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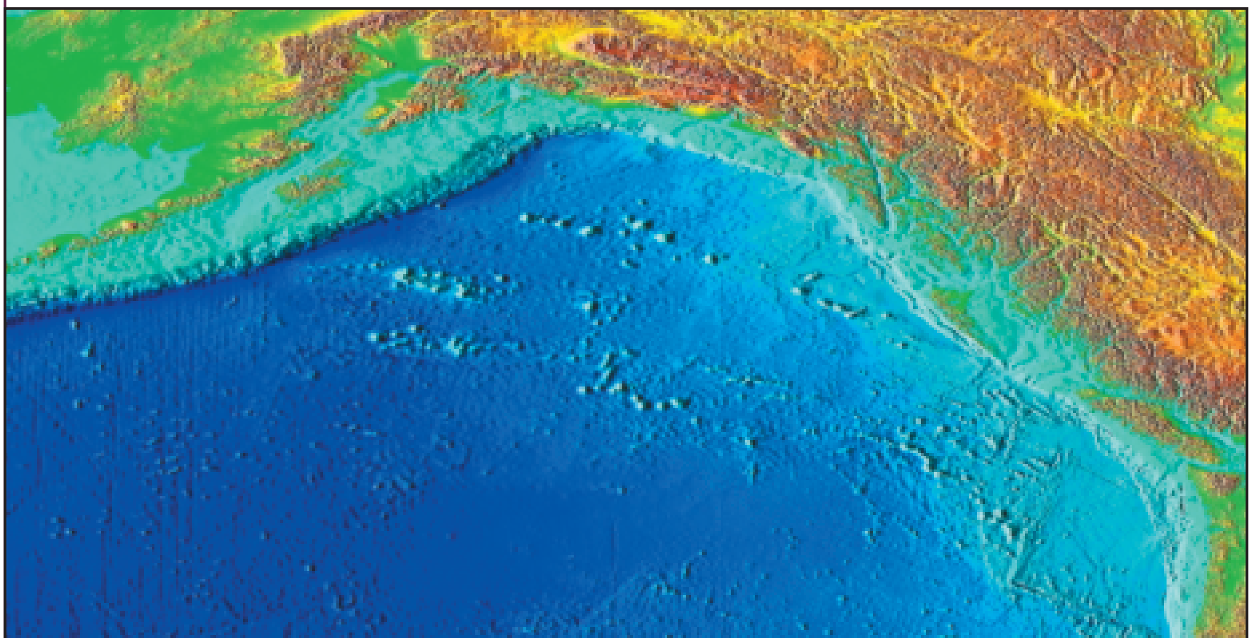
Gulf of Alaska

highlights



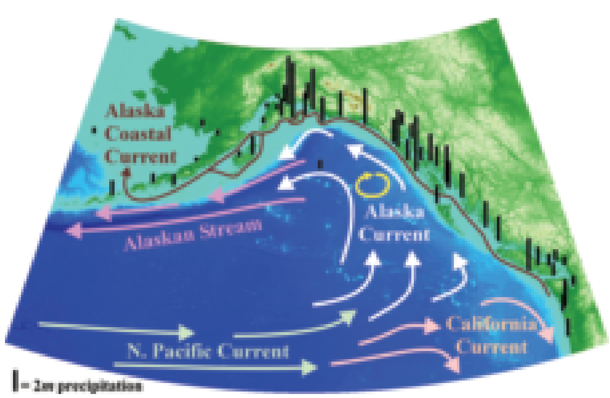
- For decades, the depth of the surface mixed layer had become increasingly shallow, reducing nutrient levels. A deepening of the mixed layer from 1999-2002 temporarily reduced this trend, but the winter of 2002/03 was the shallowest on record.
- Phytoplankton blooms on the shelf were stronger in 1999 and 2000 than 1998 and 2001.
- The seasonal peak of *Neocalanus* copepods at Ocean Station P was early in the 1980/90s and returned to the long-term average from 1999 – 2001.
- After 1976/77, the groundfish community had relatively stable species composition and abundance of individual species but, several significant changes have occurred:
    - a general decline in walleye pollock biomass over the past decade, but with strong recruitment of the 1999 year-class and early indications of strong year-classes in 2001 and 2002.
    - recruitment of most of the major commercial stocks was below average in the 1990s.
    - sharks, skates, several forage fish species, and yellow Irish lord have significantly increased in abundance and/or frequency of occurrence since 1990.
    - abundance and recruitment of many salmon stocks was above average for much of the 1980/90s, while catches have decreased slightly over the past decade. Recruitment of all brood years through at least the mid-1990s was strong.
    - in spite of moderate declines in abundance and below-average recruitment of some commercial stocks, most groundfish, salmon, and herring fisheries remained healthy throughout 2002 with no indications of overfishing or “fishing down the food web.”
    - king crab and shrimp stocks have not recovered from a collapse in the early 1980s.
- Populations of marine mammals, in particular sea lions and harbour seals, have declined dramatically over the past decades, while seabird populations have not shown consistent trends. Declining trends in sea lions and harbour seals have slowed in recent years or, in some cases, reversed.

background

The region is bounded on the east and north by tall, rugged coastal mountains that are separated by a continental shelf from abyssal depths in excess of 3000 m in the eastern Gulf of Alaska and 5000 m in the Aleutian Trench.

The continental shelf has a total area of approximately 370,000 km^2 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 topography that promotes an exchange of shelf water with deeper waters.

The coastal mountain range receives large amounts of precipitation resulting in large volumes of nutrient-poor freshwater runoff into coastal areas (Figure 105). The buoyancy of freshwater and local winds drive a nearshore current, the Alaska Coastal Current, which follows the perimeter of the Gulf of Alaska for 2500 km from British Columbia to the Bering Sea.[240] In the northern Gulf of Alaska, the Alaska Coastal Current is separated by a salinity front from the highly variable mid-shelf region, which is separated by another salinity front from the more nutrient-rich waters of the Alaska Current. The region is characterized by pronounced changes in water properties, chemistry, and species composition (phytoplankton, zooplankton, and fish) across the shelf. Superimposed on these cross-shelf gradients is considerable mesoscale variability resulting from eddies and meanders in the boundary currents.[240]



[Figure 105] Major ocean currents in the Gulf of Alaska and average annual precipitation around its margin

Circulation in the central Gulf of Alaska is dominated by a counterclockwise gyre. The southern limb of the gyre is formed by the North Pacific Current, flowing eastward from Asia between about 30 and 45°N. When the North Pacific Current reaches the west coast of North America it splits to form a southward flowing California Current and a northward flowing Alaska Current.[241] The broad and sluggish (three to six meters per minute) Alaska Current brings warm water from the south into the northern Gulf of Alaska and plays an important role in the regional heat budget.[240] The Alaska Current follows the coasts of northern British Columbia and Southeast Alaska before turning westward along the continental slope off the coast of central Alaska. It continues as the much swifter (18 to 60 m per minute) Alaskan Stream as it follows a southwestward course along the Alaska Peninsula and the Aleutian Archipelago (Figure 105). 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.[241] 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.[242]

Variations in ocean circulation are driven by seasonal and interannual variability in the wind and thermal regimes over both the shelf and ocean and in freshwater discharge along the coast. Winds are strongly related to the strength and position of the Aleutian Low, a low-pressure area resulting from the passage of storms along the Aleutian storm track.[243]

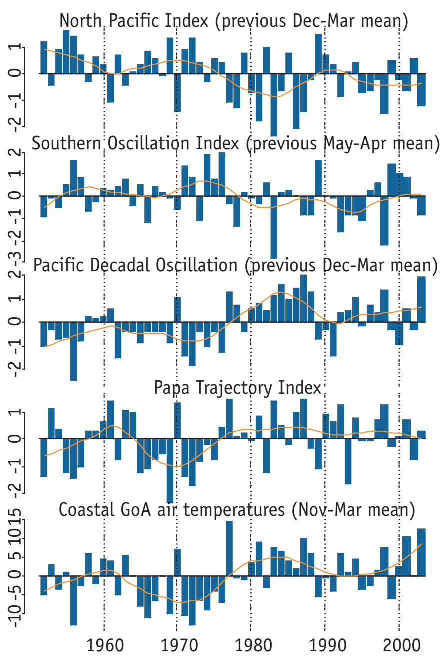
Strong seasonality in storm intensity and frequency cause strong seasonality in coastal forcing. During the winter, intense alongshore winds cause downwelling and increased water transport around the perimeter of the Alaskan Gyre. In the summer, the Eastern Pacific High Pressure system expands into the Gulf of Alaska and the associated weak and variable winds cause a relaxation in downwelling, and occasional divergences and upwelling along the coast, particularly in the western Gulf of Alaska. Freshwater input varies seasonally with maximum discharge in the fall and minimum discharge in winter, when much of the precipitation is stored as snow.[244]

Water density in the Gulf of Alaska is primarily driven by variations in salinity, hence freshwater input, along with wind mixing, determines the onset and the strength of stratification in the spring and summer with important implications for ocean productivity.

Beginning in 1999 changes in several climate indicators, including the Pacific Decadal Oscillation, coupled with several years of strong La Nina conditions, caused some authors to speculate that we are witnessing a return to conditions that characterized the Northeast Pacific prior to a major regime shift in 1976/77. These and other recent changes are discussed in more detail below.

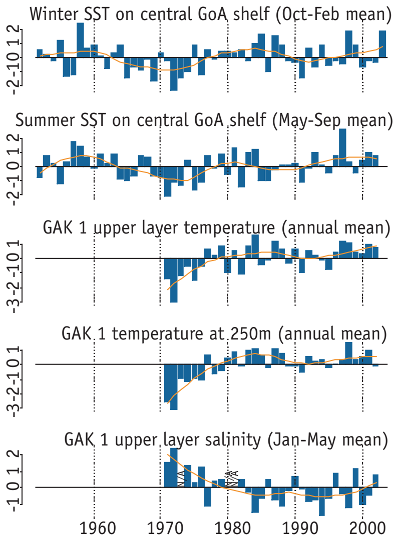
Status and trends

Hydrography



After several years of a relatively weak Aleutian Low and cold conditions initiated by the La Niña of 1999, the coastal Gulf of Alaska appears to be returning to conditions similar to those that prevailed throughout much of the 1980s and 1990s. Recent climatic and oceanographic conditions, as described below, are characterized by a stronger Aleutian Low, enhanced circulation and upwelling, and above normal coastal temperatures. However, it is not yet clear whether this trend will persist and some indicators suggest that the 1999 regime shift is persisting or that we are entering a new and different regime.

[Figure 106] Standardized time series of North Pacific Index (December–March mean), Southern Oscillation Index (May–April mean), Pacific Decadal Oscillation (December–March mean), Papa Trajectory Index (final latitude on February 28 of OSCURS simulated drifter originating at Ocean Station Papa on December 1 of previous year), and winter air temperature (November–March) averaged across 5 coastal stations (Sitka, Yakutat, Cordova, Homer, Kodiak). All series standardized by substracting the 1952-2003 mean and dividing by standard deviation. A LOWESS trend line is shown in red.



[Figure 107] Standardized time series of winter SST (October–February) and summer SST (May–September) for a 2° lat/long square centered at 58°N 150°W,[245] estimated annual mean upper layer (0-20m) temperature at GAK 1 (59° 50.7′ N 149° 28.0′ W), estimated annual mean bottom temperature (250 m) at GAK 1, and estimated late winter upper layer salinity (0-20m, mean of all January – May observations) at GAK 1. LOWESS trend line is indicated in red.

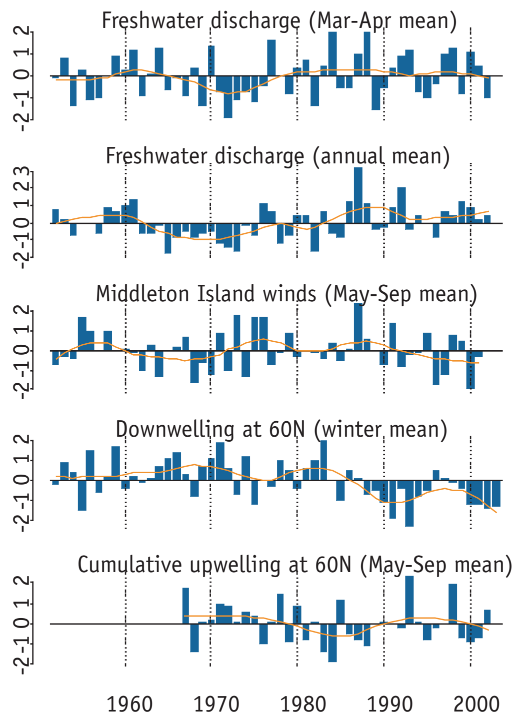
El Niño / La Niña The strong 1997/1998 El Niño resulted in the transport of heat into the Gulf of Alaska, beginning in the coastal area and spreading offshore. This was followed by a strong La Niña event resulting in reduced sea-surface temperatures (SST) during and after 1999. A moderate El Niño developed in 2002/2003 as evident in the Southern Oscillation Index (Figure 106) but tropical SSTs returned to near-normal in the summer and fall of 2003.[246]

Aleutian Low The North Pacific Index (Figure 106) has been below average throughout most of the last decade and was well below average in the winter of 2002/2003, suggesting a continued strong Aleutian Low and intense circulation over the Gulf of Alaska. Other indices, such as the Atmospheric Forcing Index and the Aleutian Low Pressure Index (ALPI), confirm the presence of a strong Aleutian Low in 2002. The ALPI suggests an extremely intense low in 1998, moderate lows from 1999-2002, and a return to an extremely high value in 2002. Intense Aleutian Lows are associated with increased upwelling in the center of the Alaska Gyre and increased productivity.

Pacific Decadal Oscillation (PDO) After an apparent return to below-average values in 1999, the PDO reached its highest values since 1987 in the winter of 2002/2003 (Figure 106), suggesting a strong pattern of warm coastal SST and cool temperatures in the central Northeast Pacific. This pattern, which is characteristic of the positive phase of the PDO, is evident in monthly surface marine observations.[247]

Papa Trajectory Index (PTI) The PTI, which is based on modeled surface currents for the Gulf of Alaska,[248] suggests that surface transport from Ocean Station Papa (OSP at 50°N, 145°W) during the winter of 2002/2003 (December – February) has been further to the north than average, indicative of enhanced transport in the Alaska Current. There is little evidence that surface circulation patterns have returned to conditions prevalent before the 1976/77 regime shift, when surface transport from OSP was predominantly to the east or south.[248]

Coastal temperatures Coastal air and sea surface temperatures in the Gulf of Alaska have been consistently above normal in the summer of 2002 and the winter of 2003, which may signify a return to warmer conditions after a cool period brought on by the 1999 La Niña. Winter SST on the northern Gulf of Alaska shelf (Figure 107) and upper ocean temperatures along the Seward line in the northern Gulf were below or near average from 1999-2002.[240,250] In contrast, winter SST on the shelf (Figure 107), temperatures along the Seward line in March 2003[250], and monthly SST throughout the eastern Gulf of Alaska[247] suggest a return to warm coastal conditions, consistent with a positive PDO index. Temperatures at GAK 1 were well above average in March and April of 2003 throughout the water column.[249] Similarly, recent air temperatures (November 2002 - March 2003) at coastal stations around the Gulf of Alaska were warmer than at any time since 1977 (Figure 106).



[Figure 108] Standardized time series of late winter / early spring (Mar-Apr) freshwater discharge, total annual freshwater discharge, summer wind mixing at Middleton Island (mean magnitude from May – Sep), winter downwelling index at 60°N (previous October – April mean, averaged across 146°W and 149°W) , and cumulative spring / summer upwelling at 60°N (Sum of all positive daily upwelling indices, May – September).

Temperature along Line P Similar to the northern Gulf of Alaska, temperatures along Line P (Southern tip of Vancouver Island to OSP) were below or near average from 1999-2002.[254] Unlike at the Seward line, subsurface temperatures remained below-average through spring 2003.[318]

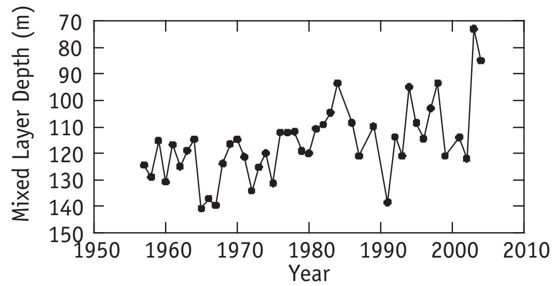
Freshwater discharge Annual freshwater discharge into the coastal Gulf of Alaska, which drives the Alaska Coastal Current, has increased since the 1960s and 1970s and has been above the long-term (1950-2000) average for most of the 1980s and 1990s. Annual average discharge has been near average in 2001 and 2002 (Figure 108). Freshwater discharge is a major determinant of salinities in the upper water column within the ACC and is important to the timing and strength of stratification in the spring and summer.[240] March-April discharge has been above average in 1997-98 and 2000-01, but well below average in 1999 and 2002 (Figure 108). High discharge in 1998 resulted in low salinities and strong stratification on the central Gulf of Alaska shelf, while stratification in 1999 and 2002 was weak due to low discharge and high upper layer salinities.[240]

Salinity Relatively few long-term salinity observations are available for the Gulf of Alaska. Surface salinities at the GAK 1 station (59° 50.7′ N, 149° 28.0′ W) at the mouth of Resurrection Bay are indicative of conditions within the Alaska Coastal Current. They tend to be inversely related to freshwater discharge and were below normal throughout most of the 1980s and 1990s (Figure 107). Notable exceptions are 1996 and 1999, years with below-average discharge (Figure 108). In March 2003, winter sea surface salinities at GAK 1 and over much of the inner shelf along the Seward line were well below average,[250] consistent with high precipitation rates. Upper-layer salinities in the southern Gulf of Alaska along line P displayed a similar pattern with more saline conditions in the mixed layer in 1999, near-normal salinities in 2000 and 2001, and less saline conditions in 2002. Subsurface waters along line P continued to have below-average salinities through spring 2003 and were characterized by a highly unusual salinity/ temperature combination (colder and less saline subsurface waters).[318]

Ocean transport Variability in the volume of water transported within the Alaska Coastal Current and Alaska Stream is thought to be an important factor in overall productivity on the shelf and has been monitored with satellite-tracked drift buoys since 1986. Transport in Shelikof Strait and on the western Gulf of Alaska shelf was weaker than usual in the summers of both 2001 and 2002.[316]

Wind mixing and ocean upwelling Wind mixing and upwelling conditions on the shelf may play an important role in the supply of nutrients from offshore sources onto the northern Gulf of Alaska shelf.[240,251] The wind magnitude at Middleton Island, a shallow island off Prince William Sound, can serve as a proxy for wind mixing on the shelf. Summer wind mixing at Middleton Island displays high interannual variability, but appears to have decreased in average magnitude from the late 1980s to the present (Figure 108). Winds were very calm during summer 2000 and slightly below the long-term mean in 2001. Similarly, wind mixing near the southern end of Shelikof Strait (57°N, 156°W) has been below average for the January-June period from 1997-2002, which is associated with higher survival of pollock larvae.[316] Average winter downwelling strength at 60°N (average of downwelling indices, i.e. the inverse of upwelling, at 146°W and 149°W) has decreased substantially since the early 1980s and has been well below average from 2000 through 2003 (previous October – April). A cumulative summer upwelling index during the production season (May-Sep) indicates below average upwelling in 1999-2001 and above-average upwelling in 2002.

Mixed-layer depth A strong trend towards shoaling of the mid-winter mixed-layer depth in the southern Gulf of Alaska at Ocean Station Papa has been apparent over the last several decades[252,253] which has implications for the supply of nutrients to the mixed layer (Figure 109). Previously, the shallowest mixed layer was observed during the El Niño of 1997/98, but decreased sharply to below-normal values in the cold winter of 1998/99. Negative salinity anomalies at the base of the mixed layer in February 2001 and February 2002 (no data for 2000) indicated a further deepening and resulted in increased nutrient levels in the mixed layer.[254] The trend towards a shallower mixed layer continued in 2002/03 with the shallowest mixed layer on record in February 2003.[289] The mixed-layer depth at GAK 1 on the northern Gulf of Alaska shelf deepened slightly between 1974 and 1998, although the trend is not statistically significant.[255]



[Figure 109] Depth of the winter mixed layer at Ocean Station Papa (50°N 145°W) in the Gulf of Alaska

In summary, recent atmospheric and oceanographic conditions suggest that the cool phase following the 1999 La Niña has ended and that the Gulf of Alaska returned to conditions typically associated with the positive phase of the PDO during 2002/2003. These conditions include strong cyclonic circulation over the Gulf of Alaska, warm coastal temperatures over land as well as in the ocean, and possibly enhanced nutrient levels in the central regions and on the shelf. However, not all indicators support a return to a "warm" regime and may indicate a new system state (see also *Ocean/Climate* chapter). It remains to be seen whether biological productivity on the shelf remains as high as it was during the 1980s and 1990s, as evidenced in many biological time series.

Chemistry

After several years of low nutrients in the surface mixed layer (as exemplified by conditions at Ocean Station Papa), recent hydrographic conditions have resulted in increased nutrient levels in Gulf of Alaska surface waters. The chemical properties and nutrient dynamics in the Gulf of Alaska are poorly understood at present due to a paucity of observations. The only long-term dataset available (at Ocean Station Papa) reflects conditions in the southern Gulf of Alaska, which may reflect nutrient conditions throughout the central gyre and may impact nutrient supplies to the coastal shelf through advection within the Alaska Current. Productivity in the Alaska Gyre is related to the supply of nutrients to the surface layer through vertical mixing, which in turn is linked to the density of the upper layer.

Low temperatures and high salinities in the upper ocean increase upper-layer densities, which destabilizes the water column and allows for deeper mixing, hence bringing nutrients to the surface. Except in nearshore areas, nitrate is rarely depleted in the Alaska Gyre because plankton are limited by other factors.[256,257]

The high biological productivity observed on the shelf is somewhat paradoxical because downwelling conditions prevail along most of the coast and the shelf receives a large amount of nutrient-poor freshwater.[240] Recent research suggests several potential pathways by which nutrients are supplied to the shelf. First, the relaxation and occasional reversal of downwelling during the summer promotes fluxes of dense, nutrient-rich bottom water onto the shelf, creating a deep nutrient reservoir that is eventually mixed into the upper water column during the winter months.[240,251] Second, onshore Ekman surface transport during fall and winter can transport nutrient-rich oceanic water onto the shelf.[240] Third, a sub-surface maximum of chlorophyll-*a* in late summer over the deeper portions of the shelf[258,259] suggests that nutrients are mixed into the upper layer through vertical mixing events in the summer. Fourth, drifter studies suggest that nutrient-rich offshore waters are advected via submarine canyons onto shallow banks off Kodiak Island, where they are mixed throughout the water column by intense wind and tidal mixing.[260] Thus nutrients may be continuously replenished on these banks and sustain high levels of production throughout the summer. Finally, eddies traveling along the continental shelf and slope may play an important role in enhancing nutrient levels and biological production through vertical mixing and cross-shelf exchanges,[261,251] while eddies spawned in the eastern Gulf of Alaska transport nutrients, as well as freshwater, heat, and organisms offshore into the central Gulf of Alaska.[262]

Recent conditions and trends in nutrient levels for the central Gulf of Alaska and on the northern Gulf of Alaska shelf suggest that nutrient levels, which were very low during the 1997/98 El Niño, may have been increasing since 1999, associated with a deepening of the mixed layer in the central Gulf of Alaska.

Alaska Gyre / OSP Late-winter nutrient levels at OSP were reduced for most of the 1990s following the onset of the 1991 El Niño and culminating in the 1997 El Niño event, which resulted in strong stratification and reduced winter nitrate levels in February 1998.[263] In 1999, mixed layer depth and nutrient levels began to increase and have continued to increase through spring 2002.[254] In 1999, the mixed layer depth and nutrient levels began to increase and continued to increase through the spring of 2002. This was followed recently by the shallowest mixed layer on record in the spring of 2003 and a repeat of this unusual event during the winter of 2003/04.

Northern GoA shelf No long-term series are available for the shelf region, but recent studies on the northern Gulf of Alaska shelf suggest substantial interannual variability in nutrient dynamics. Observations by the US GLOBEC LTOP program suggest an increase in nutrient levels on the northern Gulf of Alaska shelf from 1998 to 2000 along the Seward line with the highest nutrient levels observed over the outer shelf and slope.[251] High nitrate concentrations were observed in December 2000, suggesting elevated nutrient levels during the winter of 2000/2001. Highest levels of new production over the three-year time period were observed over the mid-shelf in April and May of 2000. Nitrate levels and estimates of new production on the northern Gulf of Alaska shelf are substantially higher than comparable estimates from Ocean Station Papa.[251]

Harmful Algal Blooms No data reported.

Contaminants No data reported.

Plankton

Although plankton dynamics have been examined in the central and southern part of the Alaska Gyre, particularly at Ocean Station Papa, very little information is available for the shelf region. In the central gyre, the growth of large cells (diatoms) is limited by iron in late spring and summer while irradiance is limiting in winter.[256] Chlorophyll and primary productivity are relatively low and show limited seasonal variation. Annual new production shows large interannual variations and ranges up to approximately 80 gC m^{-2} yr^{-1} in the central gyre[258,257] and as high as 150-200 gC m^{-2} yr^{-1} at Ocean Station Papa. Primary productivity at Ocean Station Papa is fuelled by regenerated nitrogen and phytoplankton is dominated by small cells that appear to be primarily controlled by microzooplankton grazers.[264]

In contrast, primary production on the shelf and in coastal embayments shows extreme seasonal variability with high phytoplankton standing stocks, extremely high productivity, and nutrient depletion in the summer. Annual new production on the shelf has been estimated at 300 gC m^{-2} yr^{-1}.[258] Productivity and plankton composition is characterized by high spatial variability and strong cross-shelf gradients.[240] Distinct plankton communities populate the inner, middle, and outer shelf with large-celled diatoms and smaller cyanobacteria dominating blooms on the inner and outer shelf, respectively. Microzooplankton are the dominant consumers of phytoplankton and consume much of the production on the shelf.[265] They are in turn consumed by mesozooplankton, such as *Neocalanus*, which serve as important prey for larger zooplankton, fish, seabirds, and marine mammals.

While at least 290 species of zooplankton have been reported from the oceanic, shelf, and coastal waters of the northern Gulf of Alaska, three species of *Neocalanus* dominate the mesozooplankton throughout the subarctic Pacific in spring and summer. Zooplankton standing stocks are typically low in the central gyre, ranging from 1.5 g m^{-2} in winter to 30 g m^{-2} in the summer, while nearshore waters have a high standing stock of up to 1,600 g m^{-2} in the summer and fall.[266] Estimates of annual production are scarce and questionable, but suggest that zooplankton production is about 30-50 gC m^{-2} yr^{-1} on the shelf and in nearshore areas and approximately 13 gC m^{-2} yr^{-1} at Ocean Station Papa[266]. Like the phytoplankton community, zooplankton species composition on the shelf is characterized by a strong cross-shelf gradient in at least some years, although considerable cross-shelf exchanges can occur.[266] The zooplankton community on the inner shelf and within coastal embayments typically consists of a mix of oceanic (primarily *Neocalanus*) and neritic (e.g. *Pseudocalanus*) species. Strong alongshore currents tend to homogenize species composition along much of the shelf.

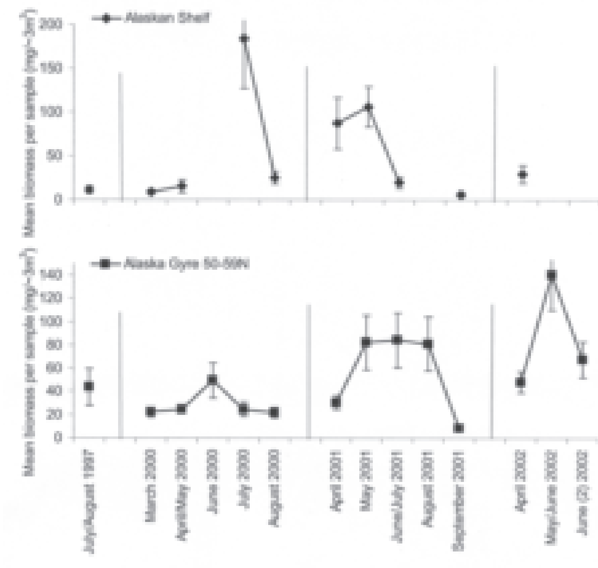
Recent research on plankton communities in the subarctic Pacific suggests interannual and interdecadal variability in productivity and composition of phytoplankton and in the total biomass, species composition, and developmental timing of mesozooplankton.

Phytoplankton Total average chlorophyll-a levels at Ocean Station Papa show very little variation among years[264] and chlorophyll concentration in 2000 was within the range observed previously.[267] Chlorophyll-*a* levels estimated from SeaWiFS ocean color data suggest a more intense spring bloom along the Gulf of Alaska shelf extending further offshore in 1999 and 2000 compared to 1998 and 2001,[268] consistent with the observed elevated nutrient levels in the surface layer during 1999 and 2000. The spring bloom was weak and delayed in 1998 and 2001, while the 2002 bloom appeared to be stronger.[269]

There is evidence that the composition of the phytoplankton community changed between 2000 and 2001. While phytoplankton at OSP is typically dominated by autotrophic flagellates, over 50% of the phytoplankton biomass in spring and summer of 2000 was made up of coccolithophores.[267] Similarly, color satellite data (SeaWIFS) indicates high abundances of coccolithophores in June 2000 throughout the Alaska Gyre, while there was no evidence of coccolithophore dominance in June 2001.

Few reliable estimates of primary production are available for either the shelf or the central GoA, but there is some evidence that annual production at OSP was higher in the 1980s and 1990s than in the 1960s/70s,[256] and that primary productivity at OSP is elevated during El Niño years.[270] Estimates of new production from the Alaska Gyre and the Subarctic Current System were low from 1995 through 1999 and increased to record high rates in 2000. This increase was associated with high silicate depletions in the Alaska Gyre, indicating increased diatom production.[257] A large increase in new production was reported during the 1997/1998 El Niño in the coastal regions south of the Aleutian Islands.[257] New production estimates from the northern Gulf of Alaska were also relatively high over the inner shelf in 1998.

Zooplankton Total zooplankton standing stocks vary on both interannual and interdecadal time scales.[286] Summer season biomass in the Alaska Gyre was about twice as high in the 1980s as in the 1950s and 1960s. Recently, mesozooplankton biomass has been estimated periodically on the shelf and in the Alaska Gyre using the Continuous Plankton Recorder on commercial shipping vessels of opportunity. Results suggest high variability in the timing and magnitude of the zooplankton bloom on the shelf and a possible increase in biomass in the Alaska Gyre from 2000-2002 (Figure 110), consistent with increases in nutrient levels at Ocean Station Papa.



[Figure 110] Mean mesozooplankton biomass (estimated from abundance) for Continuous Plankton Recorder transects sampled in 1997 and between March 2000 and summer 2002.[271] Error bars are one standard error.

The seasonal timing of the peak biomass of *Neocalanus* at Ocean Station Papa varies by more than a month among years and correlates with spring mixed-layer temperatures.[272] *N. plumchrus* completed its upper ocean growing season about 50-60 days earlier in the 1990s than in the 1970s. Starting in 1999, and continuing through 2001, time of peak biomass has returned to the long-term average.[273]

Although located at the transition zone between the Alaska Current and California Current, recent changes in species composition along the west coast of Vancouver Island may be indicative of similar changes on the northern Gulf of Alaska shelf. The shelf and offshore zooplankton communities off Vancouver Island are typically dominated by boreal and subarctic species, but were characterized by large abundances of "southern" species throughout most of the 1990s.[272] An abrupt reversal took place in 1999 with a sharp decrease in the southern species and a sharp increase in boreal / subarctic species. These changes have persisted through 2002. While few of the southern species are common on the northern Gulf of Alaska shelf, higher densities of several species with southern affinities were observed on the northern shelf in 1998 following the strong El Niño of 1997/98, compared to subsequent years.

Similarly, data collected by the Continuous Plankton Recorder in the fall of 1997 and from 2000 to 2002 suggest a change in the relative abundance of southern and boreal species in the Alaska Gyre and a more northerly distribution of southern species in 1997 compared to 2000-2001.[274]

The species composition of zooplankton on the northern Gulf of Alaska shelf was examined during recent US GLOBEC cruises. No marked interannual differences in any of the major taxa were observed between 1998 and 2000, in spite of the strong 1997/98 El Niño. While large spatial variability makes it difficult to compare abundances among years, *Neocalanus* tended to decrease from 1998-2000, while several smaller zooplankton species were most abundant in 2000.

Fish and Invertebrates

The Gulf of Alaska shelf is highly productive and supports a number of commercially important fisheries such as walleye pollock, salmon, Pacific halibut, other flatfish, Pacific herring, crab, and shrimp. Annual landings from 1999-2002 for the Alaska portion of the shelf averaged approximately 250,000 mt of groundfish,[275] 290,000 mt of salmon, and 20,000 mt of herring and shellfish.[276] Salmon catches and groundfish species composition and abundance in the nearshore areas of the Gulf of Alaska changed dramatically during the late 1970s and early 1980s[277,299] concurrent with a pronounced shift in a number of climatic and oceanographic indicators.[278,26] A number of marine mammal and bird populations, in particular Steller sea lions and harbour seals, have substantially declined in the Gulf of Alaska following the 1977 regime shift.[279] There is some evidence for a subsequent regime shift in 1989 based on a number of biological time series.[26] Causes for these changes remain poorly understood.[280]

The fish fauna of the Gulf of Alaska consists of a mix of temperate and subarctic species, resulting in a large gradient in species composition along the shelf from the eastern to the western Gulf of Alaska.[299] At least 383 species belonging to 84 families of marine and anadromous fishes have been reported from the Alaska continental shelf, slope, and offshore areas.[281] The shelf and slope support a large biomass of groundfishes, particularly the wide shelf and banks around Kodiak Island. The largest catch-per-unit-effort (CPUE) during summer typically occurs at or below the shelf break and there are strong cross-shelf gradients in species composition and diversity.[299]

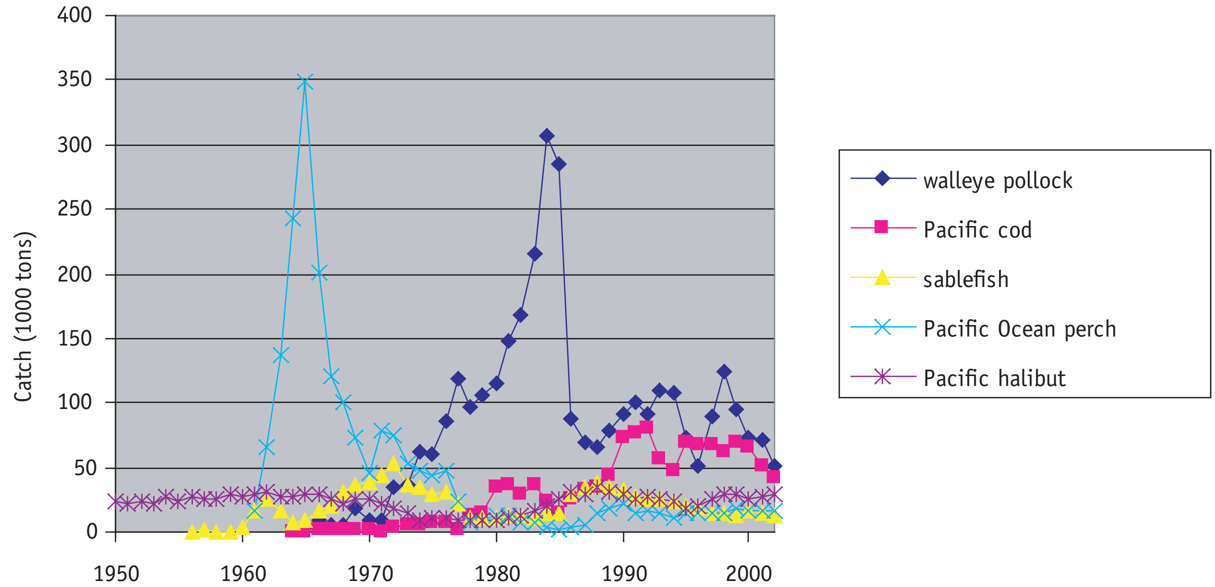
The 10 most abundant groundfish species make up more than 75% of the biomass caught in bottom trawl surveys, dominated by arrowtooth flounder (*Atheresthes stomias*), Pacific Ocean perch (*Sebastes alutus*), walleye pollock (*Theragra chalcogramma*), and Pacific halibut (*Hippoglossus stenolepis*). Shellfish such as crab and shrimp currently make up a relatively small proportion of the survey CPUE on the shelf and support comparatively small fisheries. Little is known about demersal species on the deeper parts of the slope, continental rise, in the deep central basin and on the numerous seamounts.

The nearshore areas serve as important spawning grounds and as nursery grounds for juveniles of numerous demersal and pelagic species, including salmon, pollock, Pacific cod, crab, and over 20 species of flatfishes. The life history of many of these species is closely tied to the cyclonic boundary currents, which transport eggs and larvae, and serve as important migratory pathways for juvenile salmon.

The large nekton of the central Alaska Gyre is dominated by salmon throughout the year, while Pacific pomfret (*Brama japonica*), Pacific saury (*Cololabis saira*), and albacore tuna are common in the summer. The southern part of the central gyre supported large-scale squid (*Ommastrephes bartrami*) driftnet fisheries until a moratorium prohibiting use of this gear was established by the United Nations General Assembly in 1992. The area provides the principal feeding habitat for many species, particularly Pacific salmon.[282] High abundances of several squid species and large zooplankton provide important prey for the larger nekton. Species composition in the nekton displays a strong latitudinal gradient and the distribution of most species correlates with sea surface temperature.[283] With the exception of salmon, which return to and are assessed upon their return to natal streams, only the Hokkaido University time series can be used to assess interannual variability in the nekton of the central gyre.

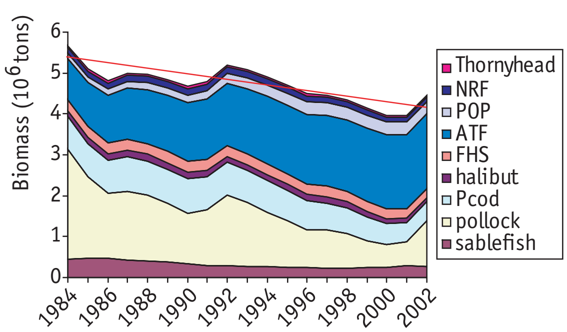
Catch and abundance trends While catch records provide the longest time series of fisheries data, they are often poor indicators of abundance because harvest rates can vary greatly as a result of management decisions and other factors. However, catches may be indicative of changes in abundance and are provided for a longer-term perspective and for comparison to other regions which often have catch data only. Stock assessments provide estimates of abundance and recruitment for the major commercial species, while triennial bottom trawl surveys conducted by the US National Marine Fisheries Service provide indices of abundance for commercial as well as non-commercial groundfish species. The summary below refers to the Alaska portion of the Gulf of Alaska shelf only and does not include fish stocks occurring off the coast of British Columbia.

Groundfish Catches of the major commercial species in the Gulf of Alaska have fluctuated widely with major peaks in the mid-1960s and mid-1980s (Figure 111). Reported catches during the early part of the century and through 1960 were dominated by Pacific halibut, which have remained relatively stable over the period of record. Pacific Ocean perch was first exploited in the early 1960s, increased rapidly to a peak in 1965, followed by a rapid decline to very low levels in the late 1970s. Exploitation of walleye pollock began in the late 1960s and pollock soon replaced Pacific Ocean perch as the major commercial species. Catches increased exponentially through the 1970s to a peak in 1984, supported by several years of strong recruitment in the late 1970s. Walleye pollock catches declined precipitously after 1984 but continue to dominate total landings. Pacific cod catches increased slowly from 1964 to the early 1990s and have remained at relatively high levels since then. Sablefish catches have undergone relatively large fluctuations with peaks in 1962, 1972 and 1988, and gradually declining catches since 1988.



[Figure 111] Catches of major commercial groundfish species in the Gulf of Alaska from 1950 to 2002. Catches of sablefish include the Aleutian islands and eastern Bering sea region. Catches of Pacific ocean perch after 1978 include other slope rockfish species. pacific halibut catches include commercial landings only.

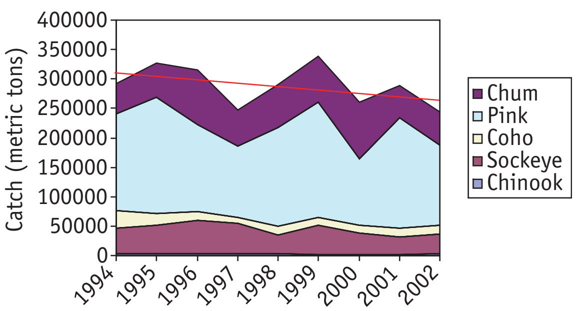
Although changes in survey gear greatly complicate the assessment of long-term trends in abundance, it is generally believed that total groundfish biomass on the Gulf of Alaska shelf increased substantially after the 1976/77 regime shift.[284,299] However, the increase followed a substantial decrease in heavily exploited Pacific Ocean perch populations and coincided with the collapse of crab and shrimp fisheries, suggesting a replacement of these species by cod and flatfishes due to a combination of overfishing and climate changes. Recent trends based on age-structured stock assessments of commercially important species suggest that the biomass of major commercial groundfish species has undergone a statistically significant decrease between 1984 and 2002 (Figure 112). The trend was largely a result of changes in walleye pollock biomass, which decreased through 2001 but increased substantially in 2002 due to a strong 1999 year class. Arrowtooth flounder, which is currently not the target of a direct fishery and is a major predator of walleye pollock, has replaced pollock as the dominant groundfish species in the last decade.



[Figure 112] Biomass estimates for major commercial groundfish species in the Gulf of Alaska from 2002 stock assessment reports (NPFMC 2002). Sablefish includes Gulf of Alaska and eastern Bering Sea (NRF = Northern rockfish, POP = Pacific Ocean Perch, ATF = arrowtooth flounder, FHS = flathead sole, Pcod = Pacific cod). These species comprise approximately 80% of the total biomass in 1999 bottom trawl surveys. Red line indicates linear trend for total catch, fit by generalized least squares with autocorrelated errors.

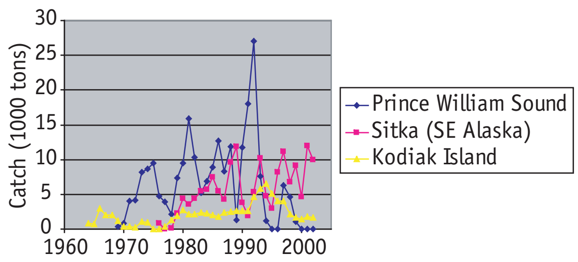
Pacific Salmon The total number of mature salmon that return to systems bordering the Gulf of Alaska has undergone large interannual and decadal-scale fluctuations, as evident in long-term catch series (see *Pacific Salmon* chapter). Decadal-scale trends in total catch have been associated with fluctuations in ocean climate[277], and marine survival rates of pink, chum, and sockeye salmon in Alaska are on average higher during years with warm coastal temperatures.[285] Catches throughout much of the North Pacific increased after the 1976/77 regime shift and have been high in the Gulf of Alaska for most of the 1980s and 1990s. However, a large portion of the increase can be attributed to massive hatchery releases of sockeye, pink, and chum salmon. The most recent catch trends suggest an approximate 10% decrease in catches of Gulf of Alaska salmon stocks between 1994 and 2002, which is not statistically significant (Figure 113). Catches in Figure 113 include both wild and hatchery fish, whose contribution to total catches has increased over time to approximately 20-30% of the total catch during the last decade. Trends in total abundances of Pacific salmon are similar to catch trends and are summarized in the *Pacific salmon* chapter.

Oceanic species Large shifts in abundance have also been documented for large epipelagic nekton in the Northeast Pacific, including salmon shark, Pacific pomfret, jack mackerel, albacore, and three squid species.[286] Except for jack mackerel all species had much higher catch rates during surveys done in the late 1980s compared to surveys in the late 1950s, suggesting a higher carrying capacity for these pelagic species in the later period. No recent updates are available due to a lack of monitoring.

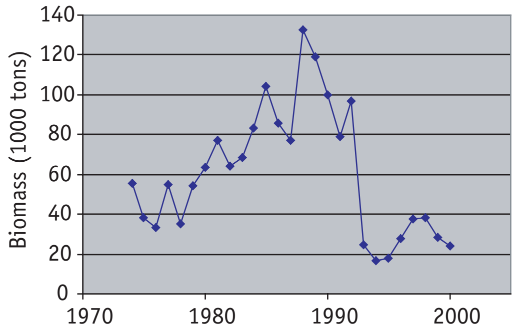


[Figure 113] Catch trends for five species of Pacific salmon in the Gulf of Alaska (combined catches of Southeast, Prince William Sound, Cook Inlet, Kodiak, Chignik, and Alaska Peninsula district stocks, including hatchery fish). Red line indicates linear trend for total catch over time.

Pacific herring Herring are widely distributed in the North Pacific and spawn in numerous locations around the Gulf of Alaska. Major spawning aggregations, which are believed to reflect distinct populations, occur in SE Alaska near Sitka, in Prince William Sound, and on Kodiak Island. Catches of these populations have fluctuated widely (Figure 114) with the largest catches between 1970 and 1992 occurring in Prince William Sound (except in 1989 when the fishery was closed as a result of the Exxon Valdez oil spill). Catches in Prince William Sound declined precipitously after 1992 and the fishery has been closed in recent years due to very low abundances (Figure 115). Very high prevalence of viral hemorrhagic septicemia and of the fungus *Ichthyophonous* have been documented in Prince William Sound herring, and it seems likely that the populations are controlled by disease.[287,288] In the western Gulf of Alaska, including Kodiak and the Alaska Peninsula, spawning habitats are limited and appear to support smaller populations relative to other areas of the GoA. Herring populations in the Kodiak area appear to be at low abundances, supporting harvests of only 1,000 – 2,000 t annually, which stand in sharp contrast to the height of the fishery in 1934-1950, when average harvests were more than an order of magnitude higher (31,600 t). Herring abundances in Sitka Sound have been generally stable and have supported the largest herring fishery in the GoA in recent years (Figure 10).



[Figure 114] Catches of three major herring stocks in the Gulf of alaska, 1964-2002. [289]



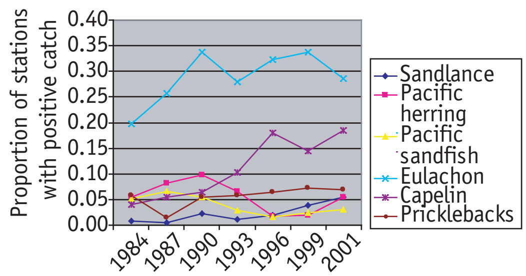
[Figure 115] Estimated pre-fishery run biomass of Pacific herring from age-structured analysis. Biomass for 1974-1979 was estimated based on a linear regression of biomass on mile days of spawn.

Shellfish In the past, the Gulf of Alaska shelf has supported significant catches of crustaceans, including tanner crab (*Chionoecetes bairdi*), Dungeness crab (*Cancer magister*), red king crab (*Paralithodes camtschaticus*), and 5 species of shrimp. Many of these fisheries collapsed in the early 1980s and some remain closed today, particularly in the western Gulf of Alaska. While catches exceeded 90,000 t in the 1960s and 1970s,[304] recent catches of all shellfish combined (1995-2001) ranged from 5,000 t in 2000 to 7,800 t in 1998, with 6,100 t of shellfish caught in 2001.[290]

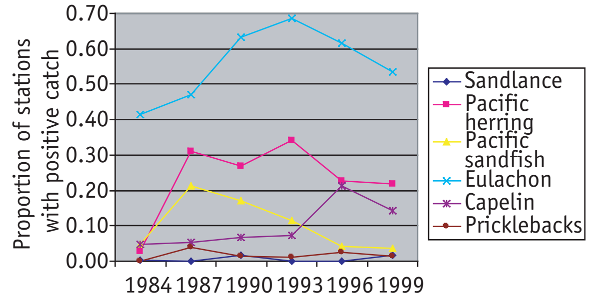
Nearshore groundfish Based on small-mesh surveys in the central Gulf of Alaska (Kodiak and Alaska Peninsula), a large shift in species composition was documented in the nearshore groundfish community in the late 1970s and early 1980s and is believed to be associated with the 1976/77 regime shift.[284,299] The nearshore community was dominated by shrimp and small forage fishes (primarily osmerids) in the 1960s and 70s. In contrast, large piscivorous gadid and flatfish species have dominated catches since the early 1980s. The most recent surveys suggest that shrimp and osmerids began to increase in some nearshore areas in 2001 and 2002, but CPUE is far below levels observed in the 1970s and 1980s.[291,292] At the same time, gadids decreased somewhat in 2001, while flatfish CPUE remained constant.

Forage fishes Large-mesh trawl-based indices of biomass for small forage fishes are unreliable due to the large influence of a few unusually large catches, which results in large interannual variability and few consistent trends.[316] An index based on frequency of occurrence (FO) may provide a better indicator of abundance, assuming that spatial distribution expands (contracts) as populations increase (decrease). Estimates of FO are more stable and suggest significant increases in sandlance, capelin, and pricklebacks from 1984 to 2001 in the central and western Gulf of Alaska (west of 147°W; Figure 116). FO of Pacific sandfish and Pacific herring changed non-linearly with a minimum in 1996 and 1999, respectively, and a subsequent increase to 2001 (Figure 116). Trends were similar in the eastern Gulf of Alaska, but only the increase in capelin was significant (Figure 117). Estimates of FO prior to 1990 should be viewed with caution due to different gear types used in these years. The above trends were significant whether 1984/87 estimates are included or not.

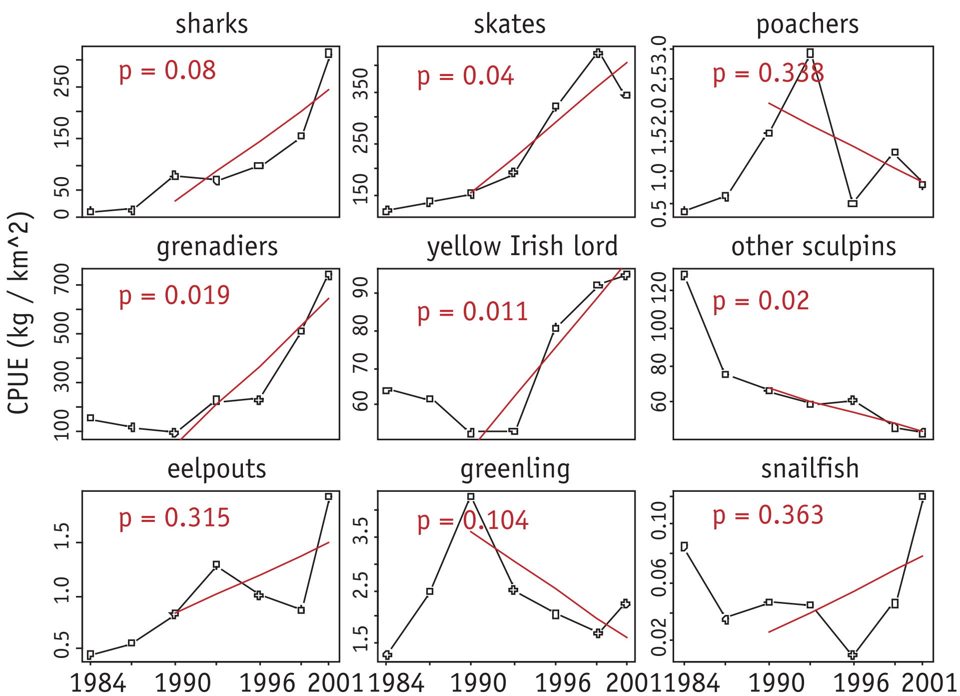
Other non-target species Changes in CPUE and FO of non-target species may be evident from bottom trawl surveys, although such surveys are primarily designed for assessing large target species such as gadids and flatfishes. Trends in CPUE for several groups are summarized in Figure 118 and suggest significant increases in sharks (Sum of spiny dogfish, *Squalus acanthias*, and Pacific sleeper shark, *Somniosus pacificus*), skates (Rajidae), grenadiers (primarily *Albatrossia pectoralis*), and yellow Irish lord (*Hemilepidotus jordani*), while other sculpins (primarily *Myoxocephalus* sp. and *Hemitripterus bolini*) decreased significantly. Trends in frequency of occurrence are similar, but less pronounced. A large increase in sleeper shark abundance over the last two decades is also evident in a recently developed index based on bycatch rates in longline surveys.[293] Trends in several non-commerical invertebrate groups have been summarized previously.[316] Trends in these and other groups suggest large increases over time in the frequency of occurrence of starfishes, sea urchins, snails, sponges, bryozoans, and other invertebrate groups.[294] However, it is not yet clear how much of this increase is attributable to grouping invertebrates at coarser taxonomic levels in early years of the survey.



[Figure 116] Frequency of occurrence of 6 groups of forage fishes in the western Gulf of Alaska bottom trawl surveys (west of 147°W) from 1984-2001. Increases in sandlance, capelin, and pricklebacks were statistically significant although estimates prior to 1990 should be viewed with caution due to differences in gear.



[Figure 117] Trends in frequency of occurrence of 6 groups of forage fishes in the eastern Gulf of Alaska bottom trawl surveys (east of 147°W) from 1984-1999. Only the increase in capelin was statistically significant at a 95% confidence level. Estimates prior to 1990 should be viewed with caution due to differences in gear.

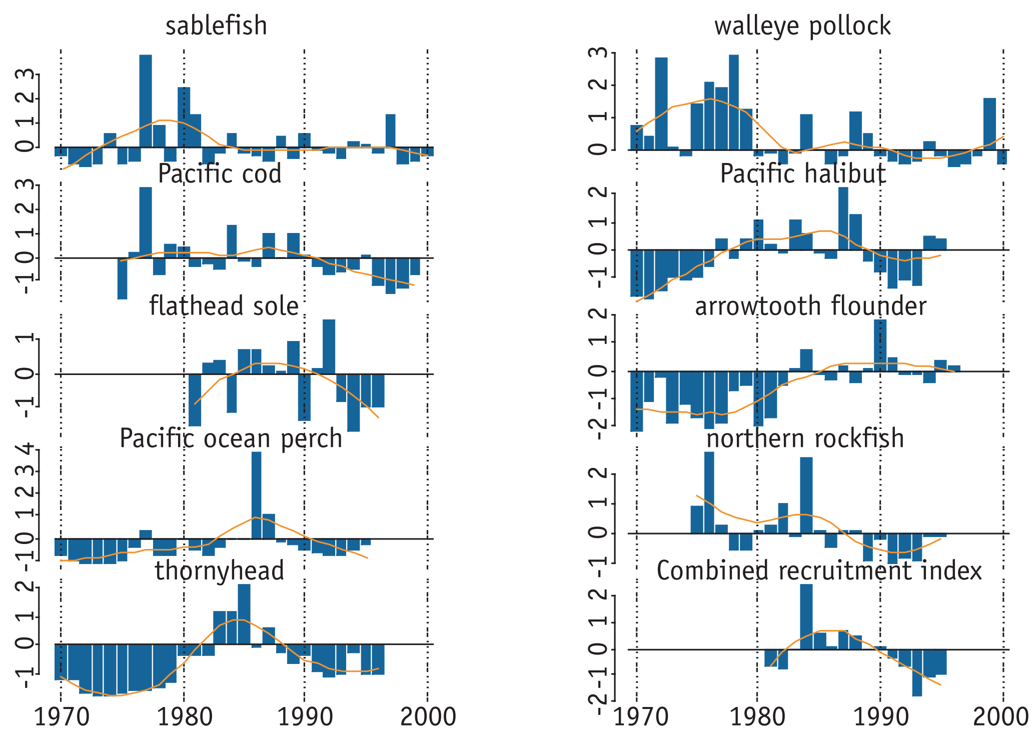


[Figure 118] Trends in catch-per-unit-effort for nine non-commercial fish groups in the western Gulf of Alaska (west of 147°W) from 1984-2001. Estimates prior to 1990 should be viewed with caution due to differences in gear. Trend lines and p-values are based on simple linear regressions of CPUE on year from 1990-2001

Recruitment trends Recruitment estimates for some groundfish species are highly variable, while others show relatively smooth trends (Figure 119). In part these differences stem from the models used in stock assessment. For species that do not recruit to the fishery or survey gear until they are several years old, no recruitment estimates are available for year classes after the mid-1990s. Recruitment of most assessed groundfish species was relatively poor throughout the 1990s, with the exception of a strong 1992 flathead sole year class, 1997 sablefish year class, and the 1999 pollock year class. A combined recruitment index (sum of standardized recruitments across all major stocks) indicates good overall recruitment during much of the 1980s, particularly in 1984, and poor recruitment during the first half of the 1990s (Figure 119). For stocks with more recent data, recruitment has been below average in sablefish (1998-2000) and Pacific cod (1996-2000). Forecasts based on larval abundances suggest strong recruitment of walleye pollock in 2001 and 2002.[316]

Recruitment trends of adult salmon can be estimated by allocating returns to brood years based on the estimated age composition of returns. Recruitment and survival rates for sockeye, pink, and chum salmon for Gulf of Alaska stocks have been previously estimated.[295,296,297] The combined recruitment of these three species across the Gulf of Alaska (Figure 121) increased from the early 1970s to the mid-1980s and has been mostly above average since then through 1996. Recent catch trends (Figure 113) suggest continued strong recruitment, assuming that harvest rates and age composition remained stable.

Herring recruitment has high interannual variability, but stocks from Southeast Alaska to Kodiak display similar patterns of variability.[298] The combined recruitment of all major stocks in this region (Figure 121) shows three exceptional year classes: 1984, 1988, and 1993, the last year for which recruitment estimates are available. A sharp decline in biomass of herring in Prince William Sound after 1992 suggests very poor recruitment to this stock throughout the 1990s.



[Figure 119] Standardized estimates of recruitment (number of annual recruits by year class) for major commercial species with a trend line indicated in red. The Combined Recruitment Index is the sum of all nine standardized recruitment indices, hence giving equal weight to each species regardless of abundance.

No time series of recruitment by year class are currently available for crustacean stocks in the Gulf of Alaska because most species cannot be aged reliably. A time series of male crab numbers by size class for Kodiak tanner crab suggests that recruitment in recent years has been higher than at any time during the 1987-2002 period.

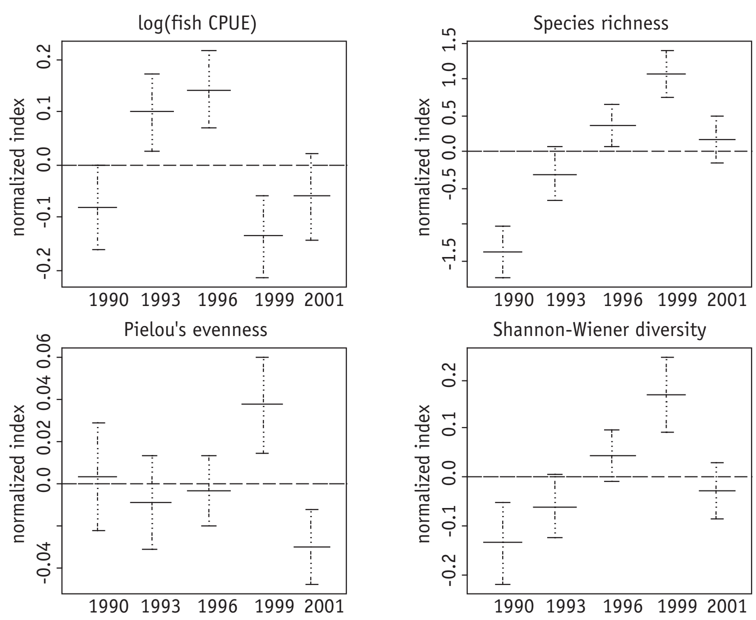
Community and catch-based trends A survey-based index of total (log-transformed) summer catch-per-unit-effort of all groundfish captured in the western Gulf of Alaska (west of 147°N) by standard survey gear suggests increased abundances in 1993 and 1996, and a significant decrease after 1996 (Figure 120).[299] Estimates of total groundfish biomass in the western Gulf of Alaska decreased by 16% between the summer of 1996 and 1999.

Groundfish richness, evenness, and diversity. Species richness, evenness and diversity show significant trends over time, most notably an increase in species richness and diversity through 1999 and a significant decrease between 1999 and 2001 (Figure 120). The average number of species per haul decreased from approximately 11 species per haul in 1999 to 10 species in 2001 (adjusted for differences in area swept and seasonal trends).

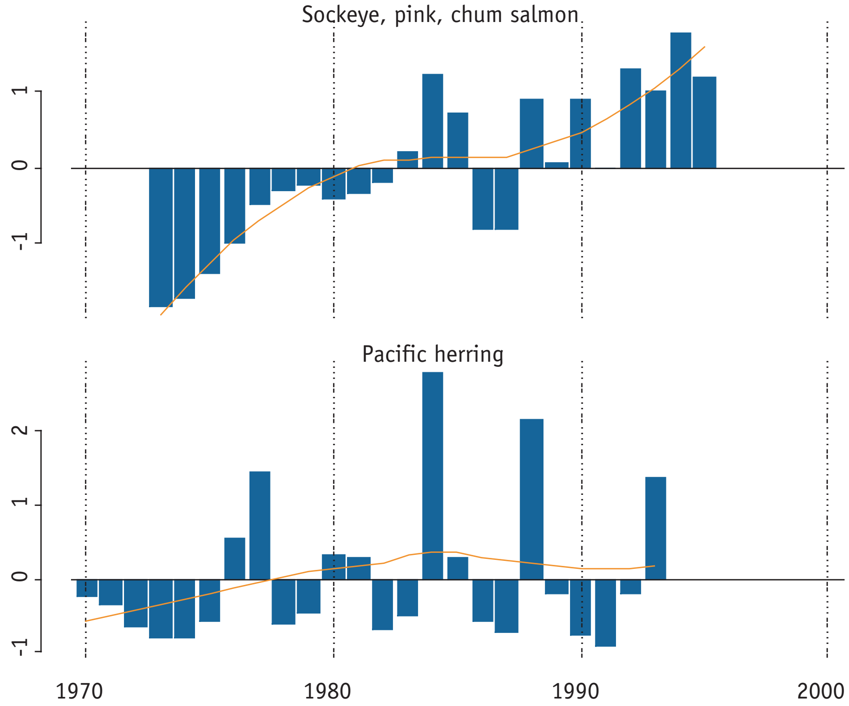
The trend in diversity paralleled the trend in species richness. Evenness was highest in 1999 and decreased significantly between 1999 and 2001.

There is concern that fisheries throughout the world increasingly rely on small, low-value species as a result of the intense exploitation of large, predatory fishes.[300] These changes can be assessed on the basis of changes in the average trophic level of the catch[301] and the Fishing-in-Balance index.[302] While the average trophic level of the catch has varied by more than one in the Gulf of Alaska, there is no indication of a long-term trend from the 1960s to the present.[316]

The status of Alaskan groundfish, crab, salmon and scallop stocks managed under federal fishery plans in 2002 was assessed in the April 2003 National Marine Fisheries Service report to Congress.[303] Out of 25 major stocks, 14 stocks (9 groundfish stocks, 5 salmon species) were listed as not overfished, while the status of 11 major stocks and of all 80 minor stocks was unknown. Shellfish stocks managed by the State of Alaska are not listed in the NMFS report and include a number of crustacean stocks that are considered to be overfished, although no formal evaluation has been completed.[304]



[Figure 120] Estimated means and 95% confidence intervals by year for log-transformed total fish CPUE (adjusted for time of day), species richness (number of species per haul, adjusted for area effect and seasonal differences), Pielou's evenness (adjusted for area and seasonal effects), and Shannon-Wiener diversity (adjusted for seasonal differences).[299]



[Figure 121] Standardized estimates of number of recruits by ocean entry year for salmon and by year class for herring. All major stocks from northern BC through Kodiak Island are included.

Marine birds and mammals

At least 18 species of marine mammals and 38 species of marine birds use the shelf and offshore habitats of the Gulf of Alaska.[305] Seabird densities are highest over by more than 50% from 1990-1999, and has slightly increased from 1999-2001.[316] Time series for effort by other gear types, such as longlines and pots, are currently not available. Fishing directly impacts target and bycatch species and may have adverse impacts on habitat structure and function. Numerous areas are closed to trawling to protect benthic habitat, reduce bycatch of prohibited species (salmon, crab, herring, and halibut), and protect Steller sea lions. with frontal features.[279] Seabirds feed on a variety of prey species, including euphausiids, small squid, capelin, and sandlance. Seabird populations on the Gulf of Alaska continental shelf during summer (June – August) contain approximately 16 million individuals, which are estimated to consume 500,000 tons of prey during this period.[305] Marine mammal populations during the summer include an estimated 126,000 individudals of Steller sea lions, harbor seals and harbor porpoise. They are important top-level predators and consume a minimum of 166,000 tons of fishes, squids, and crustaceans on the continental shelf from June through September, not including predation by sea otters, whales, and porpoise.

Two species of marine mammals are regularly surveyed in the Gulf of Alaska, Steller sea lions, *Eumetopias jubatus*, and harbor seals, *Phoca vitulina*, and both have declined significantly over the past three decades. Causes for the decline remain controversial and are likely due to a combination of various factors, including the reorganization of the ecosystem after the 1976/77 regime shift, predation by killer whales and sharks, harvests and incidental catches, diseases, parasites, and contaminants. A recent review identified nutritional stress as a result of the reduced availability of suitable prey as a likely cause for the observed declines in Steller sea lions.[306] A number of seabird rookeries in the Gulf of Alaska have been monitored over the past 6-15 years by the US Fish and Wildlife Service to assess trends in population abundances, productivity, and diet of seabirds.[307]

Recent trends in marine mammal and seabird populations suggest that the long-term decline in the abundance of Steller sea lions and harbor seals in the western Gulf of Alaska has slowed or reversed. However, current population sizes are only a fraction of the historical maximum. Seabird population trends differ among species and sites, while sea bird productivity was generally above the long-term average in 2001.

Aerial surveys suggest a 70% decline in sea lion populations in the Gulf of Alaska and Aleutian Islands between 1960 and 1989,[308] which prompted a listing of the Steller sea lion population as "threatened" under the United States Endangered Species Act in 1990. The western stock (west of 144°W) continued to decline at an average annual rate of 4.2% from 1991-2002 and was listed as "endangered" in 1997. Although still very low, the count of non-pups at trend sites in the western Gulf of Alaska increased by 5.5% between 2000 and 2002, the first increase in two decades. In contrast to the western stock, the eastern stock increased from 1979 to 1997,[309] and has remained stable or increased slightly in recent years.[316]

Comprehensive Steller sea lion pup counts are conducted every 4 years since 1990 and suggest declining production throughout the 1990s. Pup counts continued to decline in the most recent surveys in 2001/2002, but showed a 5.5% increase at rookeries in the western Gulf of Alaska region (western part of Alaska Peninsula) between 1998 and 2002. Pup counts in the eastern Gulf of Alaska increased 11% from 1998 to 2002.

Harbor seals at Tugidak Island provide an index of regional abundance.[310] The population declined from 1976 to the late 1980s, stabilized during the early to mid-1990s, and has increased since then. However, the population remains well below that of the 1970s. The recent increasing trend is confirmed by aerial surveys in the Kodiak Island region, which estimated a 5.6% annual increase from 1993 to 1999. Aerial surveys in Southeast Alaska suggest increasing trends in harbor seal abundance from the early 1980s to 1998.

Population trends of seabirds differ greatly among species and sites.[311] Many species show different trends at colonies in the eastern and western Gulf of Alaska. Cormorants are the only species that have decreased substantially over the period of record throughout most of the Gulf, with the exception of St. Lazaria in Southeast Alaska, which showed a large increase in abundance from 1994 to 2001.

Productivity is measured as chicks fledged per egg and has remained relatively stable at most sites over the period of record. Productivity for most species-site combinations was below average in 1999, near-or above average in 2000, and almost uniformly above average in 2001.[312] This suggests that productivity in the feeding areas has increased from 1999 to 2001, consistent with increasing nutrient levels and primary and secondary production on the shelf over this time period.

critical factors causing change

Natural variability in the Gulf of Alaska occurs at interannual to decadal scales.[313] Major sources of variability are large-scale interdecadal changes in the atmosphere-ocean system occurring throughout the Northeast Pacific and episodic events associated with El Niño variability that propagate via the atmosphere and/or through the ocean to northern latitudes (Figure 122). It is not yet clear whether these sources of variability describe two independent modes or are inherently linked. Decadal-scale variability is commonly described by the Pacific Decadal Oscillation (PDO), which has gone through two full cycles over the past century: "cool" PDO regimes from 1890-1924 and from 1947-1976, and "warm" PDO regimes from 1925-1946 and from 1977 through (at least) the late-1990s.[314] In contrast to the tropics, which are dominated by short-frequency variations, the decadal time scale appears to be the dominant scale in the northern North Pacific, which may be a result of positive feedback mechanisms between the atmosphere and ocean that promote multi-year persistence in North Pacific upper ocean temperature anomalies.[21,314] Such interdecadal changes in ocean climate have widespread impacts on biological variability at multiple trophic levels. There is strong evidence that the productivity and possibly the carrying capacity of the Alaska Gyre and of the continental shelf were enhanced during the recent "warm" regime. Thus, understanding ecosystem variability both within and between regimes has become a major impetus for much of the research in the Northeast Pacific.

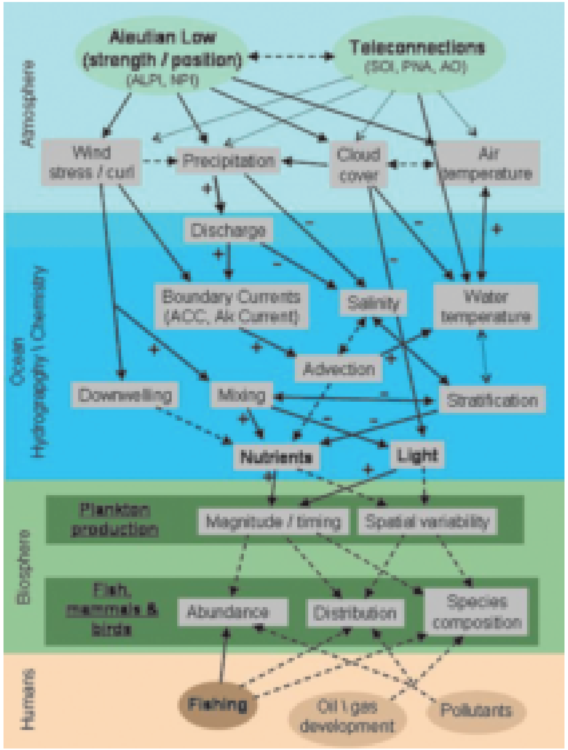
At local to regional scales, physical variability on the shelf is primarily related to wind mixing, downwelling conditions, and freshwater input, which help determine the onset and magnitude of the spring bloom and subsequent production[240]. These factors, in turn, are linked to large-scale atmospheric and oceanographic variability,[315] although such links have not been fully explored to date.

Compared to other large coastal systems, ecosystem dynamics on the Gulf of Alaska shelf are poorly understood at present.

Fishing is the predominant direct human impact on the Gulf of Alaska ecosystem. The amount of fishing effort (measured as bottom trawling time) decreased by more than 50% from 1990-1999, and has slightly increased from 1999-2001.[316] Time series for effort by other gear types, such as longlines and pots, are currently not available. Fishing directly impacts target and bycatch species and may have adverse impacts on habitat structure and function. Numerous areas are closed to trawling to protect benthic habitat, reduce bycatch of prohibited species (salmon, crab, herring, and halibut), and protect Steller sea lions.

Global climate change resulting from increasing levels of greenhouse gases in the atmosphere is projected to increase air and sea-surface temperatures and raise sea levels globally. Climate change may alter the geographic distribution of marine organisms, the flow of energy within the ecosystem, and ecosystem productivity. At present we do not know how the Gulf of Alaska ecosystem will respond to future climate changes.

Other factors impacting the Gulf of Alaska include coastal development, recreational and commercial vessel traffic (including cruise ships and oil tankers), oil production facilities, aquaculture, invasive species, and contaminants originating from coastal runoff and atmospheric transport. Although population densities around the Gulf of Alaska are relatively low compared to other marine ecosystems, new development and expanding tourism are likely to increase pressures on coastal marine resources.



[Figure 122] Schematic representation of Gulf of Alaska ecosystem dynamics. Solid arrows indicate strong and well-documented relationships, dashed arrows indicate poorly understood relationships, and dotted arrows indicate weak and / or poorly understood relationships

issues

Important issues affecting the ecosystem of the Gulf of Alaska and its management include recent environmental changes, scales of variability, ecosystem productivity, the lack of monitoring programs for major components of the ecosystem, the impacts of fishing, and continuing concerns over Steller sea lion populations.

There is some evidence that another regime shift may have occurred in the Gulf of Alaska in 1999; from warm conditions associated with the predominantly positive phase of the PDO (1977-1998) to a cool regime associated with a predominantly negative PDO starting in 1999, following a major La Niña event. This may have major implications for the productivity and species composition of Gulf of Alaska fish communities, including salmon and groundfish stocks.

Biological responses associated with the cooling that began in 1999 have primarily been observed in the transition zone off southern British Columbia. These include changes in zooplankton species composition,[317] improved feeding and growth of juvenile salmon, and large returns and increased marine survival of pink and coho salmon to southern B.C.[318] Similar responses have not been reported from the northern Gulf of Alaska. The response of Alaska salmon stocks is expected to be opposite to that of B.C. stocks[272,285] prompting concerns over a downturn in salmon productivity.

While the focus of much recent research has been on large-scale, interdecadal changes, other spatial and temporal scales are clearly important. For example, regional spatial scales on the order of hundreds of km are the dominant scale of spatial variability in salmon survival rates.[285] Spatial variability in groundfish dynamics is poorly understood because almost all stocks are assessed as a single unit in the Gulf of Alaska and current assessments do not take into account spatial variability. Small-scale variability in circulation and plankton dynamics have been examined through a number of mesoscale studies such as the Fisheries-Oceanography Coordinated Investigations and the recent GLOBEC program in the central Gulf of Alaska. However, variability at local to regional spatial scales and its effects on ecosystem dynamics remain poorly understood although it may well be the most important scale of variability for nutrient and plankton dynamics on the shelf, as well as for higher trophic levels. Similarly, short-term temporal variability at annual and interannual scales dominate recruitment dynamics of many demersal fishes in the Gulf of Alaska, but remain poorly understood.

While trends in abundance and productivity of individual species are available, there are currently no reliable indices that track overall system productivity for major ecosystem components. Estimates of new production at lower trophic levels are not available or time series are too short and/or localized to assess changes. However, indices based on satellite-derived estimates of chlorophyll-a levels may hold promise for monitoring primary productivity.

Secondary productivity is difficult to measure adequately, while estimates of productivity at higher trophic levels is typically not available for many years due to the longevity of many fish species and the lack of monitoring of juvenile stages. Seabird productivity and abundance is now routinely monitored for numerous species and sites and may provide useful indices that reflect overall system productivity at regional or larger spatial scales. Clearly, effective monitoring of ecosystem productivity should be a priority for future research.

While the direct impacts of fishing on target species and "prohibited species" (crab, halibut, herring, and salmon) are addressed in current fishery management plans, there is increasing concern over effects on non-target fish species, seabirds, mammals, and habitat. Various management measures have been put into effect to reduce bycatch and discard levels and the North Pacific Fisheries Management Council (NPFMC) is taking steps towards actively managing non-target species. Indirect effects, such as potential interactions between fisheries and sea lion feeding, are also being investigated at present. Numerous studies have documented potential effects of fishing on habitat (albeit not many in the Gulf of Alaska), and steps to mitigate adverse impacts are being taken by the NPFMC as mandated by the Magnuson-Stevens Act.

The decline of Steller sea lions in Alaska is presently the subject of intense investigation, including potential negative impacts of fishing as discussed above. It has recently been proposed[319] that the decline of large whales in the North Pacific due to industrial whaling during the 20th Century may have caused their main predator, the killer whale (*Orcinus orca*), to prey upon smaller marine mammals such as sea otters and seals in Alaska. While environmental changes may ultimately be responsible for the decline in Steller sea lion populations, a precautionary approach (and the law) requires that steps be taken to minimize adverse impacts of fishing on sea lions. To that effect, closures around sea lion rookeries have been established throughout the Gulf of Alaska and their impacts on fisheries and the ecosystem should be monitored closely.

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