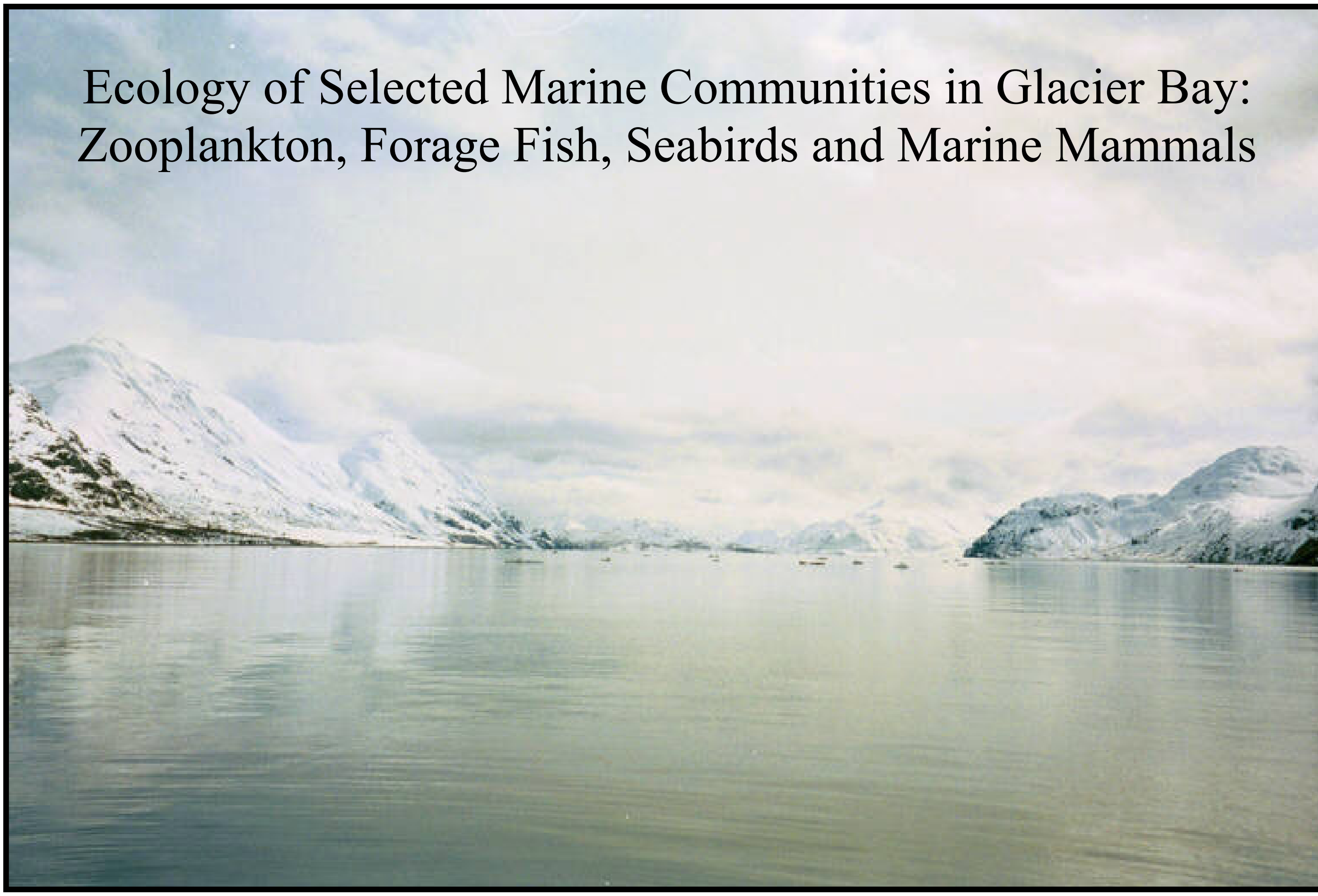
Ecology of Selected Marine Communities in Glacier Bay: Zooplankton, Forage Fish, Seabirds and Marine Mammals



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Project Summary

Objectives

- Sample and assess relative abundance of zooplankton and fish in Glacier Bay.
- Hydroacoustically sample Glacier Bay to assess spatial abundance of pelagic fish.
- Identify specific areas of importance associated with high abundance and/or diversity of prey.
- Estimate marine predator densities (marine birds and marine mammals).
- Link forage fish predator distributions to spatial patterns of forage fish abundance.
- Provide a detailed report of research methodology, extent of data, and overview of initial analysis and findings. Full synthesis of data from different disciplines was beyond the scope of this report. Please contact author for information about ongoing analyses of data.

Key Findings

- Areas of high fish abundance can be correlated with the oceanographic or limnic features of Glacier Bay.
- Areas in close proximity to tidewater glaciers as well as in the recently non-tidewater upper-inlets support some of the highest abundances of prey species (zooplankton and forage fish) in Glacier Bay.
- The outlets from salmonid streams appear to impart a strong positive local influence on the nearshore marine ecosystem.
- Glacier Bay supports spawning stocks, and provides nursery areas for several key forage fish including sand lance, capelin, and walleye pollock.
- The areas of high euphausiid or forage fish abundance within Glacier Bay are clearly defined, encompassing a relatively small part of the total Bay area. These areas are critical to the biological function of the Bay – Upper inlets, river and stream outlets, Whidbey Passage.
- The east and west arms of Glacier Bay supported differing fish community structures. Capelin predominated in the East Arm of Glacier Bay, whereas pollock dominated elsewhere in the Bay and in Icy Strait.
- Acoustically determined forage biomass was concentrated in relatively few areas and in shallow, nearshore waters.
- High-density patches of prey were very rare, and less than 8% of the survey area contained patch densities suitable for foraging marine birds and mammals.
- Glacier Bay supports seasonally dependent assemblages of predators (marine birds and mammals) that are both abundant and diverse.
- The picivorous and surface feeding marine birds and mammals using the Bay were often associated with high-density patches of prey (acoustically determined).
- Marine birds and mammals in Glacier Bay were found to use predominantly nearshore habitats.
- Compared to 1991 surveys, our surveys in 1999 and 2000 indicated most apex predator species are either stable or increasing, e.g. humpback whales; however, both Kittlitz's and marbled murrelets have declined.
- Alternative survey designs were examined and could be sufficient for monitoring population trends of most but not all species.

Abstract

We studied oceanography (including primary production), secondary production, small schooling fish (SSF), and marine bird and mammal predators in Glacier Bay during 1999 and 2000. Results from these field efforts were combined with a review of current literature relating to the Glacier Bay environment. Since the conceptual model developed by Hale and Wright (1979) 'changes and cycles' continue to be the underlying theme of the Glacier Bay ecosystem. We found marked seasonality in many of the parameters that we investigated over the two years of research, and here we provide a comprehensive description of the distribution and relative abundance of a wide array of marine biota.

Glacier Bay is a tidally mixed estuary that leads into basins, which stratify in summer, with the upper arms behaving as traditional estuaries. The Bay is characterized by renewal and mixing events throughout the year, and markedly higher primary production than in many neighboring southeast Alaska fjords (Hooge and Hooge, 2002).

Zooplankton diversity and abundance within the upper 50 meters of the water column in Glacier Bay is similar to communities seen throughout the Gulf of Alaska. Zooplankton in the lower regions of Glacier Bay peak in abundance in late May or early June, as observed at Auke Bay and in the Gulf of Alaska. The key distinction between the lower Bay and other estuaries in the Gulf of Alaska is that a second smaller peak in densities occurs in August. The upper Bay behaved uniformly in temporal trends, peaking in July. Densities had begun to decline in August, but were still more than twice those observed in that region in May. The highest density of zooplankton observed was 17,870 organisms/m^3 in Tarr Inlet during July. Trends in zooplankton community abundance and diversity within the lower Bay were distinct from upper-Glacier Bay trends. Whereas the lower Bay is strongly influenced by Gulf of Alaska processes, local processes are the strongest influence in the upper-Bay.

We identified 55 species of fish during this study (1999 and 2000) from beach seines, mid-water trawls, and rod and line catches. The diversity of physical, oceanographic, and glacial chronological conditions within Glacier Bay contribute a suite of factors that influence the distribution and abundance of fish. Accordingly, we observed significant differences in the abundance and distribution of fish within the Bay. Most significantly, abundance and diversity (primarily juvenile fish including walleye Pollock, eelblennies, and capelin) were greatest at the head of both the east and west arms where zooplankton abundance was greatest – in close proximity to tidewater glaciers and freshwater runoff.

All of Glacier Bay and Icy Strait were surveyed hydroacoustically for plankton and fish during June 1999 surveys. Acoustically determined forage biomass was concentrated in relatively few important areas such as Pt. Adolphus, Berg Bay, on the Geikie-Scidmore shelf, around the Beardslee/Marble islands, and the upper arms of Glacier Bay. Forage biomass (primarily small schooling fish and euphausiids) was concentrated in shallow, nearshore waters; 50 % of acoustic biomass was found at depths < 35m, 80 % of biomass at depths < 80m. During our sampling, high density patches of prey were very rare, and less than 8 % of the area surveyed in Glacier Bay contained patch densities suitable (e.g., > 0.01 fish/m^3) for seabirds foraging on zooplankton and small schooling fish. Less than

1 % of the area contained patches suitable (e.g., >0.1 fish/m^3) for whales foraging on zooplankton and small schooling fish. High-density aggregations of 0.1-10 fish/m^3 were comprised mostly of schools containing capelin, pollock, herring or euphausiids (0.1-1 kg/m^3).

During predator surveys (1999-2000), we observed 63 species of birds and 7 species of marine mammals. Seasonal distribution and abundance of these "apex" predators was highly variable by species. Glacier Bay supports high numbers of seabirds and marine mammals that consume zooplankton and small schooling fish. Nearshore areas had higher densities of both birds and marine mammals. Several areas, such as Pt. Adolphus, Berg Bay, on the Geikie-Scidmore shelf, the Beardslee/Marble islands, and the upper arms of Glacier Bay were focal points of small schooling fish and zooplankton consuming marine birds and mammals. Comparisons between surveys and a prior study (1991) suggested that the assemblage of birds and marine mammals in the Bay is undergoing change. Most notable was a clear decline in *Brachyramphus spp*. murrelets while other apex species are increasing or remaining stable.

It should be noted that many of the birds and mammals observed during this project, e.g. mergansers, do not forage on zooplankton and small schooling fish; rather they forage on benthic fish and sessile invertebrates. While distribution and sampling data for these marine predator species are valid, this study did not sample benthic fish and sessile invertebrates. Thus, recommendations made by this project should be interpreted as generally specific to the zooplankton/small schooling fish marine food web components of the Glacier Bay Ecosystem.

Introduction

Reason for Work

Although this report synthesizes work from several specific projects (e.g., oceanography, plankton surveys, small-schooling-fish surveys, hydroacoustic surveys, predator surveys), the reason behind, and objectives of, any ecosystem level project in Glacier Bay can fall under the motives suggested by Catton (1995):

> *"In coming years, the critical test of biocentric resource management will be to assess what is happening to the park's marine environment. With greater sophistication and breadth than ever before, the NPS will attempt to differentiate between natural and anthropogenic environmental changes occurring in Glacier Bay"*

Any attempt to link observed changes in Glacier Bay to either one of these causes (natural or anthropogenic) can only be speculative without a thorough understanding of the Bay's ecosystem. Glacier Bay is composed of living organisms interacting both with each other and with the non-living environment. These interactions should be viewed holistically, rather than as a collection of unrelated objects. This forms the foundation of the science of ecology (Hale and Wright, 1979) and is the underlying principle of this study, which quantitatively investigates the components of the Glacier Bay marine ecosystem, both spatially as well as temporally. In summary, over the last 300 years as Glacier Bay has been revealed by retreating ice, a thriving marine ecosystem has developed. In this report, we provide a thorough description of the small-schooling fish and zooplankton based ecosystem from physical processes to upper-trophic level predators as it appears in 1999 and 2000.

Glacier Bay hosts an abundant variety of marine predators during summer including significant populations of humpback whales (*Megaptera novaeangliae*) and *Brachyramphus* murrelets. The distribution and abundance of small schooling fish in Glacier Bay affects both the geographic and temporal status of many of these predators (e.g., humpback whales; Krieger and Wing, 1986). Southeastern Alaska humpback whales for example, were only encountered in areas where concentrations of prey were extensive and dense (Krieger and Wing, 1986). However, with the exception of the limited work done by the NMFS Auke Bay Marine laboratory (Wing and Krieger, 1983; Krieger and Wing, 1984; Krieger and Wing, 1986), little is known about temporal and spatial patterns of forage species in the Bay (Hale and Wright, 1979). Due to logistical hurdles, tracking of these forage species has been and will likely remain problematic. Instead, tracking marine predators, the trophic apex of the small-schooling fish and zooplankton ecosystem, may reflect changes to other portions of the ecosystem composition and function. Hence, by understanding the abundance and distribution of fish, whales, and seabirds in Glacier Bay we may be able to understand the relationships between trophic levels. This study represents the first comprehensive survey of predators and their small-schooling fish and zooplankton prey in Glacier Bay.

The distribution and health of marine predator populations, the most visible portion of marine ecosystems, depends on the abundance and distribution of their prey species. For example, declines in some seabird and marine mammal populations in the Gulf of Alaska have been linked to shifts in abundance and composition of their prey species, primarily small schooling fish (SSF – see page 6 for a definition), over the past 45 years (Anderson and Piatt, 1999). Changes in SSF populations have in turn been linked to long-term changes in the physical environment of the northern Gulf of Alaska. Small schooling fish distribution is largely influenced by local oceanography and availability of food (primarily zooplankton). Therefore, we assume that an understanding of both temporal and spatial patterns of oceanography and productivity will lead to a greater understanding of the distribution and abundance of small schooling fish and the predators that rely upon them.

Zooplankton support much of the life in the oceans as the prey of many fish, whales, and seabirds. Zooplankton abundance and composition directly influences survival and distribution of those predators as well as nutrient cycling. The zooplankton community provides a nexus between primary production of the oceans and larger animals, fueling the dominant food web of marine systems. Zooplankton includes temporary members of the planktonic community termed meroplankton (larval stages of benthic animals) and icthyoplankton (fish eggs and larvae); as well as permanent members of the community such as euphausiids, copepods, and chaetagnaths. Benthic animals such as crabs, sea urchins, sea stars, mussels, and barnacles all reproduce by releasing planktonic larval stages that disperse and settle as juveniles. Knowledge of zooplankton abundance and composition is key to understanding dispersal of benthic animals and the trophic web of marine systems.

Oceanography and productivity are particularly important factors to understand within the Glacier Bay ecosystem due to the complexity of sills, constrictions, large currents, and numerous glaciers. Questions, such as posed by Brattegard (1980): “Do such deep fjords have deep water faunas mainly composed of shallow water species, or do we find faunas similar to those found at corresponding depths in the ocean, or do we find elevated deep-sea faunas?” are still relevant today for fjord ecosystems like Glacier Bay. Brattegard goes on to highlight several studies that have shown deep-sea species assemblages (such as the trophically important mesopelagic myctophids; Matthews and Heimdal, 1980) living in coastal fjords. Furthermore, tidewater glaciers can significantly influence the circulation, water properties, and sedimentation of glacial fjords (Cowan, 1992), and the potential for enhanced biological activity at their faces has been known for over 60 years (Hartley and Dunbar, 1938); although Hale and Wright (1979, p83) do not make note of this in their Glacier Bay ecosystem model. Finally, in temperate fjords, such as those in Southeastern Alaska, there are large diurnal and seasonal differences in freshwater and suspended sediment discharged from glaciers (Cowan, 1992). Most glacial-melt enters fjords during the summer from large conduits located at the base of the glacier. This turbid water, usually less dense than the more sailine fjord, rises to the surface, and may result in seasonal water properties and circulation, that are unlike that of fjords where melt-water enters at sea-level (e.g., Kostaschuk, 1985).

Ecosytem-level research in Glacier Bay also provides a unique opportunity to study post-glacial succession in the marine environment. Research has usually focused on vegetative colonization in Glacier Bay (e.g., Lawrence et al., 1967) and more recently the colonization of postglacial freshwater streams (e.g., Milner, 1987; Sidle and Milner, 1989). Colonization of new freshwater streams, particularly by anadromous species presumably influences the nearshore marine community. Additionally, newly exposed marine areas will also provide unique opportunities for opportunistic marine species that are able to live in highly turbid waters.

Separating natural post-glacial succession processes from other non-glacial long-term changes from anthropogenic perturbations is a challenge for both scientist and resource manager. Notable recent changes of predator distributions and abundance within Glacier Bay include humpback whales that historically made greater use of the upper Bay (Hale and Wright, 1979; Wing and Krieger, 1983; Krieger and Wing, 1984; Krieger and Wing, 1986), although they are present in greater numbers in the lower Bay (Doherty and Gabriele 2001); dramatic declines in abundance of the Kittlitz's murrelet over the last decade; apparent movements of seals from the East to West Arms (Taggart, *personal communication*); and the recent rapid range expansion and abundance of sea otters in the Bay since first noted in 1993 (Bodkin et al. 2000). In all these cases ecosystem level research will be invaluable to separation of cause and effect, whether it be a result of anthropogenic (e.g., vessel disturbance) or natural (e.g., increased kelp in nearshore areas as a result of sea otter predation on urchins) origin.

<u>Small Schooling Fish: A Definition</u>

The terms "small schooling fish" (SSF) and "forage fish" have been frequently used, sometimes interchangeably in recent ecosystem studies (e.g., Exxon Valdez Trustee Council funded Sound Ecosystem Assessment, "SEA" and Alaska Predator Ecosystem Experiment "APEX" projects). The terms are loosely defined, sometimes by species composition (e.g., Springer and Speckman, 1997) and sometimes also by size (e.g., Litzow et al., 2000). The current project was originally defined as a "small schooling fish project" and encompasses the description of forage fish used by the organizing committee for the 1996 Forage Fishes in Marine Ecosystems conference (cited in Springer and Speckman, 1997):

> *"Forage fishes are abundant, schooling fishes preyed upon by many species of seabirds, marine mammals, and other fish species. They provide important ecosystem functions by transferring energy from primary and secondary producers to higher trophic levels."*

Springer and Speckman (1997) proposed that Gulf of Alaska SSF include Pacific sand lance, capelin, eulachon, herring, juvenile walleye pollock, lanternfishes (myctophidae), and juvenile Pacific salmon.

Marine fishing technology is still relatively primative, even though methods to find fish are highly advanced. In almost all cases, a net is put into the water that non-selectively collects fish bigger than its mesh size. Therefore, our research collects most fish in a targeted area rather than just the "small schooling fish" and our report reflects this diversity of catch. In this regard, the "Small Schooling Fish Project" has grown from the original efforts to solely characterize the prey of humpback whales. Glacier Bay is also home to numerous other predatory species that prey upon small fish, which either do not school or are demersal (solitary or schooling), and frequently left out of the ‘forage’ or ‘SSF’ definition. Stichaeids (the pricklebacks and gunnels) are a prominent example in the Glacier Bay ecosystem. Furthermore, key macroinvertebrate prey species such as jellyfish, euphausiids, and cephalopods are caught in conjunction with fish catches and are all prey species for numerous predators. Although not technically SSF, we discuss all of these species, highlighting those that are of importance to specific predators within the Bay.

Because our focus was SSF, our investigations centered on processes and taxa that are either important to SSF in terms of production (e.g. phytoplankton and zooplankton) or consumption, (e.g. piciverous or zooplankton consuming marine predators). Although we report distributions and densities of all marine birds and mammals sighted on surveys, this report focuses on the SSF associated food web. Investigation of other trophic webs would enhance the management of marine resources in Glacier Bay and could potentially explain patterns of marine bird and mammal predator distributions not associated with SSF.

Methods

Study Area

The rapid recession of a Neoglacial ice sheet within the last 250 years exposed Glacier Bay, a Y-shaped fjord in southeast Alaska, which is approximately 100 km long (Figure 1). Width of the Bay varies from 4 to 8 km in the lower Bay; widening to approximately 15 km in the middle-Bay, and then narrows again in the upper-Bay. The Fairweather range dominates the head of Glacier Bay, with numerous peaks over 3,000 m culminating in Mt. Fairweather at 4600 m. Numerous glaciers (12 tidewater) discharge ice and turbid water into the upper arms and inlets. Glacier Bay is connected to the Gulf of Alaska via Icy Strait (Figure 1).

Glacier Bay became a National Monument on 25 Feb 1925, and currently lies within the 11,030 km^2 Glacier Bay National Park and Preserve, established on 02 Dec 1980. The area was designated wilderness on 02 Dec 1980, designated a Biosphere Reserve in 1986, and a World Heritage Site in 1992.

Within Glacier Bay, numerous sills (submerged glacial moraines) separating deeper basins (up to 458 m deep) and constrictions affect water movement. Hooge and Hooge (2002) highlight the role of this bathymetry in influencing oceanography and primary productivity. Glacier Bay also experiences a very large tidal range. The tidal cycle is mixed semi-diurnal (two high and two low tides per day, of unequal heights), with a tidal range (difference between mean high and mean low tides) averaging from 3.7 m at Bartlett Cove to 4.2 m at locations approximately half-way up both the West and East arms. The tidal range further up-Bay is even greater. During the largest spring tides, the tidal range can reach 7.3 m at Bartlett Cove, and exceeds 7.8 m in the upper arms.

Glacier Bay is an important wildlife area, providing habitat and feeding opportunities for numerous marine mammals, seabirds, and commercially exploited fish species. Perhaps the best recognized of these wildlife species is the humpback whale. Each summer 15 to 20 humpback whales regularly feed in park waters, concentrating in the lower part of the Bay. Tidewater glaciers, and wildlife species such as the humpback whale, Steller sea lion, and Kittlitz's murrelet draw numerous visitors. Despite the relativly remote setting, 442,607 tourists visited the park during 1999, most on large cruise ships.

Research Platforms

Field work for this project was conducted over two years (Table 1) and from several vessels (Figure 2). All beach seining was carried out from a 5 m aluminum hulled Naiad inflatable with 45 hp Honda 4-stroke outboard. Mid-water trawls and oceanography during 1999 were conducted from the Alaska Department of Fish and Game (ADF&G) 22 m stern trawler, the RV *Pandalus*. Oceanography and plankton samples during March and May 2000 were taken from the RV *Alaksan Gyre* (formerly RV *Tamnik*). All summer samples during 2000 (oceanography, zooplankton (after May), trawls) were from the RV *David Grey*, a 9-m Uniflight. Predator surveys were made from all the above research vessels (RV) and the *Lutris II*, an 8 m Boston Whaler.

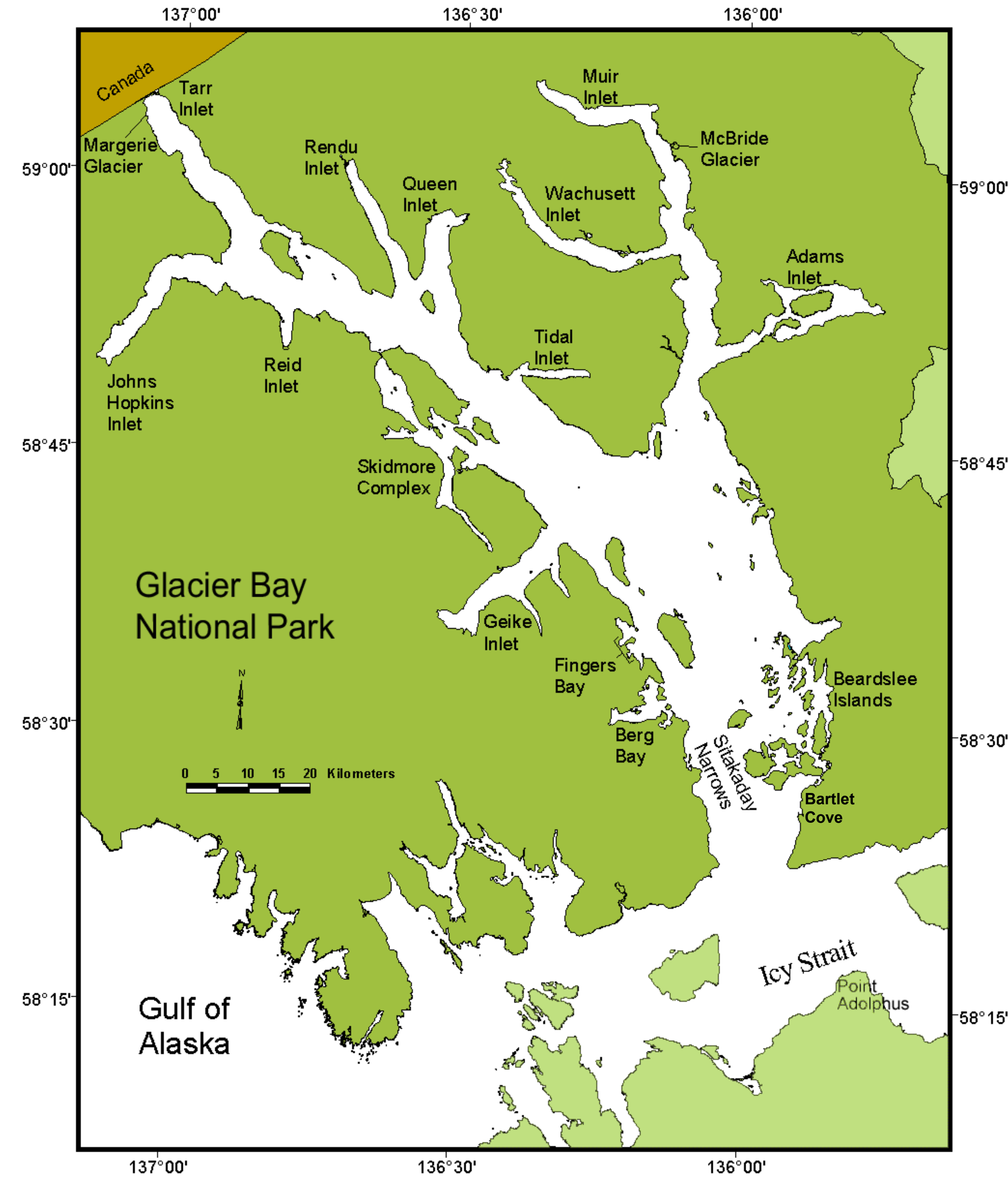

Figure 1. Glacier Bay study area, with place names used throughout the report.

Table 1. Time periods for surveys of Glacier Bay (fishing and predator surveys)

Year	Nearshore Zooplankton Hauls	Pelagic Zooplankton Hauls	Icthyoplankton Trawls	Beach Seine	Mid-Water Trawls	Predator Surveys
1999				10 Jun to 23 Jun	10 Jun to 23 Jun[H]	10 Jun to 23 Jun
						5 Nov to 12 Nov
2000		17 Mar to 21 Mar				17 Mar to 22 Mar
		10 May to 17 May	24 May to 29 May			
	31 May to 9 Jun	10 Jun to 14 Jun	10 Jun to 14 Jun	31 May to 9 Jun		17 to 22 June
	12 Jul to 20 Jul	26 Jul to 31 Jul		12 Jul to 20 Jul	26 Jul to 31 Jul[I]	
	1 Aug to 10 Aug	12 Aug to 16 Aug		1 Aug to 10 Aug	12 Aug to 17 Aug[I]	

[H] Modified Herring Trawl; [I] Isaacs Kidd Mid-Water Trawl

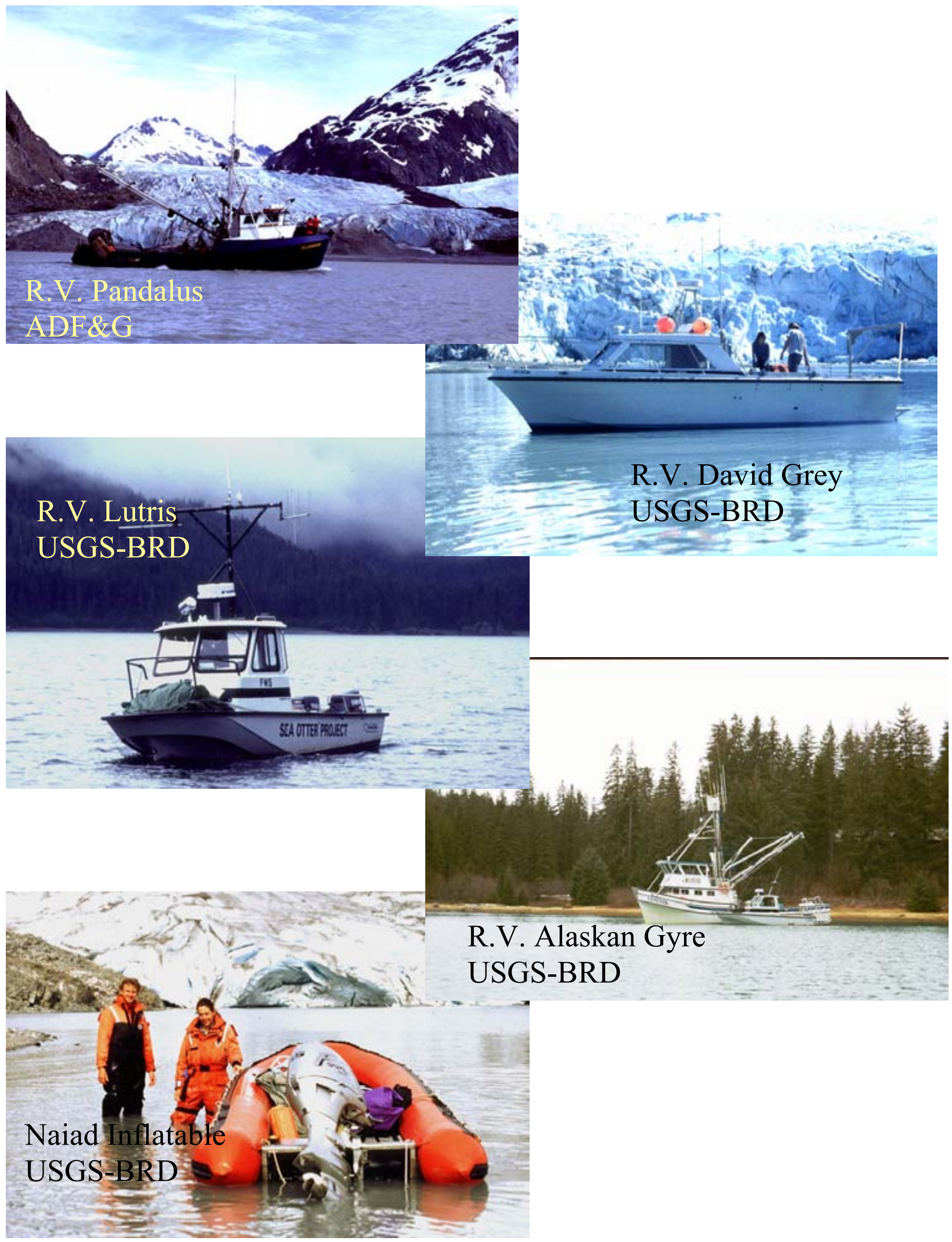

Figure 2. Research vessels used during the small schooling fish research project in Glacier Bay during 1999 and 2000.

Oceanography

We used three sources of oceanographic data to relate physical water parameters to biological observations: 1) Previously published oceanographic information (Matthews and Quinlan 1975; Simenstad & Powell 1990), 2) Unpublished data collected by USGS Biological Resources Division, Glacier Bay Field Station in an 9 year oceanographic investigation of Glacier Bay (Hooge and Hooge, 2002); and 3) A CTD recorder (Sea-Bird SBE 19 SEACAT Profiler profiling conductivity-temperature-depth probe CTD; Sea-Bird Electronics, Bellevue, Washington, USA) was used to acquire oceanographic data (Figure 3). The instrument primarily used in this study had a Sea-Bird SBE 5-01 submersible pump, a LI-COR LI-192SA photosynthetically active radiation (PAR) sensor (LI-COR, Inc., Nebraska, USA), a D&A OBS-3 turbidity sensor (D&A Intstrument Co., Port Townsend, Washington, USA) and WET Labs WetStar (WET Labs, Inc., Philomath, Oregon, USA) flurometer, in addition to the standard temperature probe, conductivity cell, and pressure port. The CTD was used in conjunction with each fishing and zooplankton tow. Casts were made to 90% of water depth or a maximum of 240 m (Background data collected by Hooge and Hooge (2002) used a maximum depth of 335 m).

Figure 3. CTD apparatus ready for deployment on the *RV David Grey.*

SeaSoft software modules (Sea-Bird Electronics) were used for initial processing of the raw instrument data. The data were processed through six functions; these first converted the data to engineering units, then passed conductivity and pressure through low-pass filters. The temperature and conductivity measurements were then temporally aligned to compensate for the different response times of the respective sensors. Next, all scans in which reversed pressure indicated slowdowns or failure of a minimum velocity test (< 0.25m/sec) were removed. The derived variables salinity, density, and depth in saltwater were then calculated. Finally, the data were averaged into 1-meter depth bins (for detailed processing see Hooge et al. 2000)

In this paper, depth is calculated as depth in seawater derived from pressure, temperature is presented in degrees Celsius, salinity is reported in parts per thousand (ppt) and is derived from conductivity, density is presented as sigma-t (density anomaly) in kg/m^3, and fluorescence is reported in mg/m^3. We did not calibrate the fluorometer for the in-situ Glacier Bay phytoplankton assemblages; therefore chlorophyll-*a* measurements are most appropriate for relative comparisons within this study and for gross comparisons with other studies. The CTD reports optical backscatter (OBS) in microvolts, which can be recalculated into mg/m^3 of sediment based on the instrument's calibration.

The OBS sensor used in this study has not yet been calibrated for the sediments found at the oceanographic stations along the length of Glacier Bay. Therefore, the voltage values do not have absolute meaning and are only presented for relative comparisons within Glacier Bay. Due to variations between casts and surveys in the time of day and amount of cloud cover, photosynthetically active radiation (PAR), which is measured in microeinsteins/ sec/ m^2, has been standardized as a proportion of the (maximum) surface value for each cast. This standardization allows comparisons of relative light penetration between casts and surveys, but does not provide an absolute measure of PAR.

Stations established by Hooge and Hooge (2002) were used as a basis of site selection for several of the temporal collections; pelagic zooplankton stations, Tucker trawls, and Isaacs Kidd mid-water trawls. The first station is located in Icy Strait (Figure 4). Subsequent stations are spaced approximately every 9.3 km (5 nautical miles) to the head of Tarr Inlet in the West Arm and to the head of Muir Inlet in the East Arm. We chose to biologically sample every second station leading to a total of 11 regular samples sites with a separation of approximately 19 km (10 nautical miles).

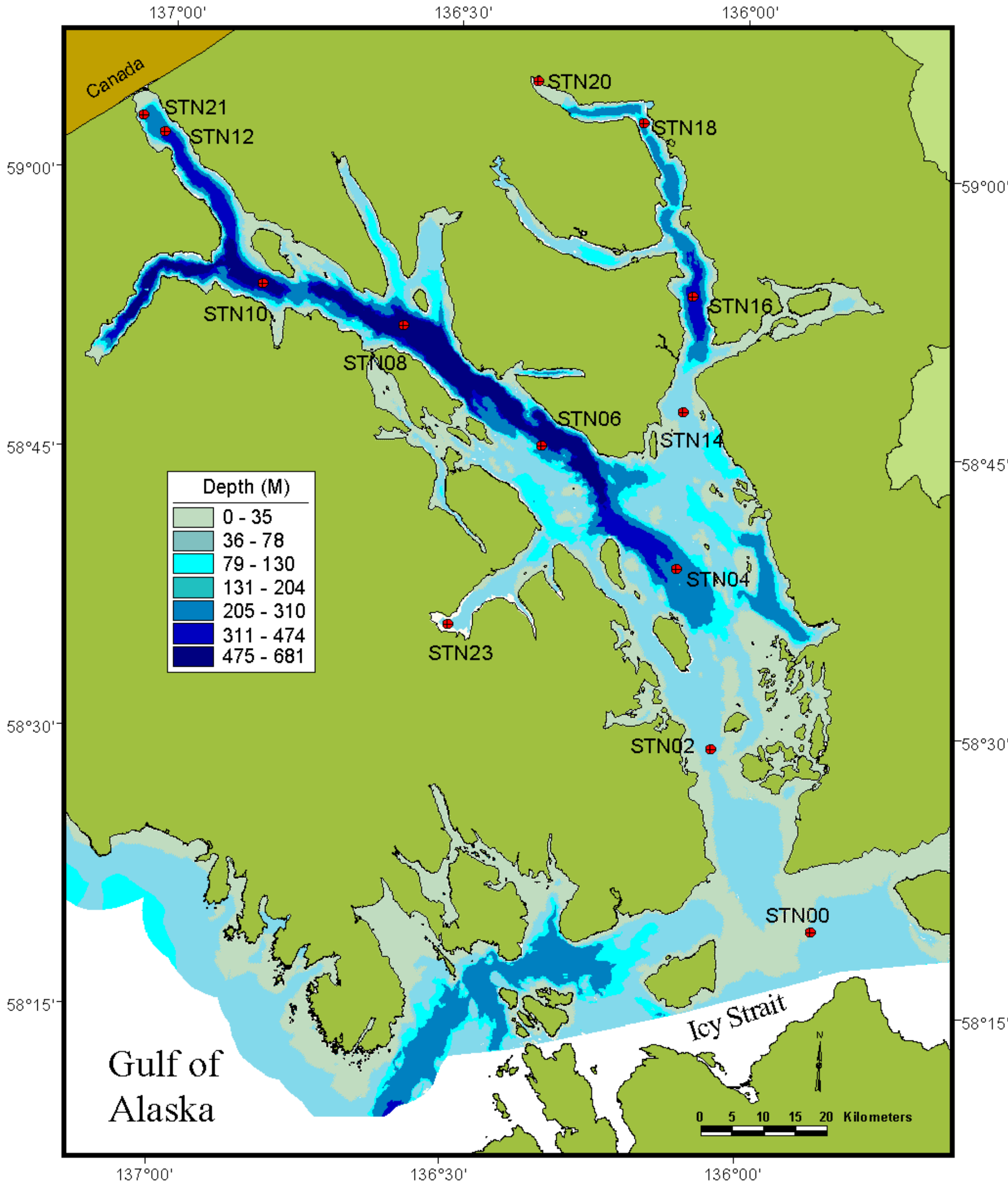

Figure 4. Glacier Bay's bathymetry with pelagic study stations indicated. Locations are derived from Hooge and Hooge (2002) (exact locations are given in Appendix 1).

Hydroacoustic Survey

During 10-23 June, 1999, we conducted simultaneous hydroacoustic, predator, and trawl surveys throughout Glacier Bay and in the eastern half of Icy Strait, from the mouth of Glacier Bay east to Lynn Canal. For these surveys we used the R/V *Pandalus*, a 22 m stern trawler operated by the Alaska Department of Fish and Game.

Hydroacoustic data were collected with a Biosonics DT4000 echosounder using a single beam 120 kHz transducer with a 6º beam angle. This transducer was capable of transmitting and receiving to depths of ca. 185m, but the quality of data collected below about 130m may be questionable. We limit most of our analyses of acoustic data to depths of less than 100m. Threshold for data collection was set at –80 dB. The transducer was attached to a hydrodynamic sled and deployed off the side of the survey vessel 1-2 m below the water surface. All data were logged directly to a computer in real time. GPS locations were obtained from a Rockwell Precision Lightweight Global-positioning Receiver (PLGR), which has a worst-case horizontal position accuracy of ±10 m at speeds <36 kph (Anonymous 1995). At the beginning of the cruise, the hydroacoustic system (transducer, cable and sounder) was calibrated in the field using a tungsten steel sphere of known target strength.

In order to quantify forage fish biomass for GIS mapping, hydroacoustic transect data were binned into 30 second (horizontal) by 5 m (depth) bins and integrated using EchoView© (Sonar Data Pty. Ltd., Hobart, Tasmania) to determine S_A (mean backscattering per nm^2) of each bin. For mapping purposes, data were further summed into 10 min. bins and 25 m depth intervals. Mean backscatter (S_A) is a common currency used for spatial comparisons of hydroacoustic data (e.g., Hewitt and Demer 1993, Brodeur and Wilson 1996). The integration threshold was set at -90 dB, but because of an EchoView software error (that we later uncovered), the actual threshold for integration was 27 dB higher, i.e., -63 dB. Because we were very conservative in setting the initial threshold, the functional threshold of -63dB was still low enough to detect common forage fish such as capelin and pollock at lengths of less than 10 mm, and herring at lengths of less than 30 mm, and therefore adequate for the purpose here of describing spatial distribution of "forage fish" (typically >50mm) in Glacier Bay. As we prepare to publish these data, we plan to reanalyze the acoustic data using updated Echoview software (See Appendix 4 for detailed EchoView© protocols).

Significant schools identified on acoustic echograms were trawled to assess species composition. A total of 48 tows at 38 stations were conducted during the course of hydroacoustic surveys (see section 4.5.1). In order to assess absolute prey densities of these schools comprised of known species from trawls, relative measures of acoustic biomass (S_A) were converted to absolute estimates of fish density (fish/m^2) by dividing S_A by σ (backscattering cross-sectional area of single prey) for species with the following known target strengths: Pollock $TS=20Log(L_{cm})-66$ (Foote and Traynor 1988); Capelin $TS=20Log(L_{cm})-65$ (Rose and Leggett 1988); Herring $TS=26Log(L_{cm})-76$ (Thomas and Kirsch 1999); Euphausiids $TS= 34.8Log(L_{mm})-127.5$ (Hewitt and Demer 1993); Physoclist $TS=20Log(L)-65.5$ (Foote 1987). Mean lengths (and ranges, in mm) of common fish captured in trawls (see Pelagic Fish Community: Modified herring mid-water trawls in June 1999 for details) were: Pollock 140.9 (12-602); capelin 65.6 (14-109); Herring 208.4 (165-235); Euphausiids ≤ 30mm; All fish combined (weighted by CPUE of each species) 98.1 (10-602). Integration thresholds were set at –73 to –83 dB (corrected values) when calculating S_A for known-species schools.

Zooplankton

Zooplankton samples were collected using a 333µm mesh net with a 0.6-meter opening (Figure 5). Vertical hauls were taken from 50 meters, if possible, or 2 m from bottom. We sampled at even numbered physical oceanography sites (Figure 4), and immediately offshore beach seine sites (within 0.25 mile; Figure 6). In this manner our collections were synchronized with physical oceanography data collection and small schooling fish sampling at 17 nearshore and 13 mid-channel stations. Mid-channel stations were sampled for only plankton and oceanography from March to May; fish sampling and nearshore stations were added from June to August. Samples were preserved in 4 % formalin.

Figure 5. Preparing the vertical-haul zooplankton net for deployment at Station 18 in upper Muir Inlet.

Samples were analyzed using a Wild dissecting scope at 30-60X magnification, according to the methods of Edmondson and Litt (1982). Samples were diluted to a known volume that varied according to abundance. Sample volume ranged from 200-1050mL (107 samples), one sample was counted entirely. Five-milliliter subsamples were pipetted out using an automated draw pipetter. We analyzed the subsamples using a modified Bogorov tray and all animals were recorded. Replicate subsamples were done with a minimum of 100 individuals of the most common taxa-lifestage grouping counted twice. The volume of water filtered was calculated for each sample and all analysis results are quantified as number of individuals per cubic meter of water integrated over the sampling depth.

Not all species found in Glacier Bay by this study were identifiable to species. Therefore, some taxa are reported at Genus or Family taxanomic levels. Animals were identified into 44 taxa-lifestage groupings listed in Appendix 2. Copepods were not generally identified to species in samples, and species present are given in Appendix 3. Adults and copepodids were counted together, grouped by size as small (<2.5mm) or large (>2.5mm). Nauplii were counted as a separate taxa grouping. As copepod nauplii were not quantitatively retained by our net, trends in nauplii abundances should be considered as relative, rather than an absolute index of abundance trends.

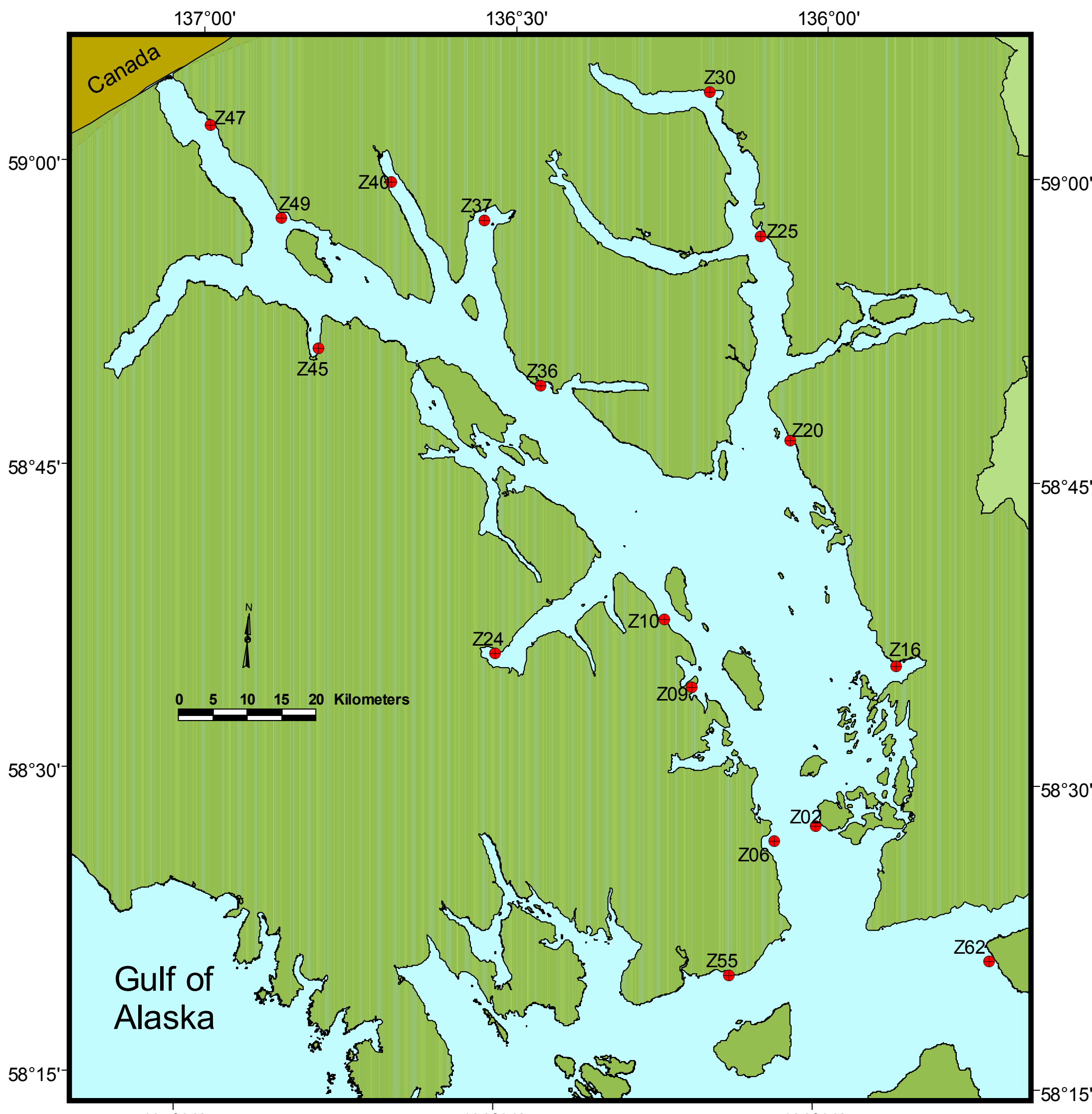

Figure 6. Glacier Bay nearshore zooplankton stations. Numbers and locations correspond with select beach seine stations (exact locations are given in Appendix 1).

Ichthyoplankton
Icthyoplankton samples for this study were collected from the RV *David Grey*, a 9-m glass fibre Uniflight. Horizonal plankton tows were taken at discrete depths by using a 1-m^2 Tucker trawl, rigged with two 505-µm mesh nets (Figure 7).

Figure 7. Deploying the Tucker Trawl at Station 21 (Margerie Glacier). Note tripping mechanism holding chains connected to net frames at top of net.

Depths in the Bay range to as deep as 458 m and were unattainable due to limitations of our small winch. We expected a key component of the larval fish assemblage to be walleye pollock. Based on depth distributions for this species in Prince William Sound (Müter and Norcross, 1994) we decided to obtain samples from each of the following depth strata per station: 0-25 m, 25-50 m, 50-75 m, and 75–100 m (three stations located on sills were shallower and were sampled to the bottom). Although depths were determined by wire angle and scope, precise depths were recorded using a Wildlife Computers MK7 time-depth recorder attached to the net. The nets were rigged with a double-tripper which allowed the second net to be opened and closed via a messenger from the surface. The net was towed for five minutes in the direction of tidal flow at a towing speed of 1.8 to 2.2 knots. Only daytime tows were made. Volume filtered during each tow was calculated from a General Oceanics flowmeter that was attached to the central portion of the mouth of the net. Samples used for analysis were immediately preserved in 50 % isopropyl alcohol. The alcohol was renewed after 24 hours and after 2-3 days.

Littoral Zone Fish Community
We used beach seines to sample nearshore fish communities in June 1999 and in June, July, and August 2000. This fishing method effectively and non-selectively samples

shallow, inshore waters with sandy or smooth bottoms (Cailliet *et al.*, 1986). Our variable-mesh net was 37 m long. The wings were tapered from 2.4 m in the middle to 0.5 m at the outer-edge using 28 mm knotless nylon stretch mesh. The seine was equipped with a 6 mm stretch mesh bag located in the middle of the seine. Thirty meters of rope were attached to the ends for deployment. The net was set parallel to shore about 15 m from the beach as described by Cailliet *et al.* (1986; Figure 8).

Figure 8. Typical beach seine set in upper Muir Inlet.

We sampled 59 sites in Glacier Bay and Icy Strait during 1999 (Figure 9). These sites were chosen based on our ability to seine them (i.e., all low to medium angled beaches with substrates ranging from mud to cobble); where several suitable beaches existed in close proximity, we chose the optimal seine location based on the above criteria. We attempted to seine each site at both high and low tide. However, several sites could not be seined at high tide due to large rocks, or at low tide due to large rocks or mussel beds. During 2000, we streamlined the study to a more even distribution of beaches. Only those beaches that could be repeatably sampled on both low and high tides were used (Figure 9). Four beaches from the original 1999 survey were visited to facilitate this. Several of the beaches sampled in 1999 were in close proximity to each other, particularly the case in lower regions where the Bay is largely carved from a glacial outwash plain (Hale and Wright, 1979). The inlets in the upper Bay are characterized by steeply sloping shores usually composed of bedrock. Few possible seine beaches exist in these areas and most were utilized in this study.

Beach seining was conducted within two-hour windows on either side of high and low tides. A single set was made as this usually provides good representation of species richness and dominant species rank (Allen *et al.*, 1992; Robards *et al.*, 2000). Fish were sorted by species, counted, and subsampled individuals were weighed and measured. When sampling large catches, subsamples were taken with the remaining fish still in shallow water to minimize mortality.

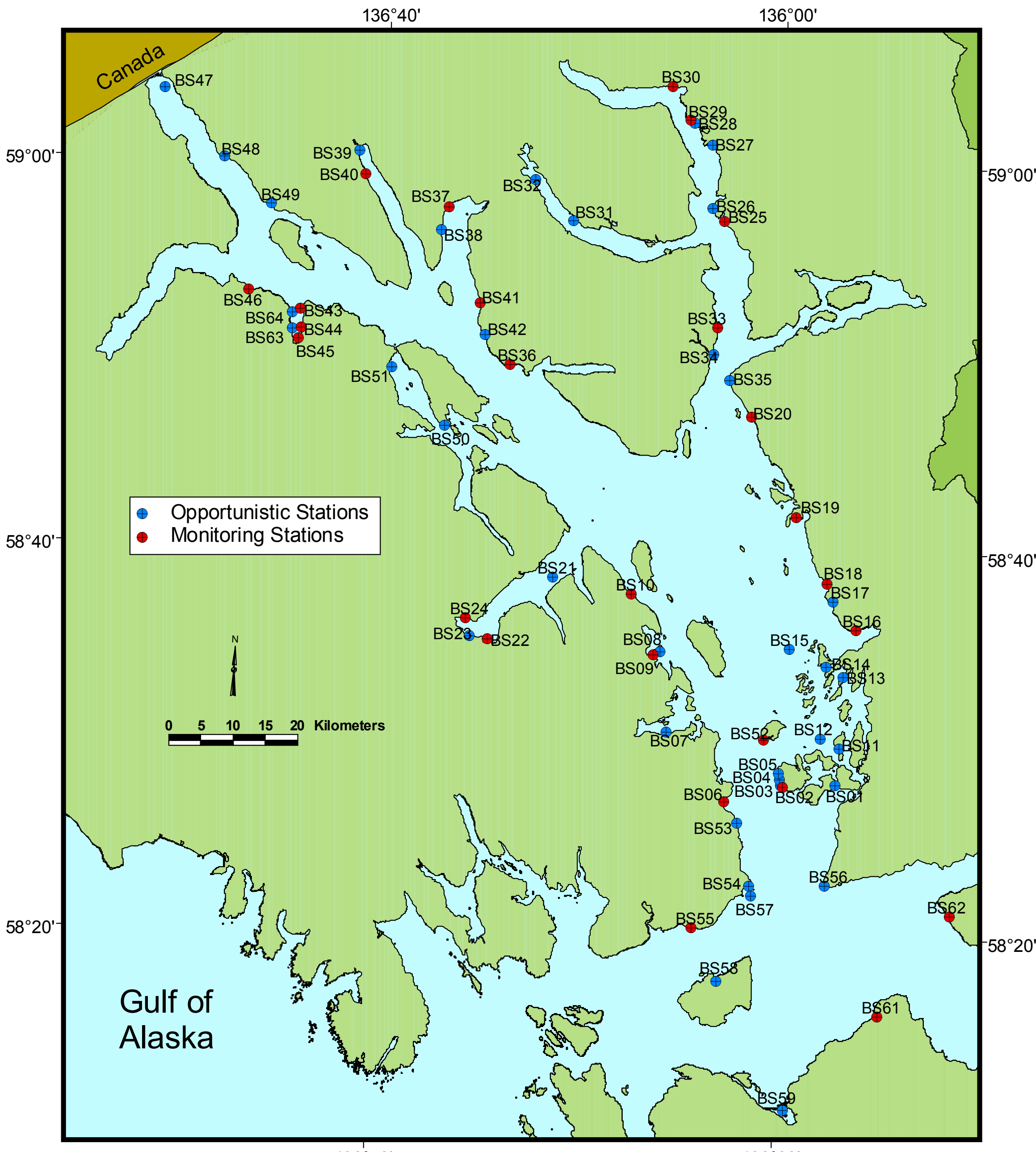

Figure 9. Glacier Bay beach seine locations. Monitoring stations were developed as a set of sites that could be sampled repeatably on both high and low tide. Opportunistic sites were sampled at least once, but could not be sampled at both tidal states or were in close proximity to another beach seine station (exact locations are given in Appendix 1).

High-latitude fish assemblages, particularly those found in shallow water habitats, are subjected to large seasonal variations in temperature and day length. These physical factors impart a strong natural seasonality to community structure (Nash, 1988). Some fish species move from shallow water habitats to deeper waters in winter when thermal tolerances are exceeded (Allen and Horn, 1975; Allen, 1982; Bennett, 1989). Decreases in catch size between spring and fall peaks have also been observed by many investigators (e.g., Livingston, 1976; Horn, 1980; Allen, 1982; Thorman, 1986; Methven and Bajdik, 1994; Robards et al., 2000). We sampled from June until August to establish seasonal species composition and abundance within nearshore areas of Glacier Bay during summer.

Pelagic Fish Community

Mid-water fish were caught by two means, a modified herring mid-water trawl during June, 1999; and an Isaacs Kidd mid-water trawl (IKMT) during summer, 2000.

Modified herring mid-water trawl

Mid-water trawls during summer 1999 were collected from the RV Pandalus. Small schooling fish were located with a Biosonics DT4000 digital 120kHz echosounder, and significant targets were fished. A modified herring mid-water trawl with a mouth opening of 50 m^2 was used to sample the bioacoustic signals in the pelagic zone. This net is larger than the Isaacs Kidd net used in 2000 and uses large steel doors to sink the net and keep it open. Mesh sizes diminished stepwise from about 50 mm in the wings to 10 mm at the cod-end, which was lined with 3 mm mesh. A plastic cod-end collecting bucket with 1 mm mesh openings was then attached to the end of the cod-end, and was detached and rinsed after each tow. A Furuno net-sounding system monitored the depth of the headrope while fishing. A temperature-depth recorder (MK VII TDR, Wildlife Computers) was mounted on the headrope to continuously record the exact depth of the net while fishing.

The target towing speed was about 2.5 knots, and the average tow duration was 20 minutes. All fishing was done during daylight hours. After each fishing tow, the water column was sampled with a CTD. If multiple fishing tows were taken at a station, only one CTD cast was conducted.

All fishes were identified and measured to the nearest 1 mm fork length (FL). Stomach contents of adult walleye Pollock were identified. Capelin, Northern Smoothtongue, and Northern lampfish were frozen and weighed on land with an electronic balance to obtain length-weight relationships.

Isaacs Kidd mid-water trawl

Mid-water trawls during summer, 2000 were collected from the RV *David Grey*, using an IKMT (Figure 10). This net is reliable and stable, and is easily handled from a moderately sized vessel such as the *RV David Grey* in general sea conditions (Isaacs and Kidd, 1953). The net has Mid-water trawls during summer, 2000 were collected from the

RV *David Grey*, using an IKMT (Figure 10). This net is reliable and stable, and is easily handled from a moderately sized vessel such as the *RV David Grey* in general sea conditions (Isaacs and Kidd, 1953). The net has a 2.8 m^2 opening and uses a depressor bar rather than weight to reach depth and can be towed at relatively high speeds (> 4 knots). Oblique tows were taken between the surface and 50 m depth. Although depths were determined by wire angle and scope, precise depths were recorded using a temperature-depth recorder (MK VII TDR, Wildlife Computers) attached to the net. The net was towed for a total of 30 minutes in the direction of tidal flow at a towing speed of 3.5 to 4.5 knots. Only daytime tows were made. Volume filtered during each tow was calculated from a General Oceanics flowmeter that was attached to the central portion of the mouth of the net. Small schooling fish were separated from larval fish and zooplankton. Samples used for analysis were immediately preserved in 50 % isopropyl alcohol. The alcohol was renewed after 24 hours and after 2-3 days. We calculated a mean shrinkage of 6% for fish preserved in alcohol (*n*=100). Lengths were adjusted to fresh sizes for analysis.

Figure 10 Deploying the Isaacs-Kidd mid-water trawl. Note the ‘V’ shaped depressor bar to which the net is attached.

During July we visited oceanographic stations 00, 02, 04, 06, 08, 10, 14, 16, 18, 20, and 21 (Figure 4), making one tow at each location. During August we visited the same stations but fished an additional 2 times at Station 21 to better quantify fish abundance at the face of a tide water glacier (Margerie). During August we also fished additional inlets of Glacier Bay to compare fish abundance between tidewater influenced and non-tidewater influenced inlets. These inlets were Johns Hopkins (Station 24), Reid (Station Z45), Rendu (Station 26), Queen (Station 27), Geike (Station 23), and Wachusetts (Station 28).

Predator Survey
Predator surveys of marine birds and mammals were conducted in June of 1999 and 2000. Surveys included all of the coastline areas of Glacier Bay as well as sampling pelagic areas with transects spaced approximately 2.5 km apart. In addition to Glacier Bay itself, transects were surveyed in Icy Strait, and in 1999 there was also sampling in Dundas Bay following the grounding of a tourist vessel (*The Wilderness Adventurer)*. Surveys were made from the research vessels (RV) *Pandalus*, *Alaskan Gyre*, *Lutris II*, and *David Grey*. Ground speed for vessels was approximately 11-15 km/h (6-8 knots). To examine seasonal patterns of use of Glacier Bay by marine birds and mammals, we surveyed a systematic subset (approximately 30 %) of the more extensive summer transects in November of 1999 and March of 2000.

Surveys were conducted, with some modifications, according to protocols established by the U.S. Fish and Wildlife Service for marine birds (Gould et al., 1982; Gould and Forsell, 1989; See Appendix 5 for additional resources used on surveys). Surveys from the *Pandalus* and *Alaskan Gyre* counted and identified swimming birds and mammals within 150 m on either side or 300 m forward of the boat to species. Because of their lower viewing angles we limited the area of identification to 100 m on either side of the *Lutris II*, and *David Grey*. Birds were recorded as flocks, when possible, and the following behaviors were recorded: on the water, feeding, standing on flotsam or jetsam, or swimming with a fish held in the bill.

We counted all flying birds that crossed within transects. This allowed us to make comparisons with a previous survey conducted in 1991. Birds that were flying while holding fish were noted as such. Summing the numbers of flying birds and birds on the water for a given transect yields a density estimate (birds/km^2). Unusual bird or mammal sightings outside the transect boundaries were recorded as "off transect" and not used for analysis.

Bird and mammal sightings were recorded by entering them directly into a real-time computer data-entry system (DLOG; Glenn Ford, ECI) that plots sighting positions continuously using GPS coordinates. GPS locations were obtained from a Rockwell Precision Lightweight Global-positioning Receiver (PLGR). DLOG also provides the bottom depth and the distance to the nearest shore for all sightings.

At all times, 1 person entered data into a laptop computer, located in the wheelhouse, while observers surveyed from the best vantage points on each research vessel (RV). On the *Pandalus*, 1-2 observers surveyed from the bow, with a deck-height of 3.4 m above the water's surface. On the *Alaskan Gyre*, 2 observers surveyed from the wheelhouse, located 3.7 m above the water's surface. On the David Grey observers surveyed from top of the wheelhouse (2.4 m). Two observers on the *Lutris II* observed from water level (usually one of these observers was also navigating the vessel).

Observers actively scanned ahead of and alongside the survey vessel, and species identifications were confirmed using 7 – 10 power binoculars. Standard guides were used for identifications. Sightings were immediately called to the data entry person over hand-held VHF radios. If observers felt weather conditions were unsuitable for sighting small seabirds at 150-300 m, surveys were discontinued until conditions improved. Ancillary data on weather, sea conditions, observation conditions, bird behavior or plumages, and species of fish held by birds were collected for each transect.

All bird distribution maps were plotted using spatial locations from the Dlog data file. Latitude, longitude, species, and numbers were summarized in 1-minute blocks and imported into an ArcView GIS. The GIS was then used to develop maps of common species and specific species of interest.

Analysis Considerations

For gross comparisons of selected plankton and fish taxa, we divided Glacier Bay into four regions. Icy Strait; the lower-Bay is defined as south of a line between Rush Point and the northwestern tip of Young Island (i.e., Sitakaday Narrows); the middle Bay lies between there and a line between Muir Point and the northern entrance to Geike Inlet; and the upper Bay lies from there to the head of the western and eastern arms of Glacier Bay (Figure 11).

Abundance of fish caught does not represent true abundance because the efficiency of our nets is unknown. Furthermore, the efficiency of any type of net differs between species. For example, in beach seines, efficiency of catch for demersal species such as flatfish may be in the order of 30 – 40% (*Pleuronectes platessa*, cited in Gibson et al., 1996). Because of these limitations, we have made no estimates of absolute abundance in nearshore areas. However, based on the same net and deployment being used at all sites, and in both years, relative comparisons are still valid.

Data from predator surveys were summarized in a variety of ways. For completeness and basic comparisons, raw counts were provided from all surveys. For interannual comparisons, densities were calculated by averaging densities across all transects. To look at trends over the period 1991-2000 we used a unpublished survey conducted by John Piatt (USGS) and Allen Springer (UAF) in Glacier Bay during the summer of 1991 as a baseline. That data was then compared to a subset (nearshore transects) from the summer of 1999 and 2000 surveys. A randomization test was written and run on a number of common species to identify changes from the 1991 baseline. All comparisons were made with an apha level of 0.05. Finally, to compare survey intensities we used densities from varying numbers and arrangements of transects within Glacier Bay.

We have used common names throughout this report. A full list of Latin names is included in Appendices 2, 3, 8, and 9.

Results and Discussion

Oceanography

Temperature and salinity data were collected in conjunction with all pelagic fishing events conducted during this project, and are now included in the Glacier Bay oceanography database (Hooge and Hooge 2002). This report summarizes oceanographic parameters for the Bay but does not derive associations among specific CTD casts and fishing sets. Rather then replicating the comprehensive research of Hooge and Hooge, we have quoted or paraphrased from that report for conciseness.

Glacier Bay can be modeled as a tidally mixed estuary near the mouth leading into deep basins that stratify in summer, with the upper arms likely behaving as traditional entrained estuaries. The Bay is characterized by renewal and mixing events throughout the year, and by markedly high and more sustained levels of phytoplankton than in many neighboring southeast Alaska fjords (Hooge and Hooge, 2002).

Detected salinities in Glacier Bay ranged from approximately 3.8 to 31.9ppt. The least saline waters were found in narrow surface lenses near tidewater glaciers, and the most saline were found at depth near and just outside the mouth of the Bay; salinity trends in general followed this same pattern, with overall salinity decreasing towards the heads of the fjord. Although surface pan ice is common in the upper fjords in winter, detected water temperatures ranged from 1.9 to 12.2°C and were generally coldest at the heads of the Bay's two arms near glacial input and warmer near the Bay's mouth. The density of the waters sampled varied from 2.8 to 25.2kg/m^3. Density usually closely followed salinity patterns, and was generally least within narrow surface lenses in front of tidewater glaciers. The densest water was located at the bottom of the Bay's deepest basins or at the Bay's mouth. Water density increased with depth except in lower Glacier Bay during rapid tidal current flow, when density was virtually homogenous throughout the water column.

The lower part of Glacier Bay, from Sitakaday Narrows through the Bay's mouth and extending out to Cross Sound, is an area of intense mixing and upwelling due to strong tidally induced currents passing through the constrictions and shallow sill in this area. Visual observations of standing waves, whirlpools, and roils, as well as images from Advanced Very High Resolution Radiometry (AVHRR; Hooge and Hooge, 2002), all confirm the CTD data about turbulence in this region. Suspended particulates that are elevated at the heads of the Bay decrease in mid-Bay due to settling, but are re-suspended in the lower Bay's mixed area. The turbulence within this area was clearly demonstrated by trawls that collected particles of gravel despite fishing over 10 m above the substrate surface (as confirmed by TDR recorder).

In sharp contrast to the lower Bay sill area, the mid-Glacier Bay area from Willoughby Island to the East Arm's entry sill and from the mouth of the West Arm to the Gilbert Peninsula exhibits a strong pattern of stratification for much of the year. This water column stability is initiated each spring by both precipitation and glacial melting that supply fresh water that "floats" on the surface, and it is sustained through the summer and early fall by increased insolation and warmer temperatures that heat the surface waters (Hooge and Hooge, 2002).

The upper arms of Glacier Bay are colder year-round, and are usually characterized by a surface lens of less saline water from glacial melting. Although no evidence was found for strong traditional estuarine circulation in the upper arms of the Bay, most intermediate and deep water in the West Arm was indistinguishable from that of the mid-Bay. The one notable exception was the farthest up-Bay basin of the West Arm, which consistently exhibited the greatest salinities seen within Glacier Bay proper. At a depth of 240m, that basin's entry sill is well below the depth of any entrained water and thus does not prevent renewal per se. However, the slightly higher salinities observed behind it probably do indicate increased residence time in the basin. Periodic renewal events may deliver dense waters throughout sub-surface Glacier Bay; subsequent freshening of the central Bay's intermediate and deep waters could then prevent circulation over this sill, leaving the bottom of this basin temporarily saltier. In the East Arm there are three sills, of which the shallowest is 60m, probably deeper than the level of most entrained water. Although CTD cast data indicated that these sills restricted some movements of water in the East Arm, renewal of the entire arm occurred throughout the year except for short periods. This pattern of circulation is the same as described by Matthews and Quinlan (1975) for this inlet.

Stratification is well established during the summer months at the heads of both the West and East Arms. There was no evidence for upwelling at the heads of the inlets, as indicated by localized shallowing of the isopycnals or isohalines (Hooge and Hooge, 2002). However, clearly observable 'boils' close to tidewater glacier faces suggest that the momentum of upwelling meltwater from sub-surface injection is high, resulting in a jet that intersects the water surface (Cowan, 1992). These upward currents at the face of the glaciers probably bring deep-water nutrients to the surface. Furthermore, "brown zones" (Hartley & Dunbar, 1938; apparently upwelling brown-colored water) and other upwelling phenomena were observed in these areas. Oceanographic results indicate that these phenomena are local and do not propagate very far from the tidewater glacier faces.

The amount of chlorophyll-*a* in Glacier Bay waters reached an annual low in early winter, then peaked in March followed by slightly lower and generally decreasing levels through the summer into early fall. Maximum fluorescence values were no greater than 2.0mg/m^3 in winter and usually less than 1.0mg/m^3, but there was always some fluorescence at all times of year and at all stations (maximum values no less than 0.5mg/m^3). During the March peak, depth-integrated chlorophyll-*a* averaged 300mg/m^2 at 15m and 420mg/m^2 at 35m. However, maximum levels of chlorophyll-*a* greater than 50mg/m^3 were observed for at least one station in all months between March and September. In 2000, a secondary peak of chlorophyll-*a* in June nearly reached the intensity of the first bloom, and was followed by one or more smaller peaks. In early spring through late fall, phytoplankton was principally confined to a narrow surface depth range, except for areas where there was no water column stratification and the phytoplankton was distributed evenly from the surface to the seafloor. The sub-surface fluorescence maximum generally occurred at 5-10m, with little phytoplankton in the top

1m. Chlorophyll-*a* concentration rapidly decreased below the photic zone to less than 0.3mg/m^3 below 50m. In winter, chlorophyll-*a* was more broadly dispersed through the water column. There was high variability both spatially and temporally in chlorophyll-*a* levels, with the central Bay area exhibiting the most consistently high phytoplankton standing stocks. In the mixed areas of the lower Bay, the total amount of chlorophyll-*a* throughout the entire water column was less than in adjacent stratified stations. In the well-stratified upper West and East Arms, fluorescence profiles taken during a few mid-late summer surveys demonstrated elevated levels of chlorophyll-*a* throughout the water column, particularly in the sub-surface layers. The chlorophyll-*a* levels in these periglacial areas were anomalous for both their depth and continuous distribution through the water column, as well as for the absolute magnitude of production that they represented.

Phytoplankton levels in Glacier Bay were found to be surprisingly high and sustained. The peak levels of depth-integrated chlorophyll-*a*, a proxy for primary productivity, were as high in Glacier Bay as the peaks of most years in Southeast Alaska's Auke Bay (Ziemann et al. 1990). This pattern was observed despite the limited number of surveys made each year; our infrequent sampling could easily have missed much higher but short-lived peaks, which characterize all blooms in Alaskan fjords (Burrell 1986). In sharp contrast to Auke Bay and other Alaskan fjords (Burrell 1986, Sambrotto & Lorenzen 1986, Ziemann et al. 1990), Glacier Bay's average phytoplankton standing crop was sustained at a high level throughout the spring, summer, and fall. The early onset and peak of phytoplankton abundance was in March, corresponding to the onset of stratification. Although this bloom was approximately one month earlier than in Auke Bay (Ziemann et al. 1990), the timing is not atypical for Southeast Alaskan fjords (Burrell 1986). More surprisingly, some of the first sites in the Bay to evidence a bloom were the central and upper arms, which were still experiencing very cold temperatures. Subsequently, average fluorescence values decreased, but not precipitously, and again reached levels close to the maximum later in mid-summer. In contrast, the typical Southeast Alaskan bloom lasts only a few weeks before nutrients are depleted and standing crop levels plummet (Burrell 1986, Sambrotto & Lorenzen 1986, Ziemann et al. 1990). Moreover, summer conditions elsewhere are characterized by general nutrient depletion and by only occasionally renewed phytoplankton growth driven by nutrient-enhancing events (Iverson et al. 1974). In the late summer or early fall a smaller secondary bloom may occur in Alaskan coastal waters, but heavily silted systems such as glacial fjords are thought to have suppressed fall blooms (Burrell 1986). In Glacier Bay there was neither a precipitous drop in the standing crop following the initial spring bloom nor suppression of high phytoplankton levels in fall. No other fjord system in Alaska has been documented with this type of sustained productivity (Burrell 1986), although a similar pattern has been observed in Kachemak Bay, an estuary in Cook Inlet, south-central Alaska.

Phytoplankton production is especially important to consumers in Glacier Bay because of the limited potential for macrophytic algal growth, a limitation common to Southeast Alaskan fjords due to the steep-walled nature of the glacially carved bays (Burrell 1986).

The vertical topography and the high sediment input together restrict the proportion of area with adequate light penetration to the bottom where macrophytic algae can grow.

Two possible reasons for the high and sustained phytoplankton standing crop in Glacier Bay are a lack of zooplankton predators or persistently high nutrient availability (see also Hooge and Hooge 2002). Results from plankton surveys conducted throughout Glacier Bay by this project indicate that zooplankton populations are not depauperate in numbers. In addition, although there are few other previous data sets regarding zooplankton in Glacier Bay, at McBride Inlet in the upper East Arm, high densities of harpacticoid copepods, calanoid copepods, and other zooplankton were found even in the coldest, most brackish, and most turbid environment of the Bay (Simenstad & Powell 1990). The cold temperatures of Glacier Bay may prevent zooplankton from responding as quickly as phytoplankton can grow, due to the decrease in efficiency of respiration as compared to photosynthesis at cold temperatures (Byron 1982). However, suppressed zooplankton respiration is probably not sufficient to fully explain the high and sustained phytoplankton levels found in Glacier Bay. Further research is needed into the interactions of zooplankton and phytoplankton, particularly in light of the oceanographic complexity of Glacier Bay, which may dramatically affect species' metabolisms and temporal and spatial distributions.

The other possible explanation for high and sustained levels of phytoplankton is continual nutrient enhancement, which could result from several oceanographic processes. Foremost among these is the front that the confluence of the tidally mixed waters of lower Glacier Bay and the stratified waters of the central Bay must create. Such tidally mixed fronts are often associated not only with increased nutrient replenishment, but also with high and sustained primary production due to recently stratified (or frequently re-stratified) nutrient-rich surface waters (Pingree et al. 1975, Perry et al. 1983). In addition, deep-water renewal in Glacier Bay occurs much more frequently than previously thought; renewal ensures that deep and intermediate waters are not depleted of nutrients. When unstratified conditions occur (winter in Glacier Bay), surface waters are replenished from below with the nutrients lost due to phytoplankton uptake and subsequent settlement. However, year-round renewal of intermediate or deep water can only benefit summertime stratified near-surface waters if nutrients can diffuse upwards through the density gradient. The tidally induced internal waves observed once in Glacier Bay (Matthews 1981) and the hypothesized hydraulic instabilities associated with the Bay's high-current constricted entry sill provide mechanisms to increase the diffusion of nutrients upwards without disturbing stratification, which is usually necessary for high phytoplankton production (Mann & Lazier 1996). Such enhancement of productivity by internal waves has been observed in several studies (e.g., Shea & Broenkow 1982, New 1988). Another possible contributing mechanism is wind-driven mixing; although there are no data for Glacier Bay, summer wind events followed by water column re-stratification lead to brief secondary peaks in primary productivity in Auke Bay (Iverson et al. 1974, Ziemann et al. 1990).

If these nutrient-enhancing events are the primary cause of high phytoplankton levels in Glacier Bay, the spatial pattern of productivity should reflect these phenomena.

Phytoplankton levels were most consistently high in central Glacier Bay and the lower portions of the arms, where the strongest effects of tidally mixed fronts and internal waves would also be expected. The high average standing crop of phytoplankton in Glacier Bay did not represent universally high levels, though. While there was temporal and spatial clustering of high fluorescence values, there was also significant temporal and spatial variation between individual stations. One station could have very low phytoplankton levels during one survey and extremely high levels during the next; chlorophyll-*a* levels at stations only 5km apart could vary tremendously during a single survey. This pattern probably represents a series of sporadically depleted conditions relieved by frequent nutrient enhancing events.

Sediment load appears to play a significant role in reducing photic depth and therefore can act as a control on phytoplankton production. The deepest photic depths were associated with small sediment loads and the shallowest with high sediment loads, but both photic depth extremes were associated with low phytoplankton levels. The highest phytoplankton levels were associated with intermediate photic depths. Photic depth was significantly influenced by turbidity greater than 20mV, and by chlorophyll-*a* levels greater than $40 mg/m^3$. However, while OBS values greater than 20mV were common throughout Glacier Bay, values of chlorophyll-*a* greater than $40 mg/m^3$ were infrequent. Thus, although both phytoplankton standing crop and turbidity can reduce photic depth, sediment probably plays the greater role except for areas with very high phytoplankton levels. Despite the extremely high sediment loads throughout Glacier Bay and the clear role that turbidity played in determining photic depth, Glacier Bay nonetheless exhibited high chlorophyll-*a* levels. No broad-scale strong suppression of phytoplankton was observed during months with high sediment levels, as is common in heavily silted British Columbian and Alaskan glacial fjords (Burrell 1986).

The interaction between sediment and phytoplankton is not restricted to limitations on light penetration. During summer to early fall, a high level of chlorophyll-*a* was periodically observed throughout the water column at the heads of both arms. These levels, $0.5\text{-}1.5 mg/m^3$ of chlorophyll-*a*, were as high as those seen in productive zones of the Gulf of Alaska (Sambrotto & Lorenzen 1986). Cowan (1995) has demonstrated that silt particles can interact with organic material to form flocculants that settle more rapidly than expected. Because the water column appeared stratified in each of the observations, unlike the lower Bay region where full mixing was responsible for vertically distributing fluorescence, the deep chlorophyll-*a* anomaly is unlikely to be caused by mixing. Instead, it probably represents extremely rapid phytoplankton settling rates that result from diatoms interacting with sediments to form larger flocculants. Rapid settlement of phytoplankton out of the photic zone can significantly decrease production (Atlas et al. 1983, Ziemann et al. 1990), but might make phytoplankton available to deeper grazers beneath the surface waters. The extremely localized and brief nature of this phenomenon limits its system-wide effects. However, the sediments in this area may be significantly carbon- and nutrient-enriched (Cowan 1995).

In summary, Glacier Bay exhibits extremely high levels of phytoplankton over a very extended season. This production appears to result from enhanced nutrient availability in

Glacier Bay's surface waters, which in turn probably results from tidal mixing and frequent deep-water renewal. High phytoplankton levels were maintained despite large amounts of sediment that extended throughout the Bay and often restricted light penetration. Rather than a traditional silled fjord estuary, Glacier Bay should be modeled as a tidally mixed estuary in the vicinity of its sill, backed by stratified basins, with more traditionally estuarine upper arms. Because the neareshore zone represents a relatively small percentage of the Bay's waters, phytoplankton productivity likely contributes the majority of carbon production to the marine environment; although the contributions from phytoplankton and macroalge remain unmeasured. Glacier Bay hosts a high density and wide variety of secondary and tertiary consumers. It is clear that Glacier Bay's high primary productivity is commensurate with these large predator populations. The seasonal variation in primary productivity and its interactions with broader-scale oceanographic events as well as with predator dynamics need to be examined if we are fully to understand the impacts of oceanography on the rest of Glacier Bay's ecosystem. There is also a strong likelihood that further regional or global climatic changes could dramatically alter the primary production of Glacier Bay. A long-term program of oceanographic monitoring will be essential to understand these processes.

Hydroacoustic Survey

Acoustic biomass (S_A) in Glacier Bay was concentrated in relatively few of the areas we sampled (Figures 11, 12). We found large, relatively shallow (<75m) biomass concentrations around Pt. Adolphus in Icy Strait, in Berg Bay, around and north of the Beardslee Islands, around South and North Marble Islands and near the entrance to Muir Inlet, at the entrances to Geikie Inlet and Scidmore Bay and on the shelf between them, and in upper reaches of the West Arm and Muir Inlet (including Reid, Rendu, Waschusett, and Muir inlets). Even more striking from maps of biomass distribution (Figures 11, 12) are the large areas in between concentrations of biomass in which forage fish were scarce or virtually absent during our sampling.

This visual impression is corroborated by a frequency analysis of the individual integration cells used for mapping (see Methods). If we assume a target strength for swim-bladder bearing fish (physoclists) and scale S_A for the mean size of all fish combined, then we can approximate the frequencies of integration cells containing fish densities ranging from <0.00001 fish/m^3 to 4.6 fish/m^3 (Figure 13). Out of 6000 integrated 5x100m cells for each depth strata (5-10m, 10-15m, etc.) remarkably few cells contained mean fish densities high enough to support foraging by large forage fish predators such as some species of seabirds and marine mammals. Indeed, less than 8 % of the total area surveyed by hydroacoustics contained cells exceeding forage fish densities of 0.01 fish/m^3, and less than 1 % contained cells exceeding densities of 0.1 fish/m^3.

Another feature of acoustic biomass distribution in Glacier Bay evident in the maps (Figures 11, 12) is that the biomass was concentrated in shallow waters and close to shore. We can further examine depth distribution of biomass in two ways. First, when we plotted total acoustic biomass located in layers of water (5-25m, 25-50m, etc) versus the bottom depth of the sea floor (Figure 13), we observed that most biomass was located in the shallowest water layer (<25m) independent of bottom depth. Overall, acoustic biomass abundance was highest at depths of 25-50m. Secondly, we calculated the mean density of fish biomass in each depth strata (e.g., 5-10m, 10-15m, 15-20m, etc.). From this we found that, irrespective of bottom depth, mean densities of forage fish were 2-3 times higher in waters <50m in depth than in waters of greater depth (Figure 14). By plotting total cumulative biomass versus depth strata (Figure 15) we calculate that more than 50 % of the forage biomass was found at depths <35m, more than 80 % at depths <80m, and more than 90 % at depths <100m.

The densest forage fish aggregations illustrated in Figs. 11 and 12 were usually composed of only a few species such as herring, capelin, pollock or euphausiids. Integration of these aggregations at much finer spatial scales (1m x 20m bins) allows us to better estimate point densities of these aggregations. For example, the highest density aggregations located at Pt. Adolphus (Figures 11 and 12) were comprised mostly of adult herring (Fig. 16) and adult capelin (Figure 17), and these schools had densities in excess of 1-10 fish/m^3. Juvenile capelin and pollock aggregations at the mouth of Muir Inlet (Fig. 18) were typical of more dispersed aggregations in this area, with point densities of 0.01-0.1 fish/m^3. Euphausiid aggregations— which showed up on biomass maps (Figures 11 and 12) with relatively low S_A values owing to their weaker target strength— actually contained impressive densities of euphausiids; in the order of 0.1 to 1 kg/m3 (Figure 19).

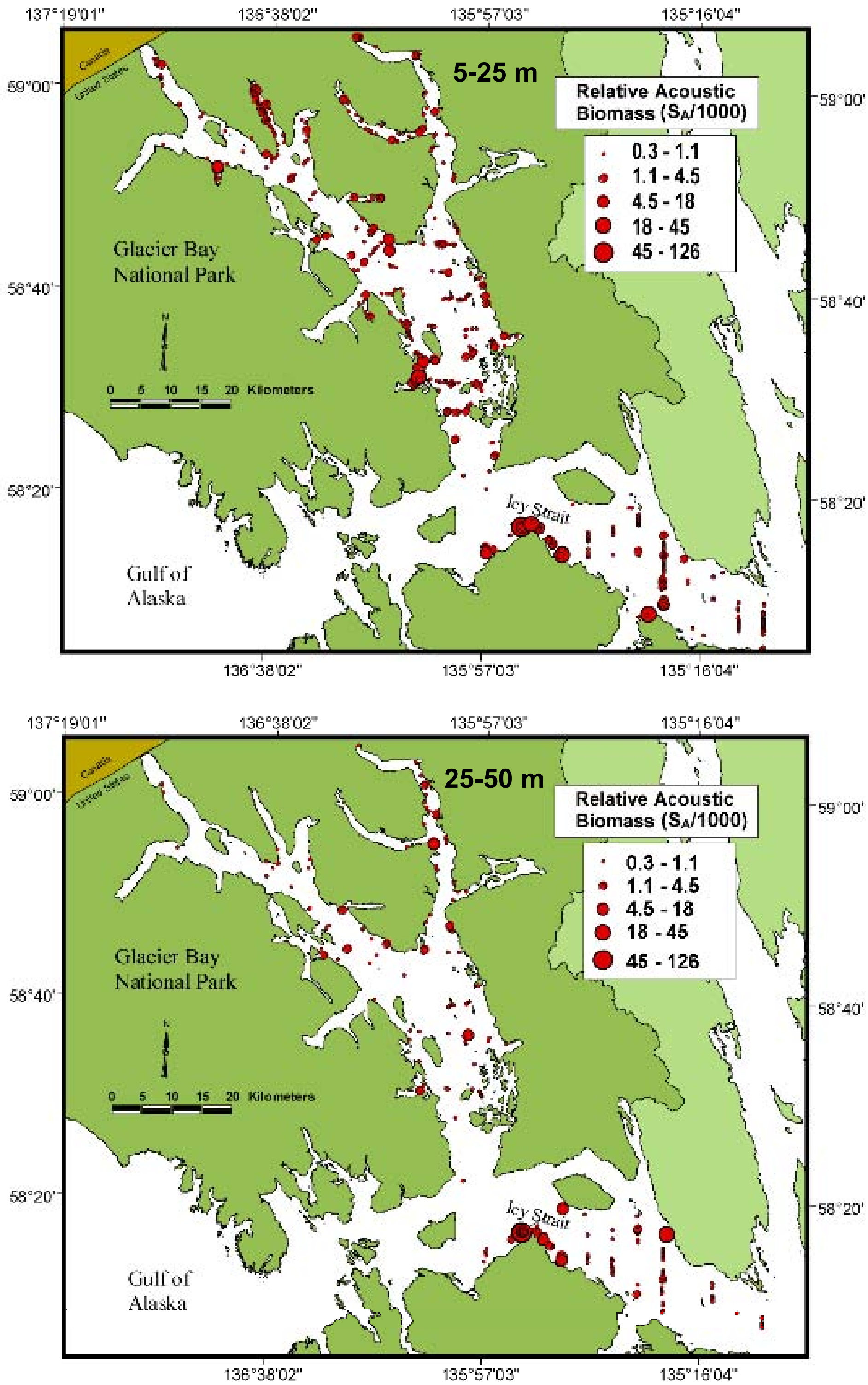

Figure 11. Distribution of fish and zooplankton Biomass (S_A, acoustic backscattering) in Glacer Bay during surveys in June, 1999. Upper map: Sum of S_A/1000 over 5-25 m depth strata. Lower map: Sum of S_A/1000 over 25-50 m depth strata.

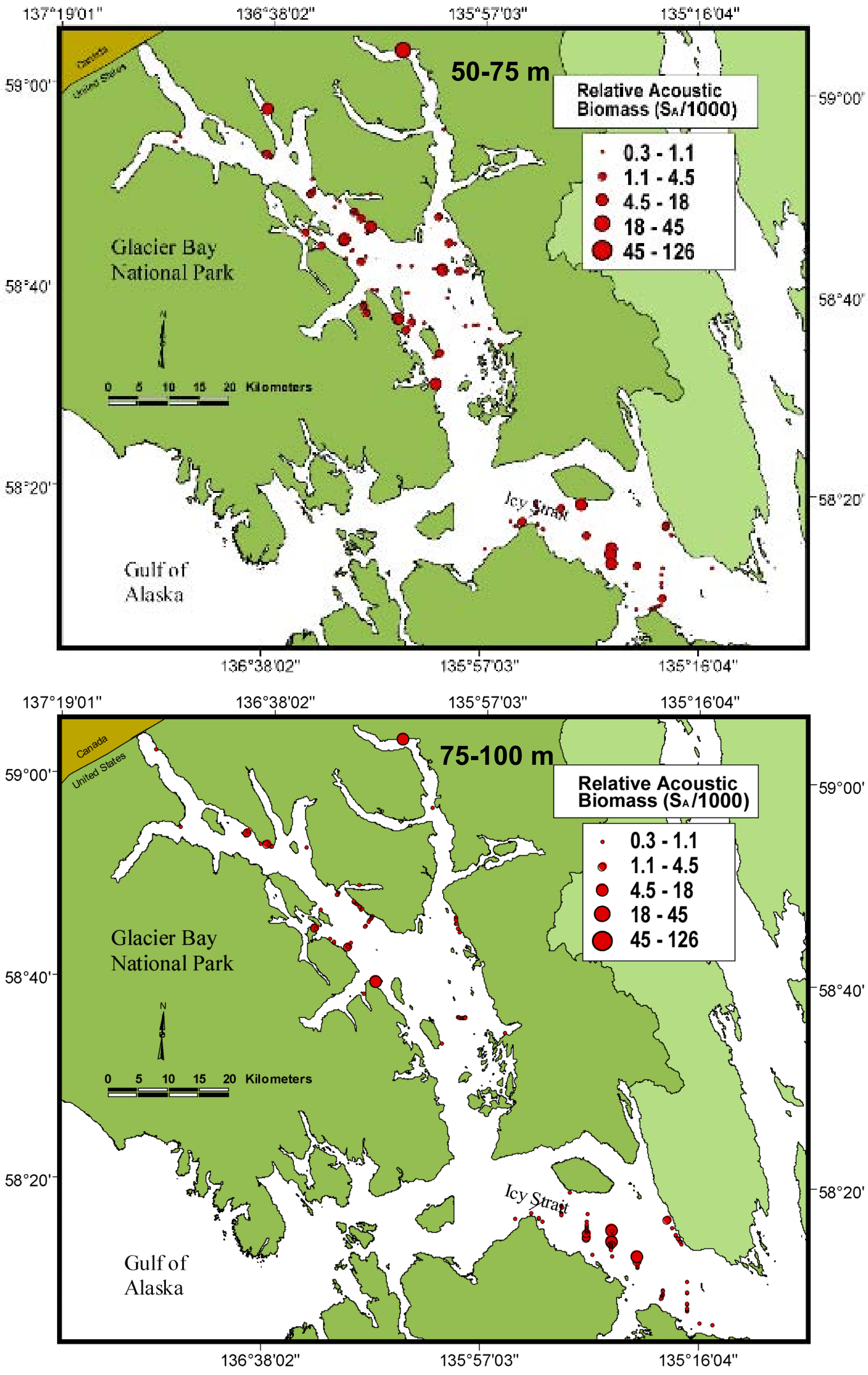

Figure 12. Distribution of fish and zooplankton biomass (S_A, acoustic backscattering) in Glacier Bay during surveys in June, 1999. Upper map: Sum of S_A/1000 over 50-75 m depth strata. Lower map: Sum of S_A/1000 over 75-100 m depth strata.

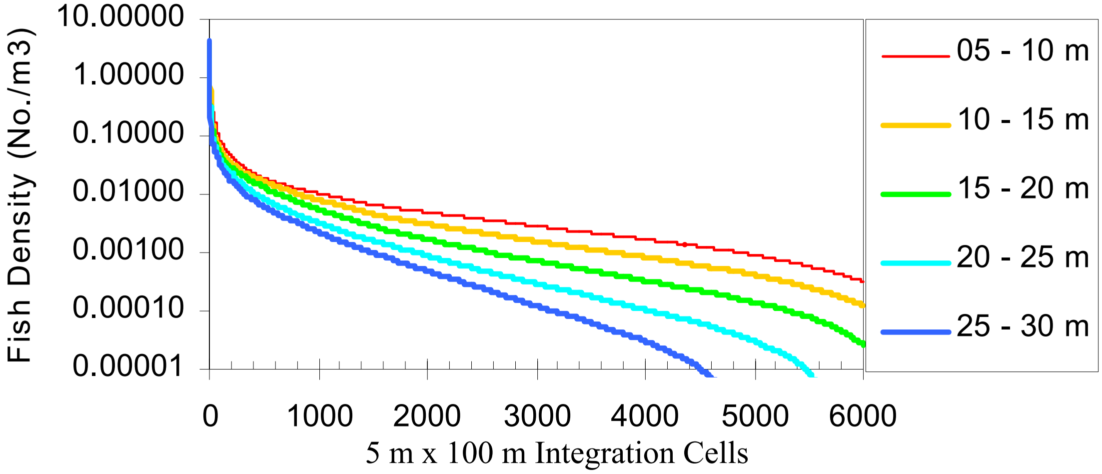

Figure 13. Frequency of high-density prey patches in Glacier Bay. Acoustic backscatter in the water column on transects was summed over moderately small (ca. 100m long by 5m deep) integration cells. Fish density was estimated in more than 6000 such cells for each 5m-depth strata. For purposes of illustration, cells from five surface strata were sorted from left to right according to fish densities in each cell. As evidenced above, cells with relatively high fish densities (>0.1 fish/m^3 in a 5x100m cell) were exceedingly rare.

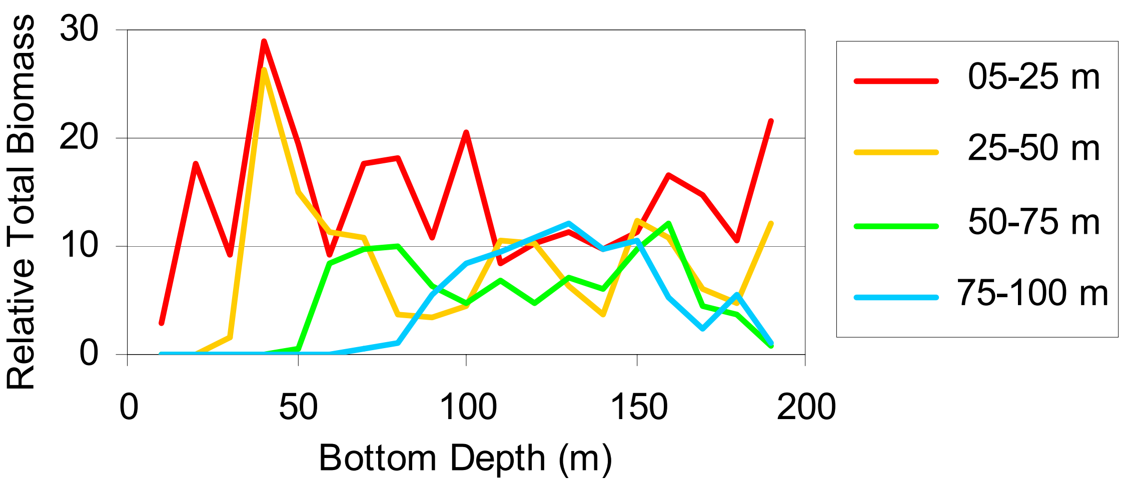

Figure 14. Distribution of acoustic biomass by water depth. Data from areas where bottom depths greater than 190m were combined into the 180-190 depth bin. Acoustic backscatter (S_A) was summed over four depth strata (25m bins), and examined with respect to depth of the ocean floor (in 10m increments). Total biomass was prorated for the amount of area surveyed at each depth. This figure shows that most biomass is found in the upper 25m regardless of depth of the sea floor.

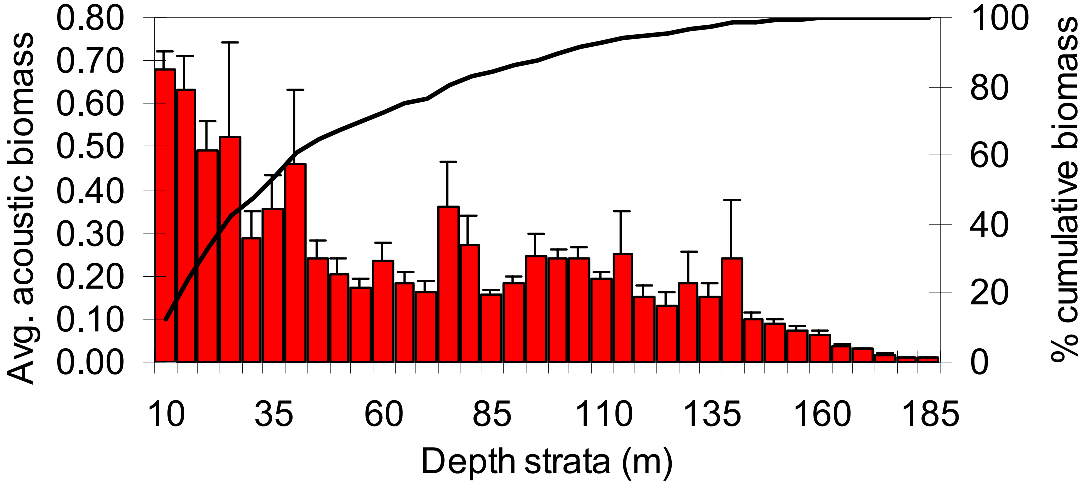

Figure 15. Average (bars, ±SE) and cumulative (line) biomass distribution in the water column (irrespective of bottom depth, see previous figure). Mean acoustic biomass in shallow (<50m) strata is generally more than double that observed in deeper strata. More than 50 % of total biomass was found at depths <35m, more than 80 % at depths <80m, and more than 90 % at depths <100m.

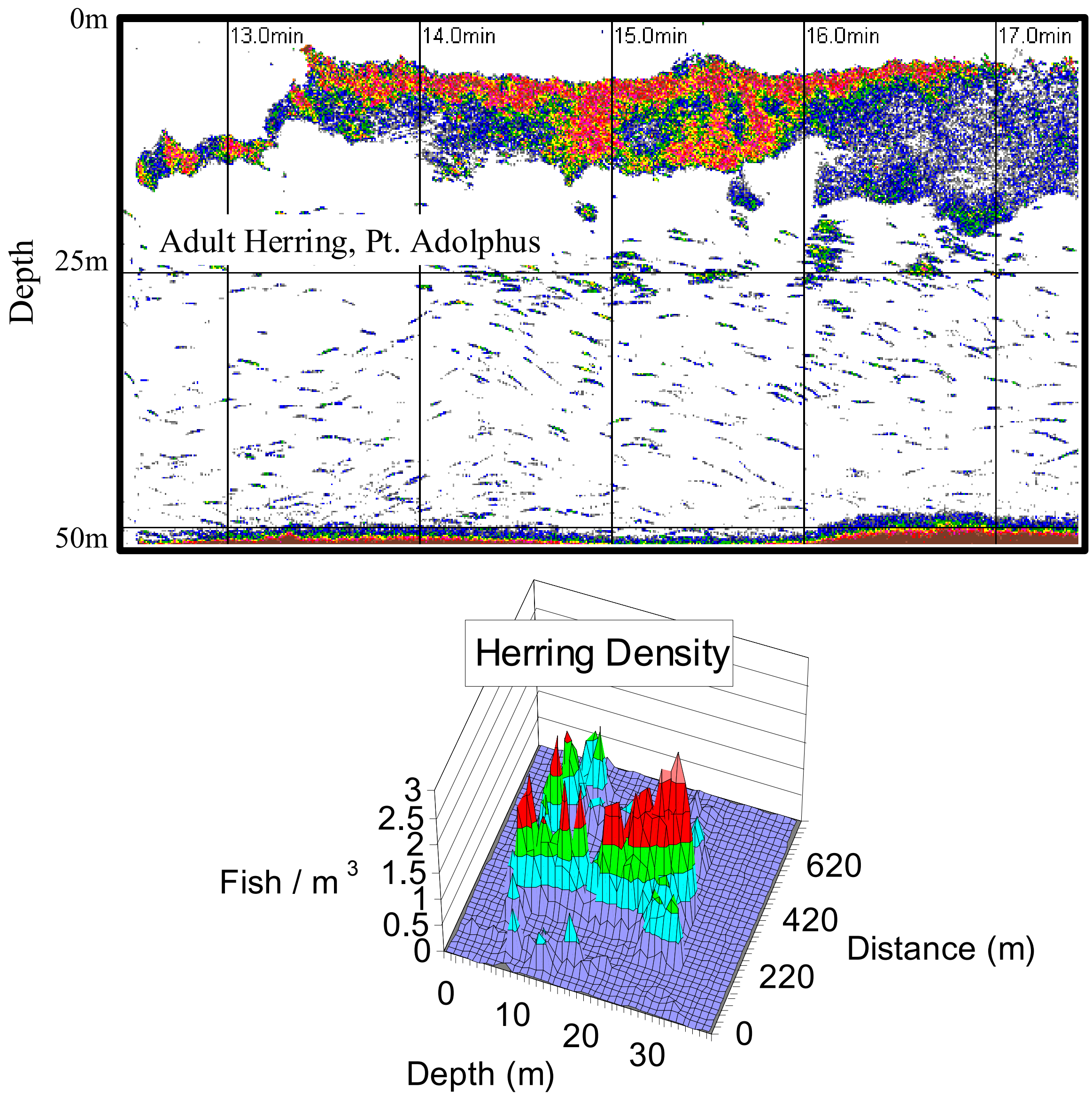

Figure 16. Hydroacoustic echogram (top) and integration analysis (bottom) of adult Pacific herring schools near Pt. Adolphus in June, 1999. Schools are large red-blue masses at top of echogram. Individual herring are seen as small blue streaks in lower half of echogram. The seafloor appears at the bottom of the echogram (dark red layer). Integration graphic shows density (in fish per cubic meter) of a selected herring school in 40 m of water along a 760 m section of the transect illustrated in the echogram.

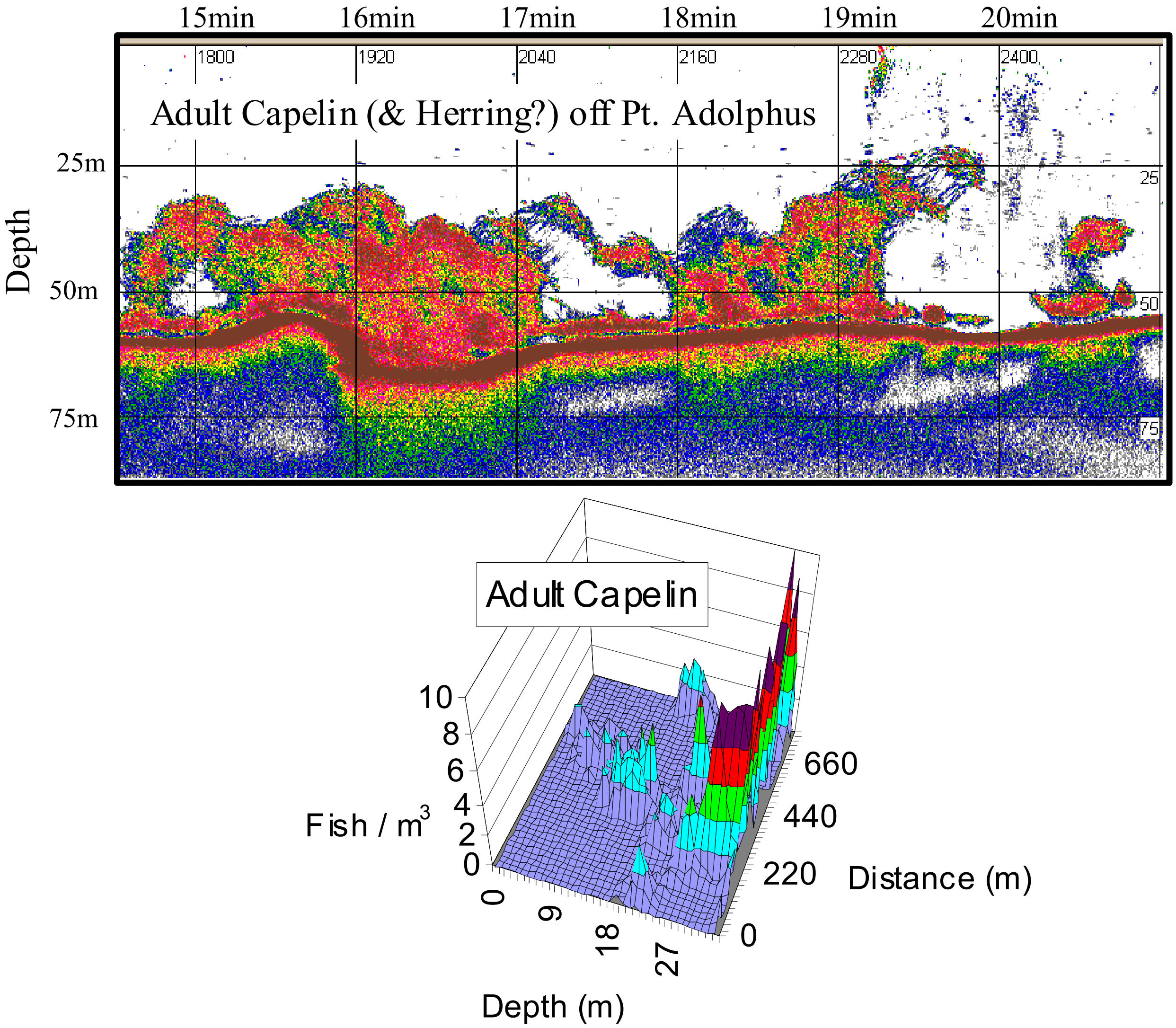

Figure 17. Hydroacoustic echogram (top) and integration analysis (bottom) of adult capelin schools near Pt. Adolphus in June, 1999. Schools are large red masses in middle of echogram, just above the seafloor (which appears as a very dark red, narrow, wavy band across the echogram). Integration graphic shows density (in fish per cubic meter) of a selected part of this capelin school in 40 m of water along an 800 m section of the transect illustrated in the echogram.

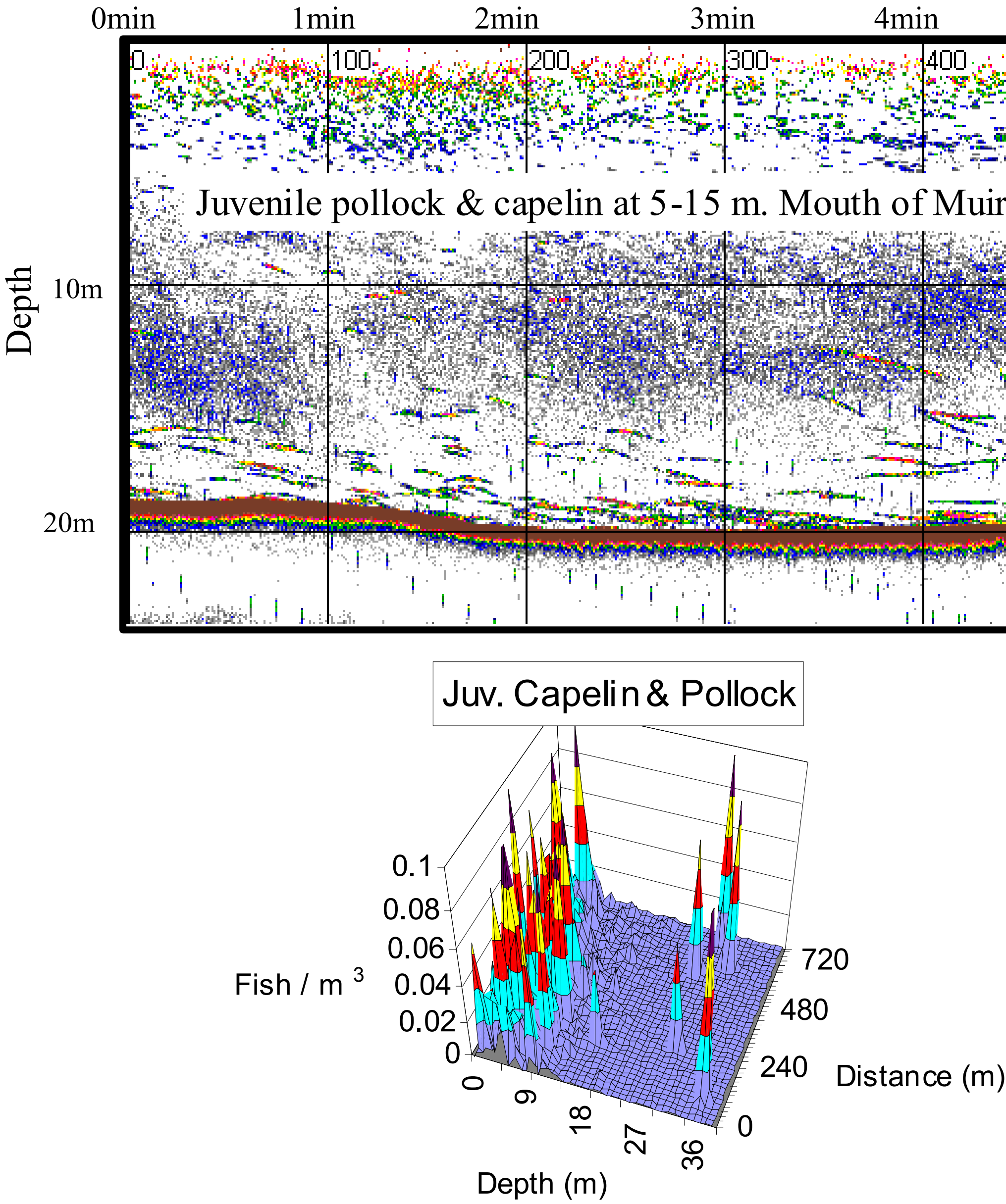

Figure 18. Hydroacoustic echogram (top) and integration analysis (bottom) of a dispersed layer of juvenile capelin and juvenile pollock in surface waters near the entrance to Muir Inlet, in June 1999. Juvenile fish appear as tiny red dots in upper 15 m of water column. The diffuse blue band in middle is layer of euphausiids and other plankton. Large red streaks near the sea floor (which appears as a very dark red, narrow band across bottom of echogram) are adult pollock. Integration graphic shows density (in fish per cubic meter) of a selected part of the dispersed surface schools of juvenile fish in the top 40 m of water along a 780 m section of the transect illustrated in the echogram.

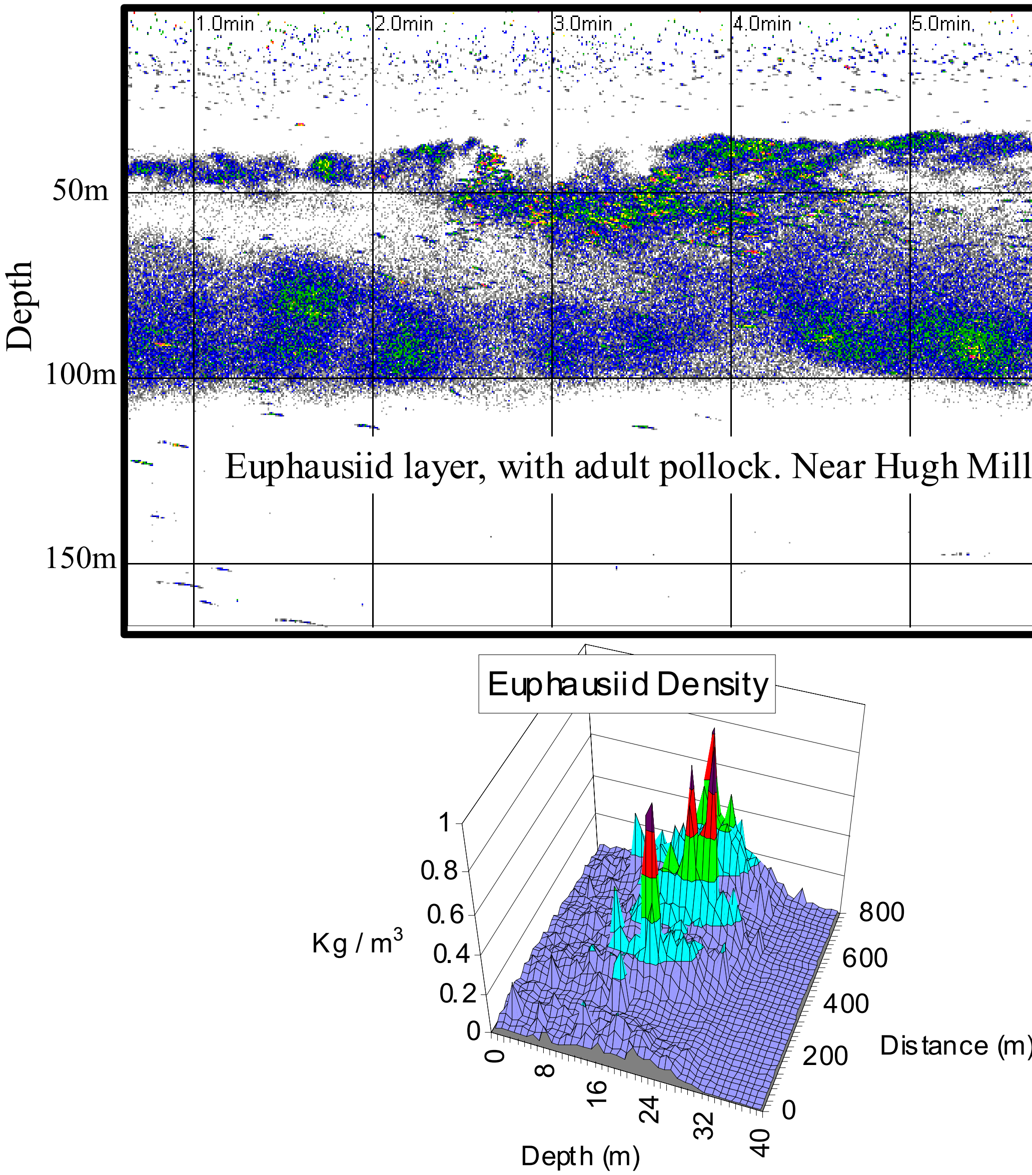

Figure 19. Hydroacoustic echogram (top) and integration analysis (bottom) of a dense layer of euphausiids near Hugh Miller Inlet in June 1999. Diffuse blue band in middle is layer of euphausiids and other plankton. Adult pollock appear as large red dots within the layer of euphausiids. The sea floor does not appear in the echogram. Integration graphic shows density (in kg per cubic meter) of a dense part of the euphausiid layer in the top 40 m of water along an 800 m section of the transect illustrated in the echogram.

Zooplankton
Previously, three surveys within Glacier Bay have included zooplankton sampling. Bruce L. Wing (NMFS Auke Bay Laboratory) assessed abundance at two Glacier Bay sites in August 1963. Vertical hauls were collected from the Beardsley Islands region and from close to the Lamplugh Glacier. These counts offer a snapshot of what the plankton community was like 37 years ago. Differences in sampling (primarily, we used a smaller mesh net which captures smaller animals) preclude direct community comparisons. However, despite the methodological differences, copepod abundance estimates were consistent with those of our study. We speculate that several other gross differences in community structure between Wing's and our data are real rather than functions of data collection differences. At the Beardsley Islands in 1963 arrow worms, ostracods, and decapod zoea were more abundant than we saw in 2000, when *Oikopleura* and *Asteroida* lavae were the most abundant taxa. Brachyuran zoea were seen in August, 1963, but only occurred in our samples in the Main Bay during June (Figure 20).

Bruce Wing and Kenneth Kreiger of NMFS Auke Bay Labs carried out a three-season summer survey of humpback whale prey (1981-83; Wing and Kreiger 1982, Kreiger and Wing 1984). They performed acoustic surveys and sampled using a 500-micron mesh Tucker trawl. They estimated zooplankton abundance by displacement volume, with composition listed as percent euphausiids, chaetognaths, and other. Both this and their studies indicate that euphausiids and chaetognaths, continue to be prominent parts of the Glacier Bay zooplankton community structure.

Simenstad and Powell (1990) sampled zooplankton at McBride glacier correlated with benthic sampling and tidewater sedimentation processes in 1984 and 1986. Zooplankton were collected with a 12.5cm opening 253µm mesh net. Their samples were dominated by copepods (principally *Pseudocalanus* copepodids), with barnacle nauplii and chaetognaths also present. These findings are consistent with our survey in composition of upper Bay inlets.

Zooplankton production is usually linked to the timing of the primary production bloom, which in turn is linked to the onset of spring stratification. The onset of stratification varies considerably between years in Glacier Bay, beginning as early as February, and as late as April (Hooge and Hooge, 2002).

Analyses of temporal and spatial zooplankton trends were done by calculating monthly means and grouping stations by region. Our samples reflect the diversity and abundance of zooplankton in the upper 50m, effectively the surface waters of the Bay. The summer zooplankton community observed in Glacier Bay is similar to community composition seen throughout the Gulf of Alaska. Temporally by region, the upper Bay (West and East Arms) and the lower Bay (Main Bay and Icy Strait) exhibited remarkably similar trends in zooplankton species number (Figure 21) and abundance (Figure 22).

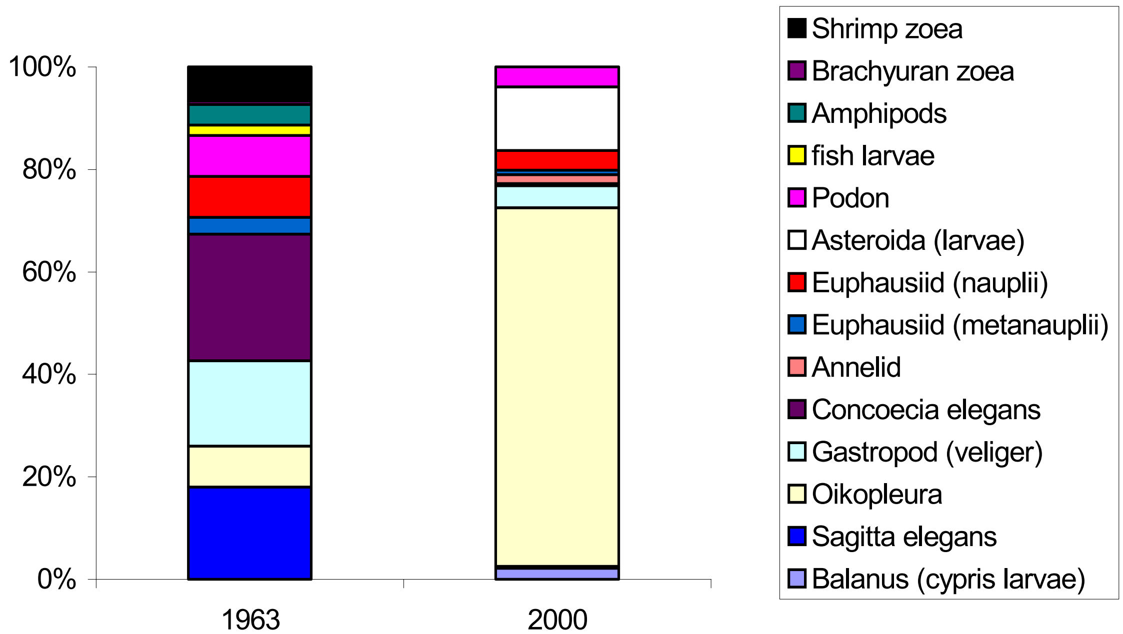

Figure 20. Relative zooplankton abundance in lower Glacier Bay in 1963 and 2000. Numerically dominant copepoda excluded highlight less abundant taxa

Peak zooplankton abundance of the lower Bay sites in late May/early June is similar to the general pattern for the Gulf of Alaska (GOA; Mattson 1978, Cooney 1987, Paul et al. 1991). The key distinction between the lower Bay and other estuaries in the GOA was the second smaller peak in lower-Bay densities during August when zooplankton densities in other areas are usually continuing to decline.

Zooplankton in both the East and West Arms peaked in July. Although densities had begun to decline in August (our final samples), they were still more than twice the densities seen in that region during May. The highest density of zooplankton observed was 17,870 organisms/m^3 seen at station Z47 (Tarr Inlet) in July. Up-Bay trends were distinct from lower Bay trends indicating that local processes are more strongly influencing zooplankton community dynamics in the West and East Arms compared to the Lower Bay which was more consistent with general GOA trends (Figure 22). Each region was unique in temporal trends for number of species observed (Figure 21).

Initial results from zooplankton analyses indicate that the different sample stations vary greatly in abundance and composition. Nearshore stations exhibited more variation in abundance and composition than mid-channel stations. Mid-channel station increased in abundance and decreased in diversity with distance up the Bay, and were never as low or as high as nearshore stations in diversity or abundance. Nearshore stations also had proportionally fewer copepods. Copepods made up similar proportions of both nearshore (81.6 %) and mid-channel samples (87.0 %).

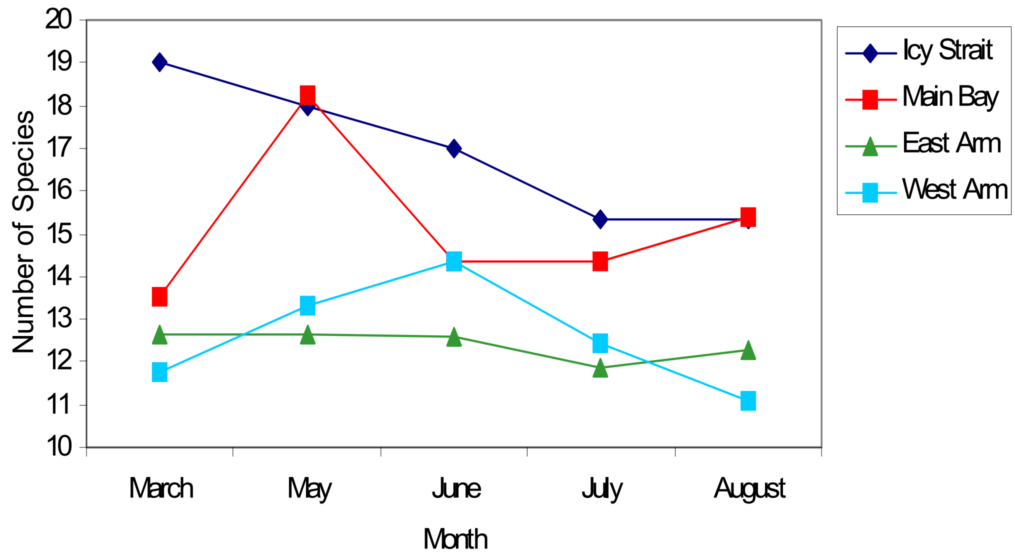

Figure 21. Spatial and temporal patterns of zooplankton species diversity, grouped by region.

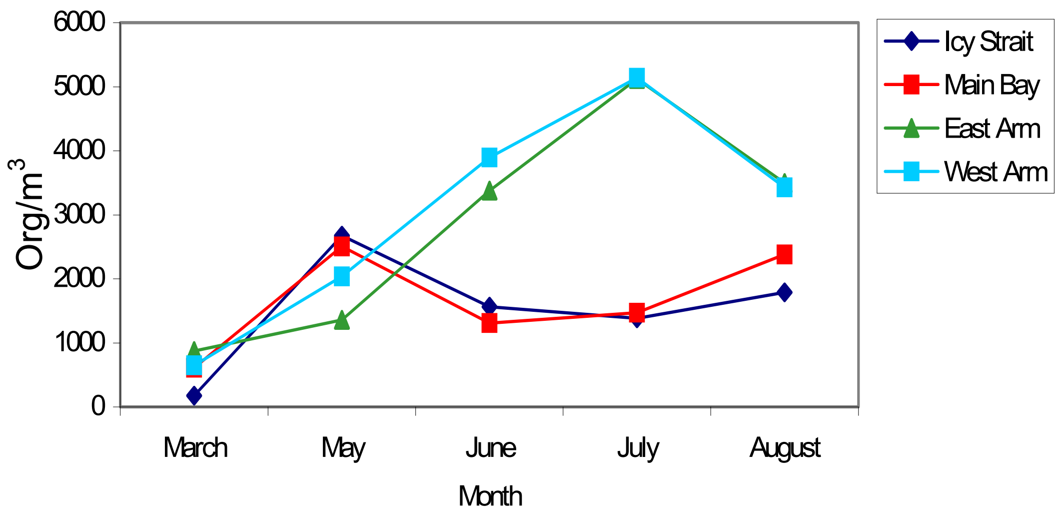

Figure 22. Spatial and temporal patterns of combined zooplankton abundance, grouped by region.

Copepods at the glacier fronts had higher levels of lipids than animals in the lower Bay. Copepods rely on lipid storage to survive the winter and reproduce; lipid levels also indicate the abundance and quality of food they are exposed to. This finding is correlated with the high levels of chlorophyll seen at the glacier fronts by USGS oceanography researchers (Hooge *et al*., 2000).

Zooplankton of sessile organisms were consistently more abundant in the Main Bay and Icy Strait than further up the Bay. This finding is consistant with generally higher clam densities in the lower and mid Bay compared to the upper arms (Bodkin et al. 2000). Estuarian bivalves and crustaceans are known to cue to environmental fluxes associated with tidal change and to adjust their migrations accordingly (Young 1995). Therefore, these taxa are likely to partially control their horizontal position in the estuary by vertically migrating in response to tidal cues. Additonally, zooplankters swimming upward in the water column, on reaching the thermocline or chemocline, suspend swimming and sink down before swimming again. Considering the glacial fjord oceanography of the Bay, this provides a possible explanation for maintaining high densities of zooplankton in Glacier Bay; keeping these animals out of surface outflow.

Larval fish and eggs were present in plankton tows from Icy Strait to the head of the West Arm (Appendix 7). Larvae and eggs were present primarily in June, with some observations earlier in the season. Only once, in Icy Strait, were eggs seen in August, otherwise they didn't appear in our samples after June. June emergence of fish larvae correlates with the high abundances of all copepod stages.

Zooplankton Diversity Indices

We calculated the Shannon-Weiner Index for each station to examine variation in species diversity. A zero index is a population of only one species; increasing numerical indices indicate an increasingly less homogeneous community structure.

We found generally higher diversity in the lower Bay than upper Bay; and greater variability in diversity at nearshore stations compared to those in mid-channel. The relationship of abundance and diversity for each zooplankton station indicated a significant negative correlation for nearshore stations (Table 2) and log (density) was the best predictor of diversity.

Glacier Bay zooplankton follow a general pattern of increasing density and decreasing diversity with distance up the Bay. Physiological tolerances may have a significant contribution to this pattern. We speculate that the high abundance at glacier fronts is at least partially a result of water currents, keeping plankters within the high productivity front of mixing waters.

Table 2 Pearson correlation coefficient for Shannon-Weiner diversity index and density.

	Density		log(Density)	
	r	p-value	r	p-value
Nearshore	-0.608	0.029	-0.717	0.004
Mid-channel	-0.368	0.719	-0.319	0.935
All Stations	-0.548	0.006	-0.605	0.002

Spatial Patterns

Cluster analysis (Cooney and Coyle, 1997) helped elucidate spatial variation of zooplankton community composition within the Bay, and using Cooney and Coyle's data, how Glacier Bay compares to Prince William Sound. Cooney and Coyle found that outer- and inner-Prince William Sound stations grouped together, with only a single station grouping outside its geographical region. Glacier Bay spatial patterns did not follow as straightforward a geographical trend (Figure 23; Table 3). Oceanographic features unique to Glacier Bay likely influence these patterns. Several West Arm Stations grouped together with outer-Bay stations, potentially indicating a high degree of oceanographic influence through the Bay, and supporting the apparent trend of advected animals using tidal mechanisms to remain at areas of high productivity. Species analysis of copepods would provide further insight about the spatial patterns of oceanic and estuarine species in Glacier Bay.

Table 3 Cluster analysis of dominant taxa collected in Glacier Bay during summer 2000.

GROUP 1

Icy Strait		Main Bay		West Arm		East Arm	
Mid-channel	Nearshore	Mid-channel	Nearshore	Mid-channel	Nearshore	Mid-channel	Nearshore
STN00	Z55	STN02	ZO2	STN08	Z36		Z24
	Z62	STN04			Z37		
					Z40		
					Z47		

GROUP 2

Icy Strait		Main Bay		West Arm		East Arm	
Mid-channel	Nearshore	Mid-channel	Nearshore	Mid-channel	Nearshore	Mid-channel	Nearshore
			Z06	STN06	Z45	STN14	Z25
			Z09	STN10	Z49	STN16	Z30
			Z10	STN12		STN18	
			ZI6	STN24		STN20	
			Z20				

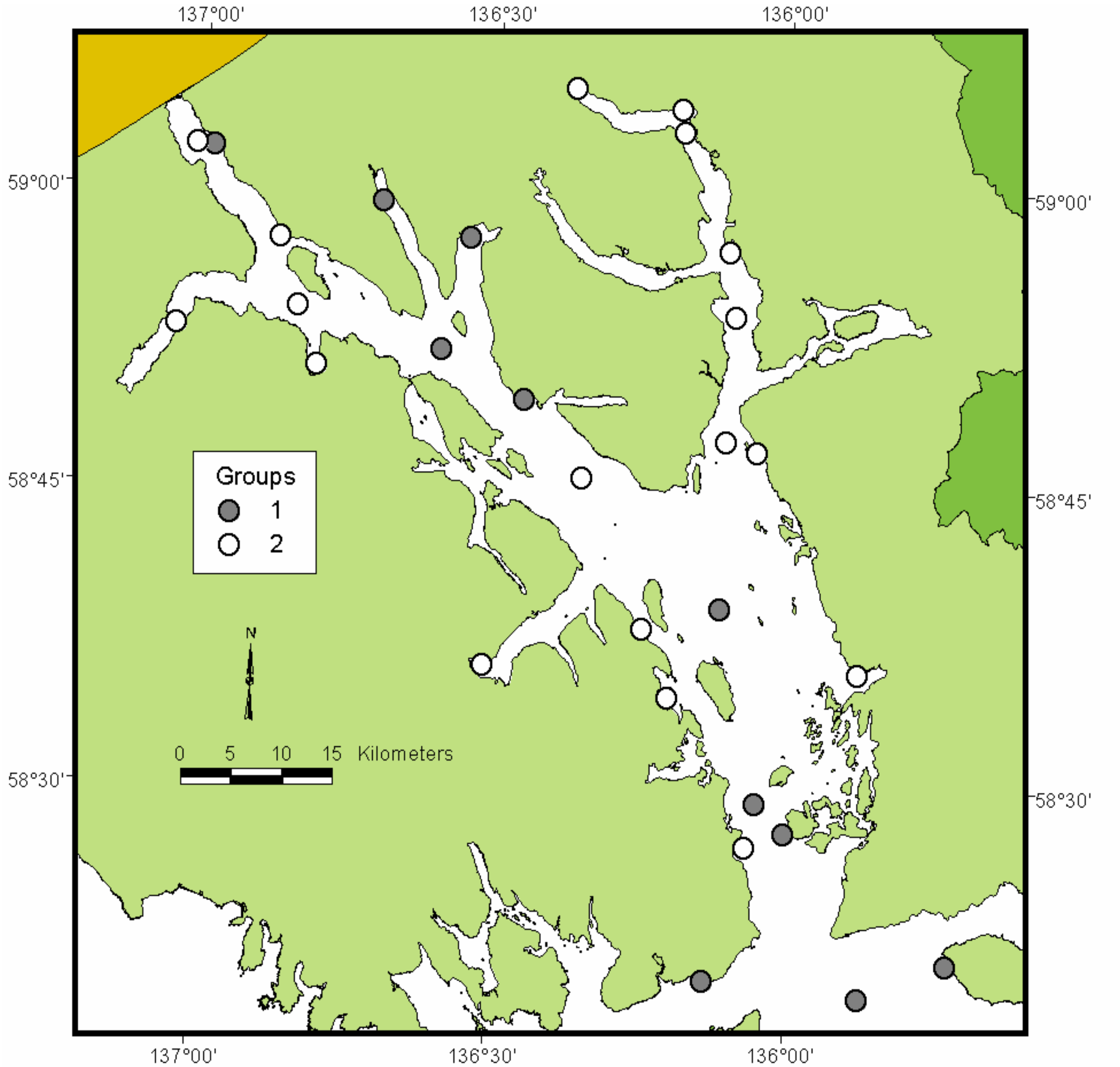

Figure 23. Geographic distribution of groups as determined by the cluster analysis of the five most abundant zooplankton taxa.

Zooplankton Taxa Profiles

The following profiles of specific zooplankton taxa provide initial snap-shots of our data. Results should be treated cautiously with recognition of the complex dynamics present in zooplankton ecology.

Phylum Arthropoda

Class Copepoda

Copepods are the dominant zooplankton taxa Glacier Bay, as has been found for all of the Gulf of Alaska and its estuaries (Cooney 1987). Copepods contribute most of the zooplankton biomass in the system, and trends are therefore important for copepods predators. Copepods hatch from eggs carried externally by a female and molt through six naupliar and five copepodid stages before becoming adults. Nauplii, copepodids (juveniles), and adults are crucial in the diets of many fish species timing of peaks in food availability and emergence of larval fish is important for fish survival. Availability of food is not the only factor regulating survival of juvenile fish, but is clearly important (Cooney 1987).

Copepod abundance in the East and West Arms followed a similar pattern, peaking in July and beginning to decline by the end of our sampling in mid-August (see Figures 24, 25, and 26). Copepod populations in the main Bay and Icy Strait were relatively stable in abundance compared to the upper-arms. The similar patterns of copepod abundance in mid-Bay and Icy Strait suggested a much closer association between these areas than the upper-Bay. These results suggest that mid and lower Glacier Bay as well as Icy Strait are closely tied to the Gulf of Alaska while more local processes are affecting the upper Bay.

Large copepods that are abundant in the Gulf of Alaska were found primarily in the upper Bay. Copepods increased their lipid stores through the season, indicating that they are growing well and are storing energy for the winter and for reproduction. Lipid presence was primarily in copepods at the glacial fronts. Oceanographic data suggests that these copepods are successfully exploiting the highly productive upper-Bay regions. Although the advection of copepods in and out of the Bay has important ecological consequences, this question was beyond the scope of this study.

*Class Branchiopoda (*Order *Cladocera)*

Podon and *Evadne*, small marine cladocerans, were present in 21% of zooplankton samples, and primarily at nearshore stations. Both species are common in the Gulf of Alaska during the summer (Cooney 1987). Abundance in Glacier Bay increased through the season, peaking in the Main Bay in August (Figure 27). Abundance increased in the upper Bay somewhat later than in lower regions.

*Class Cirripedia (*Order *Thoracica)*

Balanus nauplii or cypris larvae (non-feeding settling form) were present in 81% of our plankton samples. Barnacle nauplii and cypris larvae were present throughout our sampling (March – August), but were most abundant in March, when they dominate

samples. Their abundance is likely an important component for planktivores foraging in the early spring (Figure 28). Barnacle nauplii disperse widely. We speculate that oceanic individuals are advected by seasonally persistent onshore Ekman transport (wind driven) and probably supplement winter and early spring populations.

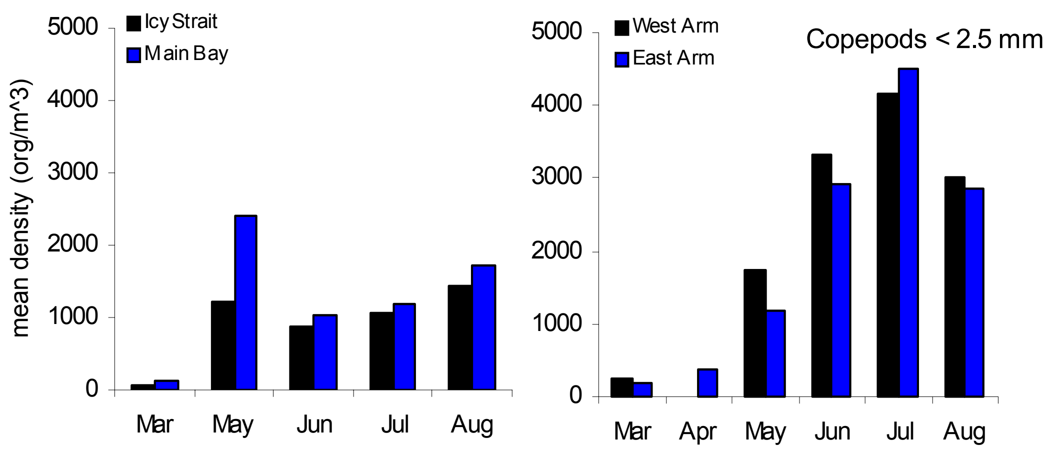

Figure 24. Monthly mean densities for calanoid and cyclopoid copepods, less than 2.5mm in length, occurring in lower and upper Bay. Except in March, small copepods dominated the zooplankton community.

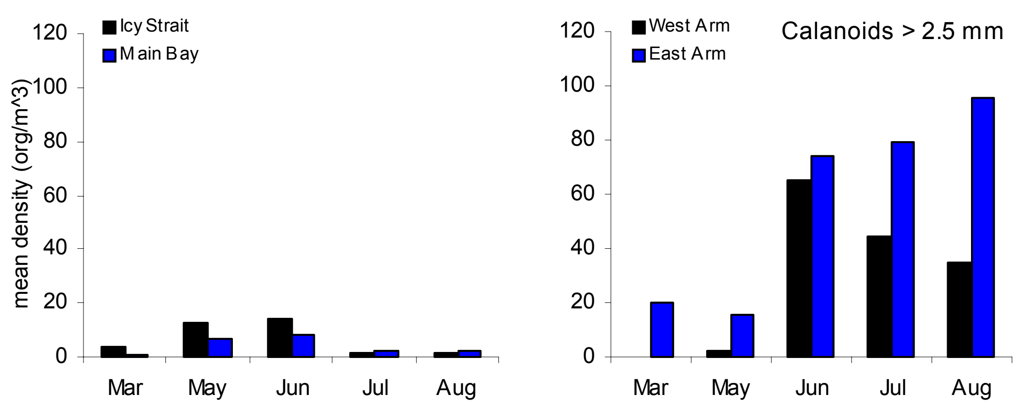

Figure 25. Monthly mean densities for large calanoids (> 2.5mm) occurring in the upper and lower Bay.

Class Cirripedia (Order *Thoracica*)

Balanus nauplii or cypris larvae (non-feeding settling form) were present in 81% of our plankton samples. Barnacle nauplii and cypris larvae were present throughout our sampling (March – August), but were most abundant in March, when they dominate samples. Their abundance is likely an important component for planktivores foraging in the early spring (Figure 28). Barnacle nauplii disperse widely. We speculate that oceanic individuals are advected by seasonally persistent onshore Ekman transport (wind driven) and probably supplement winter and early spring populations.

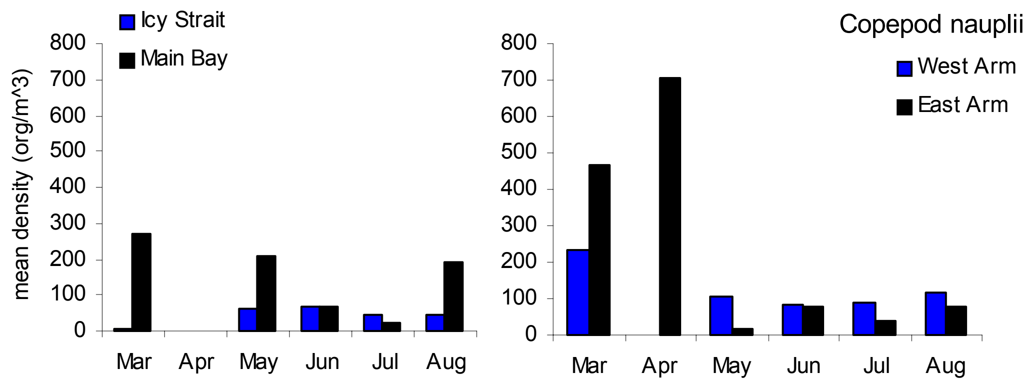

Figure 26. Monthly mean densities for copepod nauplii occurring in in upper and lower Bay.

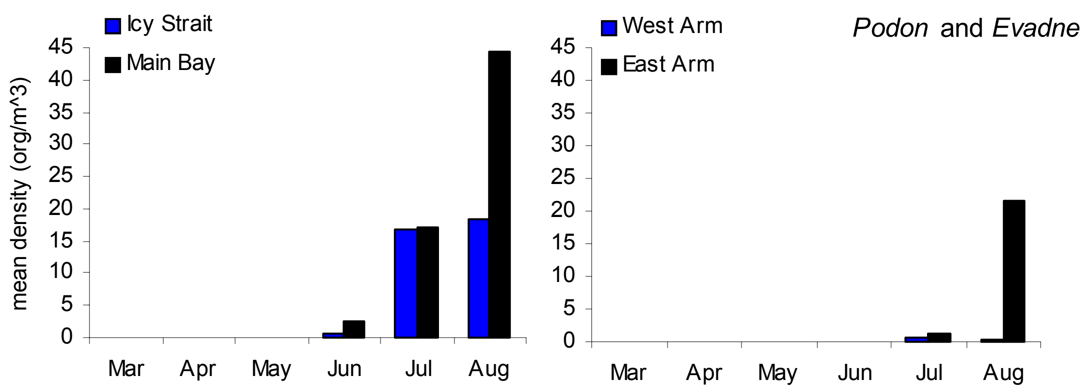

Figure 27. Monthly mean densities for marine cladocerans *Podon* and *Evadne* occurring in the upper and lower Bay.

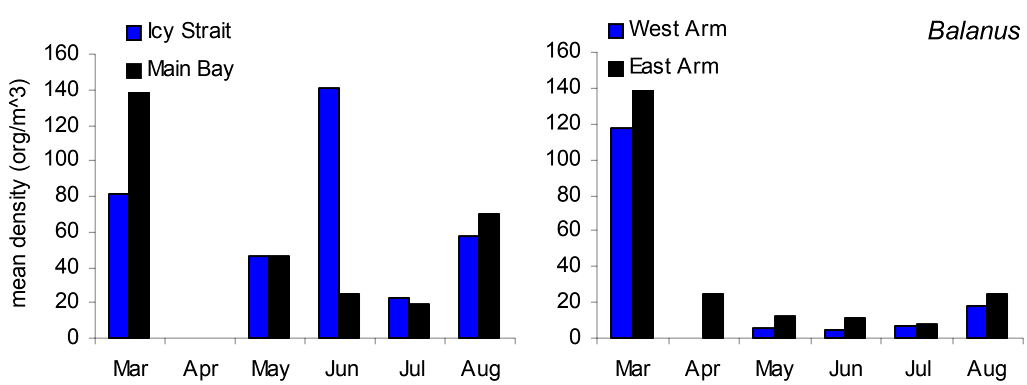

Figure 28. Monthly mean densities for *Balanus* nauplii and cypis larvae occurring in the upper and lower Bay.

<u>*Class Malacostraca*</u>

Order Amphipoda

Amphipods are common in aquatic systems throughout the world. Amphipods in Glacier Bay generally ranged from 2 -10 mm. Amphipods were present in 52% of our samples, peaking in abundance in May in the Main Bay (lower- and mid-Bay; Figure 29). *Hyperiid* amphipods accounted for 75% of the amphipods collected, and *Cyphocaris chalengeri* accounted for most of the remainder. Separate data indicates that hyperiids are an important prey item for kittiwakes, especially near glacier fronts (USGS-BRD, Elizabeth Hooge, pers comm). Numerous amphipods were also found in beach seines at the Glacial outflow from Carroll Glacier (Fig. 9 - Beach 32).

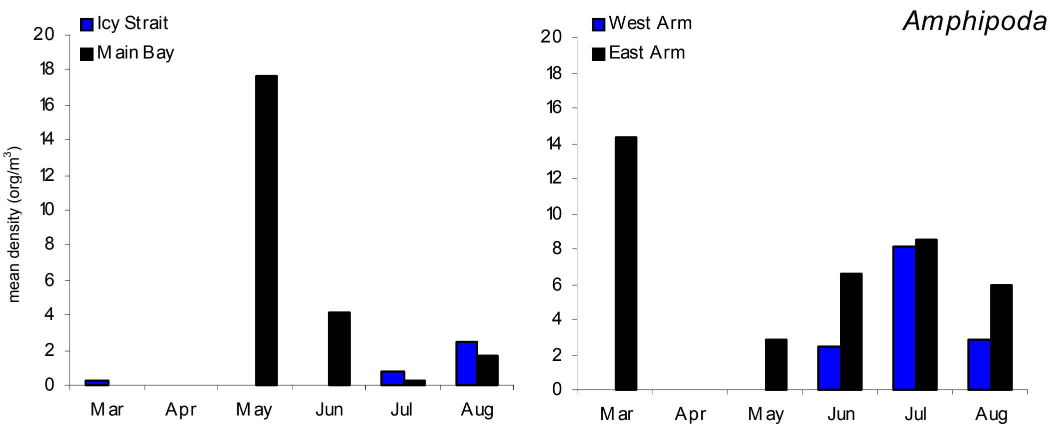

Figure 29. Monthly mean densities for amphipods occurring in the upper and lower Bay.

Order Decapoda

Decapods were present in 46% of the plankton samples, densities peaked in May. Brachyuran zoea were markedly more abundant within the Main Bay (lower- and mid-Bay; and Icy Strait in June; Figure 30). Decapod crustaceans reproduce synchronously with environmental cues (Forward, 1987); our sampling indicates favorable environmental cues existed for local reproduction in June. Brachyuran Zoea were only present in the lower Bay during June. However, during the 1963 sampling, they were present during August. Limits in sampling prevent understanding if this was a result of interannual variation, local spatial differences, or if changes in physical parameters have altered timing of larval release.

Order Euphausidacea

Euphausiids are frequently called Krill. Juvenile euphausiids were present in 58 % of our plankton samples. They dominated nearshore and mid-channel lower Bay samples (Fig. 4 - STN00 and STN02); however, abundance was much lower in the upper Bay (Figure 31). Abundance peaked in June which is later than the May peak reported for euphausiids in Resurrection Sound Bay (Prince William Sound; Paul et al.,1991). Abundance during June in Icy Strait was more then twice the peak abundance reported in Resurrection Sound Bay (during 1988). Abundance declined to zero in Resurrection Bay by June 1st, whereas juvenile euphausiids and eggs were present in Glacier Bay until August. Densities of euphausiids were much higher in nearshore samples (Figure 32). Euphausiids are important prey for numerous species including humpback whales (Wing and Krieger, 1982) and juvenile walleye pollock (Cooney 1987). Additionally, numerous euphausiids were found close to the Grand Pacific (Fig. 9 - Beach 47) and Reid (Fig. 9 - Beach 43) glaciers in beach seines.

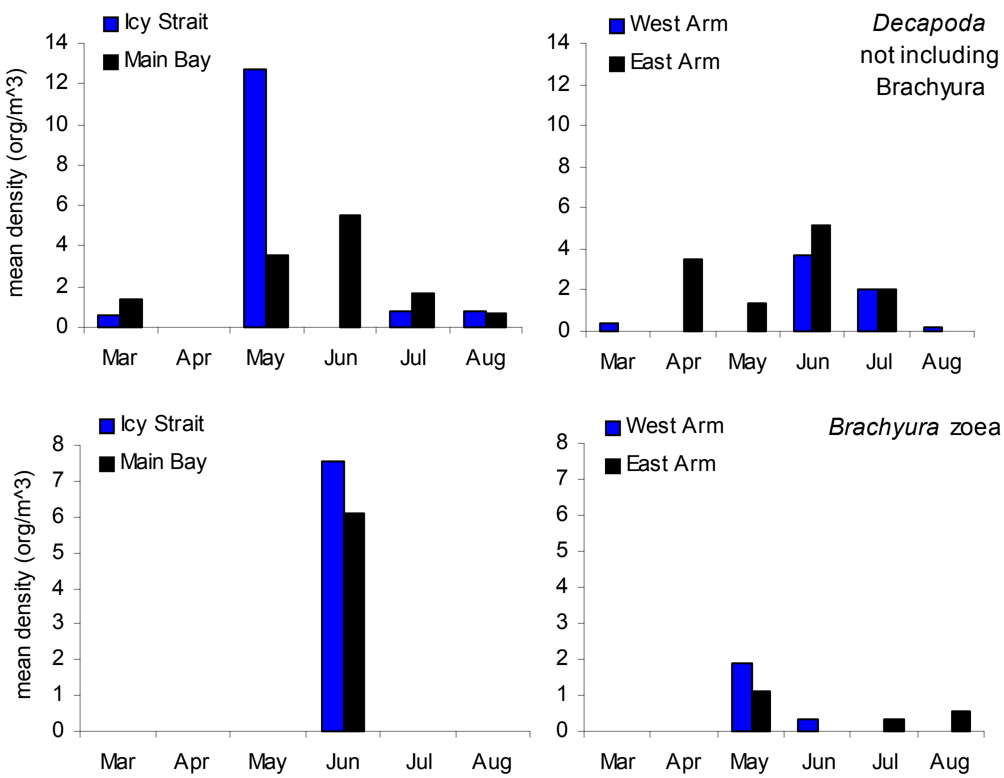

Figure 30. Monthly mean densities for decapods occurring in the upper and lower Bay. Note the difference in scales.

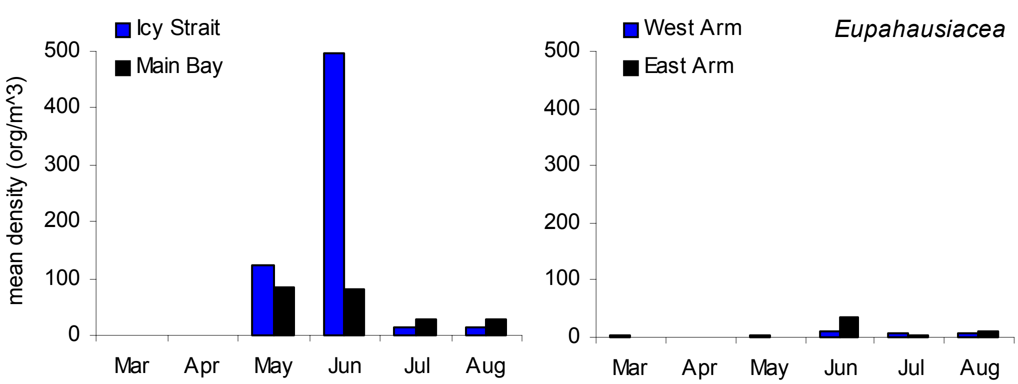

Figure 31. Monthly mean densities for euphausiid nauplii, metanauplii, and zoea occurring the in upper and lower Bay.

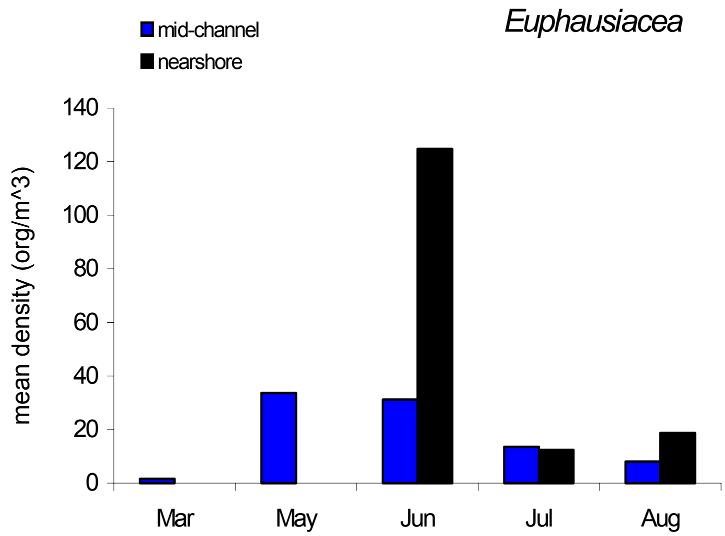

Figure 32. Monthly juvenile euphausiid densities by position in channel.

Order Isopoda

Isopods were present in 10 % of plankton samples, peaking in density in May in Icy Strait (Figure 33). Isopods were present throughout our study (March – August), although generally in low numbers. Parasitic isopods were grouped with parasitic copepods (see *Parasitic Zooplankton* Section). Isopods are important prey for many species of fish.

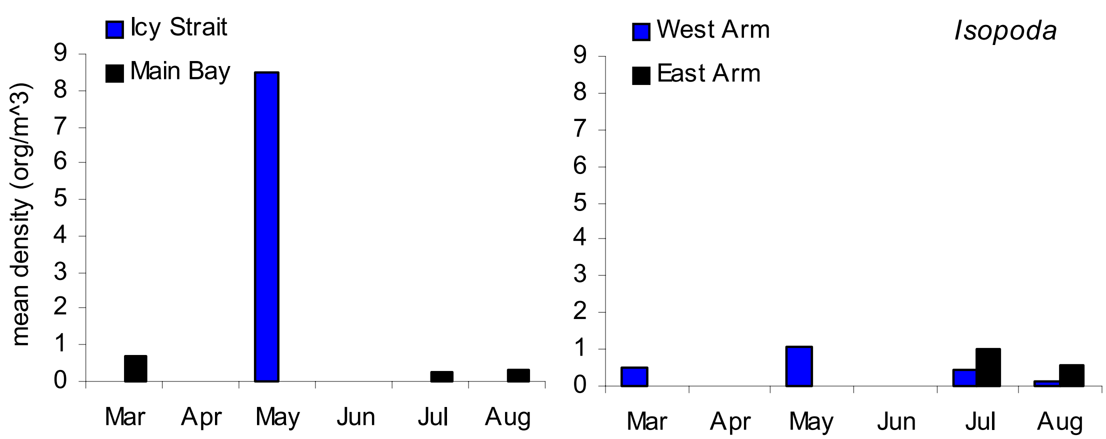

Figure 33. Monthly mean densities for isopods occurring in the upper and lower Bay.

Class Ostracoda

Ostracods were present in 34 % of plankton samples, with highest density in the East Arm. Ostracods were present at pelagic stations from STN00 to STN08 (Fig. 4) and nearshore stations throughout the Bay. Densities were relatively stable in the East Arm and had not noticeably declined by the end of the study (Figure 34). Ostracods were present in Glacier Bay in 1963.

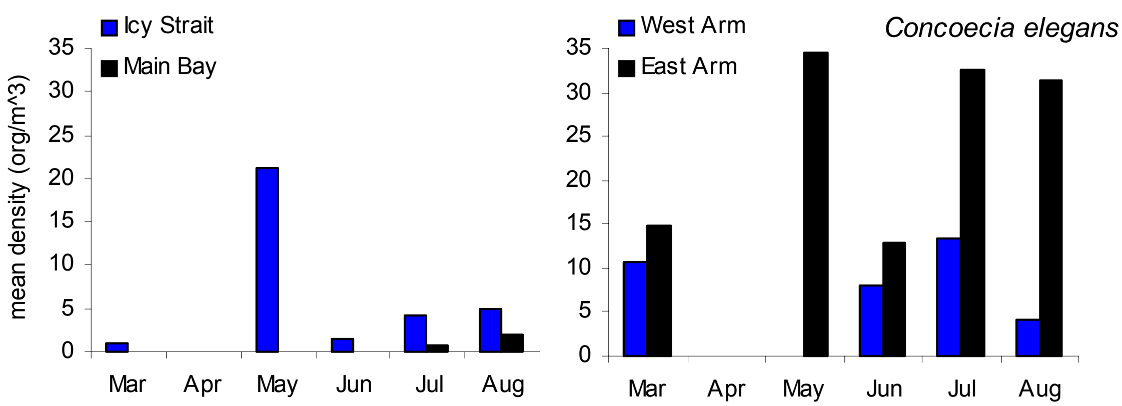

Figure 34. Monthly mean densities for Ostracoda occurring in the upper and lower Bay.

Parasitic zooplankton (Isopoda and Copepoda)

Parasitic copepods or isopods were present in 18% of the plankton samples. These organisms were caught during their brief free-living stage before finding a fish host. Most parasitic plankters were caught in the upper Bay, peaking early in the summer and then steadily declining through the season (Figure 35). The significance of parasitic isopod and copepod abundance in Glacier Bay was beyond the scope of this study.

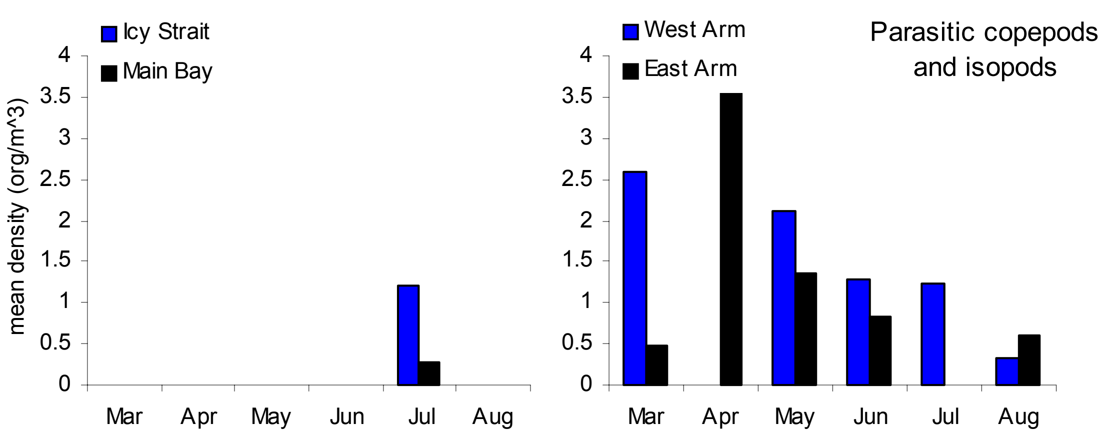

Figure 35. Monthly mean densities for parasitic copepods occurring in the upper and lower Bay.

Phylum Bryozoa

Bryozoans are sessile, colonial animals that release feeding larvae, known as cyphonautes. These larvae swim freely within the plankton community for several months before settling to the substrate. Brozoan larvae were present in 28% of our samples. Density was relatively consistent through the Bay in space and time (Figure 36).

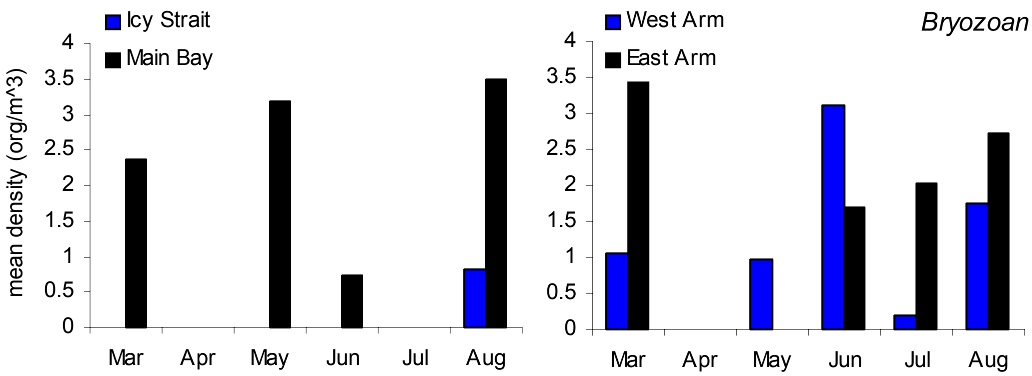

Figure 36. Monthly mean densities for bryozoa cyphonautes larvae occurring in the upper and lower Bay.

Phylum Chaetognatha

Sagitta elegans, the only chaetognath we caught, was present in 87% of our plankton samples. Peak density was in May for the lower Bay and in July for the upper Bay (Figure 37), though densities remained high in the upper Bay throughout summer. Arrow worms, as they are commonly called, are carnivorous predators specializing on copepods. They are, in turn, prey for many larger marine planktivores.

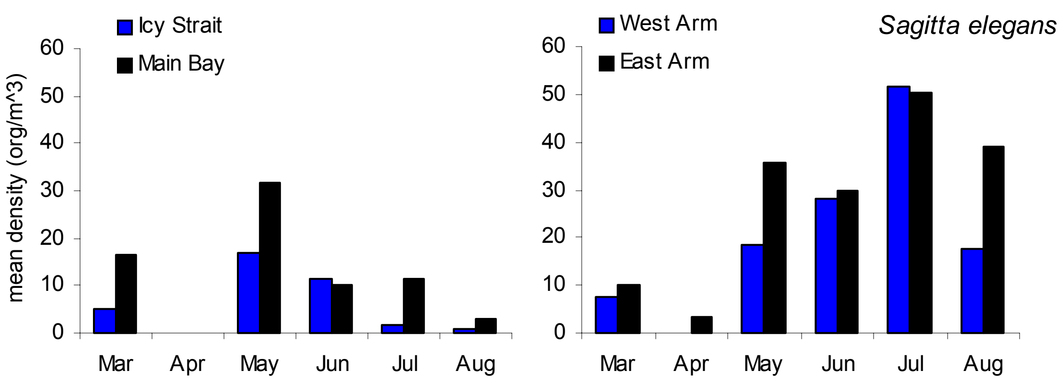

Figure 37. Monthly mean densities for *Sagitta elegans* occurring in the upper and lower Bay.

Phylum Cnidaria

Cnidaria and *Ctenophora* are carnivorous zooplankton and were present in 49% of plankton samples. The vast majority were small medusae, ranging in size from less than 2mm to several centimeters in diameter. Highest abundance was in May in the West Arm. Following early summer peaks density declined throughout the Bay (Figure 38).

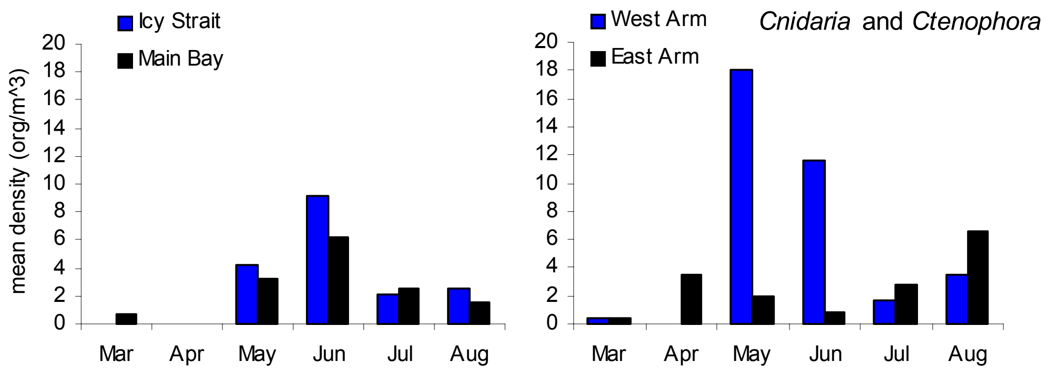

Figure 38. Monthly mean densities for *Cnidaria* and *Ctenophora* occurring in upper and lower Bay.

Phylum Mollusca

Bivalve (Figure 39) and gastropod veligers (Figure 40) were present in 87% of plankton samples, and both had similar patterns, though gastropods were always found in lower densities than bivalves. Both bivalve and gastropod veligers were more abundant in the upper Bay. Density peaked in June and July and had begun declining by August.

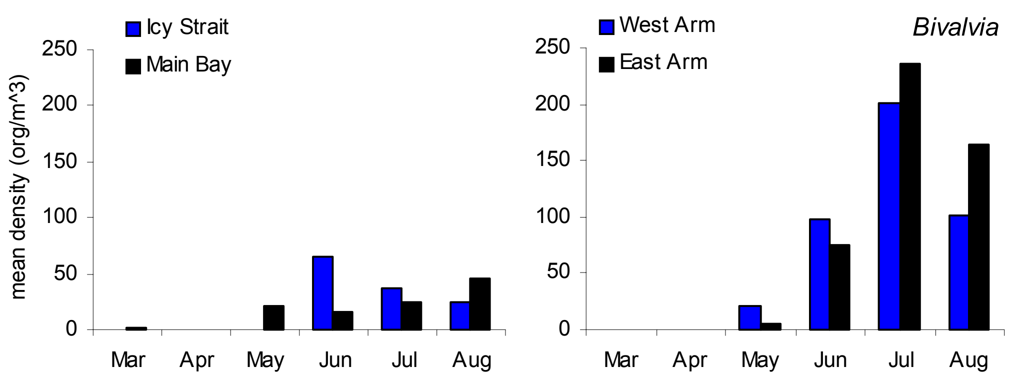

Figure 39. Monthly mean densities for bivalve veligers occurring in upper and lower Bay.

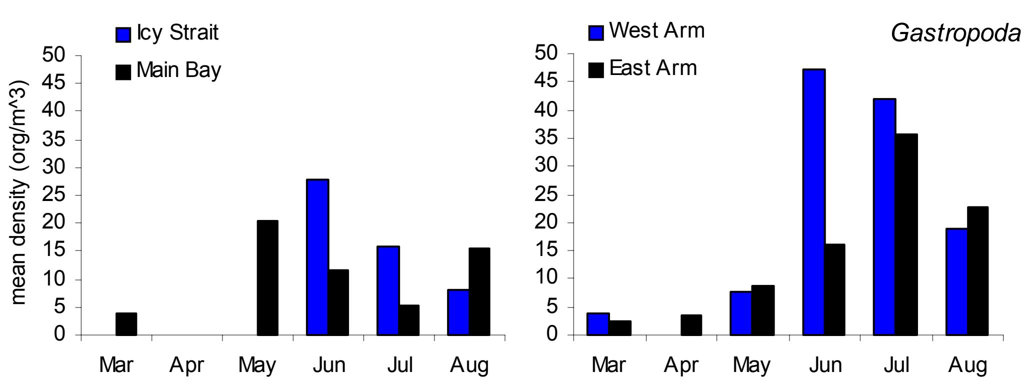

Figure 40. Monthly mean densities for gastropod veligers occurring in upper and lower Bay.

Phylum Echinodermata

Echinoderm juveniles or veligers were present in 6% of the plankton samples; *Asteroida* juveniles or veligers were seen in 48%. Density in the Main Bay peaked in August (Figure 41) with almost 60 individuals/m^3. Abundance of *Asteroida* in the Main Bay was substantially higher than Icy Strait. *Holothuroidea* auricularia larvae were present in one sample, nearshore in Geikie Inlet (Fig. 6 - Station Z20) during July. Echinoderms were present in the lower Bay in June and July, and in the West Arm in May and July (Figure 42). Although juvinile echinoderms were not observed in the East Arm, adults are locally common throughout the Bay.

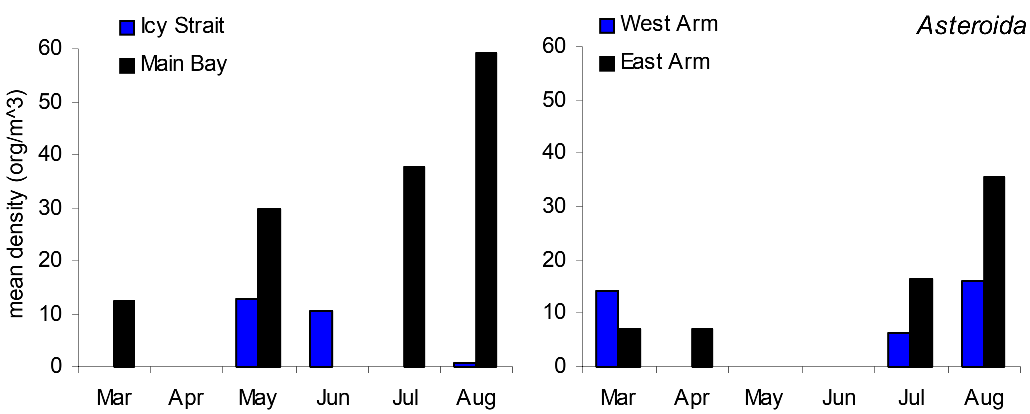

Figure 41. Monthly mean densities for *asteroida* juveniles and veligers occurring in upper and lower Bay.

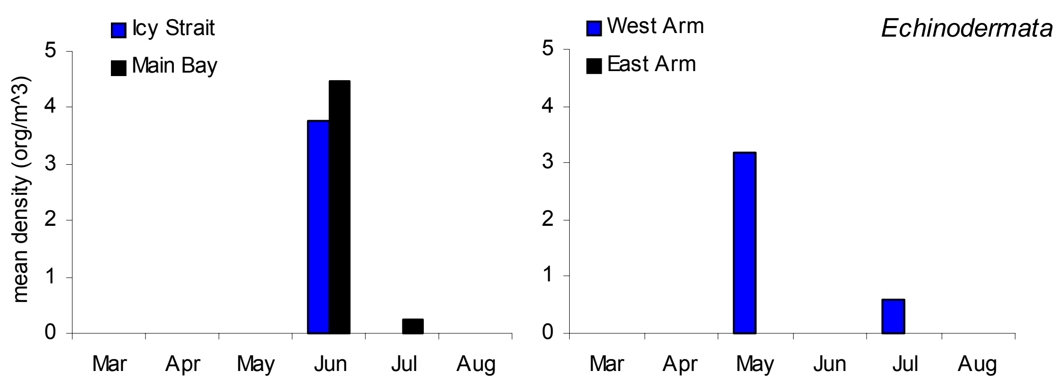

Figure 42. Monthly mean densities for echinoderm juveniles and veligers occurring in upper and lower Bay.

Phylum Phoronida

Phoronida actinotroch larvae and juveniles were present only in five of our plankton samples. They were at low density (maximum at STN02 June, 3.7 individuals/m^3) and only found within the Main Bay and West Arm (Figure 43).

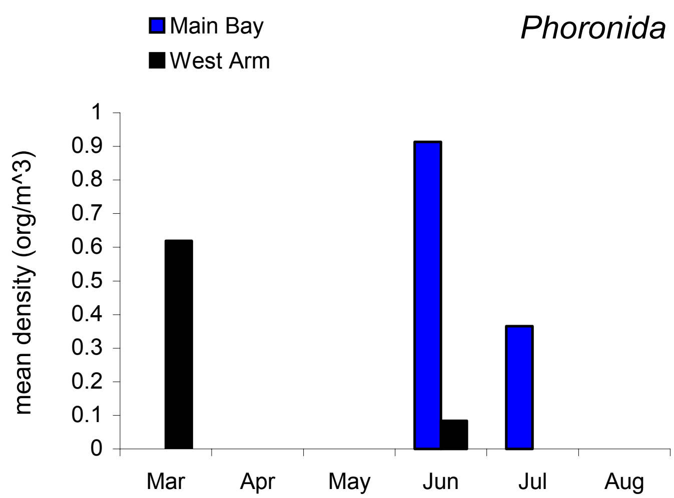

Figure 43. Monthly mean densities for *Phoronida* juveniles and actinotroch larvae occurring in upper and lower Bay.

<u>*Phylum Urochordata*</u>

Oikopleura were present in 85% of plankton samples. Density was highest in Icy Strait in June, with upper-Bay numbers remaining relatively low and constant. Aside from the June peak in Icy Strait, populations grew steadily through the summer, and had not begun to decline when the study ended.

<u>Icthyoplankton</u>

We sampled Icthyoplankton at the same 11 stations (Figure 4) in both May and June 2000 for a cumulative total of 76 samples (up to four depth strata per station visit). We identified a total of 9 fish taxa and 2 invertebrate taxa. Bathyagonus species caught on this project are probably *Agonsosis vulsa* and *Bathyagonis nigripinnis* (Bruce Wing NMFS Auke Bay Lab, *Pers. Comm.*). Numbers of fish per m^3 were over 200 times higher in June than May. Of the total catch (adjusted for equal volume) walleye pollock was the dominant taxon, comprising 57 and 72% of the fish caught in May and June respectively. Slender eelblenny (43%) and capelin (20%) were second most abundant taxa in May and June, respectively.

Walleye pollock dominance of the larval fish community mirrored that of another southeast Alaskan icthyoplankton study (Mattson and Wing, 1978) and that of Resurrection Bay (Paul et al., 1991). Mattson and Wing found capelin to be second in abundance, but Stichaeidae (e.g., slender eelblenny) only accounted for about 2% of the catch. Their more open-channel sampling likely accounted for this difference. Both our results and those of Mattson and Wing (1978) were conspicuous in their absence of larval herring, with only 3 caught (in an Isaacs-Kidd trawl in Queen Inlet) in our pelagic samples (All herring caught in the modified herring mid-water trawl were older with a minimum size of 199 mm). This contrasts with the findings of Paul et al., (1991) study where herring was a significant part of the Resurrection Bay icthyoplankton community.

Distribution of juvenile pollock within the water column declined with depth (64% at 0-25 m, 22 % at 25-50 m, 12% at 50-75 m and 2% at 75-100 m) as observed in Resurrection Bay, Prince William Sound (Müter and Norcross, 1994). Juvenile capelin were exclusively found in surface (0-25 m) waters and slender eelblenny were distributed as deep as 75 m.

Juvenile walleye pollock averaged 12.53 mm (TL; sd 3.43 mm) in June. Assuming similar growth rates of juvenile pollock in Glacier Bay to Resurrection Bay (another glacially influenced fjord), we used the formula developed by Müter and Norcross (1994) to estimate mean hatch date. We estimate that the mean walleye pollock hatch-date in Glacier Bay is around April 29. This is very similar to the Müter and Norcross (1994) estimate of 22 April for Prince William Sound pollock, and within the range of observed hatch dates in other areas of the Gulf of Alaska (23 April to 2 May; cited in Müter and Norcross, 1994).

Spatially, within Glacier Bay we only found juvenile pollock at the entrance to the west arm (Station 6) in May. Larval pollock may have been present elsewhere but deeper than our sampling (100 m), though none were found at the shallower sill areas where we fished the entire water column. In June, pollock were relatively widespread, occurring throughout most of the Bay. Numbers increased up the Bay with highest numbers found in the upper west arm; but notably not close to Margerie Glacier at Station 21. We found fewer larval pollock in the East arm and again not in the upper reaches.

Euphausiids were found in 45 of the 76 samples (59%). Spatially they were found throughout the Bay, but were exceedingly common at the face of Margerie Glacier (Station 21) in June. Numbers were generally too low to make temporal comparisons between May and June.

We examined seasonal and spatial patterns of abundance for both pelagic zooplankton (limited to zooplankton <333 µm; i.e., those caught in vertical plankton tows) and icthyoplankton and large zooplankton (> 500µm; i.e., those caught in Isaacs Kidd and Tucker Trawls; predominantly euphausiids) in Glacier Bay. Results for May to August (Figures 44, 45, 46, 47) indicate a marked seasonal and spatial pattern to the abundance of these secondary and tertiary levels of productivity. Zooplankton abundance was highest in the upper arms and at the mid-Bay Station 4.

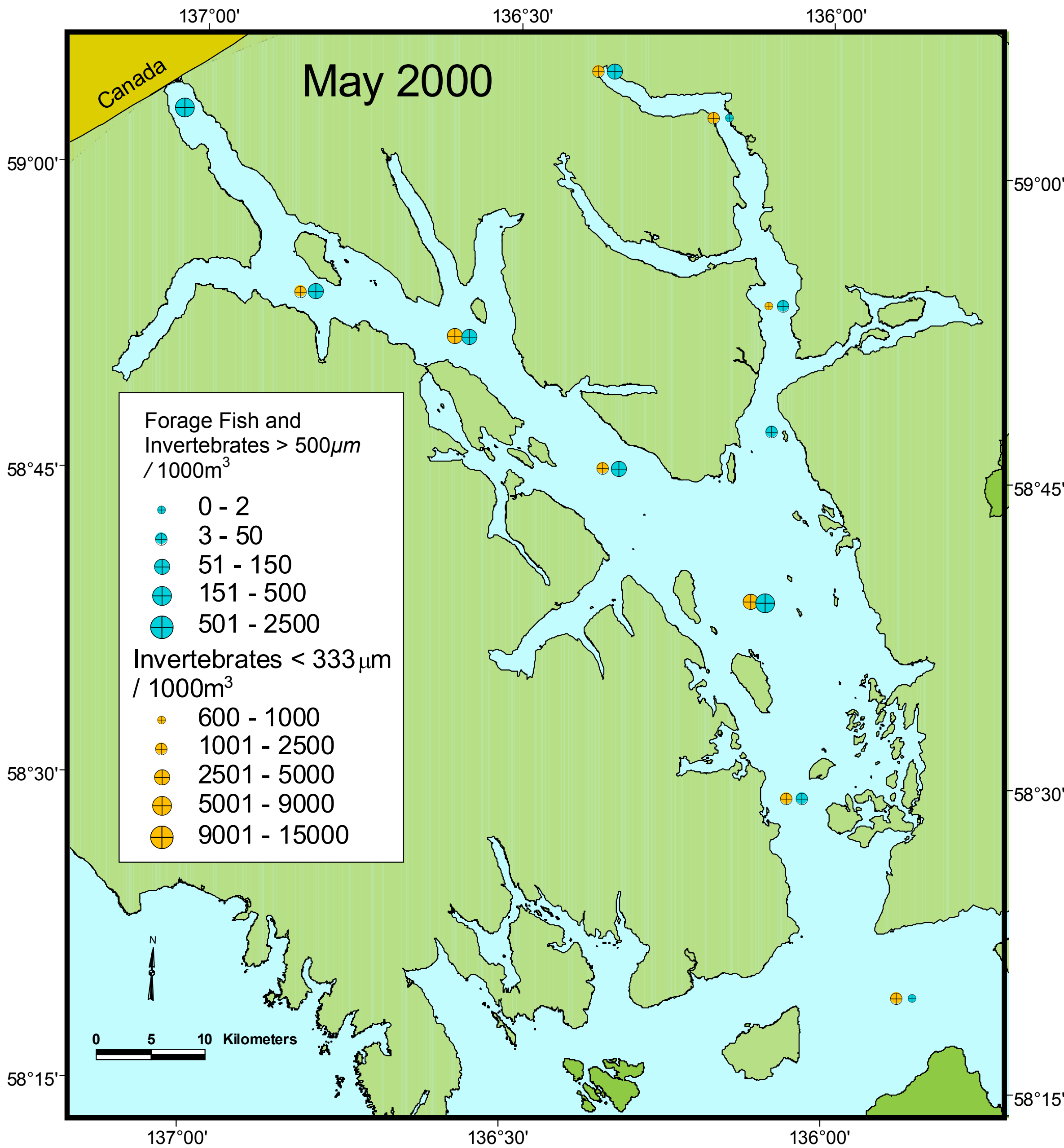

Figure 44. Spatial pattern of zooplankton caught in vertical plankton tows (yellow) and euphausiids and forage fish caught in trawls (blue) in Glacier Bay during May 2000.

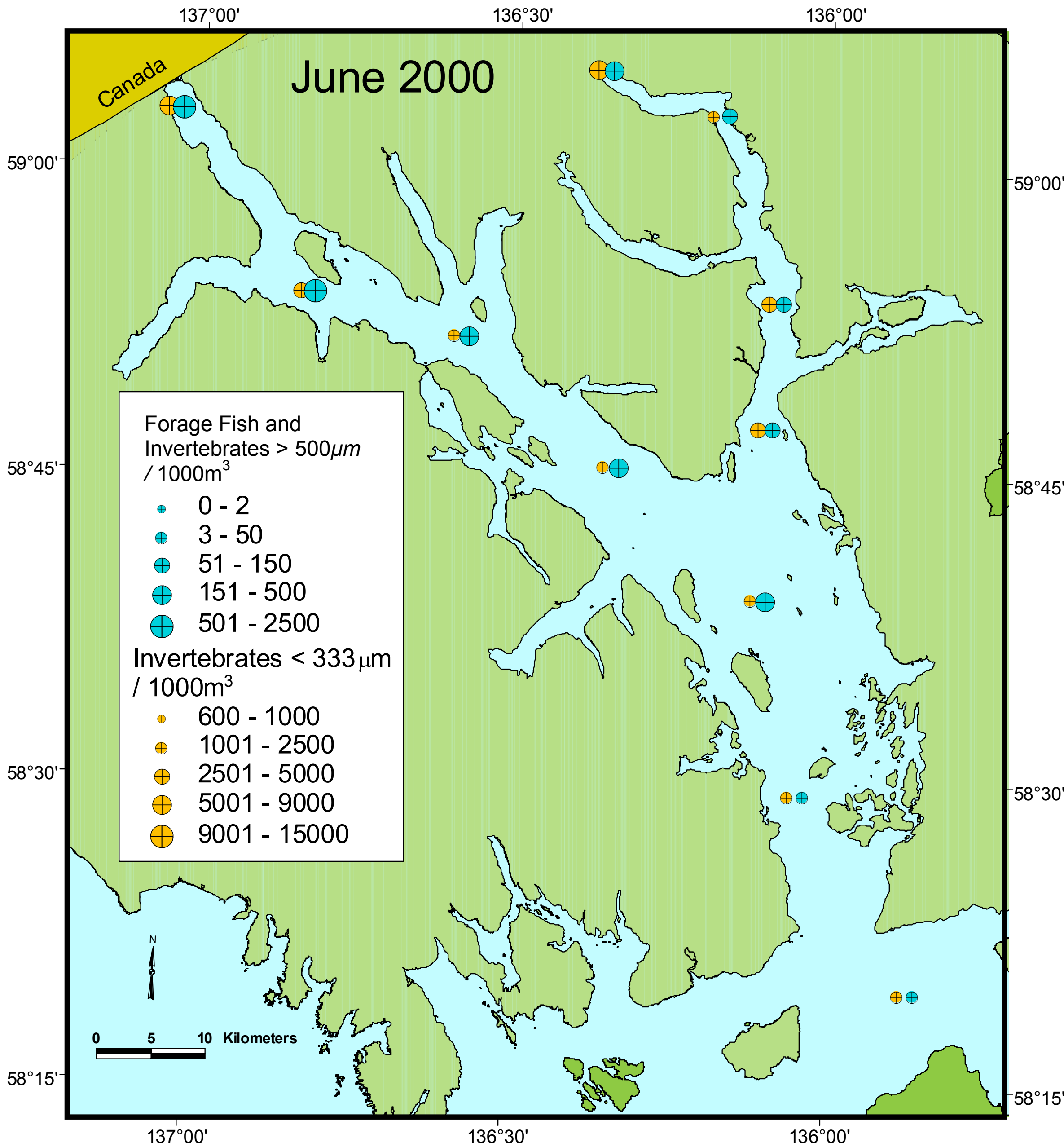

Figure 45. Spatial pattern of zooplankton caught in vertical plankton tows (yellow) and euphausiids and forage fish caught in trawls (blue) in Glacier Bay during June 2000.

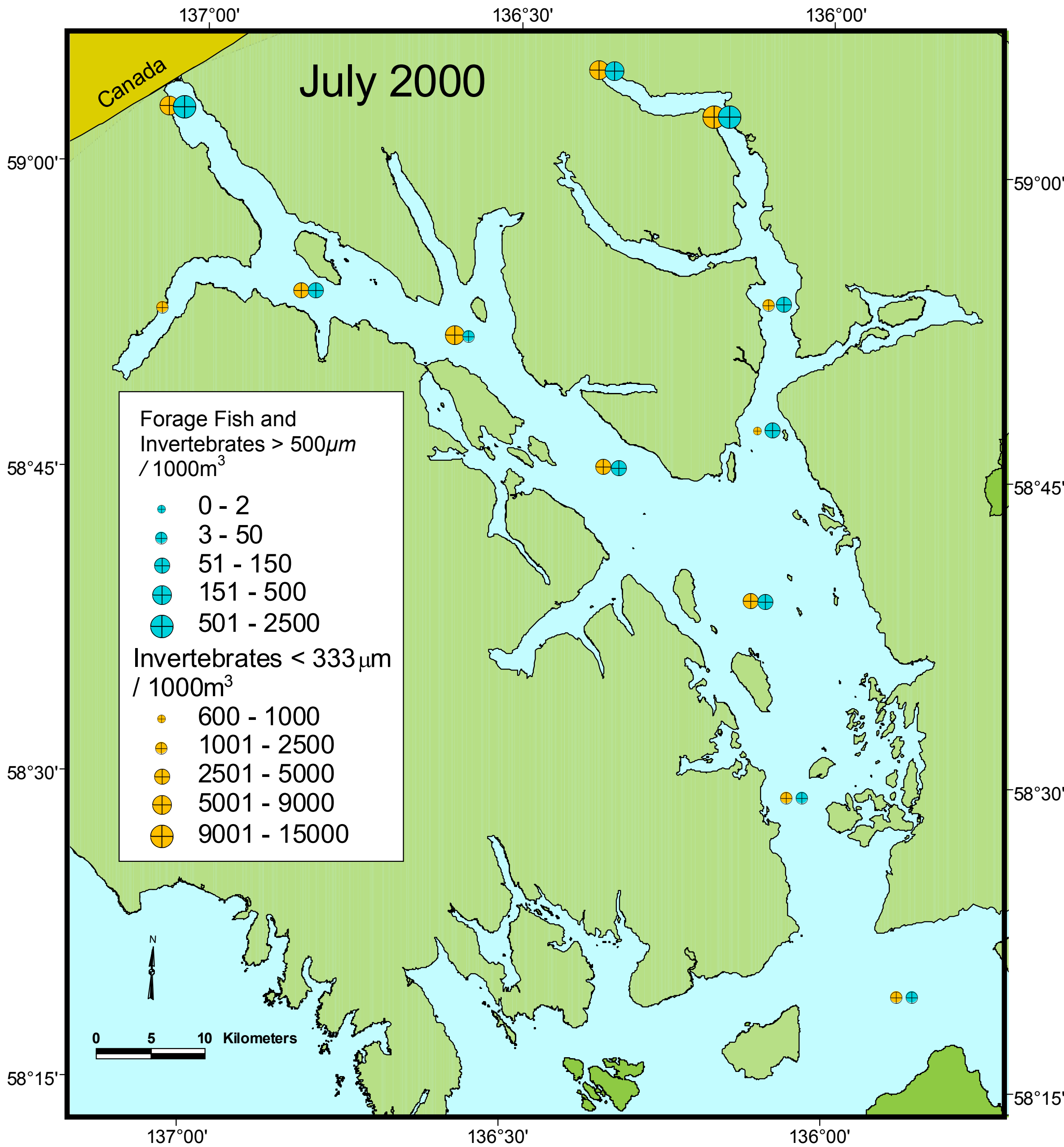

Figure 46. Spatial pattern of zooplankton caught in vertical plankton tows (yellow) and euphausiids and forage fish caught in trawls (blue) in Glacier Bay during July 2000.

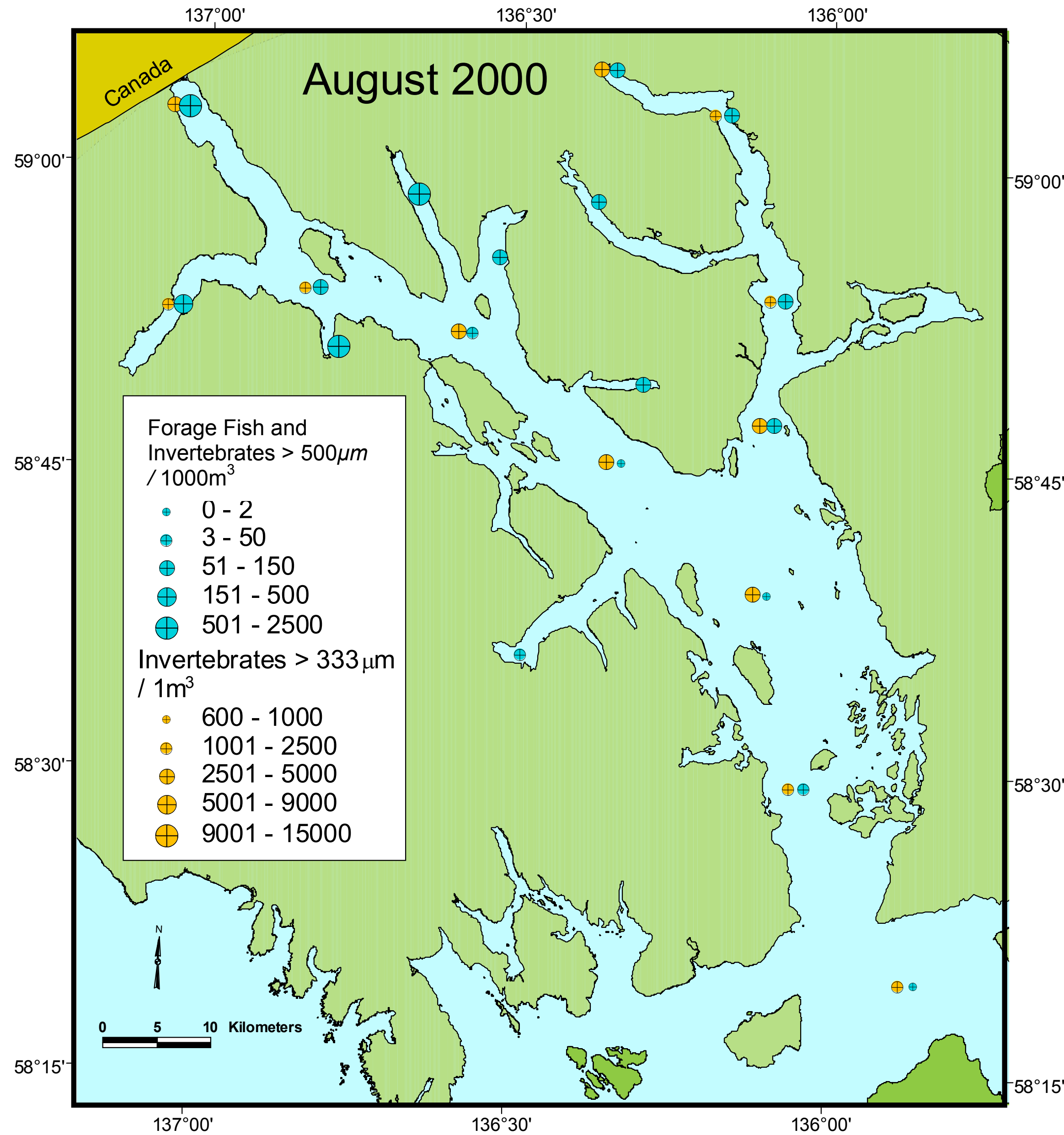

Figure 47. Spatial pattern of zooplankton caught in vertical plankton tows (yellow) and euphausiids and forage fish caught in trawls (blue) in Glacier Bay during August 2000.

Littoral Fish Community

During 1999 and 2000 we caught a total of 50,610 fish in 271 beach seines comprising at least 38 species (not all juvenile sculpins and snailfish identified to species; Appendix 8). Small subsamples (see methods) were kept for further analysis with the proportion of fish identified, counted, and returned immediately to the ocean, thus minimizing mortality. The diversity of littoral zone species in Glacier Bay (38 species) is comparable to another southeast Alaskan study in which Orsi and Landingham (1985) found 42 species. The species composition of their study included 14 species not found in our beach seines. However, four of these were found using other sampling methods than used in our study. Their study was in Icy and Chatham Strait, which are more open bodies of water, possibly explaining these differences. Species found in that study and not found by this study were; steelhead trout, slender cockscomb, snake prickleback, spotted snailfish, thorny, tidepool, crested, and manacled sculpins, red Irish lord, and tubenose poacher. Of these; spotted snailfish, crested and manacled sculpin, and tubenose poacher have never been reported elsewhere in Glacier Bay (see Orsi and Landingham for capture citations). Other nearshore areas in subarctic Alaska also produced comparable numbers of species; Robards et al. (1999) caught 52 species in lower Cook Inlet and Isakson *et al.* (1971) caught 40 species in the nearshore waters of Amchitka Island.

When broken down by area and season, as few as one species comprised 90 % of the fish caught (Table 4). In all areas and time periods the 5 most dominant species made up at least 79% of the fish caught. As expected from these patterns of relative abundance, these fish were predominantly juveniles (Gibson *et al.,*1996) and typically low in the trophic web (Allen, 1982). In estuarine, inshore, and Bay habitats in the northeastern Pacific, our results are consistant with earlier studies that found five or fewer species accounting for more than 75 % of the individuals in local fish communities, even though the total number of species comprising these communities may be much larger (e.g., Allen and Horn, 1975; Hancock, 1975; Horn, 1980; Allen, 1982; Gordon and Leavings, 1984; Orsi and Landingham, 1985).

High-latitude fish assemblages such as those in Glacier Bay, and particularly those in shallow water, are subjected to large seasonal variations in temperature and day length. These physical factors impart a strong seasonality to community structure (Nash, 1988). In Glacier Bay species composition (relative abundance; Figure 48) and frequency at which different species are caught (Table 5) indicated that early season catches (lower and middle Bay) are dominated by salmonids and late-season catches are predominantly juveniles (middle and upper Bay). Mid-summer declines in abundance may be a result of physical factors, but like here, can frequently be attributable to changes in community structure. In particular, the changes in composition and abundance are frequently related to influxes of juveniles of various species (Robards et al., 1999; Gordon and Levings, 1984). Many other investigators have also noted decreased fish abundance between spring and fall peaks (in this case July; e.g., Livingston, 1976; Horn, 1980; Allen, 1982; Thorman, 1986*b*; Methven and Bajdik, 1994).

Table 4. Percent composition (by number of individuals) for species contributing 90% of the overall beach seine catch by area and season

	June, 1999	June, 2000	July, 2000	August 2000
Icy Strait	No Data	Pink salmon (96%)	Pacific herring (64%) Great sculpin (18%) Sand lance (5%) Buffalo sculpin (5%)	Pacific cod (35%) Kelp greenling (25%) Silverspotted Sculpin (20%) Pink Salmon (10%)
Lower Bay	Pink salmon (85%) Unidentified sculpins (11%)	Pink salmon (47%) Unidentified sculpins (41 %) Dolly varden (6%)	Walleye pollock (74%) Great sculpin (13%) Dolly varden (9 %)	Sand lance (32%) Pink salmon (21%) Great sculpin (18%) Pacific herring (7%) Dolly varden (5%) Kelp greenling (4%) Silverspotted sculpin (3%)
Middle Bay	Sockeye salmon (51%) Pacific sand lance (19%) Pink salmon (12%) Coho salmon (6%) Pacific herring (3%)	Pink salmon (77%) Rock sole (11%) Unidentified sculpins (8%)	Pink salmon (46%) Great sculpin (13%) Pacific herring (11 %) Butter sole (10%) Slender eelblenny (5%) Pacific sand lance (4%) Coho salmon (3%)	Pacific herring (87%) Pacific sand lance (9%)
West Arm	Unidentified sculpins (37%) Pacific sand lance (26%) Slender eelblenny (18%) Walleye pollock (9%)	Unidentified sculpins (52%) Pink salmon (10%) Pacific sand lance (9%) Slender eelblenny (7%) Butter sole (7 %) capelin (5%)	capelin (44%) Slender eelblenny (30%) Great sculpin (11%) Rock sole (10%)	capelin (73%) Slender eelblenny (17%) Pacific sand lance (4%)
East Arm	Unidentified sculpins (34%) Slender eelblenny (34%) Pacific sand lance (15%) Dolly varden (12%)	Slender eelblenny (29%) Dolly varden (22%) Sockeye salmon (15%) Unidentified sculpins (9%) Butter sole (6%) Pacific sand lance (6%) Coho salmon (5%)	Pacific herring (42%) Great sculpin (19%) Rock sole (14%) capelin (14%) Slender eelblenny (3%)	Pacific sand lance (83%) capelin (7%)

Table 5. Frequency of capture for key taxa in Glacier Bay beach seines during 1999 and 2000. All areas are combined.

Species	1999	2000		
	June	June	July	August
Herring	31.25	0.00	47.72	38.19
Salmonid	25.36	29.16	19.95	21.81
Dolly Varden	21.47	33.04	27.35	23.19
Smelt	18.97	13.50	53.57	43.80
Gadid	47.16	11.96	7.06	17.82
Sand Lance	41.77	20.58	28.87	42.22
Sculpin	27.11	27.24	35.17	32.52
Flatfish	16.00	13.21	28.15	23.33
Other	24.47	20.53	13.97	25.31

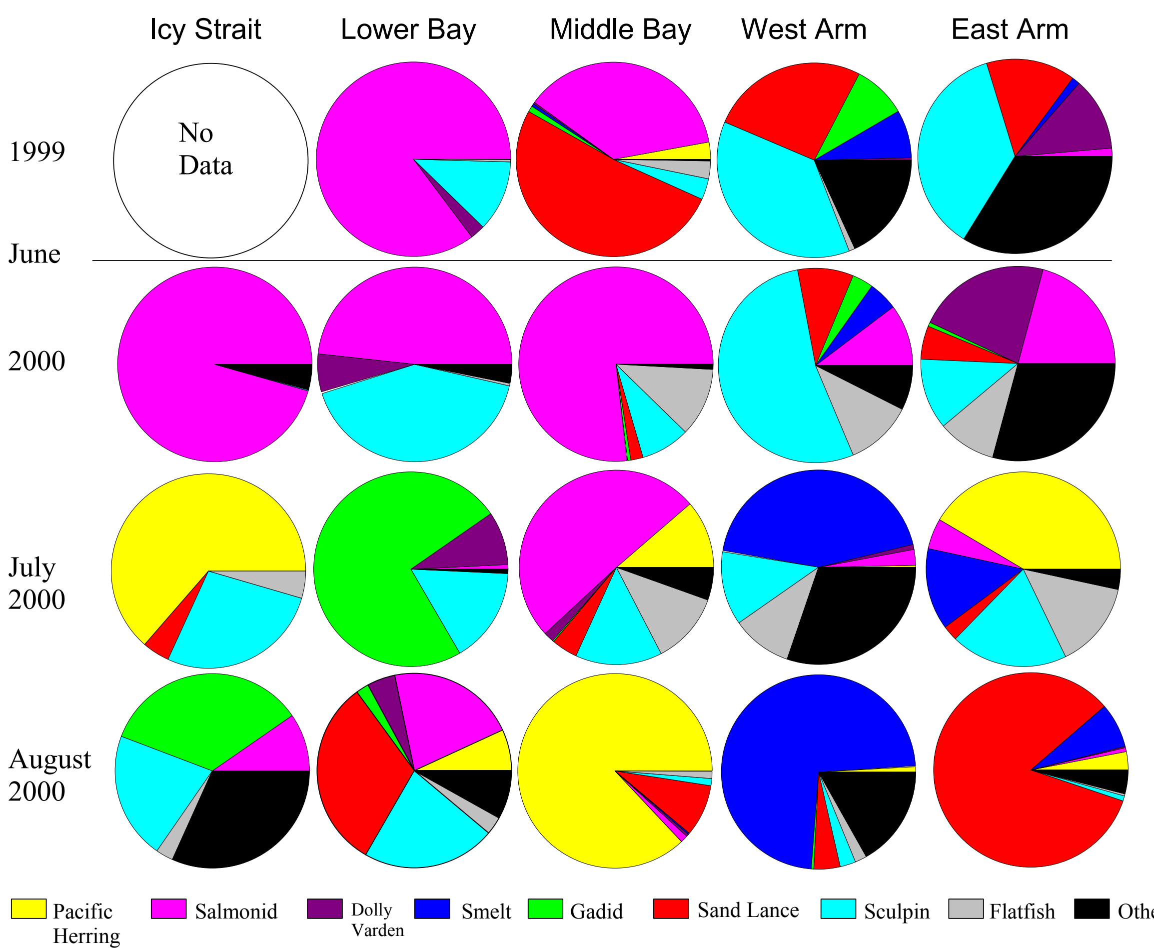

Figure 48. Species composition of beach seine catches in Glacier Bay during 1999 and 2000. Figures represent fish caught only at monitoring locations.

Although we beach seined at numerous sites, the bulk of the fish caught were from only a few sites. Furthermore, three of the top four ranked sites for catch abundance were also in the top four for number of species present at a site; sites BS19 at Spokane Cove, BS36 at Gloomy Knob, and BS09 in South Fingers (Figure 49). The high productivity and species diversity at Spokane Cove, South Fingers, and Gloomy Knob (West Arm) are perhaps not surprising as all three areas are well-developed salmonid spawning areas and are therefore subject to additional nutrient inputs from established riparian zones (Milner, 1987). Although salmonid systems exist in the East Arm, only BS 34 and BS 31 were adjacent to stream mouths. Further analysis and possible research will be needed to fully elucidate the complex relationships between salmonid streams and the nearshore marine environment.

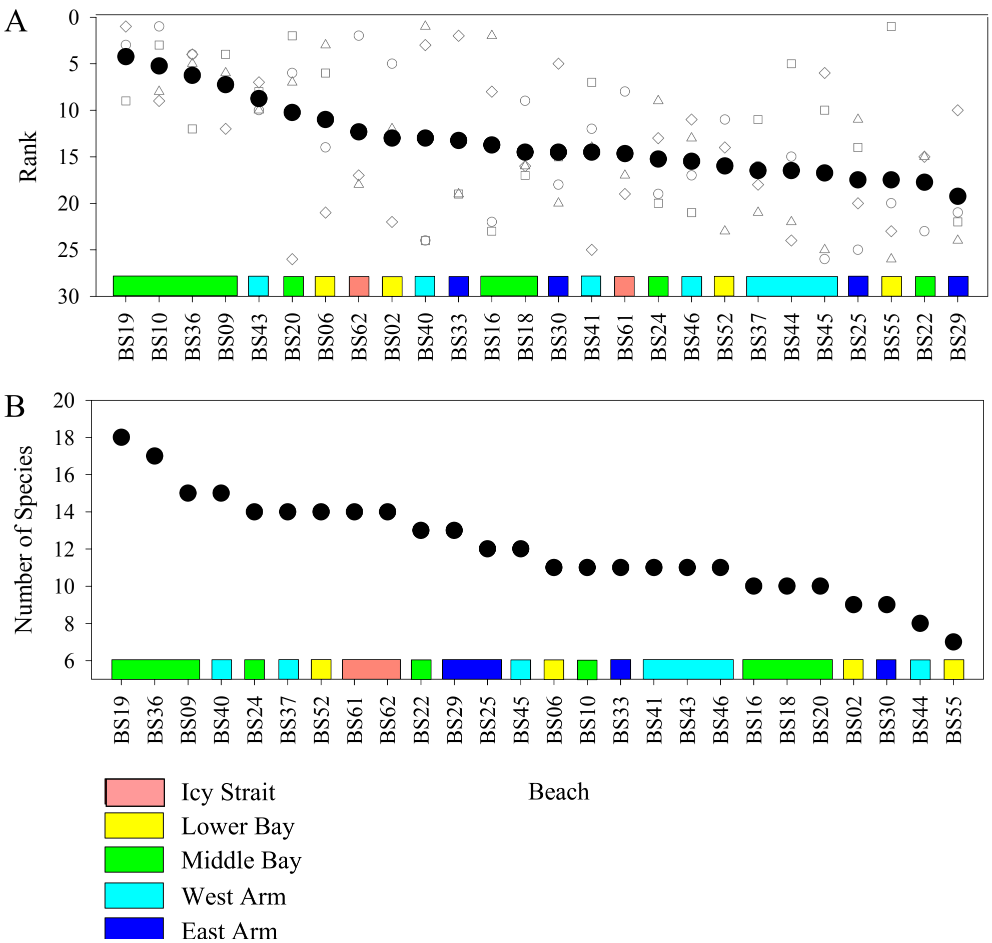

Figure 49. Beach seine stations in Glacier Bay (note different order of study sites in A and B) ranked by (A) Mean abundance rank (filled circles) of fish over the four sampling periods (□ June 1999, ○ June 2000, Δ July 2000, ◊ August 2000); and (B). Number of species caught.

Catch-per-unit-effort (per individual set) and relative taxa abundance for each month indicated a pronounced seasonality to the nearshore fish assemblages (Table 6; Figure 50). Additionally, marked spatial differences were observed around the Bay. Salmonids dominated the June nearshore community in Icy Strait (1999 and 2000) and the middle

Bay (2000 only). Our sample locations in the lower Bay apparently precluded catches of these salmonids that were regularly observed swarming around the dock in Bartlett Cove (Robards, pers obs.). Overall, catch was low in July throughout the Bay but increased dramatically in the middle Bay and upper-arms during August. A single large (18,470 individuals) catch of juvenile (first-year) herring (Figure 50) in Spokane Cove accounted for most of the increased CPUE in the middle Bay for August. This catch was surprising in light of few herring being caught in icthyoplankton samples. Juvenile (first-year) capelin (west arm) and sand lance (west and east arms) accounted for most of the increased August CPUE in the upper-arms (Figure 50).

Variability in nearly all measures of nearshore marine fish communities is profound (see Robards et al., 1999) and Glacier Bay's nearshore community is no exception. Diel variation is important for many species; however, our sampling occurred exclusively during daylight hours. Therefore, diel variation in vertical distribution was not considered here, except to say that for species such as cod, greater numbers may have been present at night than represented in our daytime sampling. Differences in nearshore fish catches at high and low tides are also apparent. Clearly, high tide catches only represent those fish that swim from the sub-tidal up into the intertidal and a few permanent intertidal dwellers as opposed to low tide catches that encompass those and all obligate nearshore subtidal species. Our results indicated order of magnitude differences between high and low tide catches (Figure 52). This should be considered when repeating our study or defining a new nearshore investigation.

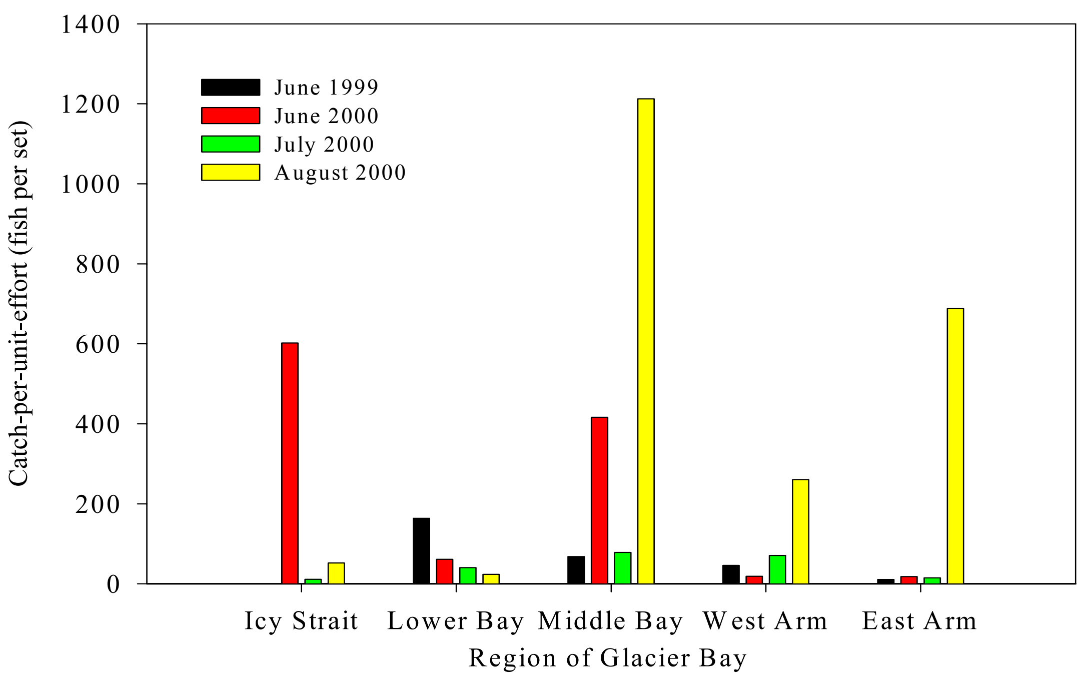

Figure 50. Catch-per-unit-effort for beach seine sets in the different regions of Glacier Bay by season.

Table 6. Catch_Per_Unit-Effort (CPUE) of seine catches in Glacier Bay during 1999 and 2000.

Region	Season	Herring	Salmonid	Dolly Varden	Smelt	Gadid	Sand lance	Sculpin	Flatfish	Other
Icy Strait	2000-June		575.50					1.00		25.50
	2000-July	7.00					0.50	3.00	0.50	
	2000-Aug.		5.00			18.00		11.00	1.50	16.50
Lower Bay	1999-June		139.50	4.00				19.38	0.63	0.13
	2000-June		29.42	3.83		0.08	0.08	25.33	0.25	1.92
	2000-July		0.30	3.60		29.80		6.40		0.30
	2000-Aug.	1.60	5.00	1.10		0.50	7.40	5.20	0.70	1.90
Middle Bay	1999-June	1.94	25.19	0.19	0.31	0.69	34.81	2.38	2.00	0.19
	2000-June		319.79	0.42	0.05	2.21	8.68	33.95	47.58	3.68
	2000-July	8.83	39.56	1.33		0.17	3.39	11.28	9.28	4.28
	2000-Aug.	1055.06	14.56	4.94	2.94	0.22	104.61	14.61	14.22	1.11
West Arm	1999-June			0.18	3.64	4.09	12.00	17.00	0.45	8.27
	2000-June		1.91		0.91	0.65	1.74	9.96	2.09	1.39
	2000-July	0.21	1.86	0.57	30.64	0.07	0.07	8.64	7.07	21.29
	2000-Aug.	2.20	0.13	0.27	189.80	1.13	11.33	6.87	5.07	43.87
East Arm	1999-June		0.14	1.29	0.14		1.57	3.86		3.57
	2000-June		3.75	4.00		0.13	1.00	2.13	1.75	5.25
	2000-July	6.13	0.75		2.00		0.38	2.88	2.13	0.50
	2000-Aug.	20.63	4.63	1.50	51.13	0.13	574.38	5.88	2.25	27.50

Figure 51. Young-of-the-year (from top) Pacific sand lance, capelin, and Pacific herring caught by beach seine close to Lamplugh Glacier (Stn. 46) during August 2000.

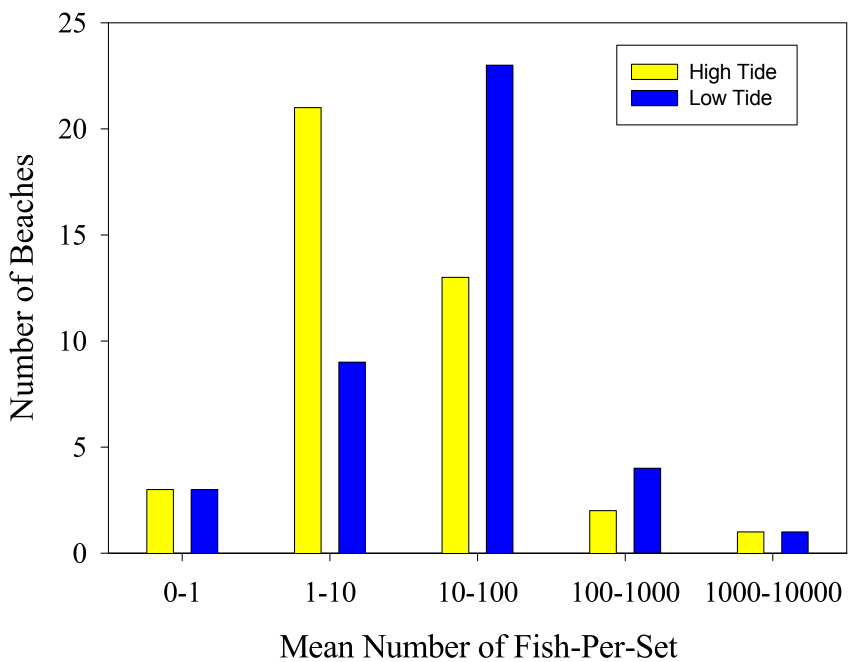

Figure 52. Size-frequency of high and low tide beach seine catches in Glacier Bay during 1999 and 2000.

Pelagic Fish Community

Modified herring mid-water trawls in June 1999

A total of 48 tows at 34 stations were sampled from June 10 to 23, 1999 (Appendix 8). A total of 5011 fish were captured, including both small schooling and larger pelagic fish. Catch numbers were standardized for catch-per-unit-effort (CPUE) - 1000 m^2 distance towed – and characterized "good" or "bad" based on efficiency of catching the acoustic target, i.e. cases where few fish were caught when a strong hydroacoustic signal was present were characterized as bad tows). We fished 6 stations in Icy Strait, 7 in Lower Glacier Bay, 10 in the Middle Bay, 5 in the East Arm of Glacier Bay, and 6 in the West Arm of Glacier Bay.

Species composition was distinct between Icy Strait and the four regions of Glacier Bay (Figure 53). Pacific herring were never captured by this method in Glacier Bay although they comprised the majority of fish caught in Icy Strait (74 %). Capelin were also abundant (14 %) in Icy Strait, and near Point Adolphus we captured Northern lampfish at 90 m fishing depth. The most abundant fish species in Glacier Bay were walleye pollock and capelin. In the Lower Bay the remaining 32 % of fish species composition were larval fish: 12 % sand lance, 7 % Sculpins (Cottidae), 7 % Pricklebacks (*Lumpenus spp*.), and 6 % flatfish (Pleuronectidae). In the Middle Bay, the 6 % other fish were mostly larval sand lance and larval pricklebacks, and in the West arm the 22 % other fish were all larval pricklebacks. Within the four regions of Glacier Bay, Muir Inlet was distinct. Other fish species in Muir Inlet were predominantly Northern lampfish (1 %) and Northern Smoothtongue (3 %). Northern Smoothtongue were only caught by this method in front of the Muir Glacier and always in conjunction with catches of Northern lampfish (Note that the Isaacs Kidd mid-water trawl caught northern smoothtongue in front of Margerie in 2000. The Isaacs Kidd was used much closer to the glacier front which may have explained this difference).

During this study 50.6% of all fish caught had fork length < 50 mm. Using the same equipment in Cook Inlet we caught much lower proportions of small fish during 1997 (1.01 %) and July 1998 (1.5 %). Mean fish length in Glacier Bay varied among the five regions. In Icy Strait 23 % of fish were between 50 and 99 mm, 31 % were < 50 mm, and 35 % were between 200-249 mm (mostly herring). In Lower and Middle Glacier Bay the majority of the fish captured (over 90 %) were larval fish with fork length < 50 mm. In the West Arm over half of the fish captured were larval species, 22 % were between 50 and 99 mm, and 16 % were greater than 300 mm (mostly adult walleye pollock). In Muir Inlet the majority of fish were size 50 – 99 mm (58 %), with 40 % < 50 mm. We did not catch any 50 – 150 mm walleye Pollock, or herring in Icy Strait or Glacier Bay mid-water trawls.

Throughout Icy Strait and Glacier Bay, mean fish CPUE was relatively low compared to similar work in Cook Inlet, with Muir Inlet having the highest CPUE at 360 fish per set. Weights of euphausiids were an order of magnitude greater than jellyfish, and CPUE of both were highest in Muir Inlet.

Adult walleye pollock (fork length 231 to 602 mm) stomach contents (169 stomachs analyzed) reflect the trend of high invertebrate/low fish abundance within Glacier Bay. The majority of pollock stomachs (65 %) had only euphausiids, whereas only 15 % had fish. Of the 25 stomachs with fish, 64 % actually contained larval fish and euphausiids; the other 36 % had capelin and northern lanternfish. Other crustaceans in pollock stomachs included mysids, amphidods, isopods, and shrimp.

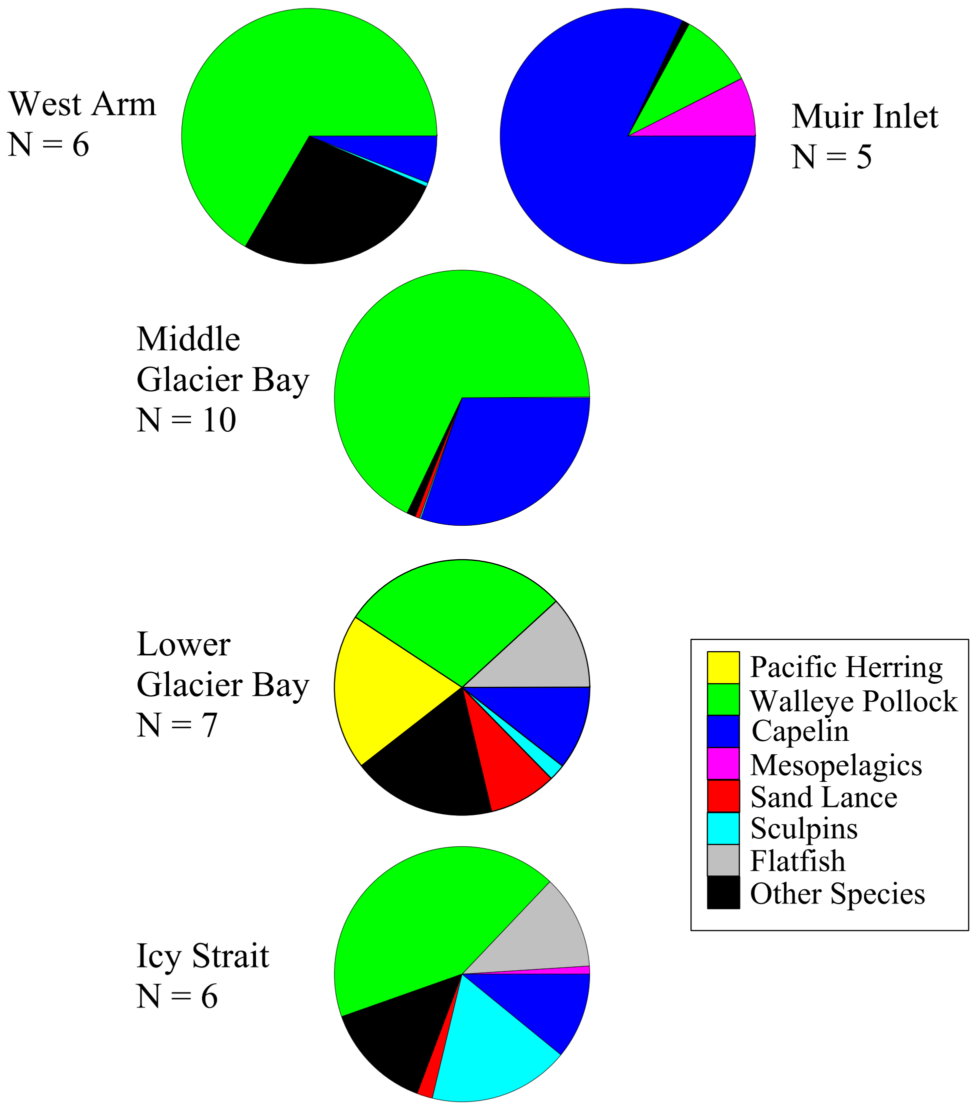

Figure 53. Relative composition of key taxa caught by modified herring mid-water trawl during June, 1999 in the different regions of Glacier Bay.

Isaacs Kidd mid-water trawls in July and August 2000

A total of 31 tows at 18 stations were sampled from July 26 to August 17, 2000 (Appendix 8). A total of 3,267 fish, 64,872 euphausiids, 3 cephlapods, 132 shrimp (Pandalus, Pasiphaea, Neomysis), and 162 jellyfish were caught.

Catches for each trawl were standardized for catch-per-unit-effort (CPUE) and adjusted for 1000 m^3 of water passing through the net. Composition of the total fish caught was dominated by young-of-the-year walleye pollock (53%) and capelin (35%). These two species, along with slender eelblenny (6%) and the two bathypelagic species – northern lampfish (3%; Figure 54) and northern smoothtounge (1 %) made up over 98% of the total catch. Size composition of the fish caught included both small schooling and larger pelagic fish (Figure 55). All but two of the fish over 60 mm (n = 189; 6% of total catch) were caught at the head of Glacier Bay adjacent to Margerie Glacier (62%), Muir Glacier (15%), and in Rendu Inlet (14%), Queen Inlet (4%), Johns Hopkins Inlet (2%), and Reid Inlet (2%).

Walleye pollock, capelin, and slender eelblenny larvae along with the northern lampfish and northern smoothtongue made up over 98% of the pelagic fish larvae caught (Figure 56), similar to results described by Mattson and Wing (1978) for inland coastal waters of southeastern Alaska. These authors found 50% of larval fish caught in June were walleye pollock, which favored channels rather than inside Bays. These authors also found osmerids to be the second most common taxa and speculated that capelin was the most abundant of these osmerids (not all identified to species).

Although the Isaacs Kidd mid-water trawl was only used in the upper 50 m of the water column we saw strong and repeating patterns within Glacier Bay. These include:

-Juvenile pollock were not commonly caught south of Tlingit Point during July and August by this method.

-Although waters around Margerie Glacier supported very high numbers of juvenile fish, the East Arm generally supported higher numbers of (primarily juvenile) capelin than the West Arm. Our fishing at Margerie Glacier may have been biased by our close proximity to the ice-front compared to our sample at McBride (Station 18; see Figure 4 for locations). Zooplankton results for June indicated about twice the abundance at Station 21 close to Margerie as at the closely adjacent Station 12. Further research is needed to describe the extent and mechanisms driving this productivity (see recommendations for future work).

-The areas close to tidewater glaciers (upper East and West arms) appeared particularly productive for fish and euphausiids (Figure 55). Rendu Inlet also appeared remarkably productive, especially when compared to neighboring Queen Inlet. Reasons for the differences between these two sites can only be speculative based on our results. However, Queen Inlet has particularly high sedimentation rates (up to 6 cm per day).

This, in conjunction with a photic depth of less than 10 m (Hooge, USGS, Glacier Bay Field Station, pers comm.) probably restricts potential productivity at this site.

Figure 54. Northern lampfish caught by the Isaacs-Kidd mid-water trawl in upper-Muir Inlet.

Figure 55. Typical catch by the Isaacs-Kidd mid-water trawl at Margerie Glacier (Stn. 21). Catch is separated into (from top) large fish (pollock and hake), small schooling fish (capelin, pollock, northern smoothtongue, slender eelblenny), and euphausiids.

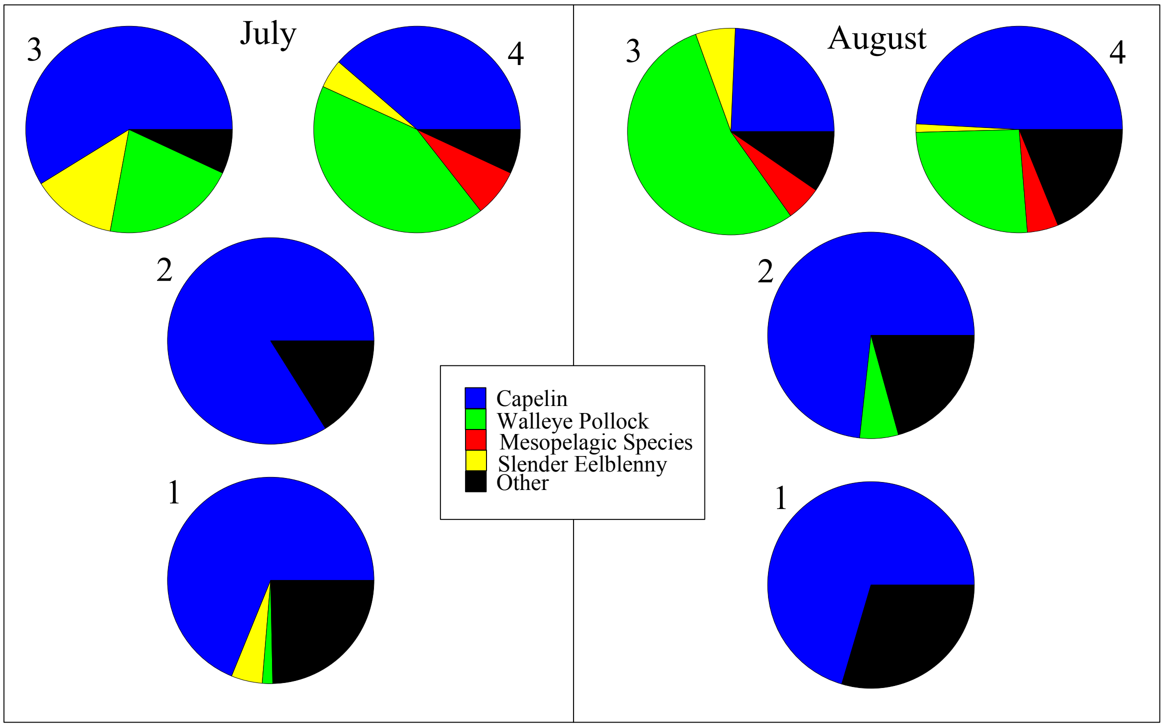

Figure 56. Relative composition of key taxa in Isaacs-Kidd mid-water trawls in lower (1), middle (2), west arm (3), and east arm (4) of Glacier Bay during July and August, 2000.

Icthyofauna

Figure 57 depicts the range of length and weight data available (on accompanying data cd) for analysis.

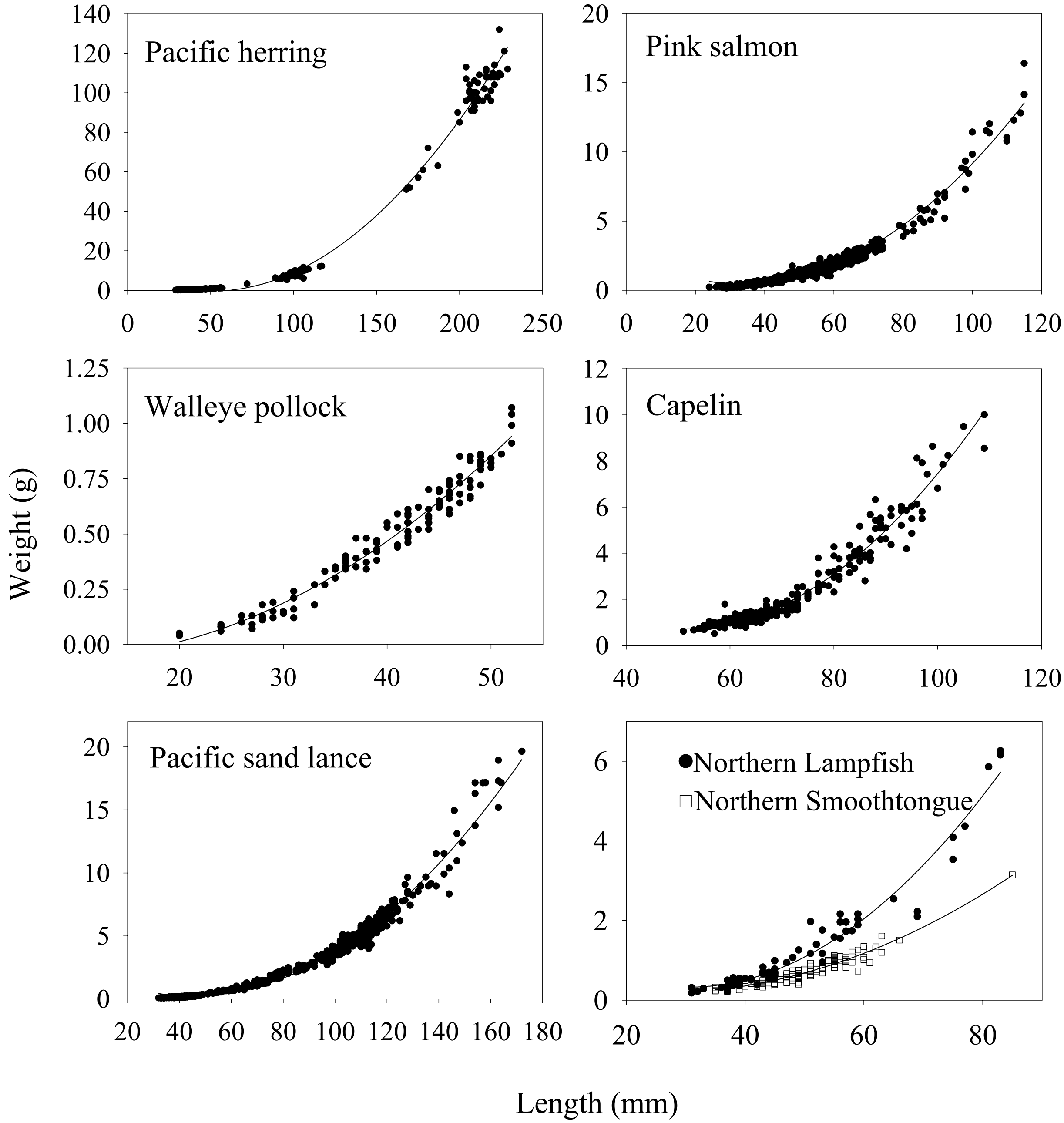

Figure 57. Length-weight relationships for key forage fish species within Glacier Bay. Plots are compiled from fish collected by all capture methods.

Discussion of Select Species

Pacific Herring

During June 1999, herring were only caught nearshore in small numbers (although relatively frequently) within the middle region of Glacier Bay. However, during 2000 when we sampled throughout the season, juvenile herring were found in extremely large numbers in the middle-Bay, particularly at Spokane Cove. The seasonal length/frequency graph (Figure 58) clearly indicates the arrival of juvenile herring in the latter part of the summer through July and August. Herring are known to congregate in shallow embayments where they take advantage of fewer predators and relatively higher food availability for growth (Figure 59). Pelagic trawls caught adult herring in Icy Strait but not within Glacier Bay. It remains unknown whether herring spawn within Glacier Bay or the juveniles found in nearshore catches are advected into the Bay from spawning that occurs outside.

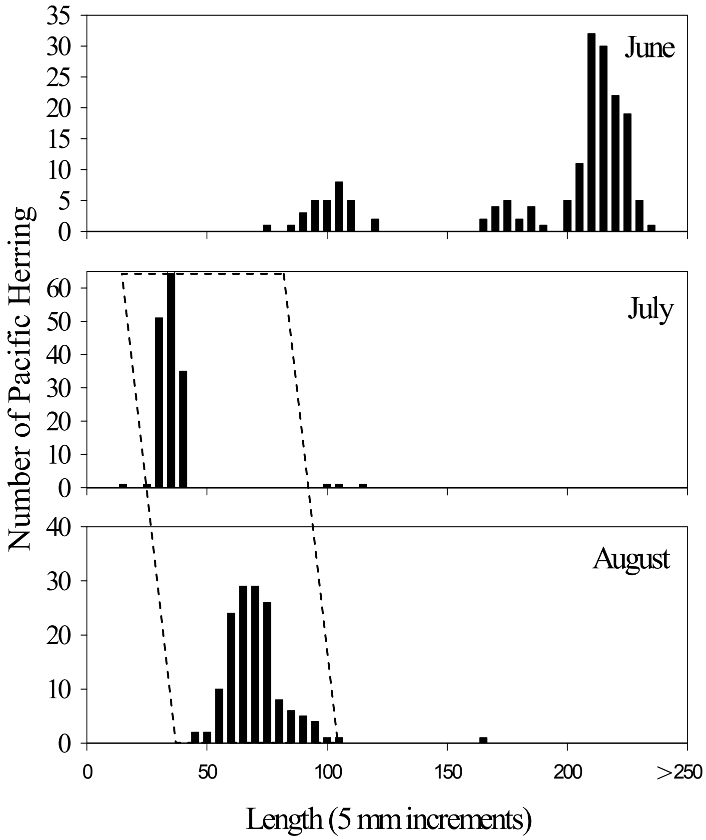

Figure 58. Length-frequency distribution of Pacific herring caught in Glacier Bay during 1999 and 2000 by beach seine and pelagic trawl. Young-of-the-year fish are indicated by the dashed line.

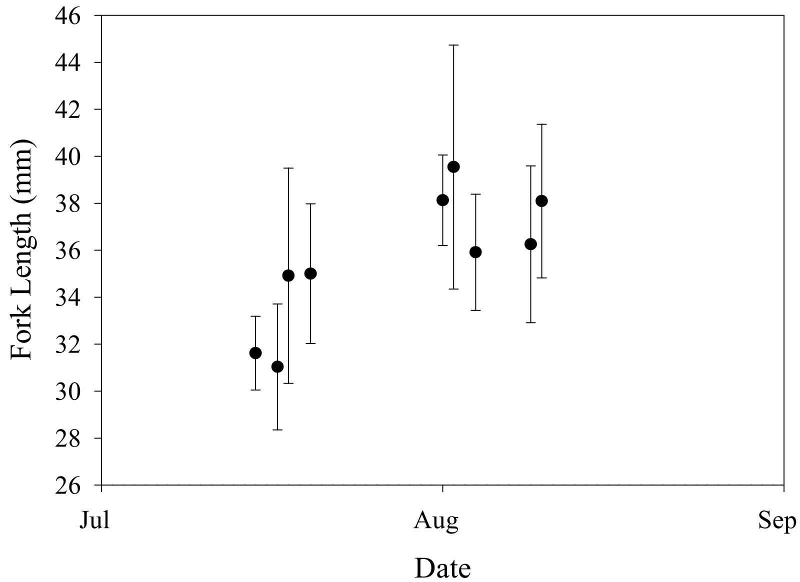

Figure 59. Daily mean (+/- sd) size (mm) of juvenile Pacific herring caught in beach seines and pelagic trawls.

Pacific Salmon

We caught juveniles of four species of salmon within Glacier Bay (chinook were not found). Most salmon were juveniles with only two adults caught (one pink and one chum). Catch rates of salmon in the nearshore were highest during early summer, in accordance with Southeast Alaska juvenile salmonid surveys conducted by the National Marine Fisheries Service Auke Bay Laboratory (Orsi et al., 1998).

Salmon species (all juvenile) ranged from common and abundant in the lower region of the Bay, to infrequently caught in the upper Bay. Quality (stability and productivity) and distribution of streams for spawning and rearing by these anadromous fish is likely the most important factor influencing their distribution. Habitat quality for salmon improves from the cold, highly turbid, recently deglaciated streams in the upper reaches of the Bay to the older, warmer, stable, clearwater streams in the lower Bay (Milner, 1987). Milner (1987) clearly showed a corresponding succession from low salmonid numbers in the recently deglaciated streams of the upper Bay to an abundance in the older lower Bay streams. Turbid waters may result in reduced development and survival of eggs and embryos, reduction or loss of sight-feeding capabilities, reduced growth, increase stress and interfere with environmental cues necessary for orientation in migration (Lloyd, 1987– cited in Milner & Bailey, 1989). Apart from turbidity and temperature, scouring of redds and dislodging of eggs/embryos during high spring and autumn discharges has been directly linked to poor salmonid production elsewhere in southeast Alaska (Tyler & Gibbons, 1973).

Pink salmon (as well as chum) appear to be two of the most suitable salmon species for initial colonization of newly formed stream systems as their fry migrate directly into the ocean, eliminating the need for suitable rearing habitat in the highly turbid waters (see next section on Dolly Varden which may be the most important early colonizer of new stream systems). However, Sockeye, Coho and Chinook are known to spawn in the lower reaches of turbid Alaskan rivers (Milner & Bailey, 1989). The ability of pink and chum salmon to outmigrate in their first year was reflected in their small size compared to other salmonids in this study. Pink salmon have also been reported as one of the species most likely to stray from their home streams (Pritchard, 1939), enhancing their ability to colonize new periglacial areas. Milner (1987) did not find pink or chum salmon in Nunatak Creek (upper east arm) and suggested that although these species can avoid prolonged freshwater residence, estuarine conditions may preclude fry development in this area. However, more recent studies by the National Park Service (Chad Soiseth – USNPS - Glacier Bay – *personal communication*) indicate pink and chum salmon have now colonized Nunatak Creek. We emphasize that even though we found juvenile salmon throughout the Bay, our results do not establish if these fish originated in Glacier Bay or whether they were advected into the Bay by currents.

Our results indicated that timing of out-migration (emigration from nearshore marine habitats to offshore areas) for juvenile salmonids largely occurred in the early part of summer (May and June). Migration of juvenile salmonids out of Glacier Bay toward the open ocean is expected to take advantage of optimal water temperatures, salinities, and food availability (Sheridan, 1962). Orsi (2000) found that the timing of seaward migration of (southeast Alaska) juvenile salmon coincided with seasonal peak periods of temperature and zooplankton. With peak zooplankton abundance in the lower Bay and Icy Strait in May and early June, this pattern appears to coincide with our results, at least for prey resources.

Length of pink salmon (Figures 60 and 61) for each days catch (daily mean length) indicated growth from a mean of about 30 mm in early June to about 60 mm in July. There was no increase in pink salmon size through July and August, the mean size of cohorts remaining at about 60 mm. The cause for this apparent cessation of growth lies in their behavioral change from a nearshore to offshore existence (Heard, 1991). The exact size at which salmon make this shift to deeper water occurs differs between areas. Cooney et al., (1978) reported 60-70 mm for Prince William Sound. Larger individuals are the first to migrate to open waters (Heard, 1991), which may explain the lack of larger-sized juvenile pink salmon in the nearshore area in this study. Offshore sampling in Icy Strait during June by the National Marine Fishery Service (Orsi et al., 1997, 1998) reported offshore juvenile salmon with sizes ranging somewhat larger than in our nearshore study (73-136 mm in 1997 and 89-150 mm in 1998; no offshore pink salmon found in May). These results suggest that smaller pink salmon continue to reside close to shore until these minimum sizes are reached. Concurrent changes in physiology (e.g., ability to withstand changes in osmotic gradient) may compound this situation. LeBrasseur and Parker (1964) indicated reductions in growth of juvenile pink salmon after lengths of 60-80 mm were reached. Numerous authors (see Heard, 1991) have reported other associated changes as juvenile pinks move offshore including lower lipid levels and formation of smaller schools (500-2,000 fish).

The importance of juvenile salmonids as prey in Glacier Bay was beyond the scope of this project. However, they are a key prey in other Alaskan areas for at least walleye pollock (Prince William Sound; Willette et al., 1999), coho salmon (Wing, 1985), spiny dogfish (Beamish et al., 1992), some marine mammals, and seabirds (Scheel and Hough, 1997), all of which commonly occur in this area.

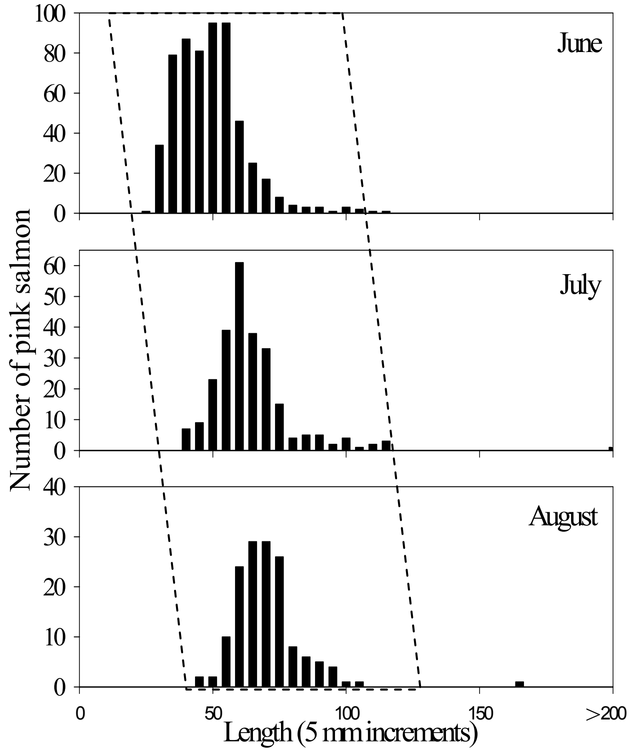

Figure 60. Length-frequency distribution of pink salmon caught in Glacier Bay during 1999 and 2000 by beach seine and pelagic trawl. Young-of-the-year fish are indicated by the dashed line.

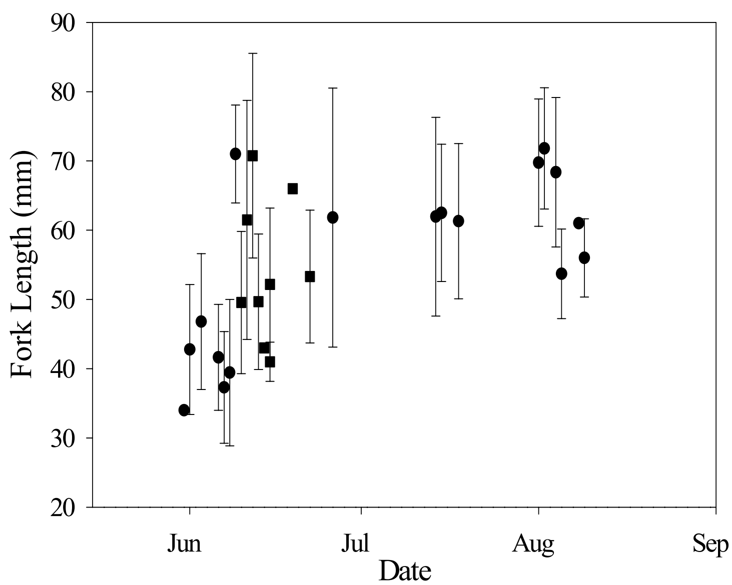

Figure 61. Daily mean (+/- sd) size of juvenile pink salmon caught in 1999 (squares) and 2000 (circles).

Dolly Varden

Dolly Varden were included in this discussion due to their frequency of capture and abundance within nearshore areas of Glacier Bay. This species was only caught in beach seines and markedly more abundant in the lower regions of Glacier Bay than in the upper-arms.

We found few Dolly Varden in the West Arm as opposed to the East Arm despite extensive sampling (Table 6). This species is a common predator in the nearshore area of Alaskan marine bays and is typically the first salmonid to colonize new stream habitats (Milner, 1994). The lower abundance in the West Arm mirrors the colonization pattern for salmonids, which are also far more prevalent in the east arm. The geography of the lower regions of the two areas is markedly different. From Muir Point in the East Arm to Wachusetts Inlet there are wide benches of vegetated land that include several lake systems. In the West Arm the land rises quickly from the water into the coastal mountains, and only includes one lake system (Vivid Lake). This topography (few steep and unstable streams) likely impedes colonization by salmonids and Dolly Varden in much of the West Arm, isolating these species to a few areas such as Vivid Lake. No clear age-class structure was present from our samples, although at least three age-classes are suggested from the length/frequency histogram (Figure 62). This species takes 3-4 years to reach average smolt size of 135 mm in fork length (Armstrong, 1970).

Table 7. Catch-per-unit-effort of Dolly Varden within Glacier Bay by sampling region during 1999 and 2000.

Area (sets)	Catch-per-unit effort
Icy Strait (22)	3.4
Lower Bay (31)	8.4
Middle Bay (85)	1.5
West Arm (91)	0.2
East Arm (42)	1.3

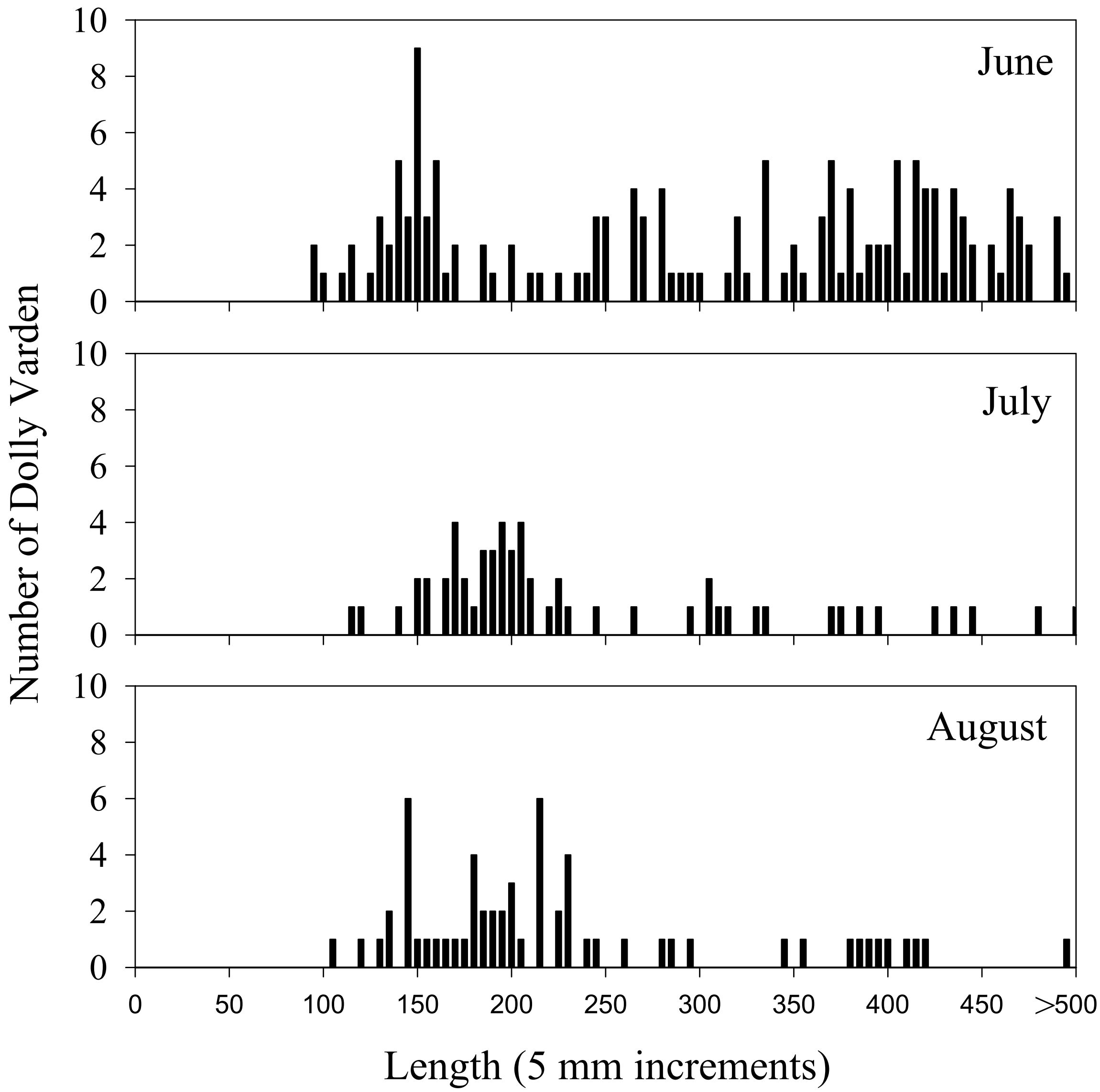

Figure 62. Length-frequency distribution of Dolly Varden caught in Glacier Bay during 1999 and 2000 by beach seine.

Walleye Pollock

Walleye pollock larvae and juveniles were the most abundant species in our Icthyoplankton trawls, Isaacs-Kidd mid-water trawls, and modified herring trawls.

Using beach seines, we caught juvenile pollock in all nearshore areas of the Bay during June of 1999 and 2000 but not in Icy Strait. Most of these pollock were caught in the upper-arms. By July numerous juvenile pollock were present in the lower Bay (Table 8). Finding juvenile pollock in the glacially influenced arms of Glacier Bay raises the question as to whether spawning occurs in this area.

Table 8. Nearshore catch-per-unit-effort for young-of-the- year walleye pollock in Glacier Bay by sampling area

Area	June	July	August
Icy Strait	-	-	0.8
Lower Bay	0.1	74.5	
Middle Bay	0.1	0.1	0.2
West Arm	2.7	0.1	
East Arm	0.5	-	-

Length of walleye pollock (Figures 63 and 64) for each days catch (daily mean length) indicated growth from a mean of about 5 mm in early June to about 50 mm in August. We estimated a late April hatch-date for walleye pollock from the larvae we caught in Tucker trawls. This is similar to hatch dates reported for elsewhere in the northern Gulf of Alaska (e.g., Müter and Norcross, 1994) and fits with spawning potentially occurring in late winter (March to early April in Shelikof Straight; Kim and Gunderson, 1988). We have no early season pelagic trawl data to confirm this. The only demersal finfish caught in the upper Bay during exploratory fishing trawls in March of 1954 (cited in Hale and Wright, 1979) was walleye pollock. Their presence at that time would be appropriate if spawning is taking place in early spring.

The only non-young-of-the-year fish in nearshore areas were captured on 6/19/99 when six juvenile pollock were caught in Reid Inlet (mean length 134 mm) and on 8/8/00 when a 403 mm adult was caught in Muir Inlet.

Anecdotally, walleye pollock were observed co-schooling with herring at the entrance to Berg Bay during underwater video work (John Brooks – 805-644 -5185 x 109).

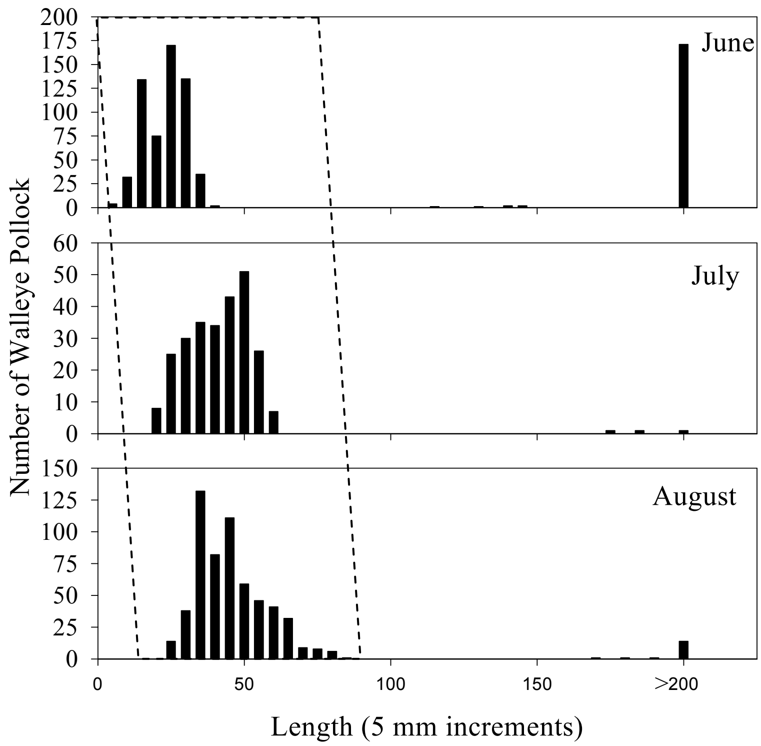

Figure 63. Length-frequency distribution of walleye pollock caught in Glacier Bay during 1999 and 2000 by beach seine and pelagic trawl. Young-of-the-year fish are indicated by the dashed line.

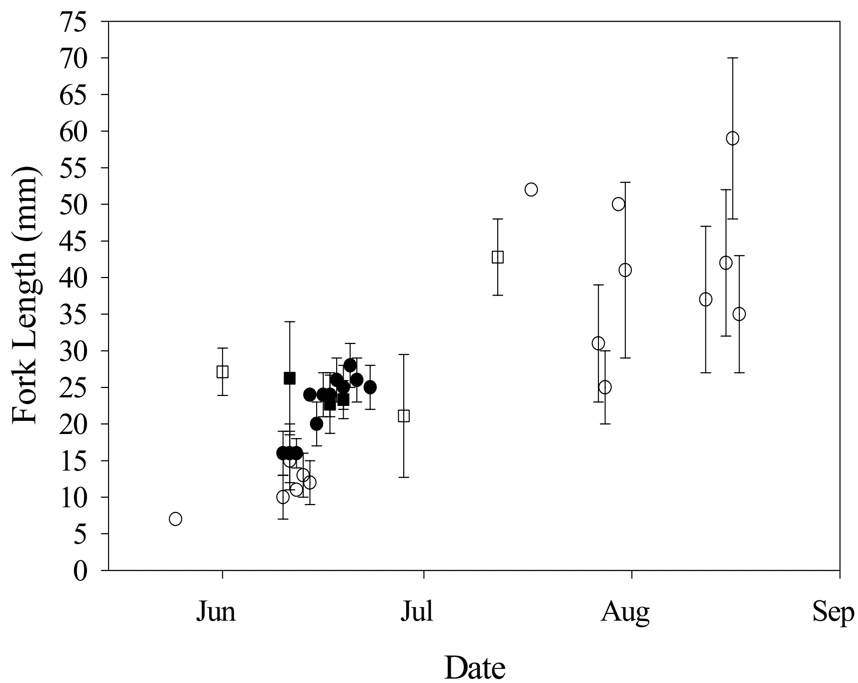

Figure 64. Daily mean (+/- sd) size of juvenile walleye pollock caught in beach seines (squares) and pelagic trawls (circles); solids = 1999, open = 2000.

Capelin

During the spring, capelin tend to concentrate along the Alaskan coast to spawn on gravel beaches. Time of spawning varies with location and water temperature, ranging from April to August at 5-10 °C (Pahlke, 1985). Preferred beaches generally have gravel substrate of grain size from 2.5 to 25 mm (Templeman, 1948; Jangaard, 1974). Observations by NPS coast walkers in Glacier Bay noted signs of intertidal spawning on June 30 1997 and during July 1998 (USNPS – Glaicer Bay - Bill Eichenlaub, personal communication). Although speculative, based on timing (Pahlke, 1985) and maturity of the few adult capelin we caught, these events are likely the result of capelin spawning (the other intertidal spawners generally spawn earlier (herring) or later (sand lance, Robards et al., 1999).

Most of the capelin that were caught in beach seines in July and August were young-of-the-year fish (Figures 65 and 66). These fish were a dominant component of the upper-arm fish community in both July and August. Peak immigration to the nearshore was clearly in August based on CPUE (Table 8). No capelin were caught in the lower Bay or Icy Strait nearshore areas, although they do exist in this region based on trawl catches.

Capelin were observed being preyed on by arctic terns at the entrance to Bartlett Cove but were not caught in seines in that region.

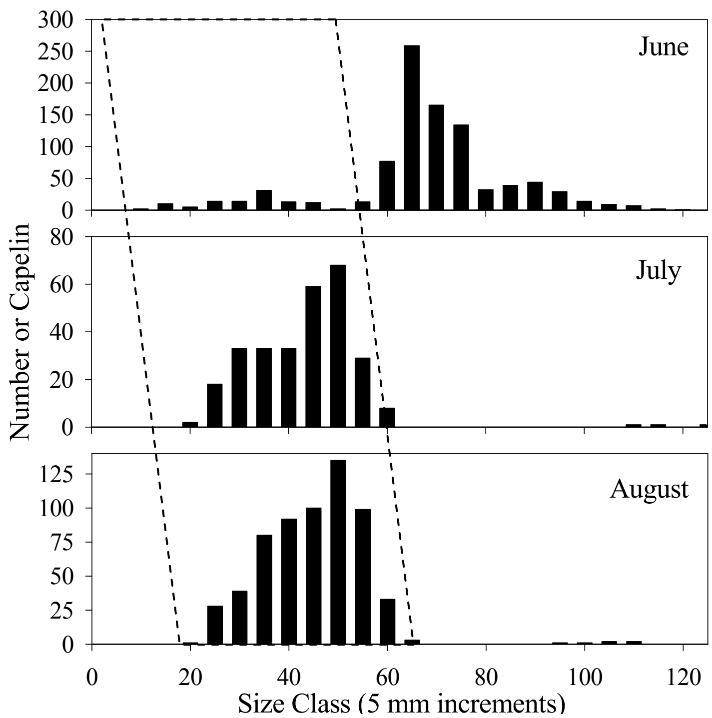

Figure 65. A. Length-frequency distribution of capelin caught in Glacier Bay during 1999 and 2000 by beach seine and pelagic trawl. Young-of-the-year fish are indicated by the dashed line.

Table 9. Catch_Per_Unit-Effort (CPUE) of seine catches in Glacier Bay during 1999 and 2000.

Region	Season	Herring	Salmonid	Dolly Varden	Smelt	Gadid	Sand lance	Sculpin	Flatfish	Other
Icy Strait	2000-1		575.50					1.00		25.50
	2000-2	7.00					0.50	3.00	0.50	
	2000-3		5.00			18.00		11.00	1.50	16.50
Lower Bay	1999-1		139.50	4.00				19.38	0.63	0.13
	2000-1		29.42	3.83		0.08	0.08	25.33	0.25	1.92
	2000-2		0.30	3.60		29.80		6.40		0.30
	2000-3	1.60	5.00	1.10		0.50	7.40	5.20	0.70	1.90
Middle Bay	1999-1	1.94	25.19	0.19	0.31	0.69	34.81	2.38	2.00	0.19
	2000-1		319.79	0.42	0.05	2.21	8.68	33.95	47.58	3.68
	2000-2	8.83	39.56	1.33		0.17	3.39	11.28	9.28	4.28
	2000-3	1055.06	14.56	4.94	2.94	0.22	104.61	14.61	14.22	1.11
West Arm	1999-1			0.18	3.64	4.09	12.00	17.00	0.45	8.27
	2000-1		1.91		0.91	0.65	1.74	9.96	2.09	1.39
	2000-2	0.21	1.86	0.57	30.64	0.07	0.07	8.64	7.07	21.29
	2000-3	2.20	0.13	0.27	189.80	1.13	11.33	6.87	5.07	43.87
East Arm	1999-1		0.14	1.29	0.14		1.57	3.86		3.57
	2000-1		3.75	4.00		0.13	1.00	2.13	1.75	5.25
	2000-2	6.13	0.75		2.00		0.38	2.88	2.13	0.50
	2000-3	20.63	4.63	1.50	51.13	0.13	574.38	5.88	2.25	27.50

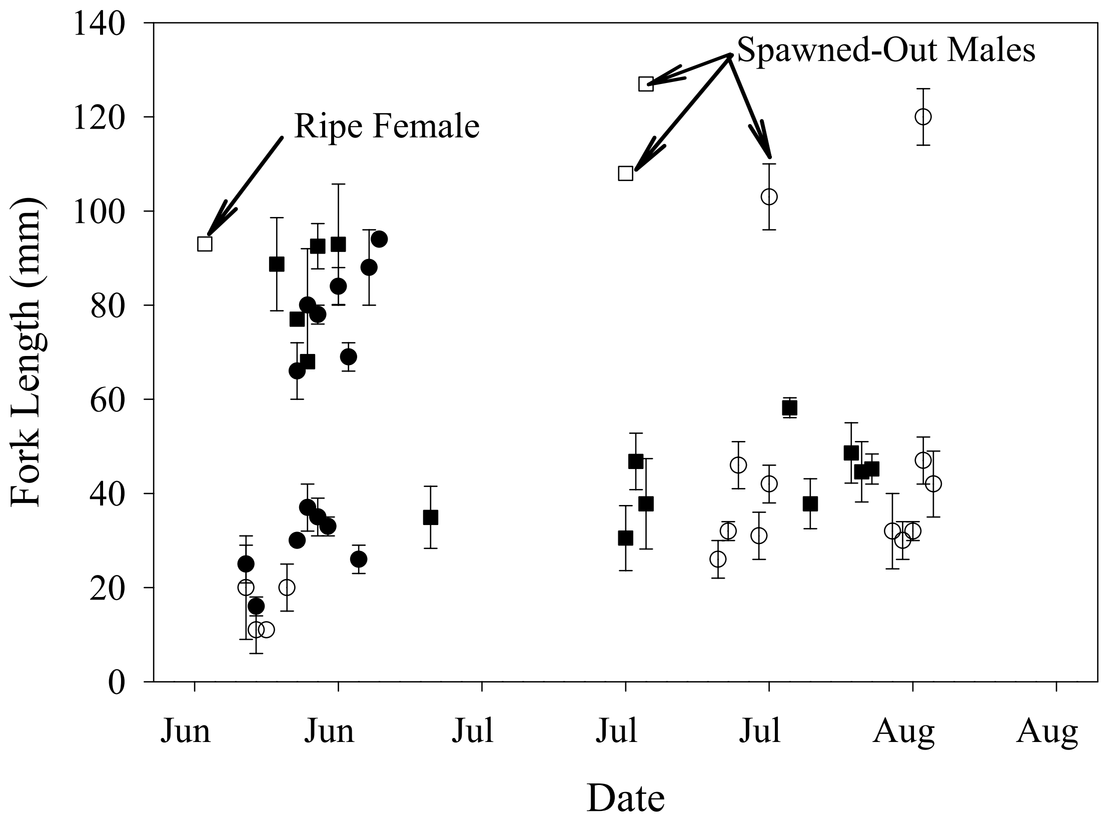

Figure 66. Daily length and standard deviation of capelin caught in beach seines. Squares represent 1999 data, circles represent 2000 data; all fish less than 60 mm are young-of-the-year fish.

<u>*Slender Eelblenny*</u>

This species (incorrectly identified as snake prickleback in 1999 report) was widely distributed in the upper parts of Glacier Bay; few were caught in the lower and middle regions. Larval eelblennys were most common except in Reid Inlet (beaches 43-45) where large numbers of adults were caught within one-half mile of Reid Glacier. Results were similar to Chisik Island in Cook Inlet, which is also a glacial-silt dominated system. In this area, numerous snake pricklebacks were also found in otherwise depauperate silty areas. This species may be an important early colonizer of nearshore areas. Size distribution showed the relative abundance of juvenile (young-of-the-year) eelblenny (Figures 67 and 68).

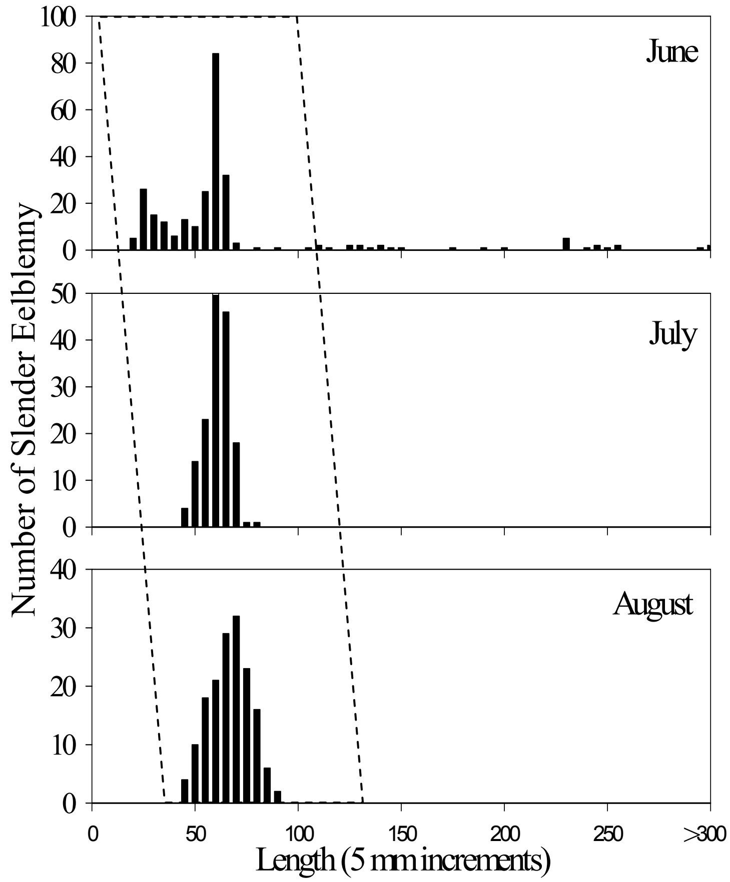

Figure 67. Length-frequency distribution of slender eelblenny caught in Glacier Bay during 1999 and 2000 by beach seine and pelagic trawl. Young-of-the-year fish are indicated by the dashed line.

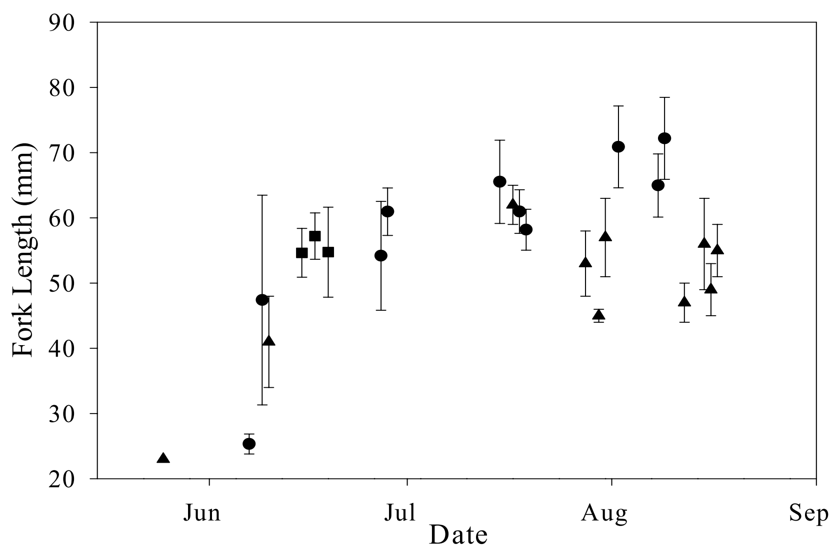

Figure 68. Daily mean size (+/- sd) of juvenile slender eelblenny caught in beach seines and pelagic trawls (squares = 1999, circles = beach seines 2000, triangles = pelagic trawls 2000).

Sand Lance

Sand lance are closely associated with clean sand substrates, in which they live for much of their lives. Areas of high water flow, such as the entrance to lagoons and outwash plains, generally provide the best substrates for sand lance. We caught sand lance in beach seines at most beaches of this type within Glacier Bay. Much of the sandy substrate in Glacier Bay is covered in mussel beds rendering it unsuitable for sand lance. Although we were unable to sample several outwash areas by seine, we established (by digging in intertidally exposed substrates) that sizeable sand lance populations exist at the following areas: the flats at the southwestern head of Geike inlet; the outwash from Dirt Glacier. Indications of the importance of sand lance are the large congregations of pigeon guillemots, glaucous-winged gulls, black-legged kittiwakes, cormorants, scoters, porpoises, and seals seen feeding at these locations - some of which were observed carrying sand lance, and at beaches 33 and 34 located opposite the entrance to Adams Inlet. Bruce Wing (NMFS- Auke Bay Lab personal communication) also indicated his observations of sand lance congregating at the entrance to Berg Bay. Hooge (USGS-BRD personal communication) also observed sand lance burrowed between Fingers and Berg in Whidbey Passage. Size distribution of sand lance clearly showed the young-of-the-year and adult sand lance (Figures 69 and 70). Without otolith analysis, number of age classes of adult sand lance could not be established.

Median size of juvenile sand lance in June 1999 (33 mm) was significantly smaller (Mann-Whitney rank sum test; $P<0.001$) than June 2000 (41 mm) even though they were caught approximately 10 days later.

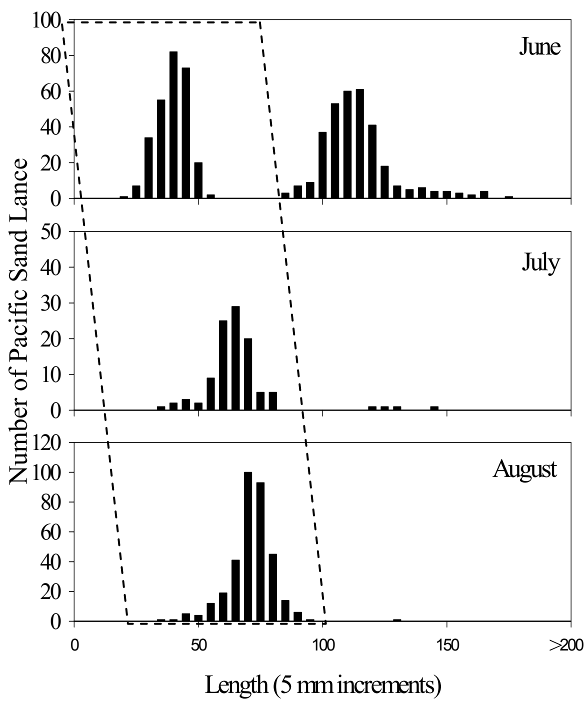

Figure 69. Length-frequency distribution of Pacific sand lance caught in Glacier Bay during 1999 and 2000 (combined data) by beach seine and pelagic trawl. Young-of-the-year fish are indicated by the dashed line.

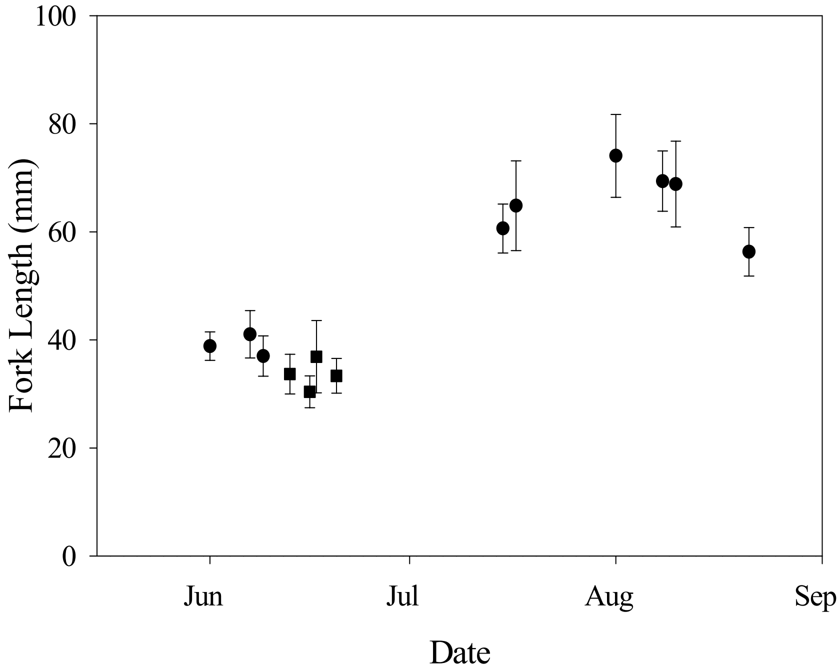

Figure 70. Daily mean size (+/- sd) of juvenile Pacific sand lance caught in beach seines and pelagic trawls (squares = 1999, circles = 2000).

Sculpins

Sculpins (mostly juveniles) were the most commonly caught taxa by beach seine in this study (predominantly great sculpin). Small juveniles ranging up to about 25 mm dominated sculpin catches. Second year fish were caught regularly, but at the rate of only one or two per set. These fish were distributed throughout the Bay, and unlike many of the other species sampled, did not display any preference for the different sample regions.

Flatfish

Flatfish were predominantly found in the lower-reaches of Glacier Bay. Rock Sole were the most common species caught within the Bay. However, in the lower reaches and particularly into Icy Strait we found larger numbers of English Sole.

At least two size classes of flatfish are evident from size-frequency histograms. Juveniles at about 30mm for both Rock and English Sole were found, as well as second year fish ranging from 60-140 mm.

Numerous reports have described the necessity for specific substrates in flatfish nursery areas (e.g., Rogers, 1992). Fine grained or muddy, well sorted sediments in shallow water are frequently required (Rogers, 1992). Furthermore the importance of adequate supplies of benthic food organisms to the settlement of flatfish larvae at metamorphosis, and to their subsequent survival and growth has frequently been documented (e.g, Creutzberg et al., 1978).

Mesopelagic Species

Both juvenile and adult mesopelagic species (myctophids and northern smooth tongue) were found as close to the surface as 10 m (modified-herring mid-water trawl) during summer 1999 and 2000. Vertical diel migrations for these species have frequently been reported, and may be a response to light intensity or hunger (e.g., Paxton, 1967, Pearcy et al., 1977; Calilliet and Ebeling, 1990). However, our sampling was not able to establish if these species are migrating each day or are persistently present in the upper 100 m at the heads of Glacier Bay. Length-frequency distributions remained similar throughout the summer months (Figure 71)

There is tremendous silt content in the marine waters of the upper-reaches of Glacier Bay. If light intensity is the cue that triggers diel migrations, and hence their uncharacteristic daytime surface water existance, then high turbidity due to glacial silt may significantly reduce light level penetration and account for the presence of northern lampfish and northern smoothtongue. However, if food is the primary cue for vertical migration, then these species may preferentially exist in the upper reaches of the water column, feeding on the elevated zooplankton abundance.

Myctophids have 2 – 10 times the lipid concentrations of other forage fish species, such as capelin and sand lance (Van Pelt et al., 1997), and they are the most important food source for a wide variety of larger fishes, seabirds, and marine mammals in the central North Pacific (Springer et al., 1999). Adult walleye pollock frequently consume both northern lampfish (Yang, 1996) and northern smoothtongue (Mason and Philips, 1985). Northern lampfish are also an important prey item for adult salmonids (Nagasawa et al., 1997; Shimada, 1948).

The occurrence of myctophids along the inside waters and fjords of Southeast Alaska makes them available to a suite of predators that may not usually find these characteristically offshore fish. For example, black-legged kittiwakes, which feed at night on northern lampfish at oceanic islands in the Aleutian Archipelago (Springer et al., 1996), may be able to regularly feed on myctophids during the day in the upper reaches of Glacier Bay, adjacent to tidewater glaciers. Marbled murrelets were also found almost exclusively consuming myctophids in Icy Strait (USGS-BRD, John Piatt, personal communication). Given the high nutritive value of these fish and the variety of predators that consume them, these mesopelagic species may play an important role in local food webs.

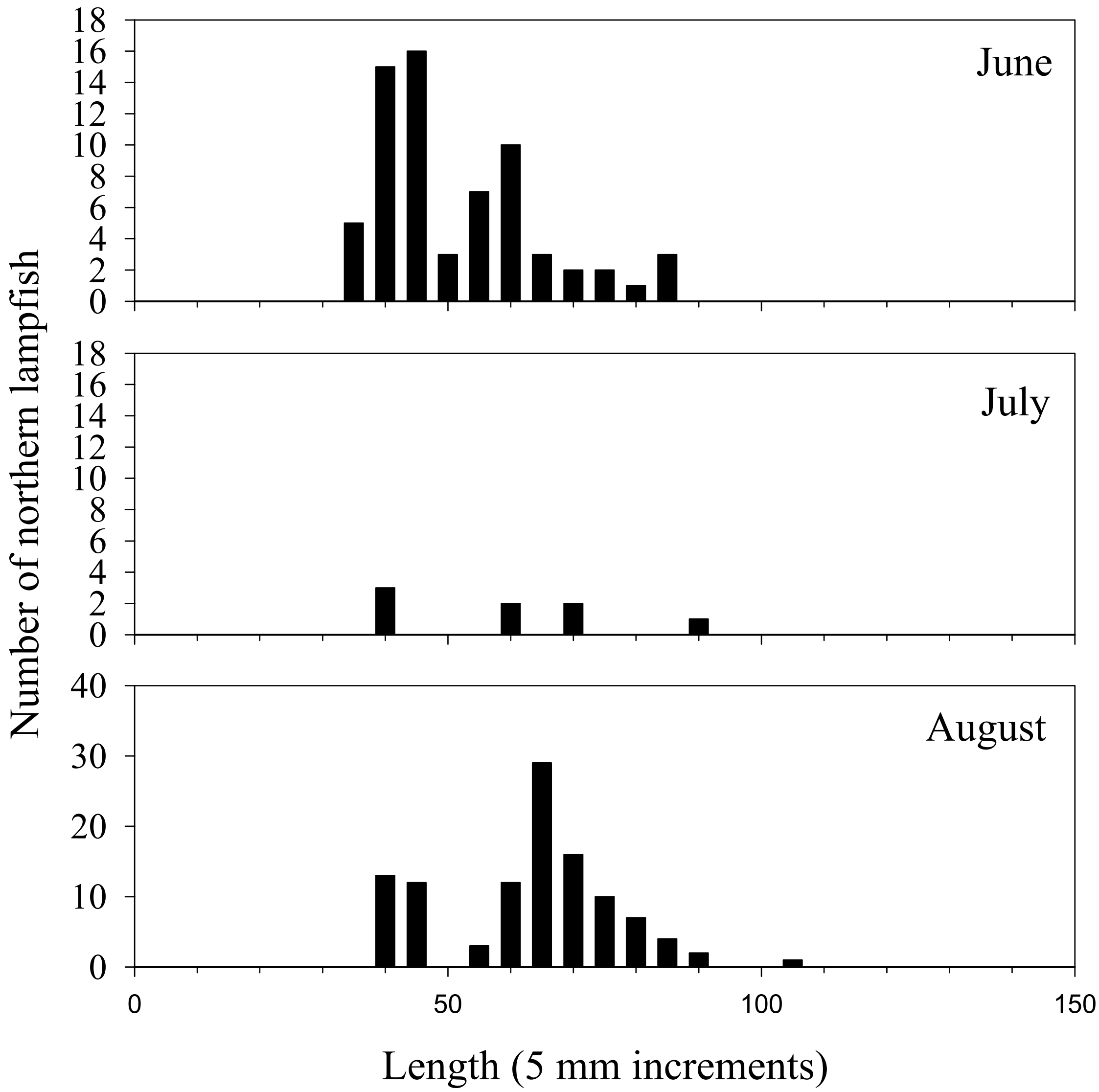

Figure 71. Length-frequency distribution of northern lamp-fish caught in Glacier Bay during 1999 and 2000 by beach seines and pelagic trawls.

Predator Survey

Species Inventory

Surveys of seabirds and marine mammals in Glacier Bay covered 1,514 km in June 1999, 440 km in November 1999), 471 km in March 2000, and 1,418 km in June 2000; Figure 72). Summer surveys covered a larger sample area including Icy Strait (1999, 2000), Dundas Bay (1999), and a denser network of pelagic transects (Figure 72). A total of 118,520 birds (64 spp.) and 1780 (7 spp.) marine mammals were identified and counted along survey transects during the 4 surveys June 1999 - June 2000 (see Appendix 9 for a complete list).

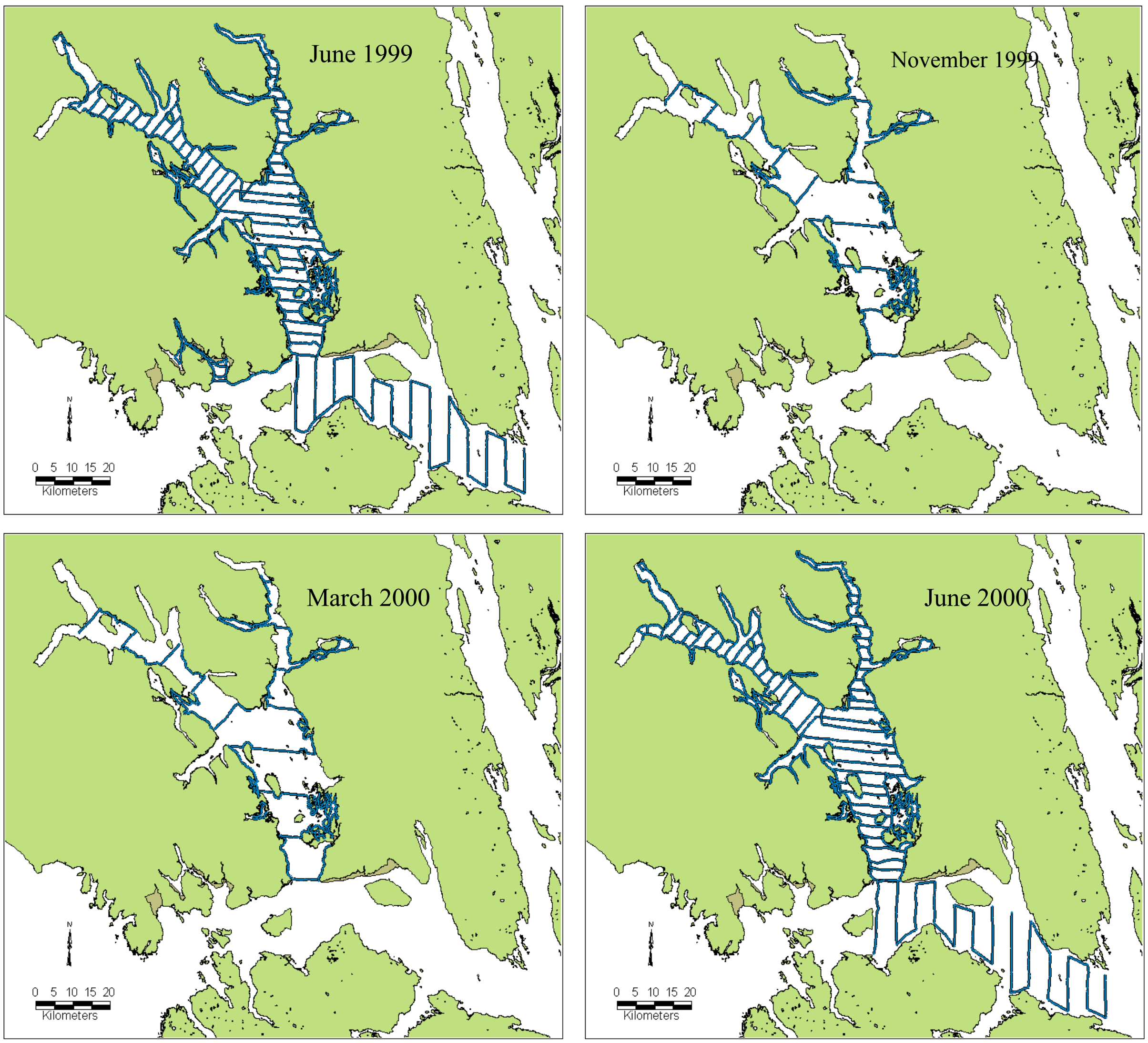

Figure 72. Survey tracks in and around Glacier Bay National Park June 1999, November 1999, March 2000, and June 2000. Surveys were conducted aboard the *RV Pandalus, RV Alaska Gyre, MV David Grey* and *MV Lutris*. Tracks represent 200 and 300m swaths (depending on vessel – see methods) within which all species observed were counted.

Seabirds

Seabirds accounted for a high of 46.8 % of all birds sighted in June of 1999 to a low of 22.0 % in the March 2000 survey (Table 9). Seabird numbers were dominated by black-legged kittiwakes (*Rissa tridactyla*), glaucous-winged gulls (*Larus glaucescens*), murrelets (*Brachyramphus* spp), and pigeon guillemots (*Cepphus columba*). Together, these species accounted for 74 % and 89 % of all seabirds identified during surveys. Black-legged kittiwakes and glaucous-winged gulls accounted for the bulk of gull numbers. Marbled murrelets (*B. marmoratus*) greatly outnumbered Kittlitz's murrelets (*B. brevirostris*) sighted in the summer surveys; however, numbers were similar in the spring 2000 survey. Fall and spring surveys generally yielded lower densities of most seabird species, with the notable exception of Kittlitz's murrelets in the spring 2000 survey. The relatively high densities of Kittlitz's murrelets in spring 2000 (similar to summer densities) may indicate an earlier arrival to Glacier Bay then the majority of migratory seabirds.

We calculated densities (birds/km^2) for some of the more common species to compensate for the effects of differential survey lengths. Densities generally followed the trends of raw counts, but provide a better method for examining seasonal trends. Seabird densities were greatest during the summer months (Table 10). Many seabirds were rare or absent during the less extensive fall and spring surveys. Densities from the June 2000 survey were lower than the densities recorded in June of 1999 for all but a few species. Densities of all *Brachyramphus* murrelets (marbled, Kittlitz's, and unidentified murrelets) were the notable exceptions. Although the densities of marbled murrelets was lower in June of 2000, there were many more unidentified murrelets. When all *Brachyramphus* murrelets were combined, there was little difference between the two summer surveys. Although they did not make up a large portion of the birds sighted, four species of loon and two species of grebes were seen on transects.

Waterfowl

Waterfowl were the most common birds seen on surveys. Sea ducks in particular constituted from between 47-56 % of all birds sighted on surveys (Table 9). Scoters (*Melanitta spp*), by themselves, accounted for 36 %-40 % of all birds counted on the summer surveys and 15 %-17 % of all birds seen on fall and spring surveys. Barrow's goldeneye (*Bucephala islandica*) accounted for less then 0.2% of birds on the summer surveys, however, in the fall and spring surveys they accounted for 16 % and 17 % of all birds respectively. Common mergansers (*Mergus merganser*) accounted for 8.6 % and 9.4% of birds seen in each of the summer surveys, but <0.5% in the fall and spring surveys. Harlequin ducks (*Histrionicus histrionicus*) constituted 1.7 % - 4.8 % of all birds sighted. Of the remaining waterfowl, Canada geese (*Branta candensis*) were the most common, though they made up only 1 % - 2 % of the birds on all surveys.

Seasonal densities of waterfowl varied widely. Canada geese and harlequin ducks were seen in similar densities in all surveys (Table 10). Barrow's Goldeneye were nearly absent in summer surveys, but in the fall 1999 and spring 2000 surveys had the highest densities recorded for any bird (Table 10). Conversely, common mergansers were found at low densities in the fall and spring surveys and relatively high densities in the summer surveys. White-winged and surf scoters were less strictly seasonal, being present in substantial densities in all surveys, white-winged scoter densities were highest in the summer surveys, and surf scoter densities highest in the fall and spring surveys (Table 9).

Shorebirds

Shorebirds were infrequently sighted compared to the frequencies of seabirds or waterfowl seen in Glacier Bay. While some shorebirds may have been missed due to the distance of boats to the shore (100m or 150m) and the potential for decreased visibility due to surf conditions, particular care was taken to ensure that few birds were missed. Shorebirds were most common during the November Survey where they made up 3.2 % of the birds seen (Table 9). Unfortunately, the majority of these birds (*n*=529) were unidentified. While densities for all shorebirds were relatively low, the higher densities of shorebird in the fall and spring suggested that Glacier Bay might provide wintering habitat for some shorebirds (Table 10).

Other Birds

Of the remaining birds seen on surveys, only bald eagles (*Haliaeetus leucocephalus*) and Northwestern crows (*Corus caurinus*) were seen in large numbers (Table 9). As a percentage of the surveys, “other birds” made up over 7 % of November and March surveys compared to 1.8 % and 2.8 % of the two summer surveys. Densities suggested that Glacier Bay might provide important winter habitat for Northwestern crows, while bald eagles appear to be year-round residents (Table 10).

Marine Mammals

Harbor seals (*Phoca vitulina*) were the most commonly sighted marine mammals followed by sea otters (*Enhydra lutris*) and harbor porpoise (*Phocoena phocoena*; Table 9). Dall’s and harbor porpoise, harbor seals and sea otters showed little seasonal variation in populations over the 4 surveys. Variations in humpback whale (*Megaptera novaeangliae*) densities by survey reflected their migratory nature. They are present in the summer, and absent in the winter months (Table 11). Conversely, Steller sea lions (*Eumetopius jubatus*) were sighted more frequently in the November and March surveys (Table 11). Overall, the low densities of many marine mammals may have led to a high degree of variability in the reported densities, i.e. at low densities even a small number of animals, seen or missed, can skew results.

Table 10. Numbers and percent composition of bird species from marine predator surveys in Glacier Bay National Park during June 1999, November 1999, March 2000 and June 2000. Numbers represent totals sighted within transects, percent composition (%) was calculated both within surveys and for all surveys combined. Note that summer surveys (June) included more transects within Glacier Bay and transects in Icy Strait (see methods).

	Jun-99		Nov-99		Mar-00		Jun-00		All Surveys	
	Number	%	Number	%	Number	%	Number	%	Number	%
Aleutian Tern	0	0.0	0	0.0	0	0.0	1	0.0	1	0.0
Arctic Tern	533	1.1	0	0.0	0	0.0	260	0.8	793	0.7
Ancient Murrelet	0	0.0	0	0.0	0	0.0	1	0.0	1	0.0
Black-Legged Kittiwake	3739	7.7	1109	5.8	321	1.9	1422	4.2	6591	5.6
Bonaparte's Gull	36	0.1	0	0.0	0	0.0	4	0.0	40	0.0
Brachyramphus Murrelet	1951	4.0	87	0.5	326	1.9	2864	8.4	5228	4.4
Caspian Tern	4	0.0	0	0.0	0	0.0	0	0.0	4	0.0
Common Loon	26	0.1	46	0.2	20	0.1	53	0.2	145	0.1
Common Murre	35	0.1	5	0.0	1	0.0	18	0.1	59	0.0
Double-crested Cormorant	0	0.0	16	0.1	0	0.0	0	0.0	16	0.0
Fork-tailed Storm Petrel	2	0.0	7	0.0	0	0.0	1	0.0	10	0.0
Glaucous-winged Gull	2068	4.3	808	4.2	703	4.2	1217	3.6	4796	4.0
Herring Gull	155	0.3	35	0.2	19	0.1	110	0.3	319	0.3
Horned Grebe	0	0.0	108	0.6	68	0.4	0	0.0	176	0.1
Kittlitz's Murrelet	506	1.0	4	0.0	163	1.0	402	1.2	1075	0.9
Marbled Murrelet	4049	8.4	85	0.4	177	1.0	1322	3.9	5633	4.8
Mew Gull	798	1.7	611	3.2	123	0.7	1156	3.4	2688	2.3
Pacific Loon	87	0.2	10	0.1	14	0.1	90	0.3	201	0.2
Parasitic Jaeger	8	0.0	0	0.0	0	0.0	2	0.0	10	0.0
Pelagic Cormorant	622	1.3	217	1.1	183	1.1	253	0.7	1275	1.1
Pigeon Guillemot	1926	4.0	504	2.6	933	5.5	1702	5.0	5065	4.3
Red-faced Cormorant	2	0.0	0	0.0	0	0.0	0	0.0	2	0.0
Red-necked Grebe	0	0.0	33	0.2	1	0.0	1	0.0	35	0.0
Red-throated Loon	36	0.1	0	0.0	0	0.0	0	0.0	36	0.0
Tufted Puffin	37	0.1	0	0.0	0	0.0	14	0.0	51	0.0
Unidentified Albatross	0	0.0	0	0.0	2	0.0	0	0.0	2	0.0
Unidentified Alcid	0	0.0	0	0.0	0	0.0	4	0.0	4	0.0
Unidentified Cormorant	23	0.0	13	0.1	11	0.1	13	0.0	60	0.1
Unidentified Gull	6006	12.4	1676	8.7	761	4.5	1249	3.7	9692	8.2
Unidentified Grebe	1	0.0	73	0.4	45	0.3	1	0.0	120	0.1
Unidentified Large Larid	0	0.0	0	0.0	0	0.0	130	0.4	130	0.1
Unidentified Loon	98	0.2	51	0.3	20	0.1	80	0.2	249	0.2
Unidentified Storm Petrel	74	0.2	5	0.0	1	0.0	0	0.0	80	0.1
Unidentified Tern	0	0.0	0	0.0	0	0.0	1	0.0	1	0.0
Western Grebe	0	0.0	0	0.0	5	0.0	0	0.0	5	0.0
Yellow-billed Loon	2	0.0	0	0.0	1	0.0	0	0.0	3	0.0
Seabirds Subtotal	22824	47.3	5503	28.5	3898	23.1	12371	36.3	44596	37.6

Table 10, Continued.

	Jun-99		Nov-99		Mar-00		Jun-00		All Surveys	
	Number	%	Number	%	Number	%	Number	%	Number	%
American Wigeon	2	0.0	49	0.3	18	0.1	26	0.1	95	0.1
Barrow's Goldeneye	45	0.1	3138	16.3	2870	17.0	76	0.2	6129	5.2
Black Scoter	8	0.0	61	0.3	64	0.4	23	0.1	156	0.1
Brant	16	0.0	0	0.0	0	0.0	0	0.0	16	0.0
Bufflehead	2	0.0	434	2.3	522	3.1	0	0.0	958	0.8
Canada Goose	997	2.1	177	0.9	368	2.2	824	2.4	2366	2.0
Common Goldeneye	7	0.0	35	0.2	193	1.1	0	0.0	235	0.2
Common Merganser	4150	8.6	47	0.2	89	0.5	3204	9.4	7490	6.3
Gadwall	4	0.0	504	2.6	52	0.3	10	0.0	570	0.5
Greater Scaup	0	0.0	0	0.0	0	0.0	2	0.0	2	0.0
Green-winged Teal	3	0.0	27	0.1	10	0.1	78	0.2	118	0.1
Harlequin Duck	1192	2.5	325	1.7	463	2.7	1645	4.8	3625	3.1
Mallard	382	0.8	1623	8.4	1449	8.6	759	2.2	4213	3.6
Northern Pintail	0	0.0	1	0.0	2	0.0	6	0.0	9	0.0
Northern Shoveler	1	0.0	0	0.0	2	0.0	60	0.2	63	0.1
Oldsquaw	11	0.0	221	1.1	24	0.1	13	0.0	269	0.2
Red-breasted Merganser	22	0.0	158	0.8	63	0.4	65	0.2	308	0.3
Scaup	0	0.0	19	0.1	81	0.5	169	0.5	269	0.2
Surf Scoter	4414	9.1	1721	8.9	965	5.7	7175	21.0	14275	12.0
Unidentified Duck	16	0.0	378	2.0	71	0.4	29	0.1	494	0.4
Unidentified Goldeneye	39	0.1	980	5.1	1991	11.8	10	0.0	3020	2.5
Unidentified Merganser	37	0.1	156	0.8	603	3.6	62	0.2	858	0.7
Unidentified Scoter	8206	17.0	902	4.7	980	5.8	483	1.4	10571	8.9
Unidentified Swan	2	0.0	0	0.0	0	0.0	0	0.0	2	0.0
Unidentified Teal	3	0.0	0	0.0	0	0.0	0	0.0	3	0.0
White-winged Scoter	4849	10.0	683	3.5	460	2.7	5829	17.1	11821	10.0
Waterfowl Subtotal	24408	50.6	11639	60.4	11340	67.1	20548	60.3	67935	57.3
Black Oystercatcher	187	0.4	74	0.4	25	0.1	214	0.6	500	0.4
Black Turnstone	0	0.0	46	0.2	140	0.8	0	0.0	186	0.2
Surfbird	0	0.0	0	0.0	25	0.1	0	0.0	25	0.0
Red-necked Phalarope	1	0.0	0	0.0	0	0.0	1	0.0	2	0.0
Spotted Sandpiper	4	0.0	0	0.0	0	0.0	0	0.0	4	0.0
Unidentified Phalarope	5	0.0	0	0.0	0	0.0	0	0.0	5	0.0
Unidentified Shorebird	3	0.0	529	2.7	148	0.9	4	0.0	684	0.6
Shorebirds Subtotal	200	0.4	649	3.2	338	1.8	219	0.7	1406	1.2
Bald Eagle	208	0.4	65	0.3	131	0.8	137	0.4	541	0.5
Northwestern Crow	563	1.4	1391	7.2	1123	6.6	753	2.2	3830	3.2
Other Birds	47	0.0 0	32	0.2 0	68	0.4 0	63	0.2 0	210	0.2
Total Number of Birds	48250		19279		16898		34093		118520	

Table 11. Densities of common bird species from marine predator surveys in Glacier Bay National Park during June 1999, November 1999, March 2000 and June 2000. Densities are calculated for all transects and averaged. Note that summer surveys (June) included more transects within Glacier Bay and transects in Icy Strait (see methods).

SPECIES	Jun-99	Nov-99	Mar-00	Jun-00
Arctic Tern	1.30	0.00	0.00	0.54
Black-Legged Kittiwake	14.23	14.37	4.29	3.09
Brachyramphus Murrelet	5.74	1.05	3.13	10.03
Glaucous-winged Gull	5.59	11.05	5.38	4.22
Kittlitz's Murrelet	1.40	0.06	1.94	1.75
Barrow's Goldeneye	0.04	27.34	26.19	0.13
Marbled Murrelet	9.97	0.80	1.95	4.20
Mew Gull	1.76	5.49	0.89	2.63
Pelagic Cormorant	1.93	1.63	0.96	0.47
Pigeon Guillemot	4.91	4.32	6.10	4.04
Canada Goose	1.32	1.17	1.72	1.29
Common Merganser	7.22	0.84	0.54	6.62
Harlequin Duck	2.93	3.64	4.57	4.33
Mallard	0.64	14.24	13.31	1.29
Surf Scoter	8.80	11.32	9.64	9.15
White-winged Scoter	15.27	6.84	5.81	9.31

Table 12. Numbers and densities of all marine mammal species from marine predator surveys in Glacier Bay National Park during June 1999, November 1999, March 2000 and June 2000. Numbers represent totals sighted observed on all transects, densities are averages of all transects. Note that summer surveys (June) included more transects within Glacier Bay and transects in Icy Strait (see methods).

	Jun-99		Nov-99		Mar-00		Jun-00	
SPECIES	Num.	Density	Num.	Density	Num.	Density	Num.	Density
Dall's Porpoise	22	0.04	0	0.00	0	0.00	12	0.03
Harbor Porpoise	67	0.22	26	0.24	57	0.69	59	0.13
Humpback Whale	13	0.06	2	0.01	1	0.02	25	0.12
Minke Whale	0	0.00	0	0.00	1	0.01	0	0.00
Sea Otter	149	0.55	137	1.21	76	0.65	167	0.55
Harbor Seal	255	0.57	161	0.85	67	0.31	331	0.78
Steller Sea Lion	14	0.03	46	0.45	76	0.68	56	0.15

Variability in Habitat Use

Comparisons between nearshore and offshore transects provide useful information on the spatial distribution of species in Glacier Bay. The majority of marine bird species disproportionately used nearshore areas compared to offshore areas (Figure 73, Table 12). Overall, >80 % of all birds were found on nearshore transects. There was also general consistency between the surveys, with species favoring either nearshore or offshore in all surveys. Marbled murrelets were one of the few species whose distribution was not consistent between surveys (Table 12). This inconsistency was not related to season and may not be biologically significant. Summary densities of marine birds suggested that only Kittlitz's murrelets and unidentified (*Brachyramphus spp.*) murrelets were found predominantly in offshore transects (Table 12). However, examination of GIS maps (next section), revealed that gadwalls were in fact primarily sighted in nearshore areas.

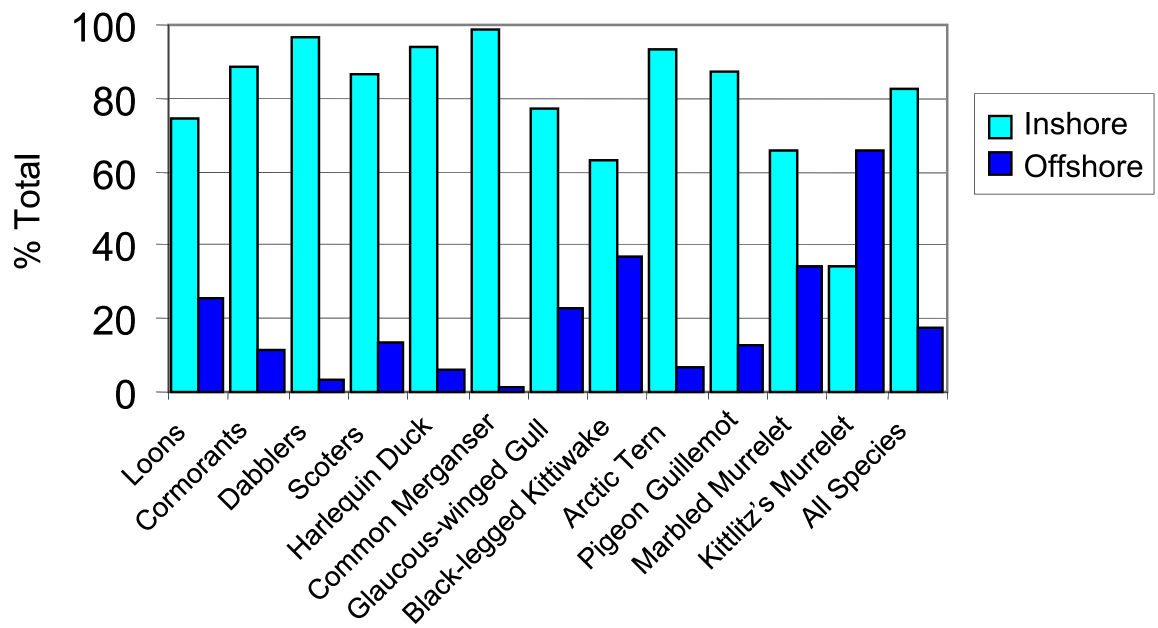

Figure 73. Distribution of seabirds on nearshore versus offshore transects.

Like marine birds, marine mammals were sighted more frequently on nearshore as opposed to offshore transects (Table 12). The only marine mammals that were sighted more frequently on offshore transects were harbor porpoise. However, the limited numbers of marine mammals seen make generalizations tentative (when numbers sighted are low the differences made by sighting even a few animals more or less can have a disproportionate effect on density calculations). There may be a bias in the density calculations for harbor seals as counts included both observations at sea and on haul-outs, while surveys were conducted independent of tidal height.

Table 13. Densities of common seabirds and marine mammals sighted on nearshore and offshore surveys in and around Glacier Bay National Park June 1999 – June 2000.

	Jun-99		Nov-99		Mar-00		Jun-00		Ratio	
SPECIES	coastal	offshore	coastal	offshore	coastal	offshore	coastal	offshore	coastal	offshore
Arctic Tern	1.75	0.76	0.00	0.00	0.00	0.00	0.90	0.09	0.76	0.24
Barrow's Goldeneye	0.07	0.00	34.83	10.48	34.89	6.77	0.24	0.00	0.80	0.20
Black-Legged Kittiwake	20.48	6.72	7.16	30.59	5.12	2.44	4.47	1.42	0.47	0.53
Black Scoter	0.03	0.00	1.13	0.54	0.67	0.00	0.04	0.06	0.76	0.24
Brachyramphus Murrelet	4.70	6.99	0.87	1.44	2.35	4.85	4.45	16.71	0.29	0.71
Glaucous-winged Gull	7.85	2.87	15.43	1.18	6.81	2.18	6.58	1.39	0.83	0.17
Herring Gull	0.56	0.14	0.37	0.05	0.33	0.09	0.45	0.20	0.78	0.22
Kittlitz's Murrelet	0.83	2.07	0.09	0.00	1.44	3.06	0.85	2.83	0.29	0.71
Marbled Murrelet	12.01	7.53	0.50	1.46	1.72	2.44	3.04	5.59	0.50	0.50
Mew Gull	2.99	0.29	6.91	2.30	1.15	0.30	4.06	0.91	0.80	0.20
Pelagic Cormorant	3.26	0.33	1.68	1.52	1.31	0.17	0.70	0.19	0.76	0.24
Pigeon Guillemot	7.65	1.61	5.61	1.42	7.68	2.59	6.33	1.29	0.80	0.20
Bufflehead	0.01	0.00	5.18	0.33	6.17	0.00	0.00	0.00	0.97	0.03
Canada Goose	2.37	0.07	1.69	0.00	2.49	0.02	2.36	0.00	0.99	0.01
Common Goldeneye	0.01	0.00	0.54	0.00	1.72	0.37	0.00	0.00	0.86	0.14
Common Merganser	12.87	0.42	1.20	0.02	0.77	0.01	11.46	0.83	0.95	0.05
Harlequin Duck	5.11	0.30	4.83	0.97	6.46	0.34	7.35	0.70	0.91	0.09
Long-tailed Duck	0.03	0.03	2.03	0.07	0.18	0.00	0.09	0.00	0.96	0.04
Mallard	1.10	0.08	15.94	10.41	16.94	5.22	2.37	0.00	0.70	0.30
Surf Scoter	15.43	0.83	15.71	1.45	12.71	2.79	13.58	3.84	0.87	0.13
White-winged Scoter	26.63	1.61	8.91	2.17	8.37	0.09	11.95	6.15	0.85	0.15
Golden Eagle	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Harbor Porpoise	0.25	0.18	0.17	0.40	0.54	1.00	0.13	0.14	0.39	0.61
Harbor Seal	0.94	0.13	1.22	0.02	0.45	0.01	1.29	0.17	0.92	0.08
Humpback Whale	0.08	0.03	0.02	0.00	0.02	0.00	0.08	0.17	0.50	0.50
Sea Otter	0.84	0.20	1.72	0.07	0.48	1.03	0.91	0.13	0.73	0.27
Steller Sea Lion	0.03	0.03	0.53	0.27	0.92	0.14	0.10	0.20	0.71	0.29

The comparison of species densities on nearshore and offshore transects suggests an underlying habitat association. The classification of nearshore and offshore can be viewed as a proxy for bottom depth. We examined associations between bottom depth and species occurrence by looking at cumulative occurrence through 5 depth classes. We found all common species tended to use relatively shallow habitats (Figure 74). For example, >70 % of all common mergansers were found in water <25m in depth, and almost all were found at <100m depth. Similarly, >50 % of all birds were located in depths <50 m, and >75 % of all birds were in water <100 m deep. Some species clearly favored shallow, nearshore waters (e.g., mergansers, guillemots), while others, such as murrelets (spp.) and kittiwakes, routinely foraged in deeper waters.

Marine mammals like marine birds showed distinct differences in use of habitats. A plot of cumulative occurrence by depth class indicated that harbor seals occur in extremely shallow areas whereas Dall's porpoise, an oceanic species, distinctly favored the deepest waters to be found in the study area (Figure 75).

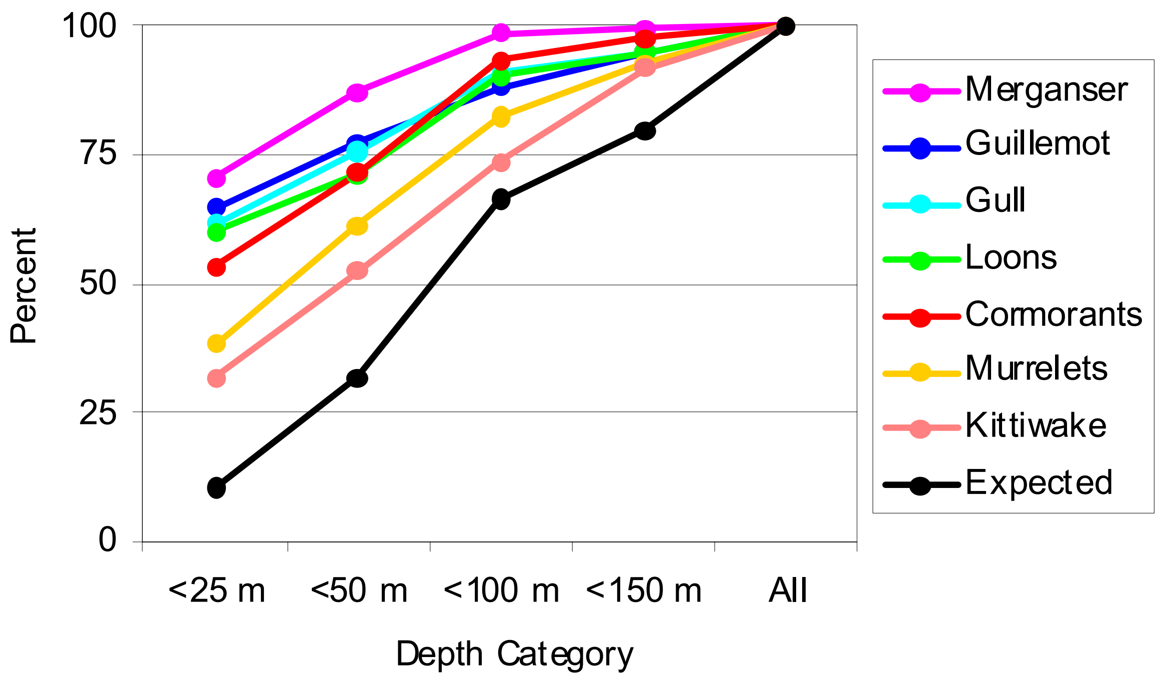

Figure 74. Cumulative distribution of common seabirds in Glacier Bay with relative to ocean bottom depth.

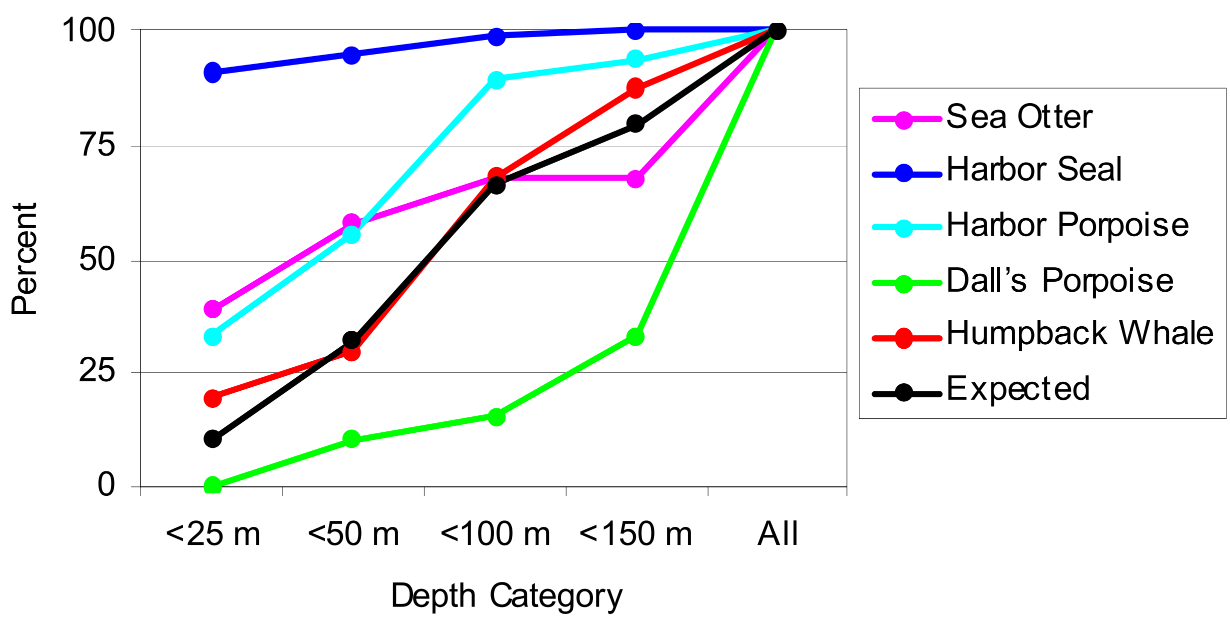

Figure 75. Cumulative distribution of common marine mammals in Glacier Bay relative to ocean bottom depth.

Distribution Maps

Maps of species distributions were developed using GIS software, allowing visual comparisons between surveys, seasons, and species. While tabulated comparisons of transects categorized as "nearshore" or "offshore" can assist our understanding of survey data, categories are not always exclusive and the process of categorizing tends to lose information. We mapped many of the more common species of seabirds and waterfowl, as well as a number of the marine mammals. Although only a subset of species is presented, the GIS database can be used to access any of the remaining species in the future.

Seabirds

Black-legged kittiewakes and glaucous-winged gulls were distributed throughout the Glacier Bay area (Figure 76 and Figure 77). Although sighted most commonly on nearshore transects, neither species was restricted to nearshore areas. Both species seasonally use Glacier Bay for nesting and reproduction. A decrease in the survey counts of June 2000 compared to the June 1999 survey was noted for both species.

Maps of marbled murrelets sighted on surveys illustrate their occurrence throughout Glacier Bay (Figure 78). In addition, the even distribution of marbled murrelets between nearshore and offshore areas (as indicated in table 13) was clearly evident As with the gulls, marbled murrelets were more common in Glacier Bay in June 1999 then they were in June of 2000.

Kittlitz's murrelet distribution was more clustered than that of marbled murrelets (Figure 79). There was also a difference in how these species used marine habitats. While marble murrelets were seen equally on both nearshore and offshore transects, Kittlitz's murrelets were more commonly seen offshore. Although foraging distances for Kittlitz's murrelets are not well known, these patterns could also reflect the interaction between foraging and nesting habitat. If foraging distances are limited then the distribution of terrestrial nesting habitat may limit marine foraging habitat. Like marbled murrelets, Kittlitz's murrelets were clearly seasonal residents, all but disappearing during the winter months. Surprisingly, a number of Kittlitz's murrelets were sighted in Wachusett Inlet during the March 2000 survey, though they were not seen in that Inlet in large numbers during either of the summer surveys.

Pigeon Guillemots were evenly distributed throughout the nearshore areas of Glacier Bay in the summer months; but few were sighted in Icy Strait. November 1999 and March 2000 survey maps suggest that pigeon guillemots use the more sheltered Beardslee Islands for over-wintering habitat (Figure 80).

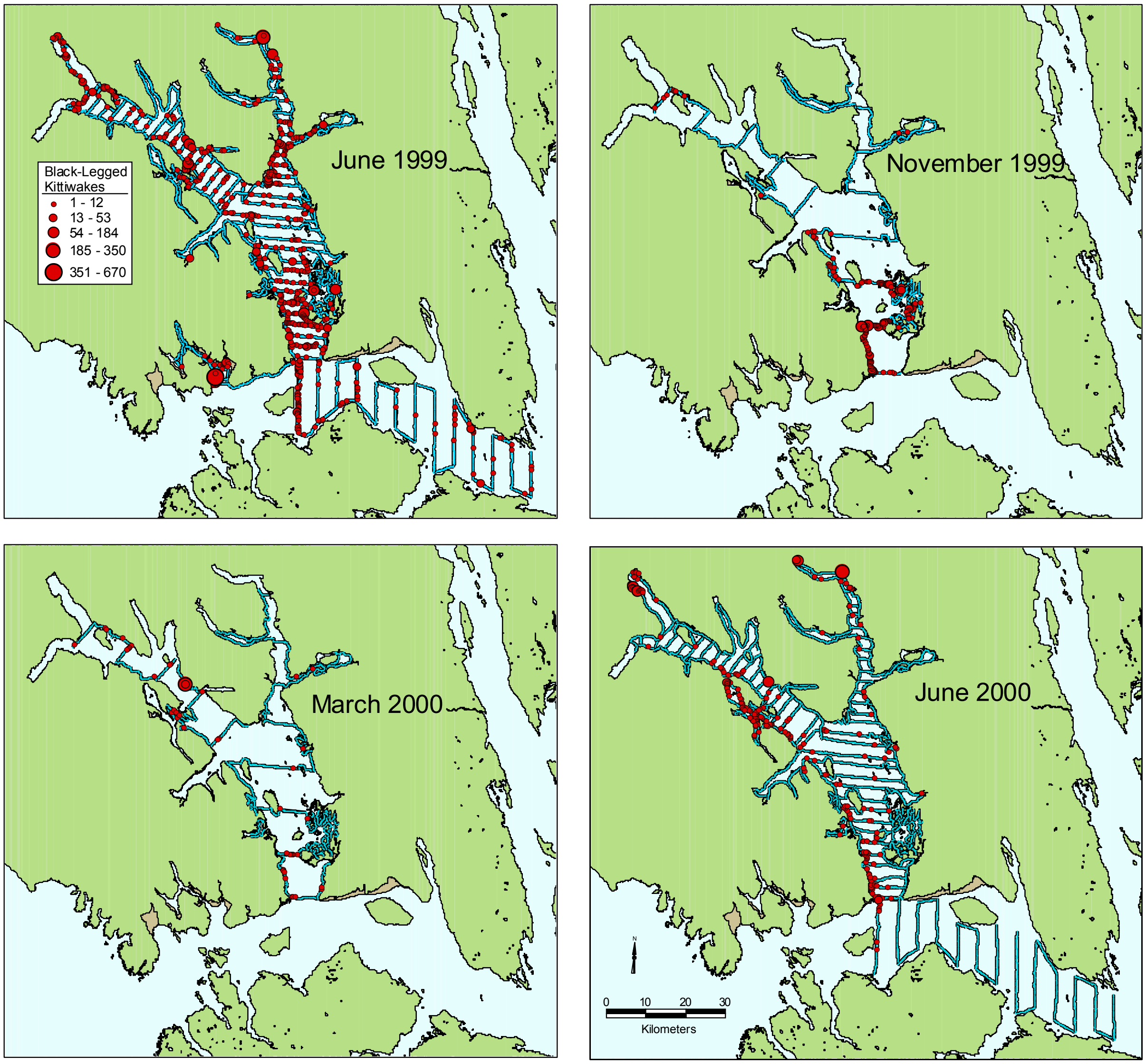

Figure 76. Black-legged kittiwake sightings in and around Glacier Bay National Park during surveys conducted between June 1999 and June 2000. Blue lines indicate survey tracks. Surveys were conducted from the *RV Pandalus, RV Alaska Gyre, MV David Grey* and *MV Lutris* by U.S. Geological Survey and National Park Service personnel.

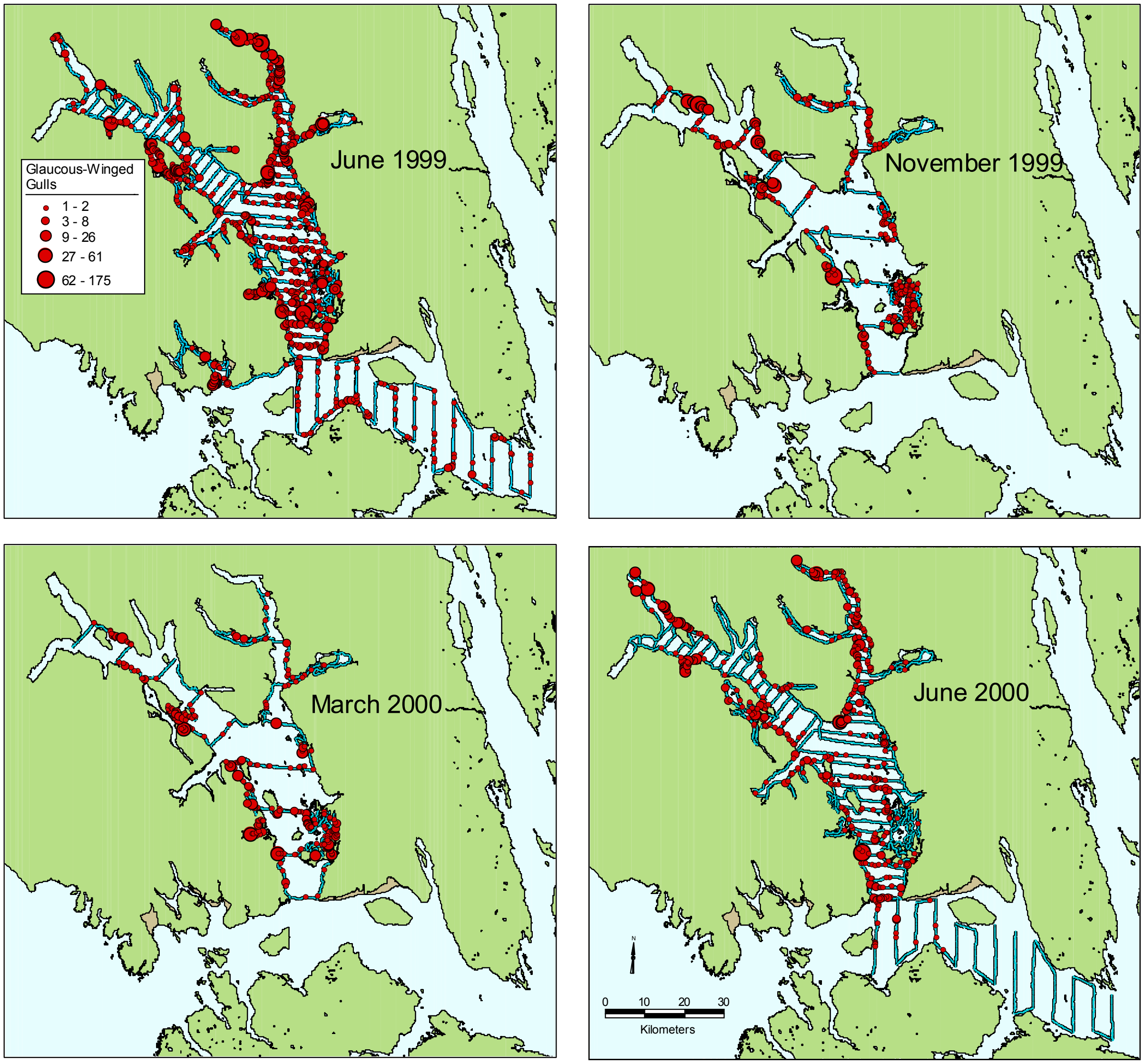

Figure 77. Glaucous-winged gull sightings in and around Glacier Bay National Park during surveys conducted between June 1999 and June 2000. Blue lines indicate survey tracks. Surveys were conducted from the *RV Pandalus, RV Alaska Gyre, MV David Grey* and *MV Lutris* by U.S. Geological Survey and National Park Service personnel.

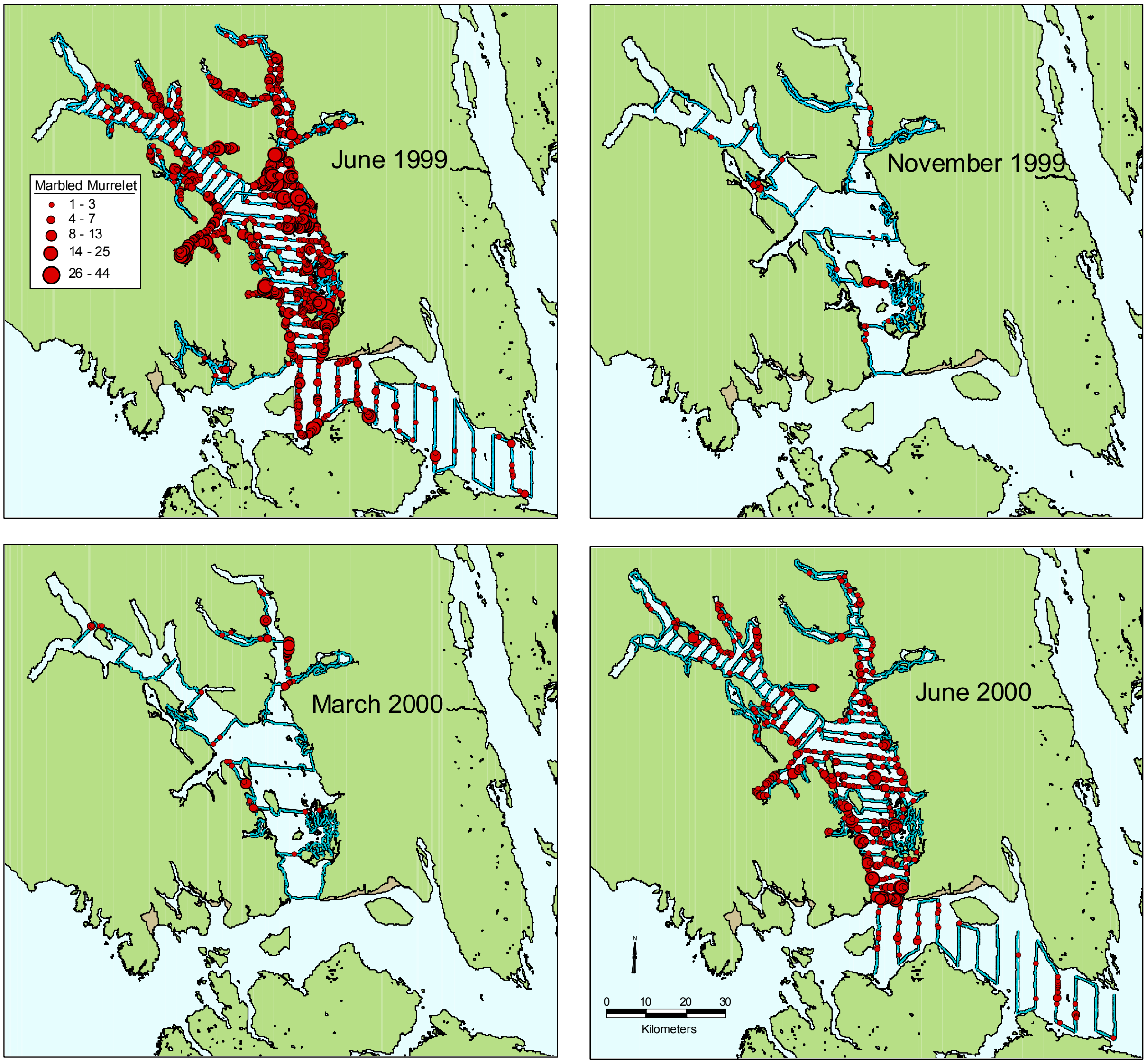

Figure 78. Marbled murrelet sightings in and around Glacier Bay National Park during surveys conducted between June 1999 and June 2000. Blue lines indicate survey tracks. Surveys were conducted from the *RV Pandalus, RV Alaska Gyre, MV David Grey* and *MV Lutris* by U.S. Geological Survey and National Park Service personnel.

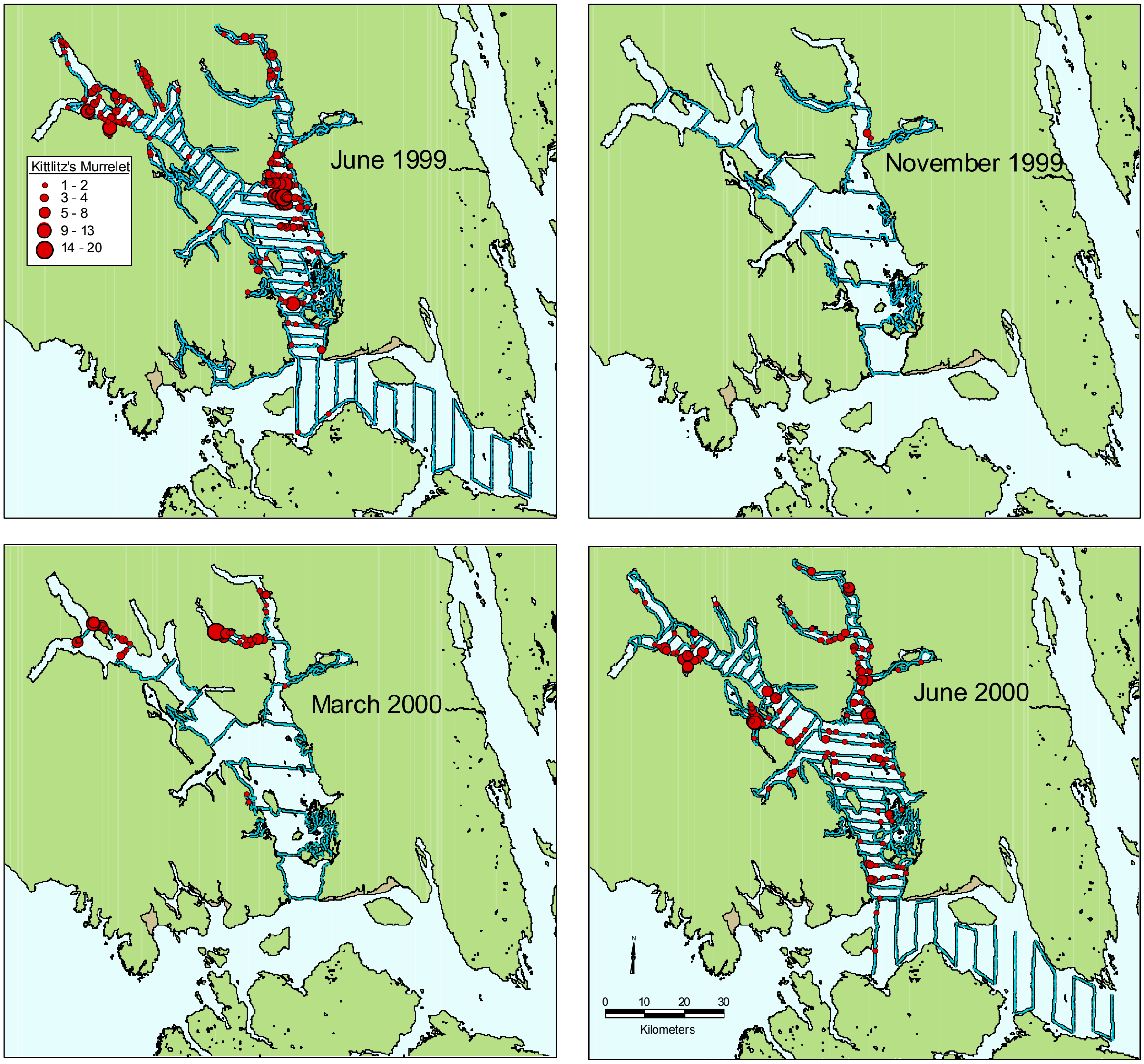

Figure 79. Kittlitz's murrelet sightings in and around Glacier Bay National Park during surveys conducted between June 1999 and June 2000. Blue lines indicate survey tracks. Surveys were conducted from the *RV Pandalus, RV Alaska Gyre, MV David Grey* and *MV Lutris* by U.S. Geological Survey and National Park Service personnel.

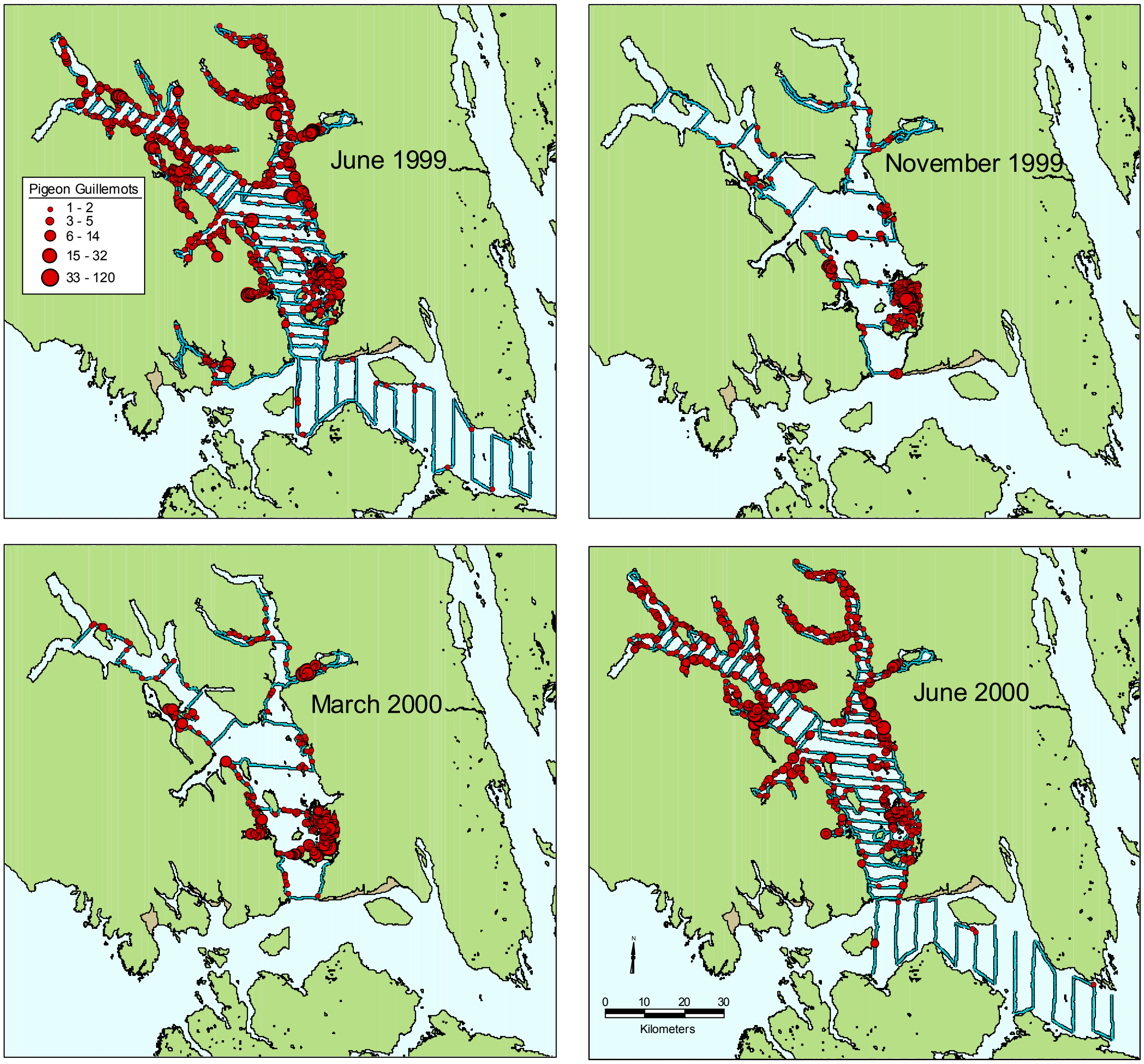

Figure 80. Pigeon guillemot sightings in and around Glacier Bay National Park during surveys conducted between June 1999 and June 2000. Blue lines indicate survey tracks. Surveys were conducted from the *RV Pandalus, RV Alaska Gyre, MV David Grey* and *MV Lutris* by U.S. Geological Survey and National Park Service personnel.

Waterfowl

Barrow's goldeneye exhibited strong seasonal patterns of occurrence in Glacier Bay (Figure 81). Although they were one of the most common birds in the fall and spring surveys, they all but disappeared in the summer months. Thus, Glacer Bay appears to be an important wintering area for this species. In terms of distribution, Barrow's goldeneye were sighted throughout the nearshore areas of Glacier Bay in the fall and spring. When present, local densities were relatively high.

Common mergansers were also seasonal residents in Glacier Bay. In contrast to Barrow's goldeneye, they were seen almost exclusively in the summer months (Figure 82). Sightings of common mergansers were primarily on nearshore transects. Although mergansers were seen throughout Glacier Bay, they were most numerous in the Beardslee Islands, Berg Bay, and Adams Inlet.

Mallards were seen in all surveys, though numbers clearly increased in the fall and spring surveys (Fig 83). As with other waterfowl, mallards were found only in nearshore areas. In the summer months the mallards that remained in Glacier Bay were located primarily in small Bays and inlets. In the fall and spring, mallard numbers rose dramatically and they expanded their range to include the Beardslee Islands, Berg Inlet, and Fingers Bay. This shift suggests these areas are important wintering habitat.

Harlequin ducks, though not as numerous as some other waterfowl, were found throughout Glacier Bay during the summer surveys (Fig 84). Harlequin duck use of Glacier Bay during the fall and spring appeared to shift to the south. The observations of Harlequin ducks during the fall and spring identifies Glacier Bay as an important wintering area for this species. On all surveys, their distribution was nearshore.

White–winged scoters were most common in the summer months, when sightings of large flocks were common (Fig 85). Scoters were sighted most frequently in the northern portion of the Bay, with large numbers sighted in both Muir Inlet and the West Arm. Although most common in the summer, white-winged scoters were found in Glacier Bay year-round as evidenced from the November and March surveys.

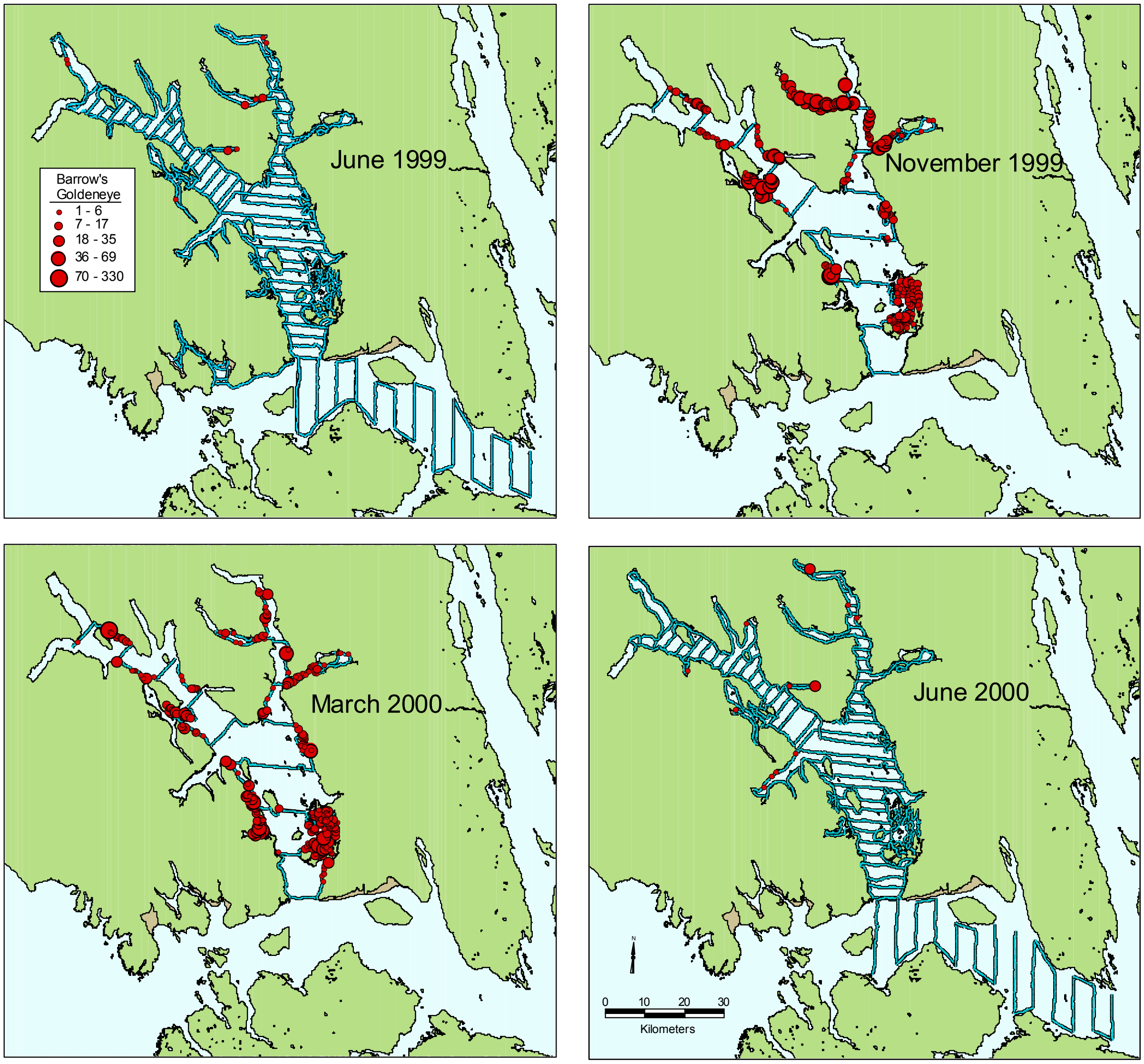

Figure 81. Barrow's goldeneye sightings in and around Glacier Bay National Park during surveys conducted between June 1999 and June 2000. Blue lines indicate survey tracks. Surveys were conducted from the *RV Pandalus, RV Alaska Gyre, MV David Grey* and *MV Lutris* by U.S. Geological Survey and National Park Service personnel.

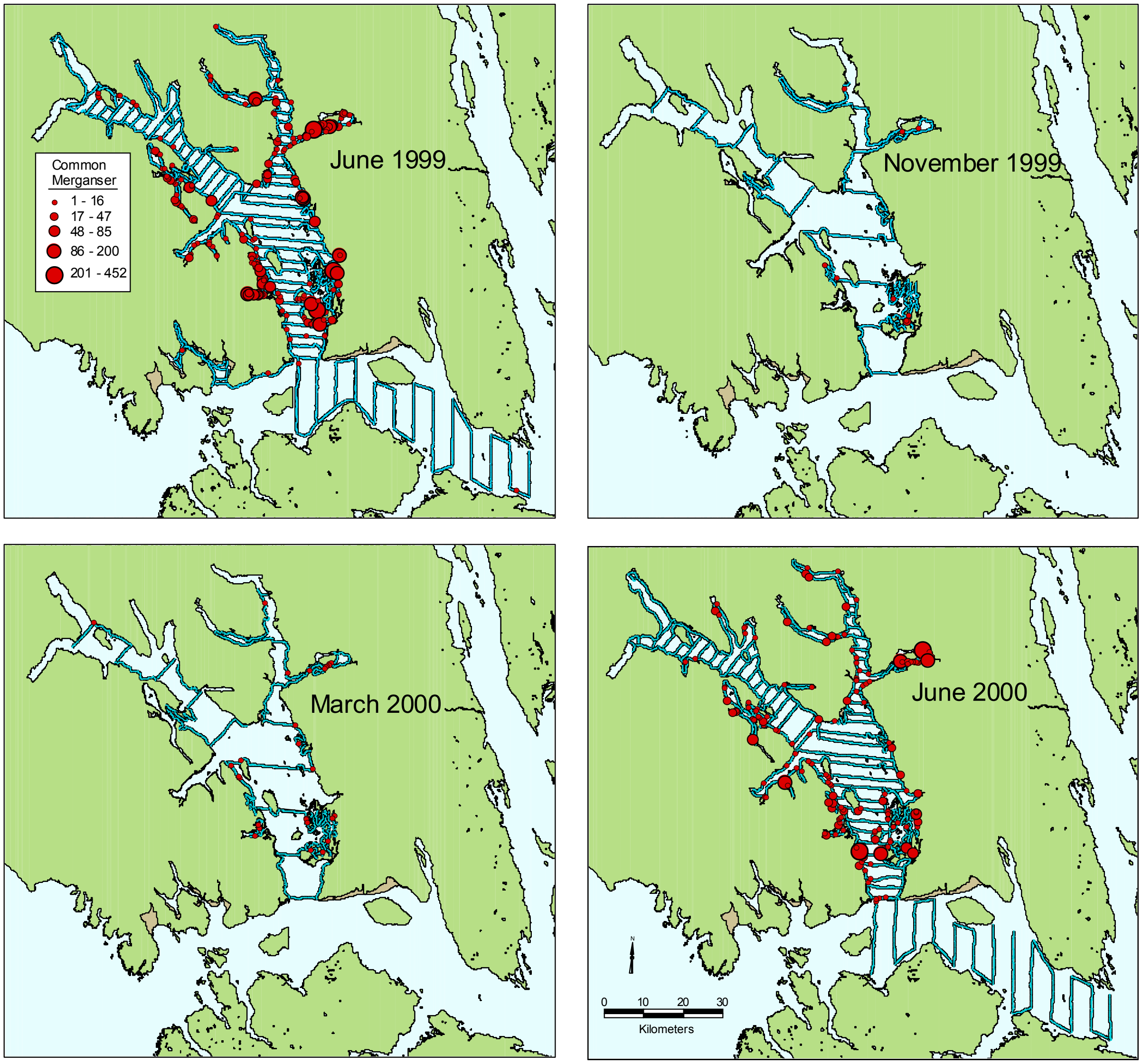

Figure 82. Common merganser sightings in and around Glacier Bay National Park during surveys conducted between June 1999 and June 2000. Blue lines indicate survey tracks. Surveys were conducted from the *RV Pandalus, RV Alaska Gyre, MV David Grey* and *MV Lutris* by U.S. Geological Survey and National Park Service personnel.

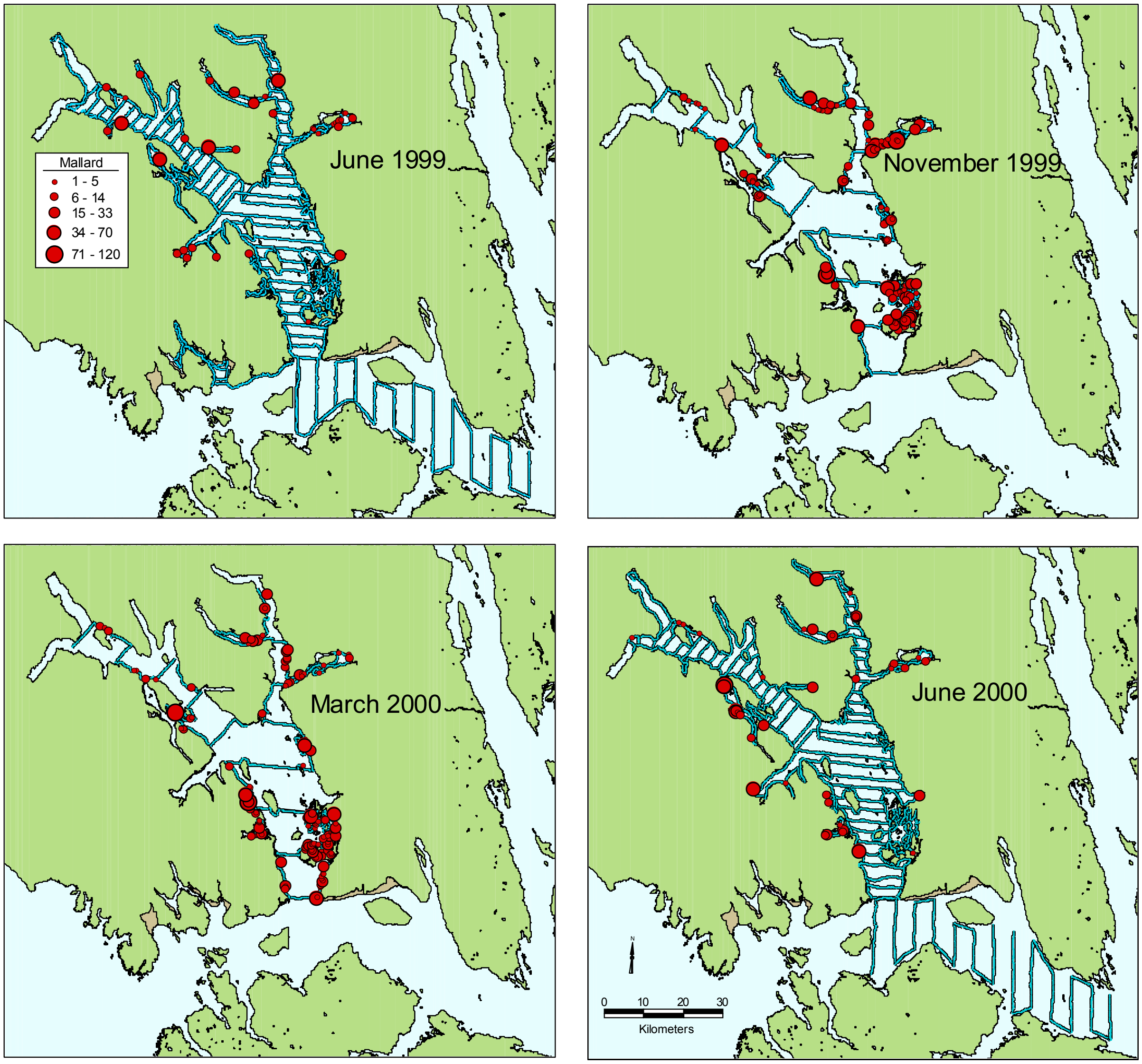

Figure 83. Mallard sightings in and around Glacier Bay National Park during surveys conducted between June 1999 and June 2000. Blue lines indicate survey tracks. Surveys were conducted from the *RV Pandalus, RV Alaska Gyre, MV David Grey* and *MV Lutris* by U.S. Geological Survey and National Park Service personnel.

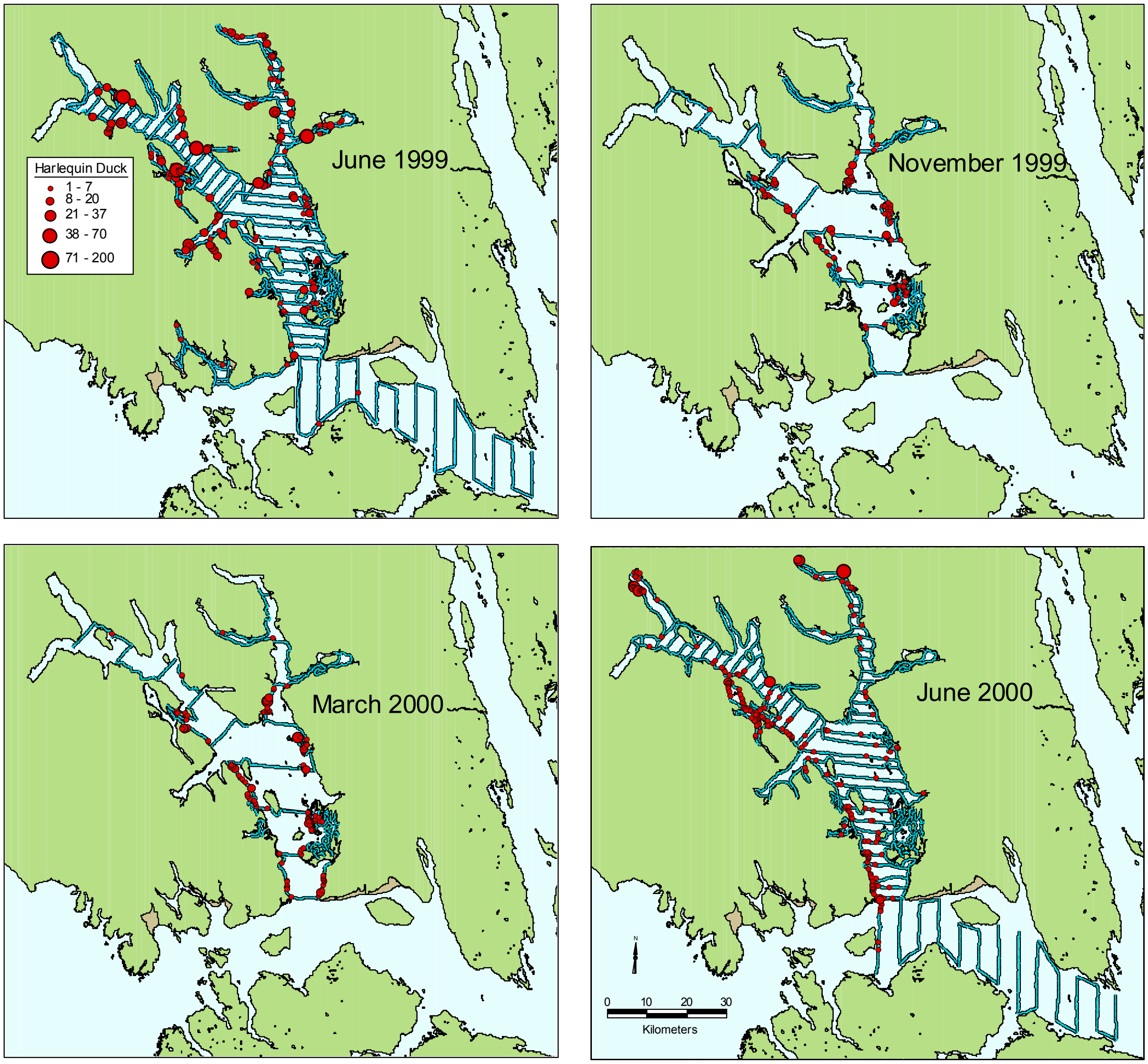

Figure 84. Harlequin duck sightings in and around Glacier Bay National Park during surveys conducted between June 1999 and June 2000. Blue lines indicate survey tracks. Surveys were conducted from the *RV Pandalus, RV Alaska Gyre, MV David Grey* and *MV Lutris* by U.S. Geological Survey and National Park Service personnel.

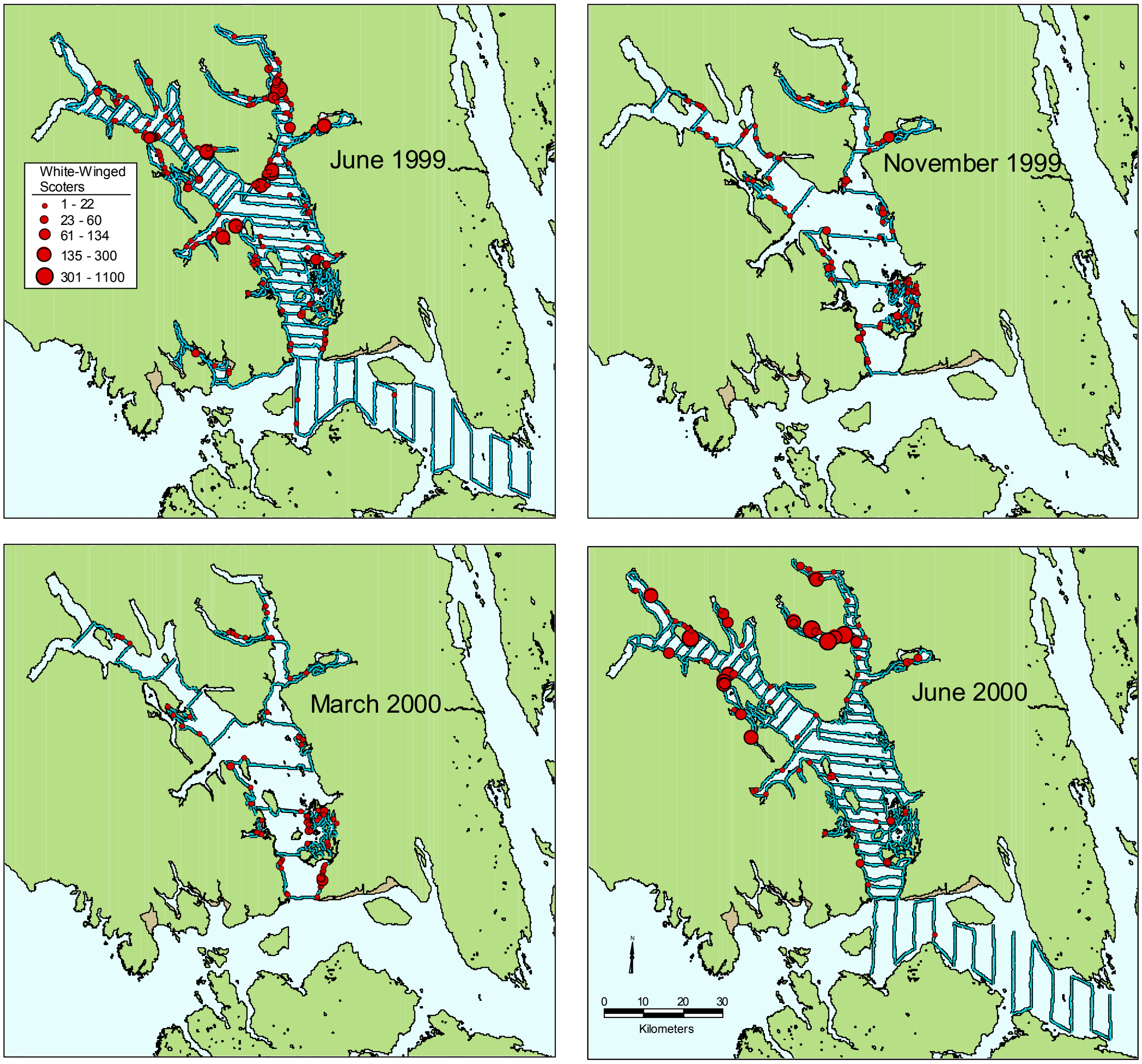

Figure 85. White-winged scoter sightings in and around Glacier Bay National Park during surveys conducted between June 1999 and June 2000. Blue lines indicate survey tracks. Surveys were conducted from the *RV Pandalus, RV Alaska Gyre, MV David Grey* and *MV Lutris* by U.S. Geological Survey and National Park Service personnel.

Marine Mammals

As with marine birds, marine mammal distributions varied spatially and temporally. Sea otters were seen in all seasons with no noticeable change in distribution throughout the surveys. Sea otters, once extirpated from Glacier Bay, have expanded their range to the northernmost extent of the Beardslee Islands (Figure 86; also see Bodkin et al. 2001). Concentrations of sea otters were greatest along the coast of the Sitakaday Narrows and the Beardslee Islands, with much smaller numbers located in Icy Strait.

Both harbor and Dall's porpoise were seen on surveys, however, they were segregated in their geographic distribution. Harbor porpoise were found throughout the offshore areas of Glacier Bay (Figure 87). In contrast, Dall's porpoise were found almost exclusively in the waters of Icy Strait outside of Glacier Bay. Due to a combination of low numbers and a lack of sampling in Icy Strait on the November and March surveys, little can be said about the seasonality of these two species.

Harbor seals were the most commonly sighted marine mammals. Maps illustrate the broad distribution of harbor seals within Glacier Bay proper (Figure 88). Their occurrence in the Bay in all surveys indicated year-round residency. Although they were seen throughout Glacier Bay, the Beardslee Islands were an area of particularly high harbor seal abundance in all seasons, though this may be related more to the location of haulouts than forage resources.

Humpback whales were seen throughout Glacier Bay on both June surveys (1999 and 2000). Despite their wide distribution, the majority of humpbacks on surveys were found in large concentrations at specific sites. During the 1999 survey, a large concentration of humpbacks was seen around Point Adolphus; in 2000 the largest concentration of humpbacks was seen at the mouth of Glacier Bay (Figure 89). These results were similar to patterns observed in the ongoing National Park Service whale monitoring study (Doherty and Gabriel 2002). Maps of the November 1999 and March 2000 surveys indicated that a small number of humpbacks either delayed their migration or possibly over-wintered in the Bay.

South Marble Island is the only Steller sea lion haulout in Glacier Bay, and our surveys did not pass close to it. Thus all sea lions sightings were of animals in the water. Steller sea lions were sighted on all surveys, though there appeared to be a shift to the north during the fall and spring surveys and to the south during the June surveys (Figure 90). We also noted that in the fall and spring surveys sea lions were seen in larger groups. The June 1999 survey had the fewest sightings, with no sightings in either arm.

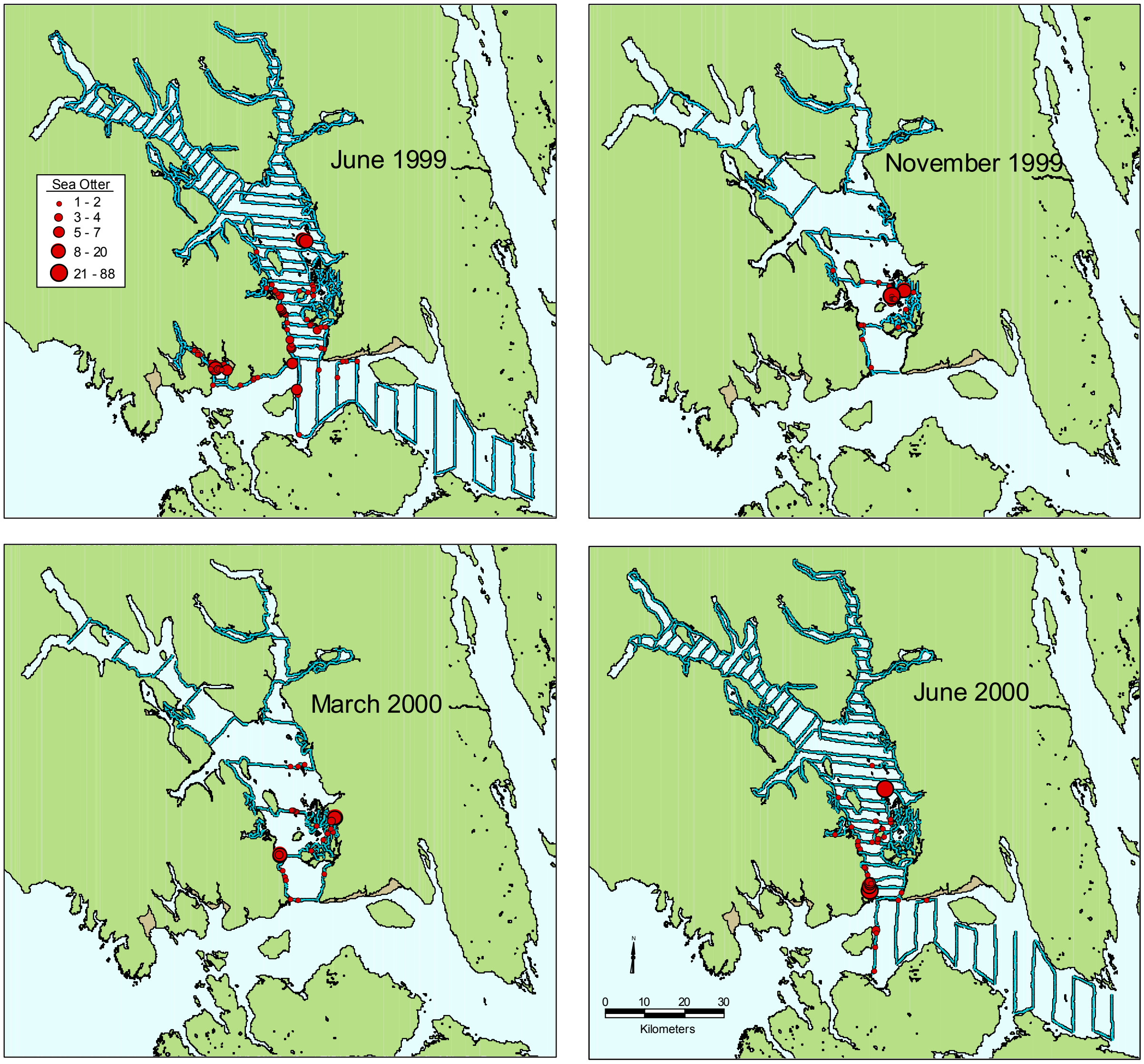

Figure 86. Sea otter sightings in and around Glacier Bay National Park during surveys conducted between June 1999 and June 2000. Blue lines indicate survey tracks. Surveys were conducted from the *RV Pandalus, RV Alaska Gyre, MV David Grey* and *MV Lutris* by U.S. Geological Survey and National Park Service personnel.

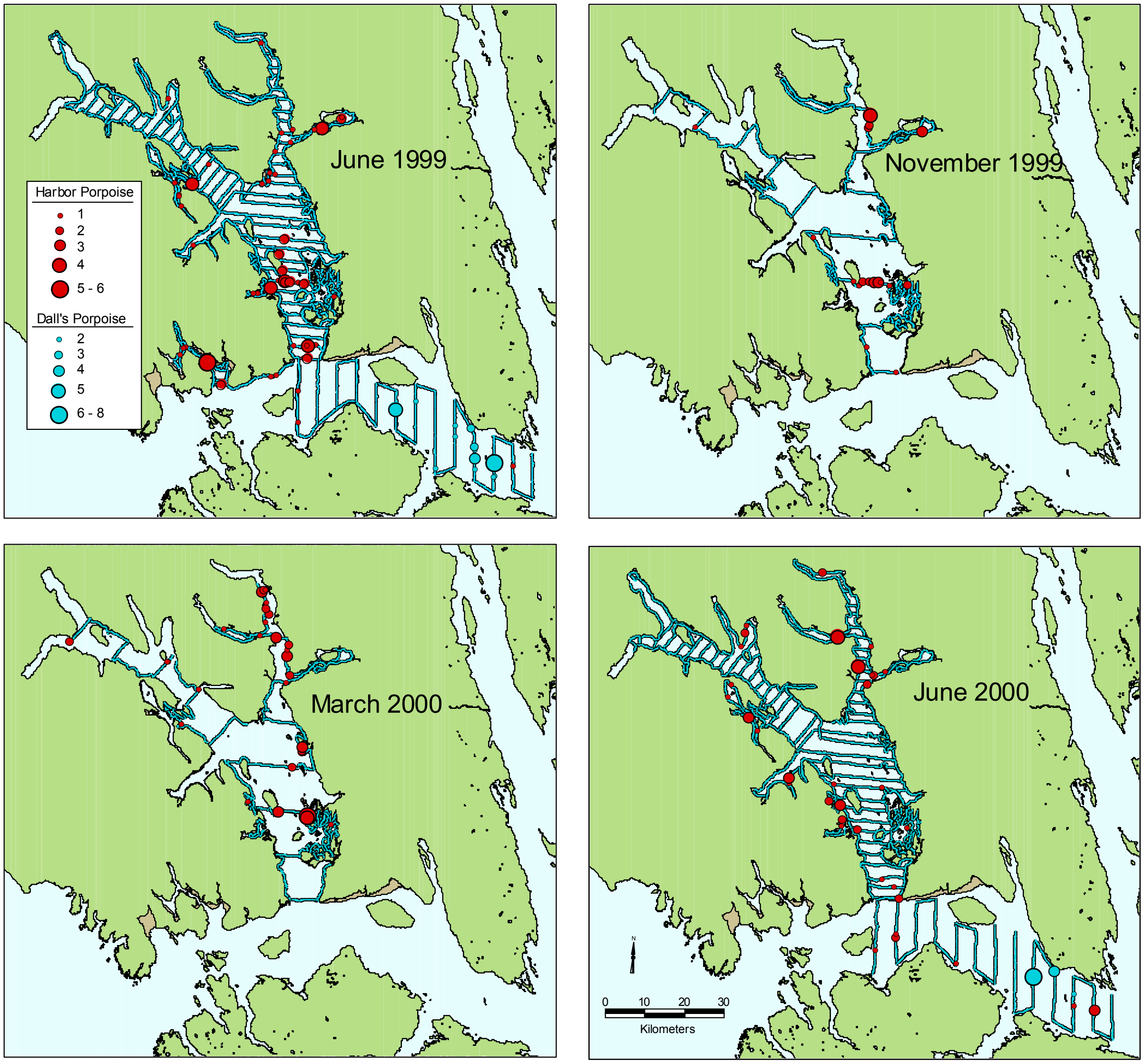

Figure 87. Dall's and harbor porpoise sightings in and around Glacier Bay National Park during surveys conducted between June 1999 and June 2000. Blue lines indicate survey tracks. Surveys were conducted from the *RV Pandalus, RV Alaska Gyre, MV David Grey* and *MV Lutris* by U.S. Geological Survey and National Park Service personnel.

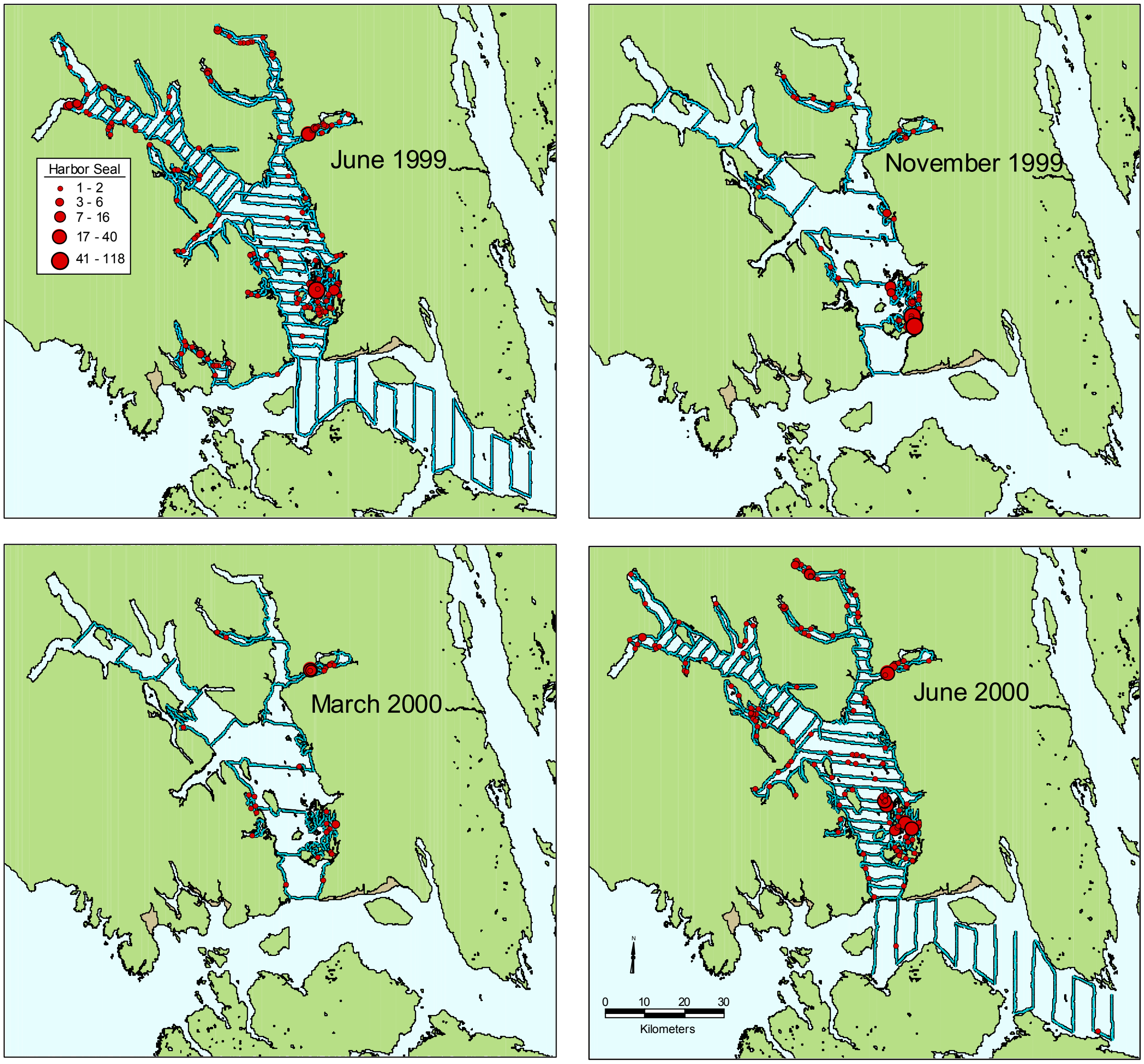

Figure 88. Harbor seal sightings in and around Glacier Bay National Park during surveys conducted between June 1999 and June 2000. Blue lines indicate survey tracks. Surveys were conducted from the *RV Pandalus, RV Alaska Gyre, MV David Grey* and *MV Lutris* by U.S. Geological Survey and National Park Service personnel.

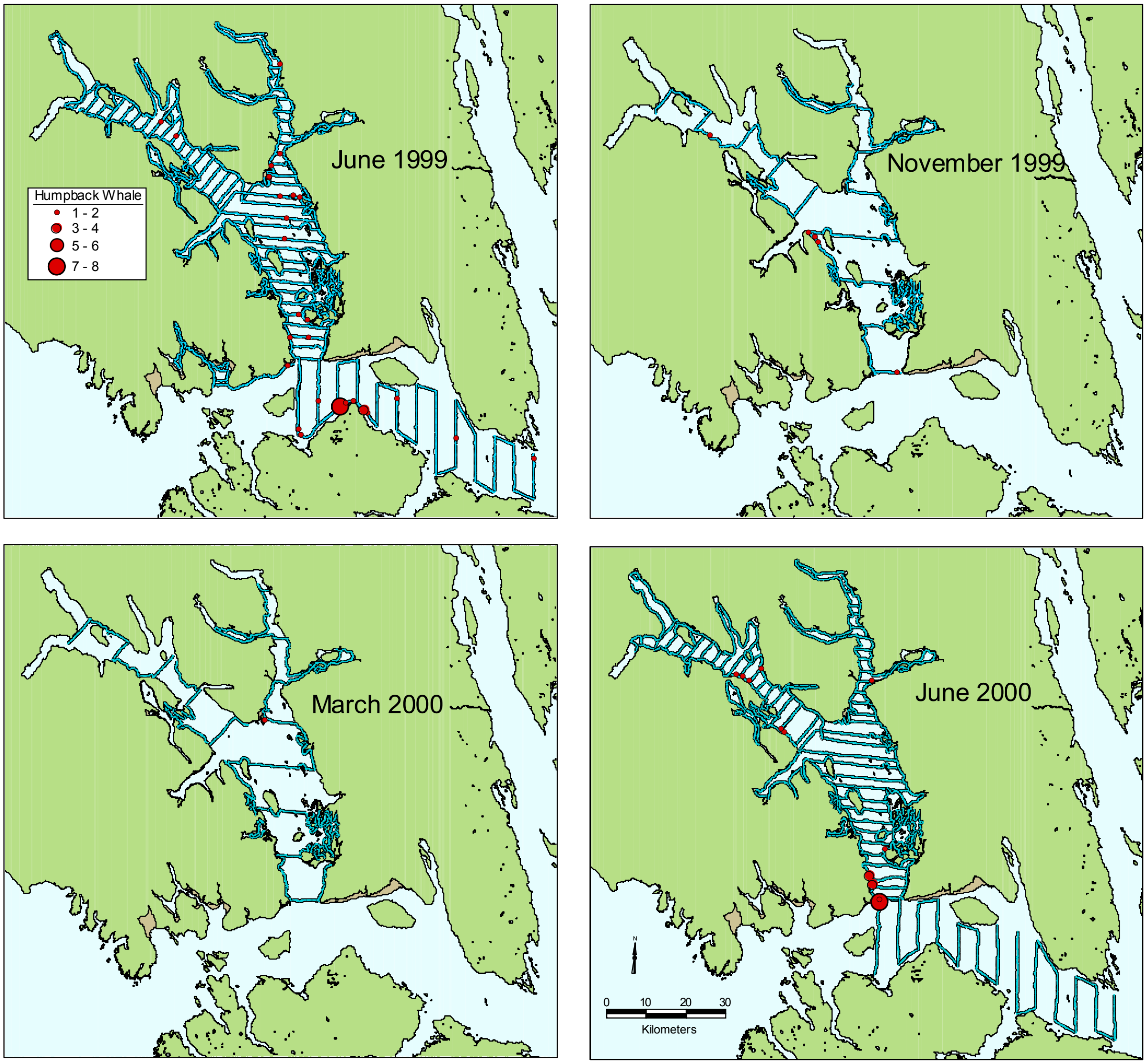

Figure 89. Humpback whale sightings in and around Glacier Bay National Park during surveys conducted between June 1999 and June 2000. Blue lines indicate survey tracks. Surveys were conducted from the *RV Pandalus, RV Alaska Gyre, MV David Grey* and *MV Lutris* by U.S. Geological Survey and National Park Service personnel.

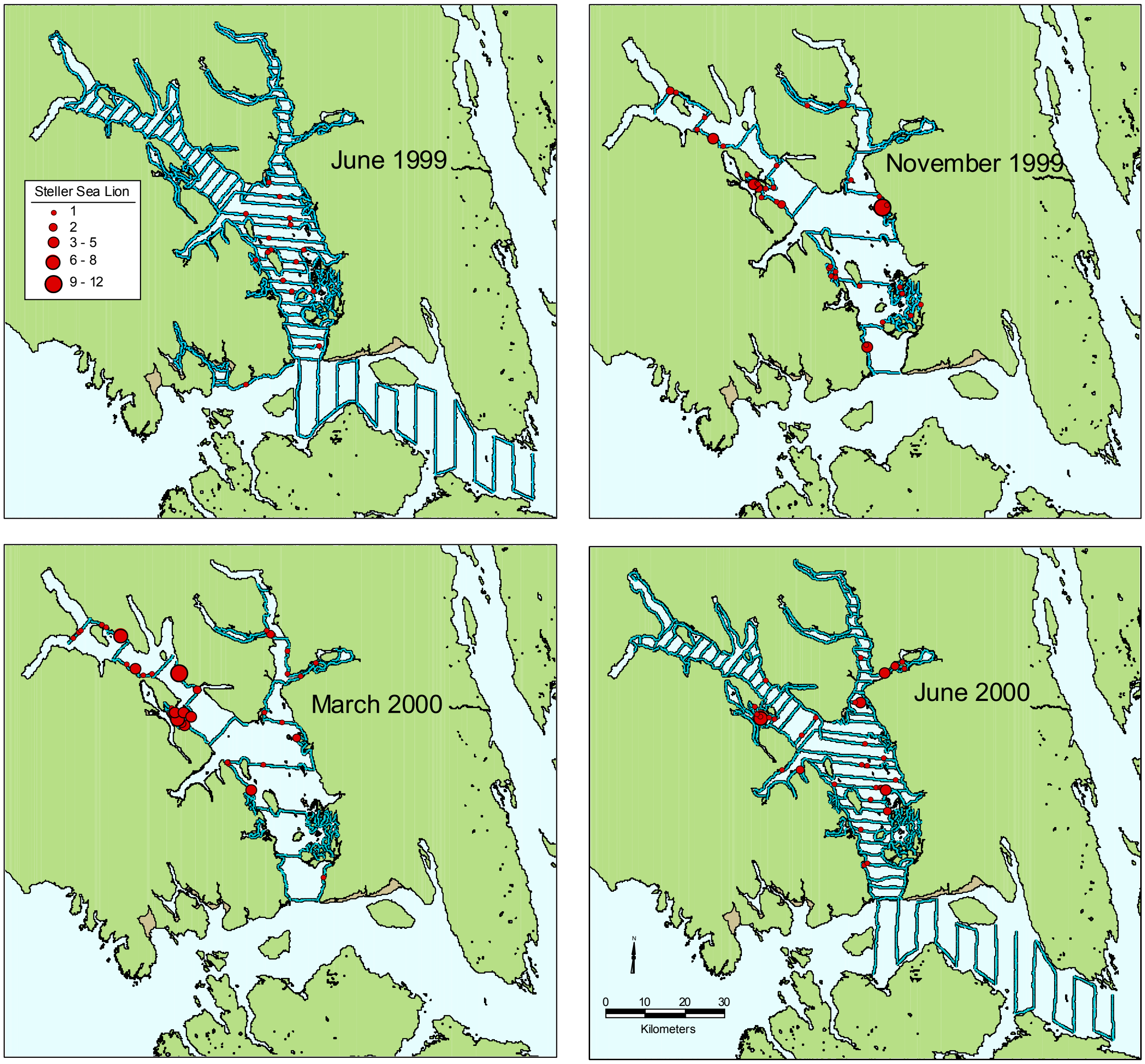

Figure 90. Steller sea lion sightings in and around Glacier Bay National Park during surveys conducted between June 1999 and June 2000. Blue lines indicate survey tracks. Surveys were conducted from the *RV Pandalus, RV Alaska Gyre, MV David Grey* and *MV Lutris* by U.S. Geological Survey and National Park Service personnel.

Species Trends

To look for temporal trends in species abundance, we compared our results from the June 1999 and June 2000 surveys with the results of a 1991 survey of Glacier Bay (Piatt and Springer, unpubl. data). The distances and areas sampled for all three summer surveys are listed in Table 13. Since the 1991 survey was primarily nearshore, for consistency, we only used the results of the nearshore portions of all three surveys, and only those transects from within Glacier Bay itself for comparison.

Table 14. Transect distances and areas sampled in nearshore and pelagic transects in Glacier Bay 1991, 1999 & 2000. Distances are given in km and areas in km^2.

	1991		1999		2000	
Survey Area	transect distance	area sampled	transect distance	area sampled	transect distance	area sampled
Coastal	651	130	772	204	779	181
Pelagic	68	14	399	120	399	91
Combination*	8	2	---	---	---	---
TOTAL	727	145	1172	323	1178	272

* Transects that sampled a combination of both pelagic and coastal areas.

There was no single trend across species. However, few species exhibited declines in density between 1991 and 1999-2000 (Table 14). Of the common species, glaucous-winged gulls (P<0.001), mew gulls (P=0.001) and pelagic cormorants (P<0.001) all indicated increasing densities between the surveys. Some species showed no discernable trend; these included black-legged kittiwakes arctic tern and harlequin duck. Pigeon guillemot densities were essentially unchanged. The only species to show evidence of decline were Kittlitz's (P=0.007) and marbled murrelets (P=0.001) (Table 14). This appears to fit the pattern of *Brachyramphus spp.* declines state-wide (van Vliet 1983, van Vliet and McAllister 1994, Piatt and Naslund 1995). Although neither species is currently listed as threatened or endangered in Alaska, marbled murrelets are listed by the U.S. Fish and Wildlife Service as threatened in Washington, Oregon, and California. Recognition of the declines in murrelets has led to the ongoing review of Kittlitz's murrelet status in Alaska.

In general, waterfowl densities appeared to be higher, however, randomization tests failed to bear this out. The general trend in marine waterfowl was one of largely stable densities between surveys. In general, high variances within years made detection of change among years difficult for species with clumped distributions. Common merganser and harlequin duck densities indicated smaller increases, while scoters appeared to be essentially unchanged.

Because of their low numbers, marine mammal trends were less apparent. While Humpback whales were seen more commonly in 1999-2000 than in 1991, the difference approached but did not reach significace (P=0.054). Harbor seals were sighted less in 1999-2000 than in 1991, but again, the difference only approached significance (P=0.077). Sea otter densities were higher in the 1999 and 2000 surveys. Sea otters were not seen at all on the 1991 survey, while they were quite common in the lower portion of the Bay in 1999-2000.

Table 15. Densities of common seabirds and marine mammals sighted on surveys in June of 1991, 1999, and 2000. Density calculations include only nearshore transects. Densities shaded green indicate higher densities in 1999 and 2000 than in 1991, while those shaded yellow indicate higer densities in 1991 then in 1999 and 2000. Confidence intervals are provided for comparison, but non–normal distributions make their direct application problematic. Comparisons were made using radomization tests.

	1991		1999		2000		
Species	#/km^2	95% CI	#/km^2	95% CI	#/km^2	95% CI	
Arctic Tern	0.33	(0.38)	2.14	(2.39)	1.05	(0.92)	
Black-legged Kittiwake	4.51	(8.31)	8.38	(4.11)	5.20	(3.77)	
Canada Goose	1.45	(1.14)	2.83	(2.97)	2.74	(2.76)	
Common Merganser	10.99	(7.33)	15.40	(6.77)	13.30	(9.73)	
Glaucous-winged Gull	1.83	(0.95)	8.09	(2.87)	7.61	(4.02)	**
Harlequin Duck	4.32	(2.17)	6.06	(2.32)	8.53	(4.42)	
Kittlitz's Murrelet	5.04	(1.91)	1.01	(0.55)	0.99	(0.60)	**
Marbled Murrelet	31.17	(7.76)	13.01	(3.69)	3.44	(1.28)	**
Mew Gull	0.98	(1.03)	2.67	(1.43)	4.63	(2.35)	**
Pelagic Cormorant	0.14	(0.11)	2.76	(2.53)	0.80	(0.71)	**
Pigeon Guillemot	13.63	(8.88)	8.55	(2.03)	7.29	(1.93)	
Unidentified Murrelets	19.74	(6.92)	5.54	(1.80)	5.08	(1.38)	**
White-winged Scoters	28.47	(25.43)	31.30	(22.21)	13.88	(11.24)	
Humpback Whale	0.01	(0.02)	0.09	(0.07)	0.10	(0.10)	
Sea Otter	0.00	NA	0.37	(0.39)	1.04	(1.51)	**
Harbor Seal	3.86	(2.45)	0.89	(0.47)	1.48	(0.93)	

Increasing
No Trend
Decreasing

** P<0.05

Survey Methods

Natural resource managers seek out efficient sampling schemes to maximize their ability to monitor populations. We tested several less intensive sampling regimes against the full survey to see if they could provide accurate information about seabird and marine mammal populations. We compared 3 different sub-sets of the June 1999 and June 2000 transects with the full surveys for each year (Figure 91). The first subset was based on the November-March survey transects, accounting for approximately 25 % of the complete set of transects. Using this set of transects simplified analysis allowing for a single set of transects and direct transect to transect comparisons across seasons. However, densities for the two summer surveys when compared to the densities for the reduced number of transects indicated that the reduced set of transects poorly reflected the actual densities of most species (Table 15). We also found a lack of agreement between the two years of reduced surveys. The densities of some species were overestimated in one year and underestimated in the other. Besides providing poor estimates of species densities, the lack of consistency between years further indicates that these reduced estimates are not robust indices of density.

The second subset of transects included 35 % of the full survey within Glacier Bay. This set of transects sampled the pelagic zone in approximately 5 km intervals as well as sampling approximately half the nearshore area. This set of transects also failed to provide density estimates that matched those of the full set of survey transects (Table 15). As with the 25 % set of transects, there was a lack of agreement in the direction of error between the two years of reduced transects, again making density estimates questionable for use as indices.

The final subset of transects included all nearshore transects within Glacier Bay. These nearshore transects (n=63) accounted for 63 % of all transect volume sampled. Of the three subsets the coastline transects showed the greatest consistency between years, however the densities of most species were higher then those calculated using the Bay wide survey data (Table 15). Murrelet densities were either lower (Kittlitz's and all Brachyramphus), or inconsistent (marbled) in comparison with the full Bay-wide survey. Humpback whale densities were also inconsistent in comparison with the results of the bay wide survey.

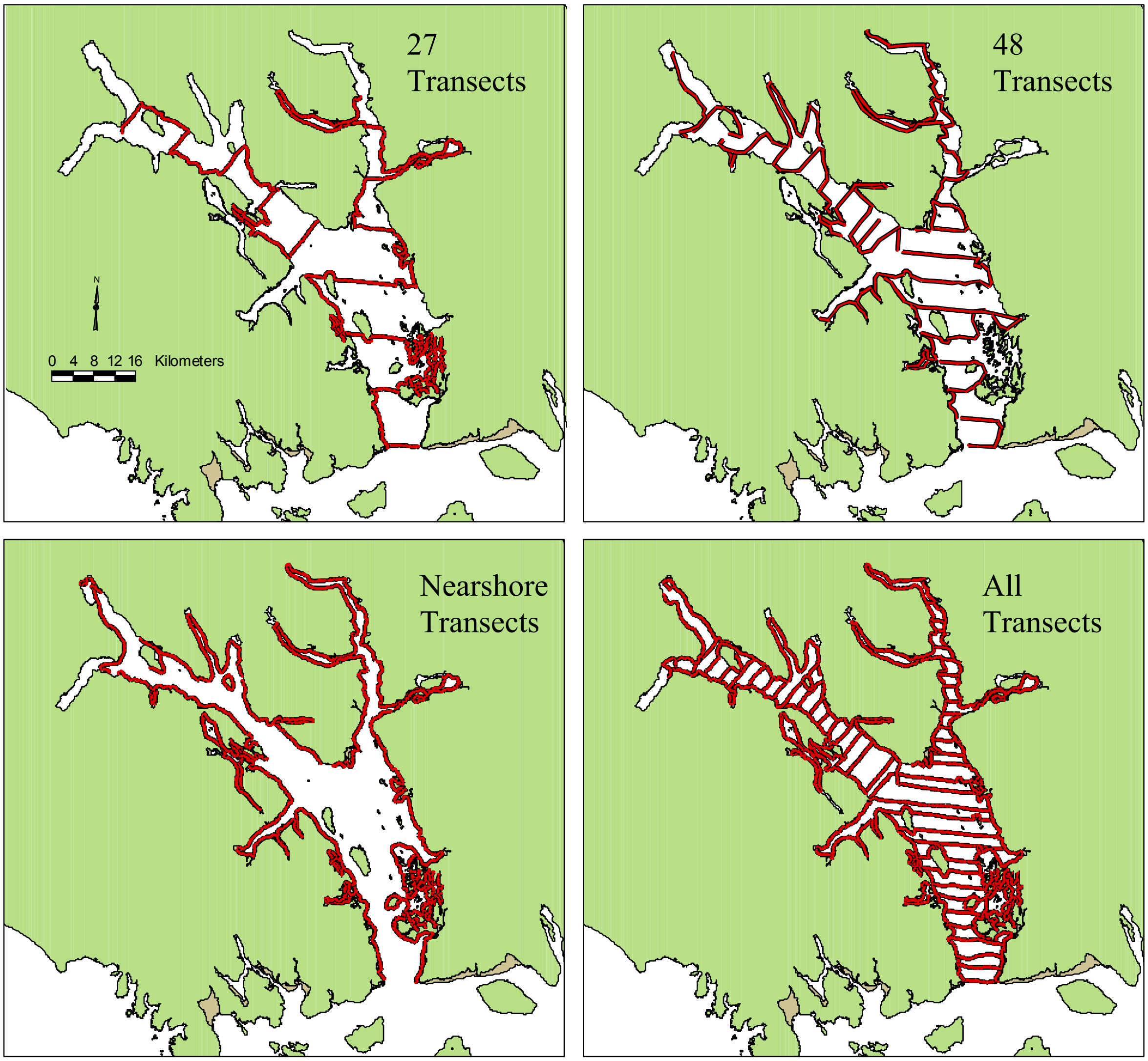

Figure 91. Various survey designs within Glacier Bay. Subsets include 25 % (27 transects), 35 % (48 transects), 63 % (nearshore transects, n=63) of the total volume of area surveyed within Glacier Bay during June of 1999 and 2000. All transects within Glacier Bay (n=112) are displayed for comparison.

Table 16. Comparisons of seabird and marine mammal densities for the full survey and 3 reduced sets of transects. Densities are only from transects within Glacier Bay. Percentages reflect the densities from reduced transects/all transects. Percentages shaded green are species that were sighted more commonly then expected, while those shaded yellow were species sighted less commonly then expected. The reduced surveys covered approximately 25%, 35%, and 46% of the full survey respectively.

	Full Survey		27 Transects				48 Transects				Nearshore Survey			
	Densities		Densities		25% Of Total		Densities		35% Of Total		Densities		46% Of Total	
	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
Arctic Tern	1.57	0.65	0.52	0.82	33.12	127.25	0.64	0.47	40.76	72.30	2.01	1.05	128.03	162.06
Black-legged Kittiwake	16.43	3.41	12.29	3.22	74.80	94.55	6.38	5.01	38.83	148.08	23.10	5.20	140.60	152.49
Brachyramphus Murrelet	6.68	9.62	7.27	9.38	108.83	97.52	4.35	13.47	65.12	141.27	5.32	5.08	79.64	52.81
Canada Goose	1.60	1.58	3.96	3.14	247.50	198.66	0.36	0.18	22.50	11.27	2.72	2.74	170.00	173.42
Common Merganser	8.67	8.06	16.73	16.09	192.96	199.65	5.91	9.33	68.17	116.77	14.78	13.30	170.47	165.01
Glaucous Gull	6.41	4.94	5.43	6.46	84.71	130.80	4.16	8.28	64.90	169.16	8.68	7.61	135.41	154.05
Harlequin Duck	3.53	5.29	5.56	8.83	157.51	166.88	2.53	4.93	71.67	94.19	5.87	8.53	166.29	161.25
Harbor Seal	0.69	0.94	1.05	1.48	152.17	156.97	0.12	0.57	17.39	60.70	1.07	1.48	155.07	157.45
Humpback Whale	0.07	0.11	0.02	0.13	28.57	122.49	0.01	0.11	11.15	100.79	0.09	0.10	128.57	90.83
Kittlitz's Murrelet	1.68	2.13	1.61	1.89	95.83	88.80	1.54	2.32	91.67	110.27	0.95	0.99	56.55	46.48
Mallard	0.77	1.58	1.41	1.38	183.12	87.19	0.23	1.19	29.87	75.86	1.27	2.75	164.94	174.05
Marbled Murrelet	11.20	4.58	11.08	3.88	98.93	84.62	9.23	5.52	82.41	121.56	13.09	3.44	116.88	75.11
Pigeon Guillemot	4.91	5.86	6.91	6.76	140.73	115.32	4.43	4.07	90.22	84.07	8.74	7.29	178.00	124.40
Steller Sea Lion	0.04	0.18	0.02	0.20	50.00	111.11	0.01	0.26	25.00	47.51	0.04	0.11	100.00	61.11
Sea Otter	0.63	0.64	0.13	0.07	20.63	10.94	0.08	0.30	12.70	149.07	0.94	1.04	149.21	162.50
Surf Scoters	10.60	11.19	21.07	4.95	198.77	44.27	10.85	8.05	102.36	72.68	17.72	15.77	167.17	140.93
White-winged Scoters	18.40	11.37	18.19	9.08	98.86	79.87	28.96	13.65	157.39	121.17	30.61	13.88	166.36	122.08

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Conclusions

Glacier Bay Ecosytem

The Glacier Bay Ecosystem represents a system under construction. The rapid retreat of glaciers in this area provides us with a glimpse of a system that has not reached a steady state. However, while the system as a whole is changing, many species appear to have consistent annual patterns of distribution that reflect the current status quo.

Oceanography and Primary Productivity

Although oceanography and primary productivity were not primary foci of this study, we collected data that was contributed to the dedicated Glacier Bay oceanography report (Hooge and Hooge 2002). The results of that study were paraphrased in this report (see page 25). Appendix 6 provides a visual model (from Hooge and Hooge 2002) of the oceanographic system of Glacier Bay. One important finding that connects the two reports concerns the abundance and distribution of zooplankton. Hooge and Hooge (2002) hypothesized that high phytoplankton abundance in the Bay could be the product of low predation pressure from zooplankton, or phytoplankton production rate that exceeds the consumption rate of zooplankton predators (generally associated with nutrient enhancements) that exceeds the ability of zooplankton grazers ability to keep them at low levels. The high zooplankton densities observed in the upper-Bays during this study suggest that the former reason is unlikely. Instead, the combination of our results and those of Hooge and Hooge (2002) indicate that Glacier Bay is an area that of sustained high primary productivity that is likely a product of sustained nutrient supply.

Zooplankton and forage fish

In early spring, onshore movement of zooplankton contributes to the abundance of shelf zooplankton communities throughout the Gulf of Alaska. Cooney (1987) estimated that on the order of 10 million metric tons of zooplankton biomass are moved shoreward each year in the Gulf of Alaska. This input of biomass at the secondary trophic level probably contributes to the productivity of the Bay.

Despite similarities in the zooplankton abundance and community structure between Glacier Bay and other Gulf of Alaska estuaries, seasonal patterns of production are strikingly different. In the Gulf of Alaska, zooplankton abundance peaks in late May or June, and steadily declines through the rest of the season (Cooney, 1987). However, persistent production in the West and East Arms of Glacier Bay leads to sustained seasonal zooplankton abundance within the upper-Bay. Mixing fronts are often highly productive (Cooney, 1987); and the heads of both Arms are no exception. The glacially influenced oceanography provides a possible mechanism of water movement that allows plankters, largely copepods advected into the Bay by Ekman transport, to congregate and remain at these fronts. The highest zooplankton abundances in this study were in Tarr Inlet – some of the coldest and most turbid waters in Glacier Bay.

At the metapopulation scale, exchange of zooplankton between Glacier Bay and Gulf of Alaska populations is largely the result of migration by larvae in the plankton. Local

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production of larvae in Glacier Bay is likely to contribute to plankton communities outside of the Bay. Environmental cues regulate timing of larval release, and correlations between oceanography, release, and abundance of larvae could provide insights into population dynamics. The potential shift in timing from 1963 to 2000 may be related to changes in oceanography as glaciers within the Bay continue to recede. These changes may, in turn, have a wider impact on surrounding marine areas.

Icthyoplankton surveys indicated that Glacier Bay provides nursery habitat for large numbers of juvenile pollock, capelin, and slender eelblenny. Abundances were much higher in June than in May, which is similar to results for other Alaskan fjord systems (e.g., Ressurection Bay; Müter and Norcross, 1994). Juvenile herring were conspicuous in their absence from our summer surveys, despite representing a large part of our fall littoral sampling. Juvenile herring appear to frequently avoid our nets, maybe due to their patchy distribution or use of habitat between areas sampled by our beach seines (littoral zone) and offshore pelagic trawls.

Catches of larval fish in the upper reaches of Glacier Bay were markedly reduced compared to the immediately adjacent down-Bay station during June, the peak for larval abundance (for example pollock (Table16) or capelin (Table 17) at stations 21 and 10, respectively). This result suggests that a limiting physical condition exists in the upper bays (e.g., Tarr Inlet) that restricts the presence of juvenile fish. Conversely, euphausiids were markedly more abundant at the very heads of the Bay (Table 18).

Table 17. Numbers per 1000 m^3 for walleye pollock larvae in Glacier Bay, Alaska (May, June = Tucker Trawl), (July, August = Isaacs-Kidd). All stations and months were fished, however, zeros left out for clarity

	Lower Bay		Middle Bay		West Arm			East Arm			
	00	02	04	06	08	10	21	14	16	18	20
May				3.9							
June		3.8	49.9	187.5	158.2	491.3		68.3	86.1		
July		0.1			4.1	1.0	3.6			7.9	7.9
August					0.1	1.0	35.3	0.4	0.8	2.4	4.2

Table 18. Numbers per 1000 m^3 for capelin larvae in Glacier Bay, Alaska (May, June = Tucker Trawl), (July, August = Isaacs-Kidd). All stations and months were fished, however, zeros left out for clarity.

	Lower Bay		Middle Bay		West Arm			East Arm			
	00	02	04	06	08	10	21	14	16	18	20
May											
June		4.4	15.6		10.9	244.9			8.4		
July	1.9	3.6		2.4	0.1	0.5	24.0	0.1		8.4	6.0
August	0.9	3.5	0.4	0.8	0.8	0.4	26.5	7.6	8.7	4.9	0.6

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Table 19. Numbers per 1000 m^3 for euphausiids in Glacier Bay, Alaska (May, June = Tucker Trawl), (July, August = Isaacs-Kidd). All stations and months were fished, however, zeros left out for clarity.

	Lower Bay		Middle Bay		West Arm			East Arm			
	00	02	04	06	08	10	21	14	16	18	20
May		14.2	441.4	47.2	128.7	134.6	218.3	9.4	37.5		107.4
June	22.7		219.7	108.3		141.6	2441.5		7.5	51.9	233.2
July		11.2	67.5	59.6	4.9	66.2	622.3	67.2	70.0	941.2	268.8
August		1.1			47.9	58.4	706.2	116.1	49.0	101.6	79.7

Nearshore communities of fish in Glacier Bay appeared typical of those found in northern regions. Tidal, seasonal, and spatial processes all imparted strong effects on both abundance and composition of fish in the Bay. Overall, the community was defined by juvenile fish that transitioned from salmonids leaving Glacier Bay in the spring, to capelin, sand lance, and herring immigrating to nearshore areas in the fall. Despite the wide coverage of our nearshore fish sampling, most fish were caught at relatively few sites – particularly those in close proximity to tidewater glaciers and those neighboring salmonid spawning streams.

Mid-water sampling of pelagic fish species indicated some clear patterns within Glacier Bay. First, marked spatial differences existed around the Bay. For the most part, the pelagic community was dominated by juvenile walleye pollock and capelin. However, capelin dominated in Muir Inlet while walleye pollock dominated in catches in the west arm, middle Bay, lower Bay, and Icy Strait.

Seasonal patterns of abundance of juvenile and adult fish in Glacier Bay were also interesting. We can compare our results with similar work conducted in Lower Cook Inlet (Piatt, 2002). Most striking was the extremely high relative abundance of juveniles in Glacier Bay (particularly the upper arms) compared to Cook Inlet. The logical explanation for this pattern is that the upper reaches of Glacier Bay are important nursery areas for juvenile fish. Seasonal sampling indicated that the juveniles were present throughout the season and grew at similar rates to those published for similar species in Prince William Sound (Müter and Norcross, 1994). Abundance of these juveniles suggest beneficial conditions in Glacier Bay for early growth, despite cold and turbid waters.

Seasonal and spatial patterns of abundance for both pelagic zooplankton and icthyoplankton in Glacier Bay indicate a marked seasonal and spatial pattern to the abundance of these secondary and tertiary levels of productivity. Zooplankton abundance was highest in the upper arms and at the mid-Bay station 4. Analysis of oceanographic data by Hooge and Hooge (2002) paralleled these results with elevated levels of primary productivity in the upper arms and mid-Bay. Clearly, processes defining the productivity in the upper arms as opposed to the mid-Bay are different. Perhaps the most interesting question is why are there high abundances of small fish in close proximity to Margerie Glacier but not in the mid-Bay?

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One of the prominent findings of our research is the relative importance of Glacier Bay as a nursery area for pelagic fish. The role of inshore habitat as an important nursery area for juveniles of many marine fish species is well known (e.g., Poxton *et al.*, 1983; Orsi and Landingham, 1985; Bennett, 1989; Blaber *et al.*, 1995; Dalley and Anderson, 1997). However, our results suggest that pelagic fish in Glacier Bay are also generally smaller than those in Cook Inlet, and more juveniles are present (Piatt, 2002). Base on our data, we also speculate that several key forage species (e.g., capelin, sand lance, and juvenile walleye pollock and herring) also probably spawn within the Bay.

Forage fish predators

Predator surveys provided us with extensive information about species occurrence and distribution in and around Glacier Bay. Although the Bay had been surveyed in the past, our efforts were the first comprehensive surveys covering the greater Glacier Bay ecosystem and will serve as a baseline for future inventories.

The heterogeneous marine environment provides a basis for explanation of the diverse and productive assemblage of species found in the Bay. Glacier Bay provides foraging, nesting, and wintering habitat for a wide variety of marine bird and mammal species (n=71 sighted in surveys). Although overall marine bird densities were somewhat less then that recorded in some of the most productive areas in the northern Gulf of Alaska, such as the Barren Islands (about 100 bird/km^2, Piatt 1994), the summer densities were nonetheless quite high (about 80 birds/km^2). Fall and spring surveys had not been carried out previously to our surveys. Seasonal trends in abundance and diversity of seabird assemblages indicated that they dominated the summer surveys, whereas waterfowl were dominant in the fall and spring.

Summer surveys indicated that while marine birds and mammals use all portions of the Bay, several areas were focal points for many species. These areas included the Beardslee Islands, Sitakaday Narrows, Hugh Miller Inlet, Berg Bay, and Adams Inlet. An integration of colony site, hydroacoustics, and fishing data may provide additional information on whether these sites are primarily associated with proximity to breeding areas, food resources, or a combination of the two. The decreased sampling area during the Fall and spring surveys limited our ability to comprehensively identify marine bird and mammal distributions during this period. However, we were able to confirm that areas that were high-use during the June surveys (Beardslee Islands, Sitakaday Narrows, Hugh Miller Inlet, Berg Bay, and Adams Inlet) were also high-use areas during the fall and spring surveys. However, a primary difference was the shift from use by seabirds in the summer to use by waterfowl in the winter. This use during the winter months suggested Glacier Bay provides over wintering habitat to several species, many of which were absent in the summer months.

Distribution of marine birds in Glacier Bay was primarily nearshore. Only Kittlitz's murrelets were more common on the offshore transects. This distribution likely reflects the nearshore nature of foraging resources. Surveys also illustrated the seasonal attendance by most marine bird species. Summer residents, including black- legged kittiwake, common mergansers, murrelets and scoters use the Bay as reproductive habitat. The vast majority of these species migrate from Glacier Bay in the fall; whereas

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other species including Barrow's goldeneye, mallard and northwestern crow overwinter in the Bay. Generally, the two summer surveys showed a consistent pattern of habitat use for most species. Of the more abundant species, only Kittlitz and marbled murrelets were not present in the same portions of the Bay in 2000 that they were in 1999. The explanation for this lack of similarity in distribution may be related to foraging resources or differing levels of disturbance by vessels; however, shifts in distribution between the two surveys were not recorded for other species.

Harbor porpoise were only found in the Bay itself while Dall's porpoise were only seen in Icy Strait. Humpback whale distributions were clumped near Point Adolphus in June of 1999 and Point Carolus in June of 2000. This localized abundance is attributed to their use of known foraging areas. The changes in whale distribution between June 1999 and June 2000 may suggest changes in the distribution of forage species during the period of the surveys. Humpbacks migrate to Hawaii during winter; therefore, few sightings of these whales were made in the November and March surveys. Harbor seals were the most common marine mammals in all surveys and found in all parts of Glacier Bay during all surveys. Steller sea lions were sighted on all surveys indicating year-round residency in the Bay. We did note that an apparent shift in their distribution, to the north during the fall and spring surveys (possibly in association with the ice-edge) and to the south during the June surveys. Additionally, during the fall and spring surveys sea lions were seen in larger groups. One question that we could not address was whether these larger groups lead to greater probability of detection.

Comparison of our surveys to those conducted in 1991 indicated that Glacier Bay is a system undergoing change. For forage fish predators, the trend was toward increasing densities of marine birds and mammals. Perhaps that is to be expected given the increased protection given to some species, e.g. humpback whales, but suggests, in general, an increase in fish abundance within the Bay. There may also be some connection with the continuing changes in the physical environment of Glacier Bay. For example, continued recession of glaciers and changes in the terrestrial environment that either directly, thorough terrestrial habitat quality (e.g. nesting habitat), or indirectly through the effects of these changes on inputs to the marine system (e.g., runoff from rapidly developing riparian areas).

Of the marine birds, densities of black-legged kittiwakes and all gull species increased between 1991 and the 1999-2000 surveys. In fact densities of most marine birds were higher in the 1999-2000 surveys than recorded previously in 1991 (Piatt and Springer unpubl. data). Among marine mammals, humpback whale and sea otters, numbers increased dramatically between 1991 and our 1999-2000 surveys. These increases reflected the generally acknowledged increases in populations of both (previously harvested) species throughout their range.

A few species declined between 1991 and 1999-2000. Average declines were on the order of 60 % for Kittlitz's murrelets and 75 % for marbled murrelets. We cannot discount the possibility that the distribution of murrelets was more offshore in 1999-2000 than in 1991. Even so, the scales of the declines are so great that we are confident that they reflect significant changes in these populations. Given that Glacier Bay represents a

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protected area, population declines in this area are of particular concern. Although declines in both marbled and Kittlitz's murrelets have been noted across the northern Gulf of Alaska (Kendall and Agler 1998), the scale of the declines in an area thought to be a core for their populations was not anticipated.

Our surveys indicated that Harbor seals had also declined. While this is not a new finding, it corroborates the findings of Mathews and Pendleton (2000). This earlier study only used counts at specific haulout sites, leaving some doubt as to whether seal populations were declining because seals were spending more time foraging (i.e, in the water), or because they had shifted their use to unmonitored haulout sites. Agreement of our pelagic surveys with those of Mathews and Pendleton (2000) suggest that the lower number of seals at haulouts (resting) is not a result of seals spending more time in the water (foraging), and therefore likely represents real declines for this species.

Our efforts to identify a lower sampling-intensity regime for monitoring predators were only marginally successful. The first two sets of reduced transects (25 % and 35 %) did a poor job of sampling the true densities of many species. That might not be a fatal flaw if only an index was required; but the variability of this index between years also appeared to be high. In large part, this appears to be a product of variable species distributions and the low abundance of some species. When we looked at using all nearshore transects (63%) we found that while most species densities were overestimated, they were consistent for all species. This is not surprising given that the majority of species were sighted predominantly on nearshore transects. Unfortunately, we found that indices for two species of concern to the park, humpback whales and marbled murrelets, were inconsistent. Other species such as Kittlitz's and unidentified *Brachyramphus* murrelets were underestimated in the nearshore surveys as their densities declined, leading to greater variance in results. Some combination of nearshore surveys and species-specific surveys might be sufficient to develop population indices. We will continue to examine this issue.

<u>Benthic invertebrate predators</u>

Although this report focuses upon the phytoplankton, zooplankton, forage fish, trophic web and the marine birds and mammals that consume forage fish, some of the bird and mammal species observed on surveys are linked to an alternative food web. The primary alternative marine food web in Glacier Bay is supported by nearshore algae and seagrass as primary producers, benthic invertebrates such as mussels, clams, urchins, crabs, and snails as primary consumers, and several species of marine birds and mammals as top predators.

The marine birds that occur at the apex of the "nearshore food web" include the most numerous taxa, the sea ducks, represented by scoters, goldeneye, bufflehead and harlequin ducks. These species were clearly associated with nearshore areas, making little use of offshore habitats. Species such as Barrow's goldeneye, common goldeneye, and bufflehead were virtually absent during the summer months but were the numerically dominent avian taxa during the winter. Winter surveys will be necessary to adequately monitor these species that use Glacier Bay as wintering habitat.

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Sea otters are the primary mammalian predator occupying the apex of the nearshore food web. Their presence, following more than 100 years of absence, is the result of translocations to the outer coast of Glacier Bay National Park approximately 30 years ago. They became reestablished in the park around 1995 (Bodkin et al. 2001) and are rapidly recolonizing the lower Bay. Sea otters are considered a "keystone" species in the nearshore community, consuming large numbers of benthic invertebrates including clams, crabs, mussels, and urchins. As sea otters continue to recover, dramatic changes to the nearshore marine communities can be anticipated. Those changes include: increases in primary production through growth in kelps, reduced sizes and densities of larger invertebrates (such as clams, crabs, mussels, and urchins), and increases in densities of species reliant on kelps as habitat or forage. Indirect effects throughout the nearshore can be anticipated. Examples include: increased disturbance to benthic sediments as otters excavate prey, modified habitats for other species, (e.g. sandlance), and modified trophic pathways as other consumers, including octopus, river otters, and sea ducks, compete with sea otters for benthic invertebrate prey.

Because the nearshore benthic invertebrate food web is constrained by depth, substrate, and light penetration, the biological resources that occupy this web are similarly constrained. Thus efforts to monitor occupants of this trophic web will be aided by limiting efforts to the available habitats. This constraint can decrease variances in population efforts, increase power, and allow better detection of population trends. As a result, various nearshore species may provide sensitive indicators of the nearshore community and the physical and biological processes that drive populations.

Critical Habitat Areas

Fjords have traditionally provided large amounts of fish protein to the local predatory populations in Norway, Scotland, British Columbia, and Greenland. This is perhaps not surprising based on the known propensity for fjord systems to be very productive (Matthews and Heimdal, 1980). Our results over the two years of study have highlighted distinct areas within Glacier Bay -- Whidbey Passage, upper Inlets, mouths of Inlets, and outflows from salmon streams -- that are highly productive. Furthermore, our results strongly suggest spawning of key forage species (walleye pollock, capelin, slender eelblenny, and sand lance) within the Bay. These areas of concentration and spawning are likely to be vital to the function of the Glacier Bay system. Current research into the value of Glacier Bay as a Marine Reserve (USGS-BRD – Spencer Taggart) should elucidate the relative importance of these spawning and nursery areas.

Glacier Bay's local oceanographic patterns result in a patchy distribution of optimal marine pelagic fish habitat. In contrast, anadromous species usage of habitat is more easily defined. Salmon spawning streams are clearly important areas both to the terrestrial system as well as the nearshore marine system.

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Recommendations

State of Current Knowledge

Hale and Wright (1979) summarized the Glacier Bay ecosystem as it was known at the time as:

> *"Glacier Bay is not a homogeneous body of water, either in time or space. Successional processes following the most recent rapid deglaciation have resulted in the development of a gradient of biological communities of the lower bay where the ice has been gone the longest to the less diverse communities found in the upper bay. These biological differences are teamed with physical differences such as greater water clarity and more constant salinity in the lower bay. The result is a gradual transition from a complex to a more simple ecosystem structure as one moves up the bay."*

Since that time, our knowledge has grown. In this report, we have highlighted some anomalies to Hale and Wright's basic ideas, most notable of which is the extraordinary level of biomass found in close proximity to tidewater glaciers. The 3-dimensionsal spatial extent of this biomass, the driving forces (e.g. source of carbon), and the downstream dispersion of organisms and nutrients are important questions to resolve, both scientifically as well as from a resource management perspective. In conjunction with this question, it is hard to conceptually separate the locations of the black-legged kittiwake colonies at Margerie and Riggs glaciers from locally elevated productivity. However, at least the Margerie colony has suffered poor reproductive success over the last decade (Elizabeth Hooge, *Pers. Comm.*). What conditions may have favored kittiwake foraging close to their colony as opposed to the southern end of the Bay (if this was the case) is a compelling question that could dovetail with an analysis of the Tarr Inlet ecosystem.

We have provided a detailed description of some seasonal and spatial processes within the Bay from production, small schooling fish, and predator perspective. We are now able to point to "productive" areas of the Bay and those areas that are routinely used by predators. However, the goal is to tie predator locations to food. We would like to see work focused on several key predators and their prey. Humpback whales and Kittlitz's murrelets would be obvious choices due to their listed status.

Recommendations for Further Research

Euphausiids are an important food resource for whales and fish. Documenting the distribution of adults, zoea, meganauplii, and nauplii will improve the understanding of euphausiid ecology in the Bay.

Describing larval development of benthic animals that are presently undescribed would be valuable, and with the incorporation of source-sink philosophy in marine resource management would provide basic data for decisions about marine reserves.

Conducting a survey targeting crab veligers in coordination with USGS-BRD Jim Taggart's Marine Reserve program on adult movement patterns would be of wide interest, and useful for identifying the spatial range of crab dispersal.

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We suggest the continuation of zooplankton surveys, using a reduced number of stations and discrete depth sampling, particularly with further analysis of copepod species. This would allow for more detailed analysis of correlations between zooplankton and physical parameters. We would also recommend biomass analysis, which would provide a clear summary of the variations in secondary productivity around the Bay, and allow comparison too many other systems. We would recommend extending the sampling season.

Further work should be initiated to describe the spatial extent and processes that drive the extraordinary levels of productivity at tidewater glacier fronts.

Further work should be initiated to establish connections between nutrient input from adult salmon to nearshore streams and the marine interface. The value of salmon derived nutrients to nearshore marine systems in development of peri-glacial marine communities is of great interest. Furthermore, this research would provide a valuable nexus between salmon studies being conducted by Sandy Milner and Chad Soiseth in freshwater systems and State of Alaska research in the marine system.

The rapid declines, as well as the potentially related increases of specific Apex predators suggest that the Glacier Bay ecosystem continues to undergo change; however, the specific causes for these declines are unknown and may be varied. Given the rapid decline in murrelets and the steady decline of harbor seals, a better understanding of the factors influencing these species will be necessary before any measures can be taken to mitigate these changes.

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Appendices

Appendix 1. Sample site locations throughout Glacier Bay.

Sample Type	Station	Location	Longitude	Latitude	Region
Beach Seine	BS01	North Side Bartlett Cove	-135.90	58.47	Lower Bay
Beach Seine	BS02	Southwestern beach on Young Island	-135.99	58.47	Lower Bay
Beach Seine	BS03	First Beach North of BS02	-135.99	58.47	Lower Bay
Beach Seine	BS04	Second Beach North of BS02	-136.00	58.47	Lower Bay
Beach Seine	BS05	Northwestern Beach on Young Island	-136.00	58.48	Lower Bay
Beach Seine	BS06	Ripple Cove	-136.09	58.45	Lower Bay
Beach Seine	BS07	South Side of Berg Bay	-136.18	58.51	Lower Bay
Beach Seine	BS08	Northern Entrance to South Fingers Bay	-136.20	58.58	Middle Bay
Beach Seine	BS09	Northwestern Corner of South Fingers Bay	-136.21	58.58	Middle Bay
Beach Seine	BS10	West of Southern Tip of Drake at base of Marble Mountain	-136.25	58.63	Middle Bay
Beach Seine	BS11	Southern Beardslee Islands	-135.90	58.50	Lower Bay
Beach Seine	BS12	Eider Island in Beardslee Islands	-135.93	58.51	Lower Bay
Beach Seine	BS13	East side of Link Island in Beardslee Islands	-135.89	58.56	Lower Bay
Beach Seine	BS14	Northern Beardslee Islands	-135.92	58.57	Lower Bay
Beach Seine	BS15	Flapjack Island (South side)	-135.98	58.59	Lower Bay
Beach Seine	BS16	West of Island on North Shore of Bear Track Cove	-135.87	58.60	Middle Bay
Beach Seine	BS17	Beach on south side of broad promentory north of Bear Track	-135.91	58.63	Middle Bay
Beach Seine	BS18	York Creek	-135.92	58.64	Middle Bay
Beach Seine	BS19	North side of Spokane Cove	-135.97	58.70	Middle Bay
Beach Seine	BS20	Mount Wright drop-off	-136.05	58.79	Middle Bay
Beach Seine	BS21	Mid-channel island in Geike Inlet	-136.38	58.64	Middle Bay
Beach Seine	BS22	Southeastern corner of Geike Inlet	-136.48	58.59	Middle Bay
Beach Seine	BS23	Southwest beach of Geike	-136.51	58.59	Middle Bay

Appendix 1. Continued.

Sample Type	Station	Location	Longitude	Latitude	Region
Beach Seine	BS24	Northwestern beach at head of Geike Inlet	-136.52	58.61	Middle Bay
Beach Seine	BS25	Immediately south of Sealers Island	-136.10	58.95	East Arm
Beach Seine	BS26	Immediately north of Sealers Island	-136.12	58.97	East Arm
Beach Seine	BS27	South of McBride entrance	-136.12	59.02	East Arm
Beach Seine	BS28	Just north of entrance to McBride	-136.15	59.04	East Arm
Beach Seine	BS29	Camping beach north of McBride entrance	-136.16	59.04	East Arm
Beach Seine	BS30	Northeastern corner of Muir Inlet	-136.19	59.07	East Arm
Beach Seine	BS31	Mid-way into Wachusett Inlet on North Side	-136.35	58.95	East Arm
Beach Seine	BS32	Outwash flats of Wachusett Glacier	-136.42	58.99	East Arm
Beach Seine	BS33	Directly opposite Maquinna Cove on west of Muir Inlet	-136.11	58.86	East Arm
Beach Seine	BS34	On outwash of Morse Creek	-136.12	58.84	East Arm
Beach Seine	BS35	Muir Point	-136.09	58.82	Middle Bay
Beach Seine	BS36	Beach nestled into south side of Gloomy Knob	-136.46	58.83	Middle Bay
Beach Seine	BS37	Northwestern corner of Queen Inlet	-136.56	58.96	West Arm
Beach Seine	BS38	Western side of Queen Inlet	-136.58	58.94	West Arm
Beach Seine	BS39	Head of Rendu Inlet	-136.72	59.01	West Arm
Beach Seine	BS40	Northwestern Rendu. Beach to north of largest aluvial fan	-136.70	58.99	West Arm
Beach Seine	BS41	Old Queen drop-off site east of Composite Island	-136.51	58.88	West Arm
Beach Seine	BS42	Gloomy knob by Vivid Lake outlet	-136.50	58.85	West Arm
Beach Seine	BS43	Northeastern corner of Reid Inlet	-136.81	58.87	West Arm
Beach Seine	BS44	Mid-eastern side of Reid Inlet	-136.80	58.86	West Arm
Beach Seine	BS45	Southeastern Corner of Reid Inlet	-136.81	58.85	West Arm
Beach Seine	BS46	Large beach east of Lamplugh Glacier	-136.89	58.89	West Arm

Appendix 1. Continued

Sample Type	Station	Location	Longitude	Latitude	Region
Beach Seine	BS47	Northeastern corner of Tarr by outlet (difficult seine)	-137.04	59.06	West Arm
Beach Seine	BS48	Large outwash fan on east side of Tarr Inlet	-136.94	59.00	West Arm
Beach Seine	BS49	Southeastern corner of Tarr before entering Russel Passage	-136.86	58.96	West Arm
Beach Seine	BS50	Southeastern Scidmore Bay	-136.56	58.77	Middle Bay
Beach Seine	BS51	Northern point in Scidmore Bay	-136.65	58.82	Middle Bay
Beach Seine	BS52	Southwestern point of Strawberry Island	-136.02	58.51	Lower Bay
Beach Seine	BS53	Just south of Ripple Cove	-136.07	58.43	Lower Bay
Beach Seine	BS54	Inside lagoon at Point Carolus	-136.04	58.38	Lower Bay
Beach Seine	BS55	West of broad headland between Carolus and Pt. Dundas	-136.14	58.34	Lower Bay
Beach Seine	BS56	Point Gustavus	-135.92	58.38	Lower Bay
Beach Seine	BS57	On outside of Point Corolus (seineable at low tide only)	-136.04	58.37	Lower Bay
Beach Seine	BS58	North side of Lemesurier Island	-136.10	58.30	Lower Bay
Beach Seine	BS59	Head of Mud Bay	-135.98	58.19	Lower Bay
Beach Seine	BS61	Point Adolphus	-135.83	58.27	Lower Bay
Beach Seine	BS62	West side of Pleasant Island	-135.71	58.36	Icy Strait
Beach Seine	BS63	Southwestern Reid Inlet	-136.82	58.85	West Arm
Beach Seine	BS64	Northwestern Reid Inlet	-136.82	58.87	West Arm
Nearshore Zooplankton	Z02	Young Island	-136.00	58.47	Lower Bay
Nearshore Zooplankton	Z06	Ripple Cove	-136.07	58.45	Lower Bay
Nearshore Zooplankton	Z09	Fingers Bay	-136.20	58.58	Middle Bay
Nearshore Zooplankton	Z10	Whidbey Passage	-136.25	58.63	Middle Bay
Nearshore Zooplankton	Z16	Beartrack Cove	-135.88	58.60	Middle Bay
Nearshore Zooplankton	Z20	Geikie Inlet	-136.05	58.78	Middle Bay
Nearshore Zooplankton	Z24	Mt. Wright	-136.51	58.60	Middle Bay
Nearshore Zooplankton	Z25	Sealers Island	-136.10	58.95	East Arm
Nearshore Zooplankton	Z30	Riggs Glacier	-136.19	59.07	East Arm
Nearshore Zooplankton	Z36	Gloomy Knob	-136.45	58.83	Middle Bay
Nearshore Zooplankton	Z37	Queen Inlet	-136.55	58.96	West Arm
Nearshore Zooplankton	Z40	Rendu Inlet	-136.70	58.99	West Arm
Nearshore Zooplankton	Z45	Reid Inlet	-136.81	58.85	West Arm

Appendix 1. Continued

Sample Type	Station	Location	Longitude	Latitude	Region
Nearshore Zooplankton	Z47	Tarr Inlet	-136.99	59.03	West Arm
Nearshore Zooplankton	Z49	N. of Russel Island	-136.87	58.96	West Arm
Nearshore Zooplankton	Z55	North Passage	-136.13	58.34	Lower Bay
Nearshore Zooplankton	Z62	Pleasant Island	-135.73	58.36	Icy Strait
Non-Routine Sample	Random	Various Locations			Random
Pelagic	STN00	Icy Strait, Mouth of Glacier Bay	-135.87	58.33	Lower Bay
Pelagic	STN01	Mouth Glacier Bay	-135.99	58.41	Lower Bay
Pelagic	STN02	Sitakaday	-136.05	58.49	Lower Bay
Pelagic	STN03	SE of Willoughby Island	-136.06	58.57	Middle Bay
Pelagic	STN04	N of Drake I and N of Marble I.	-136.11	58.65	Middle Bay
Pelagic	STN05	Between N Drake and SW Tlingit PT	-136.23	58.70	Middle Bay
Pelagic	STN06	E of Hugh Miller Inlet	-136.35	58.76	Middle Bay
Pelagic	STN07	N of Blue Mouse, W of Tidal Inlet	-136.47	58.81	Middle Bay
Pelagic	STN08	S of Rendu Inlet	-136.59	58.87	West Arm
Pelagic	STN09	S of Russell Island	-136.73	58.90	West Arm
Pelagic	STN10	E of Russell Island	-136.84	58.90	West Arm
Pelagic	STN11	Tarr Inlet	-136.91	58.97	West Arm
Pelagic	STN12	Head of Tarr Inlet	-137.02	59.03	West Arm
Pelagic	STN13	SE of Tlingit PT, NW of Sturgess	-136.11	58.73	Middle Bay
Pelagic	STN14	Muir sill	-136.11	58.79	Middle Bay
Pelagic	STN15	W of Muir PT	-136.10	58.82	Middle Bay
Pelagic	STN16	E of Hunter Cove	-136.09	58.90	East Arm
Pelagic	STN17	E of Westdahl Pt	-136.13	58.98	East Arm
Pelagic	STN18	S of Riggs, NW of McBride	-136.18	59.05	East Arm
Pelagic	STN19	Muir Inlet	-136.33	59.07	East Arm
Pelagic	STN20	Head of Muir Inlet	-136.37	59.09	East Arm
Pelagic	STN21	Marjorie/Grand Pacific	-137.06	59.05	West Arm
Pelagic	STN22	Entrance to Geikie	-136.36	58.66	Middle Bay
Pelagic	STN23	Head of Geikie	-136.50	58.60	Middle Bay
Pelagic	STN24	Johns Hopkins	-137.06	58.88	West Arm
Pelagic	STN25	Tidal Inlet	-136.32	58.82	Middle Bay
Pelagic	STN26	Rendu Inlet	-136.68	58.98	West Arm
Pelagic	STN27	Queen Inlet	-136.55	58.93	West Arm
Pelagic	STN28	Wachusetts Inlet	-136.39	58.98	West Arm

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Appendix 2: Phylogeny of zooplankton taxa-lifestage groupings used.

Phylum *Arthropoda* Crustacian (nauplii) Unidentified (nauplii) Class *Branchiopoda* Order *Cladocera* *Evadne* *Podon* Class *Cirripedia* Order *Thoracica* *Balanus* (cypris larvae) *Balanus* (nauplii) Class *Copepoda* Orders *Calanoid* and *Cyclopoid* Calanoid/cyclopoid (small) Calanoid (large) Parasitic copepod Class *Harpacticoida* Harpacticoid Order *Siphonostomatid* *Siphonostomatid* Class *Malacostraca* Order *Amphipoda* Amphipod *Cyphocaris chalengeri* *Hyperiid* *Hyperiid* (larvae) Order *Decapoda* *Brachyuran* (larvae) Decapod (larvae) Decapod (megalop) Order *Euphausiacea* *Euphausiid* (metanauplii) *Euphausiid* (nauplii) *Euphausiid* (zoea) Order *Isopoda* *Cryptoniscid* (larvae) Isopod Parasitic Isopod Class *Ostracoda* Order *Halocyprida* *Concoecia elegans*	Phylum *Annelida* Annelid (larvae) Annelid Phylum Bryozoa *Bryozoan* (cyphonautes larvae) Phylum *Chaetognatha* Class *Sagittoidea* Order *Aphragmophora* *Sagitta elegans* Phylum *Cnidaria* *Cnidarian* (juvenile) Medusae Class Hydrozoa Order *Siphonophora* Siphonophore Phylum *Ctenophora* *Ctenophora* Phylum *Echinodermata* Echinoderm (juvenile) Echinoderm (larvae) Class *Asteroidea* *Asteroida* (larvae) *Asteroida* (juvenile) Class *Holothuroidea* *Holothuroidea* (auricularia larvae) Phylum *Mollusca* Class *Bivalvia* Bivalve (veliger) Class *Gastropoda* Gastropod (veliger) Phylum *Nematoda* *Nematoda* Phylum *Phoronida* *Phoronida* (juvenile) *Phoronida* (actinotroch larvae) Phylum *Urochordata* Class *Larvacea* *Oikopleura* spp.

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Appendix 3: Calanoid copepod species.

Centropages abdominalis	*Neocalanus cristatus*
Acartia clausi	*Neocalanus plumchris*
Acartia longiremis	*Euchaeta elongata*
Tortanus discaudatus	*Epilabidocera longipedata*
Eurytemora affinis	*Metridia pacifica*
Lucicutia flavicornis	*Metridia ohkotensis*
Calanus marshallae	*Metridia lucens*
Calanus pacificus	*Pseudocalanus spp.*

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Appendix 4: Protocol for Echointegration of .dt4 files.

1) You must ensure that all files are named in such a way that, when listed in alphanumeric order, they will also be ordered in time. This is critical.

2) To begin working in Echoview, you must make a new .ev file. To make a new .ev file: go to **File**, **New**
open Transceiver 1 as the template
go to **Data**, **Add Files**
Go to the location of the files you want to analyze, select them using the shift/control keys, and hit **Open**.

3) To see the echogram, go to **View**, **Echogram**.

4) To customize analysis options, go to **View**, **Options** or click on the icon of a hand pointing to a sheet of paper.

5) Choose the **Echogram** tab, and set the following parameters:
Change Lower Display Depth to the deepest depth of the entire .ev file (200 m)
Set the minimum Sv (–90 dB for Glacier Bay)
Set the grid limits. For Glacier Bay:
For time/distance, choose Ping Number and set it to 60
For depth, choose Relative to Surface and set it to 5 meters

6) To set the constants under the **Constants** tab, you must first use another menu. Close and save the Properties settings by clicking **Okay**. Then go to **Help**, **Sonar Calculator**.
Make sure the seawater box is checked
Enter the Temperature in °C (10° C for Glacier Bay)
Enter the Salinity in ppt (32 ppt for Glacier Bay)
Enter the frequency of the system (120 kHz)
Hit **Calculate**, and then copy the speed of sound in water (MacKenzie) and the absorption coefficient. Close the **Sonar Calculator** and return to the **View Options** menu, and choose the **Constants** tab.
Enter the speed of sound (1478.64 m/sec)
Enter the absorption coefficient (0.0336230 dB/m)
Enter the frequency as 120 kHz (book-keeping)

7) Still in the Properties menu system, choose the **Integration** tab.
Check Exclude below bottom, and keep the 0 offset
Check Apply minimum Sv threshold
Check Apply maximum Sv threshold

· **Appendix 4. Continued**.

8) Still in the Properties menu system, choose the **Export** tab.
Select the spreadsheet format
Select all of the following:

Sv mean
Sa mean
Sv max
Sv min
Samples
LDepth_U
LDepth_L
Ping_S
Dist_S
Date_S
Time_S
Lat_S
Lon_S
Depth_int
Program_version
Num_layers
Num_intervals
Min_depth
Max_depth
Processing_date
EV_filename
Alpha
Gain_constant
Noise_power
Minimum_Sv_threshold_applied
Minimum_integration_threshold
Maximum_Sv_threshold_applied
Maximum_integration_threshold
Surface_excluded
Surface_exclusion_depth
Below_bottom_excluded
Bottom_offset

9) To bottom track, first select the entire .ev file using the horizontal band tool.
Right mouse click on the echogram, and a menu will pop up.
Select **Pick Bottom**
Wait until it finishes
Right mouse click again on the echogram, and select **Move Bottom Line**
Move the line –3 meters, which will move it 3 meters above the bottom. It should be above the visible bottom at all times. Check carefully where the bottom is steep, or has a thick sediment layer. You will need to painstakingly scroll along the entire .ev file, and should zoom in to a smaller area (such as 300 pings by 30 meters) to see well. To edit the bottom line, use the line draw tool to draw the bottom where you like by clicking along the line you want to draw. Then right mouse click and choose **Define Bottom**. All bottom drawn by hand will automatically be labeled "good" and have a green color. Be careful in places where fish are schooled along the bottom.

After the entire bottom is edited, use the horizontal band tool to select the entire .ev file, and right mouse click. Choose **Set Bottom**, **Good**. The entire bottom tracking line should be green.

10) In order to get an output that labels each transect by name, you must select each transect and define it as a region. Each transect can have more than one region, as long as each is named the same, i.e., uses the same transect name (for example, 45 or 87). Each region must begin at the line that forms the left-hand side (earliest side) of an interval. This is because we are using start time and position to define each interval.

· **Appendix 4. Continued**.

Transects are broken into smaller parts according to the classification of the bottom. We defined 3 categories:

A) good bottom
B) unknown bottom
C) bottom >160 m

Define a region using the vertical band tool, starting from the left and scrolling to the right using the right arrow key and holding the mouse button down until you reach the end of the region.

Right mouse click on the region, and select **Define Region**
Erase the label; type in the transect number
Type will remain integration
For classification, choose **Edit**, **Add**, and then add the types you wish to classify (good, unknown, >160m). Make sure you leave Bad Data as an option.
Then choose one of the 3 types from the classification menu

Scroll through the entire .ev file, naming regions and classifying them. The left side must begin where an interval begins, but the right side can end in the middle of an interval. Be sure to check both sides of a region by scrolling to look, and zooming in if necessary—the lines tend to wander. Each transect may contain multiple sub-regions, all labeled with the same transect name (number) but with different bottom classifications.

11) To define Bad Data Regions, circle or enclose the affected area. Bad data regions can be of any shape or size. A variety of tools exists that draw in different ways. Once a bad data region is outlined, right mouse click, choose **Define Region**, and select the classification of Bad Data. The label does not matter and using the default will just result in regions numbered consecutively.

12) Finally, after the parameters are defined, the bottom is edited, the transects are labeled and the regions classified, you are ready to echointegrate.
go to **Data**, **Export**, **Integrate Regions by Cells**
name the output and choose the destination
choose **All Classifications** (the default) and hit okay
after 20-30 minutes or less, your output(s) will show up in the directory you indicated above

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Appendix 5: Materials Used to Design and Conduct Predator Surveys

Protocols

Gould, P. J., and D. J. Forsell. 1989. Techniques for shipboard surveys of marine birds. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC. Fish and Wildlife Technical Report 25. 22pp.

Gould, P. J., D. J. Forsell, and C. J. Lensink. 1982. Pelagic distribution and abundance of seabirds in the Gulf of Alaska and eastern Bering Sea. U.S. Department of the Interior, Fish and Wildlife Service, Biological Services Program, OBS 82/48. 294pp.

Tips for Bird Surveys/Bird Identifications/Observsation Conditions/Sea Conditions.

DLOG Data entry and real-time mapping program overview (Need Ref information)

Marine Biodiversity Monitoring, protocol for monitoring seabirds. Diamond.
http://www.cciw.ca/eman-temp/research/protocols/seabirds/intro.html

Species Identifications

Field Identification of Kittlitz's Murrelet, John Piatt.
http://www.absc.usgs.gov/research/seabird&foragefish/index.html
Field guide to the birds of north america. nat'l geographic society
Peter Harrison (1983) Seabirds: An Identification Guide
Peter Harrison (1997) Seabirds of the World: A Photographic Guide.

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Appendix 6: Conceptual Model of Glacier Bay Oceanography

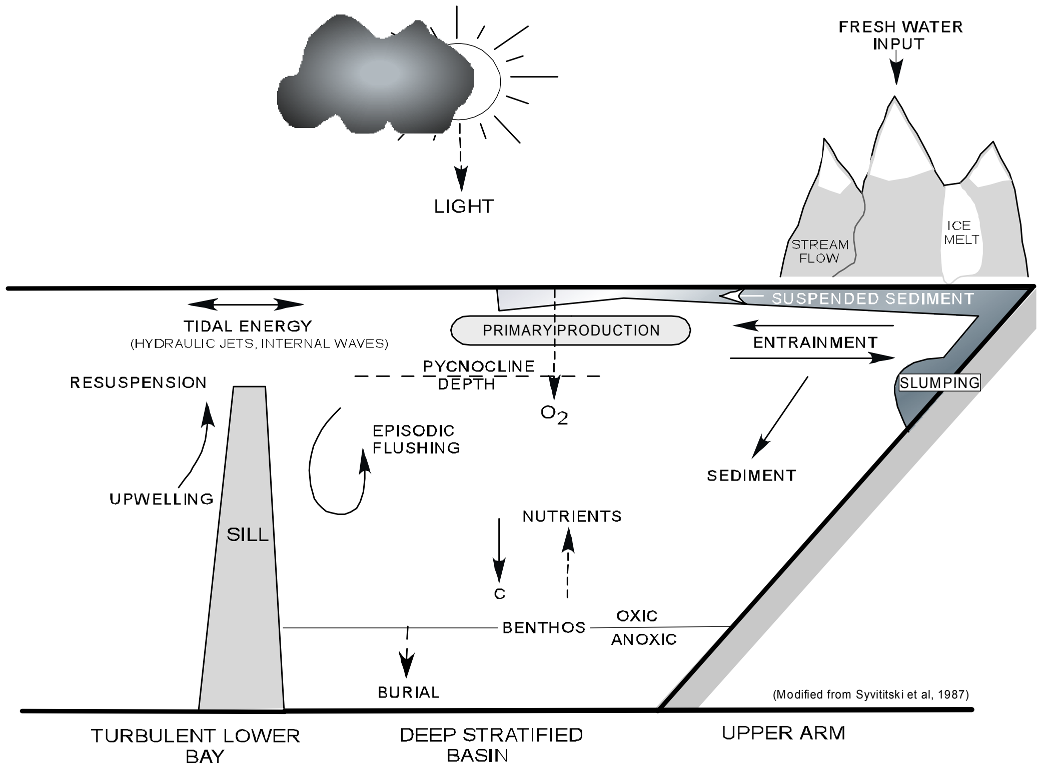

Figure 92. Conceptual model for the major processes influencing the oceanography of Glacier Bay. The model depicts the three different oceanographic regimes hypothesized by the results of Hooge and Hooge (2002). This figure is based on one in Syvitski et al. (1987).

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Appendix 7: Fish Larvae and Eggs Observed in Zooplankton Sampling.

Fish eggs
STN00 March
STN06 May
West Arm EOIN* June
Z9 June
Z10 June
Z20 June
Z24 June
Z36 June
Z37 June
Z45 June
Z49 June
Z55 August

Unidentified fish larvae
STN00 March May
STN16 March
STN06 May
West Arm EOIN* June
Z02 June
Z24 June
Z49 June

Capelin larvae
Z45 June

Unidentified fish alevin
Z02 June

*EOI- Edge of sheet ice, N-neashore, M-mid-channel

.

Appendix 8: Fish Species List.

Common Name	Latin Name
Pacific Herring	*Clupea pallasi*
Pink Salmon	*Oncorhynchus gorbuscha*
Chum Salmon	*Oncorhynchus keta*
Chinook Salmon	*Oncorhynchus tshawytscha*
Coho Salmon	*Oncorhynchus kisutch*
Sockeye Salmon	*Oncorhynchus nerka*
Dolly Varden	*Salvelinus malma*
Cutthroat Trout	*Salmo clarki*
Pacific Hake	*Merluccius productus*
Walleye Pollock	*Theragra chalcogramma*
Pacific Cod	*Gadus macrocephalus*
Capelin	*Mallotus villosus*
Northern Lampfish	*Stenobrachius leucopsarus*
Northern Smoothtongue	*Leuroglossus schmidii*
Unidentified Ronquil	*Bathymaster Spp.*
High Cockscomb	*Anoplarchus purpurescens*
Crescent Gunnel	*Pholis laeta*
Penpoint Gunnel	*Apodichthys flavidus*
Unidentified Gunnel	*Pholidae Spp.*
Arctic Shanny	*Stichaeus punctatus*
Slender Eelblenny	*Lumpenus fabricii*
Longsnout Prickleback	*Lumpenella longirostris*
Unidentified Prickleback	*Stichaeidae Spp.*
Wolf-Eel	*Anarrhichthys ocellatus*
Pacific Sandfish	*Trichodon trichodon*
Pacific Sand Lance	*Ammodytes hexapterus*
Rockfish Spp.	*Sebastes Spp.*
Lingcod	*Ophiodon elongatus*
Kelp Greenling	*Hexagrammos decagrammus*
Rock Greenling	*Hexagrammos lagocephalus*
Masked Greenling	*Hexagrammos octogrammus*
Whitespotted Greenling	*Hexagrammos stelleri*
Unidentified Greenling	*Hexagrammidae Spp.*
Unidentified Snailfish	*Cyclopteridae*
Unidentified Liparid (snailfish)	*Liparis Spp.*
Slipskin Snailfish	*Liparis fucensis*
Ribbon Snailfish	*Liparis cyclopus*
Pacific Spiny Lumpsucker	*Eumicrotremus orbis*

Appendix 8. Continued

Common Name	Latin Name
Smooth Lumpsucker	*Aptocyclus ventricosus*
3-spine stickleback	*Gasterosteus aculeatus*
Northern Sculpin	*Icelinus borealis*
Great Sculpin	*Myoxocephalus polyacanthocephalus*
Warty Sculpin	*Myoxocephalus verrucosus*
Buffalo Sculpin	*Enophrys bison*
Silverspotted Sculpin	*Blepsias cirrhosus*
Tadpole Sculpin	*Psychrolutes paradoxus*
Armorhead Sculpin	*Gymnocanthus galeatus*
Pacific Staghorn Sculpin	*Leptocottus armatus*
Brown Irish Lord	*Hemilepidotus spinosus*
Shaggy Sea Raven	*Hemitripterus villosus*
Sailfin Sculpin	*Nautichthys oculofasciatus*
Blackfin Sculpin	*Malacocottus kincaidi*
Unidentified Sculpin	*Cottidae Spp.*
Sturgeon Poacher	*Podothecus acipenserinus*
Bathyagonus Spp.	*Bathyagonus Spp.*
Unidentified Poacher	*Agonidae Spp.*
Rock Sole	*Pleuronectes bilineatus*
Butter Sole	*Pleuronectes isolepis*
English Sole	*Pleuronectes vetulus*
Curlfin Sole	*Pleuronichthys decurrens*
Pacific Halibut	*Hippoglossus stenolepis*
Starry Flounder	*Platichthys stellatus*
Unidentified Righteye Flounder	*Pleuronectidae Spp.*
Unidentified Juvenile Flatfish	*Pleuronectes Spp.*
Squid	
Octopus	
Pandalus eos (Shrimp)	*Pandalus eos*
Pasiphaea pacifica (Shrimp)	*Pasiphaea pacifica*
Neomysis rayii (Shrimp)	*Neomysis rayii*
Pandalid Shrimp	*Pandalus Spp.*
Euphausiid	
Jellyfish	

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Appendix 9: Predator Survey Species List.

SPECIES	LATIN NAME	GROUP	FUNC. GROUP	Species Code
Aleutian Tern	*Sterna aleutica*	Tern	Fish-feeder	ALTE
American Robin	*Turdus migratorius*	Terrestrial Bird	Other	AMRO
American Wigeon	*Anas americana*	Duck	Veg.-feeder	AMWI
Ancient Murrelet	*Synthliboramphus antiquus*	Alcid	Plankton-feeder	ANMU
Arctic Tern	*Sterna paradisaea*	Tern	Fish-feeder	ARTE
Bald Eagle	*Haliaeetus leucocephalus*	Raptor	Other	BAEA
Barrow's Goldeneye	*Bucephala islandica*	Duck	Invert-feeder	BAGO
Barn Swallow	*Hirundo rustica*	Terrestrial Bird	Insect-Feeder	BASW
Black-billed Magpie	*Pica pica*	Terrestrial Bird	Other	BBMA
Belted Kingfisher	*Ceryle alcyon*	Terrestrial Bird	Fish-feeder	BEKI
Black Bear	*Ursus americanus*	Terrestrial Mammal	Other	BLBE
Black-Legged Kittiwake	*Rissa tridactyla*	Gull	Invert-feeder	BLKI
Black Oystercatcher	*Haematopus bachmani*	Shorebird	T idal Feeder	BLOY
Black Scoter	*Melanitta nigra*	Duck	Invert-feeder	BLSC
Black Turnstone	*Arenaria melanocephala*	Shorebird	T idal Feeder	BLTU
Bonaparte's Gull	*Larus philadelphia*	Gull	Invert. Feeder	BOGU
Brant	*Branta bernicla*	Goose	Veg.-feeder	BRAN
Brown Bear	*Ursus arctos*	Terrestrial Mammal	Other	BRBE
Brachyramphus Murrelet	*Brachyramphus spp.*	Alcid	Fish-feeder	BRMU
Bufflehead	*Bucephala albeola*	Duck	Invert-feeder	BUFF
Canada Goose	*Branta candensis*	Goose	Veg.-feeder	CAGO
Canada Jay (Gray Jay)	*Perisoreus canadensis*	Terrestrial Bird	Other	CAJA
Caspian Tern	*Sterna caspia*	Tern	Fish-feeder	CATE
Cliff Swallow	*Hirundo pyrrhonota*	Terrestrial Bird	Insect-Feeder	CLSW
Common Goldeneye	*Bucephala clangula*	Duck	Invert-feeder	COGO
Common Loon	*Gavia immer*	Loon	Fish-feeder	COLO
Common Merganser	*Mergus merganser*	Duck	Fish-feeder	COME
Common Murre	*Uria aalge*	Alcid	Fish-feeder	COMU
Common Raven	*Corvus corax*	Terrestrial Bird	Other	CORA
Dall's Porpoise	*Phocoenoides dalli*	Marine Mammal	Fish-feeder	DAPO
Double-crested Cormorant	*Phalacrocorax auritus*	Cormorant	Fish-feeder	DCCO
Fork-tailed Storm Petrel	*Oceanodroma furcata*	Tubenose	Plankton-feeder	FTSP
Gadwall	*Anas strepera*	Duck	Veg.-feeder	GADW
Great Blue Heron	*Ardea herodias*	Shorebird	T idal Feeder	GBHE
Golden Eagle	*Aquila chrysaetos*	Raptor	Other	GOEA
Grey Wolf	*Canis lupus*	Terrestrial Mammal	Other	GRWO
Greater Scaup	*Aythya marila*	Duck	Invert-feeder	GRSC
Glaucous-winged Gull	*Larus glaucescens*	Gull	Fish-feeder	GWGU
Green-winged Teal	*Anas crecca*	Duck	Veg.-feeder	GWTE
Harlequin Duck	*Histrionicus histrionicus*	Duck	Invert-feeder	HADU
Harbor Porpoise	*Phocoena phocoena*	Marine Mammal	Fish-feeder	HAPO
Harbor Seal	*Phoca vitulina*	Marine Mammal	Fish-feeder	HASE
Herring Gull	*Larus argentatus*	Gull	Fish-feeder	HEGU
Horned Grebe	*Podiceps auritus*	Grebe	Fish-feeder	HOGR
Humpback Whale	*Megaptera novaeangliae*	Marine Mammal	Fish-feeder	HUWH
Kittlitz's Murrelet	*Brachyramphus brevirostris*	Alcid	Fish-feeder	KIMU
Killer Whale	*Orcinus orca*	Marine Mammal	Fish-feeder	KIWH
Marbled Murrelet	*Brachyramphus marmoratus*	Alcid	Fish-feeder	MAMU
Mew Gull	*Laurs canus*	Gull	Fish-feeder	MEGU
American Mink	*Mustela vison*	Terrestrial Mammal	Other	MINK
Mallard	*Anas platyrhynchos*	Duck	Veg.-feeder	MALL
Minke Whale	*Balaenoptera acutorostrata*	Marine Mammal	Fish-feeder	MIWH
Mountain Goat	*Oreamnos americanus*	Terrestrial Mammal	Other	MOGO

Appendix 9. Continued

SPECIES	LATIN NAME	GROUP	FUNC. GROUP	Species Code
Moose	*Alces alces*	Terrestrial Mammal	Other	MOOS
Northwestern Crow	*Corus caurinus*	Terrestrial Bird	Other	NOCR
Northern Pintail	*Anas acuta*	Duck	Veg.-feeder	NOPI
Northern Shoveler	*Anas clypeata*	Duck	Veg.-feeder	NOSH
Long-tailed Duck	*Clangula hyemalis*	Duck	Invert-feeder	OLDS
Parasitic Jaeger	*Stercorarius parasiticus*	Jaeger	Fish-feeder	PAJA
Pacific Loon	*Gavia pacifica*	Loon	Fish-feeder	PALO
Pelagic Cormorant	*Phalacrocorax pelagicus*	Cormorant	Fish-feeder	PECO
Pigeon Guillemot	*Cepphus columba*	Alcid	Fish-feeder	PIGU
Red-breasted Merganser	*Mergus serrator*	Duck	Fish-feeder	RBME
Red-faced Cormorant	*Phalacrocorax urile*	Cormorant	Fish-feeder	RFCO
River Otter	*Lutra canadensis*	Terrestrial Mammal	Other	RIOT
Red-necked Grebe	*Podiceps grisegena*	Grebe	Fish-feeder	RNGR
Red-necked Phalarope	*Phalaropus lobatus*	Phalarope	Plankton-feeder	RNPH
Red-throated Loon	*Gavia stellata*	Loon	Fish-feeder	RTLO
Scaup	*Aythya spp.*	Duck	Invert-feeder	SCAU
Sea Otter	*Enhydra lutris*	Marine Mammal	Invert-feeder	SEOT
Spotted Sandpiper	*Actitis macularia*	Shorebird	T idal Feeder	SPSA
Stellar's Jay	*Cyanocitta stelleri*	Terrestrial Bird	Other	STJA
Stellar's Sea Lion	*Eumetopias jubatus*	Marine Mammal	Fish-feeder	STSL
Surfbird	*Aphriza virgata*	Shorebird	T idal Feeder	SURF
Surf Scoter	*Melanitta perspicillata*	Duck	Invert-feeder	SUSC
Tufted Puffin	*Fratercula cirrhata*	Alcid	Fish-feeder	TUPU
Unidentified Alcid	*Alcidae spp.*	Alcid	Unknown	UNAC
Unidentified Albatross	*Phoebastria spp.*	Tubenose	Squid-feeder	UNAL
Unidentified Cormorant	*Phalacrocorax spp.*	Cormorant	Fish-feeder	UNCO
Unidentified Duck	*Anas spp.*	Duck	Unknown	UNDU
Unidentified Eagle	*Haliaeetus spp.*	Raptor	Other	UNEA
Unidentified Goldeneye	*Bucephala spp.*	Duck	Invert-feeder	UNGO
Unidentified Grebe	*Podiceps spp.*	Grebe	Fish-feeder	UNGR
Unidentified Gull	*Larus spp.*	Gull	Fish-feeder	UNGU
Unidentified Jaeger	*Stercorarius spp.*	Jaeger	Fish-feeder	UNJA
Unidentified Large Larid	*Larid spp.*	Gull	Fish-feeder	UNLL
Unidentified Loon	*Gavia spp.*	Loon	Fish-feeder	UNLO
Unidentified Merganser	*Mergus spp.*	Duck	Fish-feeder	UNME
Unidentified Phalarope	*Phalaropus spp.*	Phalarope	Plankton-feeder	UNPH
Unidentified Raptor	*Accipitridae spp.*	Raptor	Other	UNRA
Unidentified Shorebird	*shorebird spp.*	Shorebird	Tidal Feeder	UNSB
Unidentified Scoter	*Melanitta spp.*	Duck	Invert-feeder	UNSC
Unidentified Swan	*Cygnus spp.*	Goose	Veg.-feeder	UNSN
Unidentified Storm Petrel	*Oceanodroma spp.*	Tubenose	Plankton-feeder	UNSP
Unidentified Swallow	*Hirundinidae spp.*	Terrestrial Bird	Insect-Feeder	UNSW
Unidentified Tern	*Sterna spp.*	Tern	Fish-feeder	UNTE
Unidentified Teal	*Teal spp.*	Duck	Veg.-feeder	UNTL
Unidentified Whale	*Baleen Whale spp.*	Marine Mammal	Unknown	UNWH
Western Grebe	*Aechmophorus occidentalis*	Grebe	Fish-feeder	WEGR
Western Screech Owl	*Otus kennicottii*	Terrestrial Bird	Other	WSOW
White-winged Scoter	*Melanitta fusca*	Duck	Invert-feeder	WWSC
Yellow-billed Loon	*Gavia adamsii*	Loon	Fish-feeder	YBLO