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highlights

- Despite some colder than average years, the overall effects of a preponderence of years of relatively warm surface temperatures during the last three decades were particularly apparent in coastal areas in the Gulf of Alaska during the *focus period*. Rapid recession of most glaciers, emergence of new coastal land and displacement of tide lands in response to the loss of glacial mass, larger than usual swings in precipitation, freshwater runoff, winds, and coastal storms in the last few years are all consistent with the effects of climate change anticipated in coastal Alaska.

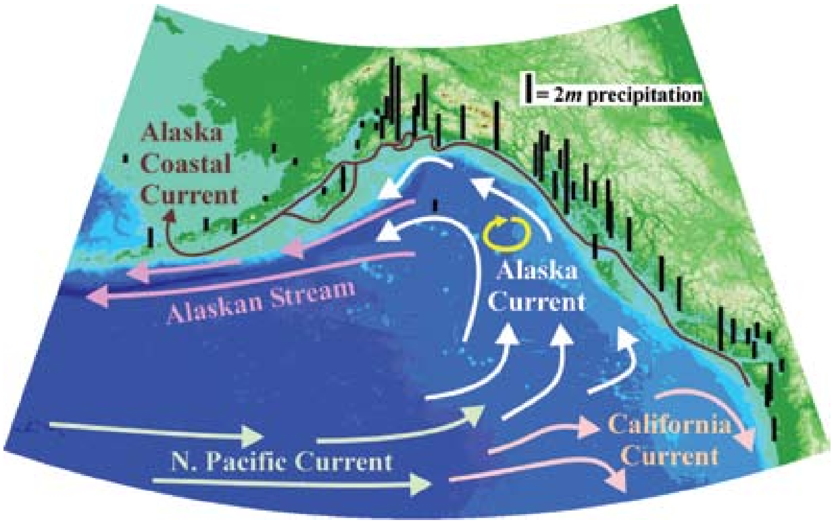
- Marine areas showed the effects of a move from very warm to very cold conditions. Pronounced annual changes in widely used indicators of climate and ocean conditions emphasized the instability of atmospheric and oceanographic conditions during the *focus period*. Warm years in 2003 – 2005 were followed by cold years in 2007 – 2008. Although sea surface temperatures in 2004 and 2005 were among the warmest on record, the water column in the north central Gulf (GAK 1) in 2007 and 2008 was colder than in the previous three decades.

- The timing and magnitude of primary and secondary productivity varied in concert with the shift from warm to cold conditions. The cross-shelf spatial extent of the spring phytoplankton bloom in the Gulf of Alaska was reduced in 2003 and the fall phytoplankton bloom was virtually non-existent in 2004 and relatively weak in 2006. In contrast, the spring bloom in 2007 was robust. During the relatively cold springs of 2006 – 2008, the spring bloom was delayed by several weeks, as was the development of the zooplankton community. Changes in zooplankton size and species composition occurred and the complex of southern species apparent in 2004-2005 became rare. Small copepods such as *Pseudocalanus* dominated the catch during warm years, whereas *Neocalanus plumchrus/flemingeri* was higher than average during cold years.

- Annual production of the key commercially exploited demersal species increased or remained stable from 2003-2008, even as production of crabs, shrimp and herring remained depressed outside of the southeastern Gulf of Alaska. No groundfish stock or stock complex is currently overfished and no groundfish stock or stock complex is being subjected to overfishing.
- A general depression in crab and shrimp production in the Gulf of Alaska has been apparent since the early 1980s. High catches of Tanner crab and flatfish, that were recorded in inshore net survey samples from 2003-2008, provide an indication of a possible recovery in these resources.
- Prominent piscivorous fish species were largely unchanged in biomass from 2003-2008 with one notable exception. While sablefish and rockfish remained stable, walleye pollock production reversed a long downward trend. Arrowtooth flounder continued to be one of the most abundant and widely distributed piscivorous fish species in the Gulf of Alaska.
- Some fish species appear to be changing geographic distribution from 2003-2008. The mean-weighted distribution of Gulf of Alaska rockfish (1990–2007), especially juvenile Pacific Ocean perch, appeared to be farther north and east and was more contracted in 2007, possibly indicating a change in rockfish distribution around. Further evidence of a change in the distributions of benthic fishes was the increase in lingcod bycatch in commercial fisheries in the northwestern Gulf of Alaska starting in 2005, increasing dramatically in 2008.
- Marine mammals showed overall growth and stability from 2003-2008 with the notable exceptions of beluga whales and the northern and western Steller sea lion. Populations of humpback whales in Gulf of Alaska were apparently at the highest recorded levels. Beluga whale is at extremely low abundance, making the extirpation of this species from the Gulf of Alaska a serious concern. Northern and western Steller sea lions remain at very low population levels, however those of southeastern Gulf of Alaska are at normal levels and continued to increase during the *focus period*.

Introduction

The Gulf of Alaska (GoA) coastal area is comprised of the shoreward Alaska Coastal Current (ACC), the offshore Alaska Current (AC) and Alaskan Stream and the eddies and meanders that cross them (Fig. GA-1). The currents may extend along the continental shelf and shelf break as far south as the mouth of the Columbia River and as far west as the Aleutian Islands (Reed and Schumacher 1986; Thomson et al. 1989; Royer 1998). The GoA (Fig. GA-1) is bounded on the east and north by tall, rugged mountains that are separated by a continental shelf from abyssal depths in excess of 3000 m in the eastern Gulf of Alaska to more than 7000 m in the Aleutian Trench. The continental shelf has a total area of approximately 370,000 km² and ranges from 5 to 200 km in width. Islands, banks, ridges, and numerous troughs and gullies cut across the shelf, resulting in a complex bathymetry that promotes an exchange between shelf water and deeper waters. The coastal mountain range captures large amounts of precipitation from low pressure systems originating in the west, resulting in large volumes of nutrient-poor freshwater runoff into coastal areas (Weingartner et al. 2009). Freshwater buoyancy and local winds drive the nearshore ACC.



[Figure GA-1] Diagram of the predominant ocean currents and average annual precipitation at onshore stations (bars) from Danielson et al. (2000).

Situated on the inner third of the continental shelf, the ACC provides a sizeable and ecologically important transition zone between the shallow, nearshore communities and the outer-shelf and oceanic pelagic ecosystems. Fed by runoff from glaciers, snowmelt, and rainfall, the well-defined coastal current is marked by a freshwater output about one and a half times that of the Mississippi River (Weingartner et al. 2005). It flows consistently to the north and west around the northern GoA from British Columbia to Unimak Pass on the Aleutian archipelago. The ACC distributes subarctic plankton communities around the region and into protected inside waters such as Prince William Sound (Kline 2006). During the summer months, the ACC has local reversals and small eddies which can concentrate plankton and small fishes in convergence zones, for foraging fish, birds, and marine mammals.

Offshore of the ACC, the AC has its origins in the North Pacific Current (Fig. GA-1). The North Pacific Current flows eastward from Asia between about 30°N and 45°N and bifurcates as it approaches the west coast of North America (Reed and Schumacher 1986). The broad and sluggish (3-6 $m \cdot min^{-1}$) Alaska Current carries variable portions of the warm North Pacific Current northward along the coasts of northern British Columbia and Southeast Alaska into the northern GoA (Freeland 2006). The AC turns westward in the northern Gulf of Alaska where it is separated from the less nutrient rich ACC by a highly variable mid-shelf region enveloped in salinity fronts. The mid-shelf region of the northern GoA is characterized by pronounced changes in water properties, chemistry, and species compositions of phytoplankton, zooplankton, and fish along cross-shelf gradients. Superimposed on these cross-shelf gradients is considerable mesoscale variability resulting from eddies and meanders in the boundary currents (Weingartner et al. 2002; Stabeno et al. 2004; Crawford et al. 2006; Ladd 2007). Forced to the south by the Alaska Peninsula the AC continues as the much swifter (18-60 $m \cdot min^{-1}$) Alaskan Stream as it follows a southwestward course along the Alaska Peninsula and the Aleutian archipelago (Weingartner et al. 2009). A portion of the Alaskan Stream turns south and recirculates as part of the North Pacific Current, closing the loop to form the Alaska Gyre. The position of the North Pacific Current and the volume of water transported vary on interannual and decadal time scales, with associated variations in the Alaska Current (Parrish et al. 2000; Freeland 2006).

This chapter contains a review of the status and trends of the Alaska Current region from 2003-2008, hereafter the *focus period*.

2.0 Atmosphere *(Bond)*

The overall effects of a preponderance of years of relatively warm surface temperatures during the last three decades continued to be apparent in the Gulf of Alaska during the focus period. Rapid recession of most glaciers, emergence of new coastal land and displacement of tide lands in response to the loss of glacial mass, larger than usual swings in precipitation, freshwater runoff, winds, and coastal storms in the last few years are all consistent with the effects of climate change anticipated in coastal Alaska.

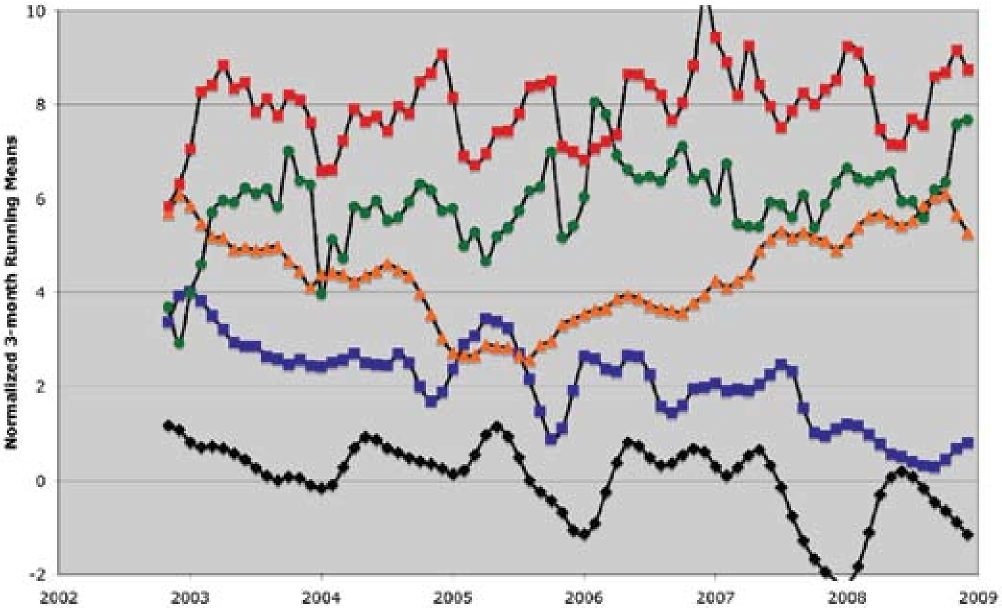
Sharp changes in short-term climate during the focus period preclude establishing a clear climate regime in the GoA. The very warm years of 2003-2005 were followed by very cold years in 2007 and 2008. Negative values of the Pacific Decadal Oscillation (PDO) developed in late 2007 and have persisted into 2008, but it remains highly uncertain whether the PDO will remain negative for an extended period. Summer temperatures from 2003 to 2005 in the GoA were among the warmest on record and coincided with a shift in forcing. The SST-based Victoria pattern, after being in its positive phase during 1999-2004, had a phase reversal in 2005. It was not consistent, however, with its atmospheric counterpart, a north-south dipole in sea level pressure (SLP). Instead, the anomalous SLP in 2005 featured an east-west dipole consisting of a negative anomaly centered along 170°W from 40°N into the Bering Sea, and a positive anomaly in the eastern Pacific from 40°N into the GoA. This combination brought about southerly wind anomalies and an enhancement of cyclonic activity for the Bering Sea shelf, and a suppression of storminess in the eastern North Pacific.

Significant anomalies in the forcing of the GoA occurred in the winter of 2006-2007 and the spring of 2007. The former featured anomalous southwesterly winds that combined with the prevailing seasonal winds to provide enhanced wind mixing and enhanced positive wind stress curl and hence upward Ekman pumping. The net effect, based on Project Argo data, was a relatively shallow mixed layer in the central GoA, and a deep mixed layer close to the coast at the end of winter of 2007, when compared with the previous year. During spring 2007, anomalously low SLP was present in the central GoA, which promotes anomalous downwelling in the coastal zone and a relatively strong ACC.

2.1 North Pacific climate and SST indices

The large-scale atmosphere-ocean climate system of the eastern North Pacific can be characterized in terms of five indices (Fig. GA-2). First, the NINO3.4 index represents the state of the El Niño/Southern Oscillation (ENSO), which is important because of its systematic impacts on higher latitudes. There appear to be two robust modes of eastern North Pacific oceanic variability, the Pacific Decadal Oscillation (PDO), which is the leading mode of North Pacific sea surface temperature (SST) variability, and the weaker but still biologically important, North Pacific Gyre Oscillation (NPGO) (DiLorenzo et al. 2008). The two principal atmospheric indices considered here are the North Pacific Index (NPI) and the Arctic Oscillation (AO). The NPI is one of several measures used to characterize the strength of the Aleutian Low. The AO signifies the strength of the polar vortex, with positive values signifying anomalously low pressure over the Arctic and high pressure over the Pacific and Atlantic at a latitude of roughly 45° N, and hence anomalously westerly winds across the northern portion of the Pacific and Alaska.

Time series of these five indices are shown in Fig. GA-2 for the period of winter the 2002-2003 through the winter of 2008-2009. The NINO3.4 index was positive early in the focus period (a moderate El Niño occurred during the winter of 2002-2003) and mostly negative late in the period in association with the moderate La Niña of the winter of 2007-2008 and the weaker La Niña during the following winter. The PDO tracked the NINO3.4 index quite closely but with a slightly more prominent decreasing trend. The decline in the PDO was accompanied by a concomitant decline in the SST along the western coast of North America from the Bering Sea to Baja California. The NPGO was positive at the start and end of the period and negative in the mid portion. A positive phase of the NPGO tends to be associated with anomalously strong equatorward flow in the California Current and relatively strong cyclonic flow along the periphery of the Gulf of Alaska. The NPI was negative at the very start of the period in association with an anomalously deep Aleutian Low, and then varied with season, with a tendency for positive values during the last half. The AO fluctuated around a neutral state on close to an annual basis. In summary, the eastern North Pacific Ocean experienced a full range of climate conditions during the focus period.

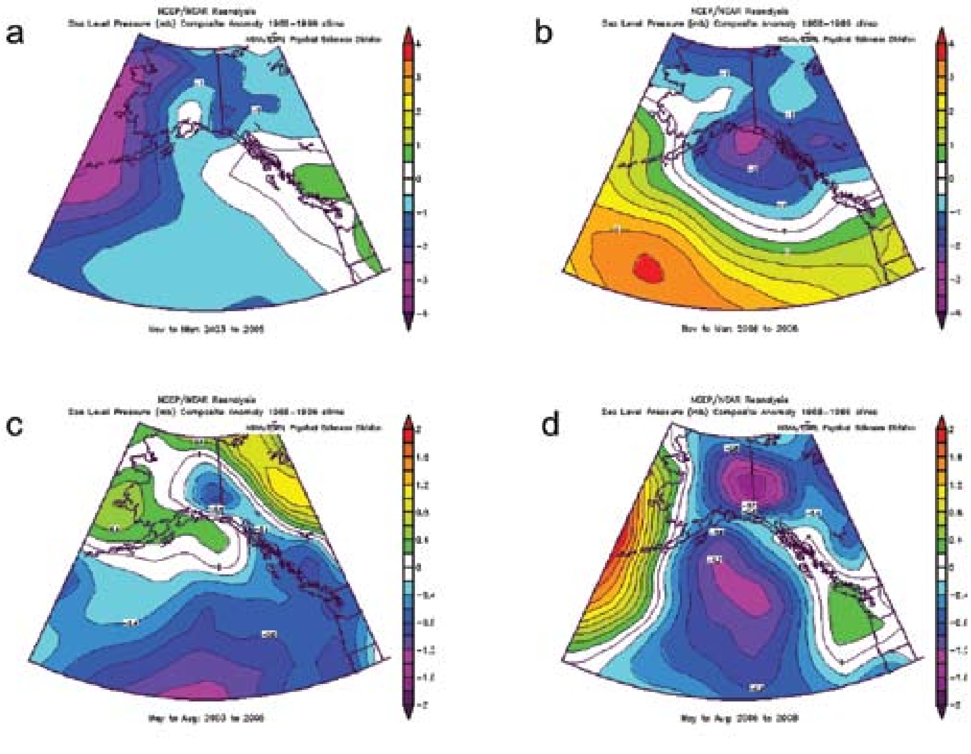


[Figure GA-2] Time series of 3-month running means of NINO3.4 (black), PDO (blue), NPGO (orange), NPI (green) and AO (red). All time series are normalized by their standard deviations, with offsets of 2 units between the individual series.

2.2 Regional circulation patterns

Regional-scale weather can be summarized with maps of seasonal mean SLP. These maps were examined for individual cool and warm seasons of the focus period. The cool (warm) season is defined as November-March (May-August) and represents the period when the net heat flux is consistently upward (downward) at the air-sea interface. This examination revealed that there was a marked shift at roughly the halfway point in the focus period with substantial commonality in the individual years comprising each half of the period. The state of the regional atmospheric circulation is therefore illustrated with composite maps of anomalous SLP for the cool seasons of 2003-2005 and 2006-2008, and for these groups of warm seasons separately (Fig. GA-3).

The cool seasons of 2003-2005 (Fig. GA-3a) featured relatively low SLP over the Bering Sea and high SLP over western North America from British Columbia to California. The consequence for the GoA was anomalous low-level winds from the south, which tend to be accompanied by relatively warm and wet conditions. A much different pattern prevailed in the cool seasons of 2006-2008 (Fig. GA-3b) which included anomalously high SLP extending from the Bering Sea towards the U.S. mainland, with a small but prominent area of low SLP in the GoA. This configuration implies an anomalously cold flow from the northwest for the western portion of the GoA and a relatively stormy environment for the central and eastern portions, including enhanced snowfall over the coastal terrain. The warm seasons of 2003-2005 (Fig. GA-3c) had relatively weak SLP anomalies with a tendency for higher (lower) SLP than normal in the western (eastern) half of the GoA, indicating generally weak wind anomalies from the north. The warm seasons of 2006-2008 on the other hand, had a mean pattern with high SLP over the Bering Sea and off the coast of the Pacific Northwest with low SLP over the GoA (GA-3d). This pattern indicates a modest enhancement in storminess and Ekman pumping in the central GoA. In an overall sense, the GoA was subject to regional forcing promoting relatively warm conditions early in the period with a shift to the opposite sense close to midway through the period.



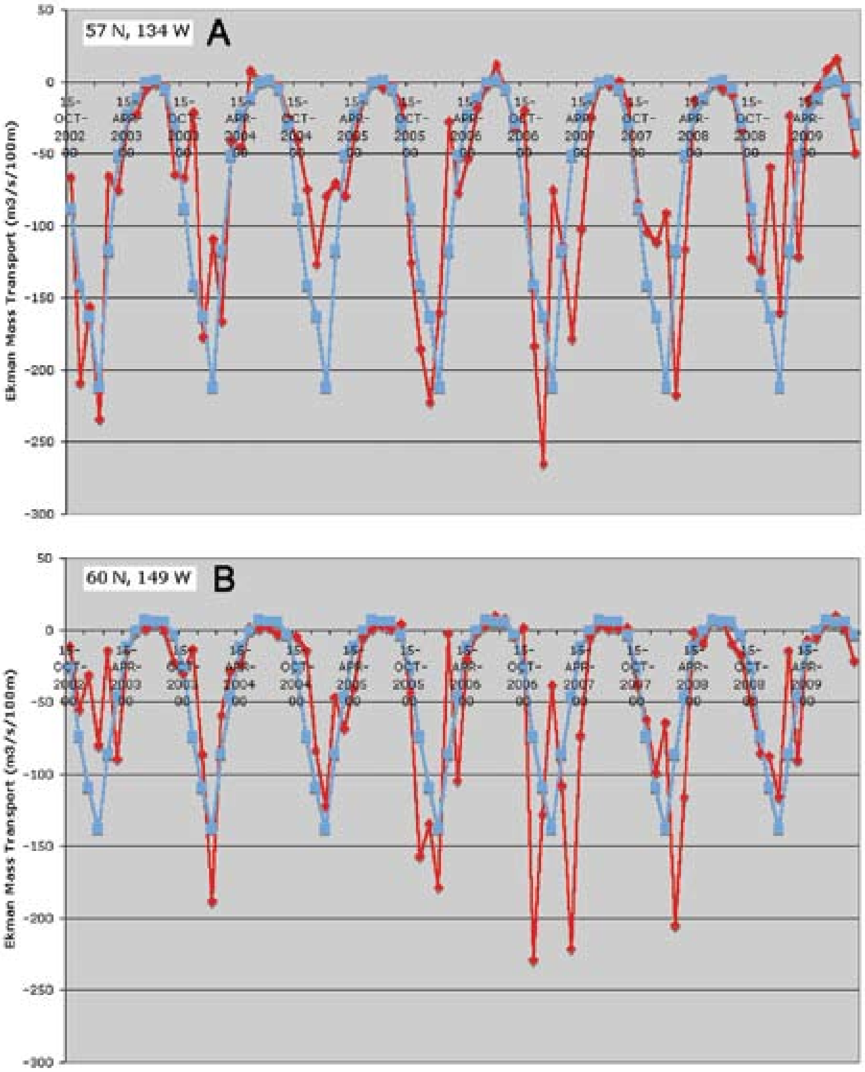
[Figure GA-3] Composite SLP anomalies for (a) the winters (November-March) of 2003-2005, (b), the winters of 2006-2008, (c), the summers (May-Sep) of 2003-2005, and (d) the summers of 2006-2008, from the NCEP/NCAR Reanalysis. The baseline period is 1968-1996. The contour intervals are 0.5 hPa and 0.25 hPa for the winter and summer SLP distributions, respectively.

2.3 Local atmospheric forcing

The local atmospheric forcing of the GoA is summarized here with regards to two variables important to the flow on the shelf, the upwelling component of the winds and freshwater runoff. The upwelling winds relate to cross-shelf flows in the ocean with implications for nutrient concentrations and along-shore mass transport on the shelf (Stabeno et al. 2004). The along-coast winds in the GoA help control the locations of boundaries between waters of different origin with different lower-trophic level communities. Freshwater runoff is a key aspect of the baroclinity that is prominent on the GoA shelf during the summer and fall seasons.

The upwelling winds that occurred along the GoA during the focus period are illustrated using monthly mean time series of upwelling indices at 57°N 134°W (near Sitka) and 60°N 149°W (near Seward) from NOAA's Pacific Fisheries Environmental Laboratory (http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/PFELindices.html).

Upwelling along the GoA coast exhibits a clear annual cycle between strong downwelling in the cool season (peaking in January) and near-zero upwelling during the summer months (Fig. GA-4). The focus period included less downwelling than normal at Sitka (Fig. GA-4a), with the winters of 2004-2005 and 2008-2009 featuring especially weak downwelling. On the other hand, Seward (Fig. GA-4b) experienced substantially weaker than normal downwelling only during the winter of 2002-2003, and for the period as a whole, mean winds were near average. The summer months at both locations were characterized



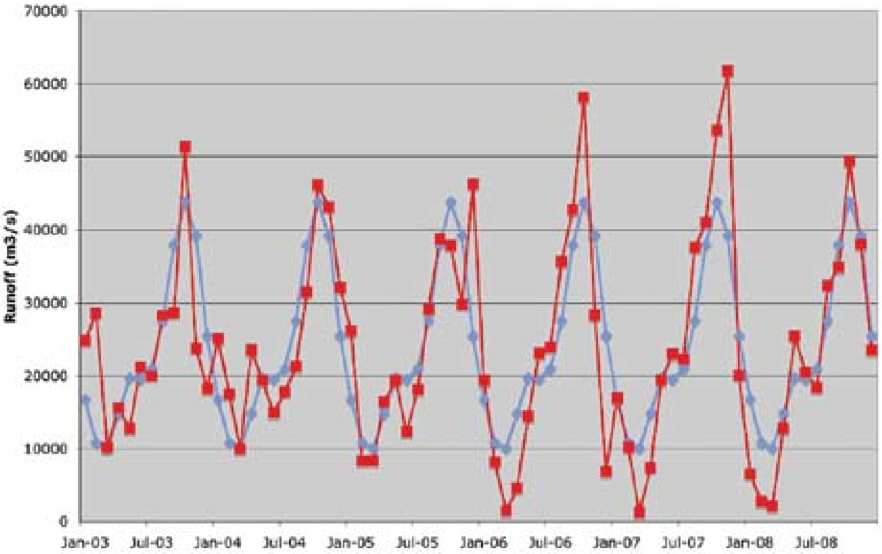
[Figure GA-4] Monthly mean upwelling (red line) near Sitka, Alaska (upper panel) and Seward, Alaska (lower panel) expressed in terms of total vertical mass transports per 100 m of coastline. The blue line indicates the climatological average.

not only by near zero winds (in the mean), but also very small month to month fluctuations. It is unknown whether these small fluctuations are sufficient to materially affect the physical and biochemical properties of the shelf waters during the summer. The timing of the cessation of the winter downwelling in spring, and its resumption in the fall varies considerably from year to year. In addition, there appears to be quite a bit of along-coast coherence in the variations in this timing. For example, both stations had weak downwelling in the spring of 2006 and relatively early onsets of strong downwelling late in 2006. The effects of anomalous upwelling/downwelling are expected to persist longer in the summer months when the flow is more sluggish, than during the cool season, especially in the near coastal region. As an aside, the Alaskan Stream is part of the deeper, gyre circulation and is impacted largely by basin-scale mechanisms on multi-year time scales.

Freshwater runoff during the focus period and its climatological mean were estimated using a simple hydrological model (Royer 1982) (Fig. GA-5). For the interval of 2003-2005, runoff was close to average, with minor month-to-month anomalies. The period from 2006-2008 features an enhanced seasonal cycle with anomalously low runoff in the spring and high runoff in the fall. This can be attributed to the relatively cold winters and cool and dry springs of 2006-2008, which resulted in a higher snow:rain ratio in coastal watersheds and a delayed snow melt. The relatively high estimated streamflows during recent autumns (especially 2006 and 2007) imply enhanced baroclinity for the ACC.

2.4 Sitka, Alaska *(Lam)*

The weather record for Sitka is the longest reliable regional climate record (mid-1800s to present) in the GoA. Atmospheric records at other localities in Alaska have only been kept for at most 60 years. Subsurface ocean temperature anomalies are correlated with air temperature anomalies at Sitka well enough for the air temperatures to have been used to infer ocean temperature near Seward (60°N 149°W) back to 1828 (Royer 1993). Nevertheless, the degree to which climate may be coherent throughout the GoA varies seasonally and interannually due to differences in coastal topographies and short term climate events such as ENSO (Royer 1989). For example, steep mountains on the GoA eastern boundary west of 150°W cause annual precipitation in the western coastal GoA to be substantially less than in the eastern coastal GoA (Fig. GA-1). Sitka precipitation is characteristic of the freshwater inputs from coastal mountain ranges on the eastern and northern boundaries of the Gulf and it is therefore a useful proxy for understanding the history of the oceanography of the coastal Gulf of Alaska. The precipitation captured by the coastal mountains of British Columbia and Alaska drives the Alaska Coastal Current (Royer 1981).



[Figure GA-5] Estimated monthly mean runoff ($m^3 \cdot sec^{-1}$; red line) for the entire Gulf of Alaska. The blue line indicates the climatological average.

The Sitka climate record was reconstructed from a combination of sites within the city. While under Russian control, precipitation was first recorded in 1842. Following the transfer of ownership to the United States, temperature was added in 1867. This record stopped in 1921. The Sitka Magnetic Observatory, located close to the coast, was established in 1899 to monitor magnetic deviations in the region and to continue the climate record. Due to the similarity between the Russian data and the Sitka Magnetic Observatory data, they were merged. On April 1, 1942, the Sitka Magnetic Observatory was moved 1 mile inland, and then in 1948, weather observations were started at the Sitka Airport near the coast. The climate record from the Sitka Airport was combined with the Sitka Magnetic Observatory dataset.

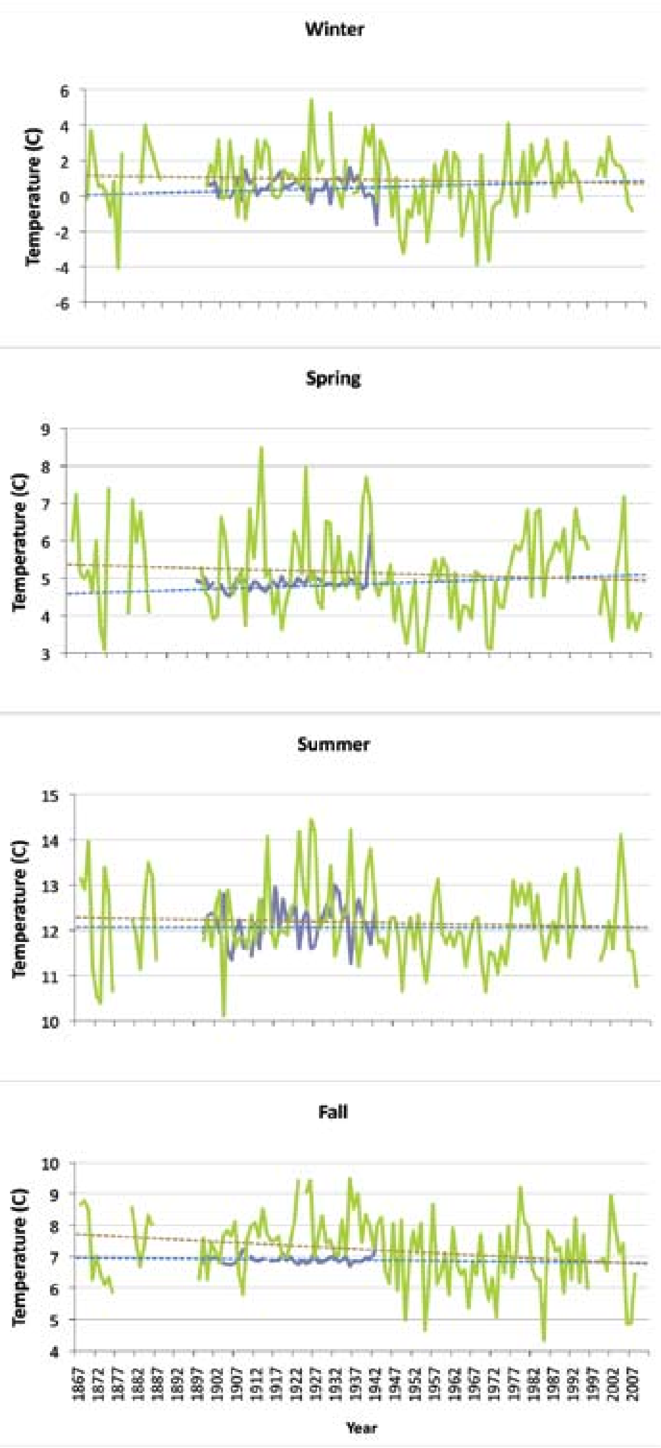
Trend analysis was performed on the temperature and precipitation datasets (Table GA-1). It should be noted that the focus period of 2003-2008 contained a distinctly warm interval (2003-2005), a distinctly cold interval (2007-2008), and a transitional year (2006). The temperature and precipitation trends per century are summarized by season (winter, spring, summer, and fall) (Figs. GA-6 and GA-7). For most periods except fall, these data indicate a warming trend in Sitka (Fig. GA-6). For most periods except summer, it is becoming increasingly wetter in Sitka (Fig. GA-7). From 2004 to 2008, Sitka experienced warmer than average summer and winter temperatures (+0.2°C warmer than the long-term averages), and wetter-than-average winter, summer, and fall. Fall temperatures in these years are much cooler, about -0.8°C below the long-term averages.

On an annual basis, air temperatures at Sitka changed on average about +0.28°C (ranges from -0.33 to +0.94°C) per century for the past 150 years. The dominant periodicity for the time series is about 55 years, and it can explain up to 28% of the variances in the time series. The 2004-2008 average annual temperature is about 0.05°C cooler than the long-term averages. Although the climate of Sitka is primarily maritime, it can occasionally be influenced by a more continental air mass from the east. The contrast between warm, wet maritime and cool, dry continental climate regimes is most significant in late fall and winter. Therefore, it is not surprising that a long-term warming trend in the winter is often accompanied by a long-term trend for increased precipitation (Schnetzler and Dierking 2008).

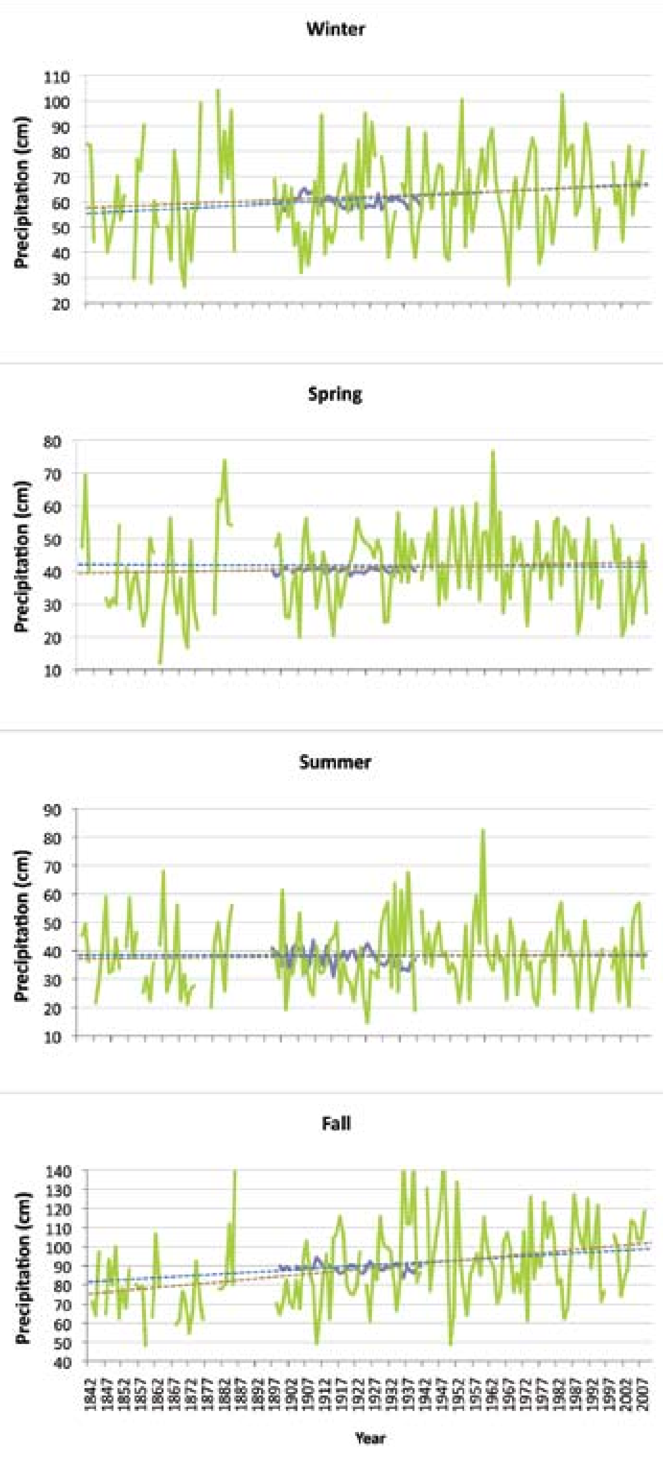
Annual precipitation from 2004 to 2008 is about 22.9 cm more than the long-term average. Winter, summer, and fall precipitation during 2004 to 2008 are greater than the long-term averages. From 2004 to 2008, winter precipitation is about 7.6 cm greater than the long-term average, summer precipitation is about 5 cm wetter than the long-term average, and fall precipitation is about 20 cm wetter than the long-term average. In contrast, spring precipitation from 2004 to 2008 is about 5 cm below the long-term average.

[Table GA-1] Summary showing long-term climate trend and recent climate in relationship to long-term averages.

Period	Temperature trend (°C per century)	2004-2008 temperature relative to long-term average (°C)	Precipitation trend (cm per century)	2004-2008 precipitation relative to long-term average (cm)
Annual	+0.29	-0.06	+20.78	+22.86
Winter	+0.64	+0.17	+5.72	+7.47
Spring	+0.29	+0.0	+0.08	-5.05
Summer	+0.17	+0.23	-0.18	+4.52
Fall	-0.06	-0.81	+14.58	+20.00



[Figure GA-6] Time series of average annual temperature in Sitka, AK from 1867 to 2008. Note that there are intermittent breaks in the data, especially before 1990. The green color is the location bias-corrected data (taking station move into account). The blue color is the dataset created by estimation using the average annual temperature time series from Juneau, Alaska.



[Figure GA-7] Time series of annual precipitation in Sitka, AK from 1867 to 2008. Note that there are intermittent breaks in the data, especially before 1990. The green color is the location bias-corrected data (taking station move into account). The blue color is the dataset created by estimation using the average annual precipitation time series from Juneau, Alaska.

3.0 Hydrography

The focus period includes significant transitions in ocean temperatures in the northern GoA upper (0-100 m) and lower (>100 m) layers. While conditions in 2003-2005 were characteristic of the continued warming of near-surface waters, northern GoA mean ocean temperatures decreased in the winter of 2006-2007 and remained below normal through 2008.

3.1 Hydrographic conditions at GAK1

(Janout, Weingartner)

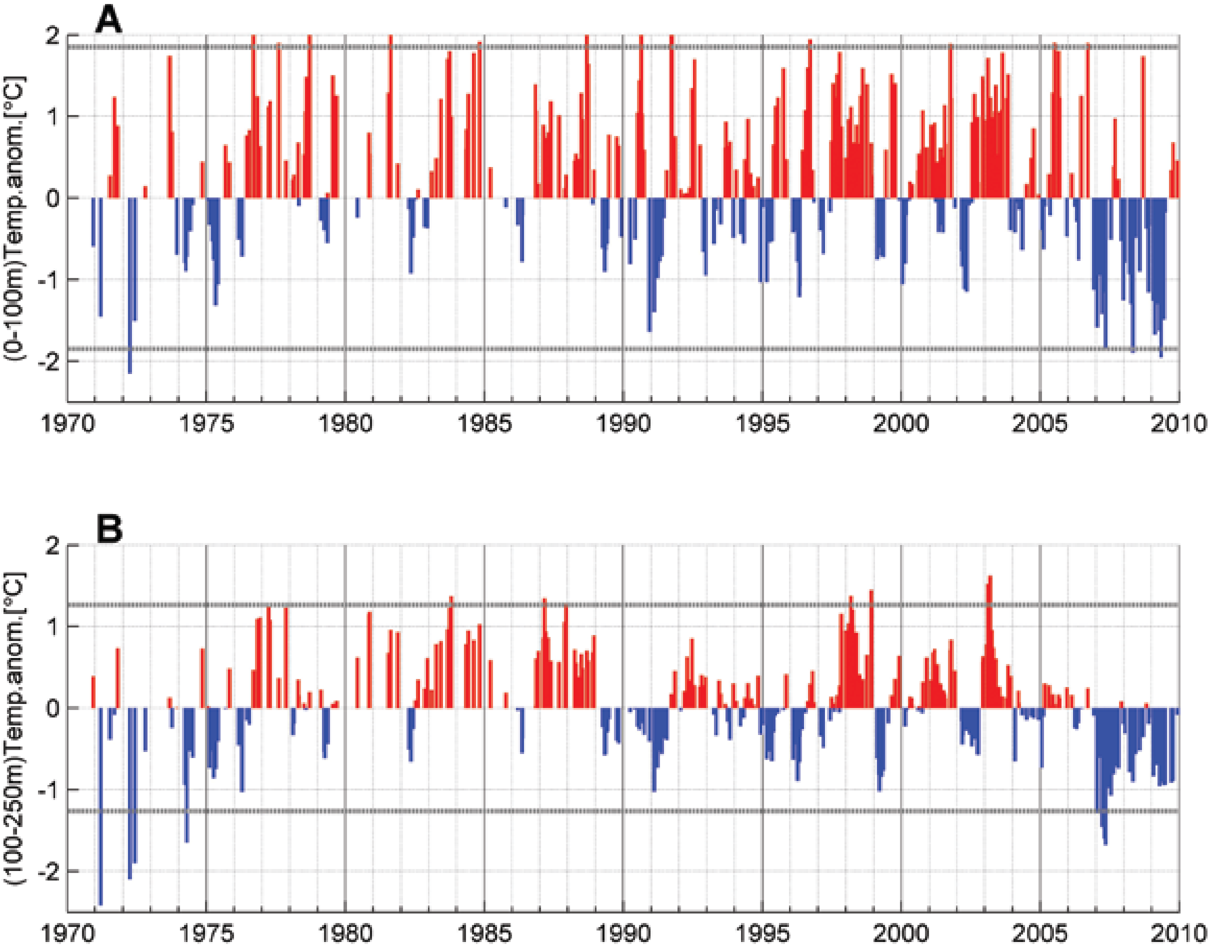
The coastal monitoring site, GAK1, is located at the mouth of Resurrection Bay (~59.8°N, ~149.5°W) where the water depth is 263 m. It is the longest hydrographic time series in the northern GoA with >450 CTD profiles collected during nearly 40 years of sampling. The CTD database is complemented by ~8 years of moored temperature and salinity records. GAK1 is the inshore station of the Seward Line, which was extensively sampled (6-7 surveys per year) during the Northeast Pacific GLOBEC program (1997-2004, Weingartner et al. 2002) and has been surveyed bi-annually since 2005 with support from the North Pacific Research Board.

The focus period includes significant transitions in ocean temperatures in the northern GoA upper (0-100 m) and lower (>100 m) layers (Fig. GA-8). While conditions in 2003-2005 were characteristic of the continued warming of near-surface waters (Royer and Grosch 2006) after the 1976-1977 regime shift (Mantua et al. 1997), northern GoA mean ocean temperatures decreased in the winter of 2006-2007 and remained below normal to present (Janout et al. accepted). The moored GAK1 temperature record suggests that the cooling began in November 2006 when strong northerly winds rapidly cooled the anomalously warm waters that were prevalent in summer 2006. Stratification was weakened by reduced coastal freshwater runoff (Royer 1982) and strong wind mixing. Near-normal atmospheric winter conditions from December-February were followed by anomalously strong heat loss in March 2007, which led to the lowest ocean temperatures since the early 1970s. The annual Seward Line monitoring in May 2007 recorded temperatures ~1.5°C lower than the May average throughout the water column, while salinity was higher (lower) than normal in the upper (lower) layer (Fig. GA-9). In May 2008 and 2009, upper layer temperatures were comparable to those of 2007 while the lower layer was slightly warmer than in 2007, although still colder than average. Seward Line temperature anomalies show that the recent cooling extended over much of the shelf in both the upper (0-100m) and lower (>100m) layers (Fig. GA-10).

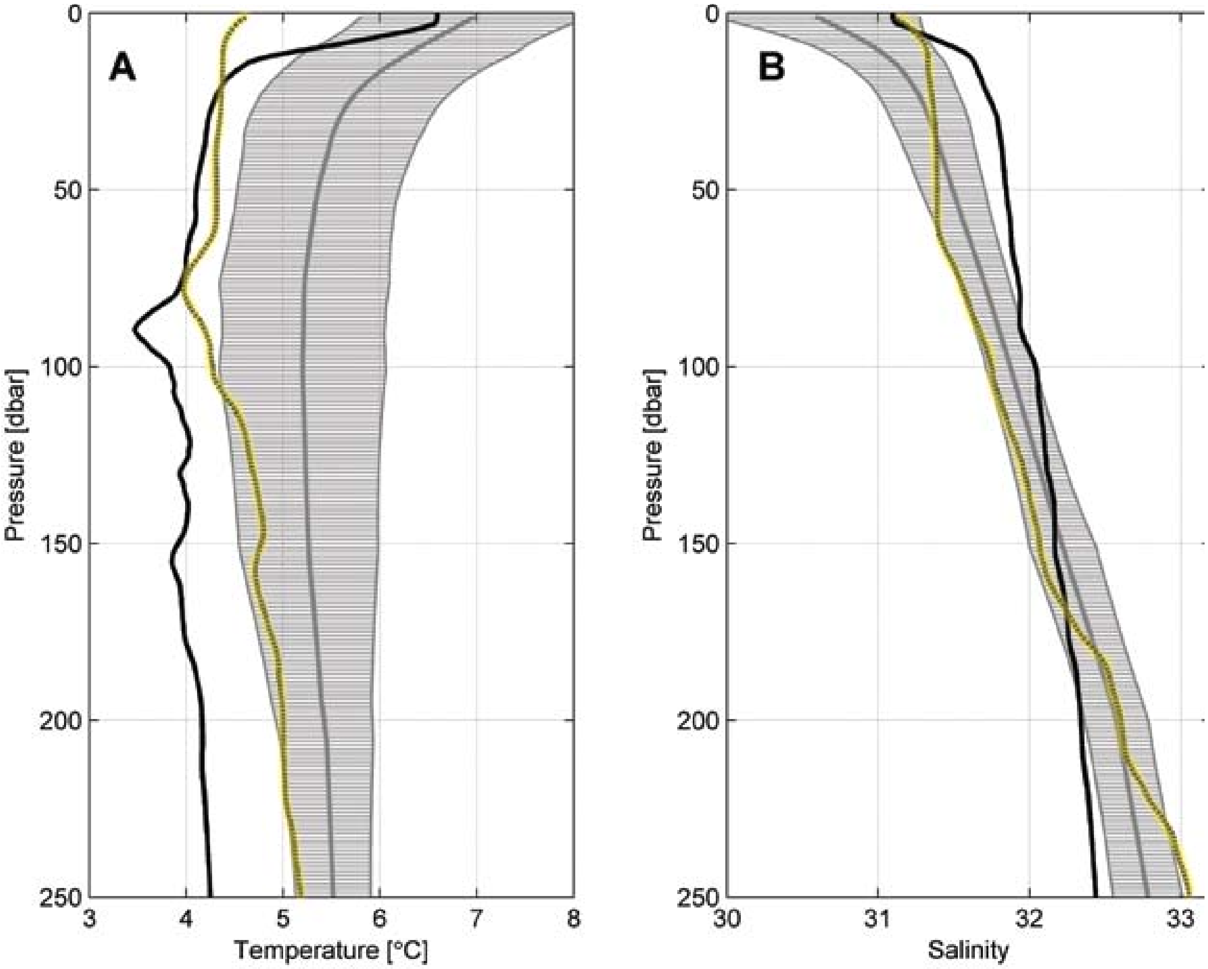
Salinity stratification, i.e. the difference between 20 m and 100 m salinities, appears to play a crucial role in shaping the lower layer temperatures at GAK1. In fact, stepwise regression analysis suggests that salinity stratification (governed by coastal freshwater runoff) and air-sea heat fluxes explain ~80% of the variability in deep temperatures (Janout et al. accepted). Therefore, the salinity stratification during the focus period followed the trend of the temperature anomalies, where 2003-2005 (2006-2008) showed anomalously strong (weak) salinity stratification. The weakest stratification, coincident with the lowest ocean temperatures since the early 1970s, was observed in spring 2007.

Besides its governing role on salinity stratification, coastal freshwater runoff is one of the forces behind the wind- and buoyancy-driven ACC (Weingartner et al. 2005). The baroclinic (i.e. freshwater–driven) portion of the ACC is estimated to be 70-90% (Williams et al. 2007), depending on the season, and therefore freshwater runoff significantly impacts the temperature variability in the northern GoA. Interestingly, geostrophic velocities in the ACC in May 2007, computed from the Seward Line density structure, were the lowest May values within the 1998-2009 record. This implies that the along-shore heat advection in the ACC was reduced and likely contributed to the anomalous cooling in spring 2007.

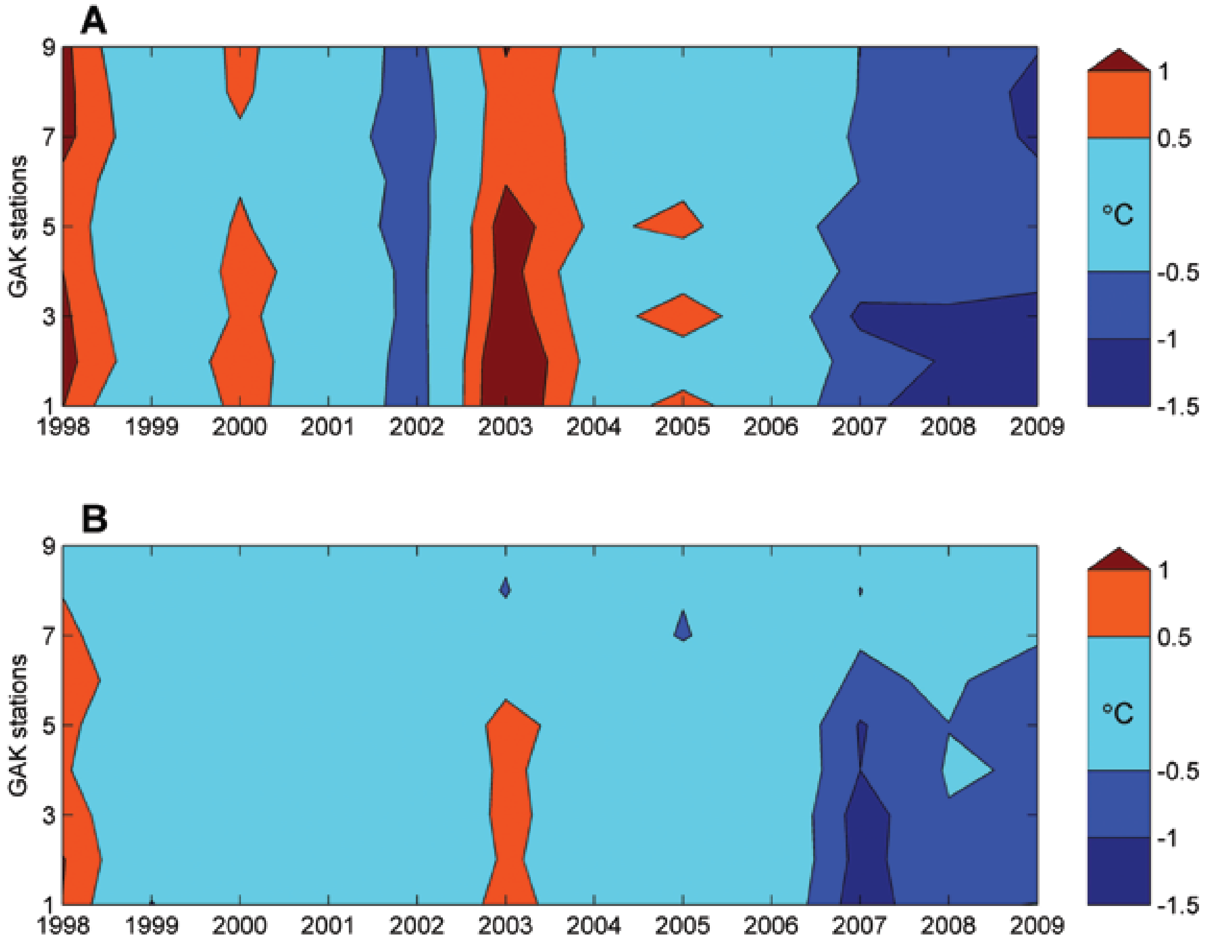
In summary, in late 2006, the northern GoA experienced a sudden shift in ocean temperatures, from warmer waters characteristic of the ocean climate after the 1977 regime shift, to colder conditions comparable to the early 1970s. This recent cooling coincided with enhanced northerly winds, which increased air-sea heat fluxes and reduced coastal runoff. The analysis of the GAK1 mooring and CTD record showed that the temperature variations in the upper layer are mainly the result of thermodynamic processes, while lower layer temperatures may in addition be regulated by salinity stratification, which is the result of three-dimensional processes affecting the freshwater dispersal on the northern GoA shelf.



[Figure GA-8] Upper layer (A) and lower layer (B) temperature anomalies at GAK1 from ~1970 to present.



[Figure GA-9] May 2007 (solid) and May 2008 (dashed-yellow) (A) temperature and (B) salinity profiles in comparison with the average May (~1970-2008) profiles (grey) including the range of ± 1 s.d.



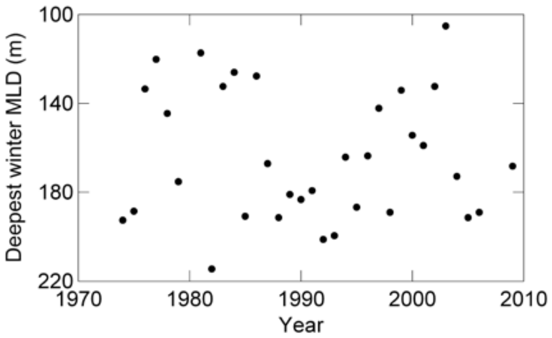
[Figure GA-10] Mean (A) upper (0-100 m) and (B) lower (>100 m) layer temperature anomalies along the Seward Line from coast (GAK1) to the shelfbreak (GAK9) during May surveys from 1998-2009.

3.2 Winter mixed layer at GAK1 *(Sarkar)*

Downwelling favourable winds predominate in the northern Gulf of Alaska coast yet the shelf is a region of high biological productivity. Various mechanisms have been suggested for the transport of nutrients across the shelf. One involves moving nutrient-rich water from the deep ocean to the shelf via cross-shelf transport along the shelf bottom, especially within submarine canyons during periods of relaxed downwelling. In this scenario, mixed layers at certain times of the year could be deep enough to mix nutrient-rich deep waters into the euphotic zone. In the northern Gulf of Alaska, mixed layers are deepest in the winter, when wind stress is high, air and water temperatures are low and salinity is high (freshwater is locked up as snow and ice; evaporation from the ocean surface is high due to low air relative humidity and strong winds sweeping the area).

The deepest winter mixed layer depths (MLD) at GAK1 were estimated using the Freeland et al. (1997) algorithm. This algorithm performs well at estimating winter MLDs (each winter is defined here as December of one year and January to May of the following year), but overestimates the summer and spring MLDs, but for our purposes, this method is adequate (Sarkar et al. 2005; Sarkar 2007). The deepest winter MLDs at GAK1 from 1974 to 2009 (Fig. GA-11) range from a minimum of 105 m in February 2003 to a maximum of 214 m in March 1987. The mean value is 164 m, with a standard deviation of 29 m. The record has only one missing value; that for the winter of 1979-1980. The MLD time series used here does not include values for the winters of 2006-2007 and 2007-2008 because of some anomalous conditions that changed the shape of the density profiles and the Freeland algorithm could not calculate meaningful MLDs. The deepest winter MLDs at GAK1 from 1974 to 2009 do not show any statistically significant linear trend. This is in contrast to studies by Freeland et al. (1997) who report a significant shoaling trend at Station Papa at the center of the Alaska gyre from 1956 to 1994.

The winters of 2006-2007 and 2007-2008 were unusual in the northern Gulf of Alaska (Janout et al. in press). Even though there were significant inter-annual differences within these years, the water column in the vicinity of GAK1 was colder than in the past three decades (mid-1970s to mid-2000s). In winter/spring 2006-2007, the anomalously low temperatures throughout the water column were accompanied by higher surface salinity, leading to lower water column stability. In winter/spring 2007-2008, the anomalously low temperatures were confined to the upper water column (0-100 m) as there was salinity stratification from large coastal freshwater runoff. The Freeland algorithm could not determine meaningful MLD values for these two years, but a visual examination showed that by late winter, both years had deeper than average MLDs. The water column appeared to be completely mixed to 263 m in March 2007, and in January 2008, the deepest mixed layer was 185 m. Both these values were determined by visual examination and have not been included in the Freeland MLD time series, as described above. Some of these anomalous temperature and salinity signals persisted up to mid-2009, though temperature and salinity values may have returned to within 1 standard deviation of the 1974-2006 values as of spring 2009 (www.ims.uaf.edu/gak1/). The Freeland algorithm returned an MLD value of 168 m for March 2009, which is close to the 35-year average for GAK1. Today, it is not possible to determine whether the events of the past few years signal a shift to another climatic state, perhaps a cold phase, as in the early 1970s (Royer 2005).



[Figure GA-11] Winter mixed layer depth (m) at GAK1 from 1974-2006.

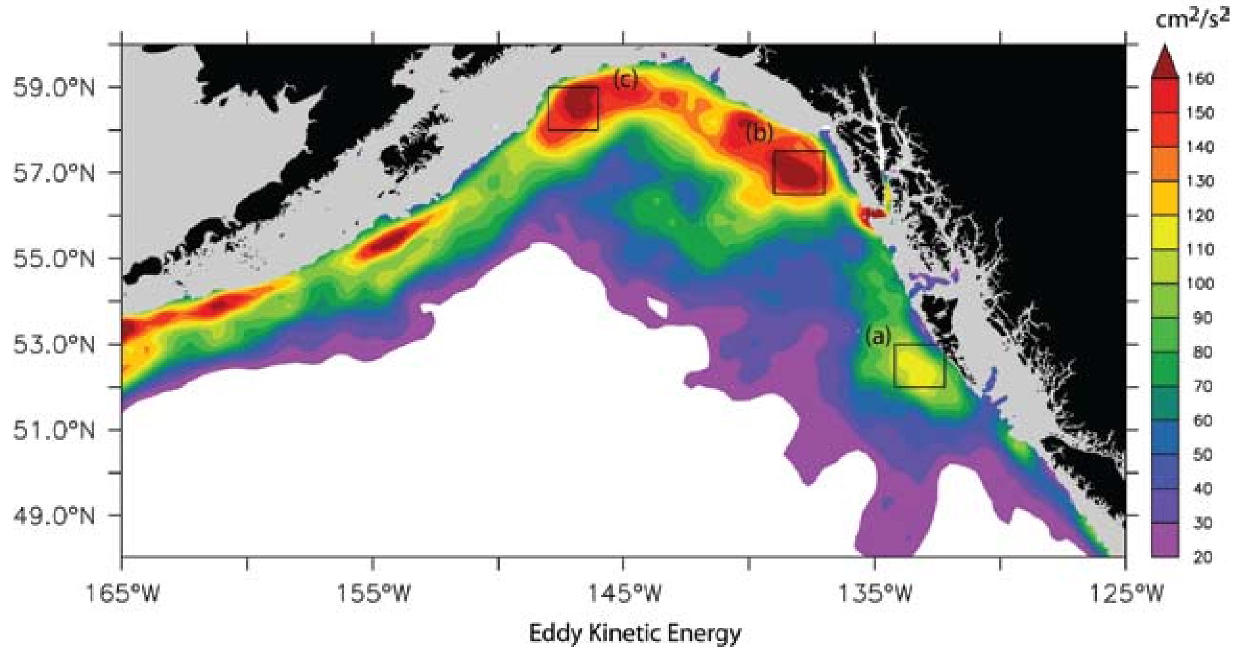
3.3 Eddies in the Gulf of Alaska *(Ladd)*

Eddies in the northern Gulf of Alaska influence the distributions of nutrients (Ladd et al. 2005; Ladd et al. 2007), phytoplankton (Brickley and Thomas 2004), ichthyoplankton (Atwood et al. submitted), and the foraging patterns of fur seals (Ream et al. 2005). Eddies propagating along the slope in the northern and western

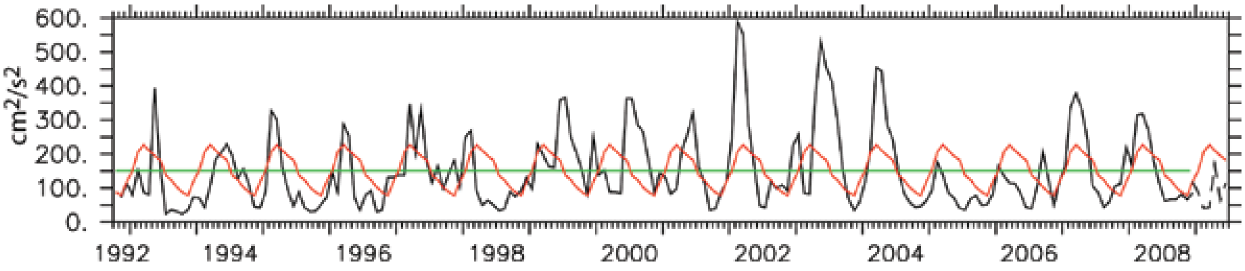
GoA are generally formed in the eastern GoA in autumn or early winter (Okkonen et al. 2001). In most years, these eddies impinge on the shelf east of Kodiak Island in the spring. Using altimetry data from 1993 to 2001, Okkonen et al. (2003) found an eddy in that location in the spring of every year except 1998. They found that strong, persistent eddies occur more often after 1997 than in the period from 1993 to 1997. Ladd (2007) extended that analysis and found that, in the region near Kodiak Island, eddy energy in the years 2002-2004 was the highest in the altimetry record (1993-2006).

Since 1992, the Topex/Poseidon/Jason/ERS satellite altimetry system has been monitoring sea surface height (SSH). Eddy kinetic energy (EKE) can be calculated from gridded altimetry data (merged TOPEX/Poseidon, ERS-1/2, Jason and Envisat) (Ducet et al. 2000). A map of eddy kinetic energy in the GoA averaged over the altimetry record (updated from Ladd 2007) shows three regions with local maxima (labeled a, b, and c in Fig. GA-12). The first two regions are associated with the formation of (a) Haida eddies and (b) Sitka eddies. Regions of enhanced EKE emanating from the local maxima illustrate the pathways of these eddies. Sitka eddies can move southwestward (directly into the basin) or northwestward (along the shelf-break). Eddies that move along the shelf-break often feed into the third high EKE region. By averaging EKE over region (c) (see box in Fig. GA-12), we obtain an index of energy associated with eddies in this region (Fig. GA-13).

Region (c) exhibits high EKE in the spring (March-May) with lower EKE in the autumn (September-November). EKE was particularly high in 2002-2004 when three large persistent eddies passed through the region. Prior to 1999, EKE was generally lower than the ~16-year average, although 1993 and 1997 both showed periods of high EKE. Low EKE values were observed for 2005-2006 indicating a reduced influence of eddies in the region. Higher EKE values were observed in the spring of 2007 and 2008 as eddies moved through the region. EKE levels were low in the spring of 2009. This may have implications for the ecosystem. Phytoplankton biomass was generally more tightly confined to the shelf during 2005-2006 due to the absence of eddies, while in 2007 and 2008 phytoplankton biomass extended farther off the shelf. In addition, cross-shelf transport of heat, salinity and nutrients were likely to be smaller in 2005-2006 and 2009 than in 2007 and 2008 (or other years with large persistent eddies). The altimeter products were produced by the CLS Space Oceanography Division (AVISO 2008).



[Figure GA-12] Eddy Kinetic Energy (cm²·s⁻²) averaged over October 1993-October 2007 calculated from satellite altimetry. (c) denotes region over which EKE was averaged for Figure GA-13.



[Figure GA-13] Eddy kinetic energy ($cm^2 \cdot s^{-2}$) averaged over Region (c) shown in Figure GA-12. Black (line with highest variability): monthly EKE. Red: seasonal cycle. Green (straight line): mean over entire time series.

3.4 Chemical oceanography

3.4.1 Nutrients

Long term systematic observations of the chemical properties of GoA waters with which to evaluate the status and trends during the focus period are currently unavailable.

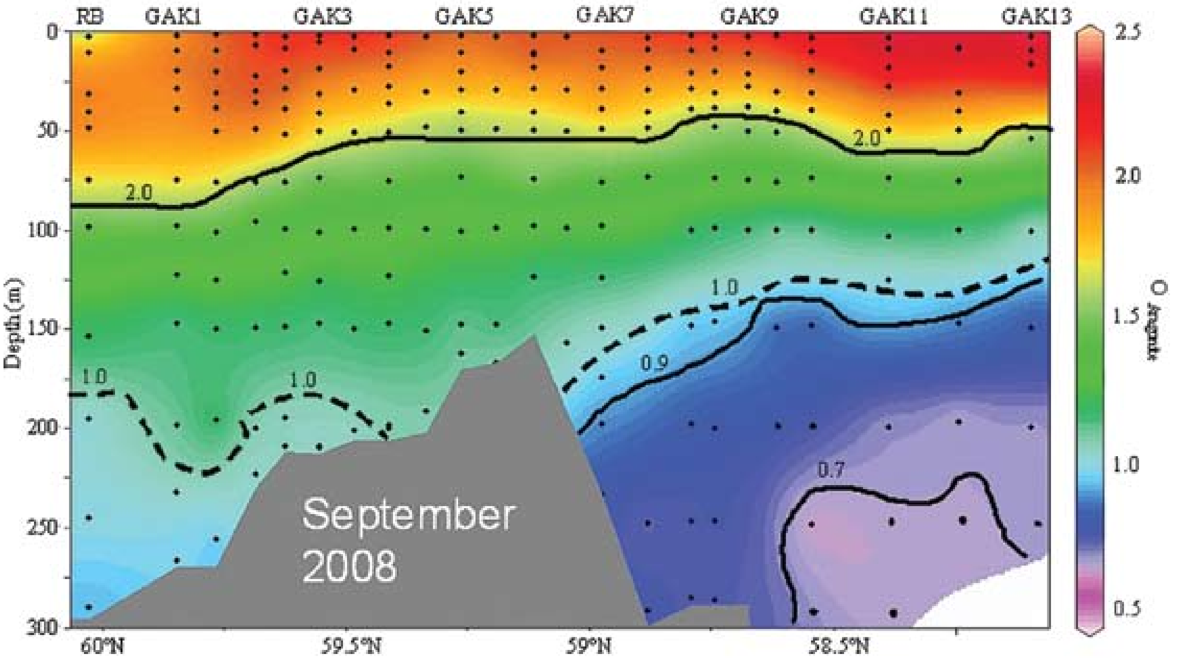
3.4.2 Ocean acidification *(Mathis)*

An extensive study measuring pH off the coast of Washington State from 2000-2008 demonstrated a clear decline in ocean pH of nearly 0.4 (Wootton et al. 2008). This was a much greater decline than most models predicted. The study also documented that the number of mussels and stalked barnacles declined as the acidity increased. Acidification will affect Alaskan waters earlier than more southerly latitudes due to a combination of the shallowness of the carbonate saturation depth and cold temperatures. The saturation horizon for calcium carbonate (aragonite) has become shallower in the North Pacific Ocean and is currently about 200 m. This contrasts with about 2000 m in the North Atlantic Ocean (Feely et al. 2004). Carbon dioxide is also more soluble in colder water so low pH water is available at shallower depths in the North Pacific than in other oceanic basins, and is becoming moreso with time.

Seasonal changes in saturation depth were observed during a transect line in May and September of 2009 that extended seaward from Resurrection Bay into the northern Gulf of Alaska. During these cruises, measurements were taken for dissolved inorganic carbon (DIC) and total alkalinity (TA) and when coupled with hydrographic and nutrient data allowed for the determination of the carbonate mineral saturation (i.e. Ω_{cal} and Ω_{arg}) states. In May, the entire water column inside Resurrection Bay was supersaturated with respect to Ω_{arg}, the more soluble of the carbonate minerals, with values ranging from ~1.8 at the surface to ~1.2 near to bottom (Mathis et al. unpublished). Over the inner and middle shelf, surface waters were also supersaturated with respect to aragonite with the saturation horizon (where $\Omega_{arg} = 1$) occurring at 150 m. However, by September several distinctive changes had occurred. The bottom waters both inside Resurrection Bay and on the inner shelf had become undersaturated with respect to Ω_{arg} (Fig. GA-14) likely due to the remineralization of organic matter exported from the upper mixed layer due to intense periods of late spring and summer primary production and from the relaxation of downwelling conditions which allowed deeper water, with lower Ω_{arg} to outcrop closer to the surface. The Ω_{arg} at the surface had increased to >2.0 in response to the drawdown of DIC from photosynthesis. This divergent trajectory between surface waters and bottom waters has been shown on other polar and sub-polar shelves (Bates and Mathis 2009; Bates et al. 2009; Fabry et al. in press) but this was the first time it had been observed in the Gulf of Alaska (Mathis et al., unpublished). The range of interannual variability in this seasonal cycle is not known, nor is it clear if there are any long term-trends in this biologically driven cycle.

3.4.3 Chemical contamination

Largely as a result of the Exxon Valdez oil spill and concern over mercury levels in seafood, the GoA has been a locus for contaminants work in the last two decades. Samples from locations in Alaska during the focus period have generally not detected concentrations of polychlorinated biphenyls (PCBs), pesticides, or mercury at levels of concern. In contrast, published GoA studies



[Figure GA-14] Oceanographic section taken in September 2008 in the northern Gulf of Alaska showing aragonite saturation state (Ω_{arg}). Station numbers are shown at the top with RB indicating Resurrection Bay. Gulf of Alaska station 13 (GAK13) was the outermost station. The dashed line indicates the saturation horizon for aragonite (Adapted from Fabry et al., In Press).

during the same interval (Springman et al. 2008; Short et al. 2008) have concluded that petroleum hydrocarbons, so ubiquitous in the environment, are significantly more toxic, bioavailable, and persistent in the environment than previously thought. There are no trends suggesting an increase in any of these compounds in the GoA.

The Arctic and Subarctic are believed to be particularly at risk for PCB and pesticide accumulation in the tissues of marine organisms due to enhanced transport to these regions via the troposphere in gas phase, on particles, ocean currents, and in migrating fish. The cold temperatures of the north tend to cause precipitation, releasing the chemicals into the water, where they are absorbed by aquatic organisms (such as copepods) and sequestered in lipid, later to be consumed by higher predators such as fish and seals (AMAP 2009). However, a 2004 study (Alaska Department of Environmental Conservation 2004) concluded that total PCB levels in fish were below 10 ng·g^{-1} and pesticide concentrations were largely below detection limits. Integrated samplers capable of detecting bioavailability of very low concentrations of these chemicals were deployed at 53 sites in Prince William Sound. The concentration of total PCBs and pesticides in the samplers rarely exceeded 1 ng·l^{-1}, far below the concentration likely to induce a biological response (Short et al. 2008). Concentrations of polychlorinated biphenyls and pesticides in ovaries or muscle tissue of chinook salmon returning to spawn in the Kenai River in 2004 were below 10 µg·g^{-1}, suggesting that remote delivery of these compounds was not occurring in that river (Rice and Moles 2006).

Mercury poses a high risk for pregnant women and the public remains concerned about mercury levels in fish. But a 2007 review of the extant data suggests that the levels in most commercially-harvested GoA fishes remain low. In a review of studies of mercury levels in fish species in Alaska, Jewett and Duffy (2007) concluded that concentrations of mercury were below the action levels of 1 mg·kg^{-1} of fish weight, although mercury concentration in the muscle tissues of Pacific halibut (*Hippoglossus stenolepis*) and sablefish (*Anoplopoma fimbria*) are close to the critical value for human consumption set by the EPA.

Samples of Pacific cod (*Gadus macrocephalus*) have muscle mercury concentrations (0.17 $mg \cdot g^{-1}$ wet weight) within the range known to cause adverse effects if consumed by sensitive birds and mammals (Burger and Gochfeld 2007). Similar values have been previously reported for a number of freshwater and marine fish species (Jewett and Duffy 2007). The FDA concludes that there is no evidence of an increase in mercury levels over the 30 years that the agency has maintained a database of methyl mercury levels in fish.

Polynuclear aromatic hydrocarbons (PAH), the primary toxic components in crude oil, have been monitored in the tissues of the mussel (*Mytilus trossulus)* at 12 locations in the Gulf of Alaska, including Prince William Sound, since 1993. Between 1999 and 2006, there was a decreasing trend in total hydrocarbons in the tissues of mussels at all sites. Levels in 2006 were below 100 $ng \cdot g^{-1}$ dry weight. However, PAH could still be detected in 2004 at sites impacted by the Exxon Valdez oil spill in 1996, and these hydrocarbons were still capable of inducing a biological response (as measured by induction of the liver enzyme CYP1A) when injected into fish (Springman et al. 2008; Short et al. 2008).

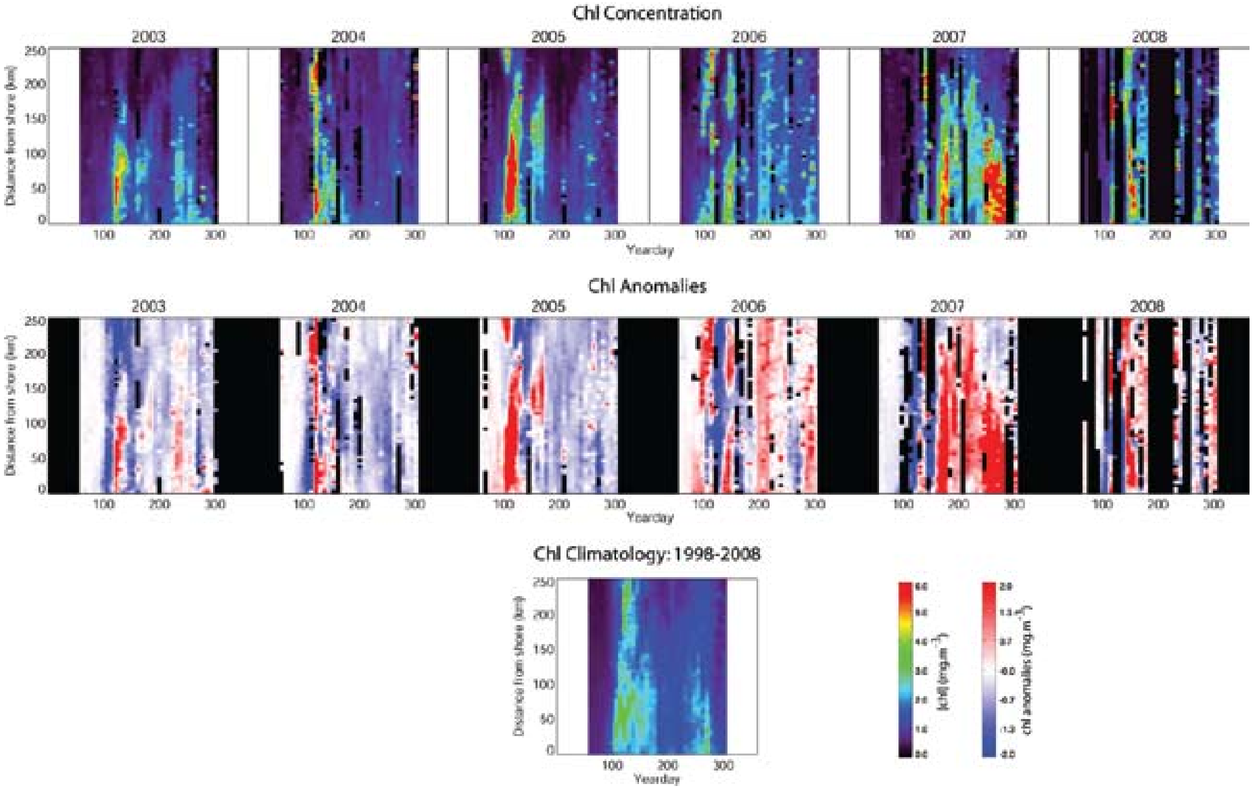
4.0 Biological Ocean

4.1 Phytoplankton *(Hopcroft, Thomas)*

Like most of the important physical processes in the coastal GoA, primary production varies on seasonal and interannual time scales, and exhibits pronounced cross-shelf and along-shelf gradients (Brickley and Thomas 2004). Nutrient re-supply to deep shelf waters occurs during summer relaxation of downwelling winds, and re-supply to surface waters occurs primarily during winter mixing (Childers et al. 2005; Hermann et al. 2009). Spring bloom onset is closely tied to increases in water column stability (Henson 2007) and solar irradiance (Dagg et al. unpublished). Ocean color images suggest that the bloom occurs in March in central Southeast Alaska offshore of Sitka, and in the inside waters near Wrangell, slightly later (early April) within Prince William Sound, and in late April or early May within the northern coastal Gulf of Alaska. Duration and intensity of the shelf spring bloom may be related to variations in bloom timing, with earlier blooms supporting higher chlorophyll concentrations (Henson 2007).

Macronutrient (N, Si) limitation of phytoplankton growth and production is evident during the latter part of the spring bloom as soon as biomass peaks (April or May), and continues throughout the summer months (Strom et al. 2006; Whitney et al. 2005). Episodic mixing due to tides and winds can stimulate summer production by delivering nutrients to surface waters, and primary production “hot spots” in the coastal GoA are typically associated with tidal mixing over banks and through channels (Stabeno et al. 2004; Hermann et al. 2009; Cheng et al. submitted). Study of the GoA during the U.S. GLOBEC Northeast Pacific program revealed strong cross-shelf gradients in plankton community composition, growth rates, and macronutrient distributions. These gradients are consistent with the hypothesis the iron may limit production at times on the mid and outer shelf (Strom et al. 2006). This is supported by dissolved Fe measurements from the same region (Wu et al. 2009) which show sharply decreasing surface Fe levels from the inner to mid and outer shelf, and a strong depth gradient on the outer shelf. The main sources of iron and macronutrients to the shelf are probably deep-water and freshwater runoff, with riverine inputs high in Fe and potentially, Si, and deep water enriched in N, Fe, and Si (Stabeno et al. 2004; Whitney et al. 2005). Light limitation clearly plays a role in spring bloom timing and magnitude (Napp et al. 1996) and light is sometimes considered the key limiting resource for this high-latitude ecosystem (Gargett 1997; but see above).

Temporal variability of satellite-measured chlorophyll concentrations along a transect across the Alaskan shelf at Seward (the GAK line), from the coast to 250 km offshore during the focus period is presented in Fig. GA-15. Data were measured by daily orbits of the SeaWiFS satellite and processed to chlorophyll using the standard NASA algorithm. The data shown are sub-sampled from 8-day composite images (the temporal resolution of the figure) that have 4 km spatial resolution (the cross-shelf resolution). Each cross-shelf value is the mean over ~50 km in space perpendicular to the transect. The top panel shows concentrations over the focus period. The middle panel shows anomalies, calculated by subtracting from each 8-day period the climatological annual seasonal cycle along the transect. The bottom panel shows this climatological annual cycle, calculated over the SeaWiFS mission period of (1998 – 2008). There are no data in the winter due to the low light conditions and data are



[Figure GA-15] Satellite-measured chlorophyll variability along the Seward (GAK) line extending from the coast to 250 km offshore as a colour contour map in time (2003-2008) and distance (0-250 km).

unavailable during cloudy periods. The SeaWiFS satellite had some data gaps in 2008 due to technical issues.

These data clearly capture the spring bloom in mid-late April, its duration and its cross-shelf structure. In many years, this event extends 250 km offshore (the 500 m isobath is approximately 150 km offshore). Concentrations are lower in summer across the entire shelf when the water column stratifies. *In situ* chlorophyll profiles show that this period is often characterized by a sub-surface chlorophyll maximum not visible to the satellite. Low summer surface concentrations are followed by a fall bloom in ~mid August of weaker intensity and less cross-shelf extent that the spring bloom. Interannual variability in both concentrations and spatial structure is strong. Prominent features in these data are the reduced cross-shelf extent of the spring bloom in 2003, the virtual absence of a fall bloom in 2004, relatively weak blooms in 2006, and a strong fall bloom in 2007.

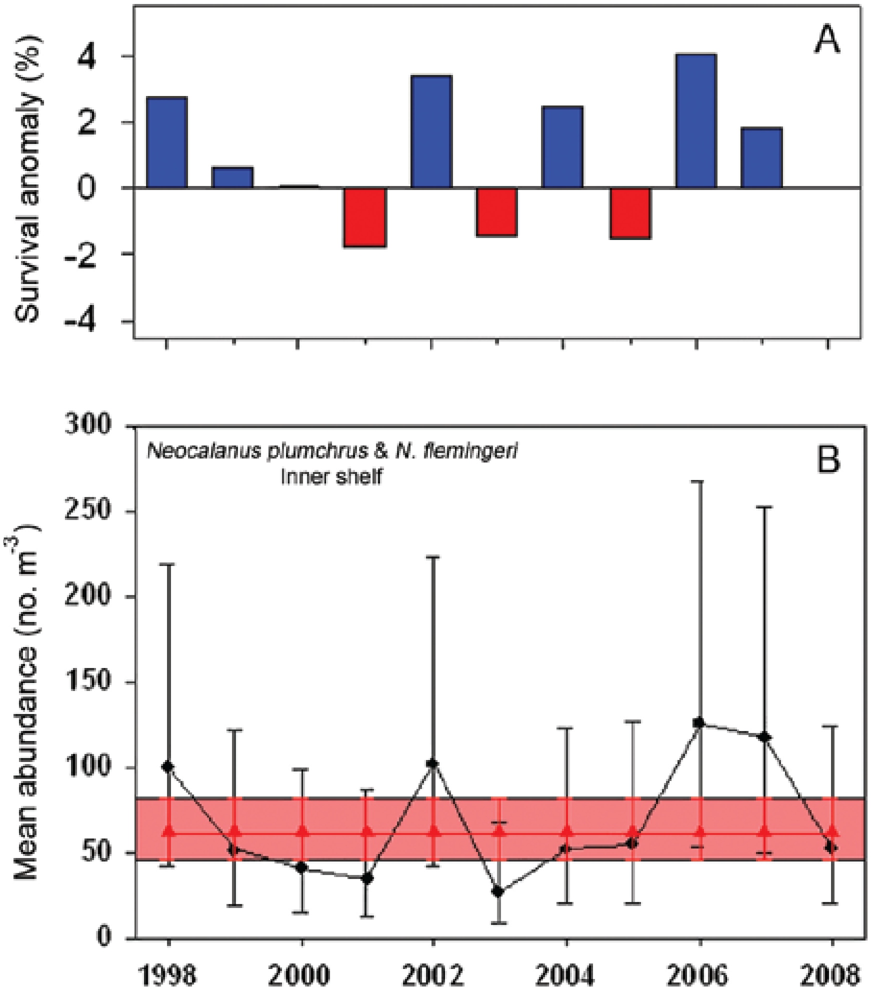
4.2 Meso- and macrozooplankton

(Hopcroft, Sturdevant)

Mesozooplankton on the GoA shelf are a mixture of two major species complexes, composed of neritic and oceanic taxa. During May and early June, the oceanic complex, consisting primarily of *Neocalanus flemingeri/plumchrus, N. cristatus, Metridia pacifica* and *Eucalanus bungii*, dominates the biomass. In July or August, abundances are dominated by smaller copepods, *Pseudocalanus* spp. and *Oithona similis*. Organisms of secondary importance in terms of abundance and biomass include the euphausiids (four *Thysanoessa* species plus *Euphausia pacifica*), the pteropod *Limacina helicina,* and larvaceans (*Oikopleura* spp.). All of these taxa contribute to the diets of various fishes during their early life-histories.

Prior to the GLOBEC program (1997-2004), little information was available on interannual variations in zooplankton stocks in the northern Gulf of Alaska and the physical mechanisms influencing those variations. Post-

GLOBEC sampling has continued along the Seward Line during 2005-2009, although confined to May and early September only. This sampling has revealed significant inter-annual differences in abundance, biomass and cross-shelf distribution of zooplankton over the past 12 years (http://www.ims.uaf.edu/GLOBEC/). For example, during May of 1998, 2002, 2006 and 2007, populations of *Neocalanus* were two to five times higher than populations during other years (Fig. GA-16b). These years coincided with years of high pink salmon (*Oncorhynchus gorbuscha*) survival (Fig. GA-16a). *Pseudocalanus* abundances in July 1998 and 2004 were about five times higher than in other years. Zooplankton abundance and biomass have been negatively correlated to salinity on the shelf, particularly in the region between the outer boundary of the ACC and the shelf break (Coyle and Pinchuk 2005). Examination of cross-shelf salinity-temperature profiles has further revealed that zooplankton abundance and biomass were depressed when oceanic water was pushed across the shelf, confining the mixing zone to a narrow band along the outer boundary of the ACC. High zooplankton abundance was observed when physical conditions created a middle shelf domain that extended from the outer boundary of the ACC to the shelf break. The exact cause of enhanced zooplankton abundance and biomass in the middle shelf mixing zone is uncertain, but release of iron limitation of primary production may play a role where low-nutrient high-iron ACC waters mix with high-nutrient low-iron oceanic waters. Interannual differences in zooplankton abundance and biomass within the ACC were much less pronounced. Thus, the abundance, biomass and productivity of zooplankton on the shelf are not simply determined by the magnitude of cross-shelf transport of dominant species such as *Neocalanus* and euphausiids, but are affected by the degree of mixing with shelf waters during along-shelf transport.



[Figure GA-16] The survival anomaly for Prince William Sound hatchery-released pink salmon tracks the abundance of *Neocalanus* copepods observed along the inner domain of the Seward Line. Red-band indicated long-term mean and 95% confidence interval.

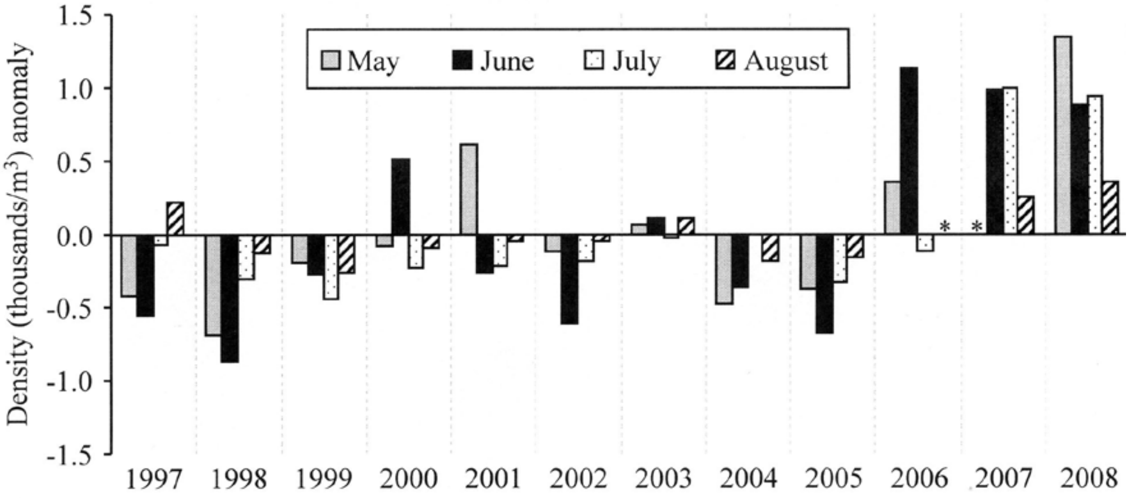
Significant variation has also been observed in the composition of the zooplankton community along the Seward Line. During cold springs such as 2002, and 2006-2009, the spring bloom was delayed, as was the development of the zooplankton community dependant upon it, by at least several weeks. Under these conditions some key zooplankton species have done better than average, while others have not. Specifically, abundance during May of the key copepod species *Neocalanus plumchrus/flemingeri* was higher than average during these cold years. Also notable has been the presence of "southern" species in warm years. During the 1997-1998 El Niño the copepods *Mesocalanus tenuicornis* and *Calanus pacificus* became more abundant (Coyle and Pinchuk 2003). During the warmer summer of 2003 the southern small copepod *Paracalanus parvus* began to appear in samples and it became unusually common during fall of 2005, persisted into 2006 concurrent with increases in *C. pacificus*, then disappeared from 2007 to the present. All of these southern species are smaller than corresponding resident species, and therefore replace larger prey items that may be more nutritious per individual for larval fish.

An unexpected revelation from the GLOBEC study was the importance of larvaceans and thecosome (shelled) pteropods in the diets of pink salmon, challenging the traditional view that *Neocalanus* and euphausiid species are the only key dietary elements (Boldt and Haldorson 2003; Armstrong et al. 2005; Cross et al. 2005). Years when juvenile pinks had high percentages of these species in the diet (2002 and 2004) were correlated with year classes of higher pink salmon growth and survival, albeit over a short (4 year) time frame (Malick et al. unpublished). The role of these under-studied taxa in the diets of other fish species may hold similar surprises.

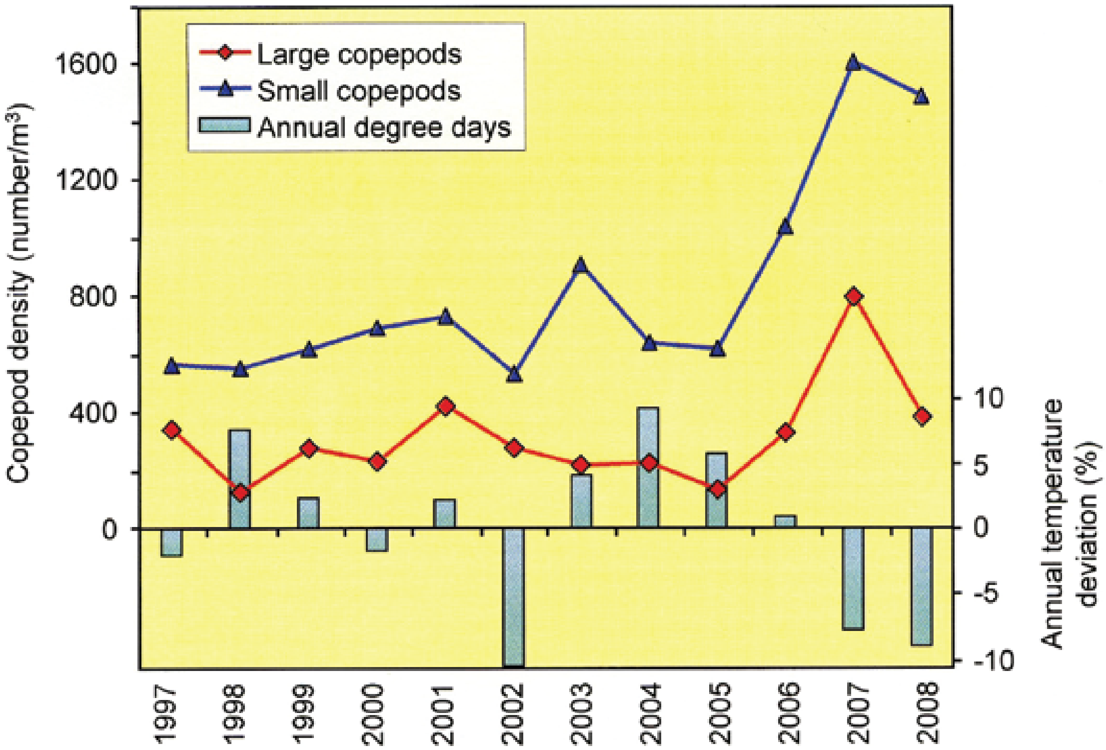
Similar to zooplankton communities along the Seward Line, patterns in zooplankton variability and trends were noted in studies using a continuous plankton recorder (CPR) across the North Pacific Ocean, which included sampling in the central and northern Gulf of Alaska (http://www.pices.int/projects/tcprsotnp/default.aspx). Mesozooplankton abundance tended to peak later in the year and was longer in duration in cool, PDO-negative years (2007, 2008) compared to warmer, PDO-positive years (2003, 2004, 2005), when the peak abundance was earlier in the year and of shorter duration. The 9 years of CPR data show an ~6 week range in the timing of peak *Neocalanus* biomass in offshore waters. Data from both the CPR survey and the Line P surveys carried out by DFO Canada (http://www.pac.dfo-mpo.gc.ca/SCI/osap/projects/linepdata/default_e.htm) show the same signal, likely caused by warmer surface conditions since they are correlated with sea surface temperature anomalies (Mackas et al. 2007). During the warmer years development is faster (although this does not account for all of the time difference) than in the cool years. The estimated timing in 2008 was later than in 2004-2006 and similar to the earlier cool period. 2007 was intermediate between the two groupings of years.

In Southeast Alaska, NOAA personnel have also assessed status and trends in zooplankton from 1997-2009 in the upper water column of the neritic waters of the ACC up to ~65 km offshore (http://www.afsc.noaa.gov/ABL/MSI/msi_secm.htm). Both standing stock ($ml \cdot m^{-3}$) and abundance ($number \cdot m^{-3}$) of total zooplankton show strong seasonal patterns, peaking in May or June and declining over the summer. Standing stock was highest in the strait habitat (Icy Strait 58.25° N 137.5°W) in summer and lowest in the coastal habitat (Icy Point 58° N 137.5°W) throughout the 12-y sampling period. These habitat comparisons suggest that the June arrival of juvenile salmon in Icy Strait coincides with an abundant food supply. During 2006-2008, zooplankton abundances were anomalously high in every month (Fig. GA-17), principally due to abundant copepods. In contrast, integrated (0-20 m) temperatures and salinities were anomalously low in 2008; the temperatures were low in all four months, while salinity and MLD varied in May and June, then were anomalously low in late summer (Orsi et al. 2009).

As with the northern and central Gulf of Alaska, the abundance of the dominant copepods of the zooplankton community varied from year-to-year in coastal Southeast Alaska, at least partially in response to climate. The 12 year time series of large (e.g., *Metridia* spp., *Calanus marshallae, Neocalanus* spp.) and small (e.g., *Pseudocalanus* spp., *Acartia* spp., and *Centropages abdominalis*) calanoid abundances showed different responses to annual temperature signals (Fig. GA-18) (Park et al. 2004). Abundance of large calanoids most often increased during cooler years and decreased during warmer years. Small calanoids may be more responsive to short term, within-season, temperature fluctuations because they can produce multiple generations per year, while many of the larger GoA copepods have life-history strategies that constrain them to a single generation per year.



[Figure GA-17] Zooplankton concentration (thousands·m^{-3}) across a 12 year time series from Icy Strait in the northern region of southeastern Alaska, 1997-2008. Data are monthly anomalies by year (deviation from mean monthly density, patterned bars). Samples represent "deep" (≤200 m depth; *n* = 4 stations) 333-µm mesh bongo net towed in double oblique fashion during daylight. Asterisk indicates no samples collected.



[Figure GA-18] Trends in average summer abundance of large and small calanoid copepods in Icy Strait, Southeast Alaska. Data are average concentration (number·m^{-3} in 333-µm mesh bongo nets) for May-August compared to annual percent deviation of average sea surface temperature (cumulative degree days from prior September-August, in °C, at 0 m) in Auke Bay, 1997-2008.

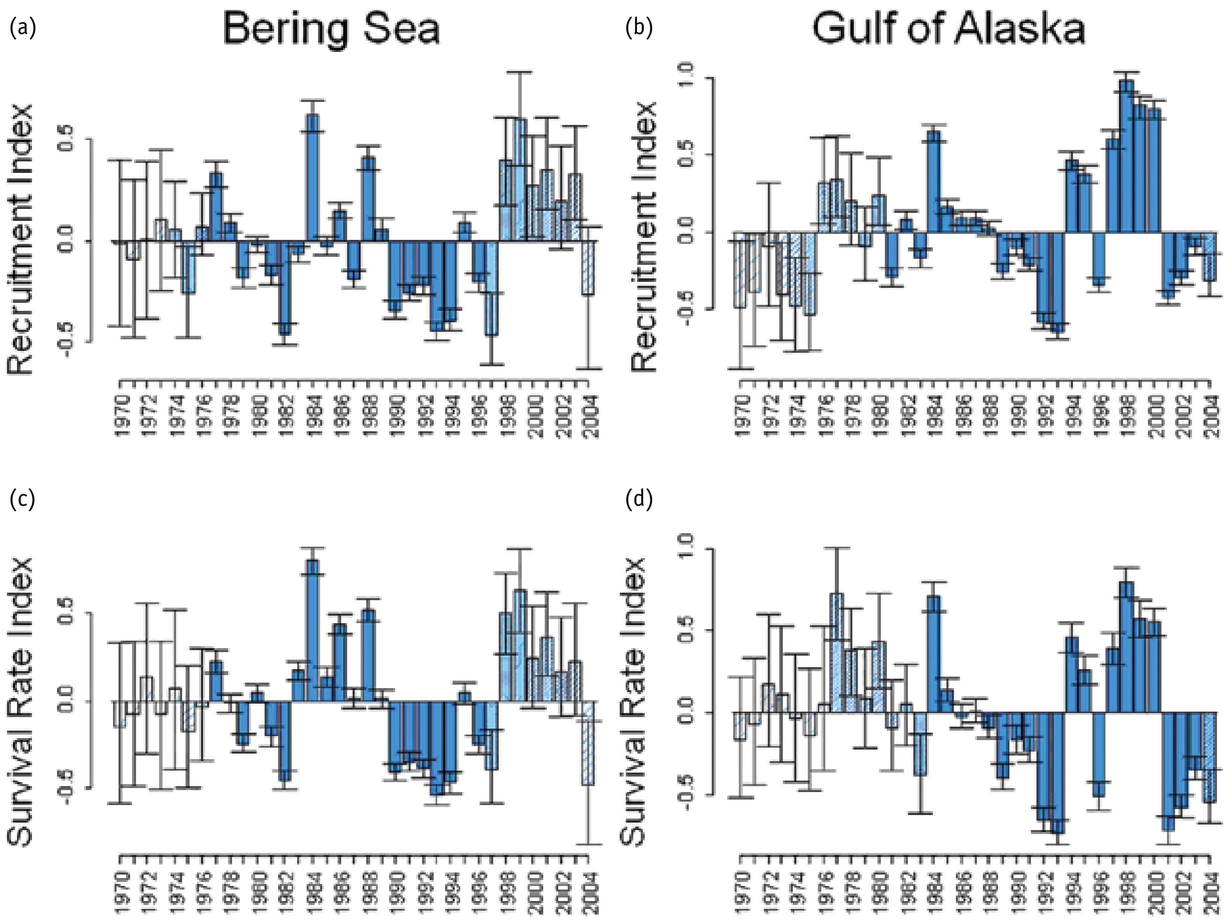
5.0 Fishes and Invertebrates

5.1 Groundfish recruitment and survival

(Mueter)

Decadal-scale variability in climate may affect groundfish survival and recruitment (Hollowed et al. 2001). Indices of recruitment and survival rate (adjusted for spawner abundance) across the major commercial groundfish species in the Gulf of Alaska (GoA, 11 stocks) provide an index of interannual and decadal-scale variability. Time series of recruitment and spawning biomass for demersal fish stocks were obtained from the 2007 SAFE reports to update results of Mueter et al. (2007). Only recruitment estimates for age classes that are largely or fully recruited to the fishery were included. Survival rate (SR) indices for each stock were computed as residuals from a spawner-recruit model. Each time series of log-transformed recruitment (logR) or SR indices was standardized to have a mean of 0 and a standard deviation of 1 (hence giving equal weight to each stock in the combined index). A combined standardized index of recruitment (CSIR) and survival (CSISR) was computed by simply averaging indices within a given year across stocks. Stock-specific estimates of logR and SR indices were not taken into account; therefore the most recent estimates of the combined indices should be interpreted with caution.

The CSIR and CSISR suggest that survival and recruitment of demersal species in the GoA were below average during the early 1990s and above average across stocks in the late 1990s / early 2000s. Because estimates at the end of the series were based on only a few stocks and are highly uncertain, the index is shown through 2004 only, the last year for which data for at least 6 stocks was available in each region (Fig. GA-19). There is strong indication for



[Figure GA-19] Recruitment (a), (b) and survival (c), (d) indices for groundfish in the Gulf of Alaska and Bering Sea (1970-2004).

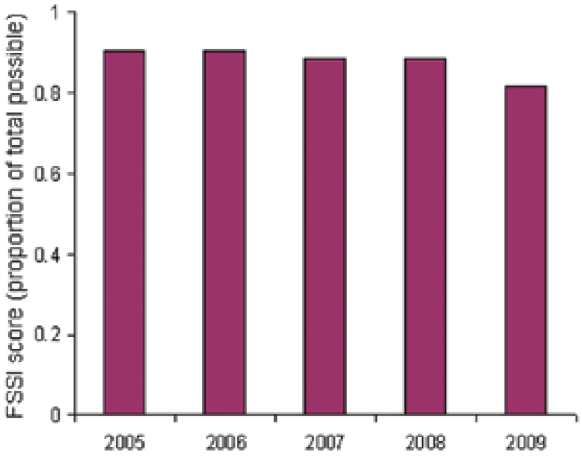
above-average survival and recruitment in the GoA from 1994-2000 (with the exception of 1996, which had very low indices) and below-average survival / recruitment since 2001. From 2001 to 2004, 9 out of 11 or 8 out of 10 stocks have had below average CSISR and CSIR indices. More recent years can not be estimated because there is no survey or catch data for most species for these years. Gadid estimates are available through 2007, but are highly unreliable.

Trends in recruitment are a function of both spawner biomass and environmental variability. Trends in survival rate indices, which are adjusted for differences in spawner biomass, are presumably driven by environmental variability but are even more uncertain than recruitment trends. Typically, spawner biomass accounted for only a small proportion of the overall variability in estimated recruitment. The observed patterns in recruitment and survival suggest decadal-scale variations in overall groundfish productivity in the Gulf of Alaska and are moderately correlated with similar indices for the Bering Sea (CSIR: r = 0.42; CSISR: r = 0.47) (Fig GA-19). These variations in productivity are correlated with, and may in part be driven by, variations in large-scale climate patterns such as the PDO or more regional measures such as ocean temperatures. The November-March PDO index for the preceding winter was positively correlated with both indices, but the correlations were not significant at the 95% level.

5.2 Fish Stock Sustainability Index *(Boldt)*

The Fish Stock Sustainability Index (FSSI) is a performance measure of the sustainability of fish stocks selected for their importance to commercial and recreational fisheries (http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm). The FSSI will increase as overfishing is ended and stocks rebuild to the level that provides maximum sustainable yield. The maximum score for each stock is 4. The value of the FSSI is the sum of the individual stock scores. In the Gulf of Alaska, there are 13 FSSI stocks and an overall FSSI of 52 would be achieved if every stock scored the maximum value (Tables GA-2 and GA-3). There are also 18 non-FSSI stocks in Gulf of Alaska (Tables GA-2 and GA-4). There are 230 FSSI stocks in the U.S., with a maximum possible score of 920.

The current overall Gulf of Alaska FSSI is 39.5 of a maximum possible 48 (Fig. GA-20). The sablefish, which are managed as an Alaskan complex, score is 4. For the entire U.S., the score is 557.5 of a possible maximum score of 920. From 2004-2009, no Gulf of Alaska groundfish stock or stock complex was overfished and no groundfish stock or stock complex was being subjected to overfishing (Tables GA-2 and GA-3). The stocks that had low FSSI scores (1.5) in the GoA are shortspine thornyhead rockfish (an indicator species for thornyhead rockfish complex), yelloweye rockfish (an indicator species for demersal shelf rockfish complex), and rex sole. These scores were low because it is undefined whether these species are overfished and unknown if they are approaching an overfished condition. Additionally, Pacific halibut is a non-FSSI stock that is now undefined in terms of its overfishing status because there is no overfishing definition contained in the FMP (only an overfishing target).



[Figure GA-20] Fish Stock Sustainability Index Score as a proportion of the total possible score.

[Table GA-2] Description of FSSI and non-FSSI stocks managed under federal fishery management plans off Alaska, March 2009.

Jurisdiction	Stock Group	Number of Stocks	Overfishing					Overfished					Approaching Overfished Condition
			Yes	No	Not Known	Not Defined	N/A	Yes	No	Not Known	Not Defined	N/A	
NPFMC	FSSI	13	0	13	0	0	0	0	10	0	3	0	0
NPFMC and IPHC	Non FSSI	18	0	11	0	7	0	0	3	0	15	0	0
	Total	31	0	24	0	7	0	0	13	0	18	0	0

[Table GA-3] This table was adapted from the Status of U.S. Fisheries website, which is updated quarterly: http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm. Information presented in this table is for FSSI stocks and was updated July 2009 (note that these are updated through March 2009 and posted online in July 2009).

Stock	Overfishing? Is Fishing Morality above Threshold	Overfished? Is biomass below threshold	Approaching Overfished Condition?	Management Action Required	Rebuilding Program Progress	B/Bmsy or B/Bmsy Proxy	FSSI score
Sablefish	No	No	No	N/A	N/A	1.05	4
Arrowtooth flounder	No	No	No	N/A	N/A	2.98	4
Flathead sole	No	No	No	N/A	N/A	2.69	4
Deepwater flatfishes	No	No	No	N/A	N/A	2.35	4
Demersal shelf rockfish	No	Undefined	Unknown	N/A	N/A	Not est.	1.5
Pelagic shelf rockfish	No	No	No	N/A	N/A	1.51	4
Thornyhead rockfish	No	Undefined	Unknown	N/A	N/A	Not est.	1.5
Northern rockfish	No	No	No	N/A	N/A	1.49	4
Pacific cod	No	No	No	N/A	N/A	0.91	4
Pacific Ocean perch	No	No	No	N/A	N/A	1.16	4
Rex sole	No	Undefined	Unknown	N/A	N/A	Not est.	1.5
Blackspotted and rougheye rockfish	No	No	No	N/A	N/A	1.6	4
Walleye pollock	No	No	No	N/A	N/A	0.79	3

[Table GA-4] This table was adapted from the Status of U.S. Fisheries website, which is updated quarterly: http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm. Information presented in this table is for non-FSSI stocks and was updated July 2009 (note that these are updated through March 2009 and posted online in July 2009). Area abbreviations: BS (Bering Sea), AI (Aleutian Islands), GoA (Gulf of Alaska).

Stock	Area	Overfishing? Is Fishing Morality above Threshold	Overfished? Is biomass below threshold	Approaching Overfished Condition?
Atka mackerel	GoA	No	Undefined	Unknown
Big skate	GoA	No	Undefined	Unknown
Other skates	GoA	No	Undefined	Unknown
Other slope rockfish	GoA	No	Undefined	Unknown
Other species complex	GoA	Undefined	Undefined	Unknown
Shallow water flatfish	GoA	No	Undefined	Unknown
Longnose skate	GoA	No	Undefined	Unknown
Shortraker rockfish	GoA	No	Undefined	Unknown
Walleye pollock	Eastern GoA	No	Undefined	Unknown
Coho salmon Assemblages	Alaska	No	No	No
Chinook salmon	Eastern North Pacific Far North Migrating	No	No	No
Bering scallop	Alaska	Undefined	Undefined	N/A
Giant rock scallop	Alaska	Undefined	Undefined	N/A
Reddish scallop	Alaska	Undefined	Undefined	N/A
Spiny scallop	Alaska	Undefined	Undefined	N/A
Weathervane scallop	Alaska	No	Undefined	N/A
White scallop	Alaska	Undefined	Undefined	N/A
Pacific halibut	Pacific coast and Alaska	Undefined	No	No

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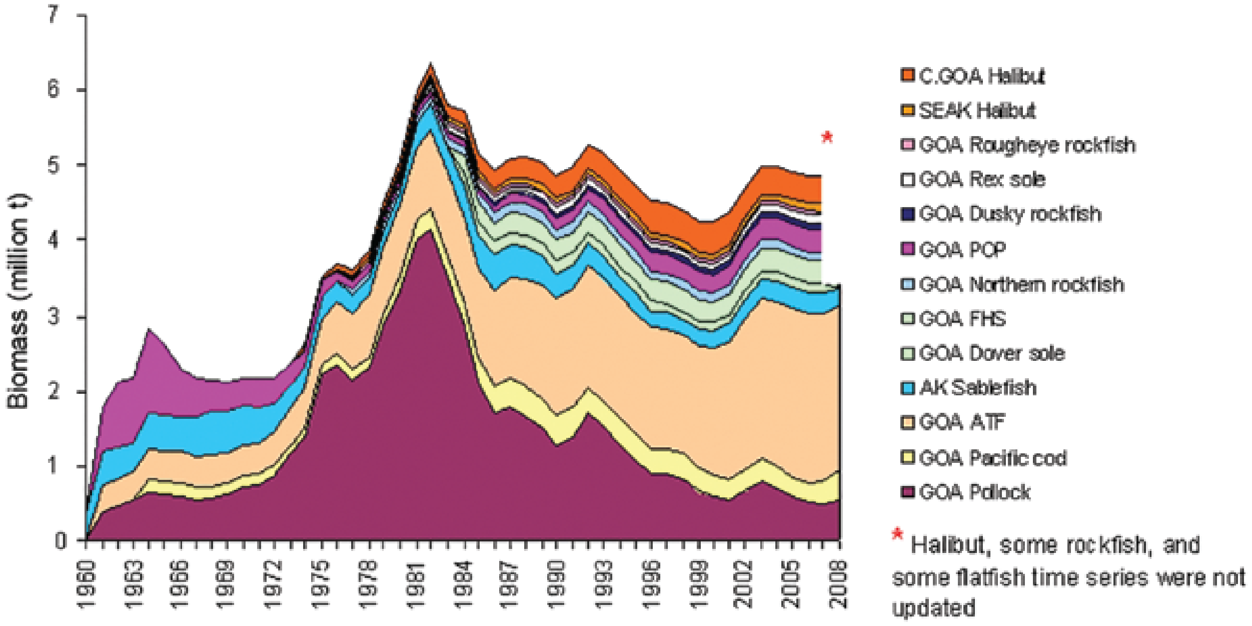
5.3 Trophic level of the catch *(Livingston)*

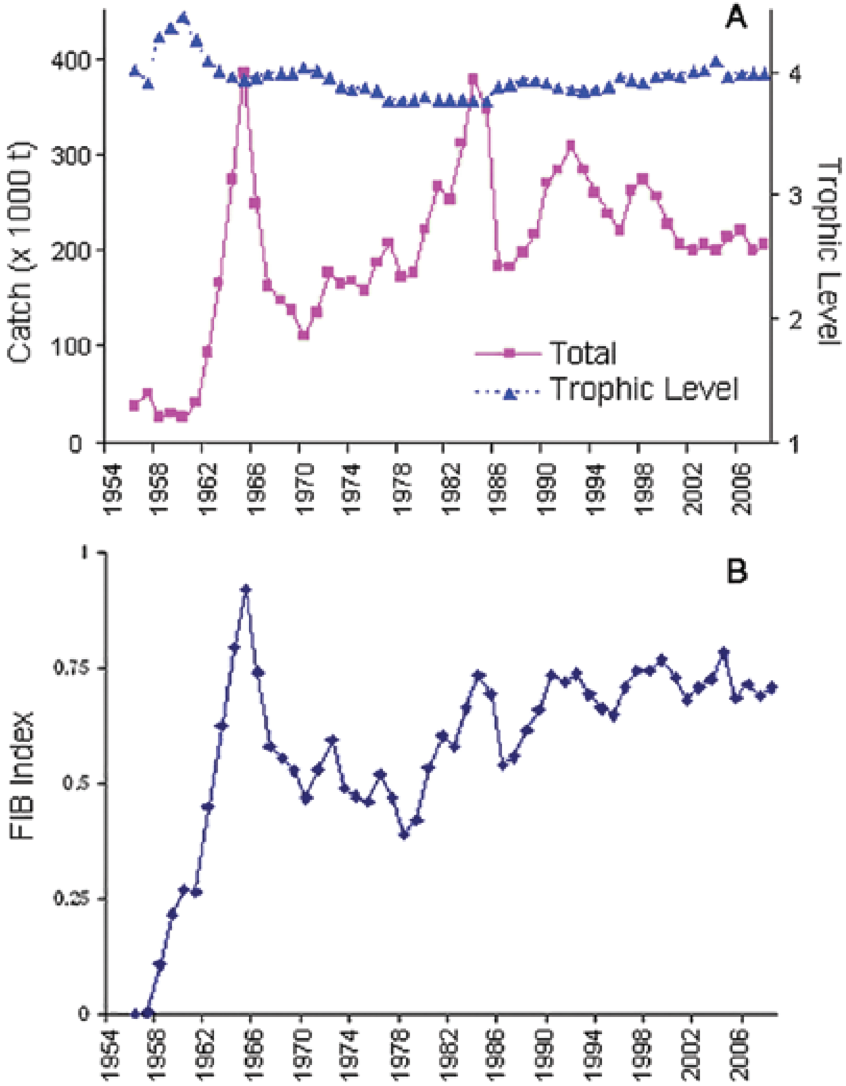
To determine whether North Pacific fisheries were "fishing-down" the food web, the total catch, trophic level of the catch (Pauly et al. 1998), and the Fishery In Balance (FIB) Index (Pauly et al. 2000) in the Gulf of Alaska were determined. Total groundfish and invertebrate composition was dominated by walleye pollock from the 1970s to at least the early 1990s (Fig. GA-21). Rockfish dominated catch prior to the 1970s. Stability in the trophic level of the total fish and invertebrate catches (Fig. GA-22) indicate that "fishing-down" the food web is not occurring in the GoA. Although there has been a general increase in the amount of catch since the late 1960s, the trophic level of the catch has been high and stable over the last 25 years.

The Fishery in Balance Index of Pauly et al. (2000) was developed to ascertain whether trophic level catch trends are a reflection of deliberate choice or of a “fishing down the food web” effect. This index declines only when catches do not increase as expected when moving down the food web, relative to an initial baseline year. The FIB index (Fig. GA-22) allows an assessment of the ecological balance of the fisheries. Unlike other regions for which the FIB index has been calculated, such as the Northwest Atlantic, catches and trophic level of the catch in the GoA has been relatively constant and suggest an ecological balance in the catch patterns. Another species of interest is arrowtooth flounder because of recent abundance increases. Since this species comprises a small proportion of the catch, it has virtually no effect on the trophic level of the catch or the FIB index in the GoA, and fishing-down the food web is not occurring in the GoA.



* Halibut, some rockfish, and some flatfish time series were not updated

[Figure GA-21] Groundfish biomass trends (t) in the Gulf of Alaska (1960-2008) as determined from age-structured models of the Alaska Fishery Science Center reported by the North Pacific Fishery Management Council (2008). Halibut data were provided by the International Pacific Halibut Commission (S. Hare, pers. comm.) but not updated for 2008 for this graph. Some rockfish and flatfish species in the Gulf of Alaska were also not updated in this graph.



[Figure GA-22] (a) Total catch (groundfish, herring, shellfish, and halibut) and trophic level of total catch in the Gulf of Alaska, 1954-2008; (b) Fishery in Balance (FIB) index for the Gulf of Alaska, 1954-2008.

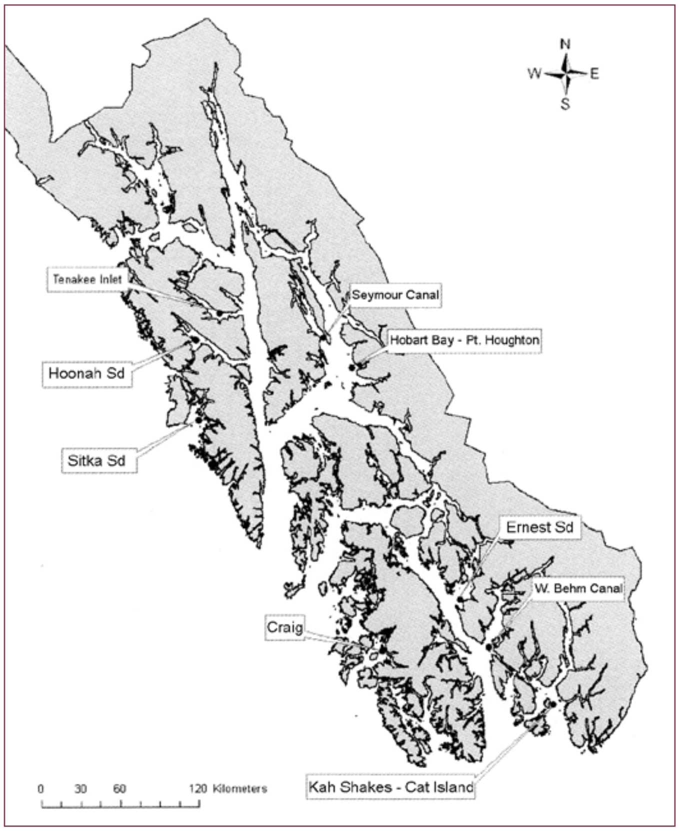
5.4 Fish species

5.4.1 Southeast Alaska Pacific herring *(Dressel)*

Southeast Alaska waters are comprised of a web of interconnected canals, inlets, sounds, and bays. Currently, there are nine major stocks of herring that reside in southeast Alaska waters, each defined on a spawning area basis: Sitka Sound, Craig, Seymour Canal, Hoonah Sound, Hobart Bay-Port Houghton, Tenakee Inlet, Ernest Sound, West Behm Canal, and Kah Shakes-Cat Island (Fig. GA-23). More limited spawning occurs at other locales throughout southeastern Alaska. Spawning at the nine primary sites for which regular assessments are conducted has probably accounted for 95-98% of the spawning biomass in southeastern Alaska in any given year. The herring that spawn in all areas of Southeast Alaska are believed to be affected by the physical and chemical characteristics of Gulf of Alaska waters, though the spawning areas on the open coast (Sitka Sound, Craig, Kah Shakes-Cat Island) may be affected the greatest or the most immediately.

Although the biomass of Southeast Alaska herring may have been greater prior to the reduction fishery and foreign fisheries that peaked around 1935 and 1970, respectively, the most reliable estimates of biomass are those from data collected since 1980, discussed here. For all stocks combined, the biomass of Southeast Alaska herring has increased since 1980 (Fig. GA-24). The combined biomass level remained relatively consistent until the late 1990s, at which time it began to increase. Age-structured assessment (ASA) modeling for the Sitka Sound, Craig, and Seymour Canal herring stocks indicated a change in herring survival in the late 1990s, which coincided with a period of climate change as described by a shift in the Pacific Decadal Oscillation index (http://jisao.washington.edu/pdo/).

For all stocks combined, five of the six highest annual biomasses since 1980 occurred during the focus period. When viewed separately by stock, the biomass of five southeast herring stocks were at high levels (Sitka Sound, Craig, Hoonah Sound, Seymour Canal, and Ernest Sound), three stocks were at intermediate levels (Hobart Bay-Port Houghton, Tenakee Inlet, and West Behm), and one stock was at a low level (Kah Shakes-Cat Island) in the focus period, compared to previous years. The low level in the Kah Shakes-Cat Island spawning area is at least in part due to a shift in spawning location to the Annette Island Reserve, which is outside the State's management authority. Levels were defined as "high" if all biomass estimates in the focus period were greater than the historical (1980-2002) average, "intermediate" if some biomass estimates in the focus period were above the historical average and some below, and "low" if all biomass estimates during the focus period were below the historical average (Table GA-5).



[Figure GA-23] Location of major Pacific herring stocks in southeast Alaska.

[Table GA-5] Estimates of mature herring biomass (t) for nine primary spawning areas in southeastern Alaska, 1980-2008, and “historical” (1980-2002) average. Values indicate either spawn deposition survey estimates plus catch (regular font), hydro-acoustic estimates (italics), or age-structured model estimates (regular font with footnote).

[a] Estimates include commercial sac roe harvest only.

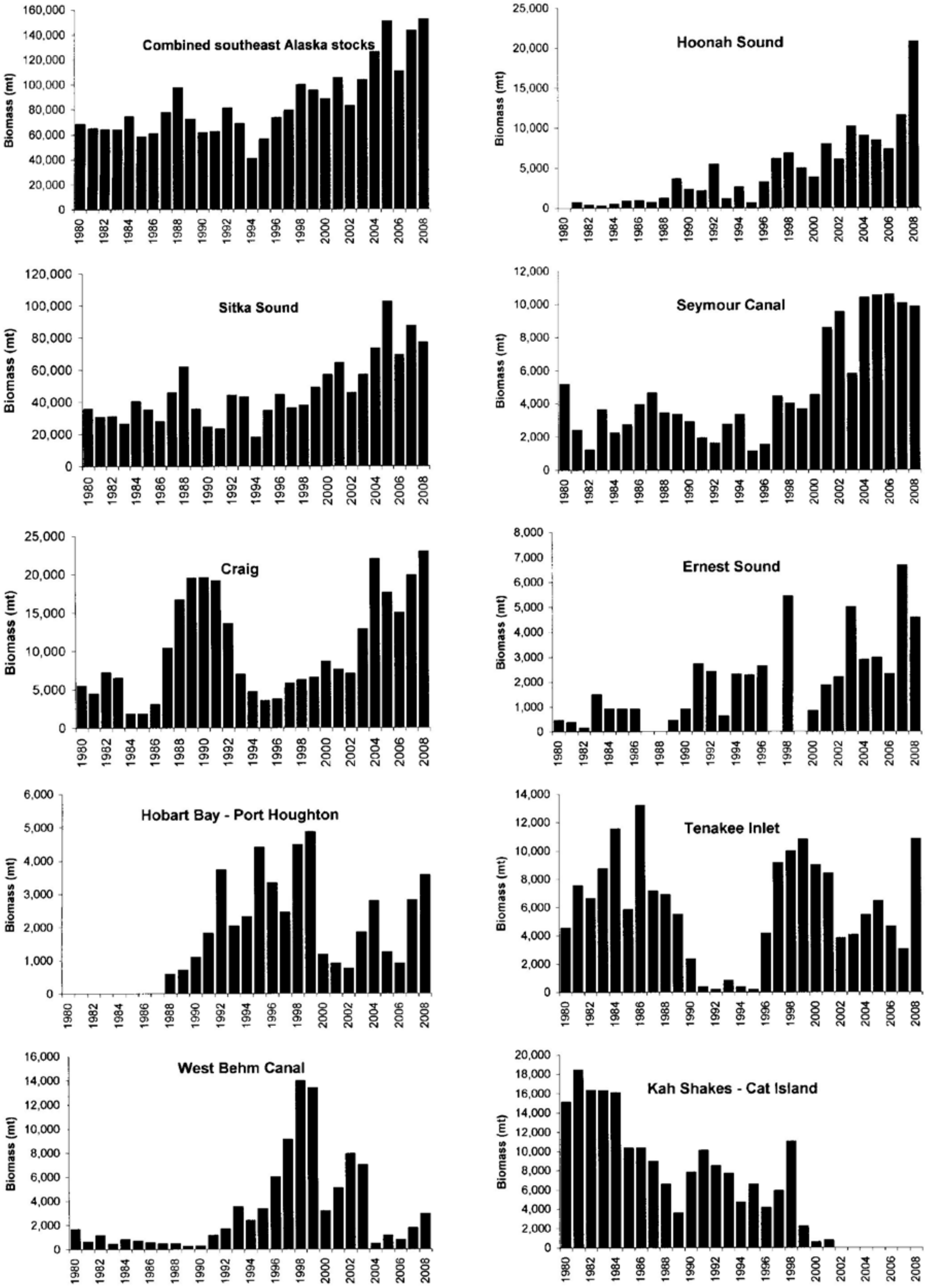
[b] Estimate based on 2008 ASA estimate because of large variability in survey estimate.

[c] Estimates are approximated because they include harvest estimates that are based on a conversion of spawn-on-kelp product to tons of herring (assumes 100% mortality of pounded herring).

[d] Unavailable due to low spawn and therefore no sampling.

[e] Unavailable due to no sampling.

	Spawning Area									
Year	**Kah Shakes - Cat Island**	**W. Behm Canal**	**Craig**	**Ernest Sound**	**Hobart Bay-Port Houghton**	**Seymour Canal**	**Sitka[a]**	**Hoonah Sound [c]**	**Tenakee Inlet**	**Combined southeast Alaska stocks**
1980	15,096	*1,654*	5,453	*454*	d	5,166	35,729	d	*4,526*	68,078
1981	18,407	*635*	4,415	*372*	d	2,389	30,396	680	*7,539*	64,833
1982	16,310	*1,134*	7,219	*145*	d	1,216	30,720	361	*6,626*	63,731
1983	16,274	*454*	6,476	*1,488*	d	3,642	26,263	240	*8,743*	63,581
1984	16,086	794	1,814	*907*	d	2,239	40,215	490	*11,538*	74,084
1985	10,338	680	1,814	*907*	d	2,722	34,904	841	5,834	58,041
1986	10,331	567	3,041	*907*	d	3,939	27,617	902	*13,190*	60,494
1987	8,926	*454*	10,415	e	d	4,628	45,555	671	7,144	77,794
1988	6,565	*454*	16,659	e	576	3,435	61,756	1,202	6,874	97,521
1989	3,549	*227*	19,497	*454*	697	3,322	35,502	3,629	5,488	72,364
1990	7,824	257	19,569	*907*	1,091	2,913	24,316	2,267	2,354	61,497
1991	10,079	1,155	19,117	*2,722*	1,814	1,905	23,050	2,123	363	62,327
1992	8,488	1,694	13,577	2,404	3,719	1,615	44,197	5,446	181	81,322
1993	7,691	3,496	6,946	628	2,030	2,726	42,970	1,119	820	68,426
1994	4,683	2,378	4,688	2,308	2,317	3,334	17,866	2,593	363	40,530
1995	6,584	3,320	3,499	2,269	4,400	1,136	34,380	577	181	56,346
1996	4,113	5,993	3,738	2,617	3,334	1,545	44,425	3,187	4,145	73,097
1997	5,901	9,091	5,779	d	2,444	4,457	36,068	6,148	9,160	79,049
1998	11,029	13,922	6,241	5,442	4,480	3,983	37,759	6,846	9,984	99,684
1999	2,184	13,355	6,513	d	4,853	3,669	48,690	4,964	10,781	95,008
2000	582	3,155	8,627	834	1,173	4,522	56,796	3,799	8,998	88,486
2001	743	5,057	7,570	1,861	901	8,549	64,163	7,960	8,417	105,220
2002	d	7,898	7,004	2,182	750	9,515	45,499	6,027	3,828	82,702
2003	d	6,968	12,768	4,997	1,834	5,771	56,879	10,182	4,056[c]	103,457
2004	d	402	21,943	2,868[c]	2,778	10,373	72,937	8,976	5,443[c]	125,719
2005	d	1,116	17,583	2,965	1,244	10,524	102,213	8,431	6,434[c]	150,464
2006	d	739	14,967	2,302	895	10,559	69,017	7,307	4,636	110,423
2007	d	1,733	19,822	6,671	2,802	10,050	87,155	11,560	3,035	142,827
2008	d	2,883	22,946	4,573[c]	3,557	9,832	76,719	20,760	10,848	152,118
Historical (1980-2002) average	8,717	3,384	8,247	1,569	2,305	3,590	38,645	2,822	5,960	73,661

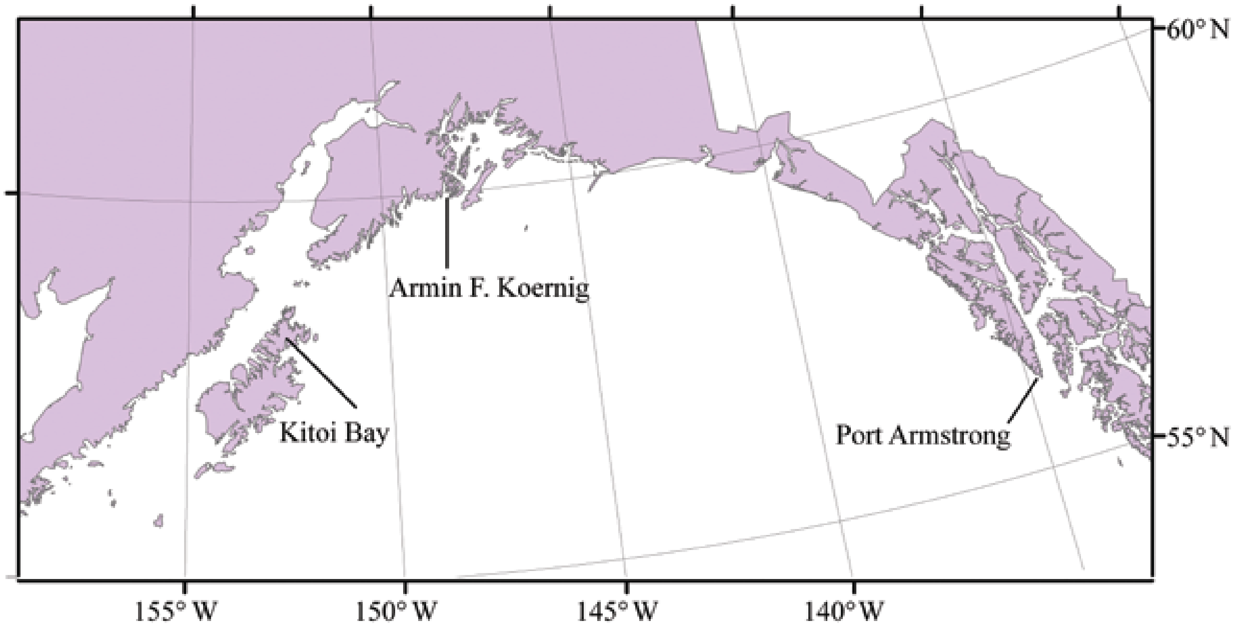


[Figure GA-24] Mature herring biomass prior to spring fishery for nine southeast Alaska stocks and all stocks combined.

5.4.2 Hatchery pink salmon *(Farley)*

Decadal-scale and interannual variability in climate and ocean productivity are known to affect total harvest of Pacific salmon (Hare and Francis 1995; Mantua et al. 1997; Francis et al. 1998; Hare et al. 1999; Downton and Miller 1998). More recent papers utilized a large pool (n >100) of salmon return and spawner (R/S) data to develop survival indices for Pacific salmon. These studies found environmental processes affecting temporal variation in salmon survival rates operated at regional scales rather than larger oceanic basin scales (Pyper et al. 2001), and that local ocean conditions (sea surface temperature, sea surface salinity, and coastal upwelling) had little to no impact on regional salmon survival rates (Mueter et al. 2005). In contrast, there was evidence that salmon survival indices positively responded to the 1976-1977 regime shift but both negative and positive responses were found for the proposed climatic regime shift of 1988-1989 (Mueter et al. 2007). Climate regime shifts are believed to have occurred during 1988-1989 (Hare and Mantua 2000) and 1998-1999 (Chavez et al. 2003; Peterson and Schwing 2003) within the GoA. Impacts of the 1976-1977 regime shift on salmon catches are well documented (e.g., Mantua et al. 1997) but further examination of this issue is warranted.

The best time series available to test for possible effects of climate regimes on hatchery pink salmon marine survival are from three hatcheries located at three representative locations in the eastern, central and western coastal Gulf of Alaska. The metric used was the ratio of the annual pink salmon fry released into marine waters to the annual number of adults returning the following year for three hatcheries, Port Armstrong (eastern), Armin F. Koernig, and Kitoi Bay hatcheries located within Southeast Alaska, Prince William Sound, and Kodiak Island along coastal waters of the Gulf of Alaska (Fig. GA-25). These hatcheries are likely representative of survival in the Gulf of Alaska since their locations minimize the effect of conditions in inside waters of Southeast Alaska and Price William Sound on early marine survival of juveniles. Hatchery data are well suited for comparisons of marine survival and climate variability because marine survival is estimated from a known number of fry released and the number of returning adults (catch + spawners), providing more accurate marine survival estimates over R/S indices used in the above papers. In addition, pink salmon only spend approximately 1 year at sea before returning to their natal streams/hatcheries to spawn.



[Figure GA-25] Pink salmon hatchery locations in Southeast Alaska (Port Armstrong), Prince William Sound (Armin F. Koernig), and Kodiak Island (Kitoi Bay).

Marine survival (1971-2007) in year t for each pink salmon cohort (eggs fertilized in year t-1) was determined by dividing the number of pink salmon fry released to marine waters of the GoA (now considered juvenile salmon) during year t by the number of returning adult pink salmon during year t+1. Pink salmon catch data (1971-2007) were assembled from Alaska Department of Fish and Game, Fishery Management Reports for Southeast Alaska (Davidson et al. 2008), Prince William Sound (Lewis et al. 2008), and Kodiak (Wadle 2007). Marine survival and pink salmon catch data were normalized and the time period of 2002 to 2007 was compared to the previous five years.

Pairwise correlations among pink salmon marine survival and catch data (regional covariation) were tested using a standard significance test, where statistical significance was determined using a two-tailed test with $\alpha = 0.05$. Positive correlation among these regionally spaced hatcheries may imply a common basin scale atmospheric/oceanic condition equally affecting hatchery pink salmon marine survival in the Gulf of Alaska.

Alaska hatcheries thermally mark otoliths of pink salmon during the egg stage. These unique thermal marks on otoliths can then be used to identify hatchery pink salmon captured during ocean surveys (Carlson et al. 2000). Otoliths were removed from juvenile pink salmon captured during the surveys and hatchery origin was determined by examining the otoliths for unique thermal marks.

Survival anomalies were negative beginning in 2002 for Port Armstrong, oscillated between positive and negative for Armin F. Koernig, and were generally positive for Kitoi Bay (Fig. GA-26). Comparing hatchery pink salmon survival anomalies from the last five years with the previous five years indicated survival anomalies generally switched from positive to negative for Port Armstrong, but no real detectible shift could be seen for either Armin F. Koernig or Kitoi Bay.

Pink salmon catch anomalies were generally positive for Southeast Alaska, with the exception of 2006, oscillating between being highly positive to near 0 for Prince William Sound, and were positive for Kodiak Island (Fig. GA-27). In Kodiak and Southeast Alaska, pink salmon catch remained positive during the last five years in all areas when compared to the previous five years.

Marine survival estimates and catch data for hatchery pink salmon were not significantly correlated ($p > 0.5$) among hatcheries and regions located around the GoA (Tables GA-6 and GA-7). Correlation coefficients were positive among hatcheries that were nearest each other and negative among hatcheries that were furthest apart. Correlation coefficients were positive among Southeast Alaska, Prince William Sound, and Kodiak pink salmon catch data but negative between Prince William Sound and Kodiak pink salmon catch data.

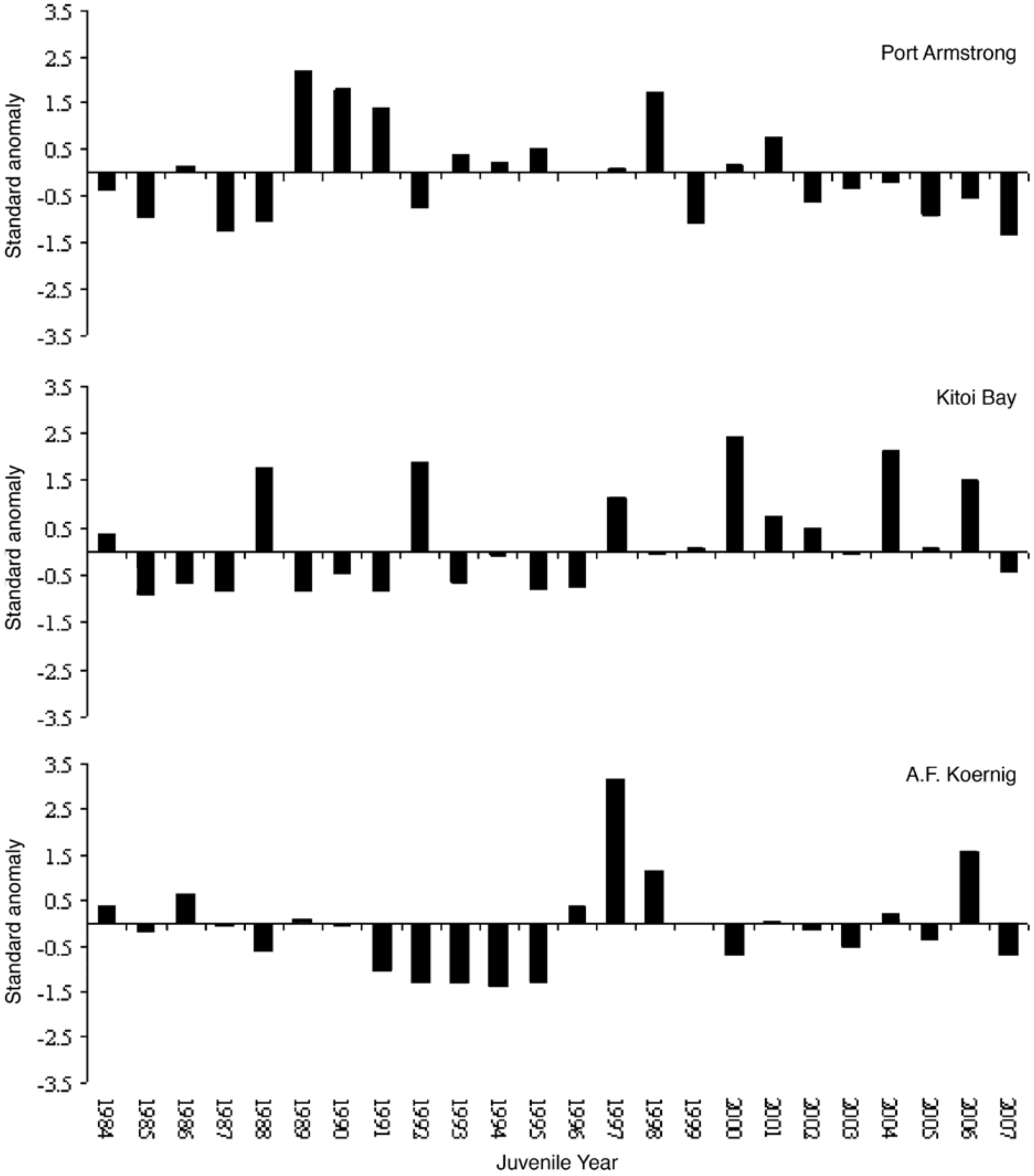
In conclusion, hatchery pink salmon survival and catch were not correlated at the regional scales examined across the GoA, further indicating that survival is likely linked to regional oceanic conditions and not basin scale conditions (Mueter et al. 2007).

[Table GA-6] Summary of pairwise correlations among pink salmon marine survival estimates (1984 – 2007) from Port Armstrong, Armin F. Koernig, and Kitoi Bay hatcheries.

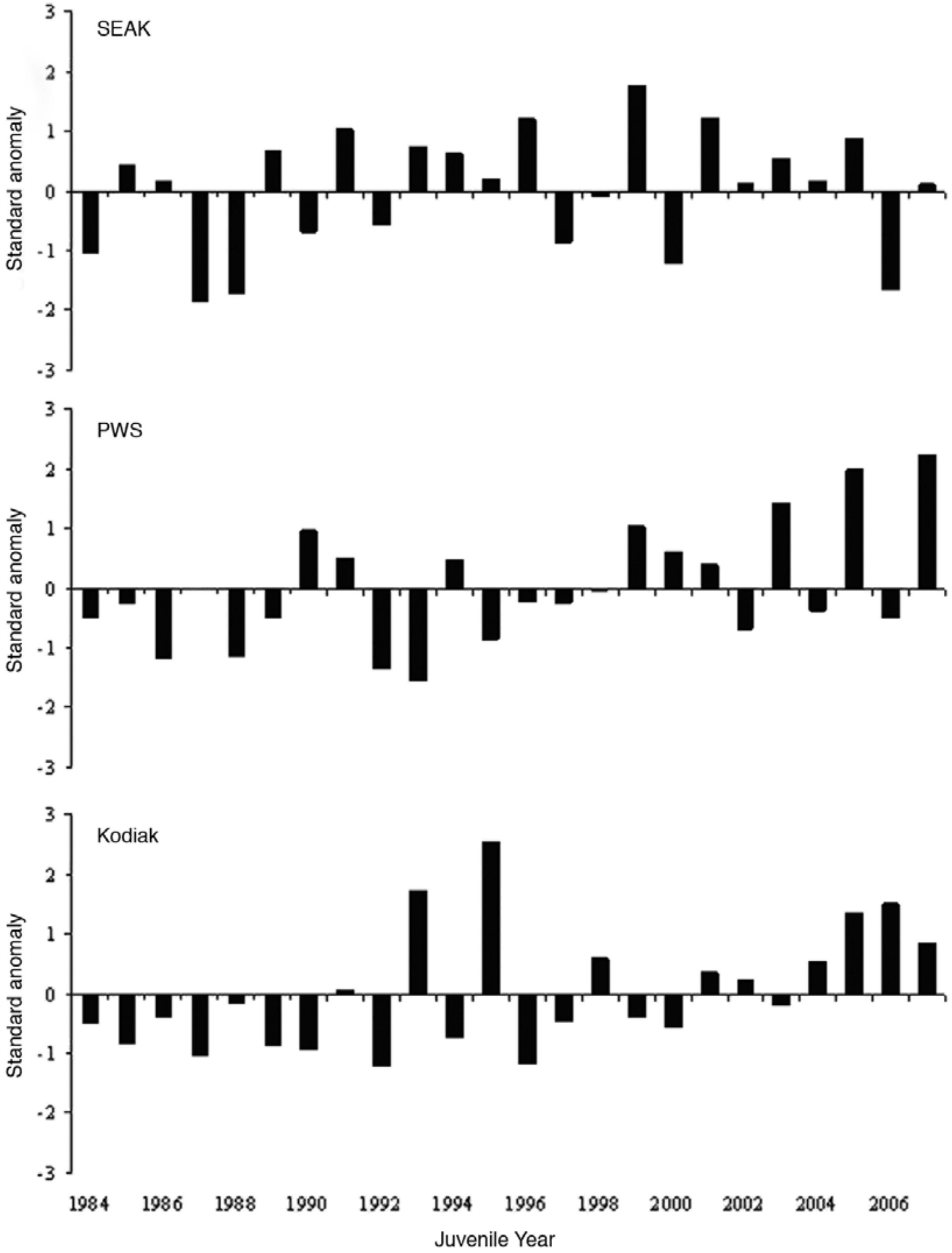
Hatchery	Port Armstrong	Armin F. Koernig
Port Armstrong		
Armin F. Koernig	0.071	
Kitoi Bay	-0.250	0.14

[Table GA-7] Summary of pairwise correlations among pink salmon catch (1984 – 2007) for Southeast Alaska (SEAK), Prince William Sound (PWS), and Kodiak.

Region	SEAK	PWS
PWS	0.28	
Kodiak	0.11	-0.00



[Figure GA-26] Standard anomalies of hatchery pink salmon survival, 1984 to 2007.

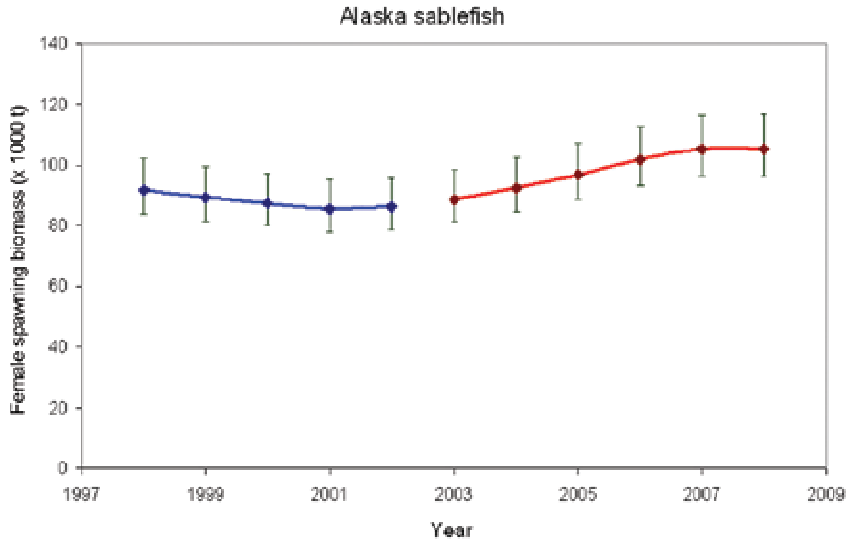


[Figure GA-27] Standard anomalies of pink salmon catch data from southeast Alaska (SEAK), Prince William Sound (PWS), and Kodiak Island, (1984 to 2007).

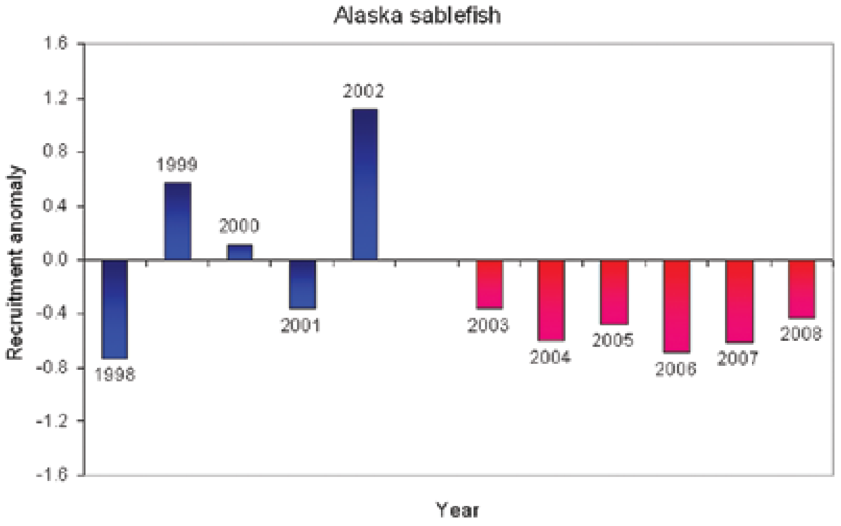
5.4.3 Sablefish

(Hanselman, Shotwell, Lunsford, Heifetz)

Sablefish (*Anoplopoma fimbria*) in Alaska are managed as a single stock so all data presented here reflect the Gulf of Alaska, Bering Sea, and Aleutian Islands regions. Sablefish abundance decreased slightly during the time period 1998-2003 reaching an all-time low in 2001 (Fig. GA-28). Since 2003, abundance has increased slightly. Sablefish abundance is highly dependent on successful recruitment. Recruitment for sablefish is defined as abundance of age-2 fish. During 1998-2002, recruitment was above average in 1999 (1997 year class) and 2002 (2000 year class) (Fig. GA-29). Annual recruitment during the focus period appears to have been below average but because it takes several years of data to accurately determine recruitment, estimates since 2002 are highly uncertain and should be considered preliminary. In general, detecting statistically significant recent trends for long-lived, late-selected groundfish is unlikely.



[Figure GA-28] Estimated female sablefish spawning biomass, 1998-2008. Error bars are ±2 times the standard deviation estimates from the stock assessment model. Blue line and markers represent the first period 1998-2002, red line and markers represent the second period 2003-2008.



[Figure GA-29] Estimated recruitment (age-2) anomalies of Gulf of Alaska sablefish, 1998-2008. Blue bars represent the first period 1998-2002, red bars represent the second period 2003-2008.

5.4.4 Rockfish species *(Rooper)*

In an analysis of Alaska rockfish (*Sebastes* spp.), five species assemblages were defined based on similarities in their distributions along environmental gradients: central GoA shelf, southeastern Alaska break, Aleutian Islands shelf, Aleutian Islands break, and Aleutian Islands slope (Rooper 2008). Data from 14 bottom trawl surveys of the GoA and Aleutian Islands (n = 6,767) were used. The distinct assemblages of rockfish were defined by geographical position, depth, and temperature (Rooper 2008). The 180 m and 275 m depth contours were major divisions between assemblages inhabiting the shelf, shelf break, and lower continental slope. Another noticeable division was between species centered in southeastern Alaska and those found in the northern GoA and Aleutian Islands. In this time-series, the mean-weighted distribution of six rockfish species along the three environmental gradients (depth, temperature, and position) was calculated for the Gulf of Alaska and Aleutian Islands. Position is the distance of each trawl from Hinchinbrook Island (60.2°N 146.6°W), Alaska. A-CPUE weighted mean value and standard deviation for each environmental variable was computed (Rooper 2008). There were no trends in distribution over the time series for depth or temperature, although the distributions of rockfish species across temperatures were more contracted in 2007 than in previous years (Fig. GA-30). However, there did appear to be a continued movement of the mean-weighted distribution towards the north and east (as indicated by the position variable). This may indicate a change in rockfish distribution around the Gulf of Alaska and is especially apparent in the distribution of juvenile Pacific Ocean perch.

5.4.5 Pacific Ocean perch

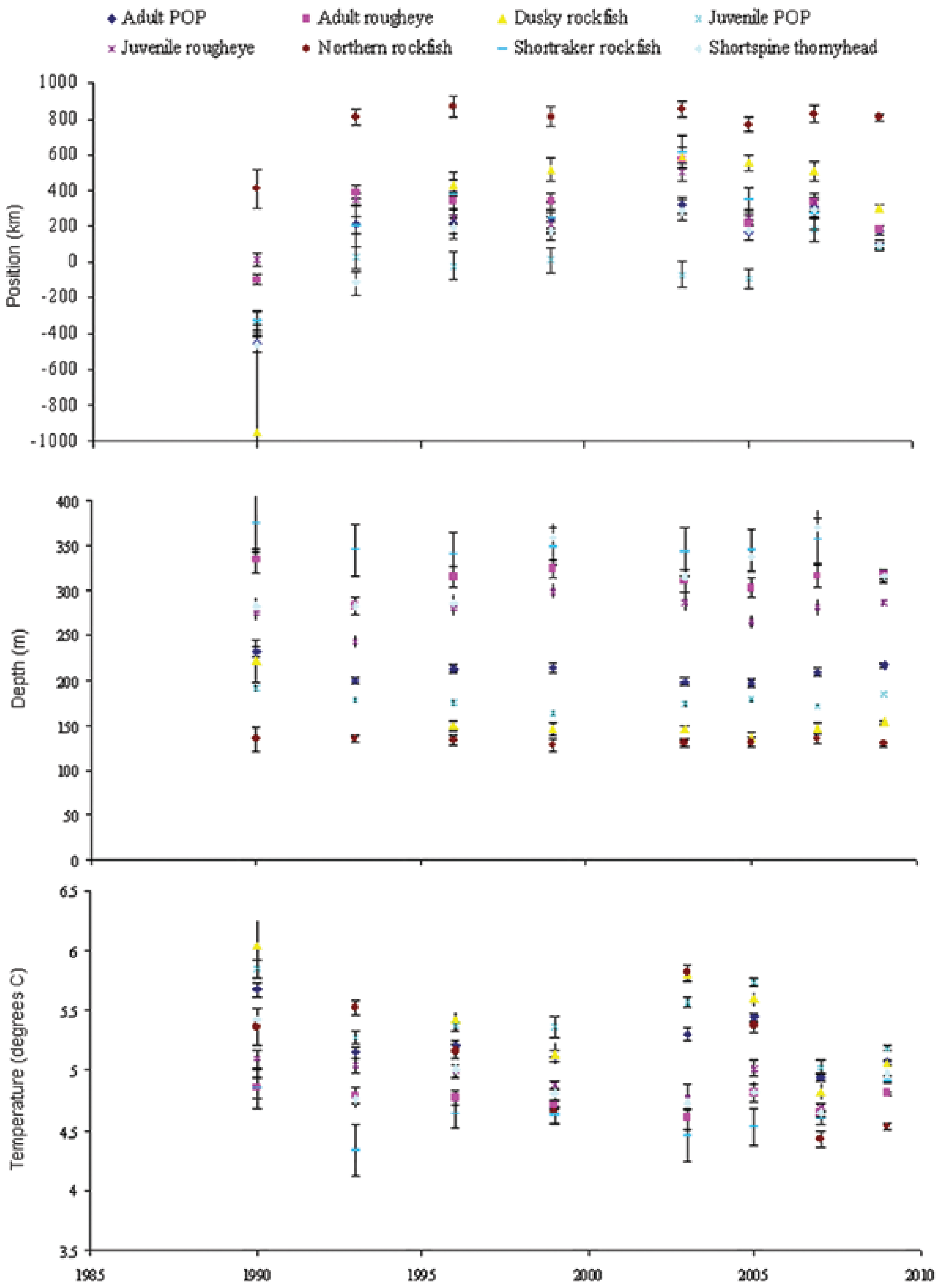
(Hanselman, Shotwell, Lunsford, Heifetz)

Pacific ocean perch (POP) (*Sebastes alutus*) is the most abundant species of rockfish in the GoA. POP abundance increased slightly during 1998-2002 and continued to increase during the focus period (Fig. GA-31). Female spawning biomass in 2008 was 29% higher than in 1998. POP abundance is highly dependent on successful recruitment, which varies widely (Fig. GA-32). Recruitment for POP is defined as age-2 fish. From 1998-2002 recruitment was near average in 1999 and 2002 (1997 and 2000 year classes), above average in 1998 and 2000 (1996 and 1998 year classes), and substantially above average during 2001 (1999 year class). Annual recruitment during the focus period appears to have been below average but, because it takes several years to accurately predict recruitment, estimates since 2002 include a high degree of uncertainty and should be considered preliminary.

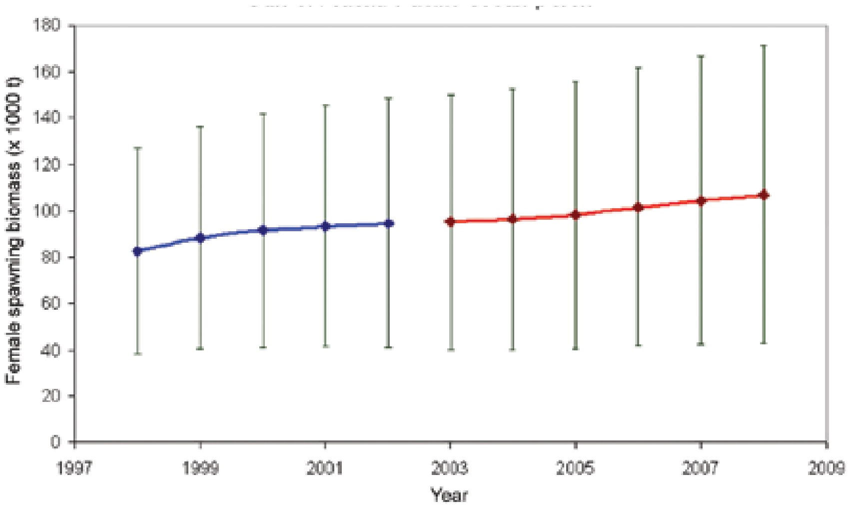
5.4.6 Northern rockfish

(Hanselman, Shotwell, Lunsford, Heifetz)

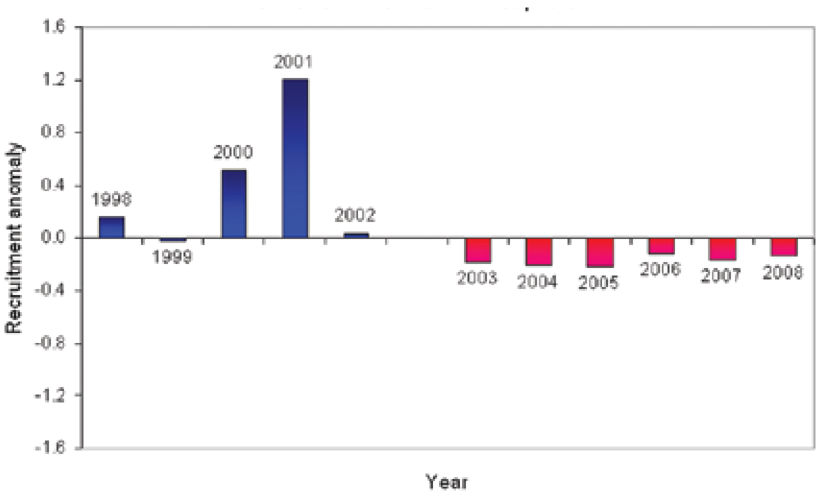
Northern rockfish (*Sebastes polyspinus*) are the second most abundant rockfish species in the Gulf of Alaska. Their abundance decreased during 1998-2002 and continued to decrease during the focus period (Fig. GA-33). Female spawning biomass in 2008 was 18% lower than in 1998. Northern rockfish abundance is highly dependent on successful recruitment which varies widely (Fig. GA-34). Recruitment for northern rockfish is defined as age-2 fish. From 1998-2002 recruitment was below average in 1998 (1996 year class), average in 1999 (1997 year class), above average in 2000 (1998 year class), and below average during 2001 and 2002 (1999 and 2000 year classes). Annual recruitment during the focus period appears to have been below average but because it takes several years to accurately predict recruitment, estimates since 2002 include a high degree of uncertainty and should be considered preliminary.



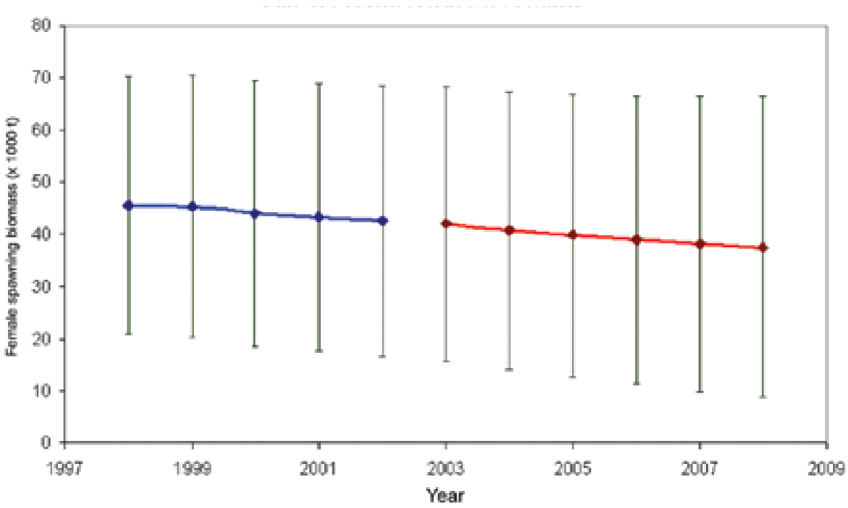
[Figure GA-30] Plots of mean-weighted (by catch per unit effort) distributions (and standard errors) of seven rockfish species groups by position in the Gulf of Alaska. Position is the distance from Hinchinbrook Island, Alaska, with positive values west of this central point in the trawl surveys and negative values in the southeastward.



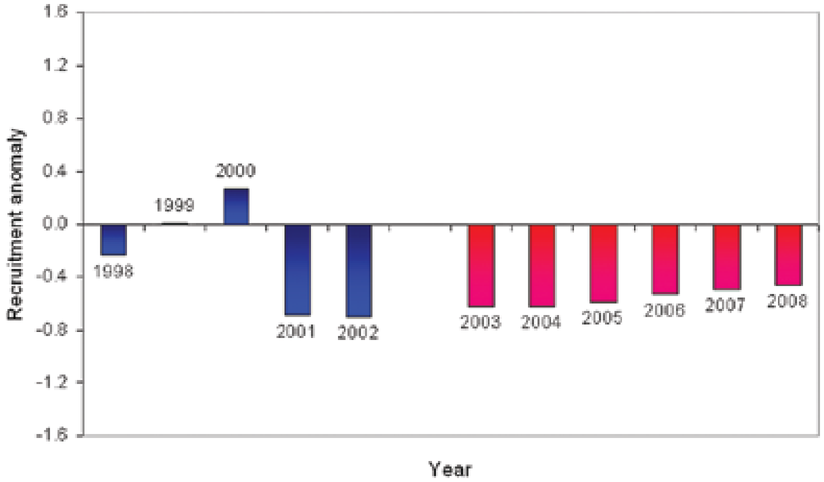
[Figure GA-31] Estimated Gulf of Alaska female Pacific Ocean perch spawning biomass, 1998-2008. Error bars are ±2 times the standard deviation estimates from the stock assessment model. Blue line and markers represent the first period 1998-2002, red line and markers represent the second period 2003-2008.



[Figure GA-32] Estimated recruitment (age-2) anomalies of Gulf of Alaska Pacific Ocean perch, 1998-2008. Blue bars represent the first period 1998-2002, red bars represent the second period 2003-2008.



[Figure GA-33] Estimated Gulf of Alaska female northern rockfish spawning biomass, 1998-2008. Error bars are ±2 times the standard deviation estimates from the stock assessment model. Blue line and markers represent the first period 1998-2002, red line and markers represent the second period 2003-2008.



[Figure GA-34] Estimated recruitment (age-2) anomalies of Gulf of Alaska northern rockfish, 1998-2008. Blue bars represent the first period 1998-2002, red bars represent the second period 2003-2008.

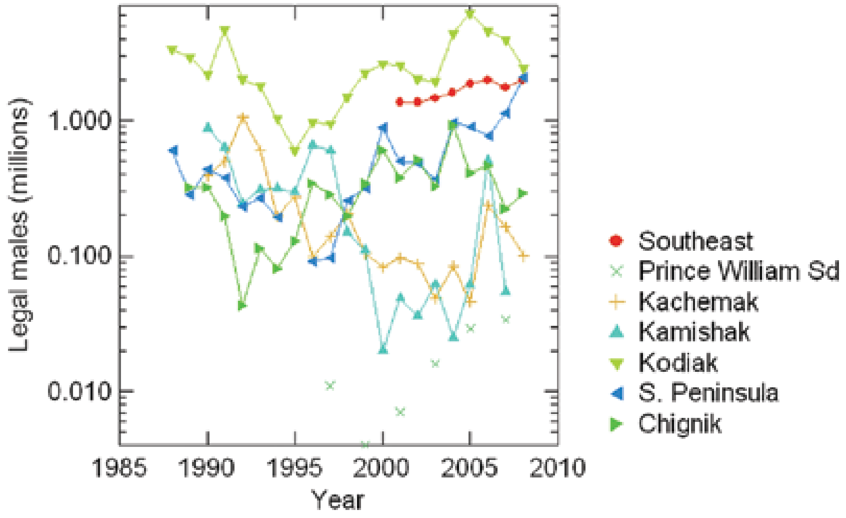
5.5 Invertebrates *(Woodby)*

5.5.1 Tanner crab

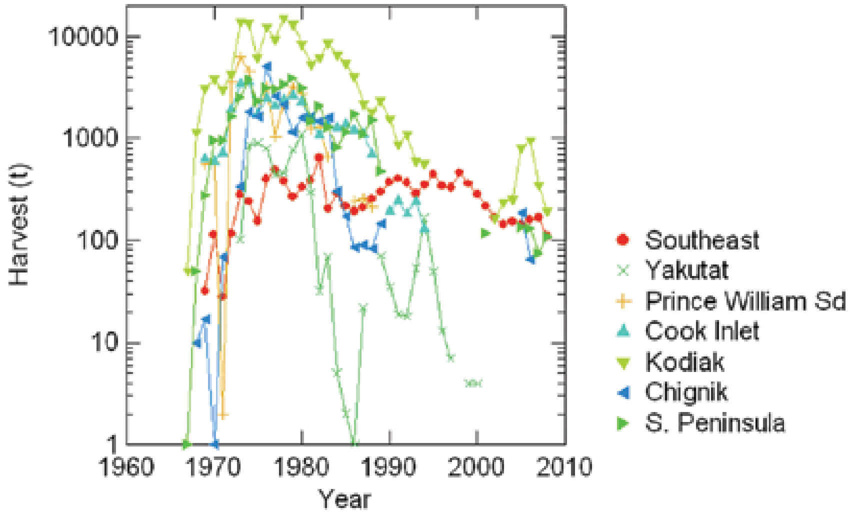
Surveys by the Alaska Department of Fish and Game indicate that Tanner crab (*Chionoecetes bairdi*) abundances have been slowly increasing during the focus period in the central and western Gulf of Alaska in waters off Kodiak (57°N, 153°W), Chignik (56.5°N, 158°W), and the Alaska Peninsula (55°N, 161°W) relative to lows in the 1990s (Fig. GA-35). The Tanner crab population in Prince William Sound (60.5°N, 147°W) has been on an increasing trend as well, however, there are no trawl survey data for comparison there prior to 1997. Populations in lower Cook Inlet at Kachemak and Kamishak Bays (59.6°N, 151.7°W and 59.2°N, 153.8°W, respectively) have continued to be depressed relative to the prior decade, with some weak signs of recovery, particularly in 2006. The Southeast Alaska (55-59°N, 131-137°W) population has been relatively stable since 2001 when Tanner crab pot surveys began there.

Commercial fisheries for Tanner crab developed in the late 1960s and 1970s in the Gulf of Alaska, with large harvests taken from Kodiak area waters, as well as from Prince William Sound and Cook Inlet (60° N, 152° W), and smaller fisheries at Yakutat (59.5° N, 140° W) and in Southeast Alaska (Fig. GA-36). Peak Gulf-wide harvests were as high as 28,500 mt in the 1973/74 season, representing about 27 million legal males (approximately 1.07 kg each). With the exception of Southeast Alaska, each of the major fisheries declined and was closed for conservation purposes, first in Prince William Sound, Chignik, and the South Peninsula fisheries in the late 1980s, followed by Cook Inlet, Kodiak, and Yakutat in the 1990s.

In the recent 5 years, commercial Tanner crab fisheries have been open only in Southeast Alaska and in the central Gulf of Alaska at Kodiak, with only a few annual openings at Chignik and the South Peninsula areas. The Southeast Alaska fishery has been relatively stable but at levels one-half or less than in prior decades. The Kodiak fishery reopened in the 2001-2002 season with recent peak harvests in the 2004-2005 and 2005-2006 seasons, followed by declines due to management decisions based on declining abundance estimates (Sagalkin 2008). Harvests in this decade in the central and western Gulf have been minor compared to peak harvests in the 1970s and 1980s, reflecting a lack of significant recruitment despite little or no directed commercial fishing from 1990 through 2001. Hypothesized explanations for the decline in abundance include a reorganization of the benthic community following a climate regime shift in 1977 (Anderson and Piatt 1999) as well as overfishing and serial depletion (Orensanz et al. 1998).



[Figure GA-35] Tanner crab survey abundance indices for Gulf of Alaska sites. All data are for legal males (at least 140 mm carapace width Gulf-wide except 135 mm in Prince William Sound) estimated by area-swept methods from trawl surveys, except in Southeast Alaska where surveys have been conducted by pots and estimates are based on catch survey analysis.

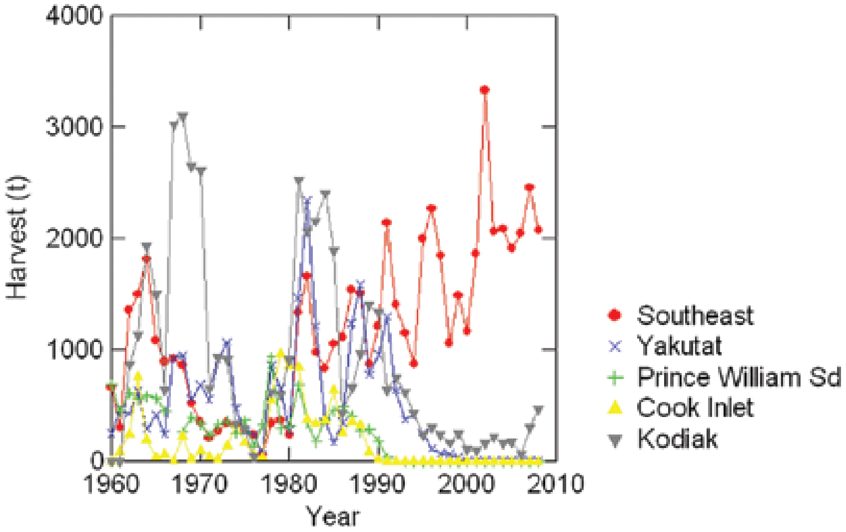


[Figure GA-36] Tanner crab commercial harvests in Gulf of Alaska fisheries. Data are confidential or missing for Chignik in 1971-1972 and for Yakutat for 1987-1988 and 1997-1998. Source: Alaska Department of Fish and Game fish ticket system, except data for Kodiak, Chignik, and South Peninsula are from Sagalkin (2008).

5.5.2 Dungeness crab

Harvests of Dungeness crab (*Metacarcinus magister*) in Alaska's extant fisheries are generally indicative of recruitment and abundance. This is because intensive fishing, since at least the 1980s, harvests the majority of the legal population each year, with the result that annual production is highly dependent on recruitment to legal size classes. Alaska's largest Dungeness crab fishery in Southeast Alaska has been at record high levels in the focus period compared to prior years (Fig. GA-37). Fisheries elsewhere in the GoA have been closed due to low stock abundance, as in Yakutat, Prince William Sound, and Cook Inlet, or are prosecuted at reduced levels, as in Kodiak.

Strong annual recruitment in the inside marine waters of Southeast Alaska is in contrast to cyclical recruitment in outer coastal regions in other jurisdictions, such as Washington, Oregon, and California, where environmental forcing, including ENSO, and density-dependent mechanisms have been hypothesized to affect recruitment through larval transport or feeding (Botsford 2001; Botsford and Hobbs 1995). The physical oceanographic connections between the inside waters of Southeast Alaska and the coastal currents of the GoA are not well understood (Weingartner et al. 2009) but the productivities of the inside waters are substantially lower than those of the outer coast.



[Figure GA-37] Dungeness crab commercial harvests in five Gulf of Alaska fisheries, 1960 to 2008. Data are confidential for Kodiak in 1977 and Prince William Sound in 1992. Data are missing for Prince William Sound in 1967. Source: Alaska Department of Fish and Game fish tickets.

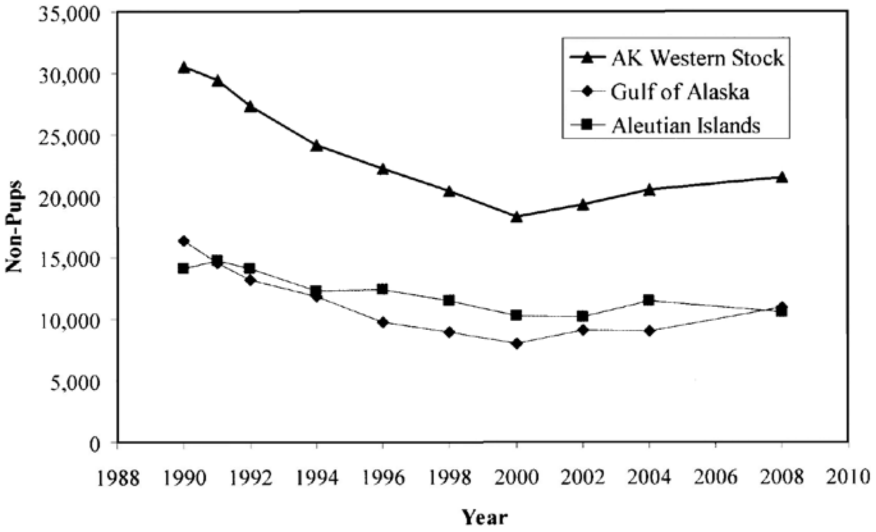
6.0 Marine Mammals *(Allen)*

Trends in marine mammal populations require extensive surveys that must often target the most vulnerable species. During the focus period in the Gulf of Alaska, the Cook Inlet beluga whale stock (2008), transient and resident killer whales (2009), northern fur seal (2008), and western (2009) and eastern (2009) stocks of Steller sea lion were assessed. In addition, new information is available for some sea otter populations.

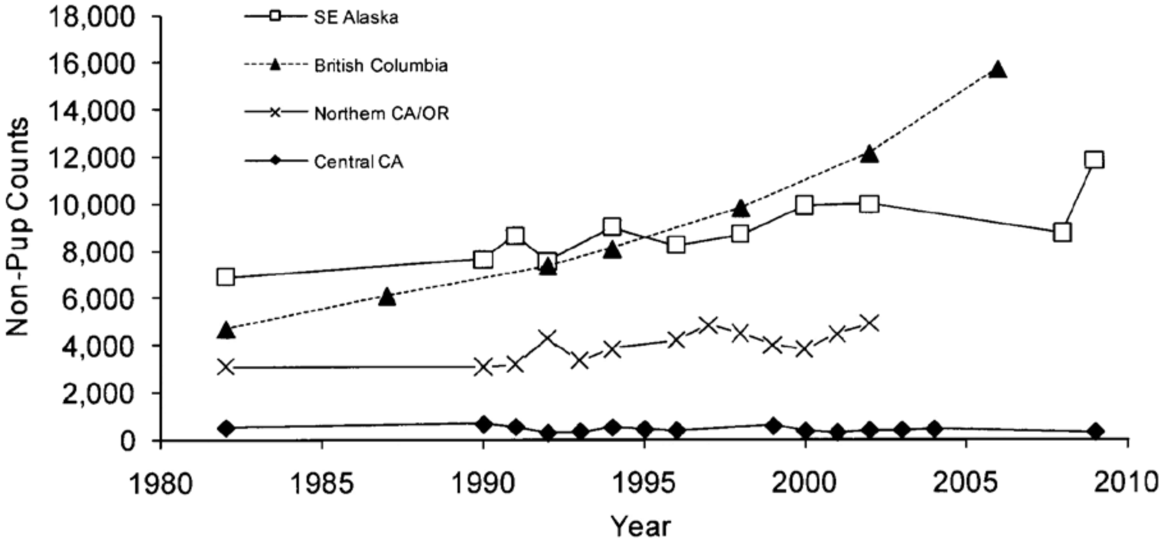
6.1 Steller sea lion

Two stocks of Steller sea lion occur in the Gulf of Alaska: the western U.S. stock, which includes animals at and west of Cape Suckling (144°W), and the eastern stock, which is comprised of animals east of Cape Suckling. The minimum population estimate for the western stock is 42,366, which is based on the 2008 counts of non-pups (31,246) and counts of pups (11,120) from 2005-2009 (Fritz et al. 2008a; DeMaster 2009). Counts of Steller sea lion at trend sites for the western U.S. stock decreased 40% from 1991 to 2000, an average annual decline of 5.4% (Loughlin and York 2000). Counts of non-pup Steller sea lion at trend sites for the western U.S. stock increased 5.5% from 2000 to 2002, and at a similar rate between 2002 and 2004 (Allen and Angliss 2010). These were the first region-wide increases for the western stock since standardized surveys began in the 1970s.

Although counts at some trend sites are missing for both 2006 and 2007, available data indicate that the size of the adult and juvenile portion of the western Steller sea lion population throughout much of its range in Alaska has remained largely unchanged between 2004 (N=23,107) and 2007 (N=23,118) (Fritz et al. 2008a). Results of the aerial survey conducted in 2008 (Fritz et al. 2008b) confirmed that the recent (2004-2008) overall trend in the western population of adult and juvenile Steller sea lion in Alaska is stable. However, there are significant regional differences in recent (2004-2008) trends. A consistent increase (7%) was observed between 2004 and 2008 in the eastern Aleutians Islands population whereas the central and western Aleutian Island populations declined 30% and 16%, respectively. An increase was seen in the populations in the central and western Gulf of Alaska between 2004 and 2007 but a decline was noted between 2007 and 2008. Non-pup counts in the eastern GoA increased 35%; however, this may be in part a reflection of a slight change in the timing of the 2008 survey and seasonal movements of animals into this area from the central Gulf of Alaska and Southeast Alaska (eastern stock). Survey results from 2009 are consistent with the hypothesis that seasonal movements into the eastern Gulf of Alaska may have affected non-pup trend analyses, and these results support the conclusion that the increase observed between 2000 and 2004 did not continue, with the population remaining stable between 2004 and 2008 (Fig. GA-38).



[Figure GA-38] Counts of adult and juvenile Steller sea lion at rookery and haulout trend sites throughout the range of the western U.S. stock in Alaska, 1990-2008. Correction factor applied to 2004 and 2008 counts for film format differences (Modified from Fritz and Stinchcomb 2005).



[Figure GA-39] Counts of adult and juvenile Steller sea lion at rookery and haulout trend sites throughout the range of the eastern U.S. stock, 1982-2009. Data from British Columbia include all sites. (Modified from Allen and Angliss 2010).

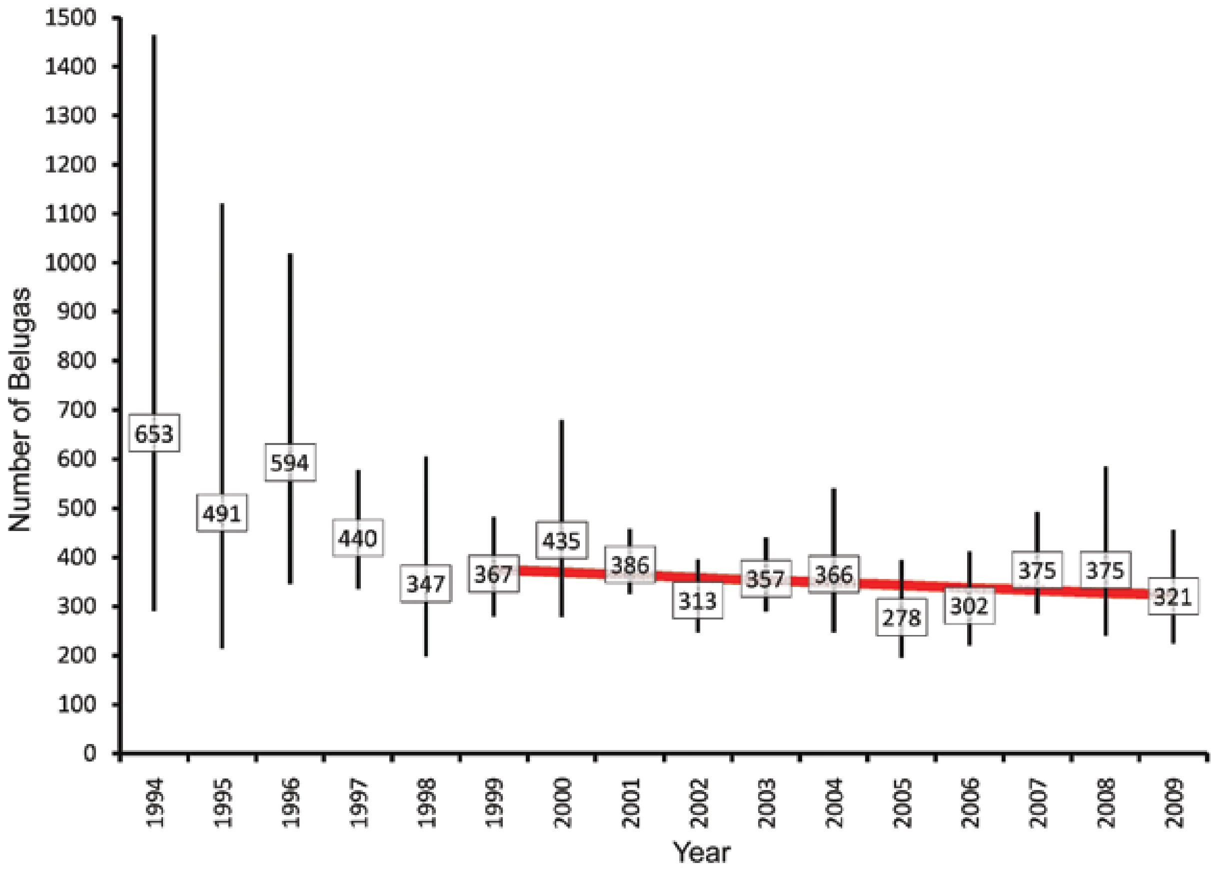
The eastern U. S. Steller sea lion stock has traditionally been stable or increasing throughout its range in the GoA. Declines in populations have been observed historically in southern and central California but overall, counts of non-pups at trend sites in California and Oregon have been relatively stable or slowly increasing since the 1980s (Allen and Angliss 2010). In Southeast Alaska, counts of non-pups at trend sites increased by 56% from 1979 to 2002 from 6,376 to 9,951 (Merrick et al. 1992; Sease et al. 2001; NMFS 2008). Between 1979-2009, counts of pups on the three largest rookeries in Southeast Alaska (Forrester Complex 54.9°N 133.5°W, Hazy Island 55.9°N 134.5°W, and White Sisters 57.6°N 136.3°W) more than tripled (from 2,219 to 6,859). In British Columbia, counts of non-pups throughout the Province increased at a rate of 3.9% annually from 1971 through 2006 (Olesiuk and Trites 2003; Olesiuk 2008). Counts of non-pups at trend sites throughout the range of the eastern Steller sea lion stock are shown in Figure GA-39. Between the 1970s and 2002, the average annual population growth rate of eastern Steller sea lion was 3.1% throughout most of their range (Pitcher et al. 2007). The minimum population estimate for the eastern Steller sea lion stock is 52,847 based on counts of pups and non-pups as old as 2001 (Washington) to as recent as 2009 (all trend sites in Southeast Alaska and California, and rookeries in Oregon) (Allen and Angliss 2010; DeMaster 2009).

6.2 Beluga whale

The abundance of the Cook Inlet stock of beluga whales (*Delhinapterus leucas*) was estimated to be 321 individuals in 2009. A statistically significant declining trend in abundance was detected between 1994 and 1998 (Hobbs et al. 2000), although the power was low due to the short duration of the time series. A Bayesian inference on the population size estimates for 1994-2005 gave a modal estimate of the current trend of -1.2% per year, with a 71% probability that the population is declining (Lowry et al. 2006). The rate of decline since a hunting quota was in place (1999-2009) has been 1.49% per year (Fig. GA-40). A recent review of the status of the population indicated that there is an 80% chance that the population will decline further (Hobbs and Shelden 2008).

6.3 Killer whale

Recent data from Matkin et al. (2008) indicate that the component of the Alaska resident stock of killer whale (*Orcinus orca*) that spends its summers in the Prince William Sound and Kenai Fjords area is increasing. With the exception of the AB pod, which declined drastically after the *Exxon Valdez* oil spill in 1989 and has not yet recovered, the component of the Alaska resident stock in the Prince William Sound and Kenai Fjords (59.9° N 149.6°W) area has increased 3.2% per year from 1990 to 2005 (Matkin



[Figure GA-40] Abundance of beluga whales in Cook Inlet, Alaska 1994-2009 (Rugh et al. 2005, Hobbs and Shelden 2008). Error bars depict 95% confidence intervals. In the years since a hunting quota was in place (1999-2009), the rate of decline (red trend line) has been -1.49% per year.

et al. 2008). Although the current minimum population count from the 2000-2009 period of 2,084 is higher than the last population count of 1,123, examination of only count data does not provide a direct indication of the net recruitment into the population, and the increase is primarily attributed to the identification of new uniquely identifiable individuals based on increased survey effort and coverage (Matkin, pers. comm. 8 February 2010). At present, reliable data on trends in population abundance for the entire Alaska resident stock of killer whales are unavailable.

In Prince William Sound, one resident pod, (AB Pod) and one transient population (AT1 Group) suffered losses of 33 and 41%, respectively, in the year following the spill (Matkin et al. 2008). Sixteen years later, AB Pod had not recovered to pre-spill numbers, and the rate of increase was significantly less than that of other resident pods that did not decline at the time of the spill. The AT1 Group, which lost 9 of its 22 members during the winter following the 1989 spill, is currently estimated to consist of seven whales (Matkin et al. 2008; Allen and Angliss 2010). Based on the continued decline of the AT1 Group, this group is now listed as depleted under the Marine Mammal Protection Act. The loss of individuals, particularly of reproductive-age females, from these two ecologically and genetically separate groups, and a declining trend in group size post-spill, suggest killer whales are highly vulnerable to environmental disasters such as oil spills. It is highly likely that the AT1 group will not recover (Matkin et al. 2008).

6.4 Humpback whale

Two stocks of humpback whale (*Megaptera noraengeliae*) occur in the Gulf of Alaska: the western North Pacific and the central North Pacific stocks (Allen and Angliss 2010). During 2004-2006, a large-scale study of humpback whales throughout the North Pacific was conducted, referred to as the Structure of Populations, Levels of Abundance, and Status of Humpbacks (SPLASH) project (Calambokidis et al. 2008). Based on SPLASH results, it is apparent that humpback whales from these two Alaska stocks mix to a limited extent on summer feeding grounds ranging from British Columbia through the central Gulf of Alaska and up to the Bering Sea. Population structure in the North Pacific based on samples collected from this study is currently being analyzed. Point estimates of abundance for Asia (Philippines, Okinawa, and the Ogasawara Islands), the wintering grounds for much of the western North Pacific stock, range from 938 to 1,107. These estimates of abundance for Asia from SPLASH represent a 6.7% annual rate of increase over the 1991-1993 abundance estimate for this stock. However, the 1991-1993 estimate did not include estimates from waters near the Philippines. SPLASH results showed point estimates of abundance for Hawaii, the wintering grounds for much of the central North Pacific stock, ranging from 7,469 to 10,103. Comparisons of SPLASH abundance estimates for Hawaii with estimates from 1991-1993 gave estimates of annual increase that ranged from 5.5 to 6.0% (Calambokidis et al. 2008). Abundance estimates from SPLASH on the summer feeding grounds for the central North Pacific stock ranged from 2,889 to 13,594 for the Aleutian Islands and Bering Sea, from 2,845 to 5,122 for the Gulf of Alaska, and 2,883 to 6,414 for Southeast Alaska/northern British Columbia (Calambokidis et al. 2008). Zerbini et al. (2006) estimated and annual rate of increase of 6.6% (95% C.I. of 5.2-8.6%) from 1987-2003 for humpback whales from the shelf waters of the northern Gulf of Alaska.

6.5 Sea otter

Estimates of sea otter (*Enhydra lutris*) abundance in Glacier Bay (58.4°N 136.0°W) in Southeast Alaska increased between 2002 and 2006 to 2,785 individuals (Bodkin and Esslinger 2006). This increase cannot be explained by reproduction alone, indicating that there has been a substantial redistribution of sea otters in the past several years with immigration into Glacier Bay in the past decade. Sea otter abundance in Yakutat Bay (59.7°N 140.0°W) has also increased over the last decade, likely through reproduction, although some amount of immigration cannot be ruled out (Gill and Burn 2007). During this process, sea otters appear to have expanded their range to include the western shores of Yakutat Bay. The current population trend for the southeast Alaska stock is believed to be stable.

With the exception of the Kodiak archipelago, there have been no new large-scale abundance surveys for sea otters in Southwest Alaska since 2002, however, additional skiff and aerial surveys conducted from 2003 to 2005 show that sea otter abundance has continued to decline in the western and central Aleutians (63%) and the eastern Aleutians (48%) (Estes et al. 2005). Aerial surveys in other portions of Southwest Alaska show further evidence of population declines. Sea otter counts in the Shumagin Islands (55°N 159°W) area south of the Alaska Peninsula showed a 33% decline between 2001 and 2004, and counts at Sutwik Island (56.5°N 157.2°W) declined by 68% over the same time period (USFWS unpublished data). Unlike the Aleutian Islands and portions of the Alaska Peninsula, the population trend in the Kodiak archipelago does not appear to have undergone a significant population decline over the past 20 years (Doroff et al. unpublished). Other portions of the southwest Alaska stock, such as the Alaska Peninsula coast from Castle Cape (56.2°N 158.3°W) to Cape Douglas (58.9°N 153.3°W) and Kamishak Bay (58.3°N 153.8°W) in lower western Cook Inlet, also show no signs of declining abundance. The estimated population size for the Southwest Alaska stock increased slightly since 2002, primarily due to a higher population estimate for the Kodiak archipelago in 2004. However, the overall sea otter population in southwest Alaska has declined by more than 50% since the mid-1980s. Thus, the overall population trend for the southwest Alaska stock is believed to be declining.

Acknowledgement

Thanks to Adam Moles for his invaluable editorial work in this chapter.

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