

3.10 Ecosystem

This section discusses the affected environment at the ecosystem level. It provides three kinds of information:

1. It summarizes relevant historical information and recent scientific data on the North Pacific Ocean ecosystem;
2. It discusses interactions among climate, commercial fishing, and ecosystem relationships in the North Pacific Ocean from a multi-species perspective, including climatic processes that may act as forcing agents on the BSAI and GOA ecosystems, producing background changes that are independent of human activities such as commercial fishing; and
3. It reviews indicators of the present status of the BSAI and GOA ecosystems that help to form the baseline for assessing and comparing potential future environmental consequences of the alternatives, including cumulative effects, in Chapter 4.

The section is subdivided as follows:

Section 3.10.1 presents a historical overview of the regional ecosystem, distinguishing the BSAI and GOA where records permit. The overview begins at the environmental reference point of 1740, the year before Vitus Bering's first expedition to Alaska, and continues to the present. It includes observational information from the eighteenth, nineteenth, and early twentieth centuries, as well as data collected after passage of the Magnuson Fishery Conservation and Management Act of 1976 (now the Magnuson-Stevens Fishery Conservation and Management Act, referred to as the MSA).

Section 3.10.2 summarizes interactions among climate, commercial fishing, and ecosystem characteristics in the North Pacific Ocean.

Section 3.10.3 evaluates the current status of the North Pacific Ocean ecosystem using indicators from three broad categories: predator-prey relationships, energy removal and flow, and biodiversity.

The main conclusions of this section are as follows:

1. The North Pacific Ocean ecosystem is within the bounds of natural variability with respect to predator-prey relationships, energy removal and flow, and biodiversity.
2. Fish and wildlife populations within the North Pacific Ocean ecosystem are naturally dynamic: at any point in history, some species are increasing in abundance while others are declining.
3. Climatic forcing agents exert a powerful influence on marine fish and wildlife populations of the BSAI and GOA. Gathering and incorporating knowledge about these forcing agents may increase their predictability and enhance the effectiveness of future fishery and wildlife management.

3.10.1 The North Pacific Ocean Ecosystem from 1740 to Present

This section reviews available historical information on the BSAI and GOA ecosystems and changes since 1740, the environmental reference point for the ecosystem analysis. While much of the earlier information is anecdotal, particularly accounts from the eighteenth and nineteenth centuries, it represents the best available observational data on the North Pacific Ocean ecosystem from those periods. More information on the history of North Pacific Ocean commercial fisheries and their management is presented in Appendix B. Detailed life history information on fish, birds, and marine mammals is presented in the individual species accounts (Sections 3.5 through 3.8).

Establishing an environmental reference point as the starting place for the historical review follows USEPA guidance for the consideration of cumulative effects (USEPA 1999). The historical review serves as the source for information about past external effects, natural and manmade, on the North Pacific Ocean ecosystem. In this case, the environmental reference point is set at 1740 because this was the year preceding Bering's first voyage, with naturalist Georg Wilhelm Steller, to BSAI and GOA waters (Steller 1743).

For this analysis, it is assumed that the BSAI and GOA ecosystems in 1740, one year prior to first contact, represent an ecologically sustainable condition. As defined by USEPA, an ecologically sustainable system "supports biological processes, maintains its level of biological productivity, functions with minimal external management, and repairs itself when stressed" (USEPA 1999). This definition allows the possibility that a sustainable ecosystem may change with respect to the details of its component parts—for example, as populations of individual species cyclically increase and decrease over time—but that the ecosystem-level characteristics with regard to overall productivity and ability to maintain structure and patterns of behavior in the face of disturbance continue without being intensively managed.

3.10.1.1 Eighteenth Century

The first fish and wildlife observations by non-indigenous visitors to what are now called the Bering Sea, Aleutian Islands, and Gulf of Alaska were made by Steller aboard the *St. Peter* in 1741 during Bering's first voyage to Alaskan waters. Steller's journals (Steller 1743) indicate that marine furbearers, birds, and fishes were abundant and easily observed at the time of first contact. In addition to whales, fishes, and many seabirds and terrestrial birds, Steller described abundant occurrences of four North Pacific marine mammal species: sea otter, sea lion, fur seal, and sea cow (*Hydrodamalis gigas*, a large manatee hunted to extinction by 1768). He collected thousands of botanical specimens and first described hundreds of plant species unknown in Europe. Having learned from indigenous people the value of certain plants (e.g., *Cochlearia officinalis*) in preventing and curing scurvy, Steller was the first European known to administer antiscorbutics to ships' crews, saving many lives.

During the half-century following Bering's first voyage, Russian traders killed large numbers of the abundant marine mammals, as well as arctic and red foxes, river otters, and other mammals for their pelts. The pelts were sold at high prices in Europe and China. Walrus were killed in large numbers for their ivory tusks. Sea otter harvests, which began in 1743, were particularly high, but mercantile records of the period have not been widely published. Some of the most complete records in English can be found in Bancroft (1886); these are summarized in Table 3.10-1.

Intensive harvesting of sea otters in the BSAI and GOA, including the waters of Prince William Sound and Cook Inlet, had been underway for 45 years by the time Gerassim Pribilof first reached the island of St. George, named for his ship, in June 1786. Bancroft described the scene as follows:

“The shores of St. George literally swarmed with sea-otters, which undisturbed so far by human beings could be killed as easily as those of Bering Island during the first winter after its discovery. Large numbers of walrus were secured on the ice and upon the adjoining small islands; arctic foxes could be caught by hand, and with the approach of summer the fur-seals made their appearance by thousands (p. 192).”

Fur seals had been previously harvested from the Commander Islands and elsewhere, with Shelikof having imported 70,000 skins prior to 1780 (Bancroft 1886). However, the Russian acquisitions of St. George and St. Paul, which Pribilof reached in 1787, immediately opened a major new trade in fur seal skins at a time when sea otter populations, having sustained consistently high annual mortality rates for decades, were rapidly declining. Veniaminov (1840) stated that at the time of first contact with the Pribilof Islands in 1786, sea otters were so abundant that their numbers in the water physically impeded access to the islands. Within six years, not a single otter was observed in nearshore waters. Veniaminov unambiguously attributed these declines to direct mortality from fur harvesting. The new, seemingly inexhaustible supply of fur seals from the Pribilofs provided a timely substitute for the declining sea otters. Bancroft (1886) recounted a letter by Shelikof, dated 1789, describing the first fur harvest following Russian occupation of the Pribilofs: “[D]uring the first year the hunters obtained on the newly discovered islands 40,000 fur seal skins, 2,000 sea otters, 400 pounds [14,400 lbs.] of walrus ivory, and more whalebone [baleen] than the ship could carry.”

In the late eighteenth century, BSAI and GOA sea otter populations had declined to the point that supplies of pelts were nearly exhausted. At the same time, the growing Russian settlement of coastal Alaska led to an expansion of the furbearer trade to include the trapping of terrestrial mammals such as mink, pine marten, and foxes, while fur seal killings continued in the Pribilofs. Concerns among the established Russian merchants to stabilize and protect their dwindling fur supplies as a growing number of competing rivals entered the market led to organization of the Russian American Company in 1799 (Bancroft 1886).

By the close of the eighteenth century, nearly 60 years of intensive fur harvesting had caused major declines in the marine mammals of the BSAI and GOA, and the Steller sea cow had been gone since 1768, hunted to extinction for meat. It is not known whether these high mortalities led to other changes to the marine ecosystem or how deeply the changes penetrated the food web. Major human impacts to upper trophic levels of the BSAI and GOA ecosystems were occurring as long as 250 years ago.

3.10.1.2 Nineteenth Century

In the early nineteenth century, the fur seal trade dominated Russian mercantile activities in Alaska. Fur seal harvest levels prior to 1817, while unrecorded, were estimated at 90,000-110,000 per year by Veniaminov (1840), who stated that the annual harvest was often undertaken without foresight. In 1803, for example, the accumulated store of fur seal skins in the Pribilofs reached 800,000, more than 700,000 of which were burned or thrown into the sea because of poor market conditions due to the Napoleonic wars.

Quantitative data on annual fur seal harvests in the Pribilof Islands were recorded from 1817 through 1837 (Table 3.10-2). The harvest declined from 60,188 in 1817 to 6,802 in 1837, a decrease by nearly 90 percent over two decades. Veniaminov (1840) wrote:

“The cause of the decrease in the number of fur seals is evident, and one can only wonder how they have survived up to the present, considering how mercilessly they have been killed year after year, that they produce but one offspring each year, and that, in addition to known perils encountered in their migrations, [they] must also be subject to some unknown ones (p. 147).”

As noted in Section 3.10.1.1, Veniaminov stated that at the time of first contact with the Pribilof Islands, sea otters were so abundant that their numbers physically impeded access to the islands; within six years, not a single otter was observed in nearshore waters. Within three decades, by 1811, none was seen in offshore waters of the Pribilofs. In the Unalashka District, over 1,000 sea otters were harvested annually in the late eighteenth and early nineteenth centuries. By 1840, 70 to 150 were taken annually (Veniaminov 1840).

Similarly, Steller sea lions had been killed in great numbers during the latter two decades of the eighteenth century, and this trend continued into the nineteenth century. By 1840, about 2,000, including young, were harvested annually from St. George, and sea lions had been entirely absent from St. Paul for many years (Veniaminov 1840).

Although quantitative data were not available, Veniaminov states that seabird populations, very numerous at the time of first contact, were greatly reduced by 1840, and that only by instituting harvest prohibitions and controls could they be conserved or increased.

Economically important groundfish populations were observed to decline. At Unalashka, several hundred cod were harvested daily during earlier decades, but by 1825 and 1826, no cod were caught. Fluctuations in cod populations are reflected in the Eastern Aleut name for the fish, which translates as "the fish that stops" (Black 1993).

Seasonal migratory fish (e.g., salmon and Dolly Varden) were harvested annually in the hundreds of thousands in the early decades following first contact. By 1840, however, annual salmon harvests at Makushin village had declined from hundreds of thousands to tens of thousands, and Veniaminov observed that:

“The same situation obtains everywhere (p. 39).”

Veniaminov attributed declines in groundfish populations to undersea volcanic activity. In 1825, immediately before a major eruption in the Unimak Range, dying cod and sculpin were observed floating in great numbers on the surface and were absent until after 1827 when a gradual recovery began. He attributed declines in salmon to the pollution of river mouths by refuse disposal and to changes brought by volcanic activity.

Following the purchase of Alaska by the United States in 1867, institution of regulatory controls on resource management began. In 1868, the U.S. Treasury Department sent agents to Alaska to protect fur seals and administer a lease to the Alaska Commercial Company for harvesting seals in the Pribilof Islands. As the Alaska salmon industry developed, government agents collected taxes on processed salmon products (Fredin 1987). Commercial fisheries for salmon and halibut expanded as technologies for large-scale canning, iced

storage, and rail trans shipment developed. Salmon canneries were established in Alaska for the first time in 1878 (Cooley 1963).

Commercial fishing in the BSAI and GOA for cod and other groundfish, however, was unregulated and proceeded on a common-pool basis in which fishery resources were available to all participants. During the final three decades of the nineteenth century, expanding commercial groundfish harvests continued on a laissez-faire basis, open to any entrants and without noteworthy federal oversight. Cod stations were established in the late 1880s throughout the Aleutians to exploit the abundant resource, an indication that the cod population had rebounded substantially since Veniaminov's observations in the 1830s (Morgan 1980).

3.10.1.3 Twentieth Century Prior to Magnuson-Stevens Act

During the first three quarters of the twentieth century, the growth of commercial fishing, whaling, and fur seal harvesting put pressures on the North Pacific Ocean ecosystem by targeting important components of the food web, including top predators. A variety of policy instruments were put in place to moderate these pressures. Prior to passage of the MSA in 1976, commercial fishing was conducted in the North Pacific Ocean, including United States territorial waters, by fleets from many nations operating within a complex framework of multilateral and bilateral agreements. Under these agreements, international commercial harvests of groundfish rose to unprecedented volumes after the 1950s. Appendix B summarizes the history of the North Pacific Ocean groundfish fisheries and their management prior to 1976.

Similarly, commercial whaling increased greatly in the North Pacific Ocean region during the first half of the twentieth century, as Atlantic and South Pacific stocks became depleted. In 1946, the International Convention for the Regulation of Whaling, signed by 14 nations including the United States, established the IWC to conserve whale stocks and regulate commercial whaling. Under IWC oversight, commercial whaling in the North Pacific Ocean continued to increase, reaching its maximum level in the 1950s and 1960s. After this, concerns over stock depletions led the IWC to establish increasingly restrictive whaling quotas and to ban all commercial whaling in 1986. Small subsistence quotas for aboriginal peoples, including Alaska Natives, remain in effect and are adjusted periodically in accordance with whale population data. These limited harvests are not thought to affect whale population characteristics. For species-specific information on the life histories and current status of the whales, see Sections 3.8.11-25.

As previously noted, the commercial harvesting of northern fur seals began on the Pribilof Islands in the 1780s and continued through the nineteenth century, with protections starting to be imposed after the acquisition of Alaska by the United States in 1867. From 1786 to 1828, roughly 100,000 northern fur seals per year, primarily pups, were killed (Baird and Hanson 1997). Commercial harvesting during this early period, which included pregnant females, is generally believed to have caused the large reductions in population size observed in the late 1800s and early 1900s. From 1912, pregnant females were excluded from the harvest, and the fur seal population grew through the 1940s. In an effort to move the population toward a level where productivity would be maximized, approximately 300,000 females were killed between 1956 and 1968. The population did not respond as expected at the time, however, and pup production decreased (York and Hartley 1981).

In 1957, the United States, Canada, Japan, and the Soviet Union signed the Interim Convention on the Conservation of North Pacific Fur Seals, which established the North Pacific Fur Seal Commission. The

Interim Convention prohibited the hunting of fur seals at sea, but allowed the annual harvest on the Pribilof Islands to continue under the oversight of the Commission. The annual harvest continued through 1966, when Congress passed the Fur Seal Act prohibiting the taking of fur seals on United States lands and waters, with the exception of Native American subsistence use. The Interim Convention expired in 1984 because it was no longer supported by the United States, which had its own protective laws in place. The northern fur seal is now managed by NOAA Fisheries under the authority of the Marine Mammal Protection Act.

As the ecosystem concept gained currency in the 1960s and later, the ongoing large, international commercial harvests of groundfish, whales, and northern fur seals discussed above were considered likely to produce changes at the ecosystem level (Trites *et al.* 1999). As discussed in Section 3.10.2, the populations of some species in the EBS showed major alterations between the 1950s and the 1980s. Among the best documented were the declines of Steller sea lions (Section 3.8.1) and northern fur seals (Section 3.8.2), and the apparent increase and dominance of groundfish, particularly pollock and large flatfish (Section 3.5.1). Trites *et al.* (1999) proposed two hypotheses to account for these changes. First, the removal of top predators from the food web through commercial harvesting was proposed as the mechanism for change. Second, a climate-related shift in physical oceanographic characteristics was implicated (for a review of physical oceanographic processes, see Section 3.3).

To test these hypotheses, Trites *et al.* (1999) used two inter-related software packages (Ecopath and Ecosim) to compare quantitatively the EBS ecosystem as it was during the 1950s, before large-scale commercial fisheries were underway, and during the 1980s, after many marine mammal populations had declined. They consolidated the hundreds of species that make up the EBS ecosystem into 25 functional groups. Some ecosystem indices derived from the two models suggested that the EBS ecosystem was more mature (that is, had more fully developed and diverse biological guilds and communities) in the 1950s than in the 1980s. However, the actual condition of the EBS in the 1950s was uncertain because of the relative paucity of data from that time. The ecosystem indices for both the 1950s and 1980s models suggested that the EBS was resilient and resistant to perturbations such as those from the commercial harvests described above. For example, removing whales from the 1950s ecosystem had a positive effect on pollock by reducing competition for food. However, commercial whaling alone was insufficient to explain the 400 percent increase in pollock biomass thought to have occurred between the 1950s and the 1980s. Nor did commercial fisheries account for the observed changes. Indeed, the magnitude of changes that occurred in the biomass estimates of all major groups in the EBS ecosystem could not be explained solely through trophic interactions influenced by commercial harvests. Instead, it was suggested that a climatic regime shift affecting hydrographic features such as the distribution of seawater temperatures was likely to be responsible (Trites *et al.* 1999). These findings are supported by traditional knowledge from many sources. For example, older residents of Sand Point and King Cove noted during the scoping process for this Programmatic SEIS that sudden decreases in marine fish and mammal populations occurred in the late 1940s and mid-1950s. Although they did not mention climate changes, these observations seem consistent with more recent scientific findings linking fish abundance to climatological conditions (e.g., Anderson and Piatt 1999, see Section 3.10.1.5). This is due to the finding that there was a large negative shift in the values of the Pacific Decadal Oscillation Index, which measures changes in North Pacific sea surface temperature variability, from the 1940s to mid-1950s. The negative phase of this index is associated with enhanced coastal productivity along Oregon and Washington and inhibited productivity in Alaska (NPFMC 2002c).

3.10.1.4 Ecosystem Trends under MSA Fishery Management Plans and Amendments

The BSAI and GOA currently support some of the largest and most productive commercial fisheries in the world. Under policies instituted by FMPs and their sequential amendments since passage of the MSA in 1976, the biological and oceanographic dynamics of these regions have been monitored to detect trends and potential sources of problems, such as overfishing or fishery-induced declines in species not targeted by commercial fisheries. The following two subsections summarize information on recent ecosystem trends in the BSAI and GOA management areas, respectively.

Ecosystem Trends in the BSAI Management Area

In a review of fishery trends and potential fishery-related impacts within the BSAI ecosystem, Livingston *et al.* (1999) examined historical biomass trends of three different trophic guilds to see if there was a relationship between fishing or climate and changes in total guild biomass or changes in species composition within guilds. For example, large fishing removals of one guild species might result in increases in other members of that guild as competitive pressures ease. Similarly, if fishing removes large numbers of a prey species important to all members of the guild, an overall decrease in the abundance of all the guild species might be observed, as well as decreased mean size at age of predators relying on that prey. Alternatively, if the factor inducing the observed change is environmental, trends in abundance or in mean size at age that correlate positively or negatively with temperature or other physical oceanographic factors might be seen. Three trophic guilds were examined:

1. offshore fish, mammals, and seabirds that consume small pelagic fish;
2. inshore fish, crabs, and other benthic epifauna that primarily consume infauna; and
3. a ubiquitous group that feeds on crab and fish (Figure 3.10-1).

Despite conservative exploitation rates, a variety of species in diverse trophic groups (e.g., arrowtooth flounder, Greenland turbot, some seabirds, and marine mammals) showed either increasing or decreasing long-term trends in abundance, and both fished and unfished species (pollock, cod, crabs, sea stars, and others) showed cyclic fluctuations in abundance over the two decades from 1979 to 1999. No link was found between species declines and prey abundance. The timing of some species declines, e.g., marine birds, was actually correlated with increases in the adult populations of their main prey species—in this case, pollock. Similarly, the timing of increases in some guild member biomass values did not relate to fishing intensity on other guild members (e.g., skate versus cod). The Livingston *et al.* study, however, did not consider spatial changes in prey abundance or availability that could occur, and these factors cannot be ruled out as potential causal links to changes in predator abundance.

Physical oceanographic factors, particularly northward or southward shifts in regional climatic regimes, were correlated with the recruitment of some guild members (see Sections 3.3.4 and 3.10.1.5), and decreases in individual growth of some species (rock sole) were linked to increases in rock sole biomass. Diversity changes in some trophic guilds were related to increases in a dominant guild member (e.g., pollock in the pelagic fish consumer guild, and rock sole in the benthic infauna consumer guild) rather than to fishing-induced changes in diversity.

The study by Livingston *et al.* (1999) showed a stable trophic level of catch and stable populations overall. The trophic level of the Bering Sea harvest has risen slightly since the early 1950s and appears to have stabilized as of 1994.

Modeling Biological Interactions Among Multiple Species

Livingston and Jurado-Molina (1999) have developed a computer-based model of predator-prey interactions among the dominant groundfish species in the EBS. Three goals have directed the development of this multi-species model: 1) to examine trends in mortality due to predation, 2) to examine the relative importance of predation versus climate in influencing fish recruitment, and 3) to provide a basis for evaluating how future changes in fishing intensity might affect the groundfish community. The model uses information on historical catch estimates and predation among the species to estimate numbers at age and predation mortality of groundfish populations. The following species are modeled as predators: walleye pollock, Pacific cod, Greenland turbot, yellowfin sole, arrowtooth flounder, and northern fur seal. Arrowtooth flounder and northern fur seal are considered “other predators,” which means that population and mortality estimates are not made directly for these species. However, it is feasible to estimate the impact of their predation on other species in the model. Prey species are walleye pollock, Pacific cod, Greenland turbot, yellowfin sole, rock sole, and Pacific herring.

Results from the modeling indicate that most predation mortality occurs on juveniles, particularly juvenile walleye pollock. This juvenile mortality varies over time, and recruitment of juveniles into the adult population also varies. Cannibalism by adult pollock explains some of the recruitment variation, but it appears that much of the variability is related to climatic variation (see Section 3.10.1.5). Understanding of predation and climate as structuring forces on groundfish communities will be advanced when multi-species predation models like these are linked to climate models that predict survival rates of larval fish before they are vulnerable to predation.

Output from this predation model can be used to evaluate the multi-species implications of various fishing strategies. One question asked about the BSAI by groundfish stock assessment biologists is: What effects might uneven groundfish harvesting rates have on groundfish community dynamics? For example, some species, such as pollock, are fished up to the recommended level of ABC, while others, such as rock sole and yellowfin sole, are fished at levels below ABC for economic and bycatch reasons. Using a multi-species model, Jurado-Molina and Livingston (2000) examined what could happen over the long-term future to groundfish population size if species were harvested more evenly or were not harvested at all. They compared these projected changes with model predictions based on current groundfish fishing rates. They also compared the results with predictions using single-species models that did not consider predation interactions.

In the scenario where groundfish were fished more evenly (F_{ABC}) than actually occurs under the present harvesting regime (F_{REF}), the single-species models predicted almost the same population changes that the multi-species model did. The biggest differences between multi-species and single-species models were seen in the predictions for prey species biomasses of herring and rock sole, but even these were not very large (Figure 3.10-2).

Small differences in the predictions are the result of evaluating relatively small changes in fishing intensity. Larger differences between single-species models and the multi-species model are seen when the present

fishing strategy (F_{REF}) is compared with a no-fishing strategy (Figure 3.10-3). Here, the main reason for the difference is that the multi-species model predicts that predators increase their consumption of prey when there is no fishing. The model results indicate that when pollock fishing is stopped, the largest beneficiary species is pollock itself. This is because adult pollock consume mostly younger (age 0 and age 1) pollock, while other predators tend to consume mostly older (age 1 and older) pollock. In the long-term, consumers of small pollock get the first opportunity to benefit from the increased abundance of juveniles when fishing stops.

In summary, the results of multi-species predator-prey modeling suggest that implementation of a more even harvesting regime would not produce effects much different from changes predicted by single-species models. The largest difference occurs in predictions under a no-fishing scenario, with the multi-species model predicting smaller increases in prey species such as pollock, rock sole, and herring than those predicted by the single-species models. Increases in predator populations, and thus predation mortality, under a no-fishing scenario are the reason for the lower rate of increase in prey populations in the multi-species model.

Multi-species Technological Interactions

Harvesting can have multi-species implications through technological interactions (i.e., co-occurrence of multiple species in a single target species fishery). When specific fisheries are unable to catch their target species exclusively, their fishing effort imposes some mortality on each species that is taken as bycatch. Bycatch of non-target flatfish species is a particularly important characteristic of several EBS target fisheries, including yellowfin sole, rock sole, flathead sole, and Alaska plaice. These species, along with Pacific halibut, occupy similar habitats on the EBS shelf and co-occur to varying degrees in the harvest. Additionally, the retention of Pacific halibut is prohibited in the federally managed groundfish fishery, and quotas of halibut bycatch—not directed target quotas—have been the main factor in restricting the fishery in recent years.

The total trawling effort for all flatfish fisheries combined imposes a variety of fishing mortality rates on the individual flatfish species. This has been evaluated with a multi-species yield-per-recruit model (Spencer *et al.* 1999). One motivation for such modeling is to consider management options that would increase the total flatfish yield, factoring in the bycatch of flatfish in the various fisheries. A main feature of this model is that a catchability coefficient is computed for each species and fishery, based on recent catch and effort data; the distribution of effort among the various EBS trawl fisheries (defined by species catch composition) is based on the same data. The slope of each line in Figure 3.10-4 is the total catchability for a particular species, resulting from all fisheries that harvest the species. For example, the catchability of yellowfin sole is higher than other species because a significant proportion of total trawling effort is directed toward this fishery, and this species has relatively high catchabilities in several fisheries.

Reaching halibut bycatch quotas early has resulted in early closures of the flatfish fisheries, thus resulting in large differences between fishing levels that would attain the ABC at F_{ABC} (triangles in Figure 3.10-4) and recent average F levels (asterisks) for most fisheries. One way to manage these species that are caught together would be to derive biological reference points for the complex as a whole. The $F_{40\%}$ level for the group combined (squares in Figure 3.10-4) would produce higher yields (in the absence of halibut bycatch quotas) than the single-species approach. This approach for managing flatfish as a group, however, would expose the yellowfin sole population to a higher fishing rate than the rate that would be recommended in a

single-species management scheme. Therefore, this strategy might not provide optimal protection for yellowfin sole. If the complex were managed to protect the weakest stock (yellowfin sole), the combined flatfish fisheries would be able to increase effort by only a relatively small amount above the current effort levels (to the level of effort that would reach the yellowfin sole ABC at F_{ABC} (triangle in Figure 3.10-4). There is a relatively small difference between the recent average yellowfin sole F and the yellowfin sole $F_{40\%}$, indicating that there would be no significant change from current practice.

The limitation currently imposed on flatfish fisheries by the halibut bycatch quota has motivated fishermen to develop methods of reducing trawling effort that has high catchability on halibut (Gauvin *et al.* 1995) and also to develop fishing gear with lower halibut catchability (i.e., halibut excluder devices). These gear improvements and the already mandated phasing-in of requirements for retaining flatfish bycatch under the improved retention/improved utilization management approach show promise for producing a fishery management system with increased protection for protected species such as halibut and a large reduction in the levels of flatfish discards in flatfish fisheries. Because the gear improvements and improved retention scheme implementation will change the nature of the effort and multi-species catch characteristics of these target fisheries, the impacts of the improvements must be evaluated before multi-species biological reference points can be developed for target flatfish.

Ecosystem Trends in the GOA Management Area

Meuter (1999) examined GOA groundfish communities using groundfish and shrimp trawl data collected over several years from the eastern and western GOA. To identify spatial and temporal patterns in community structure, the data were analyzed for species richness, diversity, total abundance, and indices of species composition in relation to depth, temperature, salinity, sediment composition, geographic location, and time of sampling. The data were then compared to local and larger scale atmospheric and oceanographic changes. In general, species richness and diversity peaked at water depths of about 200–300 m in the GOA. Higher abundance, lower species richness and diversity, and a different species composition of demersal fishes were found in the western GOA as compared to the eastern GOA. Meuter concluded that these large-scale spatial patterns were related to upwelling differences between the two regions.

With respect to long-term trends, the lowest species richness (number of species per haul) was observed in 1984, whereas the lowest species diversity (as measured by the Shannon-Wiener diversity index) was seen in 1996. It is difficult to tell whether these trends are real because of changes in trawl survey techniques and gear usage during the 12-year sample period. General increases in total groundfish biomass were seen from 1984 to 1996 (Figure 3.10-5), coupled with statistically significant changes in species composition (Figure 3.10-6). Community structure in nearshore areas around Kodiak Island changed during this same period, with decreasing populations of shrimp and small forage fish and increasing populations of large, fish-eating species such as Pacific cod and flatfish.

Meuter found that the total biomass of commercially-fished species in shelf and slope areas had increased since 1984, despite a considerable, concurrent increase in harvest effort. At the same time, the abundances of unexploited (or underexploited) species including skate, some shark species, forage species, arrowtooth flounder, and other flatfish had increased (Figure 3.10-7). Populations of an overexploited species, the Pacific ocean perch, had also rebounded from low population levels. The controlling factor for these increases appeared to be environmental, with changes in community species composition in nearshore areas linked to an increase in advection in the Alaska Coastal Current. Meuter concluded that increased flow

around the GOA may have enhanced the supply of nutrients and plankton on the shelf and upper slope areas, resulting in higher productivity.

In addition to Meuter's work, studies by Piatt and Anderson (1996), Anderson and Piatt (1999), Orensanz *et al.* (1998), Robards *et al.* (1999) and others, discussed in Section 3.10.1.5, provide evidence that physical oceanographic factors, particularly climate, have a controlling influence on biological community composition in the BSAI and GOA. An important conclusion to be drawn from these studies is that any effects of human activities on the marine environment should be considered in the context of the powerful physical forces that appear to be driving the BSAI and GOA ecosystems.

3.10.1.5 Climate-Implicated Changes in the North Pacific Ocean Ecosystem

Evidence from observations during the past two decades and the results of modeling studies using historical and recent data from the North Pacific Ocean suggest that physical oceanographic processes, particularly climatic regime shifts, might be driving ecosystem-level changes that have been observed in the BSAI and GOA. These physical oceanographic processes are reviewed in Section 3.3. Commercial fishing has not been largely implicated in BSAI and GOA ecosystem changes, but studies of other ecosystems with much larger fishing pressures indicate that fishing, in combination with climate change, can alter ecosystem species composition and productivity (Jennings and Kaiser 1998, Livingston and Tjelmeland 2000).

During 1997 and 1998, a period of warmer-than-usual ambient air temperatures (Hare and Mantua 2000), a number of unusual species occurrences were observed in the BSAI and GOA, including the following examples:

- In 1998, several warm-water fish species, including Pacific barracuda (*Sphyraena argentea*), were observed and/or caught in the GOA. Ocean sunfish (*Mola mola*) and chub mackerel (*Scomber japonicus*), occasionally recorded in southeast Alaskan waters, were documented there in unusually large numbers. Similarly, Pacific sleeper sharks (*Somniosus pacificus*) were caught (and released) in higher than normal levels in Cook Inlet, and salmon sharks (*Lamna ditropis*) were taken in fairly large numbers off Afognak Island (Kevin Brennan, ADF&G, personal communication).
- Spiny dogfish (*Squalus acanthias*) substantially increased in the Kodiak area and in Prince William Sound (Bill Bechtol and Dave Jackson, ADF&G, personal communication). In 1998, this species' inclusion in collection tows increased by more than 40 percent. A corresponding increase in spiny dogfish has been observed in the International Pacific Halibut Commission's GOA halibut longline bycatch surveys (Lee Hulbert, NMFS, personal communication).
- Individuals of several marine mammal species were seen at unusual times and/or places during 1998, including a Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) near Haines and a northern right whale (*Eubalaena glacialis*) off Kodiak Island.
- Unusual bird sightings in the GOA included a gray-tailed tattler (*Heteroscelus brevipes*) south of the Kenai Peninsula and a mallard (*Anas platyrhynchos*) several miles offshore in the open ocean. Common murre (*Uria aalge*) die-offs were reported in Cook Inlet, Kodiak, the eastern Aleutians, Resurrection Bay, and the EBS.

- Three northern elephant seals (*Mirounga angustirostris*) were spotted in nearshore waters around Unalaska during late June and early July, whereas they are usually found farther offshore and at a different time of year.
- There were poor returns of chinook (*Oncorhynchus tshawytscha*) and sockeye (*Oncorhynchus nerka*) salmon to Bristol Bay during both years.

Research on climate shifts as a forcing agent on species and community structure of the North Pacific Ocean can be found in Francis and Hare (1994), Klyashtorin (1998), McGowan *et al.* (1998), Hollowed *et al.* (1998), and Hare and Mantua (2000). The approach used in these studies assesses correlations between past climatic patterns and changes in biomass or recruitment rate for particular marine species. Because cause-and-effect relationships between temporal and spatial patterns of climate change and corresponding patterns of change in biological populations have not been proven for the BSAI and GOA, the correlations must be considered circumstantial. But there are reasons to expect that causal links do exist. For example, stronger recruitment would be expected under more favorable climatic conditions, because more juveniles would be likely to survive to adulthood, whereas harsh conditions would result in weak recruitment because fewer juveniles would survive. In both cases, the recruitment patterns would be reflected in the strength or weakness of the affected age groups within future fisheries.

Francis and Hare (1994) analyzed historical data supporting a climate shift that caused a precipitous decline in the sardine (*Sardinops sagax*) population off Monterey, California in the 1950s. Although it had been widely concluded that this decline resulted solely from overfishing, the data indicate instead that a change in sea surface temperature was closely correlated with the sardines' disappearance, and this related closely to patterns of sardine numbers in marine sediments off Southern California. Consequently, both climate and fishing are now recognized to be implicated in the sardine population decline.

Francis and Hare (1994) related the intensity of the Aleutian low pressure system (Aleutian low), a weather pattern, with production of salmon and zooplankton. Winter ambient air temperatures at Kodiak and the North Pacific Index, an index tracking the intensity of the Aleutian low during the winter, were used as indicators of climatic severity. Strong correlations were found between long-term climatic trends and Alaskan salmon production. Annual weather patterns were found to be closely correlated with changes in zooplankton populations.

For the northeastern North Pacific Ocean, McGowan *et al.* (1998) showed that interannual climatic variations linked to the ENSO and decadal-scale climate shifts can be detected in physical oceanographic data. For instance, the depth of the mixed layer in the California Current and GOA became shallower over time, whereas the mixed-layer depth in the Central Pacific deepened during the same period. This was not, however, reflected in the mass flow of the California Current. Greater depth of the mixed layer during elevated sea surface temperature events was correlated with decreased nutrient availability, plankton abundance, and shifts in community structure. These researchers concluded that climatic events such as ENSO are correlated with changes in biological populations associated with the California Current. Biological processes in the GOA appear to be more strongly influenced by variations in the Aleutian low.

According to McGowan *et al.* (1998), climate-related changes in the biological communities of the California Current system ranged from declines in kelp forests to shifts in the total abundance and dominance of various zooplankton species. Some fish and invertebrate populations declined, and the distributional ranges of

species shifted northward. In addition, seabird and marine mammal reproduction were apparently affected by ENSO conditions. Interdecadal changes in community structure also occurred, with intertidal communities becoming dominated by northward-moving southern species and changes in species proportions occurring in most other sectors of the ecosystem.

Interdecadal shifts observed in the northeastern North Pacific Ocean ecosystem have been of the opposite sign from those in the California Current system, with increases in zooplankton biomass and salmon landings observed in the GOA (McGowan *et al.* 1998, Francis and Hare 1994). These shifts have corresponded to the intensity and location of the winter mean Aleutian low, which changes on an interdecadal time scale.

Klyashtorin (1998) linked catch dynamics of Japanese sardines, California sardines, Peruvian sardines, Pacific salmon, Alaska pollock, and Chilean jack mackerel in the Pacific with an atmospheric circulation index that shows trends similar to the North Pacific Index used by other researchers. Other species, such as Pacific herring and Peruvian anchovy, are negatively associated with this index.

Hollowed *et al.* (1998) analyzed oceanographic and climatic data from the eastern North Pacific Ocean and compared those data with information on recruitment for 23 species of groundfish and five non-salmonid species and with catch data for salmon. The fish recruitment data were compared to environmental factors over various time scales and with varying time lags. Hollowed *et al.* (1998) found that, for species such as pollock, cod, and hake, recruitment was generally stronger during ENSO events. Whereas salmon and large-mouthed flatfish such as arrowtooth flounder, Greenland turbot, and Pacific halibut responded more strongly to longer-term events such as decadal-scale climatic regime shifts. Because both ENSO and decadal-scale ecosystem shifts are environmentally controlled, the results of this analysis support climate change as an important controlling factor in ecosystem dynamics.

There is considerable evidence that decadal and basin-scale climatic variability (Section 3.3.4) can affect fish production and ecosystem dynamics. Sudden basin-wide shifts in climatic regime have been observed in the North Pacific Ocean (Mantua *et al.* 1997), apparently due to changes in atmospheric forcing. Eastward- and northward-propagating storm systems dominate the wind stress on surface waters for short periods (less than one month), mixing the upper layers and altering sea surface temperatures (Bond *et al.* 1994). Because fish are very sensitive to ambient water temperature, even changes in surface temperature, if sufficiently frequent or prolonged, can alter fish distribution and reproductive success as well as recruitment (the number of juveniles that survive to enter the adult, reproducing portion of the population).

In a long-term trends analysis by computer, Ingraham and Ebbesmeyer (Ingraham *et al.* 1998) used the OSCURS model to simulate wind-driven surface drift trajectories initiated during winter months (December through February) for the period 1946 to present. The model-generated endpoints of the 3-month drift trajectories shifted in a bimodal pattern to the north and south around the mean. The winter flow during each year was persistent enough to result in a large displacement of surface mixed-layer water. The displacement also varied in a decadal pattern. Using the rule that the present mode is maintained until three concurrent years of the opposite mode occur, four alternating large-scale movements in surface waters were suggested: a southward mode from 1946 to 1956, a northward mode from 1957 to 1963, a southward mode from 1964 to 1974, and a northward mode from 1975 to 1994. As more northern surface water shifts southward, colder conditions prevail farther south, and as southward water moves northward, warmer conditions prevail farther north, both potentially affecting fish distribution and population dynamics.

Real-world evidence that atmospheric forcing alters sea surface temperatures comes from two principal sources: shorter-term ENSO events and longer-term Pacific Decadal Oscillations (Mantua *et al.* 1997). Temperature anomalies in the BSAI and GOA indicate a relatively warm period in the late 1950s, followed by cooling especially in the early 1970s, followed by a rapid temperature increase in the latter part of that decade. Since 1983, the BSAI and GOA have undergone different temperature changes. Sea surface temperatures in the BSAI have been below normal, whereas those in the GOA have been generally above normal. Consequently, the temperature difference between the two bodies of water has jumped from about 1.1°C to about 1.9°C (U.S. GLOBEC 1996).

Subsurface temperatures, potentially an even more important influence on biological processes, have been documented to change in response to climatic drivers. There was a warming trend in subsurface temperatures in the coastal GOA from the early 1970s into the 1980s similar to that observed in GOA sea surface waters (U.S. GLOBEC 1996).

In addition, seawater temperature changes in response to ENSO events occurred, especially at depth, in 1977, 1982, 1983, 1987, and in the 1990s. The 1997-1998 ENSO event, one of the strongest recorded in the twentieth century, substantially changed the distribution of fish stocks off California, Oregon, Washington, and Alaska. The longer-term impacts of the 1997-1998 ENSO event remain to be seen. Francis *et al.* (1998) reviewed the documented ecological effects of this most recent regime shift through lower, secondary, and top trophic levels of the North Pacific Ocean marine ecosystem. Some of the following impacts on higher trophic levels are based on this review:

- Parker *et al.* (1995) demonstrated marked similarities between time series of the lunar nodal tidal cycle and recruitment patterns of Pacific halibut.
- Hollowed and Wooster (1995) examined time series of marine fish recruitment and observed that some marine fish stocks exhibited an apparent preference (measured by the probability of strong year and average production of recruits during the period) for a given climate regime.
- Hare and Francis (1995) found a striking similarity between large-scale atmospheric conditions and salmon production in Alaska.
- Quinn and Niebauer (1995) studied the Bering Sea pollock population and found that high recruitment coincided with years of warm ocean conditions (above normal air and bottom temperatures and reduced ice cover). This fit was improved by accounting for density-dependent processes.

Additional evidence of marine ecosystem impacts linked to climatic forcing comes from Piatt and Anderson (1996), who provided evidence of possible changes in prey abundance due to decadal-scale climate shifts. These authors examined relationships between significant declines in marine birds in the northern GOA during the past 20 years and found that statistically significant declines in common murre populations occurred from the mid- to late 1970s into the early 1990s. They also found a substantial alteration in the diet composition of five seabird species collected in the GOA from 1975 to 1978 and from 1988 to 1991, changing from a capelin-dominated diet in the late 1970s to a diet in which capelin was virtually absent in the later period.

The effects of ten-year regime shifts on the inshore GOA were analyzed using data from 1953 to 1997 (Anderson and Piatt 1999). Three taxonomic groups dominated (approximately 90 percent) the biomass of commercial catches during this period: shrimp, cod and pollock, and flatfish. When the Aleutian low was weak, resulting in colder water, shrimp dominated the catches. When the Aleutian low was strong, water temperatures were higher, and biomass the catches were dominated by cod, pollock, and flatfish. Similar results were reported in very nearshore areas of lower Cook Inlet (Robards *et al.* 1999).

Few patterns were seen in the less-common species over the course of the study. Generally, the transitions in dominance lagged behind the shift in water temperature, strengthening the argument that the forcing agent was environmental. However, different species responded to the temperature shift with differing time lags. This was most evident for species at higher trophic levels, which are typically longer-lived and take longer to exhibit the effects of changes. The evidence suggests that the inshore community was reorganized following the 1977 climate regime shift. Although large fisheries for pandalid shrimp may have hastened the decline for some stocks (Orensanz *et al.* 1998), unfished or lightly fished shrimp stocks showed declines. Both Orensanz *et al.* (1998) and Anderson and Piatt (1999) concluded that the large geographic scale of the changes across so many taxa is a strong argument that climate change is responsible.

Other studies have linked production, recruitment, or biomass changes in the BSAI with climatic factors. For example, a climate regime shift that might have occurred around 1990 has been implicated in a large increase in gelatinous zooplankton in the BSAI (Brodeur *et al.* 1999). Recruitment in both crabs and groundfish in the BSAI has been linked to climatic factors (Zheng and Kruse 1998, Rosenkranz *et al.* 1998, Hollowed *et al.* 1998, Hare and Mantua 2000).

There are indications from several studies that the BSAI ecosystem responds to decadal oscillations and atmospheric forcing, and that the 1976-1977 regime shift had pronounced effects. A peak in chlorophyll concentrations in the late 1970s was closely correlated with an increase in summer mixed-layer stability documented at that time (Sugimoto and Tadokoro 1997). Also, on a decadal time scale, chlorophyll concentrations in the summer were positively correlated with winter wind speeds, indicating a positive response of BSAI phytoplankton to stronger Aleutian lows (Sugimoto and Tadokoro 1997).

Evidence of biological responses to decadal-scale climate changes are also found in the coincidence of global fishery expansions or collapses of similar species complexes. Sudden climate shifts in 1923, 1947, and 1976 in the North Pacific Ocean substantially altered marine ecosystems off Japan, Hawaii, Alaska, California, and Peru. Sardine stocks off Japan, California, and Peru exhibited shifts in abundance that appear to be synchronized with shifts in climate (Kawasaki 1991). These historical 60-year cycles are seen in paleo-oceanographic records of scales of anchovies, sardines, and hake as well. Other examples are salmon stocks in the GOA and the California Current whose cycles are out of phase. When salmon stocks do well in the GOA, they do poorly in the California Current and vice-versa (Hare and Francis 1995, Mantua *et al.* 1997).

In addition to decadal-scale shifts, interannual events such as the ENSO can have significant impacts on fish distribution and survival, and can affect reproduction, recruitment, and other processes in ways that are not yet understood. This is particularly true for higher-latitude regions such as the northern California Current and GOA. As noted above, the 1997-1998 ENSO event significantly changed the distribution of fish stocks off California, Oregon, Washington, and Alaska. A change that has persisted to the present. Predicting the implications of this trend for future fishery management is problematic, in part because ENSO signals propagate from the tropics to high latitudes through the ocean as well as through the atmosphere, and it is

difficult to separate these two modes of influence. Information on the dynamics of North Pacific Ocean climate and how this is linked to equatorial ENSO events is not adequate to adjust fisheries predictions for such abrupt, far-reaching, and persistent changes. Warm ocean conditions observed in the California Current during the present regime may be due, in large part, to the increased frequency of ENSO-like conditions.

In conclusion, evidence from past and present observations and modeling studies at the community and ecosystem levels for the BSAI and GOA suggest that climate-driven processes are responsible for a large proportion of the multi-species and ecosystem-level changes that have been documented. Modeling studies have been a valuable tool for elucidating the possible long-term implications of various fishing strategies. As with all computer-based models, these have been sensitive to unproven assumptions about recruitment and its relationship to climate. As the preceding discussion suggests, the models could be improved by incorporating components that include climatic effects on species, particularly with respect to recruitment. However, this approach has not been widely applied yet to species in the BSAI and GOA ecosystems.

3.10.2 Interactions Among Climate, Commercial Fishing, and Ecosystem Characteristics in the North Pacific Ocean

As the preceding discussions show, groundfish fishery management in the BSAI and GOA is implemented in a dynamic environment where both commercial fishing and climate-driven physical oceanographic processes interact in complex ways to affect the marine ecosystem. To characterize these interactions, it is necessary to distinguish, where feasible, the separate effects of fishing and climate on biological populations. The following discussion reviews current knowledge regarding these effects and their relationship to ecosystem characteristics.

Three processes underlie the population structure of species in marine ecosystems: competition, predation, and environmental factors. Natural variations in the recruitment, survival, and growth of fish stocks are consequences of these processes. The first process, competition, is a basic concept underlying many ecological theories (e.g., Hairston *et al.* 1960, Welden and Slauson 1986, Yodzis 1978, 1994). It requires an assumption that species in an ecosystem are limited in their access to critical resources such as food, space, reproductive mates, and time for important activities. Predation is important, because it changes prey density, thereby directly or indirectly affecting populations throughout the ecosystem. Finally, environmental factors, particularly climatic processes, are thought to be major agents of change in North Pacific Ocean ecosystems. Climate has the potential to influence the important biological processes of reproduction, growth, consumption and predation, movement, and, ultimately, the survival of marine organisms.

Against this complex and dynamic natural background, human activities such as commercial fishing can influence the structure and function of marine ecosystems. Like competition, predation, and climate change, the effects of commercial fishing can extend over a range of temporal, spatial, and population scales. Large-scale commercial fishing has the potential to influence ecosystems in several ways. It may alter the amount and flow of energy in an ecosystem by removing energy and altering energetic pathways through the return of discards and fish processing offal back into the sea. The recipients, locations, and forms of this returned biomass may differ from those in an unfished system. In addition, the selective removal of species has the potential to change predator-prey relationships and community structures. Fishing gear may alter bottom habitat and damage benthic organisms and communities.

Both climate and commercial fishing activity currently influence the structure and function of the North Pacific Ocean ecosystem (Francis *et al.* 1999). Since climate change and commercial fishing can co-vary, it may be difficult to distinguish the impacts of the two (e.g., Trites *et al.* 1999). The primary way in which complex scientific knowledge is integrated to further the understanding of the influence of natural and human-related processes on marine ecosystems is through the use of models. Models can be as simple as conceptual diagrams that show a picture of how we think a certain ecosystem process operates, or they can be very complicated, with quantitative descriptions of the relationships between various factors and species growth, recruitment, movement, or survival. Reviews of the status of models that have been developed to understand the effects of climate and fishing on ecosystems have been produced by Livingston (1997) and Hollowed *et al.* (2000a). These reviews outline the types of models presently being used and the state of our ability to understand and predict the effects of the two important factors of climate and fishing in marine ecosystems by using models.

Most models that consider more than one species link the species together through knowledge about their feeding (trophic) interactions. Once the trophic linkages among species are understood, questions about impacts of predators and prey on one another (Yodzis 1994), or how natural or human-induced habitat changes affect the food-web structure (Yodzis 1996), can be addressed with a variety of multi-species or ecosystem models. Another model type, called a technical interaction model, may consider the simultaneous capture of groups of species by a particular fishery or type of fishing gear.

With the exception of information on forage fish, which—unlike many marine species—are preyed on as adults and not just mainly as juveniles, most scientific advice from multi-species models is not presently being used in making short-term management decisions. These models are mainly useful for trying to understand the possible medium- (6 to 10 years) and longer-term implications of various management strategies on the ecosystem.

However, long-term predictions from single-species, multi-species, and ecosystem-level models remain uncertain, because the predictions rely heavily on assumptions about recruitment, particularly for predators (Gislason 1991 and 1993), which may be strongly influenced by environmental variation. Limitations still exist regarding the ability to predict both future changes in climate and recruitment rates resulting from a particular climate state.

Therefore, as noted by Parkes (2000) and Hall (1999a), predator-prey models are not considered reliable enough to provide directly applicable management advice at the present time. Hall (1999b) notes that ecosystem-based management advice should move toward setting single-species biological reference points for non-target species, developing single-species reference points for localized regions (i.e., spatially explicit management), and using measures of system-level properties (e.g., species diversity, trophic level of the catch, biomass-size distributions) to derive ecosystem-level reference points.

Food web models of the BSAI, specifically, the EBS shelf, ecosystem have been developed for the 1950s and 1980s (Trites *et al.* 1999). These models use the Ecopath strategy for evaluating mass-balance in marine ecosystems. Ecopath uses estimates of biomass, consumption, diet, and turnover rates of populations or groups of populations to evaluate energy flow and mass-balance in a particular ecosystem (Christensen 1990).

Ecopath creates static biomass flow models of ecosystems and represents a snapshot of the ecosystem for a given time period. Species in these models are linked, so that the biomass transfer resulting from processes such as fecundity, mortality, production, respiration, and predation are in equilibrium (balanced). These types of models provide a way to identify large-scale views of ecosystems and to highlight data gaps (Christensen 1990, 1992, 1994; Pauly and Christensen 1995).

An examination of energy flow within the ecosystem is instructive, although one must be careful in interpreting the inevitable differences among the flow estimates. For instance, although the magnitude of biomass flow from prey to tertiary consumers (e.g., juvenile pollock to seabird predators) is modest relative to that between primary producers and primary consumers (e.g., phytoplankton to crustaceans), it may nonetheless play a significant role in the dynamics of the food web (P. Yodzis, University of Guelph, Ontario, Canada, personal communication). Further, if a food web is composed of few, highly connected species in a trophic sense, removal of a predator may yield a larger ecosystem perturbation than a similar removal from an ecosystem with weaker trophic links among many predators and prey (e.g., Pimm 1982).

The Ecopath models for the Bering Sea were initially developed to see if impacts of intensive whale harvesting that occurred in the 1950s and 1960s were sufficient to explain the ecosystem structural changes that were observed in the 1980s, discussed in Section 3.10.1.3. The primary removal of energy in both decades was by harvesting whales and pelagic fishes in the 1950s, and pollock in the 1980s. The production estimate for the 1950s simulation showed baleen whales as the dominant ecosystem component. These whales were classed as a midlevel consumer with a trophic level slightly higher than pollock, due to their consumption of squid. The dominant component in the 1980s simulation was pollock, the dominant fishery. There was a slight drop in trophic level of the catch between the two periods, but this was acknowledged to be an artifact of the volume of squid assumed in the diet of the baleen whales. Without this assumption, there was little change in trophic level of harvest. Trophic level of the catch actually increased from the 1950s to the 1980s, if only fish harvests are considered. This would suggest that harvesting in the Bering Sea at present is at a level that has been sustained over long periods. A further result of this simulation was that whale harvests required an estimated 47 percent of net primary production in the Bering Sea in the 1950s. Fisheries of the 1980s, dominated by pollock, required only 6.1 percent of primary production.

Measures of ecosystem maturity show some differences between the two Bering Sea models. The ratio of primary production to respiration, net system production, and the ratio of biomass to throughput indicate a more mature ecosystem state in the 1950s compared with the 1980s. This is due to the assumption that benthic infauna biomass was lower in the 1980s. However, benthic infaunal surveys used to estimate biomass for the two models used different methods and may not be comparable.

Trophic pyramids are similar for the two time periods, and both indicate that biomass and energy flow were distributed fairly well throughout the system. The steep-sided shape of the pyramids indicates that there is a lot of energy flow at lower trophic levels. One system maturity index, the ratio of primary production to total biomass, actually indicates a more mature system in the 1980s relative to the 1950s. However, this was due to assumptions about the change in primary production between the two time periods, for which there is conflicting evidence. Conclusions about system maturity will be premature until trends in primary production and benthic infauna biomass are better understood.

The Bering Sea appears to be more mature than other modeled ecosystems, particularly with regard to total system throughput, which measures the sum of all energy flows in the system. It has ecosystem measures that

indicate it has significant strength in reserve, which makes it more resilient or resistant to perturbations compared with other ecosystems.

Ecosim, a forward-looking simulation coupled to Ecopath, was used to project the results of various scenarios. The model was run in either an equilibrium or dynamic mode. The equilibrium mode assumed that the total biomass of the ecosystem remained stable, and as the biomass of one component declined, others were required to increase to balance it. Dynamic models do not have this requirement.

The equilibrium mode of Ecosim was used to examine the results of changes in a species' abundance on interacting groups. The results of the equilibrium model suggest that changes in baleen whale numbers could significantly affect pollock populations, and that increases in sperm whale numbers could yield decreases in the numbers of Steller sea lions through competition. Reducing pelagic fish numbers reduces the numbers of seabirds that feed on them, as well as numbers of Steller sea lions and large flatfish. Increasing fishing pressure on pollock would have little effect on their biomass, and increasing fishing pressure on large flatfish would result in increased Steller sea lion populations through the removal of a competitor.

In a different approach, the dynamic mode of Ecosim was used to look at possible mechanisms involved in the historical marine biomass changes seen between the 1950s and the 1980s. Scenarios used for the dynamic model were a regime shift that resulted in changes in primary production; a commercial fishery simulation to see if fishing whale could account for the observed changes; three pollock fishing scenarios that project into the future; and scenarios which varied the fishery mortalities on pollock and pelagic fishes.

These simulations suggested that commercial harvesting of fish and whales had little likelihood of producing the changes seen in actual pollock populations since the 1950s. The effect of increasing primary production provided a much more realistic change in the pollock population. While most groupings showed increases, Steller sea lions did not.

There are substantial uncertainties about the abundance of small pelagic fish in both time periods and the abundance of pollock in the 1950s model. Low abundance of pollock and higher abundance of small pelagic fish in the 1950s was assumed. However, although non-standardized surveys by the Soviets during the 1950s showed apparently lower pollock abundance, their research on diet composition of groundfish indicated that pollock was a primary prey item of many species. It is possible that pollock may have been more abundant in the 1950s than has been assumed. Further model testing with this change in assumptions should be done.

Another dynamic simulation showed that, contrary to what might be expected, stopping the commercial pollock harvest had a slight negative effect on Steller sea lions. This is because two of the Steller sea lion prey items, small pelagic fish and juvenile pollock, declined when adult pollock increased. Adult pollock are cannibalistic and compete with small pelagic fish for large zooplankton prey in this model. More recent versions of the model, which changed the assumptions regarding recruitment now show that juvenile pollock actually increase under this scenario, but that Steller sea lions still show a slight negative effect. This is presumably because of the assumption of the dominance of small pelagic fish as a prey item of Steller sea lions. Small pelagic fish still decline under the assumption of increasing pollock, because adult pollock compete with them for large zooplankton prey.

In conclusion, these model simulations indicate uncertainty about the biomass of lower trophic level species in the two time periods. It appears that climate-related shifts in lower trophic level production could partly

explain the ecosystem changes that occurred between the 1950s and the 1980s. However, the model only captures predation-related recruitment variability and cannot show climate-related variability in recruitment, which is probably much larger. More detailed scenarios that examine the spatial availability of prey will have to be performed to improve our understanding of the complex interaction between fishery removals and predator-prey interactions.

3.10.3 Current North Pacific Ocean Ecosystem Status and Sustainability

In order to examine North Pacific Ocean ecosystem status and sustainability, we need to identify key ecosystem components and processes that characterize an ecosystem. We must identify features of these components and processes that may indicate whether Alaskan groundfish fisheries have had impacts on the BSAI and GOA ecosystems. The first step in this identification of key components and processes is to examine the definition of ecosystems.

A review of the literature shows that there are numerous definitions of what constitutes an ecosystem. One of the earliest definitions, by Tansley (1935), includes all of the organisms and all the physical factors, what he termed the habitat factors in the widest sense. These linked biological-physical systems are what he termed an ecosystem. It was clear from the definition that although most focus tended to be on the organisms in the system, those organisms could not be separated from their physical environment. Similarly, Botkin (1990) defined an ecosystem as a set of interacting species and their local, non-biological environment, functioning together to sustain life. Large marine ecosystems have been defined as regions characterized by distinct bathymetry, hydrography, productivity, and trophically dependent populations (Sherman and Alexander 1986). Odum's (1977) definition of an ecosystem also recognizes that the biological and physical aspects form a functional unit that has some characteristic trophic structure and material cycles (i.e., how energy or mass moves among the groups). Central to these definitions is the relationship of the organisms to the physical environment and the concept of trophically-dependent or interacting species or groups.

The main ecosystem components and processes that are important to evaluate in order to determine ecosystem impacts of human activities are still the subject of a great deal of research and debate. There are two fairly different scientific views of ecosystems. The functional view was expressed by Odum (1972) and the more hierarchical view was recognized by O'Neill *et al.* (1986). In Odum's functional view of ecosystems, the functional elements consist of:

- Energy flow circuits.
- Food chains (trophic relationships).
- Diversity patterns in space and time.
- Nutrient cycles.
- Development and evolution.
- Control (maintenance of a steady state at the system level by the use of feedback control mechanisms).

Functional components in this view are elements and molecules involved in material cycles (e.g., carbon, nitrogen, carbon dioxide, water); organic compounds that link living and non-living ecosystem components (proteins, carbohydrates, etc.); climate regime (temperature, rainfall, etc.); producers (mainly green plants), consumers (mainly animals that consume other animals or organic matter); and decomposers (mainly bacteria) that break down organic matter and release substances that can be used by producers. This view of ecosystems places energetics as the central focus. It deals with cyclic causal pathways and feedbacks that are often unobservable, but essential to ecosystem maintenance. In its extreme form, energy flow and nutrient cycling are more important than the living entities performing the function. This view tends to ignore the role of species in the system and makes it difficult to detect total ecosystem changes. Therefore, ecosystem study at this level of organization tends to be model-dominated.

Another dominant form of studying ecosystems is the population-community approach, in which ecosystems are considered as networks of interacting populations of different species. The abiotic environment is viewed as more of an external influence on the biological system and is not seen as an integral part of it. This level of study is observation-dominated, since most field research is focused at the population-community level. This view has limitations, in that it is difficult to infer ecosystem properties from species properties, although an exception might be the use of indicator or key species. The isolation of organisms from their biotic and abiotic environment in this approach can also make it difficult to understand ecosystem dynamics.

These two somewhat dichotomous views of ecosystems can be reconciled somewhat by recognizing that species serve important functional roles in ecosystems. An integrated view of the population-community level of study and the process-functional approach recognizes that ecosystems consist of sets of biological communities in which populations of organisms serve various functional roles (O'Neill *et al.* 1986). This view of ecosystems links the community-population studies that have been a dominant research focus with the process-functional approach that is typical of Odum's ecosystem definition, where the focus is more on flows of energy or matter.

Given these views of ecosystems, it seems an evaluation of North Pacific Ocean ecosystems should include key ecosystem processes or functions outlined by Odum, such as trophic relationships, diversity patterns, energy flow, and the role of the physical environment in influencing the dynamics, as well as information about species and communities. Because ecosystem features may be difficult to observe at the broad functional level that Odum describes, we should consider important observable processes at the species or community level that can provide an indication of changes that might be occurring at the ecosystem level.

Costanza (1992) prescribes three types of measures that might indicate overall ecosystem "health." These measures are vigor (a measure of system activity, metabolism, or primary productivity), organization (includes diversity and connectivity), and resilience (ability of a system to maintain structure and patterns of behavior in the face of disturbance). He suggests network analysis and simulation modeling to develop these measures. However, as was noted in Section 3.10.2, simulation models are not well developed in this regard, and we may need to rely more heavily on indicators that are direct measures of small pieces of the system in order to evaluate the present status of North Pacific Ocean ecosystems. Therefore, we will focus more on species- and community-level measures that indicate changes in trophic relationships, diversity patterns, energy flow, and the role of the physical environment in influencing these changes.

Because of the need for further validation of predator-prey and ecosystem models, there has been a large effort to develop indicators of ecosystem change based on more observable aspects of ecosystems and factors

influencing them, such as fishing and climate. The Ecosystem Considerations Chapter of the Groundfish Stock Assessment and Fishery Evaluations Reports (NPFMC 2002) provides a compendium of status and trends of various ecosystem components and present status of knowledge with regard to human and climate-induced factors that might be influencing these components. Key indicators of ecosystem change with regard to trophic relationships, diversity patterns, and energy flow can be derived from these species- and community-level measures.

As noted above, commercial fishing can influence ecosystems by altering predator-prey relationships, not only by removing key species but also through the introduction of non-indigenous species; by adding or removing energy and redirecting pathways of energy flow through fish removals and the return of discarded biomass to the sea; and by altering biodiversity as measured in a variety of ways, including species-level diversity, functional diversity, and genetic diversity. Any fisheries management policy that allows commercial fishing will create the potential for such effects to a greater or lesser degree. Since passage of the MSA in 1976, fisheries management policy in the BSAI and GOA has been implemented against the background of a relatively mature and resilient ecosystem that has exhibited changes in species composition, guild and community structure, production, recruitment, geographic distribution, and biomass. As discussed in Sections 3.10.1.5 and 3.10.2, the factors driving these ecosystem changes remain speculative, but decadal-scale climate shifts and interannual climatic variations linked to the ENSO phenomenon have been suggested as forcing agents (McGowan *et al.* 1998). For example, increases in zooplankton biomass and in salmon landings documented in the GOA have been correlated with the intensity and location of the winter mean Aleutian low pressure system, which changes on an interdecadal time scale (Francis and Hare 1994, McGowan *et al.* 1998, Orensanz 1998, Anderson and Piatt 1999, Robards *et al.* 1999). Beyond such correlations with climatic indices, cause-and-effect relationships between climate and ecosystem changes have not been proven, but climate-related changes in physical oceanographic factors such as temperature, salinity, current patterns, upwellings, sediment composition, and nutrient supply have been implicated (e.g., Meuter 1999).

Changes in BSAI and specifically in EBS species composition within guilds and in total guild biomass have been examined to determine if they might be correlated with fishing pressure on predator-prey cycles. Livingston *et al.* (1999) found that long-term increases and decreases in the abundance of selected invertebrate, fish, bird, and marine mammal species did not show positive correlations with prey abundance, and that cyclic fluctuations in abundance occurred in both fished and unfished species. Furthermore, these workers found that changes in species diversity within guilds related to increases in a dominant guild member (e.g., pollock, rock sole) rather than to decreases in abundance caused by fishing pressure. The authors concluded that the EBS ecosystem shows two indicators of stability. First, the trophic level of the harvest, after rising slightly since the 1950s, appears to be stable as of 1994, suggesting that present harvest levels are sustainable. Second, the fish populations examined are stable, i.e., fluctuate normally without showing prolonged trends in a particular direction. This conclusion is supported by modeling results indicating that the Bering Sea ecosystem is more stable, i.e., more resilient or resistant to perturbations, than other modeled ecosystems. That the system is more mature, i.e., biomass and energy flow are distributed more evenly at various trophic levels than in other modeled ecosystems.

Commercial fishing can remove predators, prey, or competitors, thus altering predator-prey dynamics in the food web. Fishing can selectively remove fish-eating predators, then move down the food web and begin removing the next trophic level down, such as plankton-feeding fish. This process is known as fishing down the food web. Trophic level of the fish and invertebrate catch from the BSAI and GOA was estimated from

the 1960s to the present (Queirolo *et al.* 1995, Livingston *et al.* 1999) to determine whether such fishing-down effects were occurring. Trophic level of the catch in both management areas has been relatively high and stable over the last 30 or more years. There is no evidence from the present fishery management regime that this fishing-down-the-food-web process has occurred.

Fisheries can have direct impacts on top predators such as sharks, seabirds, and marine mammals that are not part of the directed fishery but may be caught as bycatch. Sections 3.5.3, 3.7, and 3.8, respectively, describe the present-day baseline effects of the groundfish fishery bycatch on these top predator groups. Historical whaling has resulted in low present-day abundance of whale species in the North Pacific. Shark bycatch rates are variable by region, and present-day groundfish fishery impacts are unknown. There is no evidence that present levels of seabird and mammal bycatch in groundfish fisheries are an important source of mortality for most species.

Groundfish fisheries, through selective targeting or bycatch, can remove prey and thus negatively affect other ecosystem components that rely on those prey. Recent concerns have focused on the availability of pelagic prey in the North Pacific Ocean ecosystems in this regard. Thus, measures of the availability of pelagic prey such as walleye pollock, Atka mackerel, Pacific herring, and forage species are an indicator of possible groundfish fishery impacts on predator-prey relationships. See Sections 3.5.1, 3.5.2, and 3.5.4, respectively, for details about the present baseline for these species. Studies of pelagic forage availability show BSAI pollock and Atka mackerel above MSST, GOA pollock at low abundance levels, and BSAI herring as stable. Biomass estimates for forage species are not available, but bycatch estimates in the groundfish fisheries are above average, and relative abundance indices from bottom trawl surveys indicate possible increases in eulachon and capelin in the GOA (NPFMC 2002).

Also of concern with respect to predator-prey relationships is the effect that fisheries may have on prey availability at various spatial and temporal scales. Although prey availability might be high when viewed at the global or stock level, there is potential for localized prey depletion by groundfish fisheries. Previous analyses showed the potential of this effect for walleye pollock and Atka mackerel, and seasonal/spatial allocations of pollock and Atka mackerel catches have reduced the potential for this possible fishery impact in the present-day baseline. Seasonal and temporal catch allocations of pollock and Atka mackerel, along with SSL closures, have spread out fishing removals in space and time, although recent results show BSAI pollock fisheries increasing catch in northern fur seal foraging habitat.

Studies of predator-prey relationships in the BSAI and GOA regions, primarily in the EBS, suggest that there has not been clear evidence of fishing-related species fluctuations through food-web effects. Recent work done primarily in Port Valdez/Prince William Sound shows that biological introductions of non-indigenous species have occurred, although these introductions cannot be ascribed to a particular vessel type, such as oil tankers or fishing vessels (Hines *et al.* 2000). There have been 24 species of non-indigenous species of plants and animals documented in Alaskan waters, primarily in shallow-water marine and estuarine ecosystems, with 15 species recorded in Prince William Sound. One example of a likely introduction is the predatory seastar *Asterias amurensis*, which is found in other areas of Alaska but has not previously been found in Cook Inlet. Although these predators have the potential to produce a major impact on benthic communities, impacts from these introductions have not yet been observed in Alaskan waters. It is possible that most of these introductions were from tanker vessels or other large ships that have large volumes of ballast-water exchange. However, exchange via fishery vessels that take on ballast from areas where invasive species have already been established and that transit in inshore Alaskan waters has been identified as a

threat in a recently developed State of Alaska Aquatic Nuisance Species Management Plan (Fay 2002). Therefore, it is concluded to be a conditionally significant adverse effect of fishing in the ecosystem baseline.

High-volume fishing and fish processing may alter the amount and flow of energy in an ecosystem by removing energy (i.e., large numbers of fish) and by altering pathways of energy flow through the return of discards and offal to the sea. Results of mass-balance modeling by Trites *et al.* (1999) to investigate this question with respect to the EBS suggest that biomass and energy flow are evenly distributed throughout the system, and that the EBS is more mature, i.e., less disturbed (Odum 1985), than comparable shelf ecosystems. The annual total catch biomass in the EBS is estimated at about one percent of the total system biomass, excluding dead organic material. There is no indication that the annual removal of this small biomass percentage alters the amount and flow of energy sufficiently to affect ecosystem stability.

Annual surplus production is a real property of a population that can be measured or estimated. Surplus production is defined as population growth plus recruitment minus natural mortality (Ricker 1978). It is “surplus” only in the narrow technical sense that it is production not required to maintain the population at current abundance. Annual surplus production can be either positive or negative. When the population is lower than its carrying capacity, expected surplus production is positive, i.e., the population tends to increase towards its carrying capacity. At some fraction of the carrying capacity between zero and 100 percent expected surplus production reaches a maximum. These relatively simple ecological concepts underpin MSY-based harvest policies. Whether maximum surplus production occurs at 50 percent of carrying capacity or some other level is a question best addressed with empirical studies of populations living in real ecosystems. Studies such as Myers *et al.* (1994) support the use of F40% as a risk-averse approach to MSY management, which would be expected to reduce the spawning population to 35-45 percent of carrying capacity. The percent reduction of juvenile fish not targeted by the fishery is likely to be much smaller (<20 percent reduction from carrying capacity) and may even increase under MSY-based harvest policies. Since juvenile fish are often targeted by other top predators such as seabirds and pinnipeds, predators that depend on the same prey populations as fisheries would not be impacted to the degree implied by a 60 percent reduction in the spawning population.

From the perspective of systems theory, all carbon sequestered in the living organisms of an ecosystem must end up somewhere, either by being recycled, exported to other ecosystems, or deposited in the sediments. In the Eastern Bering Sea, predation by top predators accounts for a relatively small fraction of the total natural mortality of populations targeted by fisheries (Aydin *et al.* 2002). Disease, parasitism, and all the other hazards of longevity apparently account for most mortality, though these sources of mortality are poorly understood. Fish that die without being consumed by predators are a small fraction of the total carbon recycled into the system by decomposers. The fact that ecosystems by definition do not produce a surplus of carbon (or biomass) does not invalidate the logic behind MSY management.

The foregoing discussion has treated ecosystems as equilibrium systems that return to a stable steady state in the absence of disturbance. This static view of ecosystems is no longer prevalent. Recent research has shown the ecosystems are highly dynamic in response to decadal-scale environmental forcing. There may be unknown biological thresholds that once crossed can move the ecosystem to a new state. While it is appropriate to use single-species steady-state models to approximate overall harvest rates, a fully developed harvest policy must be robust to potential ecosystem variation not anticipated by simple equilibrium models. Several such safeguards are built in to North Pacific harvest policies. The harvest control rules for Tier 3 can be used as an example. First, the F40% harvest rate, for which FABC can never exceed, is well below

F35%, which is used as an estimate of FMSY. Second, instead of a constant F40% harvest strategy, the maximum permissible harvest rate is reduced progressively if the stock declines below B40%. For important prey species of Steller sea lions (Atka mackerel, Pacific cod and walleye pollock), harvest rates in the directed fisheries are reduced to zero at 20 percent of unfished stock size.

When a fishery occurs on prey population that is important to a top predator, a potential exists for competition to occur. Predicting how populations of top predators will respond to a reduction in prey availability is extremely difficult. Linkages between species in an ecosystem are complex and non-linear. Top predators have the ability to adapt to changing conditions by changing their foraging strategies. They can allocate more time to foraging, switch to other prey, switch to more abundant smaller fish of the same species. In some cases, fisheries may make prey more available to top predators, for example, by discard of bycatch.

Based on simple mass-balance ecosystem models (i.e. Ecopath), a numerical response of top predators to reductions in prey abundance would be expected. When a predator is obligate on a single prey species, predator abundance would decline at the same rate as prey abundance. In this extreme case, a 60% reduction in the abundance of prey would produce a 60% reduction in the abundance of the predator. However, most top predators consume a variety of species, and can switch other forage species when one becomes scarce. Diet diversity and the ability to substitute one prey species with another would tend to result in predictions from mass-balance models of a smaller percent reduction in top predator abundance. If other prey species increase in abundance due to competitive release when a fishery reduces the abundance of a target species, some top predators may increase in abundance. These directional changes in the abundance of top predators are based on general properties of simple ecosystem models that lack spatial structure. Predators forage in space, and may require a density of prey above a threshold to forage successfully. Although aggregate biomass models do not show these kinds of spatial effects, they are an important consideration.

When fish are discarded and processed wastes are returned to the sea, energy is redirected to different parts of the marine ecosystem relative to the natural state. Queirolo *et al.* (1995), working before present stricter retention requirements for pollock and cod were mandated, estimated that the total production of discarded fish and processing wastes in the BSAI and GOA ecosystems was about one percent of the unused detritus already going to the bottom. With the new retention requirements now in effect, this estimate would be substantially smaller. These authors found no changes in scavenger populations relating to changes in discard or offal production, and found the annual consumptive capacity of scavenging birds, groundfish, and crabs in the EBS to be over 10 times larger than the total production of discards and offal in the BSAI and GOA. Pathways of energy flow within the BSAI and GOA ecosystems, therefore, are apparently not redirected in any significant way by discarded fish bycatch and processing wastes that are returned to the sea.

Fishing gear can inflict unobserved mortality on target and non-target organisms that can be another source of energy redirection in the ecosystem. In particular, bottom gear can inflict mortality or make benthic organisms more available to predators. Loss of biological and physical structural habitat can lead to increased mortality of marine fish and invertebrates that rely on those structures for refuge from predation. See Sections 3.6.4 and 3.6.5 for a more complete description of fishing gear effects on bottom habitat. Consequently, an indicator of the potential for bottom gear to redirect energy in this fashion is the amount of bottom gear effort in the North Pacific Ocean. Present-day trends in bottom gear effort show there has been a decline in this effort over the last ten or more years (NPFMC 2002).

Biological diversity, the third index of ecosystem health in addition to predator-prey relationships and energetics, is measured in several ways. Species diversity can change if fishing removes all individuals belonging to a single species from the system. Comparative abundance, another measure of biodiversity, can change if fishing alters the numbers of individual representatives of one or more species relative to a defined baseline condition. Functional or trophic diversity can change if a member of a trophic guild is removed; this automatically alters species diversity, changes the way biomass is distributed within the trophic guild, and can affect the functional contribution of the trophic guild to the total ecosystem. The selective removal of organisms that share a particular characteristic, e.g., rapid growth, can alter genetic diversity. Removal of spawning aggregations has the potential to alter genetic diversity if the particular aggregation of fish removed from the system is genetically different from other aggregations.

Assessments of species diversity are lacking for the BSAI and GOA. This is a data gap that must be corrected so that a baseline for species diversity can be established for each of these ecosystems. Without such a baseline, it will not be possible to reliably quantify potential changes in species diversity under any future management regime. Although no fishing-related species removals have been documented under fisheries management policies in effect during the past 30 years, elasmobranchs (sharks, skates, and rays) are particularly susceptible to removal, and benthic invertebrate species diversity could be affected by bottom trawling. Because comparatively little is known about the taxonomic structure of benthic communities of the BSAI and GOA, the potential cumulative effect of trawling and other fishing-related activities on the species diversity of these communities cannot be quantified. Population levels of target and prohibited species show that virtually all of them are above MSST, with the exception of some Bering Sea crab populations (Section 3.5.2.4). Bottom trawl surveys provide an index of abundance for many non-target fish species, and although abundance changes have been observed (NPFMC 2002), there is no evidence in the baseline for fishing effects leading to species extinction. Trends in the number of ESA-listed species might also be an indicator of species diversity changes, but these numbers have been relatively constant, and fishery management actions have been taken to mitigate the effects of fishing on these species (Section 3.4). Area closures provide protection against species extinctions, and the amount of area closed to fishing is another measure of protection of species diversity. The amount of area closed to fishing has been increasing in the baseline and thus has provided an unknown, but presumably increasing, degree of protection against decline in species diversity (Section 3.6). The past/present effects of fishery management policies and of external actions and events on the BSAI and GOA ecosystems are summarized in Table 3.10-3.

With respect to trophic guild diversity, Livingston *et al.* (1999) investigated the variability and evenness of biomass levels in guilds of the EBS. They found no evidence that groundfish fisheries had caused declines in trophic guild diversity for the groups studied. Changes in guild biomass diversity were observed when a dominant guild component (e.g., pollock) changed in abundance, but these changes were related primarily to recruitment rather than to fishing, and there appeared to be no significant loss of functional (trophic) diversity. Bottom gear effort, which is an indicator of benthic community guild disturbance, has been decreasing (NPFMC 2002). HAPC biota (Section 3.6.2), a group of benthic organisms that might be considered a structural habitat guild, do not show fishing-related declines, and some groups (sponge, sea anemone, and sea pens) show increasing or relatively high abundance indices in recent bottom trawl surveys of the BSAI and GOA (NPFMC 2002), as discussed in more detail in Section 3.6. However, corals, which are a very long-lived component of the HAPC biota functional guild, are not well assessed in the baseline. Furthermore, present closed areas do not have much overlap with known coral distributions. Consequently, there is a potential for a conditionally significant adverse impact of fishing on structural diversity through effects of bottom gear on corals.

Genetic diversity has not been systematically studied under the current fisheries management regime, and this is another data gap that prevents establishment of a baseline against which future assessments might be gauged to determine if significant changes have occurred. If a fishery concentrates on certain spawning aggregations or on older (larger) age classes of a target species that tend to have greater genetic diversity (dating from an earlier period when fishing was less intensive), then genetic diversity will tend to decline in fished versus unfished systems. It is possible that genetic diversity has already declined in the BSAI and GOA ecosystems, but this cannot be known in the absence of a baseline. Even in heavily fished systems such as the North Sea, however, there is little evidence that selection for body length in cod has reduced genetic diversity after 40 years of intensive fishing. Genetic assessments of North Pacific pollock populations and subpopulations conducted by Bailey *et al.* (1999) have indicated genetic variations among different stocks. These studies, however, have not found genetic variability across time within the same stocks that might indicate effects from commercial fishing. There has been heavy exploitation of certain spawning aggregations historically (e.g., Bogoslof pollock), but present-day spatial-temporal management of the groundfish fishery has tended to reduce fishing pressure on spawning aggregations. It is unknown whether commercial fishing has altered the genetic diversity of stocks with distinct genetic components at finer spatial scales than the present groundfish fishery management regions.

In conclusion, the BSAI and GOA groundfish fishery management areas generally exhibit sustainable ecosystem-level characteristics with regard to overall productivity and the ability to maintain structural and functional patterns in the face of disturbance. Decadal-scale climate shifts and interannual climatic variations linked to the ENSO phenomenon have been suggested as forcing agents for ecosystem changes (McGowan *et al.* 1998). The evidence discussed here suggests that against the background of climatic variation, fishery-related effects on ecosystem parameters, while present to varying extents, have not been large, and that the contribution of the fishing side may be relatively small in comparison to the climatic drivers.

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