Distribution of Forage Fishes in Relation to the Oceanography of Glacier Bay National Park

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Abstract. Glacier Bay National Park is marked by complex oceanographic processes that influence the distribution and abundance of midwater-schooling forage fishes. We sampled marine waters in the park between 1999 and 2004 to characterize marine predator and forage fish resources and to census marine and estuarine fishes. Marine habitat was analyzed using advanced very high resolution radiometer satellite imagery as well as conductivity-temperature-depth (CTD) profiles that detail the oceanographic regimes within the park. The distribution and abundance of walleye pollock, capelin, Pacific sandlance, pink salmon, Pacific herring and northern lampfish relative to habitat parameters such as water column salinity, temperature and chlorophyll-*a* were examined using ANOVA. Walleye pollock and capelin occurred in cooler areas with lower chlorophyll-*a* levels, while pink salmon, Pacific sandlance and Pacific herring occurred in warmer areas with higher chlorophyll-*a* levels.

Introduction

Forage fishes are abundant schooling fish that provide an important trophic link between primary and secondary producers and marine predators (Springer and Speckman, 1997). In Glacier Bay, forage fishes support several marine predator species of management concern including humpback whales, Steller sea lions, harbor seals, Kittlitz's Murrelets and Pacific halibut.

This paper outlines analyses of midwater trawl and oceanography data collected between 1999 and 2004. Advanced very high resolution radiometer (AVHRR) imagery is used to elucidate general oceanographic patterns in Glacier Bay. We describe the pelagic distribution of the most abundant forage fish species including walleye pollock (*Theragra chalcogramma*), capelin (*Mallotus villosus*), Pacific sandlance (*Ammodytes hexapterus*), pink salmon (*Oncorhynchus gorbuscha*), Pacific herring (*Clupea pallasii*) and northern lampfish (*Stenobrachius leucopsarus*) in relation to general characteristics of the water column including average salinity, temperature and chlorophyll-*a*.

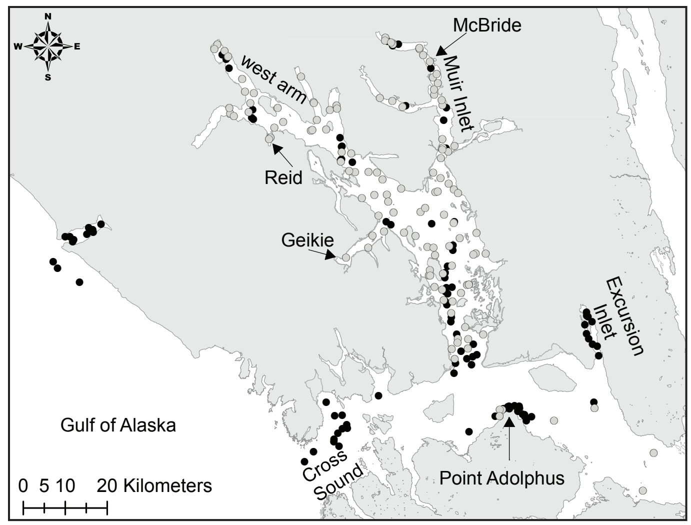

Figure 1. Midwater trawl locations in Glacier Bay National Park, Alaska, during 1999–2004. Stations where midwater trawl and oceanography data were collected concurrently are indicated as grey circles and stations where only trawls were conducted are indicated as black circles.

Methods

Mean sea surface temperatures were analyzed using 53 AVHRR satellite images taken between 1986 and 2000. Owing to the coarse spatial resolution of AVHRR images, the nearshore bands could not be interpreted because of contamination from terrestrial pixels.

The pelagic, offshore habitat was sampled with a modified-herring midwater trawl at 226 stations during four separate projects between 1999 and 2004 (fig. 1). We targeted forage fish wherever they occurred in the water column for all projects except the fish inventory, where we sampled discreet depth strata in randomly selected areas to sample at least 90 percent of marine fish species occurring in Glacier Bay. The catch was sorted by species and enumerated. A subsample of 50 individuals from each species was saved for fork length (FL) measurement. For the purpose of this paper, only forage-sized fish (FL<180 mm) are reported. We used the length at transformation for each species (Matarese and others, 1989) to separate larval fish from other life stages. However, we did not separate larval fish from other size classes for Pacific sandlance, pink salmon and northern lampfish because they were infrequently detected.

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We also collected oceanography data at 115 midwater trawl stations in 1999 and 2004 (fig. 1). Oceanographic parameters were sampled with a CTD profiler equipped with additional sensors. In 1999, we used an instrument that measured temperature, salinity, chlorophyll-*a* and turbidity. In 2004, we used a CTD rosette that measured temperature, salinity, chlorophyll-*a*, beam transmission, dissolved oxygen, photosynthetically active radiation (PAR) and contained an auto-fire mechanism for collecting water samples at discreet depths for nutrient and phytoplankton analyses.

We analyzed species occurrence relative to measured oceanographic parameters using ANOVA followed by Tukey-Kramer HSD ($\alpha<0.05$) to detect pairwise differences. Average water column values for salinity, temperature and chlorophyll-*a* were log transformed to minimize. Northern lampfish were excluded from the analysis due to low sample size.

Results

Satellite measurements of sea surface temperature provide data about the dynamics of upwelling, mixing and mass water transport in Glacier Bay and surrounding waters (fig. 2). Strong thermal fronts during summer indicate the ocean water is highly mixed as it floods and ebbs through the lower bay. The cooler water at the head of the bay results mostly from glacial processes. In contrast, the cooler water near the mouth of the bay results mostly from turbulent mixing and tidal influx of water from Cross Sound and the Gulf of Alaska. Note also the tidally influenced front at Point Adolphus.

Larval walleye pollock (FL<30 mm) were collected in 46 percent of all midwater trawl stations and comprised 31 percent of the total walleye pollock catch. The most abundant size class (between 31-60 mm) was collected at 37 percent of midwater trawl stations and made up 66 percent of the total walleye pollock catch. Juvenile pollock (110-180 mm) were collected in 12 percent of trawls. Walleye pollock was the most abundant and widely distributed forage fish species sampled in Glacier Bay and surrounding waters (fig. 3).

Larval capelin (11-60 mm) were collected in 69 percent of trawls while adult capelin (FL>60 mm) were collected in 54 percent of trawls. Capelin were most abundant at the head of Muir Inlet, over the sill at the entrance to Muir Inlet and in the lower bay (figs. 1 and 3). Larval capelin (<60 mm) comprised 38 percent of the total capelin catch in Glacier Bay. In addition, adult capelin in spawning condition were collected at one station near the mouth of Glacier Bay in 2001 and in 39 percent of trawls in 2004.

Pacific sandlance (19-159 mm) were collected at 17 percent of midwater trawl stations. Although small numbers of Pacific sandlance were collected near the glaciers at the head of the bay, they were most abundant in the lower bay and over the sill at the entrance to Muir Inlet (fig. 3).

Pink salmon (FL<180 mm) were collected at 26 percent of midwater trawl stations. They were most abundant in the lower and central areas of Glacier Bay, and they were not collected in Muir inlet or in the upper west arm (fig. 3).

Larval Pacific herring (FL<30 mm) were collected in 14 percent of trawls and juvenile and adult herring (31–262 mm) were collected in 25 percent of trawls. They were

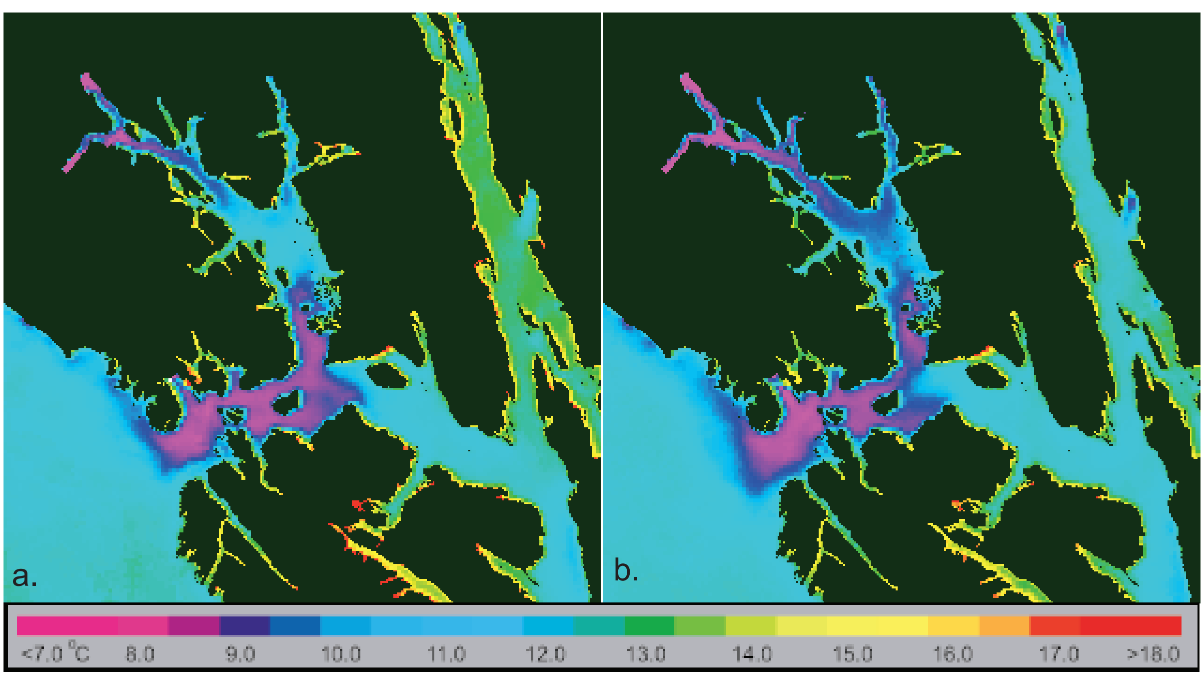

Figure 2. Advanced very high resolution radiometer (AVHRR) satellite images showing average sea surface temperature in Glacier Bay and surrounding waters during (a) Mean flood (n = 26) and (b) Mean ebb (n = 27). The nearshore warm band should not be interpreted due to terrestrial pixel contamination.

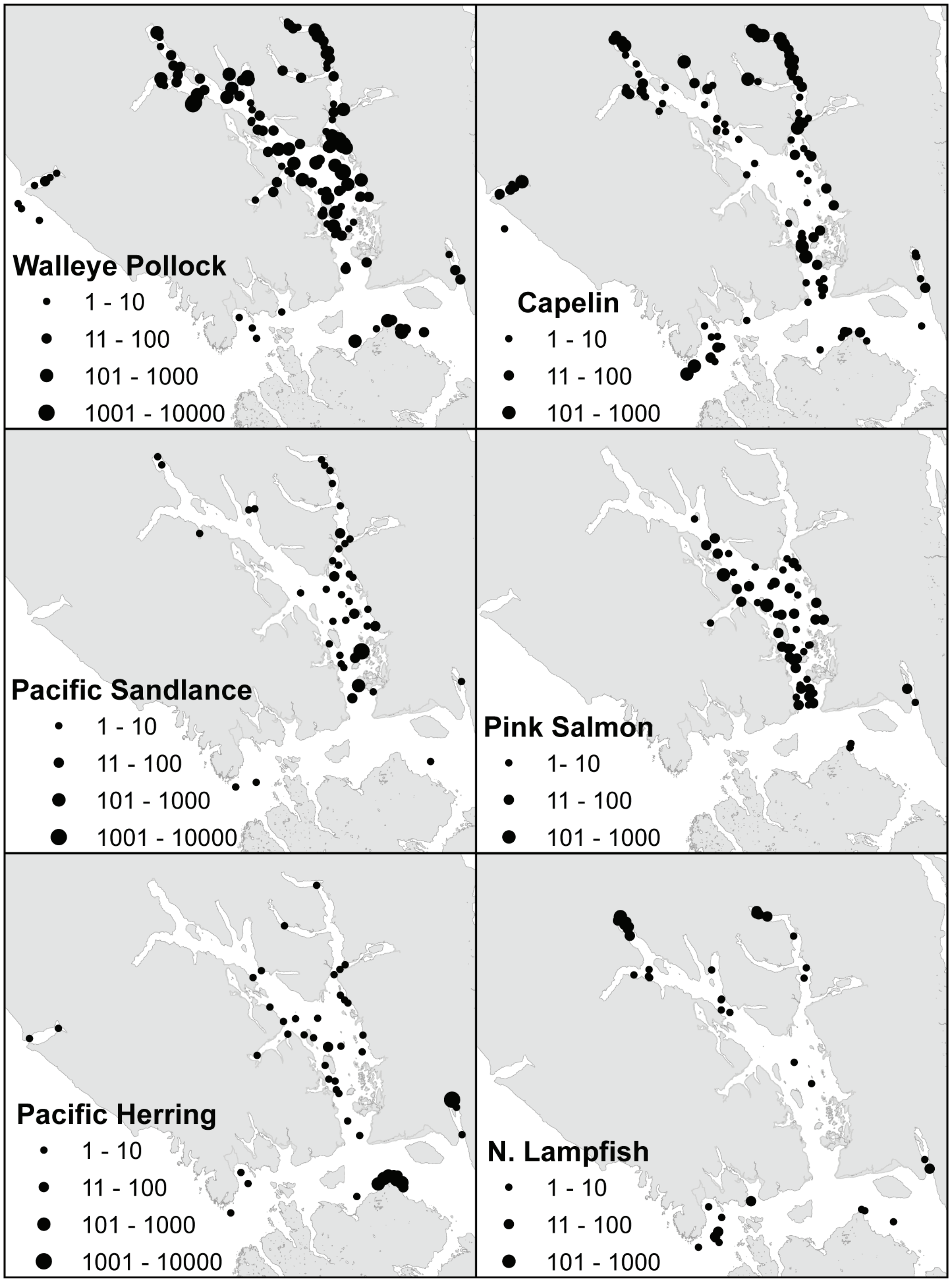

Figure 3. Relative abundance (CPUE, number of fish/km towed) of common forage fish species including walleye pollock, capelin, Pacific sandlance, pink salmon, Pacific herring, and northern lampfish sampled by midwater trawl, Glacier Bay, Alaska.

generally encountered in low numbers within Glacier Bay and were most abundant at Point Adolphus and near the head of Excursion Inlet (fig. 3).

Northern lampfish (26–125 mm) were collected in 17 percent of midwater trawls. They were most abundant near the head of Muir Inlet and the west arm in Glacier Bay proper, and in Cross Sound (figs. 1, 3). Sixty-six percent of all northern lampfish were collected in shallow water (<40 m fishing depth) during daylight hours.

We determined differences in species occurrence relative to measured oceanographic parameters (table 1). Temperature values were significantly different among species

(ANOVA: $F_{[4, 247]} = 16.11$, $p < 0.0001$) with walleye pollock and capelin occurring in cooler water than Pacific herring, pink salmon and Pacific sandlance (Tukey Kramer HSD, $p<0.05$). Chlorophyll-*a* values were also significantly different among species (ANOVA: $F_{[4, 247]} = 7.54$, $p < 0.0001$). Pink salmon occurred in waters with higher chlorophyll-*a* values compared to capelin and pollock, while Pacific herring and Pacific sandlance occurred in waters with higher chlorophyll-*a* levels compared to capelin (Tukey Kramer HSD, $p<0.05$). We did not detect a significant difference in species occurrence relative to salinity values (ANOVA: $F_{[4, 247]} = 0.54$, $p > 0.05$).

Discussion and Conclusions

The distribution of walleye pollock and capelin in the lower bay during this study is consistent with the earlier findings of Krieger and Wing (1986), who reported young of the year pollock and dense capelin schools as important humpback whale prey in the middle and lower bay. Given the high proportion of larval walleye pollock and capelin in our samples, it would appear that Glacier Bay is a nursery area for these species. Furthermore, although we had previously encountered spawning capelin in the nearshore habitat at McBride Glacier, Reid Inlet, and Geikie Inlet (Robards and others, 2003), in 2004 we found spawning capelin throughout much of Glacier Bay. The distribution of pre-spawning forage fish aggregations influences the distribution of marine predators in other areas within southeast Alaska (Womble and others, 2005) and this is likely the case in Glacier Bay.

The near-surface, daytime occurrence of northern lampfish also is an important resource for marine predators (Abookire and others, 2002). In other parts of their range, northern lampfish usually inhabit depths between 200-1,000 m during the day and migrate to the surface at night (Beamish and others, 1999). Northern lampfish and other species in the Myctophidae family are very rich in lipid content compared to other forage species (Van Pelt and others, 1997). The availability of this high-lipid forage resource in shallow waters may be important to piscivorous seabirds that capture prey in the surface waters.

Factors related to life history may explain the distribution of some forage fish species. For example, Pacific sandlance generally occur in shallow, nearshore habitats with fine gravel or sandy substrates and this may be associated with predator avoidance or due to burrowing behavior during inactive periods (Robards and others, 1999).

Life history characteristics may also be a factor in the patterns of distribution we observed for pink salmon in Glacier Bay. Pink salmon are early stream colonizers due to their ability to migrate from their natal streams as fry (Milner and Bailey, 1989). Thus juvenile pink salmon distribution in Glacier Bay may be restricted by proximity to colonized streams.

Factors such as bathymetry and topography may also explain the distribution of prey resources. The distribution of Pacific herring has been associated with tidal fronts (Zamon, 2003), such as the tidally induced frontal region near Point Adolphus. Walleye pollock, capelin and Pacific sandlance were distributed over the shallow sills that occur within the lower bay and entrance to Muir Inlet. This may be due to the strong currents that result from tidal action through constricted passages.

Differences in species distribution may be attributed in part to a range in their tolerance to differing oceanographic conditions. Walleye pollock and capelin were distributed in cooler waters with lower primary productivity. Pink salmon, Pacific sandlance and Pacific herring tended towards warmer waters with higher primary productivity.

Table 1. Sample size (number of trawls), average (±SD) and range (in parentheses) for salinity, temperature, and chlorophyll *a* values by species, Glacier Bay, Alaska.

[**Abbreviations:** PSU, practical salinity units; °C, degrees Celsius; mg/m^3, milligram per cubic meter]

Species	Sample size	Salinity (PSU)	Temperature (°C)	Chlorophyll *a* (mg/m^3)
Walleye pollock	95	30.40±0.43	6.38±0.84	3.67±2.53
		(29.10-31.27)	(4.74-8.09)	(0.36-12.37)
Capelin	62	30.41±0.43	6.20±0.97	3.47±3.02
		(29.21-31.43)	(4.55-8.09)	(0.36-13.85)
Pacific sandlance	38	30.38±0.39	6.82±0.80	4.98±3.40
		(29.31-31.24)	(4.86-8.09)	(0.53-13.85)
Pink salmon	41	30.38±0.38	7.20±0.38	5.62±3.04
		(29.10-31.43)	(6.51-8.09)	(1.67-13.85)
Pacific herring	29	30.30±0.44	6.99±0.55	4.87±2.89
		(29.01-31.47)	(5.41-7.80)	(1.13-12.37)
Northern lampfish	9	30.46±0.43	5.32±0.43	1.54±2.13
		(29.70-31.24)	(4.55-7.01)	(0.43-7.10)

Management Implications

Forage fish are key intermediaries between primary and secondary producers and dominant marine predators such as halibut, marine birds, seals, and whales. Therefore, it is useful to understand how they distribute themselves in Glacier Bay because (1) their patterns of distribution and abundance will reflect the underlying modes of productivity, and provide insight into long-term changes in fundamental bio-physical properties of the ecosystem, and (2) their patterns of distribution and abundance may largely explain the patterns of distribution of higher predators, and so act as in indicator by which potential human disturbance of marine predators should be assessed.

Acknowledgments

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