</i>	Sea Strawberry	
Sub-class Hexacorallia		
Order Actiniaria		
<i>Metridium giganteum</i>	White Plumed Anemone	
<i>Metridium senile</i>		
<i>Urticina crassicornis</i>	Painted/Christmas Anemone	
<i>Urticina lofotensis</i>	Rose-spotted Anemone	must be positively identifi
<i>Cribrinopsis fernaldi</i>	Pink anemone	
<i>Anthopleura spp</i>		must be positively identifi
Phylum Annelida		
Class Polychaeta		
Order Spionida		
Family Spionidae	Spionid Polychaete	
Subclass Sedentaria		
Order Terebellida		
Family Pectinariidae		
<i>Pectinaria granulata</i>		must be positively identifi
Order Sabellida		
Family Sabellidae		
<i>Eudistylia vancouveri</i>		must be positively identifi
<i>Schizobranchia insignis</i>	Soft-tube Plume Worm	must be positively identifi
Family Serpulidae		
<i>Serpula vermicularius</i>	Calcareous Tubeworm	must be positively identifi
Family Spirorbidae	Dwarf Tubeworms	
Phylum Arthropoda		
Subphylum Crustacea		
Class Maxillopoda		
Subclass Cirripedia		
Order Thoracica		
<i>Balanus spp.</i>	Acorn Barnacle	must be positively identifi
<i>Semibalanus spp.</i>	Rock Barnacle	must be positively identifi
Class Malacostraca		
Subclass Eumalacostraca		
Order Decapoda		
Suborder Pleocyemata		
Infraorder Caridea		
Family Pandalidae		
<i>Pandalus hypsinotus</i>		
<i>Pandalus danae</i>		
<i>Pandalus platyceros</i>		must be positively identifi
Family?		
<i>Lebbeus grandimanus</i>	Candy Stripe Shrimp	
Family Crangonidae		
<i>Sclerocrangon boreas</i>	Sculptured Shrimp	must be positively identifi
Family Hippolytidae		
<i>Heptacarpus spp.</i>	Shrimp	must be positively identifi
Infraorder Anomura		
Family Paguridae		
<i>Elassochirus gilli</i>	Pacific Red/Orange Hermit Crab	
<i>Elassochirus tenuimanus</i>	Widehand Hermit Crab	
<i>Pagurus ochotensis</i>		

Glacier Bay Species List, Field Season 2000

<i>Pagurus capillatus</i>		must be positively identifi
<i>Pagurus beringanus</i>		
<i>Pagurus spp.</i>	Hermit Crab	
<i>Paguristes spp.</i>	Hermit Crab	must be positively identifi
Family Lithodidae		
<i>Paralithodes camtschaticus</i>	Red King Crab	
<i>Rhinolithodes wosnessenskii</i>	Rhino crab	is this in the correct fami
<i>Cryptolithodes spp.</i>	Umbrella crab	must be positively identifi
Infraorder Bracyura		
Family Majidae		
<i>Pugettia producta</i>	Kelp Crab	must be positively identifi
<i>Pugettia gracilis</i>		must be positively identifi
<i>Chionoecetes bairdi</i>	Tanner Crab	
<i>Mimulus foliatus</i>	Mimicking Crab	must be positively identifi
<i>Oregonia gracilis</i>	Decorator Crab	
Family Atelecyclidae		
<i>Telmessus cheiragonus</i>	Helmut Crab	
Family Cancridae		
<i>Cancer gracilis</i>	Graceful Rock Crab	
<i>Cancer magister</i>	Dungeness Crab	
<i>Cancer oregonensis</i>	Pygmy Rock Crab	
<i>Cancer productus</i>	Red Rock Crab	
Family xxxxx		
<i>Hyas lyratus</i>	Pacific Lyre Crab	
Phylum Mollusca		
Class Polyplacophora		
Order Ischnochitonida		
<i>Tonicella lineata</i>	Lined Chiton	
<i>Tonicella insignis</i>		must be positively identifi
<i>Mopalia lignosa</i>	Woody Chiton	must be positively identifi
<i>Placiphoralla rufa</i>	Predatory chiton	
Order Acanthochitonida		
<i>Cryptochiton stelleri</i>	Giant Pacific Chiton	
Class Gastropoda		
Subclass Prosobranchia		
Order Archaeogastropoda		
Family Trochidae		
<i>Calliostoma sp.</i>		must be positively identifi
<i>Calliostoma annulatum</i>	Purple Ringed Topsnail	
Family Acmaeidae		
<i>Acmaea mitra</i>	Whitecap Limpet	must be positively identifi
Order Mesogastropoda		
Family Trichotropidae		
<i>Trichotropis cancellata</i>	Checkered Hairysnail	
Family Naticidae		
<i>Cryptonatica affinis</i>	Arctic Moonsnail	
Family Cymatiidae		
<i>Fusitriton oregonensis</i>	Oregon triton	
Order Neogastropoda		

Glacier Bay Species List, Field Season 2000

Family Muricidae		
<i>Boreotrophon sp.</i>	Trophons	
<i>Beringius kenecottii</i>		
<i>Nucella sp.</i>	Dogwinkle	must be positively identifi
Family Buccinidae		
<i>Buccinum plectrum</i>		must be positively identifi
<i>Colus sp.</i>		must be positively identifi
<i>Neptunea lyrata</i>	Ridged Whelk	
Subclass Opisthobranchia		
Order Nudibranchia		
Suborder Arminacea		
<i>Janolus fuscus</i>		must be positively identifi
Suborder Doridacea		
<i>Diaulula sandiegensis</i>	Ringed Doris	
<i>Triopha catalinae</i>	Catalina triopha	
Suborder Dendronotacea		
<i>Dendronotus rufus</i>	Red Dendronotid	
<i>Dendronotus frondosus</i>		must be positively identifi
<i>Dendronotus albus</i>	White spotted dendronotid	
<i>Melibe leonina</i>	Lion Nudibranch	
<i>Tochuina tetraquetra</i>	Tochni	
Suborder Aeolidacea	Aeolid Nudibranchs	
<i>Aeolidia papillosa</i>		
Class Bivalvia		
Subclass Lamellibranchia		
Superorder Filibranchia		
Family Mytilidae		
<i>Modiolus modiolus</i>	Northern Horsemussel	
<i>Mytilus trossulus</i>	Foolish mussel	intertidal
Family Pectinidae		
<i>Chlamys spp.</i>	Scallop spp.	must be positively identifi
Family Anomiidae		
<i>Pododesmus macroschisma</i>	Alaska Falsejingle	
Subclass Protobranchia		
Family Sareptidae		
<i>Yoldia spp.</i>		must be positively identifi
Subclass Heterodonta		
Family Cardiidae		
<i>Clinocardium nuttalli</i>	Nuttall's cockle	
<i>Serriepes groenlandica</i>	Greenland cockle	
Family Mactridae		
<i>Tresus sp.</i>	Gaper	must be positively identifi
<i>Mactromeris polynyma</i>	Arctic surfclam	
Family Tellinidae		
<i>Macoma spp.</i>		
Family Veneridae		
<i>Saxidomus gigantea</i>	Butter Clam	
<i>Protothaca staminea</i>	Pacific littleneck	
<i>Humilaria kennerleyi</i>	Kennerley's Venus	must be positively identifi
Subclass Asthenodonta		

Glacier Bay Species List, Field Season 2000

Family Myidae		
<i>Mya spp.</i>	Softshell clam	
Family Hiatellidae		
<i>Panomya sp.</i>	Roughmya	
<i>Hiatella sp.</i>		
Class Cephalopoda		
Subclass Coleoidea		
Order Octopoda		
<i>Octopus sp.</i>	Octopus	must be positively identifi
Phylum Bryozoa		
Class Gymnolaemata		
<i>Membranipora membranacea</i>	Kelp Lace	must be positively identifi
<i>Hippodiplosia insculpta</i>	Fluted Bryozoan	
<i>Microporina borealis</i>	Orange-stalked Bryozoan	must be positively identifi
Phylum Brachiopoda		
Class Articulata		
<i>Terebratalia transversa</i>	Common Lampshell	
Phylum Echinodermata		
Subphylum Eleutherozoa		
Class Asteroidea		
Order Valvatida		
Family Goniasteridae		
<i>Mediaster aequalis</i>	Vermilion Sea Star	
Order Velatida		
Family Solasteridae		
<i>Crossaster papposus</i>	Rose Star	
<i>Solaster dawsoni</i>	Morning sun star	must be positively identifi
<i>Solaster endeca</i>	Sun Star	must be positively identifi
<i>Solaster stimpsoni</i>	Northern Sun Star	
<i>Pteraster tessellatus</i>	Cushion star	
<i>Solaster paxillatus</i>		must be positively identifi
Order Spinulosida		
Family Echinasteridae		
<i>Henricia leviuscula</i>	Blood Star	
<i>Henricia aspera</i>		must be positively identifi
<i>Henricia sanguinolenta</i>		must be positively identifi
Order Forcipulatida		
Family Asteroiidae		
<i>Evasterias troschelii</i>	Mottled Star	
<i>Leptasterias spp.</i>		must be positively identifi
<i>Leptasterias polaris</i>	Six-armed star	must be positively identifi
<i>Orthasterias koehleri</i>	Long-armed star	
<i>Pycnopodia helianthoides</i>	Sunflower star	
<i>Stephanasterias albula</i>		must be positively identifi
<i>Stylasterias forreri</i>	Fish-eating Star	must be positively identifi
Class Ophiuroidea		
<i>Ophiopholis aculeata</i>	Daisy Brittle Star	
<i>Gorgonocephalus eucnemius</i>	Basket Star	
Class Echinoida		

Glacier Bay Species List, Field Season 2000

Superorder Echinacea		
<i>Strongylocentrotus droebachiensis</i>	Green Sea Urchin	
<i>Strongylocentrotus pallidus</i>	White Sea Urchin	
Class Holothuroidea		
Subclass Dendrochirotea		
<i>Cucumaria frondosa</i>	Giant Black Cucumber	
<i>Cucumaria miniata</i>	Orange Sea Cucumber	
<i>Eupentacta pseudoquinquesemita</i>	False White Sea Cucumber	must positively identify
<i>Pentamera sp.</i>		must positively identify
<i>Chiridota discolor</i>	Jelly Bean Sea Cucumber	must positively identify
<i>Psolus chitonoides</i>	False chiton	
Subclass Aspidochirotea		
<i>Synallactes challengerii</i>		must positively identify
Phylum Urochordata		
<i>Halocynthia aurantia</i>	Sea Peach	
Phylum Chordata		
Class Osteichthyes		
Family Gadidae		
<i>Gadus macrocephalus</i>	Pacific Cod	
Family Agonidae	Poachers	
<i>Podothecus accipenserinus</i>	Sturgeon poacher	identified by Mayumi Ar
<i>Hypsagonus quadricornis</i>	Fourhorn Poacher	identified by Mayumi Ar
Family Cottidae		
<i>Hemilepidotus spp.</i>	Irish Lords	
<i>Hemilepidotus jordani</i>	yellow Irish lord	identified by Mayumi Ar
<i>Myoxocephalus polyacanthocephalus</i>	Great Sculpin	
<i>Enophrys lucasi</i>		must positively identify
<i>Enophrys sp.</i>		NOT identified by Mayu
<i>Enophrys bison</i>	Buffalo Sculpin	
<i>Psychrolutes paradoxus</i>	Tadpole Sculpin	must positively identify
<i>Oligocottus maculosus</i>	Tidepool Sculpin	identified by Mayumi Ar
<i>Ramphocottus richardsonii</i>	Grunt Sculpin	
<i>Nautichthys oculo-fasciatus</i>	Sailfin Sculpin	identified by Mayumi Ar
<i>Radulinus sp.</i>	unid. Sculpin	must positively identify -
Family Scorpaenidae		
<i>Sebastes sp.</i>	Rockfish	
Family Hexagrammidae		
<i>Hexagrammos decagrammus</i>	Kelp Greenling	
<i>Hexagrammos stelleri</i>	Whitespotted Greenling	
<i>Hexagrammos octogrammus</i>	Masked Greenling	
Family Liparidae		
<i>Liparis callyodon</i>	Spotted Snailfish	must positively identify
<i>Liparis pulchellus</i>	Showy Snailfish	have picture
Family Stichaeidae		
<i>Anoplarchus purpureus</i>	high cockscomb	identified by Mayumi Ar
<i>Stichaeus punctatus</i>	Arctic Shanny	identified by Mayumi Ar
<i>Lumpenus sagitta</i>	Snake Prickleback	identified by Mayumi Ar
Family Cyclopteridae		
<i>Eumicrotremus orbis</i>	Pacific Spiny Lumpsucker	
<i>Aptocyclus ventricosus</i>	Smooth Lumpsucker	
Family Bathymasteridae		

Glacier Bay Species List, Field Season 2000

<i>Ronquilus jordani</i>	Northern Ronquil
<i>Bathymaster signatus</i>	Searcher
Family Pholidae	
<i>Pholis laeta</i>	Crescent Gunnel
Family Pleuronectidae	Unid Righteye Flatfish
<i>Lepidopsetta bilineata</i>	southern rock sole
Family Bothidae	Unid Lefteye Flatfish
<i>Eumetopias jubatus</i>	Steller Sea Lion
<i>Enhydra lutris</i>	Sea Otter
<i>Homo sapien</i>	Common Human