Ecosystem Dynamics of the Aleutian Islands

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Abstract

Ecosystem Dynamics of the Aleutian Islands

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Located between Asia and America and extending over a 1,000 mi., the Aleutian Islands have commonly been studied in a partial or fragmented manner. This dissertation presents the use of multiple spatial scales to distinguish between: i) local and ecosystem-wide processes, and ii) the ecosystem as defined by management and food web structure. Two marine food web models were developed for the Aleutian Islands area. The first is a static food web model developed for the North Pacific Fisheries Management Council area of the Aleutian Islands. The second is a series of contiguous food web models for each one of thirteen 2-longitudinal degree blocks along the Aleutian Archipelago. In addition to the central and western Aleutian Islands, this model also includes the eastern Aleutian Islands which fall within the management area of the Eastern Bering Sea (northern portion) and the Gulf of Alaska (southern portion). Based on changes in food web structure and fisheries across space I describe the basic structure of the western, central and eastern Aleutian, Islands and compare it to that of the eastern Bering Sea and the Gulf of Alaska. I also describe fisheries, longitudinal trends and changes and make policy recommendations towards a Fisheries Ecosystem Plan for the Aleutian Islands.

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Dedication

For my mom, in memoriam

I pass along her legacy…

Enjoy life to the fullest
and know the more you give,
the bigger your heart gets

Introduction

The Aleutian Islands have a fascinating natural history, brought to light by its economics. Our knowledge of the natural resources in the Aleutian Archipelago comes as a cumulative by-product of economic interests in an ever changing loop of exploitation and discovery. The fashion industry, oil, and food supplies are all behind the use of resources in the Aleutians. A strong spirit of entrepreneurship has maintained 250 years of uninterrupted commercial activities throughout the Aleutians, in spite of harsh conditions and trying weather. Successive users and property rights, from Aleuts to Russians, Americans and Japanese, from the freedom of the seas doctrine to the Economic Exclusive Zones, all have shaped the current harvest/conservation modes.

New directions in natural resource management policy aim to change the historically reactive nature of command and control policy to one that is proactive and based on user incentives for the common good (Holling and Meffe 1996, Levin 1999). In past times, and particularly before the Fishery Conservation and Management Act (FCMA) of 1976, most marine conservation efforts aimed at protecting Alaska resources only came after the severe depletion of a population(s) prompted international action (e.g., fur seals, sea otters and whales). In scope and planning, the FCMA was both innovative and far reaching. It extended U.S. jurisdiction over fisheries from 3 nautical miles to 200 nautical miles and later proclaimed US law over the Economic Exclusive Zone. This provision finally conferred the U.S. authority to manage the offshore resources of the entire Aleutian Archipelago, until then open access resources exploited by multiple nations. The FCMA also set national standards for the use of federal marine resources and decentralized management by transferring it to regional councils, a mixed body of state and federal representatives (Bean 1983). These councils were mandated to develop Fisheries Management Plans (FMP) compliant with the national standards. Under this arrangement, the Aleutian Islands are under the stewardship of the North Pacific Fishery Management Council (NPFMC).

Further amendments to the FMCA in the form of the Sustainable Fisheries Act (SFA) required National Marine Fisheries Service to appoint a panel to assess the extent to which ecosystem principles were used in fisheries management/research and make recommendations on how such principles could be implemented. In so doing, it cemented the new direction into which it had steered fisheries management policy in the United States (Fluharty 2000). The Ecosystem Principles Advisory Panel (EPAP) report launched in a nationally institutionalized manner what nowadays is referred to as ecosystem-based fisheries management (EBFM). EBFM is a holistic approach centered around a socio-ecological ecosystem where feedbacks between human and the environment are not only recognized but warranted in order to sustain an undisturbed connection among its elements. Its human component includes fisheries, politics, economics, science and culture. The environment encompasses climate, habitats and biodiversity. The confluence of these elements in time and space is intrinsically historical, evolutionary and geographical in nature (McEvoy 1986, Worster 1993, Leff 1995, Solow 1998, Levin 1999, Francis 2001, Jackson et al. 2001, Field and Francis 2005, Erlich and Levin 2005, Longhurst 2006). The key recommendation set forth by EPAP was the development of Fisheries Ecosystem Plans (FEP). FEPs should contain information on the structure and function of the ecosystem in which the fisheries take place and on the interactions between the ecosystem and fisheries (EPAP 1999).

Prompted by this movement towards EBFM and the recent unexplained declines of sea lions, sea otters and seabirds (Angliss and Lodge 2003, Doroff et al. 2003, Byrd et al. 2005), the NPFMC has started to develop a demonstration FEP for the Aleutian Islands (NPFMC 2005). Such action also follows the recognition of the inherent differences between the Eastern Bering Sea and the Aleutian Archipelago, traditionally managed jointly under the Bering Sea/Aleutian Islands FMP. While the NPFMC has been proactive in moving towards a more integrative management, and took concrete actions in this direction (Witherell et al. 2000) well before the appearance of the recent suite of reports on the status of marine resources (Pew Oceans Commission 2003, U.S. Commission on Ocean Policy 2004), it also recognizes the lag in general knowledge and research on the Aleutian Islands. A revision of the ecosystem considerations chapter, drawn by the Groundfish Plan Teams of the NPFMC since 1995 (Livingston 2003; Boldt 2004) showed ecosystem wide studies for the Aleutian Islands were lagging in scope and breadth compared to those available for the Bering Sea and the Gulf of Alaska. To address this gap, both the NPFMC and the Alaska Fisheries Science Center (AFSC) have placed strong emphasis in bringing forth such studies. Chief among the EPAP requirements to develop an FEP are: i) the delineation of the geographic extent and boundaries of the ecoystem, ii) the development of a conceptual food web, and iii) the effect of total removals in standing biomass, production, yields, mortality and trophic structure. These issues were being addressed for the Eastern Bering Sea (EBS) and Gulf of Alaska (GOA) by means of a food web model. The development of a similar model for the Aleutian Islands became the initial thrust of this dissertation.

During the initial phase of this work, it became evident that the spatial delimitation of the NPFMC statistical areas referred to as eastern/central/western Aleutian Islands did not correspond to their geographical delimitation. Essentially, the first defines the Aleutian Islands regulatory area as a region extending from 170°W to 170°E, with breakpoints at 177°W and 177°E. Geographically, the [American] Aleutian Islands span from 164°W to 170°W with breakpoints at 169°W (Samalga Pass) and 180°W (Amchitka Pass). From the NPFMC perspective, the islands located between 170°W and 164°W are outside the Aleutian Islands ecosystem and instead, the northern portion is part of the EBS regulatory area while the southern part falls within the GOA (Figure a).

This realization brought into question the very definition of the ecosystem of the Aleutian Islands. What elements define the spatial scale and boundaries of the ecosystem? What is(are) the appropriate scale(s) for management? Are the geographical/ management breakpoints that mark the eastern/central/western Aleutian Islands meaningful? If in order to achieve sustainability we must integrate the human and environmental components, then we must match their spatial scale (Francis, in prep). This is not a trivial matter as it requires knowledge of spatial processes at different scales in all aspects of these components. Unfortunately, space as a variable is usually neglected despite its relevance to understand the location of resources/ processes across disciplines (Tilman and Kareiva 1997, Agostini 2005, Pauly 2003, Walters 2003, Little in prep).

To explore the spatial scales within the human and environmental components in the [American] Aleutian Islands, I decided to use a static food web [with fisheries] modeling approach at multiple scales of spatial resolution. I have divided my dissertation into five chapters. In the first, I review spatial features of the marine environment of the Aleutian Islands and reconstruct the historical commercial use of its natural resources, with particular attention to the spatial allocation of extractive efforts, and historical management boundaries. In the second chapter I developed a static mass-balanced food web model scaled to the NPFMC regulatory area of the Aleutian Islands, and compared it to those for the EBS and GOA to identify the perceivable traits and differences across ecosystems as defined by management boundaries. In the third chapter I use a series of static food web models to cover the geographical extent of the Aleutian Islands. I do this by dividing them (from 164°W to 170°E) into 13 areas of 2-longitudinal degrees and building a simplified food web model for each one using the same methods as for the previous model. The spatial patterns in the food web structure arising from this longitudinal continuum are inherently related to the local environment and thus serve as evidence of existing boundaries. In the fourth chapter I compare the results of the food web models at each level of spatial resolution and look at how these scales inform each other. Finally in chapter five, I show one way to use food web models to assess and reduce uncertainty about the magnitude of some of the system's components. I close by summarizing the finding from previous chapters, and using them to evaluate the FMPs for the BSAI and

GOA in three ways: i) the validity of the current management areas of the Aleutian Islands in the context of an FEP, ii) their resilience to different food web structure, and iii) their ability to respond to effects of fisheries at different scales. My aim is these findings will improve the context for and make informed decisions regarding the management and conservation of the marine resources in the Aleutian Islands.

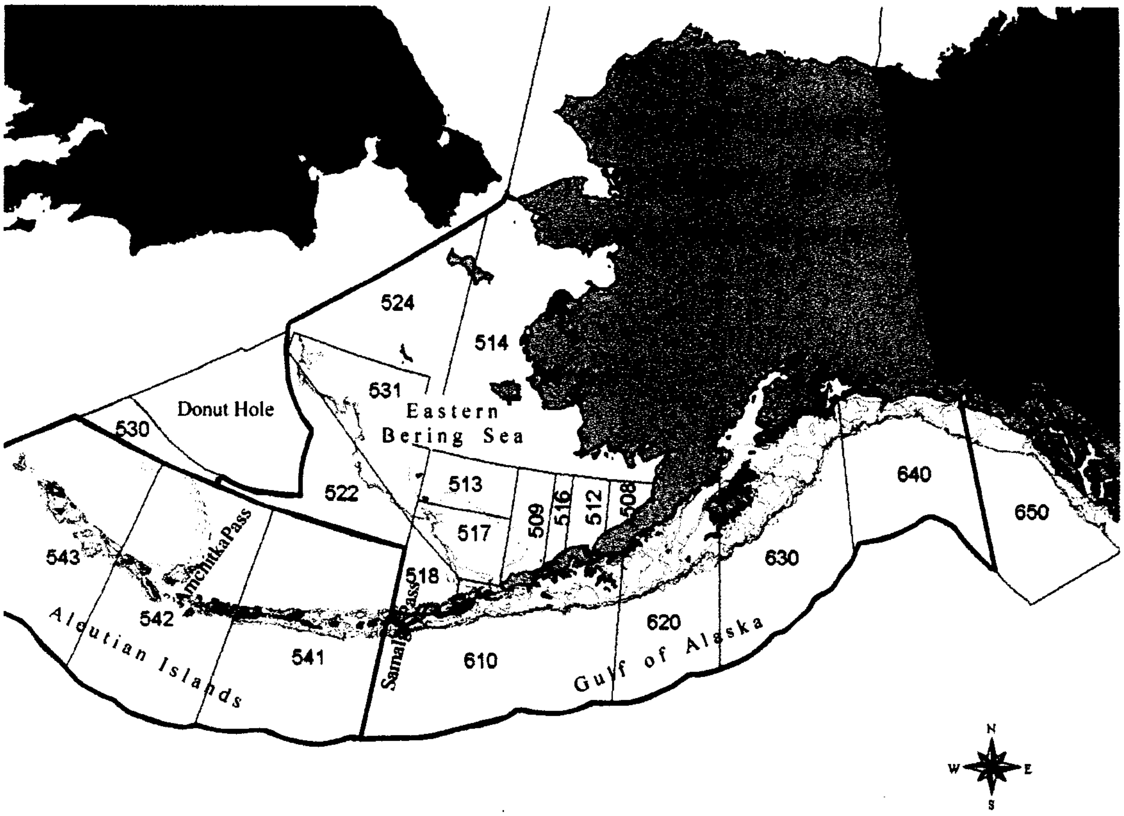

Figure a. Map of the Aleutian Islands showing the regulatory areas of the North Pacific Fishery Management Council and their corresponding statistical areas.

The regulatory areas are the Aleutian Islands, Gulf of Alaska, Eastern Bering Sea. The Donut hole area is outside the jurisdiction of the U.S. The statistical areas 541, 542 and 543 are referred to by the NPFMC as the eastern, central and western Aleutians. In contrast, the Samalga and Amchitka Pass mark the geographical breakpoints between the eastern, central and western Aleutian Islands respectively.

Chapter 1. The Marine Environment and Historical Exploitation of the Aleutian Islands

> *Winds on this island are sometimes of such violent force that men can hardly stay on their feet. And one may say that from December to March we seldom saw a clear and fair day amid the tempest and snow storms. (Khitrov 1869).*

> *"Distant water fleets and mobile traders can operate like roving bandits because global markets often fail to generate the self interest that arises from attachment to place" (Berkes et al. 2005).*

1.1 SUMMARY

The boundaries existing along the Aleutian Archipelago correspond to imaginary lines depicting biogeographical and political boundaries. The marine environment has strong boundary at Samalga Pass where oceanographical and ecological features transition from a coastal to an oceanic character. The differences east and west of Samalga Pass define in effect two distinct environments. East of Samalga the shelf is wide, water is warmer, climate follows the pattern of the Pacific Decadal Oscillation, diets are mostly neritic and fish species from the Oregonian province dominate. West of the pass the shelf is narrow, the water is cold and high in nutrients. The climate has been getting colder since the 1950s and the diversity of fish from the Oregonian province drops significantly. Feeding habits also change and rely more on plankton and oceanic species such as myctophids and squids.

Historically, waves of exploitation have advancecd both from the east and the west. The discovery of the Aleutians starts as a mixed enterprise aiming for discovery but self financed by the fur trade. The fur strade started relying on marine mammals but later extended to land mammals as soon as the Alaska Peninsula was reached. Marine mammals also supported the fist American advance, when whaling was carried out by American whalers. Once sold to the United States, the exploitation of Aleutian resources in the west was almost minimal, as most effort concentrated on the eastern Aleutians and partially extended to the central Aleutians. After World War II Japan and Russia started advancing again towards waters near the Aleutians. Multiple legal boundaries were set among the nations in the North Pacific in an attempt to claim domain or divide marine resources more than 3 mi offshore. It was only until 1977 when the United States gained domain over 200 mi offshore. The 1982 Law of the Sea later declared the area from 3 to 200 mi offshore as economic exclusive zones of coastal nations. In brief, the western islands have been exploited intensively but during distinct periods, whereas the eastern Aleutians have been exploited consistently, often relying on the marginal distribution of the main fisheries for the Gulf of Alaska and the eastern Bering Sea.

The lack of continuous and consistent records precludes a detailed reconstruction of the exploitation of resources in the Aleutian Islands. Records comprise the main feedback from the ecosystem, providing first hand knowledge of species present, minimum abundances, species distribution and species co-occurrence. Emphasis on time series has favored an aggregate view of entire ecosystems, neglecting their heterogeneity of resources, ecology and history and masking the scale of fisheries and ecological processes. A better sense of the resources allocation and marine characteristics improves our feedback on the ecosystem, and its spatial processes can only be identified from records at multiple spatial scales.

1.2 INTRODUCTION

A bridge between Asia and North America, the Aleutian Archipelago boasts a rich marine biodiversity that has evolved to withstand the strong winds, earthquakes, volcanic eruptions and tsunamis typical of the region. Despite the harsh conditions and sparsity of settlements throughout the Aleutian chain, the history of the large scale exploitation of its natural resources spreads almost uninterrupted for the past 250 years (Figure 1.1). From fur trading to whaling and fisheries, the commercial ventures in the archipelago have a complex history of exhaustive exploitation followed by reactive conservation measures. Thus the islands' current wealth of resources is the combined result of environmental conditions and cumulative exploitation/ conservation actions. Half the archipelago lies closer to Asia, half closer to North America, generating economic and environmental driving forces from opposite ends that meet in an alternating/simultaneous manner in time and space. The interplay of these forces shapes the marine environment in a longitudinal gradient of predominantly Asian/oceanic nature to the east and North American/coastal to the west. It has also divided the history of the islands into exploitation waves coming from the east (primarily Russia and Japan) and those coming from the west (mostly American, but also British/Canadian). Exploitation from the eastern nations were restricted and came to an end in 1990 with the passage of the Fisheries Conservation and Management Act (FCMA) in 1976 which extended U.S. fisheries jurisdiction to 200 mi. offshore. Since then, fishing activities are based off the Alaska Peninsula and Dutch Harbor in the eastern Aleutians.

This chapter is divided into three sections. The first provides a summary of the marine environment with special attention to biogeographical boundaries and trophic flows. The second reviews the historical exploitation of the marine resources throughout the Aleutian Islands, from the Russian fur trade beginning in the mid 1700's to multinational fishing in the 21st century. Emphasis is placed on spatial aspects such as location of harvesting effort, distribution of species exploited, and geographical boundaries set by international treaties. The purpose is to compile the set of boundaries that delimit or have delimited some portion of the Aleutian Islands. In the third section, I discuss the overlap between these boundaries and examine the validity of using them to set the spatial scale of the Aleutian Islands socio-ecological ecosystem as defined within the context of a Fisheries Ecosystem Plan.

1.3 THE MARINE ENVIRONMENT OF THE ALEUTIAN ISLANDS

The Aleutian archipelago is of volcanic origin, marking the subduction zone between the North American and Pacific Plates. Many of the volcanoes are active; earthquakes and tsunamis are common. The Aleutian arc extends from False Pass at the western tip of the Alaska Peninsula, roughly 163°30'W, to west of the Commander Islands at 165°E. The American portion of the Aleutian chain stretches some 1,900 km, with Attu as its westernmost island and the Economic Exclusive Zone ending at 170°E. The over 300 islands are usually referred to by location or group (Figure 1.2), typically:

i) Eastern Aleutian Islands: located east of Samalga Pass, they include the group known as the Fox Islands.

ii) Central Aleutian Islands: located between Samalga and Amchitka Pass, they include the Andreanof Islands and the Islands of Four Mountains.

iii) Western Aleutian Islands: found west of Amchitka Pass, they include the Rat Islands and the Near Islands.

1.4.1 Climate

The Aleutian Islands are characterized by a maritime climate: cool, wet, windy, and foggy with summer air temperatures around 5-10°C and winter air around freezing. Temperature variability is determined by the Aleutian Low, a low pressure center that may be located east of 180°W or be split in two: one center located east of the Kamchatka peninsula, and the other in the Gulf of Alaska. Depending on the strength and location of the Aleutian Low, the dominant storm track can cross the Aleutians anywhere between 170°W and 150°W, which has strong implications for climate. East of 170°W, where the storm track can vary, there is evidence of a regime shift towards a warmer climate in 1977, simultaneous with the Pacific Decadal Oscillation (PDO) (Mantua et al 1997). West of 170°W, the winds prevail along the chain. The surface air temperatures show a monotonic cooling trend since the 1950's (Figure 1.3). Synchronicity with the PDO is lost in the west (Rodionov et al. 2005). So while the weather throughout the archipelago may be very similar, the climate trend since 1977 differs substantially between the east (warming) and the west (cooling), creating distinct physiological stresses on the organisms in each region. This climatic disruption may contribute significantly to making 170°W a transition area between two biogeographical regions: the eastern and the central/western Aleutians (Rodionov et al. 2005, Hunt and Stabeno 2005).

1.4.2 Oceanographic and zoogeographical characteristics

The Aleutian Islands are a porous continuous boundary separating the Bering Sea in the north from the North Pacific in the south (Figure 1.2). On the north side of the islands the narrow Aleutian North Slope Current (ANSC) runs eastward. Upon reaching the Bering Sea shelf, the ANSC turns north along the edge of the shelf forming the Bering Slope Current (Stabeno et al. 1999, Reed and Stabeno 1999). South of the islands, there are two primary currents flowing to the west, each following a different path. One is the Alaska Coastal Current (ACC), a narrow nearshore flow that hugs the coast, turns north through the eastern shallower passes, and connects the wide continental shelves of the Gulf of Alaska, eastern Bering Sea, and eastern Aleutians, bringing to them warmer and fresher conditions (Ladd et al. 2005). The second is the Alaska Stream that runs offshore along the shelf break as a narrow high speed current, which dominates the westward flow in the central Aleutians where the shelf is very narrow. The Alaska Stream contributes largely to the ANSC through the deeper passes, particularly Amukta and Amchitka Pass. Most water transport from the North Pacific into the Bering Sea occurs through Near Strait which is located west of Attu and has both the widest cross-sectional area and the deepest sill in the entire chain (Stabeno et al. 1999, Ladd et al. 2005).

Zoogeographically, the Aleutian chain is part of the Aleutian province, bordered by the Kurile, Arctic and Oregonian provinces (Allen and Smith 1988). As a result, the Aleutian's fauna is a mélange of species occurring in Asia, the Arctic, the western coast of North America, and islands such as Hawaii. Despite the mix of provinces and high biodiversity, some large scale patterns in the distribution of the macrofauna seem to further support the existence of a coastal/ oceanic transition zone that differentiates the eastern from the central and western islands: i) there are significantly more Oregonian fish species in the eastern Aleutians, ii) fish diversity is higher (Logerwell et al. 2005) and deep water coral diversity is lower (Heifetz 2005) in the eastern Aleutians, iii) marine mammals with neritic affinities (e.g., humpbacks) are found in the eastern Aleutians while those with more oceanic affinities (e.g., sperm whales) are found on the central region (Sinclair et al. 2005), and v) seabirds are associated to shelf-species of euphausiids in the eastern Aleutians, but to shelf-break euphausiid and oceanic copepods in the central islands (Jahncke et al. 2005).

The divide between the eastern and central/western passes is also evident in the microfauna of the archipelago. The zooplankton community has mostly neritic copepods and euphausiids in the eastern passes where coastal conditions prevail, but it has mostly oceanic copepods like *Neocalanus* or *Eucalanus* and the euphausiid *Euphausia pacifica* (Coyle and Pinchuk 2005) in the central passes where oceanic conditions are typical. In these oceanic waters the vertical migration of zooplankton is an important part of the biological pump, transferring energy from the surface down to 300-600 m depth where *Neocalanus* migrates (Coyle 2005).

The characteristics of the passes further contribute to differentiate the eastern from the central/western Aleutians. In general, the passes along the archipelago are characterized by strong tidal currents with a predominantly north flow (Stabeno et al. 2005). These fast flows preclude the accumulation of chlorophyll and so blooms are favored downstream of the passes where there is both high chlorophyll concentration and stratification (Mordy et al. 2005). Eastern passes are narrower, shallower and with slower flow. Mixing is complete in the center of the passes and nutrient transport is lower as the main flow comes from the nutrient-poor ACC. Conversely, central and western passes tend to be wider, deeper and with faster flow. Mixing rarely reaches the bottom portion of the water column and nutrient transport is higher as the flow comes from the nutrient-rich Alaska Stream (Table 1.1, Figure 1.2) (Stabeno et al. 1999, Stabeno et al. 2005, Mordy et al. 2005).

Other potential transition zones may be found in the western Aleutians, around Amchitka and Buldir Pass. Oceanographic studies similar to those available to delimit the eastern/central Aleutians are lacking. The evidence comes mostly from ecological patterns in various fish and seabird distribution. These patterns are: i) the existence of progressively lower growth curves for northern rockfish and Pacific Ocean perch in the eastern, central and western islands, ii) changes in the feeding habits of Pacific Ocean perch, Atka mackerel, pollock and Pacific cod west of Amchitka/Buildir Pass (Logerwell et al. 2005), iii) ecological classification of Steller sea lion rookeries identifying the western and central Aleutians as distinct areas (Call and Loughlin 2005), iv) seabird feeding/foraging characteristics with planktivorous seabird colonies prevailing between Amchitka and Buldir Pass and nearshore seabirds west of Buldir Pass (Springer et al.1996, Stephensen and Irons 2003).

It is interesting to note that in addition to the large scale biogeographical patterns, isolated extreme environmental disturbances have caused major redistribution of marine populations. Sea otters decreased off Yunaska in the mid 1820s following volcanic eruption and earthquakes, dead fish were reported en masse near Unimak from 1826 to 1831 (Black 1981), and Bogoslof (first formed in 1796) now has resident fur seals and sea lions (Angliss and Lodge 2003). Other reports involving occasional fauna influxes or redistribution include large numbers (50,000-5,000) of walruses brought by severe north winds to the Near Islands, herds of sea otters drifting to the south shore of Umnak Islands[i] (Berkh 1823) and cod disappearing from harbors in 1915 (Shields 2001).

1.4.3 Populations under special management

Various populations are under special management either because of past exploitation or because of poorly understood declines under current conditions.

Sea otters nearly became extinct in the early 1900's. The population recovered to high biomass levels in the mid 1980's and subsequently declined for poorly understood

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[i] The herds were suspected to come from outside the Aleutians as the sea otters had reddish hair on their bellies, unlike ever killed before.

reasons (Doroff et al. 2003). Sea otter are currently classified as depleted under the Marine Mammal Protection Act (MMPA), (USFWS 2002). Whaling in the North Pacific took place from 1835 to 1972 (Starbuck 1878, Tønnessen and Johnsen 1982) and depleted several Alaskan whale stocks which extended to the Aleutians (Shelden et al. 2005; Mizroch and Rice 2006). Sperm, fin, humpback, right, and sei whales are now classified as depleted under the MMPA and Endangered under the ESA (Angliss and Lodge 2004). Both Pacific Ocean perch and King crab have been depleted significantly in the Aleutians by modern fisheries. The first was severely depleted in the 1960's by the foreign fishery. Current estimates seem to indicate the stock has been consistently increasing since the 1990s (Spencer et al. 2004). In contrast, the American fleet obtained record catches of red king crab during the early 1960s both off Adak and Dutch Harbor and the stocks have not recovered, remaining at low levels and in some cases forcing the fishery to close (NPFMC 2005). Short-tailed albatross was once numerous in the region (Yesner 1976) and still forages throughout but nests elsewhere. It was hunted to near extinction in Japan for its feathers (Tickell 2000). It is currently listed as endangered under the ESA and measures are being taken to cause recovery.

Wild populations of arctic foxes were the original target of the fur traders. They were first introduced to islands where they were non native in 1750 (Black 2004) and reintroduced by Americans from 1913 to 1940, at which point they were found in at least 90 islands throughout Alaska. Foxes depleted multiple seabird populations, extirpating some species from the larger islands (Byrd et al. 2005). Ongoing eradication efforts started in 1949 and in 2002 only 6 islands still had non-native foxes (Ebbert 2000; Ebbert and Byrd 2002).

Norway rats were introduced in Rat Island as a result of a Japanese shipwreck in 1780 (Black 1984). Since then, rats have become established in other islands such as Atka and Kiska (Bailey 1993, Murie 1959). Rats extirpate ground nesting seabirds such as Cassin's auklets, storm petrels, tufted puffins.

Lastly, ground squirrels were introduced at first by Native Alaskans and early Russians for clothing (parkas) and food (Ebbert and Byrd 2002). They were later reintroduced by American ranchers as food for foxes after the seabirds had declined and the islands were running short on food supplies. Arctic ground squirrels are known to take passerine eggs, chicks and eggs of seabirds (Geist 1933; Sealy 1966). The impacts of both rats and squirrels extend to the local flora: they feed on stalks, stems, seeds and fruits, contribute to overgrazing and kill saplings, thereby modifying the plant communities and affecting the associated fauna (Courchamp et al. 2003; Bailey 1993).

As the availability of other marine mammals (sea otters, fur seals and whales) decreased throughout the Aleutians and the Alaska Peninsula in the 1800s (Alekseev 1990), the Russians' and natives' reliance on Steller sea lion increased sharply. The sea lion population in Alaska was thought nearly extinct in the early 1900s (Bureau of Fisheries 1906), it recovered to high biomass levels by the early 1970s and then started declining in the mid 1970s throughout the eastern Aleutians. The decline extended to the central and western islands in the mid 1980's (Angliss and Lodge 2004) and the western stock is currently classified as depleted under the MMPA and endangered under the ESA (Angliss and Lodge 2004). The causes for the decline are poorly understood, but are believed to be a mixture of climate and prey availability, among other factors (NRC 2003). Like sea lions and sea otters, nearshore seabirds such as guillemots, glaucus-winged gulls and cormorants have recently declined for unknown reasons (Byrd et al. 2005).

Lastly, Steller's sea cow and Pallas (spectacled) cormorant are now extinct. They were sought as food by the numerous Russian crews that stopped in the Commander Islands. This was the only place where they were found by the time Vitus Bering's expedition discovered the islands in 1741. Both sea cows and spectacled cormorants were available year round, and so became staple food items of the Russian crews . By 1754 sea cows were reported scarce, extinct by 1768 (Stejneger 1887; Anonymous

1892); spectacled cormorants were extinct by 1850 (Stejneger and Lucas 1890; Anonymous 1892).

1.4.4 Connections across ecosystems and food webs

Perhaps the most visible widespread effect of depleted populations throughout the Aleutian archipelago is the islands' change in landscape from grasslands to maritime tundra. The reduction of seabird's nutrient rich guano to the plant communities favored less productive shrubs and forbs over more productive grasses and sedges. The marine derived nutrients delivered via guano reach beyond the plant community and are traceable to terrestrial mollusks, passerines, dipterans, and arachnids, illustrating the intricate nature of nutrient transport among ecosystems (Croll et al. 2005).

Within the marine environment, the extirpation of local sea otter populations had widespread consequences. Kelp is unevenly distributed throughout the islands but wherever they form forests, they support a marine community that includes multiple fishes, limpets, bryozoans, amphipods, tunicates, barnacles, mussels, asteroids, octopus, and other invertebrates (Simestad et al. 1978; Isakson et al. 1971). The forest's extension is regulated through herbivory pressure by sea urchins that in turn are controlled via predation by sea otters. At sites being recolonized by sea otters, sea urchin abundances have declined and kelp forests have increased as the sea otters increase; kelp and urchins have remained the same where sea otters populations have been stable (Estes and Duggin 1995). Kelp forests also incorporate allochthonous nutrient inputs from offshore in the form of seabird's guano, exemplifying the importance of nutrient transport across habitats (Wainwright et al. 1998). The organic detritus originating from kelp support a variety of benthic suspension feeders, such as mysids, barnacles, and amphipods, enhancing secondary production in the nearshore areas (Duggins et al. 1989). The current contraction of kelp forests is a potential contributing factor in the decline of nearshore seabirds (Byrd et al. 2005).

As exemplified by seabirds and sea otters, changes in parts of the Aleutian Islands ecosystem can be linked to the cycling of nutrients and energy across environments, but the processes can unfortunately go easily unnoticed until broken or degraded. The changes in landscape were observed at local or small spatial scales, however the patterns behind them required studies over larger spatial scales, reaffirming Levin's (1992) proposition for studies at multiple scales. The effects of seabirds on vegetation and sea otters on kelp also show the usefulness of food webs to identify connections among species and understand how changes in abundances and distribution manifest themselves when processed through the food web. Large scale food webs can help identify fundamental processes of nutrient cycling across areas, while local food webs and life history traits can help identify distinct ecological areas.

1.4 HISTORICAL EXPLOITATION OF NATURAL RESOURCES

The Aleutian archipelago has been occupied by humans for nearly 9,000 years (Laughlin 1975). Prior to the arrival of the Russians, the Aleut population numbered about 16,000 inhabitants with 6,000 in the western and central islands and the rest distributed from eastern islands to Port Moller. Each group of islands was occupied by independent polities with varying degrees of contact with each other as well as the mainland. Their culture was based on marine resources, with particular reliance on marine mammals such as sea otters and fur seals. Common uses of marine mammals, besides food, included fur for clothing, covers and bedding (e.g., sea lion and hair seal skins were used to sit on, sleep in, or cover objects with; guts were used for waterproof garments and utensils) (Hrdlicka 1945). Fox furs were also utilized in the eastern islands, and skins of various land and seabirds supplemented the Aleuts' needs. Down and feathers were used for clothing and decoration, bones for needles and nose sticks, beaks for jinglets and rattles, wings for fetishistic purposes. Aleuts made no traps; nets and seines were known to them yet they were not common or universal (Hrdlicka 1945, Ransom 1946). Living in the islands with little additional resources other than those available locally, the Aleuts kept close track of abundance, distribution and even behavioral changes in their surroundings. Although their population was not evenly distributed throughout the islands, their population density with respect to the marine exploitation area was uniform over the three regions (Eastern, Central and Western, see Figure 1.2) (Laughlin 1975). Close observation of spatial changes in the amount of resources and their even exploitation was lost after the Aleuts lost domain over the marine resources. The level of resource use switched from subsistence requirements to open access and maximization of catches as a safeguard against the high risk of the voyages to the Aleutians. Consequently, resource use in the Aleutian Islands has oscillated between exhaustive extraction and reactive conservation.

1.4.1 The roots of Russian expansion and exploration of the North Pacific: economic interests from the east

During the early 17th century, the increasing trade between European nations and their colonies in the East Indies, Africa and the Americas, heightened the search for new and better maritime trading routes. Trade was fundamental not only to get raw materials, but also to sell processed goods and support the industry in the mother countries. A Northwest (Northeast) Passage through the Arctic had long been sought as a safer sea route to the Orient than those going around Cape Horn or the Cape of Good Hope, where the potential for Spanish or Portuguese attack was high (Hayes 2001).

Having expanded across Siberia to Kamchatka, the Sea of Okhotsk and the Kuriles, (Gibson 1980, Hayes 2001) the Russian Empire was ideally located to conduct explorations to the Arctic (Sokol 1952). England, France and the Netherlands had established colonies on the east coast of North America (Faragher 1999) but the West coast remained unexplored. The potential for prestige encouraged the Russian Empire to finance the Great Northern Expedition in search of the Northwest Passage and a route to America (Hayes 2001).

In 1741 Vitus Bering shipwrecked and died in Bering Island on his way back from Kayak Island in the Gulf of Alaska. Half the crew died from scurvy before arriving to the island where they were forced to overwinter (Hayes 2001). Georg Steller, the scientist on board, made numerous observations on the abundance of resources and biodiversity of the island which later comprised *De Bestis Marinnis*. His work provided the first description of the fauna in Aleutian Islands, including Steller's sea cow, Steller sea lion, Northern fur seal, Steller's eider and Palla's (spectacled) cormorant. The crew brought back 900 sea otter pelts, which actually paid for the expedition[ii]. Russians had become acquainted with sea otters in Kamchatka, and upon learning of their value in China[iii] had established overland trading agreements (Williams 1920). Access to this market was unique in that China considered itself independent, outside traders were merely tolerated (Christman 1984), and bartering was the only mode of trading. Sea otters, a luxury item for high quality garments, were among the few products of interest to the Chinese (Valpy 1846).

Despite the success of the expedition in terms of discovery, the War of the Austrian Succession in 1743 forced Empress Elizabeth I to close explorations and their financing (Black 2004) The promyshleniki[iv] however, saw the commercial potential[v] of financing the exploration as the abundant and highly priced sea otters could be advantageously exchanged for Chinese tea, silk, wool, steel and glass ware[vi] (Williams 1920). The absence of other European nations minimized the chance for conflicts, and the ready availability of marine mammals and seabirds meant expeditions could depart

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[ii] Sea otter furs were considered "soft gold" due to the high prices they reached in the Chinese market.
[iii] The market sea otter trade was developed by Japan with China in the 17th century (Williams 1920).
[iv] Russian fur trader/hunter
[v] The fur traders had already played an important role going side by side with the Cossacks across Siberia, Kamchatka and the Kuriles (Alekseev 1990, Gibson 1980).
[vi] Russia's focus in the Chinese market followed its declining role in the European fur trade the previous century. The high quality of true wintering furs from Siberia had secured a place in the high end fur trade(Williams 1920, Black 2004). However Russia was out of the beaver pelt trade for hats, which at the end of 17th century was worth about 5 million per year in England alone Carlos and Lewis 2004). The place Russia held once as the center for processing beaver pelts destined to the French hat industry was lost when the hat makers (Huguenots) moved to England and the oversupply of beaver pelts from the North American colonies allowed English to experiment and ultimately master the combing techniques previously held as a trade secret by the Russians (Rich 1955).

with a minimum of provisions and obtain supplies from the islands. For the promyshleniki, exploration could not only be self-financed but actually profitable. The Aleutian Islands became the financial stepping stones for the establishment and maintenance of permanent settlements in Alaska.

1.4.2 Early Russian Period: east to west depletion of resources in the Aleutian Islands by the independent fur traders (1741-1799)

During the early Russian period, discovery and intense exploitation went hand-in-hand. Lack of involvement and direction from the Russian government[vii] allowed the traders to hunt on land, unrestrained, [viii]and investments on exploration were secured by maximizing the number of furs obtained per trip.

The discovery of the Aleutians by the Russians took some 20 years (Haycox 1997) (Figure 1.4). Along the way Aleuts were encountered and used as hunters and arctic foxes were introduced to islands devoid of them[ix] (Black 2004). The extirpation of sea otters from the Kamchatka Peninsula[x] and their decline along the western Aleutians pressed the fur traders to the east, arriving to the Alaska Peninsula in 1760[xi] (Smith 2003). By now, most voyages followed a clear pattern: vessels would leave with minimal provisions to the Commander Islands where they would winter or stay up to a year catching foxes and hunting sea cows, seals, sea lions and sea otters[xii] (Berkh 1823; Stejneger 1887; Black 2004). Once stocked, the vessels would continue east where the crew would hunt for 1 to 3 years depending on their success and the vessel

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[vii] Government limited its involvement to the 10 percent tax on fur imports imposed in 1774 (Black 2004).

[viii] The Empress Catherine the Great urged Russian subjects to treat Aleuts fairly (Black 2004), yet there are no references to her request for an estimate of resources or guidelines for exploitation.

[ix] arctic foxes were brought to Attu from the Commander islands in 1750.

[x] reported in 1750 (Smith 2003).

[xi] the Andreanov and Fox Islands were described in 1766 (Smith 2003).

[xii] Sea cows were used for meat. Dried, it was a substitute for bread and it was estimated that one sea cow would feed 33 men for 1 month. Sea otters were considered tastier than fur seals and young sea lions quite palatable. Oil was used as butter and for lamps and the skins were used for boat covers (sea cows') or general water proof covers (sea lions'). Occasionally whales were hunted too; beside meat, blubber and oil, the gut was used for water resistant shirts or raingear (Black 2004, Okun 1951). Seabirds supplemented the crew's diet and wee considered a nice change. Spectacled cormorants were commonly consumed (Stejneger and Lucas 1890).

characteristics[xiii]. Gradually, sea otter populations declined, vessels got larger, voyages lasted longer and crews increased (Berkh 1823).

The fur traders continued to exploit and explore Alaska until 1799. An earthquake had reportedly scared the sea otters away from the Kuriles in 1780, and there were subsequent declines in the sea otter populations along the Aleutian archipelago that directed exploration towards southeast Alaska[xiv] (Berkh 1823, Tikhmenev 1861, Black 2004). The western Aleutians remained as regular stops in the voyage from Russia to mainland Alaska. The Commander Islands were so heavily exploited that in 1786, sea cows became extinct (Stejneger 1887). The discovery of the Pribilof Islands and its large fur seal colonies in 1786 prompted a partial shift of hunting effort away from the Aleutians and sea otters (Hayes 2002, Berkh, 1823)[xv]. In all, the independent traders brought to Russia an estimated 1,120,000 furs: roughly 76% from fur seals, 12.5% from sea otter, and 11.5% from various types of foxes, not counting furs in storage houses or from land mammals other than foxes (Berkh 1823) (Figure 1.5). These first 50 years of exploitation by independent fur traders yielded more sea otters furs than the subsequent 65 years under the auspice of the Russian American Company.

1.4.3 1799-1867: The Russian American Co. as de facto government in the Aleutian Islands and the independent American whalers.

In 1798 Shelikov[xvi] formed the Russian American company and was awarded the fur trade monopoly in 1799 (Berkh 1823; Tikhmenev 1861; Black 2004).The Russian American Company was modeled after the Hudson Bay Company and the British East

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[xiii] When crew members had been left in some island they would remain there, surviving on their own and trapping, until some other vessel came by (Berk 1823).

[xiv] First to Kenai Bay (Cook Inlet), then to Chugatsk Bay (Prince William Sound) (Tikhmenev, 1861).

[xv] The Russians focused on sea otters, fur seals and foxes for fur; occasionally they would obtain whalebone (baleens) and walrus tusks as well. Sea otters went to China (through Kiakhta), high quality foxes went to Constantinople (now Istanbul), and fur seals were sold to the lower Russian classes (Tikhmenev 1861; Okun 1951).

[xvi] By 1795 only three Russian merchants operated in Alaska with multiple companies: Shelikov around Kodiak, Fiselev along the Aleutians and Lebedev in Chugatsk Bay. Each had established hunting grounds, yet the search for new ones always caused disagreements among for the companies (Black 2004).

Indian Company. It successfully negotiated three charters of 20 years each (Tikhmenev 1861). It was a private enterprise in charge of trade and served as the *de facto* local government. The Russian government was only involved indirectly through its board of directors. However, unlike the independent fur hunters who had no competition at the start-off, the company faced the established American and British trade, and its monopoly on fur trade was only within Russia[xvii]. The same lack of serious European opposition[xviii] to Russian colonies in Alaska allowed the American traders to flourish[xix]along the American northwest coast (Gibson 1987).

Under the Freedom of the Seas doctrine, waters 3 miles off the coast were considered international waters[xx]. James Cook's maps of the northwest coast[xxi] were widely distributed (Hayes 2002), and the stories of the high prices obtained by his crew in exchange for sea otter furs at the port of Canton were highly publicized (Haycox et al. 1997). In the late 1780s, Alaskan waters were visited by Spain, the United States, England and France[xxii] (Black 2004). Only British and American had continued sailing along the Northwest coast trading with the natives for furs (Malloy 1998)[xxiii], eventually flooding the Chinese market and causing prices to fall (Gibson 1992; Black 2004)[xxiv].

The Russians reacted to competition by increasing the number of settlements[xxv] (Okun 1951; Black 2004). However they lacked the naval capacity to fend off traders and the advance of independent American whaling vessels, even from their territorial waters

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[xvii] The RA Co. held the fur trade monopoly until 1857.

[xviii] Back in Europe, the Napoleonic wars went on from 1800 to 1815

[xix] American traders were more aggressive, they needed alternative markets to those they had lost in Europe after their independence from England.

[xx] The extent of "territorial waters" was not defined but 3 miles was of general acceptance (Bean. 1983).

[xxi] This was James Cook's third and last voyage. In search of the Northwest Passage, he mapped the North American coast from California to Bering Strait. Cook's maps were widely distributed and hence many of the English names prevailed over the earlier Russian names (Hayes 2002).

[xxii] Spain was alarmed by the Russian advance as it had colonies in Mexico, the United States had trading purposes, England was interested in exploration and trade as was France

[xxiii] in 1788 alone some 6, 600 sea otter pelts were sold in Canton by the English (Berkh 1823).

[xxiv] Russia was unsuccessful in its attempt to expand trade into the port; China did not allow it and so while British and Americans traded at Canton, Russia continued trading at Kiakhta, a much longer and harder route (Gibson 1992, Black 2004).

[xxv] Kodiak was founded in 1784, Afognak in 1786, another in Unalaska (Okun 1951; Black 2004).

(Figure 1.4). Moreover, the lack of provisions for the numerous permanent settlements[xxvi] from Amchitka and Adak to SE Alaska made the company *dependent on* the American/British trading vessels and the natives[xxvii] (Gibson 1987). The company had gained domain over the land in Alaska, but at sea the independent American whalers and traders prevailed.

The first right whale killed at Kodiak (Gulf of Alaska) in 1835 marked the beginning of American commercial whaling in Alaska (Starbuck 1878). Hunting grounds extended east to the nearby Fox Islands (eastern Aleutian Islands) where right whales[xxviii] were commonly seen (Shelden et al. 2005). After only five years (1840) there were at least 250[xxix] American vessels whaling, fishing, and fur hunting in seas which fell under the jurisdiction of the Russian American Company (Alekseev 1990). Ten years later, in 1845, catches deteriorated markedly (Bockstoce 1986) but the discovery of bowhead whales[xxx] in the Arctic and Bering Sea grounds gave rise to a second whaling surge[xxxi]. This allowed the American fleet to continue hunting in Alaskan waters until 1914 and prolonged its activities in the eastern Aleutians (Bockstoce 1986).

[xxvi] By 1820 the company had 15 permanent settlements, stretching as far south as Fort Ross in California (Berkh 1823, Okun 1951)

[xxvii] The dependence on native Alaskans was stark: young men would go to work on as many as 750 canoes along the mainland and islands. Women would stay to clean fish, sew parkas, pick berries and dig martagon; children and older men were sent hunting for birds (Okun 1951). Russians even depended on trading vessels to conduct some of fur trading (Gibson and Pinther 1976)

[xxviii] Tønnessen and Johnsen (1982) report humpback and gray whales were also hunted in the Gulf of Alaska region. The Aleutian Islands are not explicitly included but later whaling activities at Akutan (Bureau of Fisheries 1914-1939) and records from the IWC (Sally Mizroch, pers. comm.) show these species could have been hunted in the eastern Aleutians as well.

[xxix] The whaling fleet was fully developed and had already depleted the sperm whale stocks in the Pacific from 50°S to 40°N (Bockstoce 1986).

[xxx] On average, each bowhead whale yielded 100 barrels of oil and 1,500 lbs of baleen. Whale oil was used for illumination and lubricants while baleens were used for skirt hoops, corset stays and buggy whips. Flexible and resilient, baleens were the only material available similar to the more modern spring steel, celluloid and flexible plastics (Bockstoce 1986).

[xxxi] by 1860 the number of whales hunted by the Americans reportedly left the natives with only the flesh of dead whales cast ashore (Alekseev 1990).

Poor fur processing[xxxii]techniques and management plagued the Russian American Company. It lost 800,000 fur seal skins the first years, and had subsequent losses in 1810-13 including skins burnt on purpose because of their low prices[xxxiii] (Okun 1951; Tikhmenev 1978). Oversupply, spoiled skins and population decline prompted the board of directors to temporarily ban fur seal hunting[xxxiv], set maximum quotas and restrict catch to males ages 3 to 5[xxxv] (Tikhmenev 1861; Okun 1951; Black 2004,). These reactive conservation measures proved insufficient and the herd hit its lowest point under Russian jurisdiction in 1834. Catches were brought down even further[xxxvi].

The company introduced foxes to the central and western Aleutians[xxxvii] in 1828 to offset the losses. It also diversified, exporting land mammals and other fox furs[xxxviii]. The substantial decline of sea otter populations in the western Aleutians prompted the company to move out the settlements from Amchitka to Adak (1828-1850) (Black 2004). These efforts prevented the extirpation of sea otters in those islands

The Crimean War in the mid 1850's made Russia's position in America untenable. Moreover, the United States was expanding its territory[xxxix]. Overall, catches declined steadily during the company's lifetime. Sea otter catches fell from 73,000 furs to 25,000 and then 19,000 during the 1st, 2nd and 3rd charter respectively[xl]. The Russian American Company operated from 1799 to 1864, and shipped to Russia a total of 1,678,000 fur seal skins, 117,000 sea otter pelts, and 128,000 fox furs, all of them

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[xxxii] The short summer precluded adequate drying of all the furs, and "heated baths" were set up with poor results. Skins would either burn or be fire fanged, which caused the hair to fall off.

[xxxiii] Okun (1951) and Tikhemenev (1978) report skins were burned at Unalaska, Irkutsk and Okhotsk.

[xxxiv] from 1804 to 1808 only.

[xxxv] Catches were a maximum of 40,000 skins, males were 3-5 years old.

[xxxvi] 10,000 skins. year

[xxxvii] Andreanof and Rat Islands

[xxxviii] Land mammal furs were presumably exploited throughout the operations of the RA Co. but catch records are incomplete after 1822. Over 2,500,000 land mammal furs and other fox furs between obtained between 1799 and 1822

[xxxix] Louisiana was purchased in 1803, Lewis and Clark reached the West coast in 1806; Mexico ceded the Californias and Texas after the Mexican-American War in the 1840's (Faragher 1999).

[xl] Charters ended around 1820, 1840 and 1860, respectively.

largely obtained during its first charter[xli] (Figure 1.5). By the time the third charter came to its conclusion in 1861, the company faced strong criticisms[xlii]: sea otters had been continually in decline, furs were processed badly and were only accepted unprocessed in the European market, whaling was done by the Americans, and fishing was done for subsistence only. Aggravating these circumstances was Russia's lack of means to defend the colonies in the event of war, and so in 1867 the American colonies were sold to the United States in the Alaska purchase (Berkh 1823; Tikhmenev 1861; Okun 1951; Black 2004). The U.S.-Russia Convention Line of 1867 delimits the Aleutian Islands east and west of 170°E, so the Commander Islands (easternmost portion of the Aleutian Archipelago) remained under Russian jurisdiction.

1.4.4 1867-1940: Transition period

Pelagic sealing and offshore whaling

Discounting the Russian experience, American fur seal hunting was unrestrained the first year (1868) and 140,000 animals were killed on the Pribilof Islands. The U.S. Treasury Department intervened, leased the hunting rights to a private company[xliiii] and imposed the Russian practice of selecting individuals by sex and age (Riley 1967). Just like its predecessor, the U.S. did not have control over the offshore waters and as whaling vessels took on fur trading to offset declining catches, fur seal hunting shifted from land-based to pelagic operations. The pelagic hunting extended from around the Pribilof Islands to the Aleutian passes and the waters of the Gulf of Alaska (Bockstoce 1977; Jordan 1898). By the end of the first lease (1870-1889) pelagic sealing was

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[xli] British and Americans experienced the same decline on furs as the Russians, however Americans did not restrict themselves to furs alone, they catered to the needs of the natives, the Russians, and Chinese (e.g., silver, opium, furs, and ginger) expanding their commercial niche (Christman 1984, Gibson 1992).

[xlii] Okun (1951) summarized the development of the company: "In the 1st period of the company's existence there was plenty of peltry but no order, the second there was more order but less peltry and in the third one there was perfect order but the treasury was empty".

[xliii] The assets of the Russian American Co. were bought by the Hutchinson, Kohl & Company, subsequently the Alaska Commercial Company and later the Northern Commercial Company. The Alaska Commercial Company was granted a 20 year lease with an annual quota of 100,000 skins.

taking around 30,000 seals per year (Figure 1.6), one fourth of the estimated total catch. In the 1890s pelagic sealing increased to 40,000 and 60,000 seals[xliv] (86 percent of the catch) despite the Fur Seal Arbitration Tribunal banning pelagic sealing within 60 miles from the Pribilof Islands and the Act of Congress in 1897 banning pelagic sealing to all American vessels and citizens (Anonymous 1907)[xlv]. The arbitration increased effort south, towards the Aleutian passes and Gulf of Alaska, where fur seals herds could be found on their way to the Pribilofs. Pelagic sealers came from east and west as Canadians and Japanese[xlvi] continued to take seals in the water. The stock declined from an estimated 1,000,000 in 1891 to 185,000 in the early 1900s (Fur Seal Investigations 1896; Anonymous 1907). Scientific opinion was split as to the cause of the decline, some blaming the land based practices and others the pelagic catch; the issue became a highly publicized international affair. Bilateral agreements were set in place in 1893 and 1894 between Russia and Japan as well as between Russia and the U.S. However it was only after multiple negotiations that Japan, Russia, the United States and Great Britain (for Canada) accepted the North Pacific Fur Seal Convention of 1911[xlvii]. Pressed by conservationists[xlviii], the United States issued a moratorium in 1913 which was argued by some scientists to imperil the subsistence of the herd by compelling the pelagic sealing nations to reopen activities after being cheated out of their share of seal skins. The moratorium, another example of reactive conservation, lasted 5 years. The scientific debate was unresolved, and the recovery of the herd was

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[xliv] and comprised 84,, and surpassed the catch of the North American Commercial Company which was only able to take roughly between 14,000-20,000 fur seals annually throughout its contract (1890-1910) (Riley 1967).

[xlv] Although there were no rookeries or haul outs in the Aleutians islands, the fur seals had to go to through the passes to reach their breeding grounds in the Pribilof Islands. Pelagic sealers frequented the passes as shown by a sealer's notes recording plentiful seals with Akutan Island in sight. Other locations are mentioned at 167W and 54°38'N (just north of Dutch Harbor). Seals caught were usually "sleepers" (sleeping seals), sometimes "finners" (half asleep, scratching themselves) but not really "travellers" (moving in various directions and hard to get with spears, natives didn't go for them, white men do and get some *sic*) (Jordan, 1898)

[xlvi] Japanese joined in 1901.

[xlvii] Japan and Canada accepted to stop pelagic sealing in return for 15% each of the land killings in Russian and American rookeries. Pelagic sealing was banned except for native subsistence purposes.

[xlviii] Scientists Henry W. Elliot and William T. Hornaday worked with the conservation group Camp-Fire Club of America.

and is still considered one of the biggest victories of conservation efforts and management (Hornaday 1920, Jordan 1913, 1920, Riley 1967).

The whaling industry did not participate on pelagic sealing at first and was primarily in the Gulf of Alaska, Bering Sea and Arctic grounds. Bowhead whales had been depleted very quickly, but whaleships had taken walruses from 1859 to 1878 to make the trip worthwhile (Bockstoce 1986). By the time whale catches in Kodiak were rare, the Aleutian Islands were visited frequently as ships had to enter the Bering Sea through the passes[xlix] and get provisions (Starks 1923; Tønnessen and Johnsen 1982). Whale oil prices declined[l], but those of whalebone for the fashion industry and multiple other purposes consistently increased[li] . This, combined with cheaper shipping costs[lii], allowed whaling to continue (Bockstoce 1977). In 1880, offshore whaling had a third boost with the inception of steam whaling[liii] and later a final boost with the entrance of schooners[liv] to the fleet. Dutch Harbor became a frequented port, as passing steam whalers would get coal, supplies, and catch and salt cod (Bockstoce 1977). It is in this last phase that fur trade became an additional incentive for the schooners, when furs offset the losses from the declining baleen catches (Bockstoce 1977). Whaling in the western Arctic ended in 1907 but by then pelagic sealing had long become a worthwhile pursuit on Alaskan waters. American whaling profits were substantial despite the losses. From 1835 until after the Alaska Purchase, the

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[xlix] Both Seventy two Pass (Amukta Pass) and Unimak Pass were used. Initially, ships went north via the Hawaiian Islands to avoid San Francisco and the loss of sailors to gold mining. Once the gold fever passed, and with the railroad, captains went north along the coast to the arctic grounds, catching sperm whales on their way (Starks 1923, Tønnessen and Johnsen 1982).

[l] In 1861 oil wells were discovered in Pennsylvania, giving rise to kerosene oil (coal oil) and subsequently changing the primary use of whale oil from lamp oil to lubricants (Bockstoce 1986). In addition, an average of 6 ships a year were lost to war or ice in the Arctic. The North Pacific fleet – vessels operating in the Gulf of Alaska and the Okhotsk, Bering and Chukchi Sea– shrank from 59 to 17 vessels (Bockstoce 1986).

[li] After the civil war (1861-65) fashion industry was the main user, prices rose and the whaling industry turned increasingly to the bowhead fishery in the North Pacific and Arctic (Bockstoce 1977).

[lii] the completion of the transcontinental railroad in 1869 allowed whale products to be shipped cheaper and faster to the refineries in the East (Bockstoce 1986).

[liii] the first steam whaler came back having caught 27 bowhead whales, there was a second wave of activity in the arctic grounds (Bockstoce 1977).

[liv] In the late 1890's schooners (small whalers) entered the fleet, lowering operating costs (Bockstoce 1986).

northwest coast whaling grounds produced 60 percent of all the oil secured by the American whaling fleet (Kushner 1972).

An amendment to the North Pacific Fur Seal Convention also ended the international hunting of the nearly extinct sea otter, which had been recognized on the brink of extinction as early as 1895 (Dall 1896). The Act of 1911 had approved protection of the seals, sea otters, and fur bearing mammals in Alaska. The sea otter hunting had increased concurrently with pelagic sealing[lv] (Figure 1.6) (Bureau of Fisheries 1906), and by the time the Convention was signed, the total number of sea otters was estimated between 1,000 and 2,000. Although both sea lion and walrus were also reported nearly extinct at this time, no law was issued to specifically protect either one specifically. Offshore whaling (the industry behind walrus hunting) had ended (late 1800s) and sea lions were hunted by native Alaskans only. The Pribilof Islands had been named a Reservation in 1869, but this did little to prevent walrus hunting during the whaling era. Similar to the Russian's observation on the impact of whaling on native Alaskans (Alekseev 1990), the U.S. Bureau of Fisheries (1906) noted they were the most affected by the depletion of sea lions, as the native Alaskans' dependence on this particular resource was heightened by the scarcity of other once abundant marine mammals.

Fox farming and shore-based whaling

Subsequent commercial activities in the Aleutians in the first half of the twentieth century focused on fox farming, whaling and nearshore fisheries. Little information exists as to the furs produced by fox farming, except that introductions were restarted and the activity peaked from 1913 to 1940. The farming of foxes was encouraged despite an early warning by Turner (1886) in the 1870s about the decline of seabirds due to foxes. Making matters worse, ground squirrels were introduced to serve as food for foxes. All this happened after the Aleutian Islands (including Unimak and Sannak)

[lv]) From an average of 1,000 furs per year during the last forty years of the Russian American Company to 4500 per year throughout the 1880s and 1890s. Native Alaskans did the hunting; the Americans did the trading and the furs were sold in London (Bureau of Fisheries 1906).

had been declared a Reservation in 1913[lvi] to preserve breeding ground for native birds, promote propagation of reindeers and fur bearing animals, and encourage the development of fisheries. The same year saw a bill passed in which the take of fish, whales or other by non-US citizens[lvii] were prohibited in Alaskan territorial waters, at the time defined as three miles from shore. Alaska had just become a territory of the United States and the bill's purpose was to take official claim of the marine resources in the adjacent waters.

Norwegian companies interested in whaling[lviii] were directly affected, as the boats had to be registered in the U.S. and fly the American flag[lix]. A shore station was built in Akutan[lx] (eastern Aleutians); with operations lasting from 1912 to 1939 (Tønnessen and Johnsen 1982). Only in 1913 and 1921 did the shore station report no activity[lxi]. During its operations some 10,181 whales were caught at Akutan[lxii], mostly those with neritic (coastal) affinities: 37% humpbacks, 37% fin whales, 13% blue, 9% sperm, and 0.5% sei whales and the remaining 3% were beluga whales caught in Cook Inlet. Gray and right whales, once abundant, were rarely taken (Figure 1.7) (US Fisheries Bureau 1912-1939). Blue whales vanished from the east and western Pacific and only the south of the Aleutians[lxiii] sustained an average annual catch of 50 animals up until 1930. With the introduction of floating factories in the 1920s, Japan initiated pelagic whaling off the Aleutians; however these catches were outside the 3 mile limit and hence there are no records of these early catches[lxiv] (Tønnessen and Johnsen 1982). In

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[lvi] Designated by Executive Order in March 3 1913.

[lvii] Except for native Alaskans.

[lviii] The companies had dispatched "explorers" to reconnoiter the entire coast from Queen Charlotte Islands to the Bering Strait, including the Aleutians. Two Norwegian companies were formed –United States Whaling Co. and, the Alaska Whaling Co (Tønnessen and Johnsen 1982).

[lix] Marine operations were considered American coastal shipping (Tønnessen and Johnsen 1982).

[lx] by the Alaska Whaling Company

[lxi] Reconstituted in 1913 as North Pacific Sea Products Co. (Tønnessen and Johnsen 1982).

[lxii] The whale catch composition mirrored the take in shore stations at San Francisco; both humpback and fin whales migrate closer to the shore and hence were more accessible to shore-based stations (Starks 1923)

[lxiii] Blue whales were seldom encountered north of the Aleutians.

[lxiv] This changed in 1937 when an international treaty for the regulation of whaling required the biological information of the catch to be given to the International Bureau for Whaling Statistics (Tønnessen and Johnsen 1982)

1939, with the threat of World War, the facilities in Akutan were sold to the U.S. Navy, and the shore-whaling industry came to an end in the Aleutians[lxv].

Fishing

Formal commercial exploitation of fish stocks in the eastern Aleutians region started in 1906 when cod stations were opened at Unga, Sannak and Unimak Island by various companies[lxvi] (Bureau of Fisheries 1907). Vessels moved to the Alaska Banks of the Bering Sea, to south of Unimak Island, and around the Shumagin Islands to offset the end of cod fishing off the Russian coast after the 1909 season. Cod were to be found almost everywhere in the banks with less than 100 fathoms of water. The fishery operated from the permanent shore stations and was based primarily in harbors[lxvii] (Shields 2001). Overall, the Pacific cod fishery peaked during WWI when estimated annual catches ranged from 12,000 to 14,000 metric tons. Later, in 1915, there was an unexplained change in the migration pattern of cod, the fish began to disappear from harbors and a portion of the fishery moved outside the harbors (Shields 2001). The inshore winter fishery gradually declined after 1920 and ended in 1930. The rest of the fishery declined later due partly to cod deliveries by Japanese vessels and poor quality processing, which made the end product inferior to that of the East Coast. The fishery was terminated in 1950 (Dall 1896; INPFC 1979; Bakkala 1981; Shields 2001).

Most fishing stations opened in 1916 throughout the eastern Aleutians, the exception was the shore station based in Attu (western Aleutians) where mackerel and greenling were caught. Salmon canneries opened in the eastern islands of Unalaska and Umnak. Their success was limited and permits to keep stations open at the islands were not

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[lxv] Lack of success discouraged other companies from catching in the North Pacific and turned their attention south. High prices for whale products during WW I encouraged unsuccessful attempts to establish a stable catch in Alaska. The sales of canned and frozen meat never caught on, except for the wartime period. The only moderate success of whaling at Akutan was in part due to the overall decline of whale stocks in the Pacific. Hunted all along their migratory route from California to Canada and the Gulf of Alaska, only the few surviving individuals made it to the eastern Aleutians (Webb 1988).

[lxvi] the Alaska Cod Fish Co., the Seattle-Alaska Fish Co. and the Union Fish Co.

[lxvii] The summer season took place on the offshore banks, and fishing was conducted from schooners carrying small boats (dories) (Shields 2001).

renewed[lxviii]. The total 1916-1939 salmon catch from the Eastern Aleutians was only 5,521 metric tons[lxix] with a peak in 1924 of 1,803 metric tons (Bureau of Fisheries 1906-1939). The halibut fishery had extended to Dutch Harbor after successive depletion from banks all the way from Oregon to the Gulf of Alaska, but catches in the Aleutians were minor[lxx](Adams 1935; Fiedler 1940; Russell 1943). The Convention for the Preservation of the Halibut Fishery of the Northern Pacific Ocean was signed on March 2, 1923 and the U.S. and Canada signed a bilateral agreement to regulate salmon catches in 1930. Later in 1953 regulatory areas were established however it was not until 1966 that the Aleutians were included in an explicit regulatory area[lxxi]. A purse seine fishery for herring developed in the vicinity of Unalaska. Catches peaked in 1932 at 2,277 metric tons and ranged between 1,000 and 2,000 metric tons until 1937. From then on catches declined until the fishery was abandoned in 1946 (INPFC 1979, Bakkala 1981).

While the American vessels stayed in nearshore/eastern areas[lxxii], foreign fleets exploited the offshore/eastern grounds. Japan had developed a self sufficient fleet of motherships, and had the capacity to fish salmon and halibut in the high seas (i.e., outside territorial waters). However, in order to avoid conflicts with the United States over the catch of salmon or halibut (the main U.S. Alaska fisheries at the time), Japanese confined their catches to crab and the fish meal industry in which the U.S. fishing industry had no interest (Barnes 1936, Fielder 1940). From 1933 to 1939 crab was caught north of Umnak and the fleet worked its way eastward along the north coast of the Alaska Peninsula (Parker 1974). The Japan-U.S. conflict over salmon raised quite a controversy over the "ownership" of salmon stocks and access rights. Alaska was the primary supplier of manufactured fishery products and catches in

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[lxviii] Catch varied greatly from year to year. Catch was null for several stations between 1916 and 1927.
[lxix] Mostly pink salmon.
[lxx] 90% of the catch from Cape Scott to Cape Spencer and between Middleton Island and the Shumagin Islands. The rest mostly form between Cape Spencer and Middleton Island (Adams 1935, Fiedler 1940).
[lxxi] Regulatory areas in the Aleutian Islands have changed since.
[lxxii] Shore stations, except for whaling, were minor compared to the rest of Alaska. The Great Circle route from the North Pacific to the Orient passed below the archipelago for good reason. Many ships were lost among the Aleutians' "treacherous channels"; no navigational aids were available from Dutch Harbor to Attu; charts were inadequate and unreliable despite hydrographic surveys (Seeman 1937).

Bristol Bay were higher than those at Japan's fishing zones[lxxiii]. The conflict was characterized as one between conservation (on the U.S. side) and advancing techniques (Japan's motherships). The fact that Japan restricted motherships from fishing off Kamchatka for fear of damaging its own shore-fishing operations (Barnes 1938) did little to appease concerns with regard to the future of Alaska fisheries. The onset of World War II brought a temporary halt to Japan's fishing fleet expansion[lxxiv], but the controversy between conservation and advancing techniques would resurface later.

During World War II the Supreme Command Allied Powers limited fishing to coastal waters. Furthermore, Attu and Kiska were occupied by Japan, and recovered by the U.S. in 1943[lxxv]. Overall, pelagic fishing during World War II was restricted to a minimum in the Aleutian Islands (Mathieson 1958). Japan was constrained to fish inside the MacArthur line until 1952 where upon fishing resumed on the North Pacific (Miles et al. 1982).

1.4.5 1945 – present: Increased foreign exploitation of western/ offshore grounds outside US territorial waters and the passage of the Fishery Conservation and Management Act.

After World War II, whaling and fisheries by foreign fleets expanded to waters right outside the territorial waters off the Aleutian Islands and reached unprecedented catches. Control over these resources was gained through the passage of the Fisheries Conservation and Management Act in 1976. Joint foreign/American ventures followed in the 1980s and fisheries became fully American by 1990.

1.4.5.1. Whaling

Whaling was the first fishery to be reactivated in Aleutian waters. The International Convention for the Regulation of Whaling of 1946 was signed by the U.S., Canada

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[lxxiii] off their home coast or off Siberia (Kamchatka).
[lxxiv] All vessels were pressed into military service and destroyed in war.
[lxxv] Aleuts were evacuated to prevent their capture.

and the Union of Soviet Socialist Republics (U.S.S.R.) among others. Japan joined in 1951 (IWC 2006) when it planned on extending its whaling grounds eastwards in the North Pacific. The signatories agreed on the establishment of the International Whaling Commission (IWC) to regulate catches. After 1952 Japanese factory ships expanded catches to the south coast of the western Aleutians[lxxvi]. The total catches in the Aleutians increased steadily from two hundred tons in the early 1950s to over 4,000 tons by the end of the decade (Figure 1.8). Soviets subsequently increased effort substantially[lxxvii] in the North Pacific, and by 1963 had a whaling fleet of 37 vessels. Baleen whales were half or less of the catch[lxxviii] while sperm whales made up the rest of it (Figure 1.7). Japanese and Soviet Union fleets operated freely in the North Pacific until their increased effort and the decline of Antarctic catches caught the attention of the IWC. By this time, global regulation was needed for both shore and pelagic whaling. The Scientific Committee of the IWC requested to limit humpback and blue whales catches in 1965[lxxix] and asked for their complete protection in 1966. This restriction, however, had little effect on the whaling activities around the Aleutians. The catch of humpbacks and blue whales rarely exceeded 200 individuals and comprised less than 10 percent of the catch throughout the archipelago. Sperm whale, followed by fin and sei whale were caught in the central and western Aleutians[lxxx] while fin whales prevailed in the eastern islands. (Figure 1.8, Table 1.4). The whaling fleets operated offshore, seldom within 30 km of the coast (Merrel 1971). Catches north of 50°N ceased after 1972, although globally stocks kept declining until a moratorium[lxxxi] was set in 1982 (Tønnessen and Johnsen 1982, IWC 2006). Failure of international agreements to restrain whale catches pushed the implementation of one of the most comprehensive conservation laws in the United States: the Marine

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[lxxvi] besides Boning Islands, and along the east coast of Kamchatka.

[lxxvii] There was only one whale catcher from 1932 to 1961

[lxxviii] Baleen whales catch shifted east, to the Gulf of Alaska. By now blue and humpbacks had been heavily exploited but no concrete regulation was submitted by the Pacific Committee and none was dealt with by the IWC. The Convention of 1945 was concerned mostly with pelagic whaling in the Antarctic.

[lxxix] to those in 1964.

[lxxx] In 1967, the catch in the NP was higher than in the Antarctic. Only 25% of the sperm whales were caught in the Antarctic compared to 63.3% in the North Pacific.

[lxxxi] on commercial catches

Mammal Protection Act (1972). The far reaching umbrella of this law established the legal grounds for many of the conservation and management actions of fishery-related resources in place today (Bean 1983).

1.4.5.2 Foreign fisheries

Paralleling the trend in whaling activities, foreign fleets expanded their operations to waters right outside the territorial limit of the U.S, encroaching into the eastern Bering Sea and the western Aleutians. Japanese had started fishing for salmon near the Aleutians in 1952 when it extended its salmon gillnet fishery eastward to the western islands. The International North Pacific Fisheries Convention was signed by Canada, the U.S. and Japan in 1953[lxxxii]. By 1955 the Japanese fleet was in full recovery[lxxxiii] with 12 independent flotillas operating in the Aleutian area (Mathieson 1958). Meanwhile the U.S. fleet operated west of Unimak Pass[lxxxiv]. Pink salmon was the primary species (>90 percent) caught in the Aleutian Islands area and were taken almost exclusively in the bays of Unalaska (INPFC 1979). Alaska had gained statehood in 1959, and this transferred government of the coastal fisheries from the federal to the state government. The Treaty established the division between Japan and Canada/U.S. areas of fishery and fisheries conservation with Japan restricting activities east of 175°W. Towards the west, fishing activities were regulated by a Treaty between with the U.S.S.R. and Japan. This left fisheries beyond the 3 miles limit in the central and western Aleutians effectively outside U.S. jurisdiction and open to Japanese, Russian and other foreign fishing fleets (Merrel 1971).

The year 1960 marked the operation of the Japanese and Soviet fishing fleets in full force in the Aleutian Islands (Figure 1.9). They were later joined by Korea (1967), Taiwan (1974) and Poland (1979) (Bakkala 1981). The initial targets were Pacific

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[lxxxii] This was a few years after Japan had resumed whaling in the North Pacific

[lxxxiii] Japan's vessels had been pressed into military service and subsequently destroyed. It seemed economically sound to let Japan resume fishing in the areas it had expanded to before WWII. Grounds were used by other nations and food shipped to Japan was an expense to Allied nations. Japan's self-sufficiency was desirable. It was acknowledged the expansion should be regulated, given the intensive use of resources by the Japanese fleet in the past (Espenshade 1949).

[lxxxiv] only purse and hand purse seines were used until 1976.

Ocean perch[lxxxv] and walleye pollock, but soon expanded to sablefish and Greenland turbot (1963), Pacific cod (1964) flatfish[lxxxvi] (1970), and Atka mackerel (1972). Maximum total groundfish catches occurred early in 1965 when almost 112,000 metric tons were taken, mostly Pacific Ocean perch off the central and western Aleutians[lxxxvii] (Merrel 1971). Pacific Ocean perch remained the primary target until the 1970s when the stock declined and catches comprised only about a third or less of the total harvest in the region. Between 1973 and 1977 total catches were below 50,000 metric tons (Bakkala 1981) (Figure 1.10).

Meanwhile the American fleet started fishing for Red king crab off Adak[lxxxviii] and Dutch Harbor in the central and eastern Aleutians respectively (NPFMC 2005). Shortly after, in 1964, the U.S. ratified the UN Convention of the Continental Shelf and designated both king and tanner crabs as shelf creatures; bilateral agreements were concluded with Japan and the USSR. The Soviets remained in the fishery until 1971 and the Japanese until 1974. Meanwhile the U.S. crab fishery developed rapidly during the 1960s and was securing half the catches by the early 1970s. With both Japan and the Soviets out of the grounds, the fishery was fully domestic by 1975, only this did not prevent the overfishing of crab stocks. Originally targeting red king crab, the fishery gradually switched to golden king crab which by the early 1980s comprised most of the catch, albeit the volume was never as high as for red king (Otto 1981). At its peak, the combined catch of red king crab from Adak and Dutch Harbor was over 17,000 metric tons per year (Figure 1.11).

1.4.5.3. Joint ventures and American fisheries

In response to foreign exploitation rates in waters adjacent to its 3 miles limit the U.S. was in favor coastal nations asserting full management of waters to 200 miles offshore. The U.S. passed the Fishery Conservation and Management Act in 1976

[lxxxv] POP complex included red rockfish: POP, northern, shortraker, sharpchin, and rougheye rockfish.
[lxxxvi] Not halibut
[lxxxvii] catches taken at Andreanof, Rat and Near Islands, Seguam Pass, Tahoma Reef and Stalemate Bank
[lxxxviii] Fishery in Adak started 1961 (Merrel 1971)

(FMCA) which established the Fishery Conservation Zone (FCZ) from 3 to 200 miles offshore[lxxxix]. Its objective was to rebuild depleted groundfish stocks, achieve and maintain an optimum yield for the various fisheries and "Americanize" the foreign fleets. Foreign countries were allocated quotas[xc] based on their contribution to develop the domestic industry, and so the groundfish fisheries went through a period of joint ventures that lasted through the 1980s (Figure 1.12). These ventures shifted foreign involvement from the fleets to investments in shoreside processing and destination markets.

During the 1980s groundfish catches increased back to over 100,000 metric tons. Joint ventures successfully increased U.S. fisheries. A domestic processor operation for Pacific cod was carried out in the southeast Bering Sea; U.S. vessels fishing for pollock, cod and yellowfin went into joint ventures with the USSR and Korea; Japan's new shipboard methods[xci] to produce surimi at sea rapidly increased the pollock fishery (Bakkala 1981). The pollock fishery had peak catches in the Aleutians during the 1980s[xcii]. By 1990 the fleets were domestic, and total catches remained in excess of 150,000 metric tons throughout the decade. In 1999 the pollock fishery was severely restricted due to concerns regarding the fishery's impact on Steller sea lion (Barbeaux 2004). Since then, total groundfish catches have averaged slightly above

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[lxxxix] As international fleets expanded fisheries off territorial waters of other countries, concern grew regarding the massive exploitation carried out by nations with highly mechanized fishing fleets and large factory ships (Heinzen 1959). The Geneva Convention of 1958 established as a states' duty to implement adequate conservation measures of living resources in the high seas, yet it did not set an overall extension for the territorial waters. Distances of 3 and up to 12 miles were accepted and customary (Bishop 1962). In 1976 the United States, through the Fishery Conservation and Management Act (FMCA) Act established the Fishery Conservation Zone (FCZ) from 3 to 200 mi offshore, a move later adopted by the international community through the Convention of 1982 which established the Economic Exclusive Zone of coastal states. The FMCA was largely prompted by the perceived need to conserve and assert possession over the extensive fishing grounds off Alaska.

[xc] Having full management over fisheries in the 200 miles zone also enabled the use of access to fisheries resources as a means to exert influence on political negotiations and retaliatory restrictions on international trade. The USSR allocation was decreased in retaliation for Afghanistan invasion; Japan's domestic market was opened to U.S. groundfish imports in exchange for undiminished catch allocations for its fishing fleet within the U.S. FCZ (Crutchfield 1964, Stokes 1981).

[xci] The improvement followed the decline of yellowfin sole in 1963-65 in the eastern Bering Sea.

[xcii] Preceded by a peak in the EBS during the early 1970's.

100,000 metric tons and are roughly 50% Atka mackerel, 30% Pacific cod and 15% Pacific Ocean perch.

1.5 DISCUSSION

In this section I integrate the spatial and temporal aspects of the marine environment and fisheries of the Aleutian Islands. One provides evidence of ecological and oceanographical processes which might affect population trends/ growth/ feeding habits, with implication for fisheries management. The second provides the extractive history of an area, hinting at past baseline abundance and distribution of the populations. Without these quantitative records of extractions, perspective on the current level/trend of a population is lost. I discuss the benefits and drawbacks of the current management boundaries and their future use in an FEP for the Aleutian Islands.

1.5.1 Consideration of environmental and historical boundaries for the Aleutian Islands FEP

Historically, the western, central and eastern Aleutian Islands have been subjected to different exploitation regimes. Spatial explicit information is very scarce, and here it has been compiled from several databases and individual records. The data on marine mammals was extracted from records to and databases to reflect information exclusively for the Aleutian Islands. The western islands were the first to be exploited, with a hiatus from the purchase of Alaska in 1867 to the 1950s when foreign fleets started whaling and fishing in the region. In contrast, the eastern islands have remained consistently under exploitation since the establishment of the Russian colonies in the 1760s. The state of Alaska initially kept detailed records for activities in the Aleutian Islands –separate from the rest of mainland Alaska. With the overwhelmingly higher catches of salmon and other species in the mainland, the Aleutians were promptly grouped as one large area appended the Alaskan Peninsula.

Since then, catch records in the eastern Aleutians have remained combined with catches from the EBS and/or GOA.

Why should we care about all these imaginary, mostly political lines? The problem with imaginary lines is we make them real by attaching historical catches to a given area, and by allocating quotas within their boundaries, making them our main feedback with what lies beneath. The larger the area, the larger the time scale of our feedbacks (Wien 1989), and with slower feedbacks the more the natural communities from which we obtain goods cease to have a tangible meaning and reference, ultimately becoming a literal <<stock>> from which supplies are retrieved. Assuming the political will or stewardship is such that it encourages prompt action, having a higher spatial resolution cuts the feedback loop by identifying local depletions/changes which happen in a shorter time frame.

Ecological boundaries

The review of the marine environment shows evidence of three biogeographical boundaries. The first is located between 169°W and 170°W, coinciding with Samalga Pass, the first deep pass (>200m) from east to west along the islands. The body of evidence for this boundary is oceanographical, ecological and climatological. Support for a second biogeographical boundary at 180°W (Amchitka Pass) is restricted to ecological evidence from seabirds, sea lions and fish, with no oceanographic or climatological information available to support it. The breadth of species showing changes east and west of the pass, suggest this boundary might be legitimate at least within the top 400 m. The least support available is for a boundary at Buldir Pass, where modest evidence is available from nearshore seabirds linked to the relatively extensive shelf in the westernmost islands and declining fish species diversity west of the pass. Most fish species present west of Buldir are distributed at least to Samalga Pass. For species spreading from the Kurile province the biogeographical boundary would seem to be Near Strait, the stretch between the Commander Islands and Near Islands, not Buldir. Buldir in this respect would seem to be a one directional boundary.

However, because nearshore seabirds are also found on the western Bering Sea, it is hard to determine which populations the nearshore birds are coming from and whether Buldir may be acting as a boundary from east to west for nearshore seabirds coming from the east, past which shelf areas are very limited. The distance between Buldir and the Commander Islands is less than that from Buldir to the Alaska peninsula. In any case, there seem to be at least two moderately well defined biogeographical boundaries and a third weak or potential one.

Management boundaries

The most significant current management boundaries in the Aleutian Islands are the ones set by the North Pacific Fisheries Management Council. The Aleutian Islands regulatory area is defined west of 170°W, which includes the central and western islands. It is further subdivided into 3 statistical areas with breakpoints at 177°W and 177°E. The islands between 164°W and 170°W fall within the Eastern Bering Sea (northern portion) and GOA (southern portion) regulatory areas. Other than defining the geographical coverage of the BSAI FMP as that of the Economic Exclusive Zones off the Bering Sea and Aleutian Islands (to the U.S. – Russia Convention Line of 1867), there is no rationale offered in the FMP as to the subdivision of the Bering Sea / Aleutian Islands regulatory or statistical areas. A historical look at the current boundary at 170°W can be traced to the division of areas by the International North Pacific Fisheries Commission (INPFC). The INPFC considered the Aleutian Islands as the areas between 170°E and 170°W, same as the FMP. The north/south division of the eastern Aleutian Islands can also be traced back to this institution. The catch records for the western and central Aleutians are not consistent due to changes in the statistical areas. The INPFC's split the catch report east and west of 180°W. In contrast, the FMP defines three equivalent areas with breakpoints at 177°E and 177°W. In addition to the NPFMC the International Pacific Halibut Commission (IPHC) considers the Aleutian Islands as starting roughly at the tip of the peninsula (164°W) and extending towards the west, with a split at 172°W. (Figure 1.13)

These divisions essentially define the level of spatial resolution for the BSAI FMP as two large ecosystems which can not be expected to have the same structure and function based on their landscape, species composition, and flow of nutrients (Polis et al.2004). Stocks crossing multiple boundaries, potentially associate to different species, play a different role in the food web and even have different life history traits, increases substantially.

Under the current catch recording and allocation system, stocks which are primarily distributed in the Aleutian Islands (Table 1.5), biomass and catches are tracked within the [3] statistical areas, providing some to distinguish between the western and central Aleutians. Boundary definitions between the western and central islands have changed –so the feedback they provide does not necessarily reflect the western and central communities directly. For stocks managed as a single unit across the EBS and AI, allocating catch across the three statistical areas is not standard practice.

Similarly, bycatch estimates are calculated for the entire regulatory area. The FMP sets up maximum bycatch rates and imposes severe restriction on the fishery when the bycatch quotas are met. Most fishermen will recognize the change in bycatch at smaller spatial scales and will use this information if given the chance or rewarded for it (Annala 1995, Levin 1999). The BSAI/AI FMP is not set up to allow or reward the fishermen to use this information. Bycatch estimates rely on either biomass estimates or reliable history of total catches –which means that for a population without a biomass estimate, it must first be sufficiently fished down with respect to the target population (not its own population) before any type of action is prompted. This problem could be alleviated somewhat by breaking up quota allocation into statistical areas or at least presenting catches/bycatches divided by statistical area.

I have taken the example of bycatch because it is one aspect of fisheries that is most recognizably linked to space. However the problem of mismatched spatial feedback or mismatch between boundaries delimiting the spatial extent of management and natural communities permeates to all interactions in which species removed by fisheries participate: density dependent processes, competition, food webs. Without the existence of preventive measures or a system that rewards fishermen's behavior, the burden of proof for effects in these species lies in the government, which has the obligation to supply evidence and rationale to support the regulation/ monitoring of unmanaged resources/ processes. This perpetuates a lag in response time that can be further aggravated by inadequate response mechanisms, be it in their legal foundation, framework flexibility or lack of resources. A system that keeps track at smaller spatial scales than the regulatory/ecological areas or a more proactive law/ management framework could change/lower the burden of proof. Identifying bycatch/ depletions/ changes at a smaller scale might trigger faster response systems when high rates are detected but in a much less extensive area. This challenge is only more pressing with the move toward ecosystem-based management.

Feedback is not restricted to just perceiving a level of change. We have to make a judgement, and act upon it, decide whether our actions are pushing the ecosystem against it's inherent organization. Can we then improve the feedback loop between changes in these processes and our perception of them if we learn to recognize them by observing them at smaller scales or identifying fundamental processes and patterns of organization? In the next chapters I attempt to compare the changes in food web structure that can be perceived depending on its spatial scale and boundary definitions of the Aleutian Islands ecosystem and examine how the changes in pathways can affect the way fisheries removals are processed through the system. The purpose of examining different spatial scales is to attempt to understand how the system reorganizes itself locally in response to changes in the abundance and properties of its components. Ultimately, the challenge is to develop a socio-ecological framework that can adapt smoothly to these reconfigurations at small and larger scales in order to preserve ecosystem integrity.

Table 1. 1 Characteristics of passes in the Aleutian Archipelago

(modified from Hunt and Stabeno 2005)

Region	Pass/ Strait	Depth (m)	Total regional cross-sectional area (km^2)	Flow into Bering Sea $10^6 m^3 s^{-1}$
Eastern Aleutians	Unimak, Akutan, Umnak	52-7	3.9	~0.2
Central Aleutians	Samalga, Chuginadak, Hebert, Yunaska, Amukta, Seguam, Tanaga, Amchitka	165-1155	87	>8.8
Western Aleutians	Kiska, Buldir, Semichi	105-640	36.5	0.7
Commander-Near Straits	Near, Commander	105-2000	335.3	14.4

Table 1. 2 List of species under special management/ conservation status

Common name	Scientific name	Status	Regulation
Fin whale	*Balaenoptera physalus*	Depleted/ endangered	MMPA/ESA
Humpback whale	*Megaptera novaeangliae*	Depleted/ endangered	MMPA/ESA
Right whale	*Eubalena japonicai*	Depleted/ endangered	MMPA/ESA
Sei whale	*Balaenoptera borealis*	Depleted/ endangered	MMPA/ESA
Sperm whale	*Physeter macrocephalus*	Depleted/ endangered	MMPA/ESA
Sea otters	*Enhydra lutis*	Endangered	ESA
Steller sea lion	*Eumetopias jubatus*	Endangered	ESA
Palla's (spectacled)/ Cormorant		Extinct	IUCN
Steller sea cow		Extinct	IUCN
Short-tailed albatross	*Phoebastria albatrus*	Endangered	ESA
P. guillemot		Declined	USFW
Cormorants	*Phalacrocorax* sp	Declined	USFW
Glaucous-winged gulls	*Laurus glaucescens*	Declined	USFW
Whiskered auklets	*Aethia pygmaea*	Concern	USFW
King crab		Depleted	USFW
Pacific Ocean perch	*Sebastes alutus*	Depleted	NMFS
Corals		EFH	EFH
Fox		Invasive/ partially eradicated	USFW
Rat		Invasive/ partially eradicated	USFW
Ground squirrel		Invasive/ partially eradicated	USFW

Table 1. 3 Timeline of exploitation of natural resources in the Aleutian Islands and key historical events

1745-64	Discovery Aleutian Islands	Bering arrives to Commander Islands	1741
1750	Arctic fox introduced in Attu; sea otter extinct in Kamchatka		
1768	Sea cow extinct	First wintering at Kodiak	1763
1784	Permanent settlements at Kodiak and Unalaska	Cooks's third voyage California-Bering Strait	1776
1786	Discovery Pribilof Islands	Ships from Flanders, France, Spain, England and California reach Alaska and Aleutians	1785-87
1792	Sea otters extinct at Kodiak-Kenai Bay; new settlement at Chugatsk Bay	English sell sea otters at Canton	1788
1796	Sea otters extinct at Chugatsk Bay; new settlement at Yakutat	Beginning of Russian American Company	1799
1802	800,000 fur seal skins spoiled in storage	Fur prices drop in China	1803
1804	Fur seal hunting ban by RA company board	Second charter of Russian American Co.	1819
1808	Ban removed	15 Russian permanent settlements in Alaska	1820
1810-13	700,000 skins burned in Unalaska	English trade throughout AK, except near Russian colonies	1825
1812	New Russian settlement Ross Fort in California	Native trade for Russian American Co. in Yukon-North Slope	1826
1820	Sea otters extinct at Yakutat, Icy Bay, Cape St Elias	Panic of 1837 (economic depression)	1837
1828	Fox introduced to Andreanof/ Rat Islands; only 300 sea otters furs at Atka; trade minimal		1840-50
1828-50	Moved people from Amchitka to Adak and Atka to stop harvest of sea otters at Rat Islands	Third charter of RA company begins	1844
1835	First whale killed at Kodiak by Yankee whalers	Sea otter fur prices decline	1845
1840	700 whaling, fishing and fur hunting American vessels active I North Pacific	Gold Rush in California	1848
1848	Arctic whaling begins, Dutch Harbor main stocking station	Russian-American Co loses fur monopoly	1857
1867	American whaling in AK; pelagic sealing	Oil well discovered in Pennsylvania	1859
1880	First steam whaler returns from Arctic	Sale of Alaska to the United States/ Independence of Canada	1867
		US transcontinental railroad completed	1869
1884/85	Fur Seal Agreement in NW Pacific between US, Russia and Japan	Fashion for wide skirts crinolin made of baleen	
		Gold rush at Nome	1899
1905	Steller sea lions scarce	International migratory seabird agreement	1910
1912	Shore whaling station at Akutan	North Pacific Fur Seal Convention	1911
1920	Peak cod fishery	Alaska becomes US territory	1912
1934	Japan starts exploratory fishery		
1939	Akutan shore whaling station closes	Aleutian Chain Reservation established	
1913-40	Fox farming	WWI	1914-18
1950-72	Modern whaling	International Pacific Halibut Convention	1923
1952	High seas salmon fishery	Great Depression	1929
1960	Foreign crab & groundfish fisheries begin	WWII	1944
1962	POP and pollock fisheries start	International Whaling Convention	1948
		International North Pacific Fishery Commission	1953
1963	Sablefish and Greenland Turbot fisher5es start	Foreign fleets restricted to west of 175°W	
1970	Flatfish fishery beg5ns	Alaska and Hawaii become states	1959
1972	Atka mackerel fishery beg5ns	Marine Mammal Protection Act	1972
1980	US Joint ventures begin	Endangered Species Act	1973
1990	Groundfish fleet fully domestic	Fisheries Management Conservation Act	1977
1997	Steller sea lion listed endangered under ESA	US 200 mi EEZ	1982
2000	Pollock fishery restricted severely for political reasons		

Table 1. 4 Number of whales caught in the western, central and eastern Aleutian Islands by species (1925-2004).

	Western AI	Central AI	Eastern AI	Total
Sperm whale	16035	15642	4009	46084
Fin whale	2001	3603	5961	15277
Sei whale	835	1360	1732	6098
Humpback whale	322	137	780	1626
Blue whale	29	185	423	811
Gray whale	31			31
Minke whale	4			27
Baird's whale		3		16
Right whale		6		6
Total	19257	20936	12905	69976

Table 1. 5 Species for which the NPFMC requires stock assessment reports in the Bering Sea/ Aleutian Islands area.

Species	Bering Sea/ Aleutian Is	Gulf of Alaska	BSAI catch distribution EBS eastern Bering Sea; AI Aleutian Islands
Flatfish species/ complex			
Alaska plaice	✓		Minimal in AI
Arrowtooth	✓	✓	✓
Dover sole		✓	
Flatfish		✓	
Flathead	✓	✓	Less 10% biomass in AI
Greenland turbot	✓		✓
Other flatfish	✓		Less 10% biomass in AI
Rocksole	✓		✓
Yellowfin sole	✓		Minimum in AI
Rockfish species/ complex			
Atka mackerel	✓	✓	Three seperate stocks within AI
Demersal shelf rockfish		✓	
Northern rockfish	✓	✓	✓
Other rock fish	✓		✓
Pacific Ocean perch	✓	✓	Mostly in AI
Pelagic shelf rockfish		✓	
Shortraker/ rougheye & other slope rockfish	✓ w/o slope rockfish	✓	✓ w/o slope rockfish
Thornyheads		✓	
Other species/ complex			
Forage fish		✓	
Pacific cod	✓	✓	✓
Sablefish	✓	✓	✓
Squid & other species		✓	
Walleye pollock	✓		✓
	✓	✓	EBS and AI separate reports

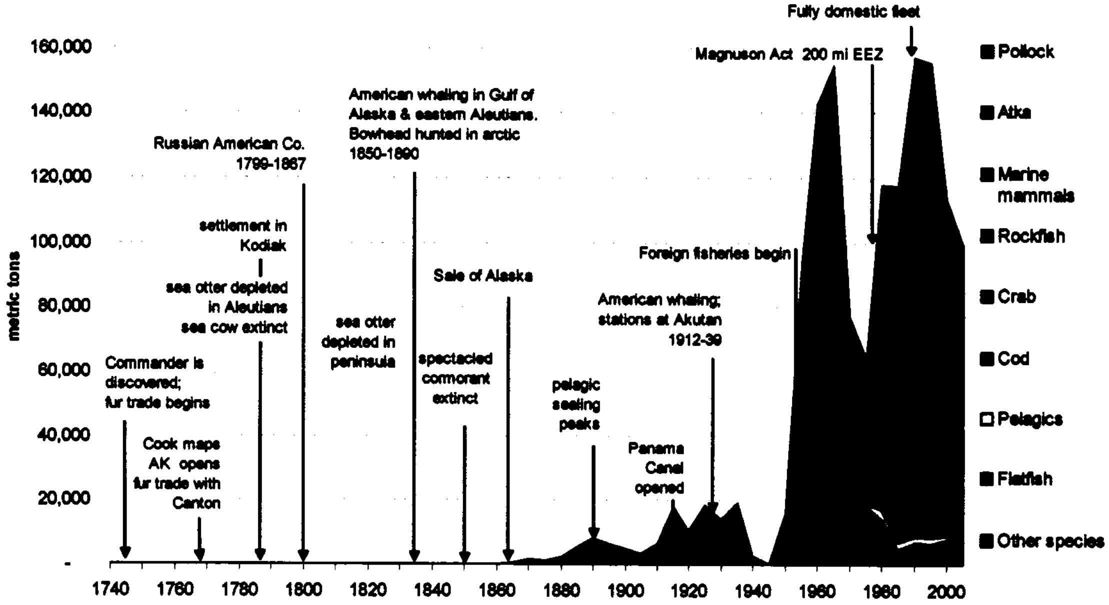

Figure 1. 1 Five year average of fisheries catches in the Aleutian Islands 1745-2004.

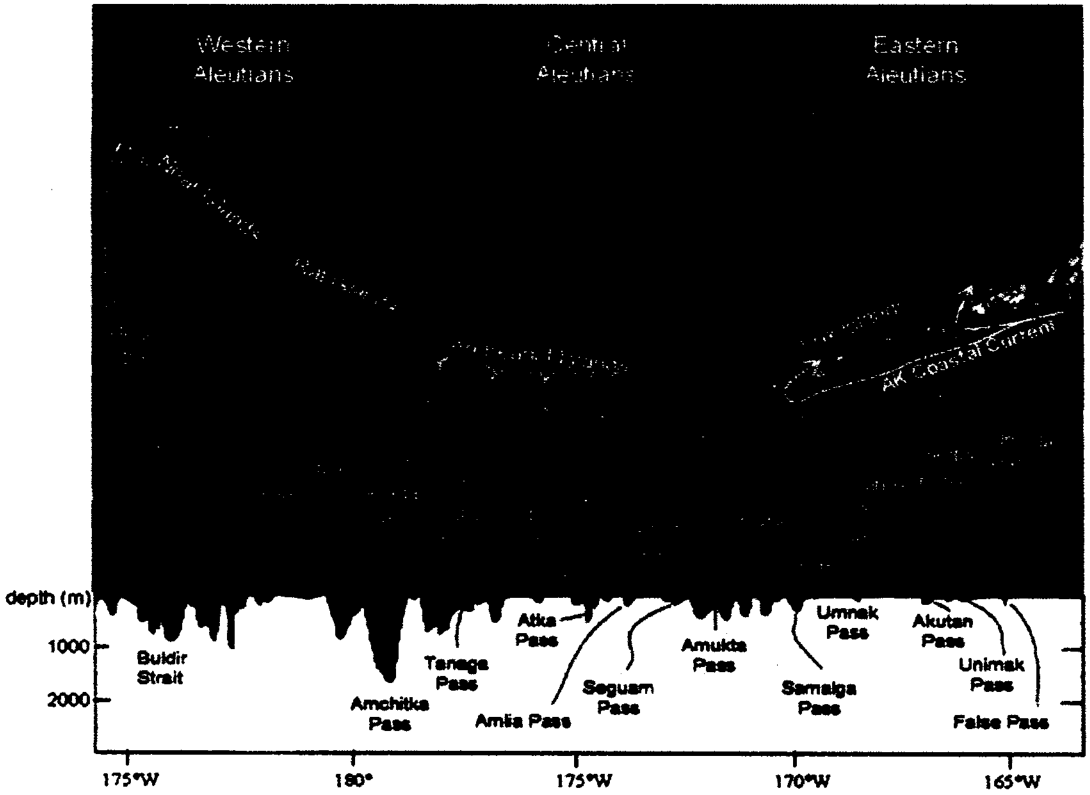

Figure 1. 2 Main currents, passes, and island groups of the Aleutian Islands. (modified from Stabeno et al. 2005)

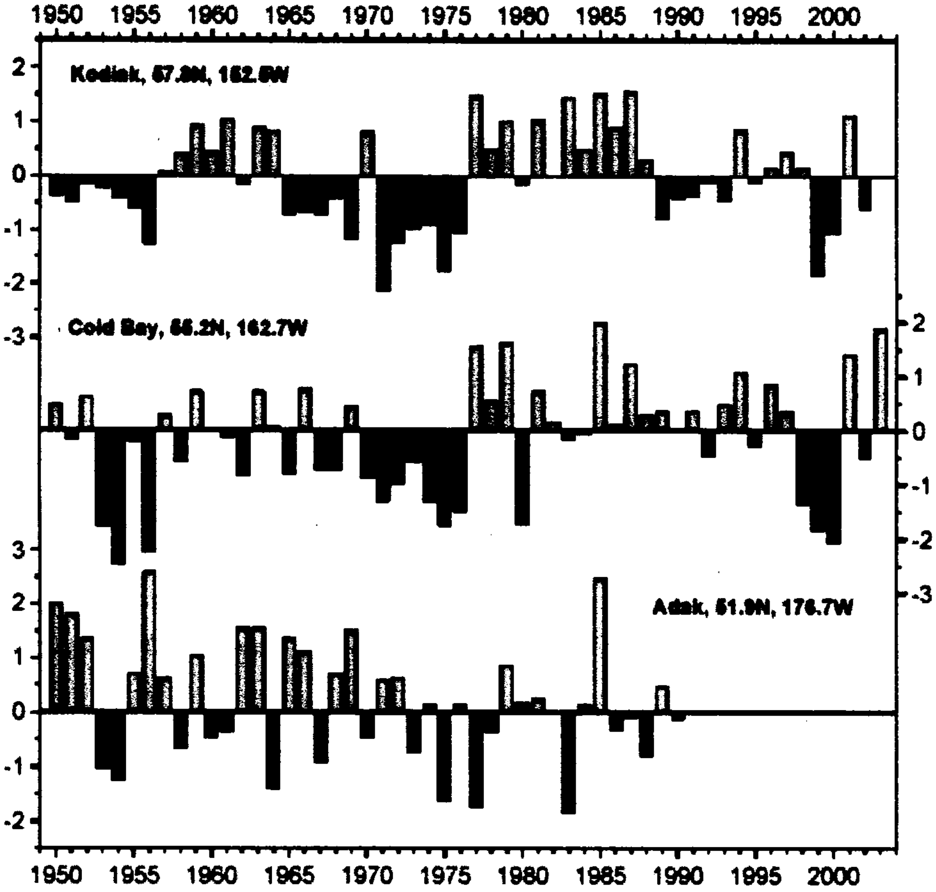

Figure 1. 3 Normalized mean winter (DJF) Surface Air Temperature anomalies (from top to bottom), Kodiak, Cold Bay and Adak (from Rodionov et al.2005).

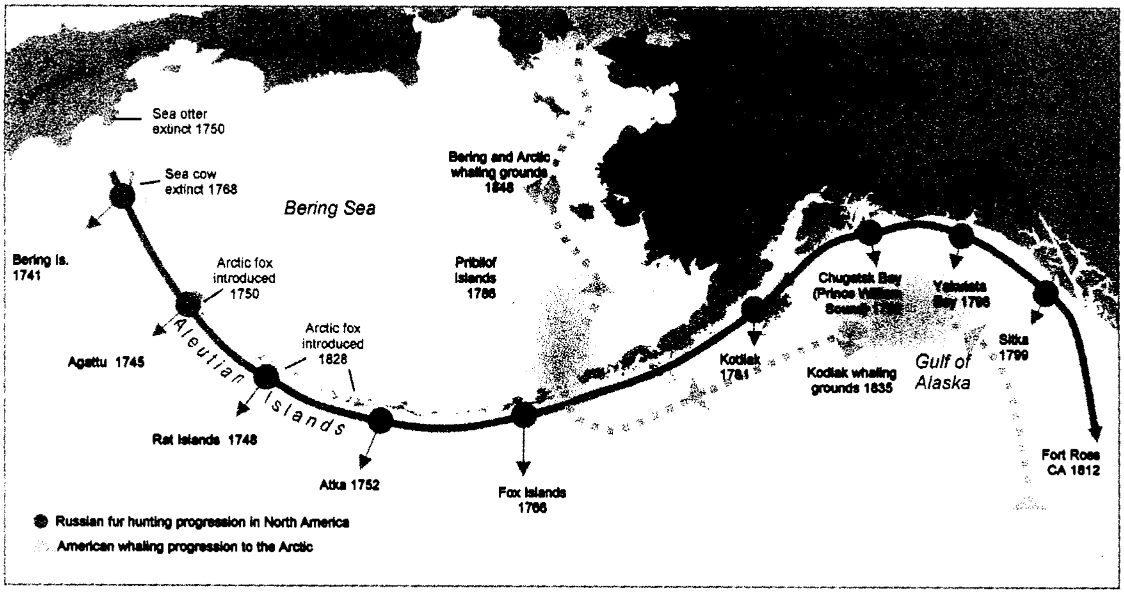

Figure 1. 4 Initial advance of Russian fur hunters and American whalers during the Russian period 1741-1867.

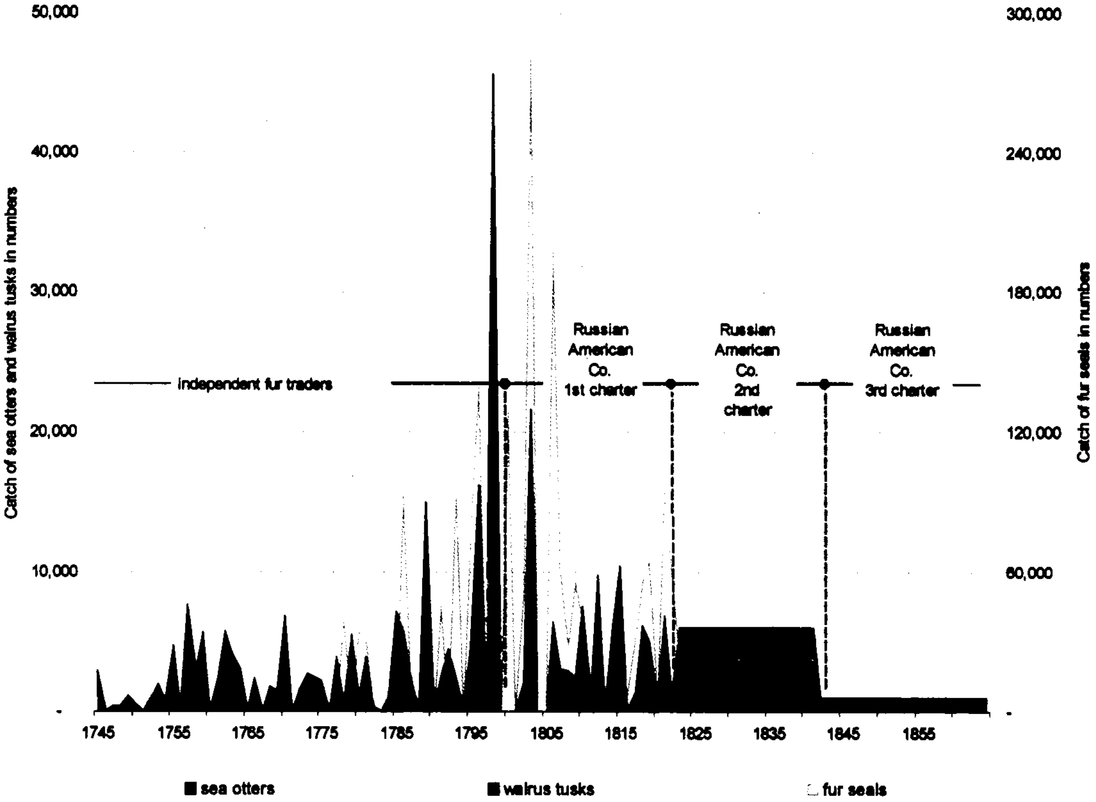

Figure 1. 5 Annual report of marine mammal products* during the Russian period 1745-1867

* Whale catches not included

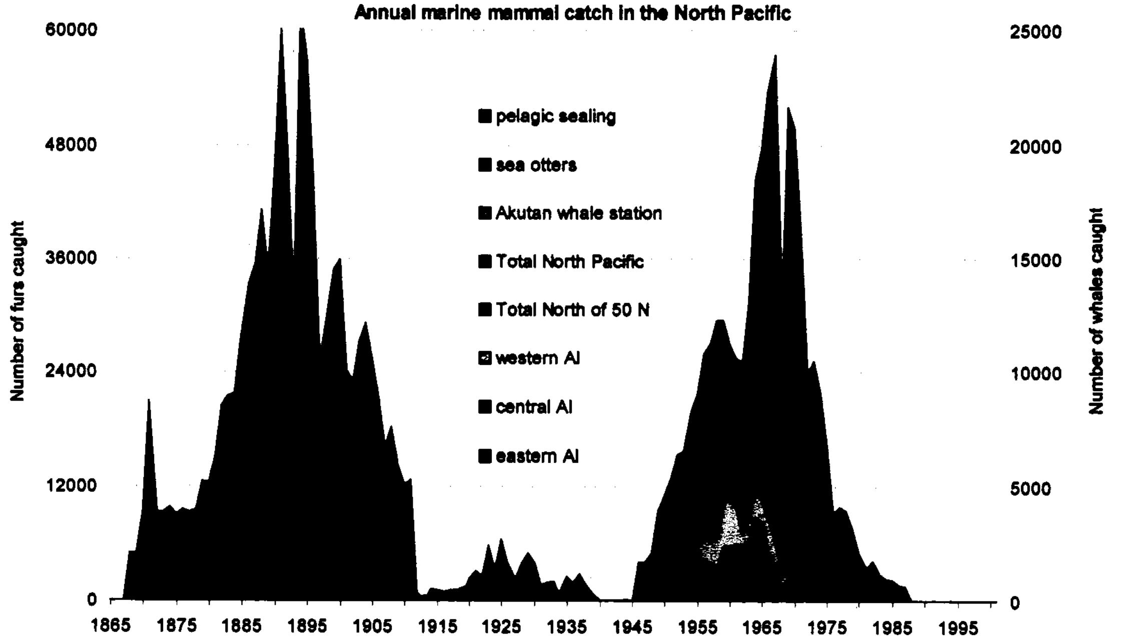

Figure 1. 6 Number of marine mammals caught in the North Pacific during 1865-2001).

(modified from Mizroch and Rice, *in press*)

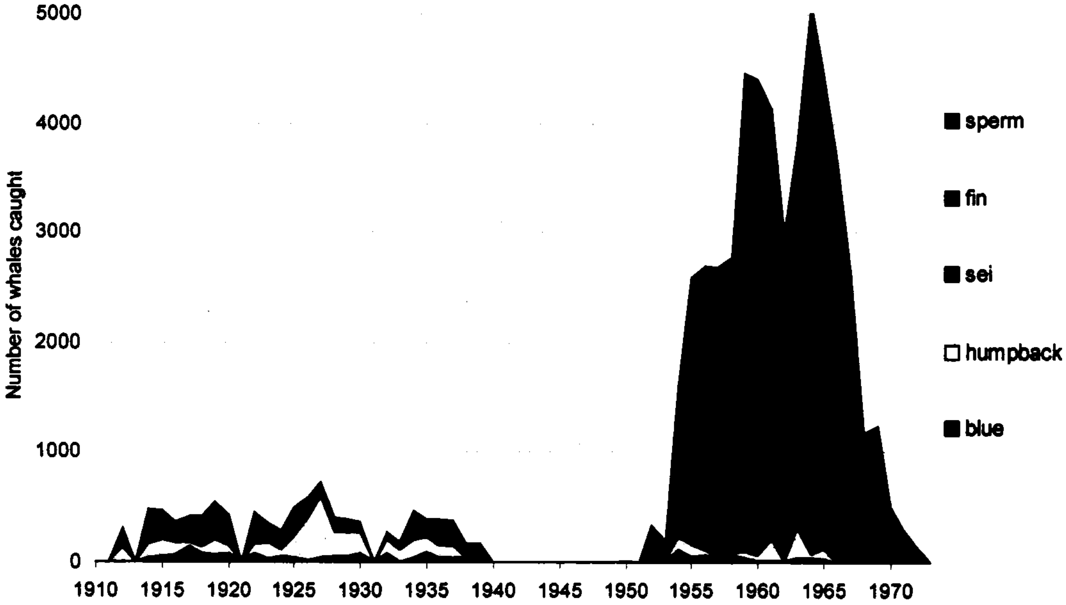

Figure 1. 7 Catch by species from Akutan shore whaling station (1912-1939) and modern whaling in the eastern, central and western Aleutian Islands combined (IWC 1950-1973).

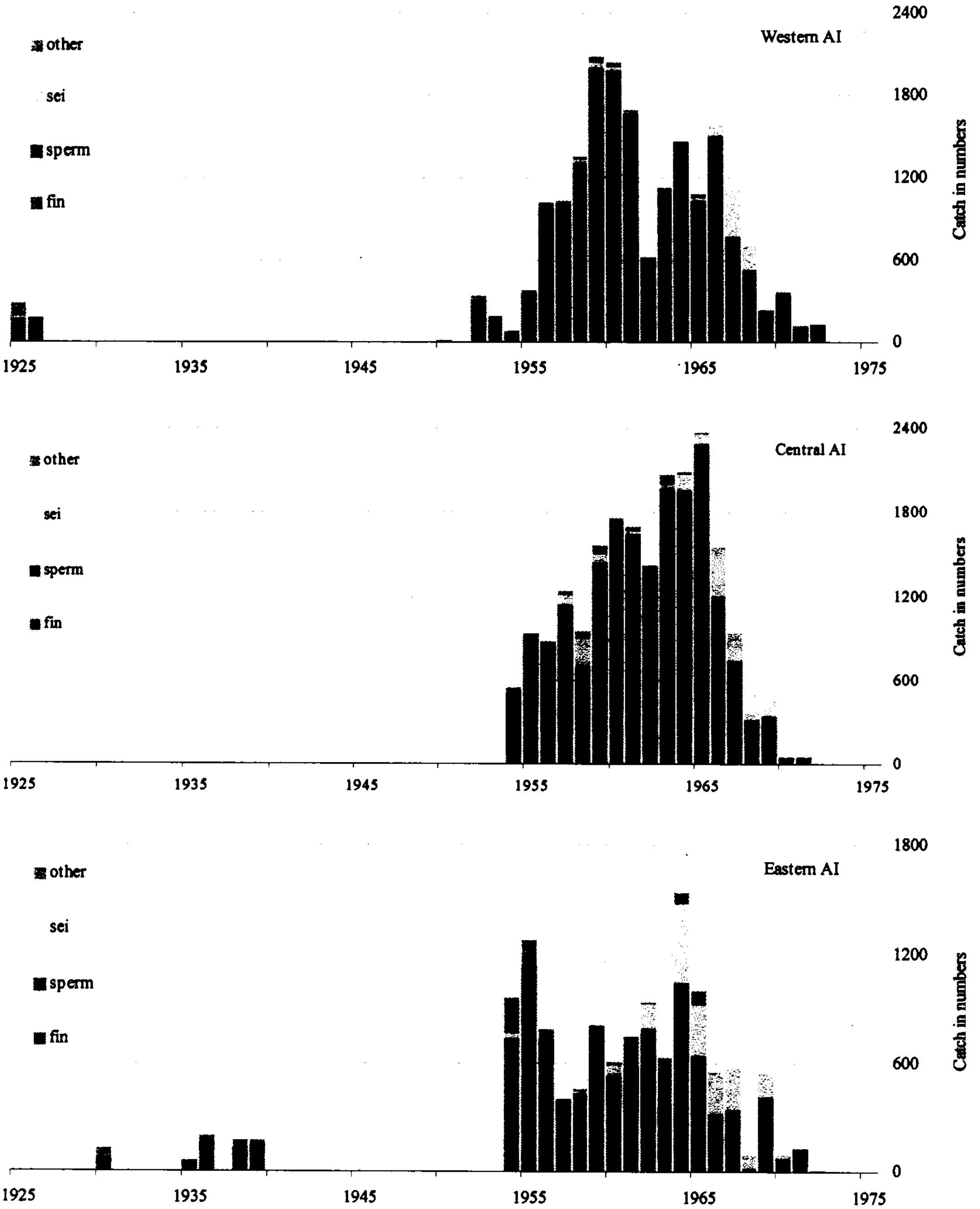

Figure 1. 8 Annual catches by species in the western, central and eastern Aleutians (IWC 1925-1973).
Other whales mostly humpbacks and blue whales

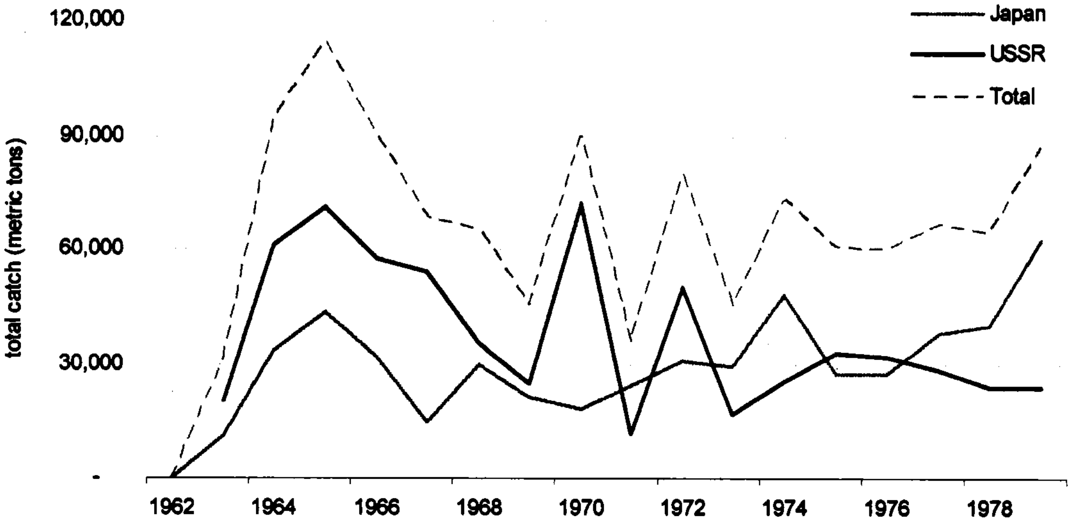

Figure 1. 9 Total catches by Japan and USSR fleets in the Aleutian Islands (170°E-170°W) from 1962-1979.
(modified from Bakkala 1981)

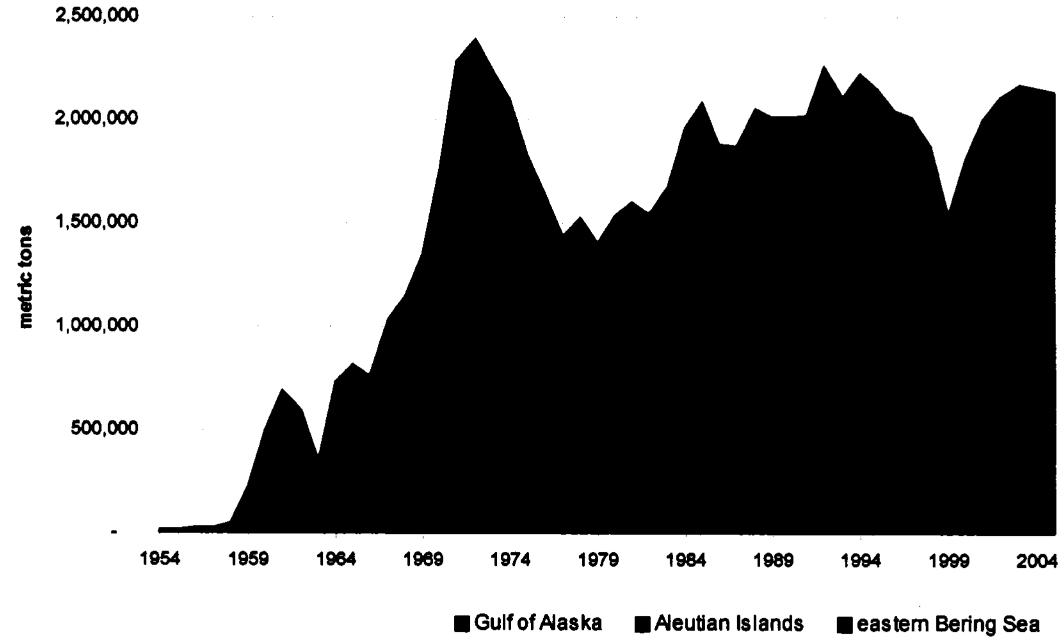

Figure 1. 10 Total fisheries catch in Alaska 1954-2005.

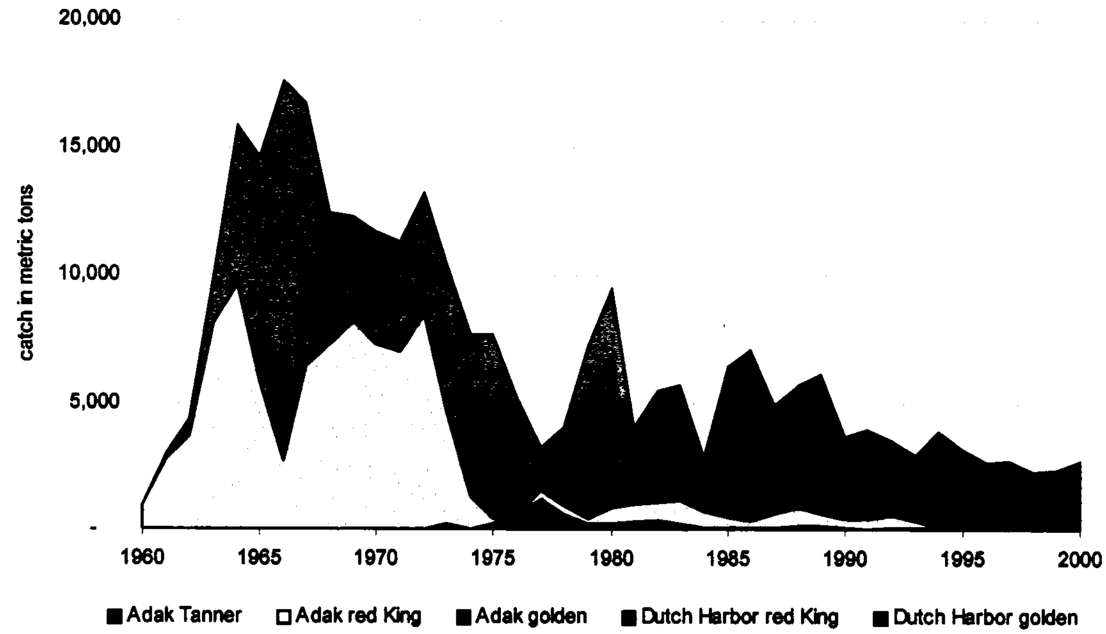

Figure 1. 11 Catch of crab fisheries in the Aleutian Islands 1960-2000.

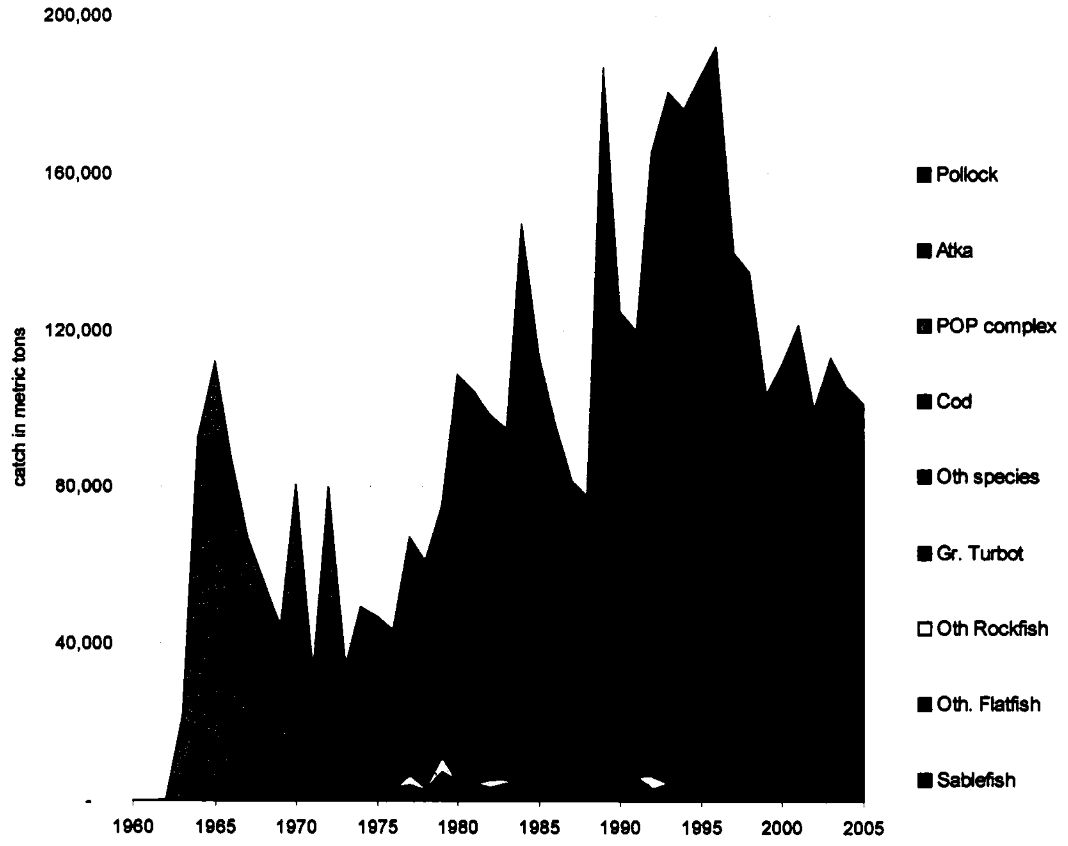

Figure 1. 12 Fisheries catches in the Aleutian Islands 1960-2005.

Key dates: 1960-1979 foreign fisheries, 1980s joint ventures, 1990 –present fully American fleet. 1977 implementation of FMCA. Atka stands for Atka mackerel.

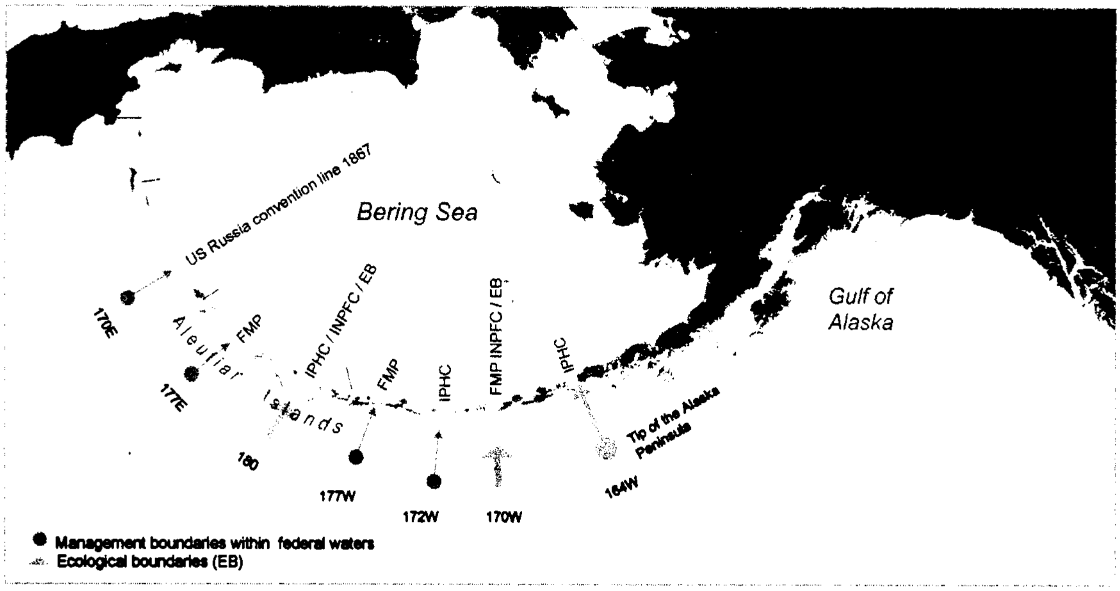

Figure 1. 13 Management and ecological longitudinal boundaries in the Aleutian Islands.

Current organizations having regulatory areas in federal waters are the International Pacific Halibut Commission (IPHC) and the North Pacific Fisheries Management Council (NPFMC). INPFC stands for the International North Pacific Fisheries Council which regulated the Bering Sea/ Aleutian area prior to the Magnuson Stevenson Fisheries Management and Conservation Act of 1976.

Chapter 2. A food web model for the central and western Aleutian Islands (NPFMC regulatory area of the Aleutian Islands)

> *In the real world species interactions change at least seasonally and not all interactions are equally strong. Food webs are thus caricatures of nature. Like caricatures, though their representation of nature is distorted, there is enough truth to permit a study of some of the features they represent (Pimm 1982).*

2.1.1 SUMMARY

A static mass-balanced food web model was used to characterize the connections between fish populations and fisheries removals within the NPFMC regulatory area of the Aleutian Islands. The results show that the main fish biomasses under early 1990s conditions are those of Pacific Ocean perch, Atka mackerel, and Myctophids where these last two contribute a large proportion of numerous species' diet. The nature of the system is open, pelagic, with plankton as its primary energy source and myctophids and squids as a subsidy from adjacent areas. In contrast, pollock and yellowfin sole are the main fish species in the Eastern Bering Sea, its nature is benthic with detritus as its primary source channeled by benthic invertebrates. In the Gulf of Alaska, arrowtooth flounder and halibut comprise the main groundfish biomasses. The nature of this system is evenly mixed, with shrimps channeling energy from the detritus and forage fish from plankton. These differences in system organization are reflected in the role of two widely distributed species in all three systems: walleye pollock (a prey) and Pacific cod (a predator).

The production of pollock contributing to other species' diet relative to its contribution to fisheries is highest in the Gulf of Alaska and lowest in the Aleutian Islands, with the Eastern Bering Sea lying in between. In contrast the production of Pacific cod going to fisheries is relatively even across systems but it is supported by the consumption of Atka mackerel and other fish in the Aleutian Islands whereas in the Gulf of Alaska and Bering Sea it is supported by pollock and benthic invertebrates. Cod as a predator

controls different stocks throughout the systems. The competition for pollock between population and fisheries is highest in the Gulf of Alaska, least in the Aleutian Islands and fisheries removals from Pacific cod reduce the predation mortality of different commercial species across systems.

2.2 INTRODUCTION

Food web models have fast become a staple of the ecosystem approach to fisheries (EAF). Software availability, the inclusion of non-target species, and the push for a more holistic approach, have fueled their widespread use (Christensen and Walters 2004, EPAP 1998). Food web models increase the feedback on the effects of fisheries removals in the ecosystem. They extend the information from the target species population's dynamics to its position relative to the other populations in the system, commercial and non-commercial, and regardless of whether they have a direct connection with them or not. Food webs provide a framework to represent ecosystem structure and integrate species interactions, biodiversity, productivity, and population dynamics among others, hightening the ecosystem as a whole (Pikitch et al. 2004, Link et al. 2005). There is however, a trade-off on the level of detail achievable on the population dynamics for any one particular species, and because of this, EAF is more strategic than tactic. Food-web models are not meant to replace single species stock assessments but rather to complement them and provide a context for the fisheries (Hollowed 2000, Christensen and Pauly 2004). Within a management context, trophic models help improve our understanding and visualization of how fisheries removals propagate through the food web and their potential consequences (Sala and Sugihara 2005).

The management of the fisheries in Alaska is under the stewardship of the North Pacific Fishery Management Council (NPFMC). The NPFMC has been proactive in developing an ecosystem approach for the management of groundfish fisheries. The Groundfish Plan Teams have included (since 1995) an ecosystem considerations chapter along with the annual Stock Assessment Fishery Evaluation (SAFE) reports.

This section addresses issues on a fishery by fishery basis, as recommended in the November 30, 2000 Comprehensive Biological Opinion by NMFS (Livingston 2003, Boldt 2004). The council created an Ecosystem Committee in 1996. Several ecosystem considerations are already underway, such as conservative catch and bycatch limits, closed areas and special measures for marine mammals and seabirds. Further progress will be based on the guidelines for its EAF policy, and the ability to link the goals of EAF with ecosystem research and scientific advice beyond that of single species stock assessments (Witherell et al. 2000, Livingston 2003). Acting upon the guidelines of the Ecosystem Principles Advisory Panel (EPAP 1999), to develop a Fisheries Ecosystem Plan for each of its regulatory areas, the NPFMC in conjunction with the Alaska Fisheries Science Center (AFSC), has encouraged the development of food web models. Accordingly, mass-balanced food web models were developed for the regulatory areas of the Eastern Bering Sea (EBS) and the Gulf of Alaska (GOA) (Trites et al. 1999; Aydin et al. 2002; Gaichas 2006) using Ecopath with Ecosim (Polovina 1985; Christensen and Pauly 1992). Both the EBS and GOA models have been used to provide support for competing stock assessment models as well as to identify key/ vulnerable species within an ecosystem and data incompatibilities, contributing substantially to the ecosystem considerations section of Stock Assessment and Fisheries Evaluation (SAFE) reports. In 2002, a comparative approach among Alaskan ecosystems prompted a joint effort to update and redesign existing food web models for the EBS and GOA, and develop one for the Aleutian Islands. The need for a food web model of the the Aleutian Islands is based not only on its role as a framework for the fisheries within the Aleutian Islands. It is essential to understand how the role of a species managed jointly for the Eastern Bering Sea and the Aleutian Islands changes across ecosystems. For most shared managed stocks, the magnitude of the population sizes in the EBS overwhelms those in the Aleutians, and without a characterization of the Aleutian Islands ecosystem its needs are overridden by those of the EBS. For example, the lack of a model for the Aleutian Islands has based the ecosystem considerations section of the SAFE reports mostly on EBS dynamics.

The NPFMC does not consider all the Aleutian Islands, which extend from 164°W to 170° E, under one regulatory area. Rather, they are split among its three regulatory areas: the EBS, the GOA and the 'Aleutian Islands'. The northern portion of the islands from 164°W to 170°W are in the EBS, the southern portion in the GOA and the islands from 170°W to 170°E are under the Aleutian Islands regulatory area. This partitioning does not allow for an accurate representation of the entire Aleutian chain. The islands from 164°W to 170° E are probably overridden by the coastal/shelf nature of the GOA and EBS ecosystems and the transition from a coastal to an oceanic nature will be lost for the portion of 170°W to 170°E. However all the information, catches, stock sizes, quota allocations are captured under this format. This is the way the NPFMC *views* the EBS, the GOA and Aleutian Islands. It is therefore a valid exercise to see what the perception of this ecosystem is, defined by management boundaries in contrast to more ecologically defined boundaries.

In this chapter, I use a static food web model to characterize the structure within the Aleutian Islands regulatory area, identify its main components and characterize the most important energy sources and conduits. I then compare this structure to that of the EBS and GOA by using the existing models (Gaichas 2006, Aydin et al. *in review*) and highlight the different processes driving each system. I show how these different processes can change the role of the same species by focusing on two species widely distributed throughout all three ecosystems: walleye pollock and Pacific cod. Each of these species is a commercial target across the ecosystems. The population structure of pollock is defined by 3 separate units, one in each ecosystem. In contrast, Pacific cod population structure has two: one in the GOA, the second shared between the EBS and Aleutian Islands.

2.3 METHODS

The model was developed jointly with those redesigned and updated for the EBS and GOA. The goal was to homogenize both the modeling approach and parameter estimation techniques. The effort resulted in a higher resolution (higher number) of functional groups, distributions and diets for all three ecosystems. Following is a general description of the model, sources and techniques to estimate input parameters. Full details can be found in (Aydin et al. *in review*). Species descriptions and an explanation of the basic parameters are included in the Appendix.

2.3.1 Model approach

The mass-balance modeling methodology and Ecopath approach have both been described (Polovina 1985, Christensen and Pauly 1992, Walters et al. 1997, Christensen and Walters 2004), and scrutinized elsewhere (Hollowed 2000, Plagányi and Butterworth 2004). The description that follows is only general and pertains almost entirely to the main differences between the standard Ecopath and Ecosense, the modified version used for this model (Aydin, *in prep*). The code was reviewed and modified for formal parameter estimation in Microsoft Excel, Visual Basic, and C++ development environments. The revisions allow (1) automating links between surveys and assessment databases to allow consistent updating of the regional submodels on a regular basis, and (2) implementing formal parameter estimation procedures (Aydin et al. *in review*).

The Ecopath master equations do not require equilibrium or steady state. Rather, they require that mass balance occur during the period under consideration, e.g.,, within a given period there can be one or various points in time when there is excess consumption as long as they are compensated by lower consumption at other time(s) so that they are thermodynamically consistent. The exception to this happens when there is a known trend, either a decrease or increase in mass which is accounted for as "biomass accumulation". The master Ecopath equation, for each functional group i with predators j, is:

$$B_i\left(\frac{P}{B}\right)_i * EE_i + IM_i + BA_i = \sum_j\left[B_j * \left(\frac{Q}{B}\right)_j * DC_{ij}\right] + EM_i + C_i \qquad \textbf{Equation 1}$$

where: *Bi* and *Bj* are biomasses; *P/Bi* is the production/biomass ratio (equivalent to total mortality, Z, in most cases (Allen 1971)); *EEi* is the fraction of total production (*B*(P/B)*) consumed within or caught from the system (*i.e.,* ecotrophic efficiency); *Ci* is the fisheries removals; *Q/Bj* the food consumption per unit biomass of *j*; *DCij* is the contribution of *i* to the diet of *j*; IM_i and EM_i stand for mass moving in and out of the system respectively (not used in the AI model); and BA_i is the biomass accumulation. EE_i is hard to measure in the field and is usually the unknown to be estimated when the equation is solved, but any one of the four key parameters (B, P/B, Q/B, and EE) can be estimated –provided the remaining parameters are specified. In practice, the equations are solved mostly for either *B* or *EE*.

The estimated values of EE_i are the primary tool for calibrating data in Ecopath. Initial solutions often imply higher total mortality than production, resulting in values of $EE_i > 1$ that are incompatible with the mass-balance assumption (Christensen et al. 2000). All *EE* values greater than 1 are used to diagnose mismatches between production and mortality; the input data are reviewed and adjusted for consistency until all *EE* values are equal or less than one ($EE_i \leq 1$). This iterative process called "balancing" the model ensures that there are no alternate sources of production unexplained by the model. The pitfall of this procedure is that consistency with the mass balance assumption does not translate into accuracy; uncertainty in the model has to be assessed by other means (see Chapter 5).

2.3.1.1. Differences with standard Ecopath

Traditionally, Ecopath is set up so that there is only one set of input parameters (diet, removals, B, P/B, Q/B, and/or EE) for each functional group. The version used here has an option for intermediate subregional inputs for diet, biomass and/or *EE*. Depending on data availability for each functional group, the final diet was either as entered (if only regional data were available), or estimated by weighting the subregional diets according to biomass and/or area of the subregion(s). Likewise, biomass values were estimated either at a regional level or as the sum of the subregional values. The subregions used in this model were based on RACE survey strata (Table 2.1) and include three depth (shallow, middle, and deep) and location (eastern 541, central 542 and western 543) categories for a total of nine depth/location subregions. The subregional inputs allow a wider range of data treatments: the traditional method assumes homogenous consumption or production throughout the ecosystem; the most heterogeneous case considers functional groups as different populations in each modeled subregion, and effectively encodes predator depth and location preferences into the diet matrix, limiting consumption to the production in the subregion where it takes place.

The second major difference with the standard Ecopath is the way the diet composition is partitioned among prey items. The first and simplest method was by assigning a fixed proportion to each functional group that was a prey item for any one given predator. This was possible when the diet composition data (regional or subregional) had equal or better taxonomical resolution than the functional groups in the model (e.g., groundfish diets). The second method, called "preference", was used when taxonomical resolution was poor (as for marine mammals and seabirds) and a given prey category could be assigned to several functional groups, giving rise to a "prey cluster" (*e.g.,* the category "cephalopods" can be assigned to functional groups "squids" and "octopi" which together constitute the "cephalopod" prey cluster). For the preference method, the functional groups that comprise a prey cluster are identified first. Then, the cluster is assigned a fixed proportion of the diet composition, and finally, the proportion assigned to the cluster is partitioned among the functional groups based on availability to groundfish. The underlying assumption is that the more abundant prey are also more available for consumption, hence consumption is proportional to abundance.

2.3.2 Geographic coverage

The model covers the NPFMC regulatory area for the Aleutian Islands which extends from 170° W to 170°E. It is limited to waters within 0 to 500 m. deep and covers and area of 56,936 km^2. The NPFMC regulatory area has three statistical areas: (Figure 2.1):

i) Area 541: from 170°W to 177°W (roughly from Samalga to Tanaga Pass),

ii) Area 542: from 177°W to 177°E (roughly from Tanaga Pass to just west of the Rat Islands), and

iii) Area 543: from 177°E to 170°E (from W of the Rat Islands to Attu Island)

These statistical areas are often referred to by the NPFMC as the eastern, central an western Aleutian Islands. Note these terms only denote the relative position of the statistical areas, not their geographical locale with respect to entire [American] Aleutian chain, which extends east up to 164°W. When referred to the entire Aleutian chain the NPFMC regulatory areas cover the central and western Aleutian Islands only.

As mentioned earlier, the geographic range was selected to model the stocks on the same scale as the NPFMC manages the major commercial groundfish species. This greatly facilitated the use of available data derived from fisheries and surveys. The easternmost boundary of the NPFMC regulatory area (and the model) is 170°W which does coincide roughly with Samalga Pass, a transition pass between the "shelf" passes to the east and the "oceanic" passes to the west. As a biogeographical boundary, Samalga is the first deep (200 m) pass from east to west and it marks the transition from the wide North Pacific shelf to the east, and the narrowing shelf to the west (Ladd et al. 2005). Community structure, diets and distributions for demersal fish, corals, seabirds, and marine mammals in general differ east and west of this boundary (170°W, Samalga Pass) (Heifetz et al. 2005, Jahncke et al. 2005, Logerwell et al. 2005, Sinclair et al. 2005).

There are some caveats in using this large area as a whole to characterize the system and assuming that species composition, fisheries and trophic relations are the same throughout the ecosystem. The Aleutians are really an open system, a porous boundary between the Bering Sea and the North Pacific with complex bathymetry and a variety of habitats ranging from kelp forests to coral gardens and rocky walls (Heifetz et al.2005, NRC 1996). What the model best represents are "trawlable and fishing grounds within 0 to 500 m deep" that is areas accessible to trawl surveys and fishing gear (longline, pots and trawlers). Groundfish populations and fisheries outside this narrow band are not well represented.

2.3.3 Defining the period

The base period is 1991-1994, with data from adjacent years included as necessary. This period covers two bottom trawl surveys in the Aleutians, the primary data source for groundfish. Marine mammals and seabird estimates come from more recent years, 1997-2002. Average bycatch rates from 1997-2002 were used to estimate average bycatch volumes in 1991-1994. The model is annual, but fish diets are derived from summer collections (for the most part) and many of the seabirds and marine mammals are only found in the Aleutians during the summer (May-September). Fish growth and consumption rates are scaled to totals; the annual averages were used as it is believed that most consumption occurs during summer. No temporally dynamic modeling was done.

2.3.4 Defining the functional groups

Besides the representation of the Aleutian food web, one of the main objectives of this model was to facilitate the comparison across the three Alaskan regional models (AI, EBS and GOA). To achieve this, we tried to aggregate as few species as possible into functional groups, which increased the total number of groups forming the food web. This was the preferred arrangement as it:

a) optimized the use of the taxonomical resolution of the raw data,
b) heightened the differences among ecosystems in species and diets compositions;
c) addressed individual species or groups of special management or conservation concern; and finally;

d) facilitated the update and incorporation of new information, particularly for the benthic invertebrates and forage fish in general.

The functional groups include cetaceans (9), pinnipeds and sea otters (8), seabirds (10), elasmobranchs (11), groundfish (43), pelagics (13), crustaceans (5), other invertebrates (17), zooplankton (10), primary producers (3) benthic bacteria (1) and detritus (5 non-living groups). Table 2.2 of Appendix A shows the functional groups in detail. These groups were modeled as total biomass or split into juvenile/adult pools, depending on available information. Juvenile fish groups were fish less than 20 cm in length, which roughly corresponds to 0 through 2 year olds. Emigrating and immigrating salmon (*Oncorhychus* spp) were considered separate (unlinked) groups. Their "pulse" presence in the system precludes estimation of in-system growth with respect to total growth during their lifespan.

Zooplankton species were split into 10 functional groups, following the taxonomic resolution of the groundfish diets. The input parameters for the zooplankton groups are currently rough estimates and can be improved in future updating. The detrital pool was divided into pelagic and benthic particulate organic matter with no flow to/from the outside detritus pool. To reflect the combination of shallow and deep areas in the western and central Aleutians, the flow of a functional group to the pelagic: benthic detrital pools was partitioned 50:50, or 10:90 favoring the benthic route (Table 2.2). Both fisheries discards and offal were included as part of the non-living groups. Offal is easily recognizable in the stomach contents of several groundfish and constitutes a non negligible contribution to their diet.

2.3.5 Assembling estimates of biomass, PB, QB, diet, fisheries and pedigree

Ecopath accepts data as collected for fisheries management and biological surveys. The data were supplied from the following agencies and programs: the Alaska Fisheries Science Center (AFSC) Resource Assessment and Conservation Engineering (RACE), Resource Ecology and Ecosystem Modeling (REEM) and National Marine

Mammal Laboratory (NMML) divisions. Additional data came from the Alaska Department of Fish and Game (ADF&G) and the US Fish and Wildlife Service (USFWS). A brief description of the general data sources and estimation techniques for the main parameters used to assemble the model is presented below. A more extensive explanation of the methods and estimation techniques are available from Aydin et al. (*in review*).

Biomass

Biomass estimates for the marine mammals were derived in conjunction with researchers at NMML and were based on abundance estimates reported by NMML in stock assessments for Alaska marine mammals or published literature. Rather than specifying emigration and immigration, the abundance estimates were weighted by the amount of time spent and area used by each stock within the ecosystem. The abundance estimates were converted to biomass using species specific average weights from Hunt et al. (2000). Abundance estimates for the marine mammals reflect values for 1997-2002. Steller sea lion numbers was the average of 1991 and 1994 abundance at rookeries and haulouts in the Aleutians as estimated by a spatial model (Fay 2003). Weights at age for female, male and pregnant females (Winship 2001; York 1994) were averaged to get a juvenile (age 1) weight and an adult weight (ages 2-24). These average weights were then used to convert abundance into biomass estimates. Sea otter biomass was based on counts in the Aleutians (USFWS 2000) for 1992. Seabird biomasses were calculated by multiplying colony counts from the central and western Aleutians, and average body weights for each species (Hunt et al. 2000). Colony counts for nesting seabirds are available from the Beringean Seabird Colony Catalog (2002-2003) maintained by the USFW. Groundfish and elasmobranchs biomass estimates were the average of the 1991 and 1994 mean biomass estimates from the AFSC/ RACE bottom trawl survey for the Aleutians Islands when available (RACE database) or published literature otherwise. Salmon, anemones, corals, tunicates and sea pen estimates were based on density estimates from GOA 1990 and 1993 bottom trawl survey estimates (RACE database); jellyfish biomass estimate was based on the density estimate from Prince William Sound (Purcell et al. 2000). Sponge biomass was extrapolated from the average of GOA 1990 and 1993 bottom trawl survey estimates (RACE database). The king crab biomass estimate was based on a logistic model using catch history. Biomass for all other groups were estimated by assuming an EE of 0.8 ("top-down balanced").

P/B

Barlow and Boveng (1991) modified Siler's competing risk model (Siler 1979) to estimate mortality at age for marine mammals by using surrogate life tables and an estimate of lifespan. Using this model and lifespan values from published literature, P/B was estimated as the averaged mortality at age. Steller sea lion was the only marine mammal group that was split; juvenile P/B was the natural log of survival at age 1; for adults it was the average of mortality at ages 2 to 24. The values were estimated using the same model as for the rest of the marine mammals. Seabird P/B was assumed equivalent to Z (natural mortality) with survival values taken from published literature. P/B for managed groundfish was estimated using the generalized Von Bertalanffy growth function (Essington et al.2001) fit to weight at age data from the AI (when available) and scaled to the 1991 age structure from the stock assessment (when available). For stocks with good data coverage, this method provided an estimate where compensatory responses to environmental variability are implicitly incorporated. Otherwise, values were taken from the literature and or adjacent areas (typically estimates from data for the EBS or GOA). Preference was given to values from similar areas first and similar period second.

Q/B

Q/B for marine mammals and seabirds was estimated based on energy requirement values provided by Hunt et al. (2000). For multispecific functional groups, Q/B was the weighted average of the individual species Q/B. Consumption rates for managed groundfish was estimated using the generalized Von Bertalanffy growth function

(Essington et al. 2001) fit to weight at age data from the AI and scaled to the 1991 age structure from the stock assessment when available. Otherwise, values were taken from the literature and or adjacent areas (typically estimates from data for the EBS or GOA). Preference was given to values from similar areas first and period second.

Diets

Cetacean diets were obtained from a NMML review conducted by S. Harkness (*unpubl*). Pinniped diets were supplied from literature with additional information contributed by E. Sinclair (*pers. comm.*). Diet composition for groundfishes and some skates was calculated from a detailed analysis of the food habits database of the Resource Ecology and Ecosystem Modeling group at the Alaska Fisheries Science Center. These estimates included bootstrap estimation of diet uncertainty. When available, stomach contents from samples collected in the Aleutians during 1991 and 1994 were used exclusively, other years were included as needed. When no samples were available from the Aleutians, samples from the closest subregions of the EBS or GOA were used. Diets for the rest of the species were provided from literature values. For any given functional group the proportion consumed of each prey item was either estimated directly from samples, estimated by preference (see description above, differences with standard Ecopath) or a combination of both (some individual prey items were assigned a fixed proportion while some prey clusters were estimated by preference). The resulting diets are shown in Tables 2.3 to 2.12 of Appendix A.

Fisheries

A total of 15 fisheries identified by gear and target species were incorporated into the model. Fisheries values include total removals of both target and non-target 'bycatch' species within the top 500 m. layer. Groundfish fisheries removals for target species are the sum of retained and discarded catches. The catches were derived from the NPFMC Blend database by averaging 1991 through 1994 values. Groundfish fisheries removals of non-target species were based on a bycatch analysis conducted for NMFS groundfish fisheries in its Draft Programmatic Supplemental Environmental Impact Statement (DPSEIS; NMFS 2003). The estimates were based on average bycatch rates calculated from data available for 1997-2000 from the Observer Program Database, which were then applied to the 1991-1994 average catches. Supplemental information for other fisheries came from state fisheries records (including subsistence catches) and the International Pacific Halibut Commission records for area 4B.

Pedigree

Pedigree is the degree of data quality according to specific criteria based on data precedence and characteristics. Christensen and Walters (2004) developed the criteria for assigning pedigree ranks; these have been refined for the current Alaskan models (Table 2.14, Appendix A). Based on these criteria the estimated Biomass, P/B, Q/B, Removals and Diet inputs were assigned a rank from 1 to 8 (Table 2.15 Appendix A) which corresponds to specific confidence intervals to be used in sensitivity analyses. Within the ranking system, 1 represents the highest data quality. The pedigree rank also facilitated the decision making process when selecting the input data to adjust during the balancing procedure.

2.3.6 Balancing

The purpose of the balancing procedure is to ensure that the data collected from individual species in an ecosystem satisfies the fundamental thermodynamic constraints when assembled as a whole. The risk of forcing a changing ecosystem into an inappropriate static form is avoided in practice by following strict criteria when changing input values. The model was balanced by proceeding from the highest to the lowest EE values that exceeded one. Parameters to be modified were chosen based on their pedigree; values with low data quality were adjusted before those with higher data quality. Alternative parameter values were either taken from the estimated parameter distribution (in the case of survey biomass estimates) or from published literature when available. Diets were only modified when they were taken from other systems and hence reflected a higher availability of specific prey items. Biomass accumulation terms were added when there was a clear known trend in the stock biomass during the modeled period. Remaining unbalanced groups with poor or non-existent biomass estimates were top-down balanced by assuming an EE of 0.8.

2.4 RESULTS

In this section I characterize the structure of the food web as defined by the NPFMC regulatory area for the Aleutian Islands. To do this, I identify its main components, the primary source of energy, and the groups that channel most the energy.

2.4.1 The food web of the NPFMC Aleutian Islands regulatory areas (central and western Aleutians)

The general numerical model results (data gaps, balancing issues, final parameter values, diets, fishery removals and pedigree rankings) for the central/western Aleutian Islands are found in Appendix A, Tables 2.2 to 2.15. Species descriptions and an explanation of the basic parameters are included in Appendix B.

The food web has 149 groups, 134 of which are predator/ prey groups and 15 are fisheries. There are 1813 links between predators and preys, and 506 additional links when fisheries are included. The visual representation of the food web is shown in Figure 2.2, where euphausiids and copepods are the most dominant groups of low trophic levels. The bottom up flow stems predominantly from planktonic groups (phytoplankton, euphasiids and copepods). This main source of energy is transferred up the food web through myctophids, forage fish, and squids giving the system its pelagic nature. Among the forage fish, myctophids dominates the biomass at mid trophic level. Flow through benthic routes is secondary. Within this route, non pandalid shrimps are an important prey for benthic feeders. The main top predators (TL 5.1-5.5) include transient orcas and all fisheries, except for the Atka mackerel, rockfish (mainly Pacific Ocean perch), and pollock trawl fisheries, crab pot, and salmon fisheries. These fisheries comprise the 'second tier' of top predators (TL 4.5-4.9) along with sharks and piscivorous marine mammals.

Rather than presenting results for the entire food web, detailed results are presented for the three fish species/groups with the largest biomass: Atka mackerel, Pacific Ocean perch (POP) and myctophids. All three are planktivorous species. Together, Atka mackerel and POP comprise 35% of the groundfish biomass and 33% of the total groundfish removals. Historically, they account for the largest (unsustainable) catches in the western and central Aleutian Islands. Myctophids comprise 50% of the estimated forage fish biomass (including cephalopods); their mortality from fisheries is minimal (<0.0001%).

Atka mackerel contributed 23% of the groundfish biomass and supported 28% of the total groundfish removals during the 1991-1994 period. It has been the main target species in the Aleutians since the early 1990s. Figure 2.3 shows a visual representation of the trophic links of adult Atka mackerel within the food web. Juvenile Atka mackerel (not shown) is eaten primarily by adult pollock (53%) and arrowtooth (24%). The trophic links vary in terms of their strength. That is, the amount of production contributed to/taken from groups connected to Atka mackerel. The largest amount of production transferred to one predator is 25% and goes to Pacific cod (their major predator), followed by that going to pollock (7%), large flatfish and skates. Overall, groundfishes account for slightly more than 40% of Atka mackerel's total mortality. Juvenile and adult Steller sea lions account for 30%. Atka mackerel are most abundant in the AI, with the population expanding intermittently to the GOA. They grow to a maximum of 55 cm and an age between 13 and 15 years. Assuming the food web estimates are reliable, the production of Atka mackerel is almost entirely consumed within the boundaries of the ecosystem (95%) with fisheries consuming ~20% of it. This makes Atka mackerel a key species in the food web not only because of its high abundance and importance as a fisheries target, but also because of its contribution as a prey item numerous groundfish and endangered marine mammals. For management then, both potential fisheries removals and availability of Atka mackerel to other species in the system is of major relevance.

POP supported the highest historical removals of any target species in the 1960's. Both total biomass and spawning biomass have increased monotonically since 1977 (Spencer et al. 2005). The population is currently at around 66% of its estimated biomass in the early 1960s. POP inhabit the outer continental shelf and upper slope. They are relatively small but long-lived fish with an estimated lifespan of 90 years (Spencer and Ianelli 2003). The population is managed as a shared stock with the EBS, but the majority of the catches take place in the central and western Aleutians where their abundance is estimated to be higher. POP has a large number of trophic connections with other groups in the food web. However, in contrast to Atka mackerel, the amount of its production transferred to predators and fishing is lower (17%) (Figure 2.4). If we assume the structure of the food web is reliable, sperm whales (currently depleted), fulmars and Kamchatka flounder consume about 4% each of POP's production. Unlike the Northern California Current, where juvenile rockfish have been shown to play an important role in the productivity of diving piscivorous seabirds such as auklets and murres (Field et al. *in review*), no such trophic relation has been observed at least for the western Aleutians (Springer et al. 1996). An additional 13% of POP's production goes to fisheries. Based on these results the large biomass of POP in the ecosystem gives it an dominant trophic role and its major management relevance is as a species exploited commercially.

Myctophids comprise a composite taxonomic group containing all lanternfish members of this family in Alaska. Most myctophids are less than 10 cm. long, but some reach up to 30 cm. They exhibit diel migration with peak abundances between 300 and 1200 m during daytime and between 10 and 100 m. at night (Nelson 1994). Acoustic surveys show the horizontal distribution of myctophids extends far off the shelf break, and overlaps marginally with that of pollock near the outer shelf and shelf break (Steven Barbeaux, *pers. comm.* see Figure 2.5.). The vertical migration and overlap towards the shelf seems to make them available to a wide variety of species in the system, and they have 20 trophic connections to groundfish alone. Its production goes largely to pollock (responsible for 30% of their total mortality), giant grenadier (23% of total mortality), and Kamchatka flounder (6 % of total mortality) (Figure 2.6). The latter feeds on myctophids almost exclusively, although this could be a bias in feeding habits due to the small sample size. Provided seabirds and killer whales consume forage fish in proportion to their abundance (as assumed in the model) then myctophids contribute substantially to the diet of killer whale's, albatrosses and kittiwakes. The number and strength of the trophic interactions of myctophids make them a key prey items across groups in the Aleutian Islands. Changes in the production of myctophids can have widespread effects across the food web, and for this reason, they are of management interest. Both production and distribution determine the availability of myctophids to the rest of the groups in the food web.

The distribution of squids coincides with that of myctophids (Steven Barbeaux, *pers. comm.).* Both squids and myctophids appear to be a major conduit of energy from adjacent pelagic waters into the shelf habitat of the Aleutians, a spatial subsidy (Polis et al. 1997, Loreau and Holt 2004, McCann et al. 2005). This influx of energy seems to occur throughout the top 500 m depth layer uninterruptedly, as they are consumed by species at relatively shallow depths (100-200m, like Atka mackerel) as well as at deeper ones (500m, like giant grenadier). Squids and myctophids seem to have overlapping distributions close to the shelf break, however predators consume them in different amounts. For example, Mud skates consume 86% squid, <1% myctophids, Greenland turbot 29 and 54%, halibut 22 and 2%, Atka mackerel 10 and <1%, pollock 2 and 22%. The only predator that consumes relatively equal amounts of squid and myctophids is giant grenadier, 44 and 46%. This suggests there is a strict partitioning of pelagic resources in the outer shelf, with some groups feeding on squid and others on myctophids. In addition, although squids are only 10% of Atka mackerel's diet, this species consumes 40% of the estimated production of squid. If squids are primarily available on the outer shelf, then the high total biomass of squid consumed by Atka could limit its availability to other predators that forage in the outer shelf/shelf break, in particular those foraging at the same depths. The split consumption along the shelf break of myctophids or squids make both these species a good candidate for monitoring. The relative contribution/ abundance/ availability of these species could provide insight regarding changes in the oceanographic characteristics and potential direct consequences throughout the food web. This potential, as an indicator of changes in the productivity/ routing of energy, makes it particularly relevant for management.

Since both myctophids and squids experience diel migrations and they consumed throughout the 0-500m depth layer, the resulting biomass and estimated consumption of these groups suggest the lower depth boundary of the model is open and has a high influx of pelagic prey. Other species, such as sablefish and shortspine thornyheads have continuous distributions beyond 500m (Jacobson et al. 2001), reinforcing the idea that the 500 m. limit does not reflect the ecosystem's lower boundary. The depth boundary at 500 m was chosen arbitrarily as a function of the information available. It reflects nothing more than the difficulty of finding trawlable grounds at lower depths. The use of trawl nets as the sole sampling device has turned the once random sampling stations into fixed ones; the effort needed to find suitable new trawling grounds being extremely time consuming. Because of this open bottom boundary and the model's bias to species/diets distributed above 500m deep, the predation mortality on deep fish may be underestimated, predation on rockfish may be underrespresented.

The discrepancy between foraging/distribution ranges and the area delimited as "boundaries" of the ecosystem is further supported by the high density estimates for zooplankton, phytoplankton, myctophids, squids, polychaetes and shrimp. All these were top-down balanced, meaning their biomass was estimated to satisfy their consumption by other populations in the model. It seems improbable that myctophids and squids are feeding on plankton produced solely within the boundaries of the ecosystem as defined. At least some portion of the biomass must be assumed to come from outside. Local production and imports are set *a priori* in Ecopath, and it is beyond the model's capacity to fine tune what is produced within the ecosystem and what permeates through its boundaries. It is not useful to scale the system's production with respect to the imports. Despite its open boundaries, the model is bound by the groundfish data. The fluxes and connections close to the main groundfish species represent the most accurate quantitative assessment available for the area. They validate the usefulness of the model as a way to identify the information relevant to management in an ecosystem context. The model also provides a useful framework to theoretically explore/guide field research on the connections between the shelf and shelf break regions of the Aleutian Islands and the surrounding pelagic realm.

2.5 DISCUSSION

In the results section, I characterized the food web of the Aleutian Islands by its source of energy, nature of its major conduits, and main components. Here, I compare this structure to that of the EBS and GOA by using the existing models (Gaichas 2006, Aydin et al. *in review*). All models are based on the NPFMC regulatory areas, and they essentially portray what the perception of each ecosystem is when using this delimitation of boundaries to define the spatial extent of each system. All three models were developed with standardized techniques and functional groups (Aydin et al. *in review*). To discuss whether the different structure of the ecosystems affect the role of a species within its food web, I focused on two species widely distributed throughout all three ecosystems: walleye pollock (a prey) and Pacific cod (predator). Each these species support support the main fishery across ecosystems.

2.5.1 Structure and nature of the Aleutian Islands, Eastern Bering Sea, and Gulf of Alaska

To facilitate this comparison, the approximately 140 groups of each model were aggregated into 23 groups. The main four commercial species in each ecosystem were considered as individual groups. Walleye pollock and Pacific cod support main fisheries in the three systems. Additionally, Atka mackerel and POP were isolated in the Aleutian Islands, yellowfin sole and snowcrab (Opilio) in the EBS, and Pacific halibut and arrowtooth in the GOA. The rest of the aggregated groups (which remain the same across food webs) are: fisheries, pinnipeds, toothed whales, sharks and skates, large flatfish, piscivorous seabirds, baleen whales, planktonic seabirds, pelagics, small flatfish, sea otters, rockfish and deep fish, crabs, shrimp, benthic invertebrates zooplankton, benthic bacteria, detritus and primary producers. A visual representation of the simplified food web for each ecosystem is shown in Figure 2.7

Quantifying the partition of basal sources of energy was found by Rooney et al. (2006) to be an accurate way of typifying a food web across terrestrial and aquatic systems. They concluded the partitioning among energy pools was usually asymmetric, but never complete. This was the case for the Aleutian Islands, GOA and EBS. The ratio of planktonic vs. detrital pools of energy gradually changes from primarily planktonic in the Aleutian Islands (68 to 30%), to slightly more planktonic in the GOA (52 to 44% to slightly more detrital in the EBS (44 to 54%). Accordingly, the major conduits of basal energy up the food web in each system are zooplankton and pelagics in the Aleutians, benthic invertebrates, shrimp and forage fish in the GOA and benthic invertebrates and zooplankton in the EBS. Figure 2.8. The physical characteristics of each ecosystem help explain this partitioning. Whereas the AI is a largely oceanic/exposed system with a very narrow, steep, rugged shelf, the GOA is a medium size shelf system with gullies bordered by the continental slope. The EBS in turn has a wide shallow flat shelf. This suggests that [externalities excluded], the physical environment determines the largest pool of basal energy available and hence the primary routing of that energy within a food web.

2.5.2 The different role of walleye pollock and Pacific cod depending on food web structure

The sources of mortality and diet for pollock across ecosystems are shown in Figure 2.9. As a prey, pollock is consumed mostly either by groundfish or humans (fisheries). The total joint mortality from these sources, relative to production, increases from 65% in the Aleutian Islands, to 80 % in the EBS and 98% in the GOA. The relative consumption by humans (fisheries) and groundfish is 1:1 in the Aleutian Islands, 1:3 in the EBS and 1:8 in the GOA. Putting it in different terms, either groundfish and humans may have equal access to pollock and competition is low in the Aleutian Islands, or groundfish may have eight times more access to pollock than humans and competition is high in the EBS.

Pollock's basic diet is characterized by its strongest links, i.e., the prey it eats the most. Euphasiids are the strongest strong link across systems and what contributes the second largest percentage are myctophids in the Aleutian Islands, shrimp in the Gulf of Alaska and copepods in the EBS. That is, the major conduits in each system make up 50 to 70% of pollock's diet.

Can we incorporate the facts above into the current quota estimation procedure? Under the system of the BSAI and GOA FMP, the Total Allowable Catch can be adjusted to account for bycatch, endangered species or any other concern. The flexibility to allow for adjustment to the catch of prey populations exists within the policy framework, regardless of the type of stock assessment model. This flexibility is a trade-off: the adjustments are not a routine process, and the routine itself does not have/need an objective quantitative basis (Goodman et al. 2002). The current framework is highly convenient for temporary/extraordinary circumstances, but is not adequate as a standard long-term practice, particularly when reference points are not available.

Collie and Gislason (2001) proposed to modify the TAC estimation procedure for prey populations so that the objective of the procedure is to maintain the total mortality of the prey population below a threshold relative to production. Such procedure would allow for a consistent criterion to base adjustment of the TAC for prey populations. This approach relies on a multispecies model and within the NPFMC, multispecies models are at different levels of development for Atka mackerel and pollock.

The second case study is Pacific cod. Figure 2.10 shows sources of mortality and main diet composition across ecosystems. Cod is a top predator, and its sources of mortality are very similar across systems. Fisheries removals account for 40% of the production across all systems. Cod regulates [through consumption] different populations: Atka mackerel in the Aleutian Islands and pollock in the EBS and GOA. In fact, the general type of prey in the EBS and GOA are very similar. Crabs and invertebrates, along with shrimp and pollock account for 70% of its diet. In the Aleutian Islands, the dietary complement is other fish, such as sculpins.

There are two basic management implications of cod's diet differences. On one hand, cod consumes a different portion of the production of Atka mackerel and pollock across ecosystems. On the other hand, fisheries removals of Atka mackerel and pollock impact cod differently, also across ecosystems. Cod's population is believed to have two stocks: one in the GOA, the second shared between the EBS and Aleutian Islands (with very dissimilar diets). The mechanisms for incorporating system specific effects in the future might be more challenging in the BSAI than in the GOA, as in the BSAI effects of each ecosystem have to be weighted with respect to each other.

One of the major concerns within EBFM is to incorporate/track the fisheries' effect of removing portions of prey and predator populations from the ecosystem (Link 2002, Brodziak and Link 2002). Tracking effects may be easier to implement in species which are regularly monitored. For species outside a regular sampling/monitoring scheme, it may be impractical or too costly to develop a routine system. This does not mean that these removals do not have an effect, rather the tractability of the effects may be limited by how effective, feasible and/or practical the current monitoring methods are.

The structure of the ecosystems as defined by the NPFMC seems to capture the dominant features of shelf system of the Bering Sea, the Gulf of Alaska and the central and western Aleutians. The differences in the oceanographic and physical attributes of these areas determine the ratio of detritus and plankton energy pools, which in turns favors benthic or pelagic routing up the food web. The effects of this routing can be appreciated in the changes in diet composition experienced by species common to all areas. It is questionable however that this arrangement of the ecosystem boundaries portray the eastern Aleutian Islands adequately. A biogeographical boundary at Samalga Pass seems to justify the division between the central and eastern islands. However, it is unclear which of the three food web structures do the eastern Aleutians resemble the most. Moreover, it is hard to accept the assumption that the eastern Aleutians not included in the AI model have the same structure as the EBS on the northern portion, while having a structure equal to that of the GOA on the south. In the next chapter, I assess the degree to which the local food web structure in the eastern Aleutian Islands resemble the food web structure of the rest of the central and western islands.

Table 2. 1 Basic information of the nine depth/location strata used for subregional biomass and diets in the Aleutian Islands Ecopath model.

Region *Depth*	*Eastern* *541*	*Central* *542*	*Western* *543*	*Total km^2*
Shallow 0-100	6848 (12%)	5847 (10)%	4880 (9%)	17,575 (31%)
Middle 100-200	7768 (14%)	4606 (8%)	5317 (9%)	17,691 (31%)
Deep 200-500	10584 (18%)	6090 (11%)	4996 (9%)	21,670 (38%)
	25,200 (44%)	16,543 (29%)	15,193 (27%)	56,936

Numbers in parenthesis refer to percent of total area, area values are in square kilometers (areas as estimated in database).

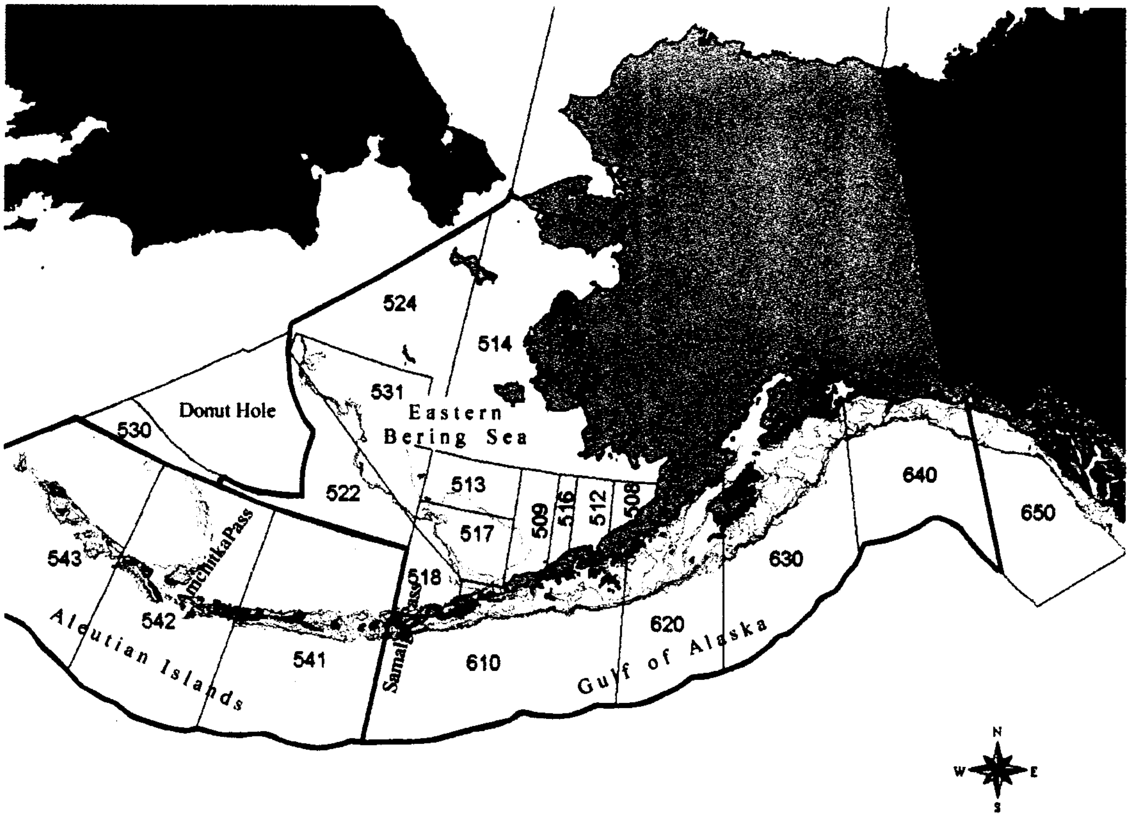

Figure 2. 1 Geographic coverage of the static food web model for the Aleutian Islands NPFMC regulatory area includes the statistical areas 541, 542, 543. The model is for the early 1990s and covers waters from 0 to 500 m deep. Shown in grey are depth contours down to 2000 m.

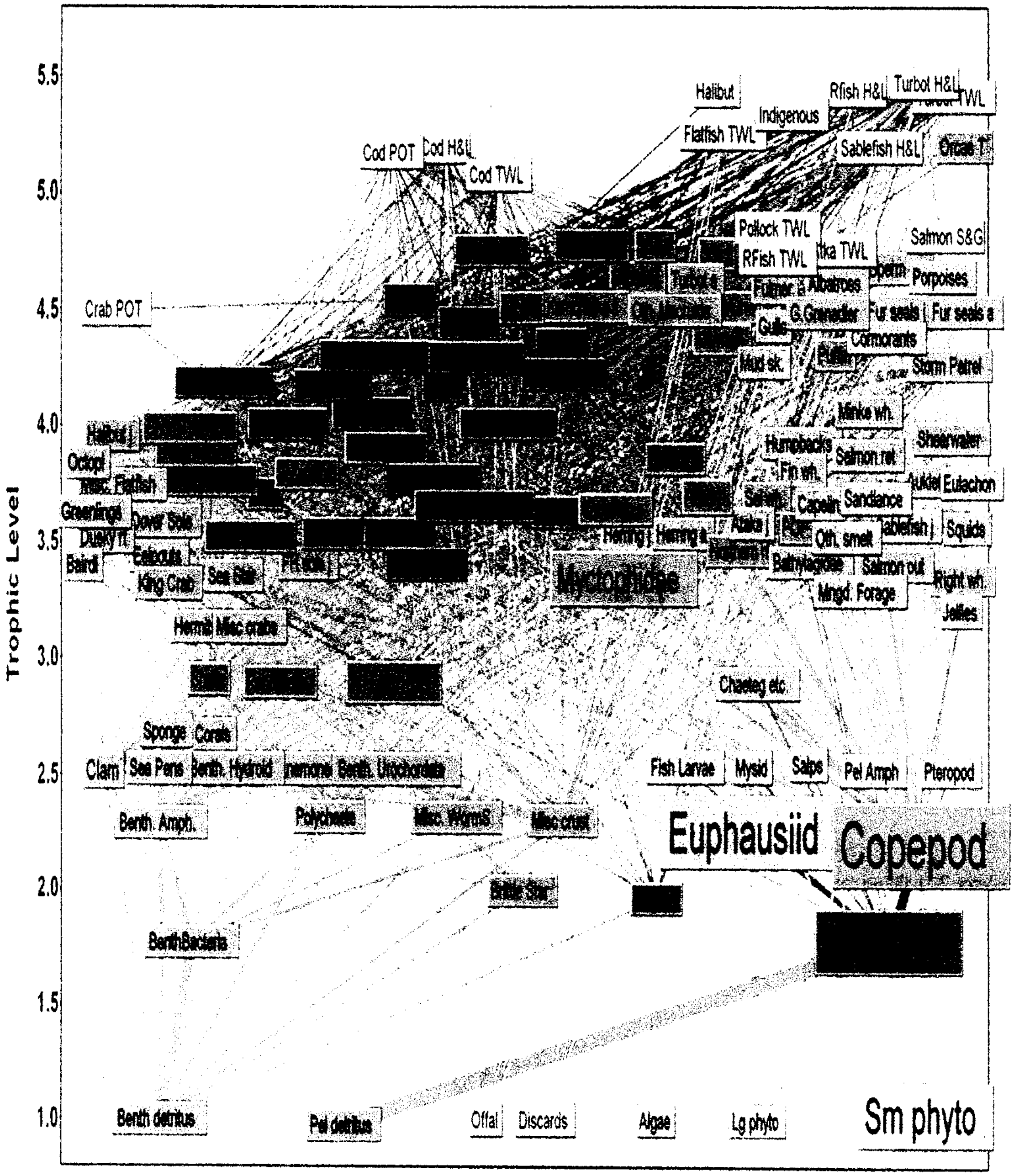

Figure 2. 2 Visualization of the Central and Western Aleutian Islands food web in the early 1990s.

Boxes represent functional groups, colors represent bottom up flow: green for flow from primary production, blue for flow from detritus and lilac orange flow from fisheries. Width of lines represents strength of flow.

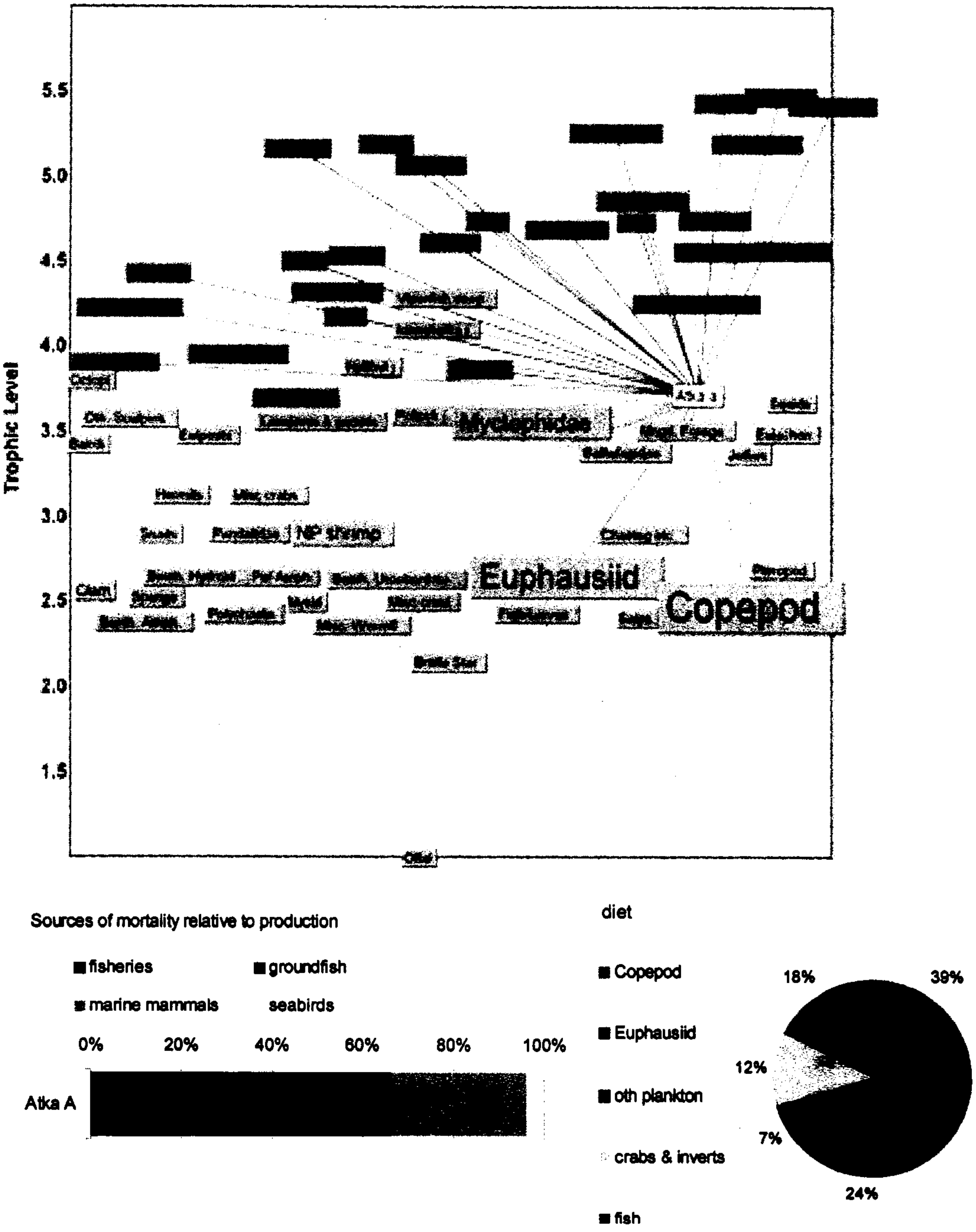

Figure 2. 3. Food web interactions of adult Atka mackerel in the Aleutian Islands during the early 1990s.

Left: food web diagram showing Atka in orange, predators or fisheries in blue and prey items in green. Predators include fisheries, pinnipeds, large flatfish, large sculpins and rockfish. Prey include zooplankton, forage fish, benthic invertebrates, small demersal fish, flatfish juveniles and pollock juveniles. Bottom left panel: bar chart highlights the main sources of mortality. Bottom right panel: pie chart shows feeding habits.

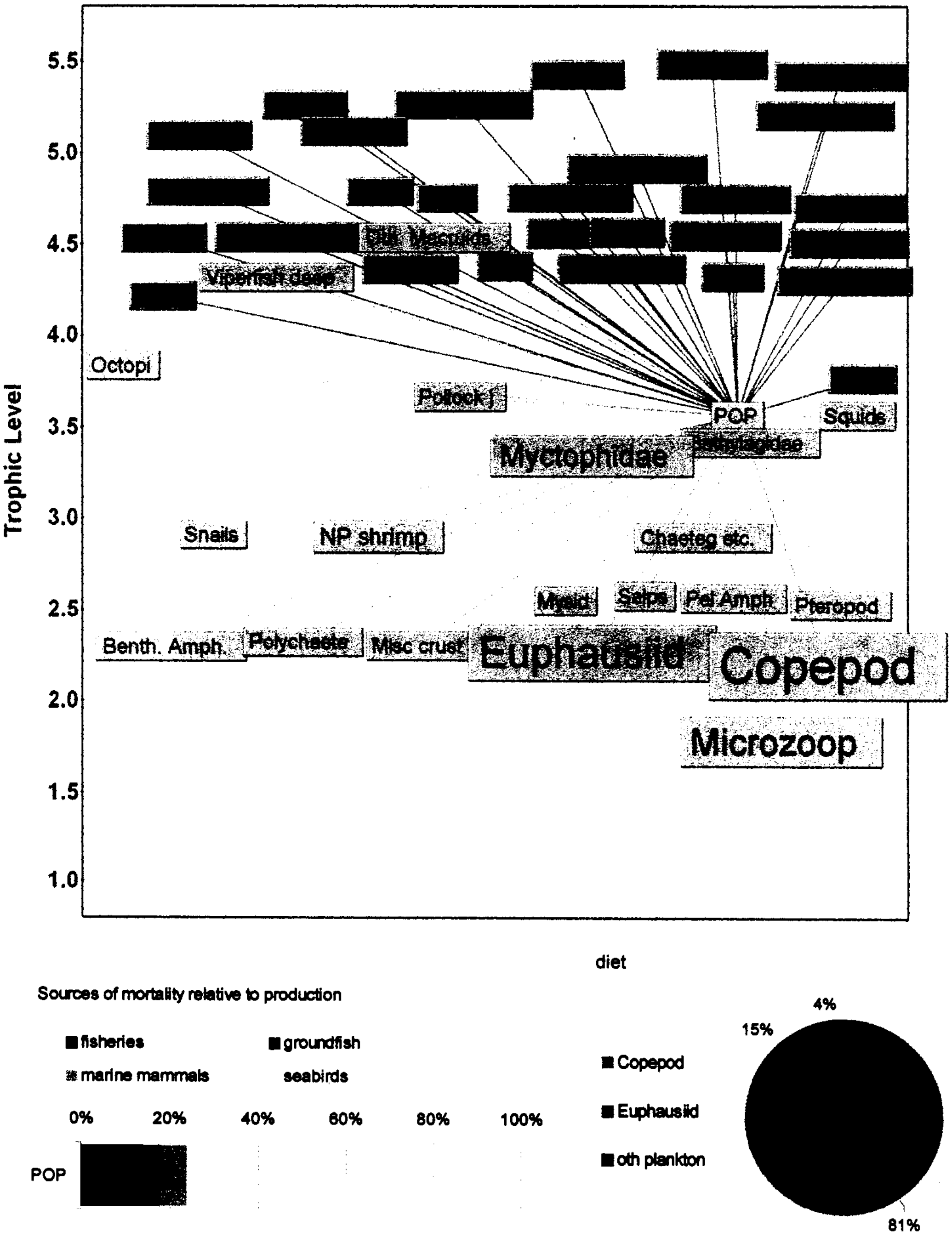

Figure 2. 4 Food web interactions of Pacific Ocean perch in the Aleutian Islands. during the early 1990s.

Left: food web diagram showing POP in orange, predators or fisheries in blue and prey items in green. Predators include fisheries, pinnipeds, sperm whales, sharks, seabirds (on juveniles), Pacific cod and Kamchatka flounder. Prey include zooplankton, forage fish, benthic invertebrates and small demersal fish. Botttom left panel: bar chart highlights the main sources of mortality. Bottom right panel: pie chart shows feeding habits.

Figure 2. 5 Acoustic biomass of pollock (green-yellow) and myctophids olong Aleutian shelf and slope (Image courtesy of Steven Barbeaux).

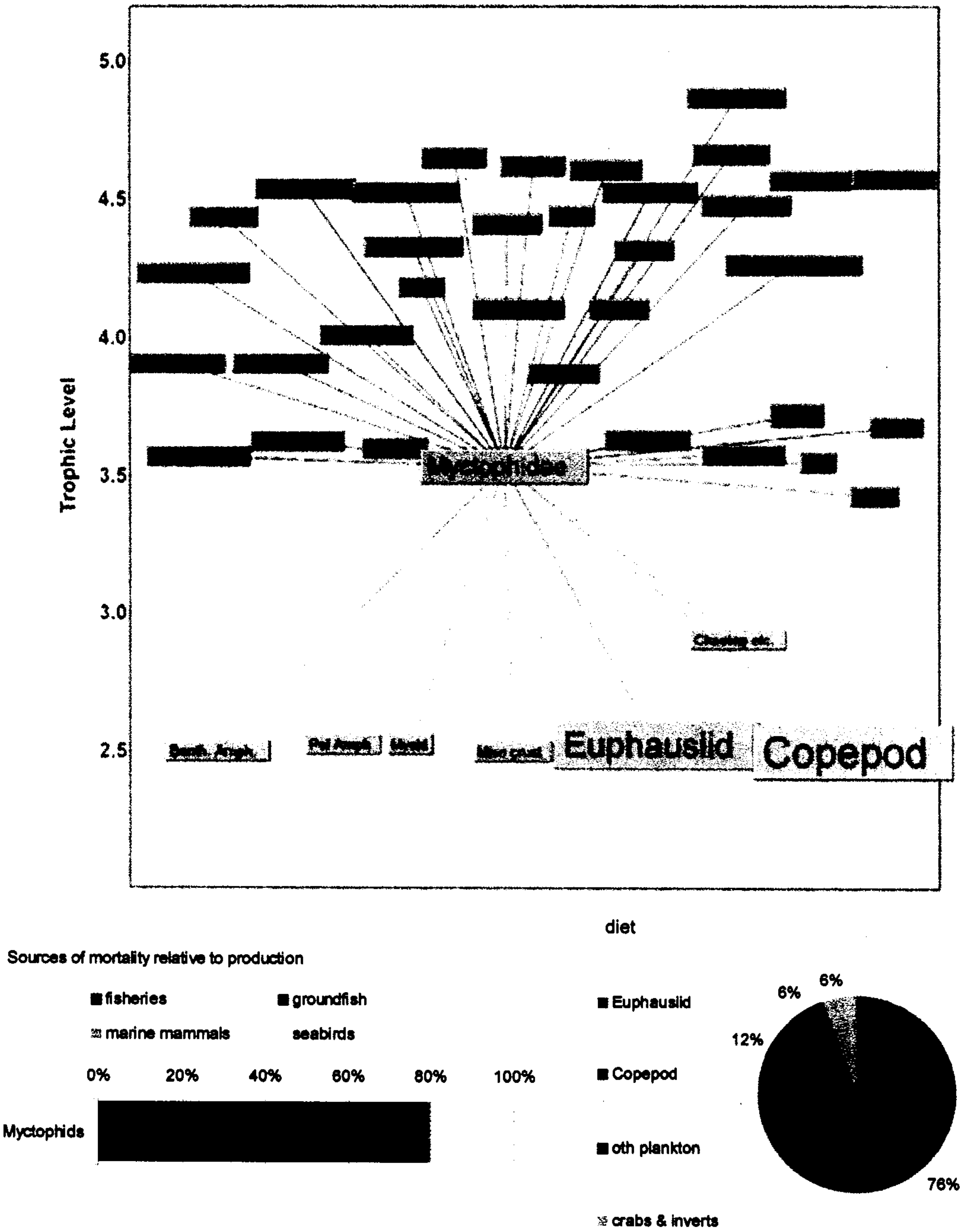

Figure 2. 6 Food web interactions of Myctophids in the Aleutian Islands during the early 1990s.

Left panel: food web diagram showing POP in orange, predators or fisheries in blue and prey items in green. Predators include fur seals and toothed whales, seabirds, skates, large flatfish, sculpins and rockfish and all main commercial groundfish: Atka, POP, sablefish, cod, pollock and halibut. Prey include zooplankton and benthic invertebrates. Bottom left panel: bar chart highlights the main sources of mortality. Bottom right panel: pie chart shows feeding habits.

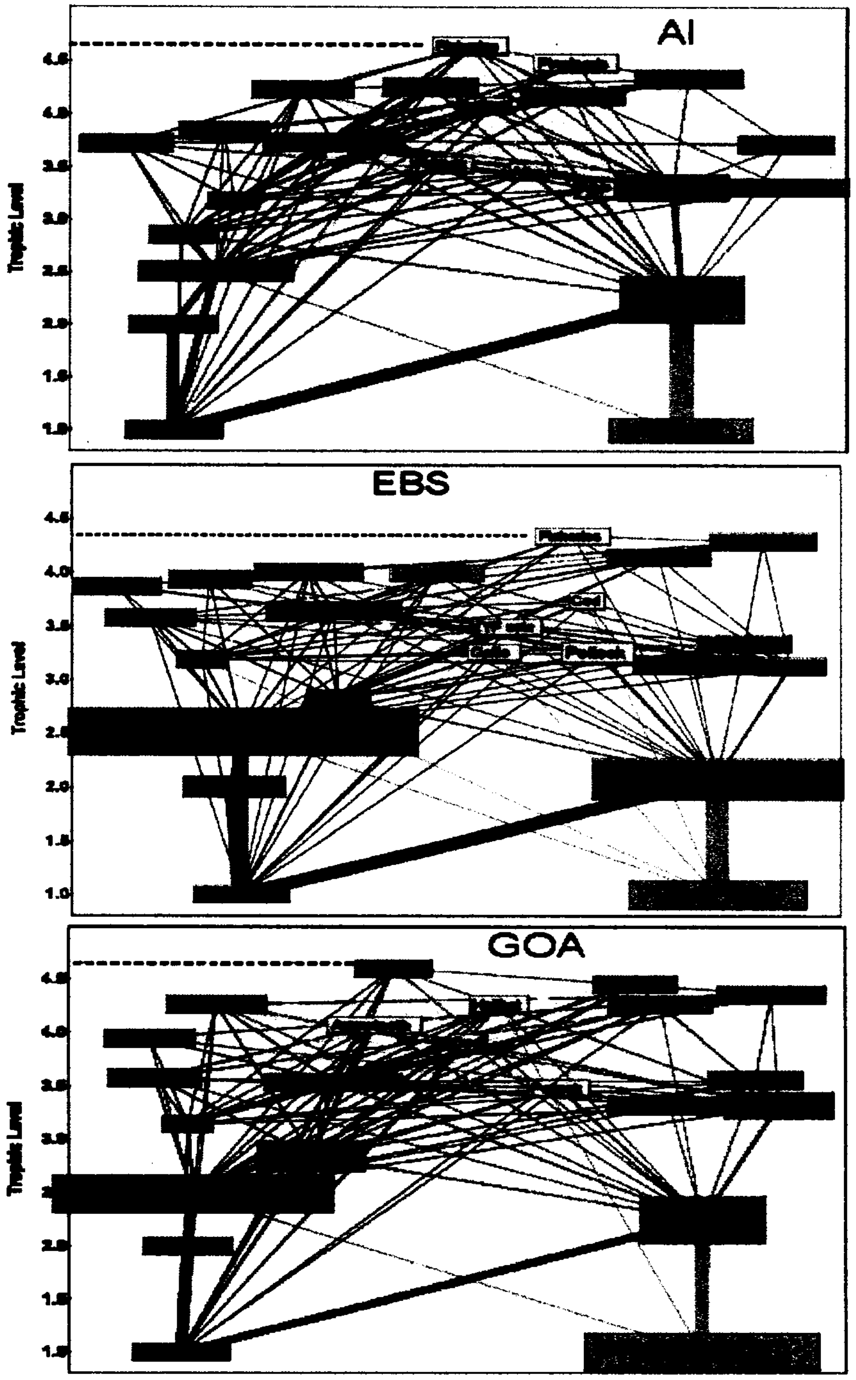

Figure 2. 7 Simplified food web of the Aleutian Islands (AI), eastern Bering Sea (EBS) and Gulf of Alaska (GOA) in the early 1990s

Boxes proportional to biomass, line width is flow strength. Blue is detrital flow, green primary production flow. Main commercial species in orange: pollock and cod are in all systems, Atka mackerel and Pacific Ocean perch (POP) in AI, yellowfin sole and crab in EBS, arrowtooth flounder and halibut in GOA. All other groups are the same in all foodwebs: fisheries, pinnipeds, toothed whales, sharks and skates, large flatfish, piscivorous seabirds, baleen whales, planktonic seabirds, pelagics, small flatfish, sea otters, rockfish and deep fish, crabs, shrimp, benthic invertebrates, zooplankton, benthic bacteria, detritus and primary production

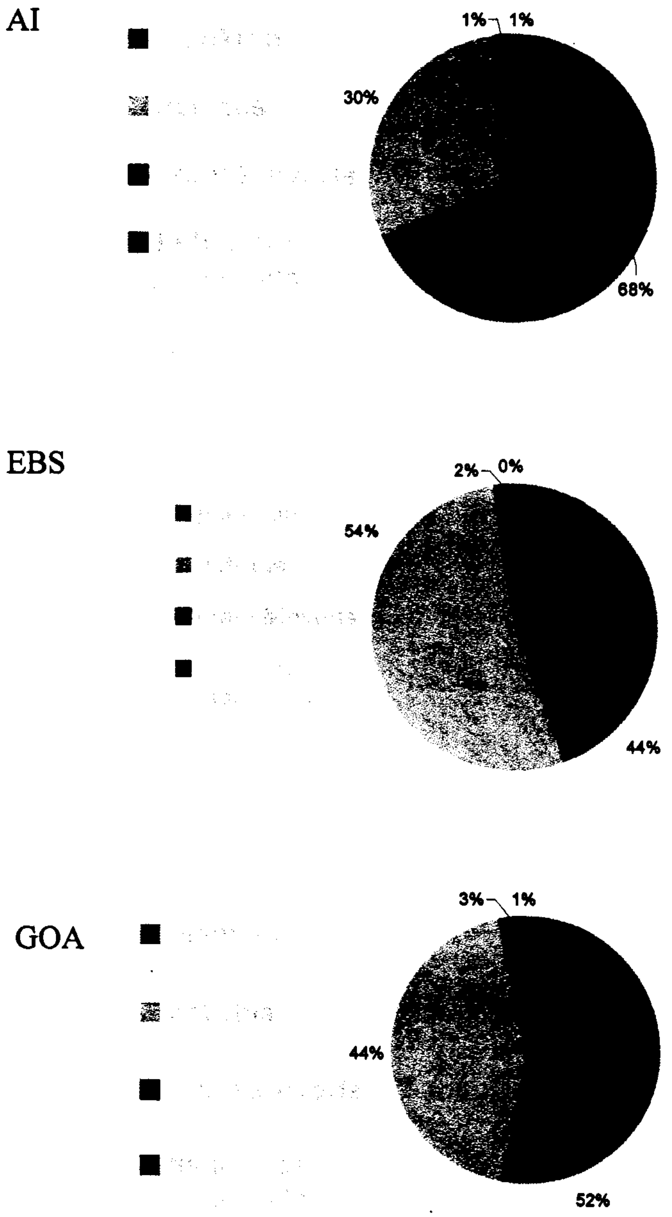

Figure 2. 8 Relative total comsumption in the ecosystems of major prey types. From left to right: Aleutian Islands (AI), eastern Bering Sea (EBS) and Gulf of Alaska (GOA).

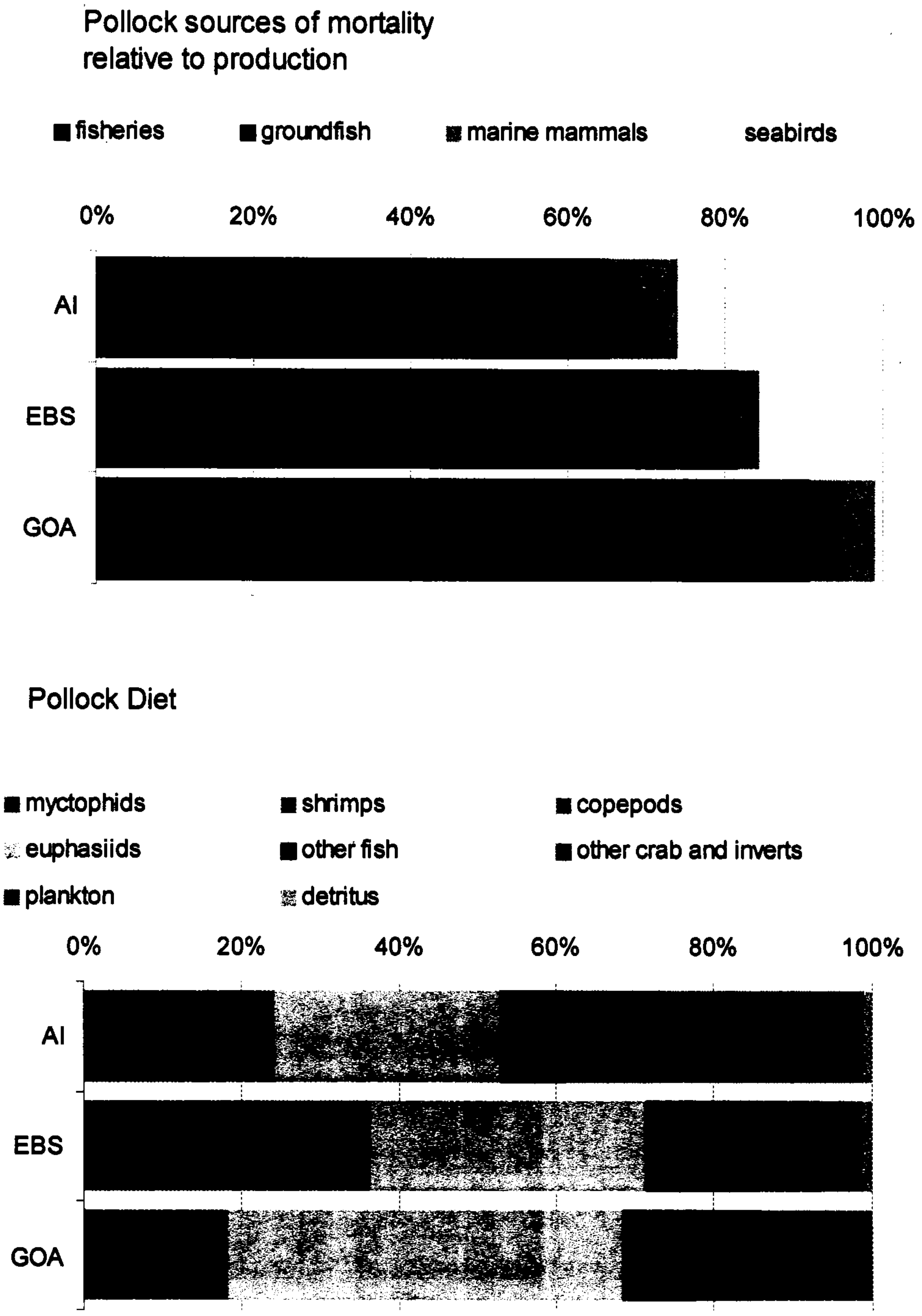

Figure 2. 9 Mortality and diet composition of adult walleye pollock across Alaskan ecosystems (AI, GOA, EBS) during the early 1990s. Top panel shows mortality relative to production; Bottom panel shows main two prey/ species and general diet in each ecosystem

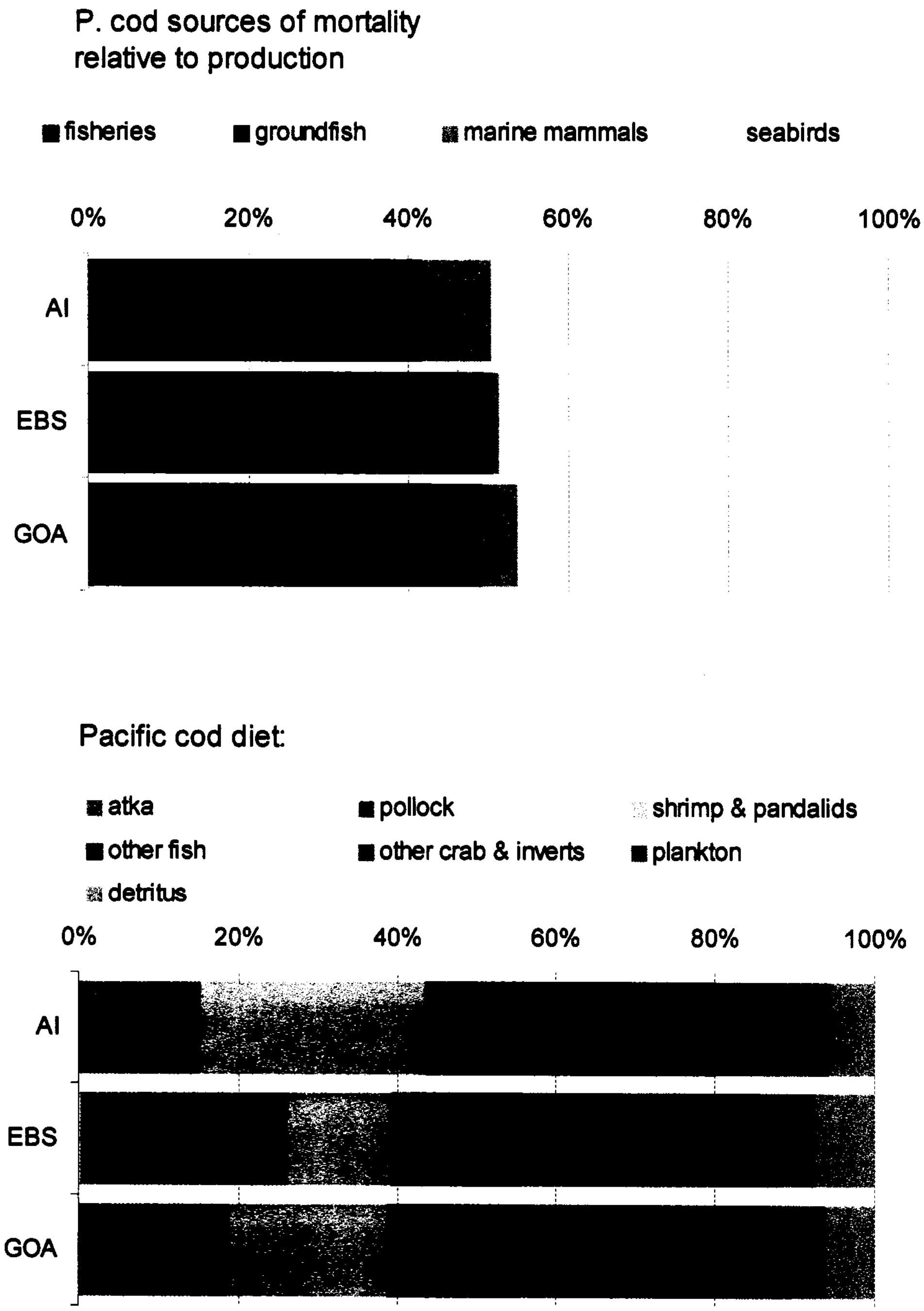

Figure 2. 10 Mortality and diet composition of adult Pacific cod across Alaskan ecosystems (AI, GOA, EBS) during the early 1990s. Top panel shows mortality relative to production; Bottom panel shows main two prey/ species and general diet in each ecosystem

Chapter 3. Changes in food web structure along the eastern, central and western Aleutian Islands

> *"Space not always matters, but when it does, to neglect it could produce major misunderstandings" Tilman and Kareiva 1997*

> *"Keystone is a particular configuration or structural organization of strong and weak links" Berlow et al. 2004*

3.1 SUMMARY

This chapter combines food web theory and spatial ecology in an empirical approach to explore changes in food web structure as a function of space. Thirteen simplified standardized static food web models covering 2-longitudinal degrees each were built across the Aleutian Archipelago from 170°E to 164°W. Food webs are based on biomass estimates of Steller sea lions, seabirds, Atka mackerel, Pacific Ocean perch (POP), walleye pollock, and Pacific cod as predators with detailed feeding habits specific to each two-degree area. Area-specific fisheries removals of Atka mackerel, POP, pollock and cod were also included in the food webs.

Two main spatial patterns determine the structure of the food webs. First, there is a longitudinal gradient from east to west along which the main prey supporting the food webs changes. Second, groundfish distribute vertically on the shelf at different depths. The combined effect of these factors structures the food webs into one of three general types. The first are food webs supported by pollock and various groundfish, with a gradually increasing proportion of myctophids and a decreasing proportion of euphasiids. The second are food webs supported by Atka mackerel, benthic invertebrates, myctophids and euphasiids. The third are food webs primarily supported by Atka mackerel, non decapod benthic invertebrates, copepods and euphasiids. Amukta and Amchitka Pass mark the breakpoints where the food web structure changes.

The longitudinal pattern is the result of large scale oceanographic processes which determine major physical attributes of the habitat and geographical boundaries for fish, playing a critical role in species richness (number of species) and species diversity (proportion of each species available within a unit of area). The Aleutian Islands is a long continuous string of islands separated by major passes: Samalga, Amukta, Amchitka and Buldir. These passes are geographical barriers of different magnitude for species from Asia and North America. The shelf area widens towards the east where it is connected to the shelf of the eastern Bering Sea and the Gulf of Alaska and narrows towards the west. The environment gradually changes from coastal characteristics in the east where flatfish and forage fish are more common, to oceanic characteristics in the west where demersal fish, myctophids and squids prevail.

In contrast, the vertical pattern results from small scale factors: amount available of shelf at depth and habitat partitioning. The relative position of the predators influences their access to prey. What the individuals eat most (strong links) is then the combination of what is available (through large scale processes) and what they can actually get to (local processes). The available resources are increased by spatial subsidies of myctophids and squids from adjacent pelagic oceanic waters and offal from fisheries.

3.2 INTRODUCTION

Advances towards ecosystem-based fisheries management (EBFM) have been centered on two of the main recommendations stemming from the report to Congress by the Ecosystem Principles Advisory Panel (EPAP): the development of large scale food webs and ecosystem indicators. Food webs provide a tractable map of trophic connections and interaction strengths among species in an ecosystem while indicators help monitor ecosystem structure and function, as well as environmental and fisheries variables (EPAP 1999; Blanchard et al. 2005; Boyle et al. 2001 & 2005; Boldt 2005; Cury et al. 2005; Link 2000). Within fisheries management, models, indicators and reference points tend to be estimated and applied in a non-spatial manner, at the level of stocks and management regions under the assumption of even implementation across the system. (Pauly et al. 2003). However recent studies have acknowledged the relevance of spatial processes in marine populations, from effects in life history and population parameters to dynamics of species interactions and effects on foraging and spawning distributions (Agostini 2005; Pelletier 2001). Just as traditional management actions have been recognized to have consequences at the ecosystem level, so have they been recognized to have spatial consequences on the distribution of fishing effort and removals, affecting local communities differently. Accordingly, spatially explicit approaches have started to emerge in EBFM literature, mainly dealing with zoning and spatial indicators based on overlapping fishing, foraging, and distribution areas (Walters 2002; Babcock et al. 2005; Freón et al. 2005). These approaches do not deal with food webs and interaction strength directly, and EBFM faces the same question as general food web theory in which spatial aspects have gone largely ignored (Brose et al. 2005): how does food web structure change when space is included? To quote Steinberg and Kareiva (1997) "*In theory* it can make a huge difference, but we don't know how often *in fact* it does make a difference". There is a gap between theoretical and empirical studies of spatial food web dynamics.

Incorporating space into the study of food webs highlights landscape heterogeneity, trophic interactions, and the spatial partition of resources via competition, facilitation and biotic disturbances that allows the coexistence of species and function of communities (Polis 1997; Berlow et al. 2004). Understanding how food web structure changes across space then, requires a joint approach from food web theory and spatial ecology.

Food web theory, in essence, attempts to draw organizational rules from general patterns of trophic connections. It has centered on how the composition and dynamics of a food web can vary according to predator-prey interactions, life history traits and nutrient/ detrital processes. At its core, it is based on the number of species in a web and the number of trophic links among such species, addressing issues of species richness, connectance, community stability, web complexity, top down and bottom-up controls, resilience, and the loss and addition of species (extinctions and invasions) (Paine 1988; Cadenasso 2004).

In contrast, spatial ecology has two main branches, community ecology and landscape ecology, each emphasizing local and regional spatial scales respectively. Traditionally, spatial community ecology deals with persistence and coexistence of local populations in space. In contrast, landscape ecology concentrates on ecological patterns, processes and interactions with adjacent ecosystems or patches integrating spatial flows (or subsidies) of organisms, inorganic nutrients, and energy across habitats, explicitly addressing the permeability of boundaries (Cadenasso et al. 2004; Loreau et al. 2003). Spatial flows have been shown to enable higher abundances of local populations than what in situ production would allow (Polis 1997; Callaway 2002; Schindler and Lubetkin 2004; Witman et al. 2004) and can even be the primary supplies for entire ecosystems (Huxel et al. 2004). Spatial flows are particularly relevant to the Aleutians Islands trophic structure, where myctophids and squids from adjacent pelagic zones appear to subsidize local groundfish populations of pollock, Pacific Ocean perch and giant grenadier (chapter 2).

A joint approach of food web theory and spatial ecology has to integrate food web structure across regional and local spatial scales while capturing the heterogeneity and complexity of the system. However integrating food wed structure across scales poses several challenges, and each scale has its advantages and disadvantages.

Traditional regional food web models, including those for large marine ecosystems, attempt to capture species richness and system complexity. However they are often constructed based on cumulative observation over time and/or space, giving the appearance that all trophic links and species abundances happen uniformly in time and space. The total number of species can greatly exceed that which coexists in any one given patch, habitat or community (Wilson 1992). Competition hierarchy theory alone would predict a reduced number of species coexisting in the exact same place and time by excluding inferior competitors from their preferred habitat, which is a non random selection. Succesively inferior competitors become increasingly aggregated over non random areas by virtue of successive site selection processes. And so it is the partition of space [and time] that reduces the intensity of competition, allows coexistence and increases the number of species in a natural ecosystem (Chesson 2000; Tilman et al. 1997; Pacala and Levin 1997).

In regional models, studies comparing habitat-specific [or local] food webs have shown that a food web's spatial location can have critical implications for the identity and interactions of organisms in the web, as well as the production, storage and movement of nutrients and detritus. Interactions among individuals and with the environment are a response to local conditions (McCann et al. 2005, Wilson 1992). The combined effect of spatial flows, competition and species' range and movement pose multiple constraints on the way species are connected, which result in unique, non random food web structures (Martinez 1993, Montoya and Sole 2002, Dell et al. 2005).

Therefore, how can multiple scales be linked? Bond and Chase (2002) suggest ecosystem function and biodiversity at local and regional scales can be linked by assuming that complementarity drives community assembly at both levels. That is each species falls into a particular functional role, and so in heterogeneous landscapes some functional roles are site specific, allowing for regional coexistence without local coexistence. Site specific and general functional roles can be filled by both permanent and temporary residents. As residents move individually and interact within the range of their movement and/or distribution, patterns arise (Pacala and Levin 1997; Levin 2002). Looking at trophic interactions specifically, individuals —as consumers— link food webs in space, and the embedded spatial structure combined with behavioral responses influence dynamics in food webs (McCann et al. 2005). This approach (like ecosystem ecology) spans across ecosystem and habitat types, levels of organizational complexity and spatiotemporal scales (Levin 2001; Sears et al. 2004; Huxel et al. 2004).

Presumably then, a regional food web can be decomposed into multiple food webs of similar scale but different spatial location within the ecosystem. A similar concept of multiple parallel systems embedded in a whole stands behind the concept of meta-communities (Wilson 1992). This construction would allow the exploration of spatial processes behind changes in food web structure, local and regional species coexistence and the spatial patterns arising from these interactions. By constructing spatial food webs from actual data, such exploration would be empirical, rather than theoretical, addressing the gap between empirical and theoretical studies in spatial food web dynamics.

In this chapter I present an empirical approach to explore changes in food web structure (with fisheries) along the Aleutian Archipelago by applying both food web theory and spatial ecology. I do this by constructing a series of contiguous static standardized food web models of similar scale based on stomach samples along a longitudinal continuum, from 164°W to 170°E. I then explore the spatial processes behind changes in food web structure, and use them to identify patterns which in turns may be used to define regions within the Aleutian Archipelago.

3.3 METHODS

3.3.1 Model approach

In order to explore changes in trophic structure across space, biomass, feeding habits and fisheries must be spatially allocated. I partitioned the extent of the Aleutian Archipelago, from 164°W to 170°E into thirteen contiguous 2-longitudinal degree areas. I then built thirteen food web models based on biomass, feeding habits and fisheries estimates allocated among these 2-degree areas. The models cover the shelf area down to 500m depth (Figure 3.1). There is no other connection among the food webs except for their respective eastern and western boundaries, which are purposefully arranged in a longitudinal continuum. The equations for the static food web models are the same as those used in Ecopath (Christensen et al. 1992;

Christensen and Pauly 2000), the platform for the model in chapter 2. The difference is I have relaxed the mass balance assumption, and have assumed the systems are open. That is, the consumption does not have to be satisfied by the production generated within the spatial extent defined for the food web. To construct the food webs in this chapter, the left portion of the equality in Equation 1 is unnecessary. However in Chapter 4, I compare the production to removals by predation and fisheries, which does require the left portion of Equation 1.

The master Ecopath equation, for each functional group *i* with predators *j*, is:

$$B_i\left(\frac{P}{B}\right)_i * EE_i + IM_i + BA_i = \sum_j \left[B_j * \left(\frac{Q}{B}\right)_j * DC_{ij} \right] + EM_i + C_i \qquad \textbf{Equation 2}$$

where: *Bi* and *Bj* are biomasses; *P/Bi* is the production/biomass ratio (equivalent to total mortality, Z, in most cases (Allen 1971)); *EEi* is the fraction of total production (*B*(P/B)*) consumed within or caught from the system (*i.e.,* ecotrophic efficiency); *Ci* is the fisheries removals; *Q/Bj* the food consumption per unit biomass of *j*; *DCij* is the contribution of *i* to the diet of *j*; IM_i and EM_i stand for mass moving in and out of the system respectively (not used in the AI model); and BA_i is the biomass accumulation. EE_i is hard to measure in the field and is usually the unknown to be estimated when the equation is solved, but any one of the four key parameters (B, P/B, Q/B, and EE) can be estimated –provided the remaining parameters are specified. In practice, the equations are solved mostly for either *B* or *EE*.

3.3.2 Geographic coverage

The model covers 94,541 km^2, from 164°W to 170°E and from surface to 500 m. deep. It is based on the Aleutian Islands and western Gulf of Alaska survey strata, designed by the Resource Assessment and Conservation Engineering (RACE) Division of the Alaska Fisheries Science Center. The survey strata cover the area contiguous to land masses along the Aleutian Islands. The corresponding fisheries management areas are 541, 542 and 543 of the Aleutian Islands management region, 610 of the Gulf of

Alaska management region, 517, 518 and 519 of the Eastern Bering Sea management region as defined by the North Pacific Fisheries Management Council (NPFMC) (Figure 3.1). Each food web model covers an area spanning 2-longitudinal degrees and is hereby referred to by the longitude of its eastern boundary. For example, the area extending from 164°W to 166°W is denoted in graphs by 164° W. In geographic terms, the areas are located as follows:

i) Eastern Aleutians (east of Samalga Pass): areas 164°W, 166°W, and 168°W.

ii) Central Aleutians (roughly between Samalga Pass and Amchitka Pass): areas 170°W, 172°W, 174°W, 176°W and 178°W.

iii) Western Aleutians (west of Amchitka Pass): areas 180°W , 178°E, 176°E, 174°E and 172°E.

The geographic range was selected to model the entire Aleutian Archipelago, irrespective of management areas. The size of each area, 2-longitudinal degrees, was selected to ensure a minimum number of stomach samples analyzed(>10) for the groundfish species. The exception was area 172°E where no stomachs of Pacific cod were available and the averaged feeding habits in areas 174 and 176°E were used as proxy. The longitudinal extent of the areas is approximately 130 km long, and this was considered a sufficiently large area as to cover the primary summer range/movement of most species and hence form a local summer food web.

Within each 2-longitudinal degree area (here in 2-degree areas), the system is assumed to be homogenous with free mixing of all species. There are some caveats to this assumption. The vertical distribution of fish varies across areas, likewise for the fisheries. The number of stomachs available for each 2-longitudinal degree did not allow vertical stratification of the diets. What is best represented by these models are "trawlable and fishing grounds"; that is, areas accessible to aerial/ trawl survey and fishing gear (longline, pots and trawlers) down to 500 m. Table 3.1shows the area in km^2 by depth layer for each 2-degree area.

3.3.3 Defining the period

The base period for biomass and fisheries estimates is 1990-1994, with data from stomach collections spanning from 1981 to 2001 with a majority of the stomachs collected between 1987 and 1996. This period covers two bottom trawl surveys in the Aleutians (1991 and 1994) and the Gulf of Alaska (1990 and 1993), and is the primary data source for groundfish. Steller sea lions biomass estimates are from 1991-1994, seabird estimates come from more recent years, 1997-2002. The models are annual, but fish and Steller sea lion diets are derived from summer collections (for the most part) and many of the seabirds are only found in the Aleutians during the summer (May-September). Fish growth and consumption rates are scaled to totals; the annual averages were used as it is believed that most consumption occurs during summer. No temporally dynamic modeling was done for the AI.

3.3.4 Defining the functional groups

The level of spatial resolution restricted the number of functional groups for which all parameters (*PB, QB, B, DC,C*) were available, including spatial specific biomass estimates and diet composition. Seven groups (plus fisheries) comprise the 'predators' in the food web. These seven groups are Steller sea lions (SSL), planktivorous (6 species) and piscivorous (10 species) nesting seabirds, Atka mackerel, Pacific Ocean perch (POP), walleye pollock and Pacific cod. These four groundfish are commercial species and have accounted for 85% of total catches in the NPFMC area of the Aleutian Islands from 1991 to 2005. In the EBS and GOA these species make up 86 and 67% of the catch respectively. By including these species, the models portray primary interactions between the commercial species and components of the food web.

The prey items of the seven predators were grouped into the same categories as those for the Ecopath model in Chapter 2. Categories contributing 10% or more to the diet of any predator in any 2-degree areas were left as individual functional groups. The rest of the prey categories were aggregated into more general functional groups. Including predators and prey, there are a total of 25 functional groups and 1 for fisheries (Table 3.2). The group 'other groundfish' groups all the prey items which individually contributed less than 1% to cod's diet (e.g., viperfish, poachers, snailfish). All groups include adults and juveniles combined. Table 3.3 of the Appendix shows seabird species by feeding strategies.

3.3.5 Assembling estimates of biomass, PB, QB, diet, and fisheries

Data were supplied from the following agencies and programs: RACE, AFSC and Resource Ecology and Fisheries Management (REFM), also from AFSC. Additional data were collected from the US Fish and Wildlife Service (USFWS). The following is a brief description of the general data sources and estimation techniques for spatial partitioning of the biomass, diet composition and fisheries removals. The values of P/B and Q/B ratios were the same as those estimated for the Ecopath model of Chapter 2, for which the methods are detailed in the appendix for Chapter 2. A more extensive explanation of the methods and estimation techniques of the P/B and Q/B ratios is available from Aydin et al. (*in review*).

Biomass

Steller sea lion numbers were the average of 1991 and 1994 abundance of non-pups at rookeries and haulouts in the Aleutians as estimated by a spatial model (Fay 2003). Rookeries and haulouts were assigned to specific 2-degree areas according to their location. Weights at age for female, male and pregnant females (Winship 2001; York 1994) were averaged to get an average weight (ages 1-24). These average weights were then used to convert the number of non pups at rookeries and haulouts into biomass estimates. Seabird colonies were assigned to specific 2-degree areas according to location. Species specific biomasses were calculated by multiplying colony counts in each 2-degrees area by the average body weights for each species (Hunt et al. 2000). Colony counts for nesting seabirds are available from the Beringean Seabird Colony Catalog (2002-2003) maintained by the USFW. To estimate groundfish biomass for each 2-degree area (B_{block}), hauls per RACE survey strata per year were allocated to each 2-degree area and the mean strata biomass estimate (B_s) was proportioned according to the sum of the weighted (CPUE) in each one. The 2-degree area survey strata estimates for each year were then averaged.

$$B_{block} = \sum_s \left[\frac{B_s}{\sum CPUE_{block} / \sum CPUE_s} \right]$$

Areas from 170°W to 164°W were based on 1991 and 1994 mean biomass estimates from the AFSC/ RACE Aleutian Islands bottom trawl surveys for the north side of the islands. For the south side of the islands, the mean biomass estimates of 1990 and 1993 from the AFSC/ RACE bottom trawl surveys for the Gulf of Alaska were used. Areas from 170°W to 170°E were estimated as the average of 1991 and 1994 mean biomass estimates from the AFSC/ RACE Aleutian Islands bottom trawl surveys.

Diets

Diets for Steller sea lions during 1990-1998 were obtained from the National Marine Mammal Laboratory diet database for Steller sea lions. Frequency of occurrence data was assigned to the 2-degree areas according to location. Diet composition for groundfishes was calculated from a detailed analysis of the REFM food habits database, with stomachs collected assigned to their corresponding 2-degree area. Table 3.4 shows the number of stomach samples available for each species per 2-degree area. Note no samples were available for Pacific cod in the westernmost area 172°E. In this case the feeding habits of cod in areas 174 ad 176°E were averaged and used as proxy for 172°E. Stomach samples were collected between 1981 and 2001 in the AI, EBS and GOA with most collected between 1986 and 1997. Feeding habits of nesting seabirds were obtained from Hunt et al. (2000), modified by information from Dragoo et al. 2004 and data from the Birds of North America database (http://bna.birds.cornell.edu/BNA/). Only one diet composition for each seabird species was obtained. The diet composition of nesting seabirds for any one area was calculated by weighting each species diet by the proportion of its biomass relative to total seabird biomass in that area, and then adding the different species diets:

$$DC = \sum_j \left[\frac{DC_{ij}}{B_j \Big/ \sum_j B_j} \right] \qquad \textbf{Equation 3}$$

Interaction strength

I defined interaction strength as the percent contribution of a prey to a predator's diet. A link is defined as a connection between a predator and a prey. Strong links were identified as those functional groups which contributed at least 10% to the diet of predators in any one 2-degree area. Prey items contributing 10% or more on average were considered strong links. Links contributing less than 10% in one area are considered weak links. Note the same predator-prey link can be a strong in one area but weak in another.

Fisheries

Fisheries removals were calculated for Atka mackerel, Pacific Ocean perch, walleye pollock and Pacific cod. Fisheries values include total removals which are the sum of retained and discarded catches of all fisheries with all gears. To estimate area specific removals, records from 1991 to 1994 from the NMFS Observer database were allocated to the NPFMC management areas in the proximity of the Aleutian Islands based on their geographic coordinates. Catches (C_{area}) were based on the total removals in NPFMC statistical areas 541, 542, 543, 610, 517, 518 and 519 (see Figure 3.1). Year and species-specific removals ($F_{block,s,y}$) in each 2-degree area were calculated as:

$$F_{block,s,y} = \frac{\sum R_{500block,s,y}}{\sum R_{500block,s,y} \Big/ \sum R_{500area,s,y}} * \frac{\sum R_{500area}}{\sum R_{500plusarea,s,y}} * C_{area,s,y} \qquad \textbf{Equation 4}$$

Where $R_{500block,s,y}$ are the observed removals at less than 500m depth, within each 2-degree area for year y and species s. $R_{500area,s,y}$ are the observed removals at less than

500m depth within a statistical area (*area*). $R_{500plusarea,s,y}$ are the observed removals at depths greater than 500m within a statistical area. C_{area} are the total removals within a statistical area (for species s, year y).

3.4 RESULTS

Feeding habits, bionmass estimates and fisheries removals are included in Tables 3.5 to 3.10. The results are presented in four parts: i) general characteristics of the food webs, ii) biomass distribution and shelf area, iii) feeding habits and interaction strength, and iv) fisheries.

3.4.1 General Characteristics of the food webs

The general structure of the food web models is presented visually in Figure 3.2 and the compared trophic structure of the thirteen food webs is visually represented in Figure 3.3. The groups in the consumption portion of Figure 3.3 have been ordered (top to bottom) by trophic level.

Longitudinal trends.

There are two inverse longitudinal trends in predator biomass (circles in Figure 3.3). Piscivorous birds and pollock decrease from east to west while planktivorous seabirds, Atka mackerel and POP increase. Both Pacific cod and Steller sea lions show no apparent trend and are distributed all along the archipelago. In general, zooplankton accounts for 50% of the consumption in the food webs, with copepods and euphassiids as the major prey items. Euphasiids are overall consumed in a higher proportion towards the east, while copepods and a variety of other zooplankton are consumed more towards the west. Among the fish, consumption of pollock and forage/ bathylagiids fish is higher towards the east and of Atka mackerel towards the west. Myctophids, cephalopods and 'other groundfish' are consumed all throughout. Invertebrates, particularly polychaetes, are consumed in higher proportions towards the west. Finally fisheries removals are higher in the east than the west.

General food web patterns

The combined longitudinal trends in biomass, consumption and fisheries give rise to different food web patterns. From area 164W to 170W (eastern Aleutian Islands) there is a strong decrease (from 65 to 10%) in the consumption of euphasiids and a strong increase (from 3 to 30%) in the consumptions of oceanic pelagics (myctophids and cephalopods). Pollock and cod make up two thirds of the groundfish biomass and seabirds are mostly piscivorous. Pollock is the dominnat fishery.

From area 172W to area 178W (central Aleutians), seabird biomass remains mostly piscivorous but drops sharply from 300 tons on average in the eastern Aleutians to 50 tons. The biomass of Atka mackerel increases significantly and constitutes 45% of the groundfish biomass as opposed to 17% in the eastern Aleutians. As pollock biomass decreases from east to west, this is the area where of groundfish switches from pollock (in 172W) to Atka mackerel (176-178W). This area also shows the highest consumption of other groundfish. Localized high consumption of specifc prey is also observed: euphasiids (174W), shrimps (176W) and benthic amphipods (178W).

The westernmost areas (180W to 172W) seabird biomass increases again (100 tons on average at each area) and is characterized by dominated by planktivorous seabirds (except area 174E). Atka mackerel and POP make up 80% of the groundfish biomass. The consumption of copepods and other non euphasiid zooplankton increases from a maximum of 20% in the eastern and central Aleutians to 36% on average. Polychaetes become a main prey, and the main fisheries are Atka and cod.

3.4.2 Biomass distribution and shelf area

In general, the shelf area (<200m) available along the Aleutian Archipelago decreases from east to west in a stepwise fashion marked by the deepest passes Yunaska/Amukta, Amchitka and Buldir Pass. The three major regions marked by the passes roughly correspond to the eastern Aleutians (east of Samalga Pass), central Aleutians (between Samalga and Amchitka Pass) and the western Aleutians (west of

Amchitka Pass). (Figure 3.4). The general convention is to divide the eastern and central Aleutians at Samalga Pass, because of the observed changes in oceanographic and biological characteristics. However, in terms of shelf area, Yunaska and Amukta at area 170°W are deeper (~400 m) than Samalga in area 168°W (~230m) and shallow shelf areas (<100m depth) are less available. The pass marks one of the 'steps' in the decreasing density of Atka mackerel and POP from west to east . There are no islands in area 172°E, only submerged land masses, and hence both nesting seabirds and Steller sea lion colonies are absent as permanent summer residents of this area. While recognizing that foraging seabirds and sea lions might frequent this area there is no quantitative abundance estimate that would enable their inclusion as part of the food web model in this area.

At a large scale, there is a correspondence in the longitudinal distribution of seabird and groundfish biomass (Figure 3.5). That is, in general seabirds and groundfish diets shift from predominantly piscivorous to predominantly planktivorous. The longitudinal trend in the distribution of piscivorous and planktivorous seabirds has been observed and studied in previous seabird biogeography studies. The planktivorous seabirds in the western Aleutians are primarily auklets, several of which are known to be restricted to highly productive upwelling areas, and are absent in the warmer waters of the Gulf of Alaska (Stephensen and Irons 2003). Most seabirds along the Aleutians have breeding grounds in the western Bering Sea as well (Shuntov 1999), so the shift from piscivorous to planktivorous reflects the overall lower abundance of shallow (<50m) small fish resources. The exception is area 174°E where both nearshore and offshore piscivorous seabird colonies dominate. Most seabirds throughout the archipelago are offshore diving feeders, the exception being northern fulmars which are primarily surface feeders and have one of their largest colonies near large passes, notably Samalga Pass and Buldir Pass (Byrd et al. 2005).

Steller sea lion abundance shows no longitudinal pattern. However, the highest abundances of Steller sea lions were all located near the largest passes, from east to west: area 168°W and 170°W where Samalaga, Yunaska and Amukta Pass are located, area 178°W where Amchitka Pass is, and close to Buldir Pass. The lowest abundance of SSL was at area 178°E coinciding with the highest local density and biomass of Atka mackerel (Figure 3.5 and 3.6).

The longitudinal trends in fish distribution are better viewed as densities per depth layer, and are shown in Figure 3.6. Atka mackerel and POP density increases significantly towards the west and they are split vertically, with Atka mackerel staying mostly above 200m depth and POP between 200-300m depth. In contrast pollock and Pacific cod inhabit a variety of depths. Pollock moves from shallow waters (<200 m depth) in the easternmost areas (164W-166W) to deeper waters (>200 m) towards the west where it shares the 200-300 depth layer with POP. Pacific cod remains mostly within 100 to 200 m depth, in between Atka mackerel and pollock but closer to whichever is more abundant. This is visually displayed in Figure 3.7.

3.4.3 Feeding habits and interaction strength

The collective diet of seabirds reflects the shift from piscivorous to planktivorous feeders as you move west. Diets switch markedly west of 178°W, albeit this shift is more representative of feeding resources available in a broader offshore area than that covered by the model. Seabirds are known to take foraging trips lasting several days during the nesting season. Pollock and forage fish are strong links throughout the archipelago, cephalopods are strong links in the westernmost areas and myctophids are strong links where storm petrels and kittiwakes are abundant. (Figure 3.8, top). Planktivorous seabirds feed on euphasiids and copepods mostly (Figure 3.8, bottom). Both are strong links.Towards the west diet diversifies as the percent of diet comprised of "other zooplankton" increases". Cephalopods, although consumed, are not a strong link for planktivorous seabirds. Dragoo et al. (2004) analyzed diet data at key colonies in Alaska and found euphasiids and copepods are common zooplankton items while Pacific sandlance, pollock and squid are frequent fish prey. Byrd et al. (2005) note that Samalga Pass is not a break point for the distribution of breeding seabird colonies, but distance to large passes is important for surface-feeding piscivores. This does not apply to nearshore feeders and rather the relatively extensive shallow shelf areas available in area 174°W help explain their high biomass in this area (Springer et al. 1996).

Feeding habits of Steller sea lion also show a strong regional component with pollock, and salmon contributing a large proportion east of area 170°W. To the west, Atka mackerel and cephalopods (squids) make up the largest portion of the sea lion's diet. These five species along with Pacific cod constitute the strong links (Figure 3.9 Table 3.5). Diet diversity increases east of 176°W where prey items are consumed more evenly and there is a lerger portion of weak links (blank space in Figure 3.9). Diet diversity has been found to be positively correlated to local SSL population trends, with rates of decrease being lower where diet diversity is high. In turn, diet diversity increases as a function of pass depth, with higher diet diversity at shallower passes in the central and eastern Aleutian Islands. The breaks by 2 longitudinal degrees do not necessarily coincide with the location of the passes, but in general areas with a larger amount of shallow shelf (<100m) do appear to have more weak links and strong links are consumed in more even proportions (Table 3.5). East of Samalga Pass population trend has been positively correlated with occurrence of herring and salmon. (Merrick et al. 1997; Sinclair and Zeppelin 2002; Sinclair et al. 2005).

Strong links of Atka mackerel include 9 functional groups (Figure 3.10, top). From east to west the consumption of euphasiids decrease as diet diversifies, with copepods, polychates and other zooplankton being consumed in the westernmost areas. POP is the groundfish with least diversified diet, with only 5 strong links in its diet which account for over 70% of its diet across all areas (Figure 3.10, bottom and Table 3.6). Both pollock and Pacific cod also have a diversified diet with 9 strong links (Figure 3.11), same as Atka mackerel. Moving to the west, pollock's diet shifts from mostly euphasiids and gelatinous zooplankton in the easternmost areas, to a diet dominated by myctophids, euphasiids and pollocks in the central areas and finally a very low consumption of myctophids in the westernmost areas along with increased proportions of euphasiids, gelatinous zooplankton and localized high consumption of shrimp and

Atka mackerel. Localized areas throughout the archipelago (e.g., 172E, 174W) also have a variety of weak links (Table 3.7).

Three prey species constitute consistent (across most areas) strong links of Atka mackerel, POP and pollock: euphasiids, copepods and myctophids (Tables 3.6 and 3.7). For Atka mackerel, only euphasiids and copepods are consistent strong links. For POP, all three are consistent strong links and for pollock only euphasiids and myctophids. POP and pollock are distributed at similar depths and their cumulative consumption of copepods, euphasiids and myctophids appears to be inverse. POP consume a larger proportion of myctophids west of area 180°W than towards the east (except at 170°W, nearby Samalga Pass). The reverse is true for pollock: myctophids constitute a larger portion of its diet east of 180°W, which decreases to the west. The prevalence of myctophids in POP's diet coincides with its biomass increase west of 180°W. A linear regression of the ratio of pollock to POP density versus the percent of myctophids in pollock diet shows a positive correlation (R^2_{adj}=0.59) (Figure 3.12). This suggests some level of competition between pollock and POP either for myctophids directly or some spatial issue that favors access to them, where the proportion of myctophids in each species diet increases as a function of density.

Finally, Pacific cod has a suite of consistent (i.e., across most areas) strong links that include Atka mackerel, sculpins, rockfish, crabs, shrimps and pollock, forage fish and "other groundfish" (Figure 3.11, bottom). West of area 176°W Atka mackerel contributes between 40 and 70% to Pacific cod's diet, east of area 176°W pollock increasingly accounts for 10 to 60% and forage fish are consumed in a higher proportion. Myctophids are a strong local link at link 170W (Table 3.8).

The degree of specialization (or lack of) of the predators can be evaluated by the number of strong links and their cumulative contribution of each species' diet (Figure 3.13). Planktivorous seabirds have three strong links which explain 100 to 95% of their diet while Steller sea lions and Pacific cod have 7 and 10 strong links each explaining 93 to 78% and 95 to 84% of their diets respectively. Based on the number of links and their contribution to diet, the feeding strategy can be thought of as a continuum from specialists to generalists with planktivorous seabirds at the specialist end and sea lions and Pacific cod at the generalist end. Generalists evolve if there is a switching benefit, specialists if there is a switching cost (Ma and Levin 2006). In this sense, peak abundances of planktivorous seabirds are aggregated over a small set of islands while Pacific cod and sea lions, with a wide distribution range benefit from having a wide variety of prey items.

3.4.4 Fisheries

The density of the fisheries removals of Pacific cod, pollock, Atka mackerel and Pacific Ocean perch is shown in Figure 3.14. Not surprisingly, the highest density of removals of the four groundfish is towards the east where fishing ports are near. In general, the easternmost areas support higher removals of pollock while removals west of area 176 W are mainly of Atka mackerel and Pacific cod combined.

The results detailed above show that from the combination of longitudinal trends in biomass distribution, feeding habits and fisheries removals, three general food web patterns can be discerned. These patterns are not represented by abrupt changes, rather they are best represented by gradients with major passes influencing the steepness of such gradients. The strong links in the diets of predators capture at least 78% of the diet of any of the predators. These strong links represent the major conduits of energy up the food webs. The type of prey items available the archipelago depend of both the amount of shelf available and the influence of the coastal waters from the Gulf of Alaska.

3.5 DISCUSSION

The results section presented the individual results of distinct characteristics of the food web components and environment. Here, I discuss spatial processes and tie trophic and non-trophic interactions observed to change food web structure along the Aleutian Archipelago.

There were two main spatial patterns affecting the structure of the food webs. The first is a longitudinal gradient along which both predator and prey compositions change (Figures 3.8 and 3.11). The second is a depth gradient along which predator biomass concentrates in distinct order (Figure 3.7). These patterns can be related to two main processes: oceanography and habitat partitioning, and are discussed below.

3.5.1 Oceanography as a structuring force of food webs

In the Aleutians, oceanography determines major physical attributes of the habitat. It also defines geographical boundaries for fish and marine mammals, playing a critical role in species richness (number of species), and species diversity (Heifetz 2004; Heifetz 2005; Ladd et al. 2005; Logerwell et al. 2005; Sinclair et al. 2005). All these processes operate at large scales.

The Aleutian Islands is a long continuous string of islands separated by major passes: Samalga, Amukta, Amchitka and Buldir. These passes are geographical barriers of different magnitude for species from Asia and North America. The shelf area widens towards the east where it is connected to the shelf of the eastern Bering Sea and the Gulf of Alaska and narrows towards the west (Ladd et al. 2005; Logerwell et al .2005; Stabeno et al. 1999). Species richness determines the variety of prey types available. The only study on fish species richness and community structure covering the entire Aleutian Archipelago is that presented by Logerwell et al. (2005). The study included 63 species of non contiguous distribution along the Aleutian chain and found there was a 28% decline in the number of demersal fish species (within 500 m depth) between Unimak/Samalga and Amukta Passes. The number of species remained relatively constant between Samalga and Amchitka and declined again (20%) west of Buldir Island.

Both flatfish and forage fish are found in the easternmost areas (east of 170W), they are much less common to the west. Towards the west, coastal forage fish and flatfish are much less common and instead, demersal fish are more frequent. While the number of samples increased significantly towards the east, the consistent lack of prey items within the small and large flatfish categories for all predators reflects the decline of these type of species towards the west.

Species diversity can be understood as the overlapping biomass densities across species which determine the local proportion of each species present. Empirical work on natural food webs (Paine 1992, Power and Mills 1995, Wootton 1997) show interaction strength is skewed towards a few strong links and many weak ones. Some studies have argued weak links may be unimportant over time if they represent rare feeding interactions (Pimm et al. 1991; Schoenly and Cohen 1991). This assertion was made in view of the overriding prevalence of time and space cumulative food webs with mismatched scales, where prey common over large areas mask the importance of locally relevant prey items that could influence predator population dynamics over time (Martinez and Dunne 1998). The results presented here show the latter is the case. If only consistently strong links are considered, the predators modeled here have between one and three strong links. If instead, strong links are defined as groups contributing significantly to diet at any one given area, then the number of strong links increases between 6 and 10 (Tables 3.5 to 3.8). Links that are strong at only particular locations are alternative energy pathways which keep the flow of energy uninterrupted, from basal sources to higher levels of the food web. For example, myctophids are a strong link for Pacific cod at only one area (170W), however at this area they comprise 18% of Pacific cod's diet (Figure 3.11, bottom). This constant flow prevents the fragmentation of food webs and potential loss of species due to 'blocked' energy passage. This has important implications for the management of biodiversity. At a large scale, it can identify a set of key species on which the food web largely relies on for its energy requirements. Disturbances on these species can potentially fragment the food webs by 'closing' food-web wide energy pathways. At a small scale it can identify local pathways and emphasize the protection of locally important species.

The gradient of coastal to oceanic characteristics as one moves from east to west, and species richness and the increase in diet diversity within food webs suggest the entire area of the eastern Aleutians, from 170°W to 164°W is a transition area. They are located at the confluence of the arctic influence from the eastern Bering Sea, the warmer waters from the Gulf of Alaska and the deeper colder open ocean waters from the western and central Aleutians. Being delimited by Samalga Pass on the west, the coastal shelf of the eastern Aleutians becomes the main bridge for population mixing between the north and south, east and west. Most areas of confluence are usually rich in biodiversity (Levin et al. 2001; Araújo 2002). This might be the case for the eastern Aleutians as well.

3.5.2 Habitat partitioning and food web structure

To talk about habitat partition we must first define habitat. I follow Agostini's (2005) definition, whereby habitat refers not only to physical structures but to the characteristics of the water column as well. In that respect, the food webs modeled here move through a series of contracted and expanded habitat dependent on the amount of shelf and depth, (Figure 3.4 and 3.7). Habitat partitioning refers to the position of the predators with respect to each other and is the result of multiple species interactions. An individual's location within the habitat usually determines access to prey (Lehman and Tilman 1997, Pacala and Levin 1997). The importance of competition as a structuring force of food webs has been tested by Quince (2005) and Gaichas (2006) who carried out a large number of simulations of multispecies food webs modifying parameters regulating predator-prey relationships. They found only a small set of parameter combinations allows coexistence of a large number of species. The displacement of pollock by POP may illustrate the mechanics of one of such competitive interactions, where competition for prey is mediated through space and does not require total exclusion among competitors. Location just gives an advantage, and allows for competitors to exist, albeit in less productive patches.

A similar mechanism may regulate the access that Steller sea lions and Atka mackerel have to squid. Atka mackerel spread throughout the shelf, however only individuals located near the shelf break can consume the squid that comes up along the slope during their diel migration. At low densities, Atka mackerel consumes a lower portion of the squid available. Both Atka mackerel and Steller sea lions would get access to squid in these cases. However, at high densities Atka mackerel can consume a major portion of the squid's production (~40%) as it comes up (see Chapter 2), out-competing Steller sea lions which have to cross the shelf and dive to access squid. Again, it is the location of the predators in space [and time] which determines access to prey.

3.5.3 Patterns in food web structure

The combined effect of large and local scale factors structures the food webs into one of three general types:

i) food webs supported by pollock and various groundfish, with a gradually increasing proportion of squids and myctophids and a decreasing proportion of euphasiids (164W to 170W),

ii) food webs supported by Atka mackerel, pollock, benthic invertebrates, myctophids, and euphasiids (172W to 178W), and

iii) food webs supported by Atka mackerel, non decapod benthic invertebrates, copepods and euphasiids (180 to 172E).

Amukta and Amchitka Pass mark transition areas where the food web structure shows stronger partial changes. Most functional groups are distributed throughout the archipelago. However, as seen from the patterns in total consumption, the amount consumed of each group changes depending on its location. As Berlow et al. (2004)

point out, the relevance of any one given species lies on the particular configuration or structural organization of strong and weak links.

The last type of food web represents the eastern Aleutian Islands. These islands are managed under the EBS and GOA regulatory areas of the NPFMC. Although both regulatory areas have food web models representing their respective ecosystems, both fail to accurately represent the food web in the the eastern Aleutians (area 164 W to 170W). Figure 3.15 compares the consumption of the seven predators between the EBS, GOA and eastern Aleutian Islands (average areas 164W to 170W). Most notably, myctophids are underrepresented as a key prey item and the combined consumption of benthic invertebrates (shrimp, crabs and benthic amphipods) is over estimated.

Myctophids are common among the three food web structures. They are consumed all along the archipelago. Schools of myctophids and squids overlap the edge of the shelf and self break, and extend faroff shore (Barbeaux et al. 2005). The models only include the shelf down to 500 m depth. Thus, it is unlikely that the myctophids and squids consumed come entirely from local communities. At least some level of spatial coupling occurs between these local communities and regional pools. If that is the case, then the archipelago receives a substantial subsidy from adjacent pelagic waters. Polis et al. (1997) define a spatial subsidy as a donor controlled resource (prey, detritus, nutrients) moving from one habitat to another that increases the productivity of the recipient habitat. The relevance of subsidies for local productivity depends on the permeability of the system and the potential for resource utilization. The ratio of perimeter-to area, currents and upwelling all increase permability or openness (Holt 2004; Witman et al. 2004). The Aleutian Islands have a large perimeter-to-area ratio to its area, are separated by passes and characterized by tidal currents and passes. More than 20 groundfish have direct trophic connections with myctophids, 18 to squids (see Chapter 2). These facts suggest the archipelago is a subsidized system where productivity on the shelf down to 500 m highly benefits from input from adjacent pelagic areas. A different type of subsidy would be that of offal from fisheries, which shift the energy favoring scavengers and in some areas support an important portion of the local consumption by groundfish. The risk of depending on subsidies is the expected low productivity when these resources are missing (Huxel et al. 2004).

The present analysis is restricted to trophic-related spatial processes. It has not taken into account the role habitat structuring species such as living substrates (corals, sponges, sea whips) which combine to provide a large variety of habitat types. For example, the 69 taxa of corals have distinct associations to groundfish (Heifetz et al. 2005). Rockfish and Atka mackerel are frequently associated with gorgonian, cup and hydrocorals, whereas flatfish and gadiids are found mostly with soft corals (Heifetz 2004). While corals are not well represented within the trophic flows of food webs, they could be an influential factor in determining the distribution and diversity of fish and invertebrates.

In addition to habitat types, temporal variations in environmental conditions and species abundance in the Aleutian Archipelago may also influence the structure of food webs. As mentioned in Chapter 1, these processes can occur over several years or be episodic; they can also be local or regional. Climate variability has been observed at regional scales both as trends over several years (e.g., the Pacific Decadal Oscillation) or episodic events (e.g., strong storms), tsunamis and volcanic eruptions act at local scales and species abundance has changed at both scales in response to natural phenomena and resource exploitation (Angliss and Lodge 2004, Berkh 1823, Black 1981, Rodionov et al. 2005). Such changes give rise to a wide variability in functional roles, favoring one set of species over another. For example, stronger winds during 1981 and 1983 are believed to have enhanced nutrient flux from the Gulf of Alaska to the eastern Bering Sea and northern portion of the eastern Aleutian Islands, favoring feeding conditions for Tanner crab larvae and strong recruitment in the following years (Bond 2005).

As spatial and temporal variability limit and enhance niches expand and contract, different functional roles and species may be benefited or resticted. The actual mechanisms of interspecific interaction and coexistence in a community, determine the dependence of population, community, and ecosystem processes on diversity (Tilman 1999). However the unpredictability of spatial and temporal variability does not allow the prediction of future interactions and coexistence, and thus the maintenance of biodiversity becomes a safeguard against the potential disruption of these processes (Chesson et al. 2002). Biodiversity must be maintained in order to allow food webs to persist through unpredictable changes across space and time.

The thirteen contiguous food webs developed here serve as replicates to explore how predators adjust to changes in food web structure across space. Because the populations of these predators are distributed over larger spatial areas than those covered by any individual food web model, the food webs are spatially correlated. Neighboring food webs may represent alternative states with different dominant species which do not completely exclude their competitors. The complementarity between alternate food webs facilitates regional coexistence (Loreau 2003, Bond and Chase 2002). The variation within the three general food web structures hint at feasible directions in which the system may respond to changes in species abundance and composition.

Fisheries removals can move the structure of food webs along a range of states by modifying the degree to which species coexist. This proportion refers not only to total abundance but to density, which affects density-dependent interactions. The effects of fisheries are cumulative with those from environmental sources and local population dynamics. So individual impacts, although small, can have a greater effect when added to the rest. The natural variability in populations and environmental conditions can not be controlled, but the magnitude, frequency and location of removals can. Understanding the range and correlations of food web structures existing within an ecosystem may inform management of the impacts of and for fisheries removals. The challenge for ecosystem-based management is to find a way in which to minimize and mitigate these impacts. In the next chapter, I explore how a cross comparison of food webs and fisheries at multiple scales can provide insight to establish some impact mitigation/ minimization strategies.

Table 3. 1 Area included in the model by depth and 2 longitudinal degree area

Longitude	*172E*	*174E*	*176E*	*178E*	*180W*	*178W*	*176W*	*174W*	*172W*	*170W*	*168W*	*166W*	*164W*	*Grand Total*
100 m	94	2,949	1,115	1,750	2,567	1,194	2,100	2,795	2,493	516	3,522	4,524	9,717	35,336
200 m	461	2,797	1,615	1,333	1,902	1,381	1,516	2,783	2,664	1,249	2,152	3,713	5,880	29,445
300 m	196	353	939	440	881	857	378	661	1,094	2,937	1,069	1,061	1,074	11,941
500 m	352	553	1,893	844	2,066	1,252	534	436	1,425	3,623	882	2,691	1,268	17,819
Grand Total	1,103	6,652	5,562	4,368	7,416	4,684	4,528	6,674	7,676	8,325	7,624	11,989	17,939	94,541

Table 3. 2 Functional groups included in food webs and their corresponding trophic level (TL based on aggregated food web of the NPFMC regulatory area of the Aleutian Islands shown in Figure 3.2)

TL	Functional groups included in food webs
4.2	other groundfish
4.2	flatfish
4.2	Pacific cod
3.7	pollock
3.7	Attka mackerel
3.6	rockfish
3.6	rephalopods
3.5	sculpins
3.5	salmon
3.5	POP
3.5	myctophids
3.5	forage fish/bathylagidae
3.2	crabs
2.9	shrimps
2.5	polychaetes
2.5	gel zoop
2.5	euphasiids
2.5	copepods
2.5	benthic inverts
2.5	benthic amphipods
2	other zoop

Table 3. 3 Feeding strategies of nesting seabirds included in the longitudinal continuum model (from Byrd et al. 2005)

	Feeding strategy
Parakeet auklet	nearshore/plankton/dive
Whiskered auklet	nearshore/plankton/dive
Crested auklet	offshore/plankton/dive
Least auklet	offshore/plankton/dive
Cassins auklet	offshore/plankton/dive
Fork tailed storm petrel	offshore/plankton/surface
Horned puffin	nearshore/fish/dive
Red faced cormorant	nearshore/fish/dive
Pelagic cormorant	nearshore/fish/dive
Glaucus winged gull	nearshore/fish/surface
Common murre	offshore/fish/dive
Thick billed murre	offshore/fish/dive
Tuffted puffin	offshore/fish/dive
Black legged kittiwake	offshore/fish/surface
Red legged kittiwake	offshore/fish/surface
Northern fulmar	offshore/fish/surface

Table 3. 4 Number of groundfish stomachs analyzed (1981-2001) pooled by two longitudinal degree area.

Longitude	*172E*	*174E*	*176E*	*178E*	*180W*	*178W*	*176W*	*174W*	*172W*	*170W*	*168W*	*166W*	*164W*	*Grand Total*
Pacific cod		190	76	136	203	190	222	305	977	171	241	469	2973	6153
Atka mackerel	40	25	40	198	190	284	37	29	1103	207	19	11	53	2236
Pacific Ocean perch	29	60	111	86	140	115	203	70	234	105	73	160	31	1417
Walleye pollock	54	108	89	130	293	326	359	216	1368	465	1001	3182	3588	11179
Grand Total	123	383	316	550	826	915	821	620	3682	948	1334	3822	6645	20985

.Table 3. 5 Percent composition of feeding habits of Steller sea lions, piscivorous and planktivorous seabirds. Strong links (in bold) are prey items contributing at least 10% to the diet in any area

	172E	*174E*	*176E*	*178E*	*180*	*178W*	*176W*	*174W*	*172W*	*170W*	*168W*	*166W*	*164W*
STELLER SEA LION													
Other groundfish		2.28	1.35	8.77	**11.15**	3.24	4.36	6.15	9.42	4.02	**11.22**	**12.14**	4.72
Rockfish		0.80	0.68	1.05	0.63	1.72	0.48	2.71	0.30	0.67	1.28	3.39	1.57
Sculpins		3.62	8.45	9.12	6.27	1.91	5.81	1.97	5.16	2.01	5.79	9.03	4.81
Flatfish		1.14		0.35	1.19	0.57	0.97	1.23	2.43	2.68	7.84	8.41	8.06
Pacific cod		5.69	5.04	**17.69**	7.71	2.35	5.73	5.65	7.70	4.90	5.06	**11.47**	9.91
Atka		**69.96**	**73.71**	**44.54**	**51.10**	**61.76**	**53.25**	**29.79**	**59.17**	**51.59**	**21.07**	**15.23**	8.82
Pollock		4.15	2.67	0.51	1.13	4.64	7.67	**14.76**	1.93	**13.61**	**19.84**	**23.62**	**32.98**
Salmon		4.42	2.70	4.21	**12.02**	5.53	**12.10**	**19.20**	4.25	6.03	**14.21**	**10.87**	9.79
Myctophids				0.70		0.38			1.82	2.68		0.38	
Forage fish/bathylagidae		1.61		2.81	1.19	0.38		6.15	1.22		7.89	2.11	**17.95**
Cephalopods		5.00	5.14	8.33	6.60	**15.03**	7.80	**10.71**	6.30	**11.80**	3.87	2.28	0.88
Polychaetes		1.33	0.26	1.92	1.02	2.50	1.83	1.67	0.29		1.93	1.07	0.51
PISCIVOROUS SEABIRDS													
Other groundfish		0.66	4.17	0.18	0.48	4.93	6.39	6.24	7.59	1.63	9.03	9.16	9.48
Rockfish			1.18		0.04	7.42	6.28	5.15	7.53	**15.02**	8.78	8.97	9.44
Sculpins		3.13	0.04	0.18	1.58	0.07	0.43	0.15	0.26	0.01	0.10	0.22	0.16
Flatfish		2.97	0.03	0.16	1.11	0.43	0.35	0.40	1.99	0.04	0.08	0.22	0.16
Cod						4.62	6.20	4.51	7.52	1.01	8.74	8.84	9.42
Pollock		8.11	6.51	**12.48**	**16.87**	**40.68**	**40.99**	**28.82**	**46.40**	**23.08**	**46.50**	**44.43**	**47.50**
Myctophids		4.07	**45.42**	1.24	0.19	4.70	0.31	**23.83**	0.25	**22.40**	2.39	4.61	0.74
Forage/bathylagidae		**44.74**	5.59	**22.15**	**40.47**	**24.24**	**32.13**	**16.76**	**26.76**	**13.40**	**22.85**	**20.88**	**22.51**
Cephalopods		**33.41**	**13.21**	**59.24**	**32.79**	7.15	2.99	0.63	0.68	**14.58**	0.20	0.02	0.04
Shrimp		0.16	0.01	0.02	0.47	0.07	0.17	0.03	0.05	0.01	0.02		
Euphasiids		1.34	1.26	1.55	1.78	1.86	1.02	0.42	0.24	0.12	0.24	0.01	0.02
Copepods		0.35	0.30	1.24	1.78	1.39	1.02	0.18	0.24	0.03	0.03	0.01	0.01
Other zoop		1.06	**22.29**	1.55	2.43	2.45	1.71	**12.90**	0.49	8.68	1.03	2.62	0.53
PLANKTIVOROUS SEABIRDS													
Forage/bathylagidae			0.02										
Cephalopods		5.42	0.01		0.06			0.15	4.47	5.37	4.06	5.30	5.01
Euphasiids		**46.80**	**31.53**	**31.91**	**33.12**	**28.34**	**49.65**	**28.93**	**49.92**	**46.36**	**49.46**	**47.99**	**46.28**
Copepods		**47.78**	**51.88**	**58.67**	**62.41**	**47.43**	**43.45**	**48.89**	**45.61**	**47.46**	**46.48**	**46.71**	**48.72**
Other zoop			**16.57**	9.42	4.41	**24.23**	6.90	**22.03**		0.81			

Table 3. 6. Percent composition of feeding habits of Atka mackerel and Pacific Ocean perch. Strong links (in bold) are prey items contributing at least 10% to the diet in any area.

	172E	*174E*	*176E*	*178E*	*180*	*178W*	*176W*	*174W*	*172W*	*170W*	*168W*	*166W*	*164W*
ATKA MACKEREL													
Other groundfish	1.58	1.26	0.75	0.14	0.01	8.16		0.04	**10.12**	0.29	0.02		0.22
Sculpins				0.19		0.01		0.30			0.11		
Flatfish		0.03				0.01					0.10		
Cod				0.005%									
Atka				3.03	1.37								
Pollock		**26.39**			0.13		0.38		4.91				5.06
Myctophids		6.85			0.12				**15.40**				
Forage/bathylagidae				0.04	0.03		0.02		1.39				
Cephalopods	**17.10**	9.88	1.10	1.60	5.58	3.43	0.03		2.70	0.60			0.31
Shrimp	0.26	2.73	0.03	1.01	0.09	0.04	0.01	0.04	2.61	0.06		0.12	1.05
Crabs				0.01	0.05		0.01		0.01	0.06		0.13	0.15
Benthic amphipods	2.38	1.86	1.43	1.35	1.79	**26.75**	0.15	0.10	1.47	0.07	1.22		
Polychaetes	**16.90**	0.06	**41.62**	2.34	7.23	0.22	0.54		0.13	0.01	0.10		
Benthic inverts	0.45	1.41	0.33	0.30	0.26	0.26	0.23	0.13	0.19	0.23	2.12	0.59	0.33
Euphasiids	2.18	**11.57**	**25.64**	**37.47**	**11.70**	**41.16**	**49.98**	**97.79**	**49.54**	**87.78**	2.31	**98.82**	**87.22**
Copepods	**43.77**	**32.62**	**22.68**	**31.74**	**55.39**	**16.99**	**29.28**	1.48	7.12	7.46	**89.97**	0.13	0.41
Gel zoop	3.17	4.28	4.42	8.24	**11.50**	2.11	**18.97**	0.06	1.22	0.01	3.44	0.20	0.34
Other zoop	**12.20**	1.06	2.00	**12.08**	4.76	0.87	0.41	0.05	3.20	3.43	0.60		4.91
Offal				0.44									
PACIFIC OCEAN PERCH													
Other groundfish			**23.95**	**13.89**	**21.17**	2.17	0.30	0.01	6.26	4.49	3.01	0.04	
Flatfish									0.41			3.17	
Pollock									3.64				
Myctophids	**70.66**	**34.39**	**30.25**	**67.88**	5.37	**16.05**		1.76	**21.56**	**75.25**	7.80		
Forage/bathylagidae										0.68	3.92		
Cephalopods	0.08		3.46	1.09	0.33	4.00			1.86	3.46	0.22	0.10	
Shrimp			0.08	0.03		0.01	5.08	0.15	3.26	0.16	0.44	**15.76**	1.93
Crabs									0.23				
Benthic amphipods		0.78	0.79	0.57	0.12	0.12	1.98	0.45	0.40	0.33	0.72	0.21	
Polychaetes			0.14	0.33			0.24	0.17	1.21	0.26	0.22		
Benthic inverts			1.54			0.20	0.03			0.02			
Euphasiids	**14.98**	**33.05**	**13.73**	8.35	**31.97**	**30.95**	**61.59**	**60.86**	**50.22**	6.80	**51.71**	**78.07**	**96.71**
Copepods	0.54	**25.82**	**20.05**	6.64	**26.20**	**32.58**	**24.78**	**31.00**	**10.05**	8.11	**25.86**	0.32	1.36
Gel zoop		0.11	0.24	0.02	0.87	0.01	2.65				1.92	0.56	
Other zoop	**13.75**	5.85	5.76	1.20	**13.97**	**13.91**	3.34	5.61	0.90	0.45	4.18	1.79	

Table 3. 7 Percent composition of feeding habits of pollock. Strong links (in bold) are prey items contributing at least 10% to the diet in any area.

	172E	*174E*	*176E*	*178E*	*180*	*178W*	*176W*	*174W*	*172W*	*170W*	*168W*	*166W*	*164W*
POLLOCK													
Other groundfish	**19.39**	0.81	6.58	1.02	6.19	4.49	7.15	**10.12**	**19.69**	**13.85**	4.80	5.41	3.14
Sculpins				0.12				0.51	0.06			0.10	0.06
Flatfish							0.10		0.62			0.07	0.03
Cod												0.02	0.63
Atka	**13.00**			**17.01**									
Pollock						5.68	4.03	**11.57**	**16.17**	1.45	3.00	7.72	1.78
Myctophids	**13.82**		0.09	1.49	**23.22**	**26.41**	**35.73**	**15.73**	**28.97**	**48.21**	**56.96**	5.12	3.75
Forage/bathylagidae					0.17	0.88	2.55		2.11	4.08	0.20	**15.10**	0.54
Cephalopods	4.81	3.51	**18.20**	3.25	1.54	7.74	3.97	0.04	1.85	3.46	1.04	5.77	2.07
Shrimp	**15.47**	**28.78**	0.78	1.95	1.26	1.04	9.08	5.92	1.80	0.73	2.03	3.58	2.43
Crabs			0.10	0.01	0.02	0.11	0.04	0.13	0.25			0.04	0.01
Benthic amphipods	1.77	4.24	8.46	3.02	0.99	1.97	3.66	9.53	0.75	1.04	0.70	0.50	0.30
Polychaetes	2.62	0.40	2.07	1.44	1.28	1.08	1.49	0.10	0.09	0.30	0.23	0.12	0.08
Benthic inverts	0.01	0.11	0.11	0.04	0.01	0.02	1.88	0.04	0.14	0.02	0.94	0.06	0.07
Euphasiids	**15.60**	**34.00**	**54.60**	**33.34**	**25.18**	**22.15**	**23.96**	**30.51**	**20.37**	3.16	**20.51**	**43.08**	**76.05**
Copepods	3.68	**19.31**	4.84	**15.35**	9.59	**24.61**	4.49	8.66	4.69	**13.60**	4.34	8.88	2.43
Gel zoop	0.32	0.04	0.39	**15.36**	**26.50**	1.67	0.59	1.65	0.14	9.27	2.73	2.19	3.96
Other zoop	4.37	8.79	3.78	6.61	4.06	2.16	1.28	5.48	2.28	0.67	2.51	1.67	
Offal	5.14								0.02	0.15		0.58	0.70

Table 3. 8 Percent composition of feeding habits of Pacific cod. Strong links (in bold) are prey items contributing at least 10% to the diet in any area.

	172E	*174E*	*176E*	*178E*	*180*	*178W*	*176W*	*174W*	*172W*	*170W*	*168W*	*166W*	*164W*
PACIFIC COD													
Other groundfish	2.63	2.63	8.05	3.71	**10.83**	**17.37**	**24.27**	3.74	**13.18**	**18.37**	2.83	3.23	9.26
Rockfish	3.07	3.07	**12.54**		8.69		8.10	**19.24**	1.86	**10.41**	0.50	0.76	0.03
Sculpins	5.98	5.98	7.18	5.52	3.24	3.51	2.92	1.01	2.86	**10.95**	4.46	0.31	0.30
Flatfish	0.04	0.04	0.07	0.01	0.52	0.02	0.06	4.56	1.26		3.93	0.71	2.94
POP									0.37				
Cod	0.01	0.01	1.50		1.82	0.11	0.28		0.17	0.88			0.35
Atka	**40.91**	**40.91**	**49.20**	**71.07**	**38.81**	**51.26**	8.12	**29.05**	**28.92**		0.46	8.60	0.86
Pollock	**15.92**	**15.92**			7.55	2.82	**25.14**	9.75	**19.21**	**15.80**	**37.83**	**62.68**	**66.49**
Salmon													1.17
Myctophids	1.82	1.82	0.24		0.14	0.10	2.70	0.27	6.21	**18.01**	0.11		
Forage/bathylagidae	0.39	0.39		0.08	0.37		2.83	5.84	0.55	0.28	**12.92**	2.90	2.17
Cephalopods	5.97	5.97	0.66	1.92	4.41	**11.80**	0.24	2.38	**15.97**	**17.90**	0.21	0.62	0.40
Shrimp	**12.35**	**12.35**	9.45	**10.02**	8.51	3.09	**10.62**	**10.63**	2.65	2.57	**11.94**	4.95	1.25
Crabs	2.23	2.23	4.35	2.25	**10.62**	1.81	7.85	9.37	1.30	0.64	**12.24**	**10.04**	6.41
Benthic amphipods	0.33	0.33	0.86	0.32	1.13	0.20	0.84	1.58	0.13	0.06	2.70	0.41	0.26
Polychaetes	0.21	0.21	0.13	0.42	1.34	0.28	2.27	1.43	0.20	0.11	1.38	1.57	0.64
Benthic inverts	7.17	7.17	0.38	0.58	0.47	1.22	3.13	0.72	1.47	0.59	1.77	0.85	1.65
Euphasiids	0.02	0.02	0.03	0.01	0.10	0.07	0.22	0.13	0.15	0.20	0.32	0.23	0.53
Copepods					0.01		0.02						
Gel zoop						0.01							
Other zoop	0.87	0.87	5.35	0.02	0.05		0.01	0.03	0.08	0.10	0.06	0.01	0.02
Offal	0.09	0.09		4.07	1.36	6.32	0.38	0.26	3.45	3.14	6.34	2.13	5.29

Table 3. 9 Biomass (in tons) of predators and estimated fisheries removals of prey items .

	172 E	*174 E*	*176 E*	*178 E*	*180*	*178W*	*176W*	*174 W*	*172 W*	*170W*	*168 W*	*166 W*	*164 W*
BIOMASS													
Steller SL	0	631	301	112	226	738	171	322	121	428	549	142	420
Pisc. seabirds		87	66	22	41	23	27	36	16	346	171	368	323
Plankt. seabirds	0.00	0.01	89.23	186.12	62.23	94.12	0.10	7.36	0.12	19.97	0.07	2.41	0.10
Atka mackerel	67078	29296	74077	248361	48821	52451	161	37442	102848	2505	5937	8231	44496
POP	38342	55140	69482	47590	44768	20598	12087	10864	55930	2695	37269	10791	1615
Pollock	1789	2044	9625	10143	12669	15129	3997	5706	36291	5580	44028	54417	56196
Pollock	441	15262	10290	38346	7820	20117	7219	7278	35739	24453	13493	15791	42907
FISHERIES REMOVALS													
Atka	0	2	596	6208	877	14550	5	65	15120	8647	2594	742	609
P. cod	0	3878	1433	2687	2048	2253	1778	3242	7984	701	1636	3650	37369
POP		4	404	171	1321	688	53	451	2150	1879	567	403	222
Pollock	1	6	22	87	100	142	39	2358	4894	3000	260	53843	313222

Table 3. 10 Estimated total consumption (in tons) of prey items.

	172 E	*174 E*	*176 E*	*178 E*	*180.00*	*178 W*	*176 W*	*174 W*	*172 W*	*170 W*	*168 W*	*166 W*	*164 W*
other groundfish	7555	3466	38610	17522	23169	36190	5619	4010	107163	14100	14894	17290	19638
flatfish	0	434	20	18	192	136	74	870	2463	289	2214	1377	3631
cod	0	867	718	540	745	545	405	629	438	1254	1796	3011	5136
atka	1445	24866	16883	107655	13502	33190	3518	7137	23603	5318	2916	3507	1681
pollock	160	50363	1223	217	2272	6552	5972	6920	73374	16713	25424	54149	93019
cephalopods	65253	21701	19336	27505	18666	24753	1126	1270	32816	15993	2788	14293	6395
rockfish	31	1190	3176	28	1593	431	1473	3627	1502	9864	1445	2991	2442
forage fish	4	3324	885	1118	1534	1074	1558	2158	12210	5118	10755	43681	10519
myctophids	49942	46408	45155	58925	17762	23907	6795	5387	162676	31783	117051	13733	9531
salmon	0	672	196	113	654	982	497	1487	124	622	1877	372	2062
pop	0	0	0	0	0	0	0	0	281	0	0	0	0
sculpins	60	2837	2303	7397	970	1895	725	1095	2432	5880	2103	730	940
crabs	30	776	1064	1910	2040	861	1293	1591	1667	340	3538	3648	6297
shrimps	2339	11436	2774	23061	2486	2149	4462	3386	23366	1529	7714	13496	9903
gel zoop	12035	7199	18959	122533	47345	7371	855	550	7324	2300	7794	5489	10742
copepods	166474	81407	127176	469841	183576	83890	6489	11792	59057	5873	56031	21732	7138
euphasiids	19862	55166	151122	554333	74550	151294	18188	226705	371317	14690	75777	165528	412442
polychaetes	64231	416	175220	34174	20947	1953	768	434	2289	146	1287	866	843
benthic inverts	1795	4834	3451	4684	820	1381	857	411	2431	343	3069	722	2513
benthic amphipods	9156	4346	10775	21069	5789	80694	1222	2990	10251	316	3037	1388	990
other zoop	56082	8736	23618	175406	27068	11747	996	3315	23231	3286	8059	5151	14231
offal	410	35	0	17595	146	5257	140	12	8475	5621	3702	3444	15690

Table 3. 11 Compared estimated total consumption of prey items by predators in the NPFMC regulatory areas of hthe Eastern Bering Sea, Gulf of Alaska and the average of the eastern Aleutian Islands (areas 170W-164W)

	Eastern Bering Sea	*Gulf of Alaska*	*Eastern Aleutian Islands*
Other groundfish	0.36%	0.29%	4.37%
Pacific cod	0.26%	0.28%	0.74%
Flatfish	0.31%	0.56%	0.50%
Pollock	11.49%	4.06%	12.56%
Atka mackerel	0.01%	0.04%	0.89%
Cephalopods	0.30%	0.96%	2.62%
Rockfish	0.00%	0.01%	1.11%
Forage fish/bathylagidae	1.04%	6.32%	4.65%
Myctophids	0.21%	0.09%	11.42%
Salmon	0.01%	0.31%	0.33%
Sculpins	0.15%	0.38%	0.64%
Pacific Ocean perch	0.00%	0.01%	0.00%
Crabs	2.00%	4.20%	0.92%
Shrimps	4.93%	13.81%	2.17%
Euphasiids	31.81%	46.96%	44.35%
Gel zoop	1.13%	3.86%	1.75%
Copepods	33.58%	8.22%	6.02%
Benthic invertebrates	0.54%	0.30%	0.44%
Benthic amphipods	3.50%	5.46%	0.38%
Polychaetes	0.59%	0.93%	0.21%
Other zoop	6.49%	2.61%	2.04%
Offal	1.28%	0.34%	1.89%

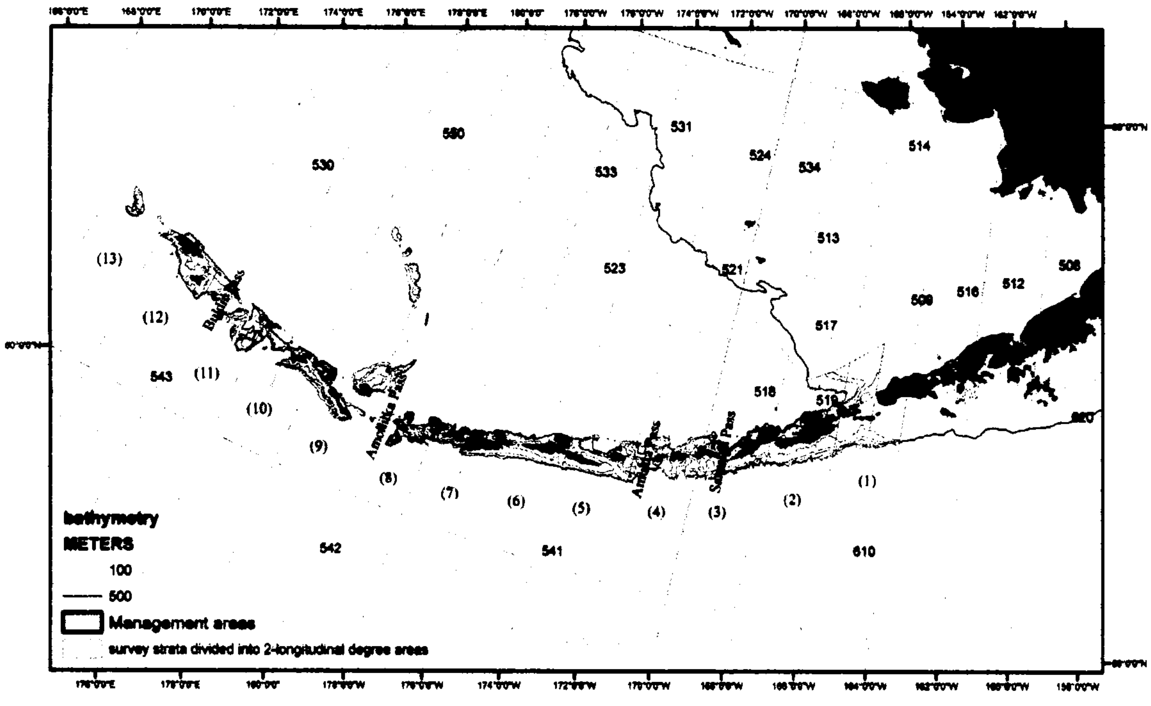

Figure 3. 1 Area included in the longitudinal continuum model.

Shaded area (in green) shows survey strata included from the Aleutian Islands and Gulf of Alaska bottom trawl surveys. Meridians show the 2-longitudinal degree divisions, number in parenthesis show the thirteen 2-degree areas for which a food web model was constructed. NPFMC management areas are shown in thick gray lines. Areas 541, 542, 543 comprise the Aleutian Islands NPFMC management region, 610 and 620 are part of the Gulf of Alaska region, the rest comprise the Bering Sea management region.

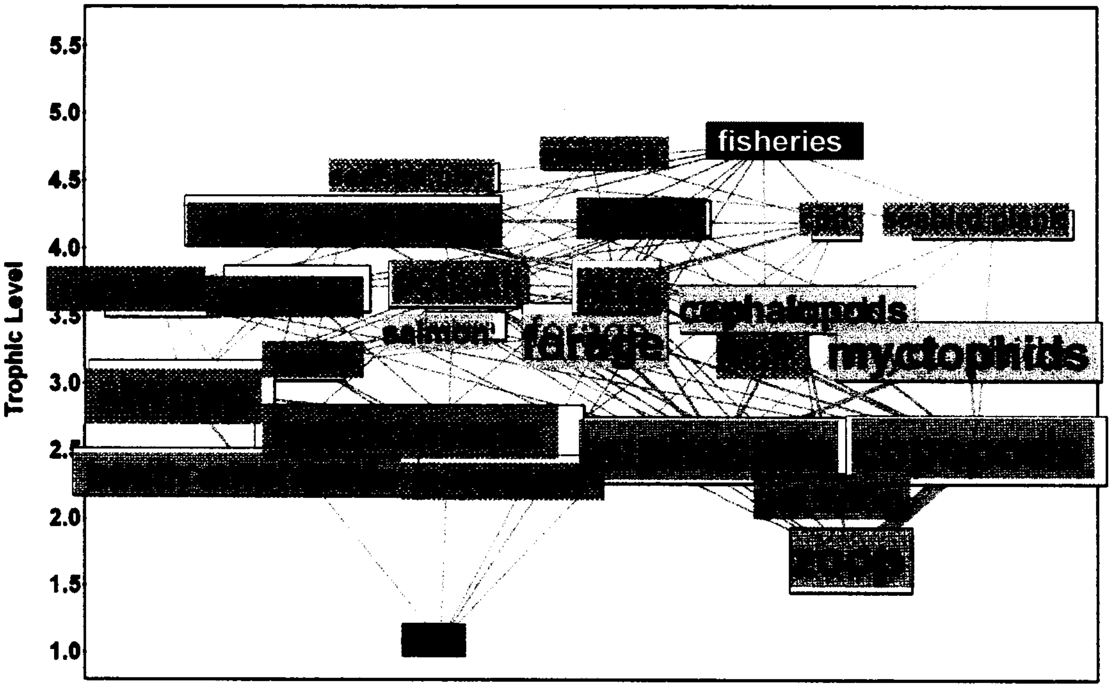

Figure 3. 2 Basic food web constructed for each 2-degree area.

The structure shown is the aggregated version of NPFMC regulatory area of the Aleutian Islands (from Chapter 2). Box size is proportional to biomass. Boxes in gray show 'predator' groups for which detailed diets/ biomass estimates were included. Diets of prey items, those in colored boxes, were not included and their biomass estimates are the sum of the consumption by predators. Fisheries include removals of Atka mackerel, Pacific Ocean perch, Pollock and Pacific Cod. Green denotes plankton groups, red denotes offal, orange refers to benthic invertebrates, blue denotes pelagic fish and pink denotes all other [generally larger] fish. The color scheme remains the same throughout the following figures in this chapter.

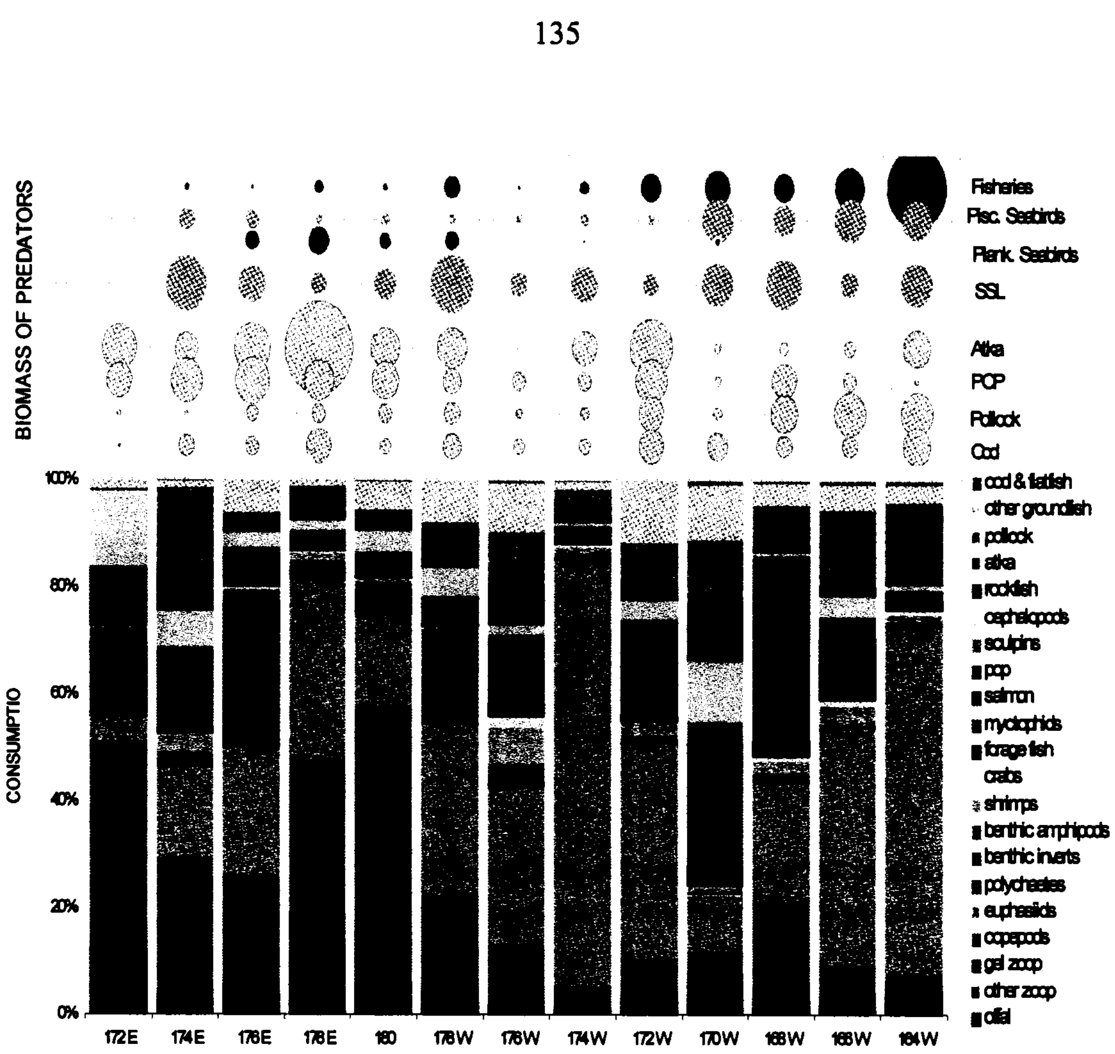

Figure 3. 3 Compared trophic structure across the 13 food webs in the Aleutian Archipelago (early 1990s).

Each vertical series represents the food web for that 2-degree area. Circles are proportional to biomass in tons. Steller sea lions and seabirds were scaled 150 times larger so they would show. Biomass of consumed prey by trophic level represents the total biomass consumed per year by predators (Atka mackerel, POP, Pacific cod, pollock, seabirds and Steller sea lions). Fisheries removals include those of (Atka mackerel, POP, Pacific cod and pollock).

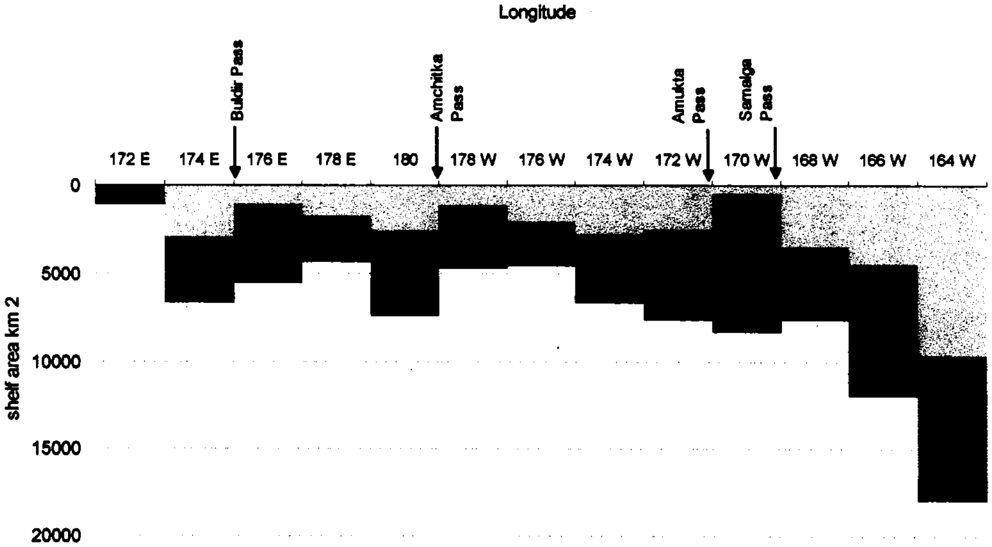

Figure 3. 4 Shelf area (in km^2) by depth layer (100, 200, 300 and 500m).

Shown by two longitudinal degree areas for the Aleutian Islands. Main passes are marked for reference.

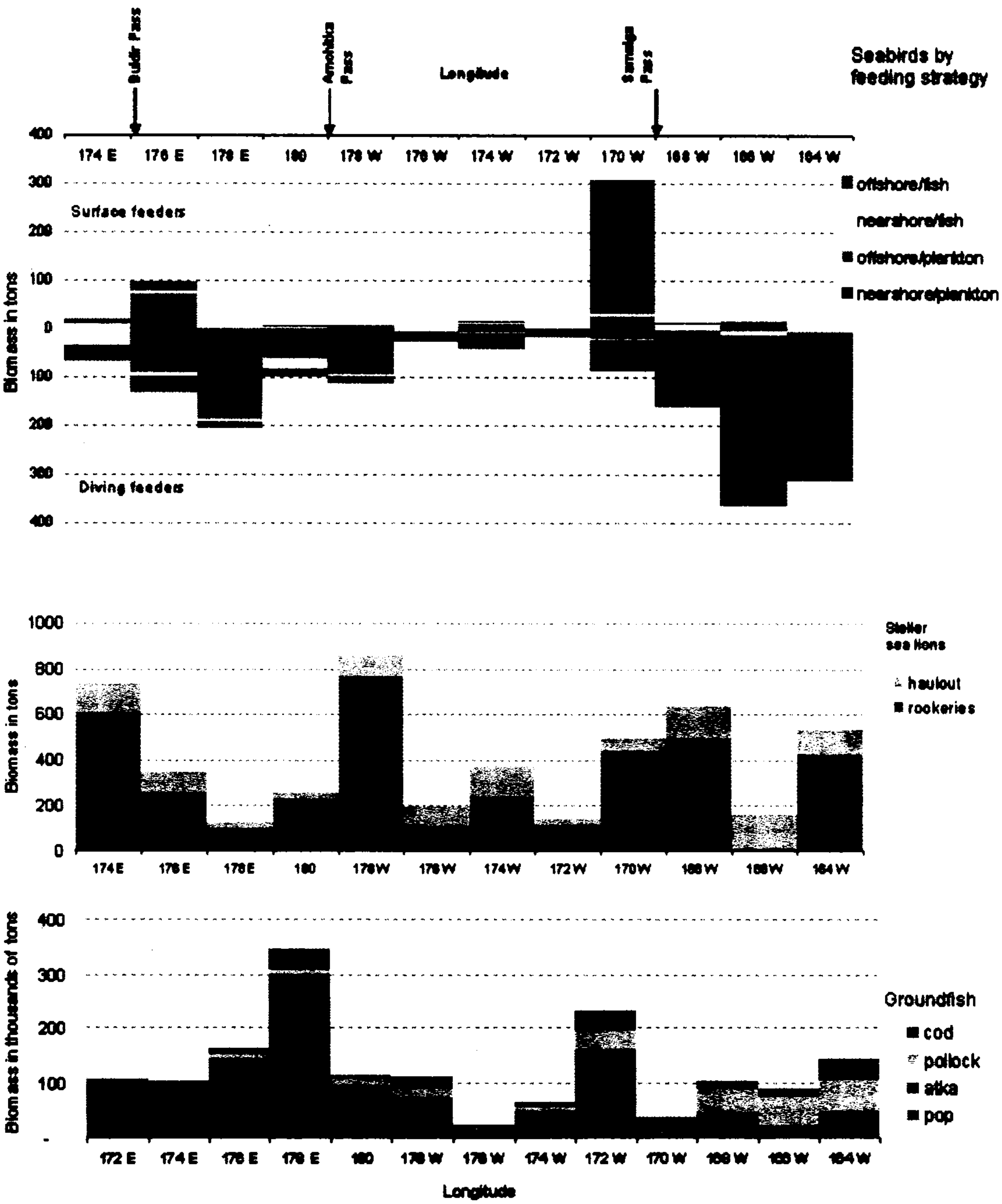

Figure 3. 5 Biomass and feeding strategy of seabirds (top), biomass of Steller sea lions in haulouts and rookeries (middle), and biomass of groundfish (bottom).

Shown by 2-degree areas. Biomass values in metric tons. Cod is Pacific cod, pollock is Walleye pollock, atka is Atka mackerel and pop is Pacific Ocean perch.

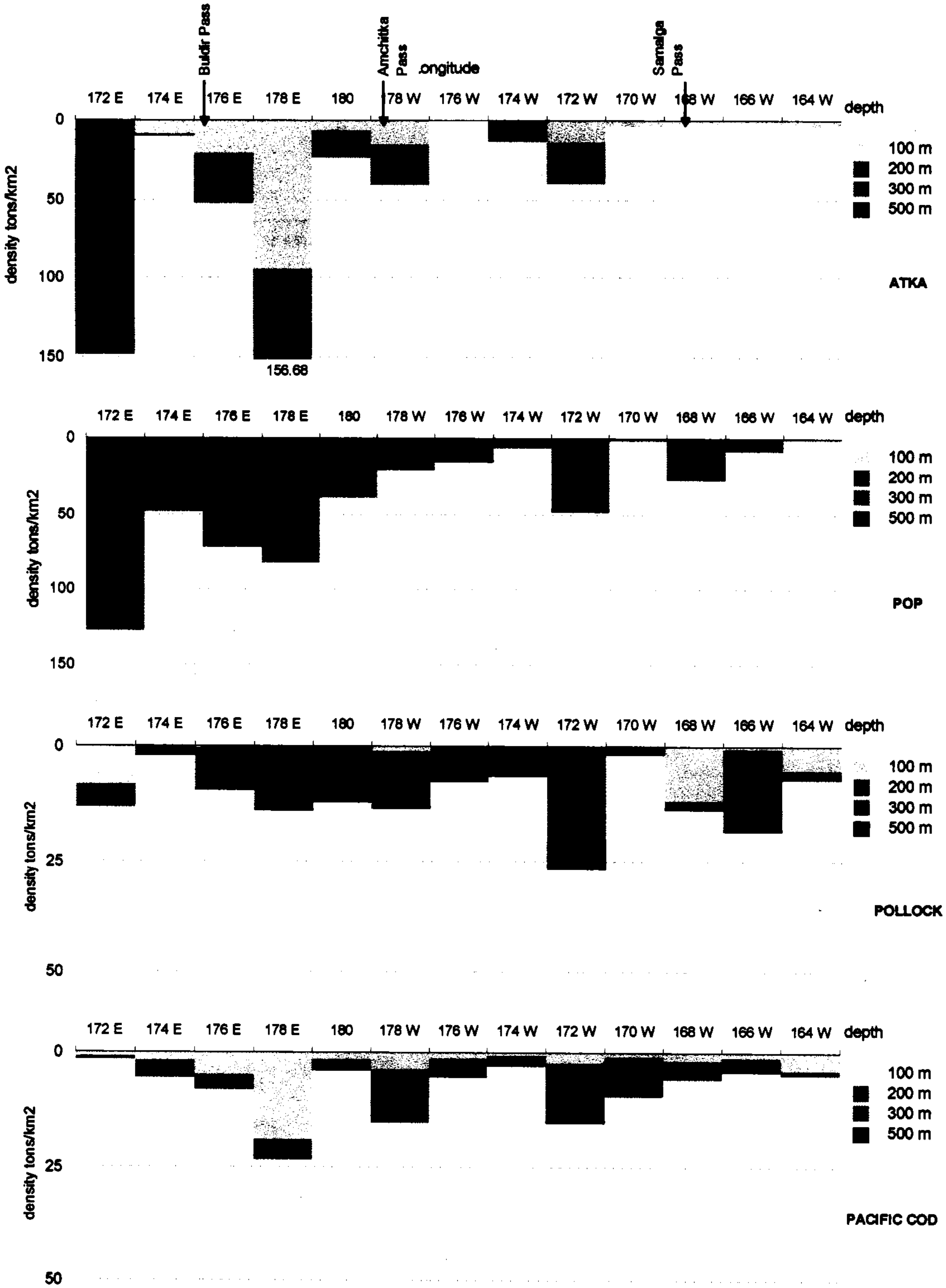

Figure 3. 6 Biomass density (tons/km^2) by depth of the main four commercial species in the Aleutian Islands.

Shown by two longitudinal degrees areas. From top to bottom: Atka mackerel, Pacific Ocean perch, walleye pollock and Pacific cod. Approximate location of main passes is shown for reference.

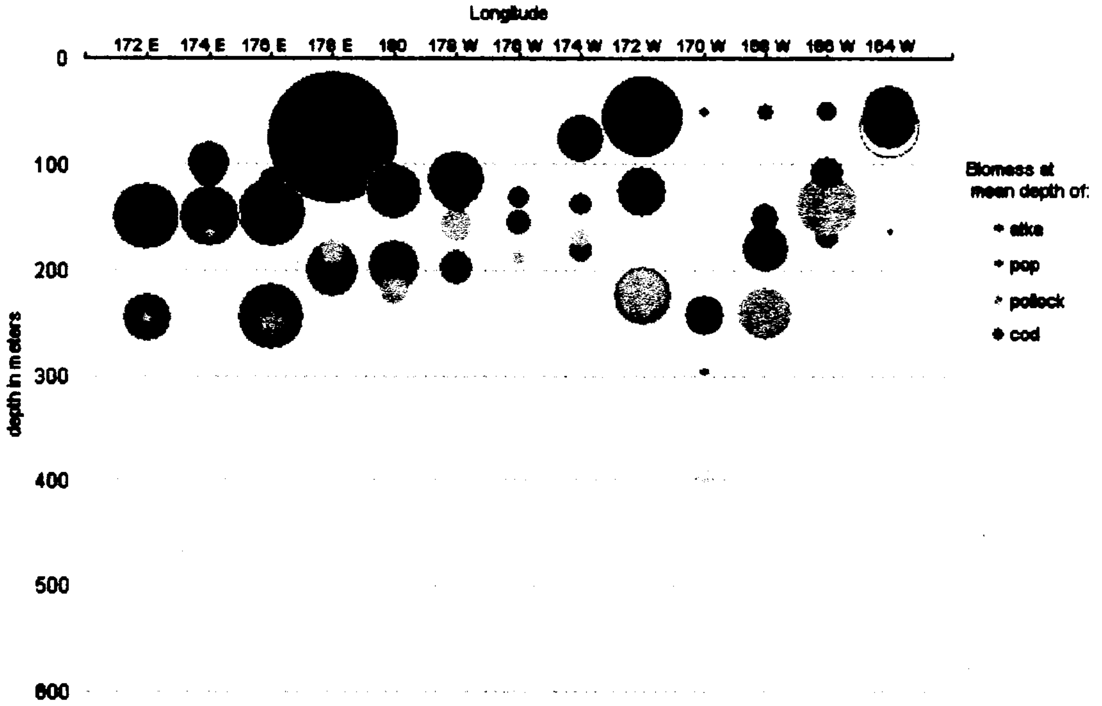

Figure 3. 7 Density (tons/km²) at mean depth of Atka mackerel, Pacific Ocean perch, walleye pollock and Pacific cod.

Each vertical series of circles represents the food web for that 2-degree area. The size of the circles is proportional to density.

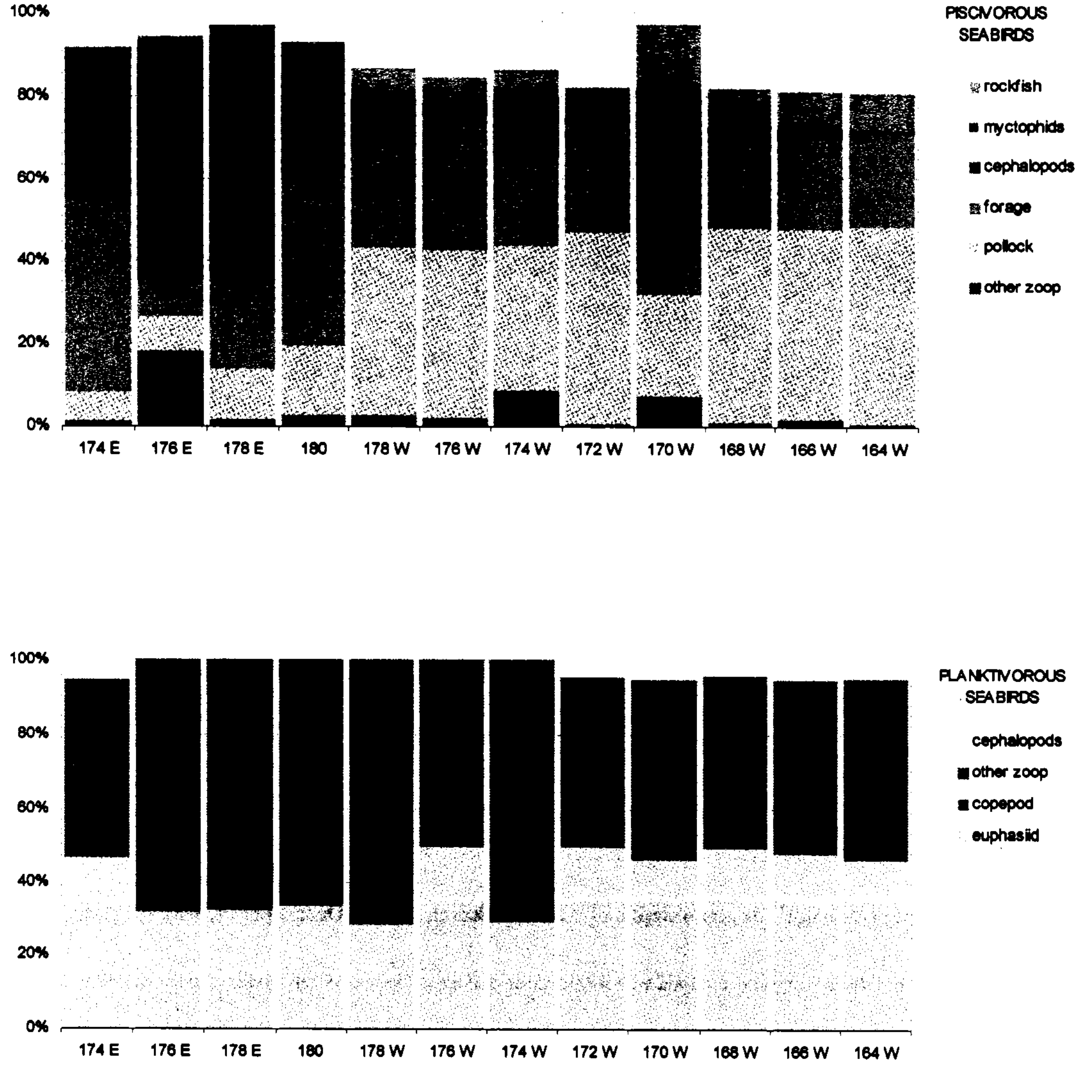

Figure 3. 8 Strong links of piscivorous (top) and planktivorous (bottom) seabirds.

Blank space represents weak links.

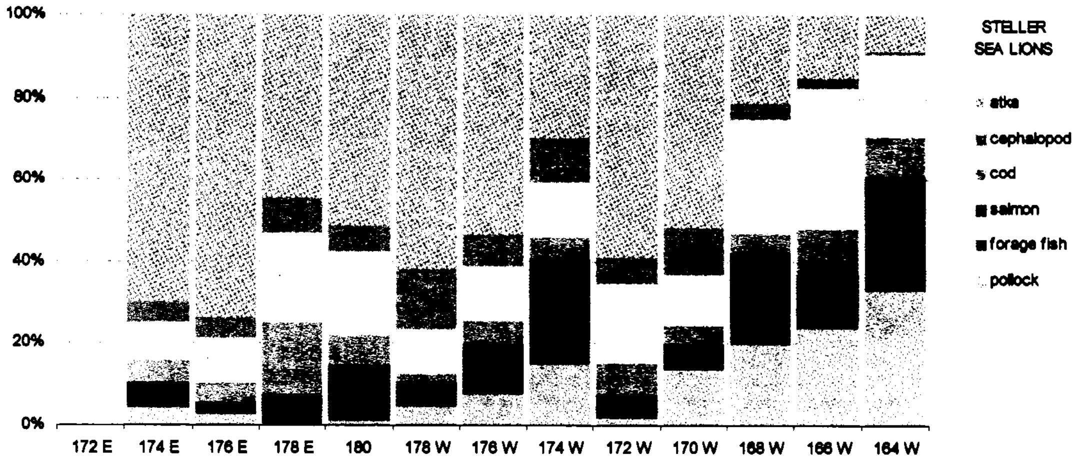

Figure 3. 9 Strong links (>10% diet in at least one 2-degree area) of Steller sea lion.

Blank space represents weak links.

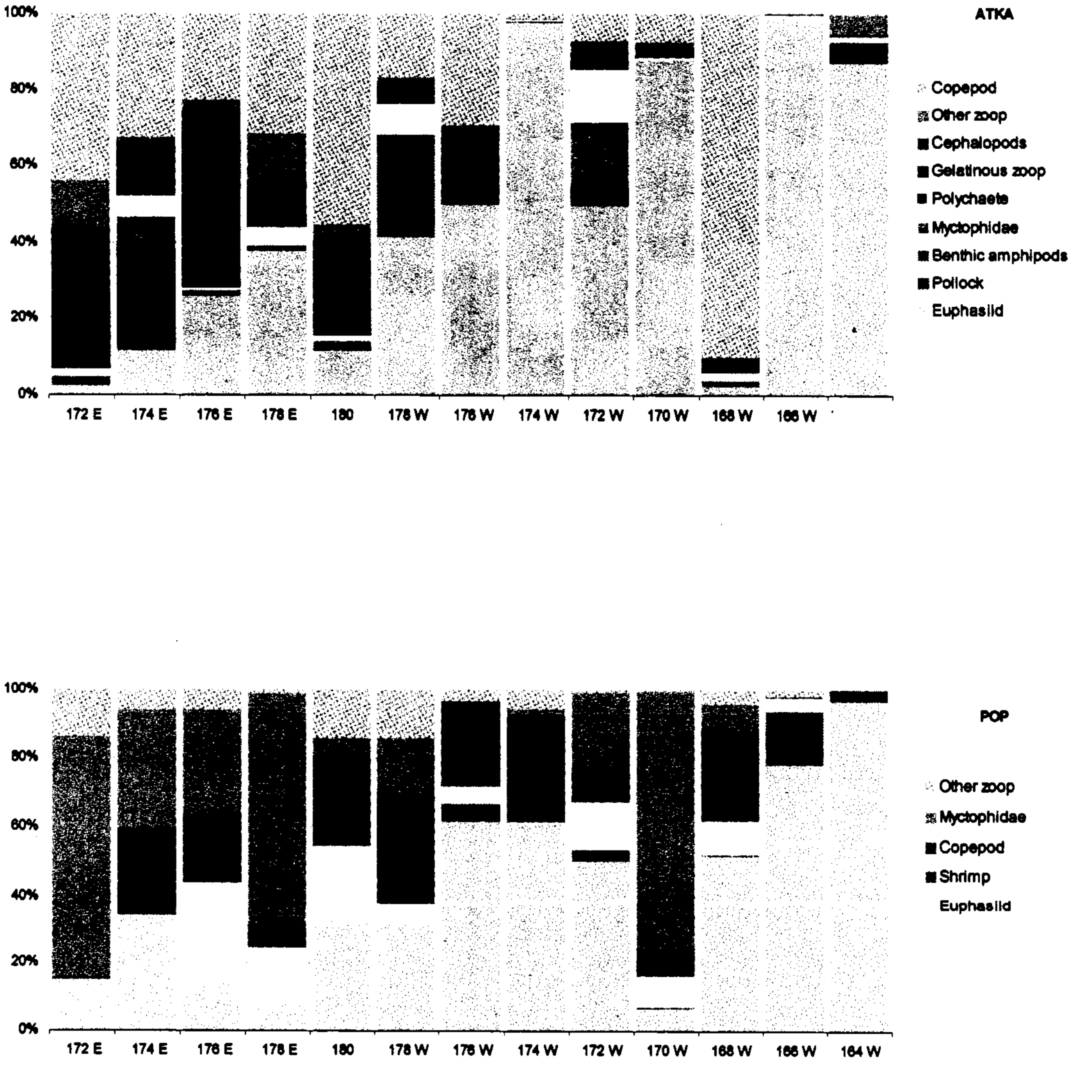

Figure 3. 10 Strong links of Atka mackerel (top) and Pacific Ocean perch (bottom).
Blank space represents weak links.

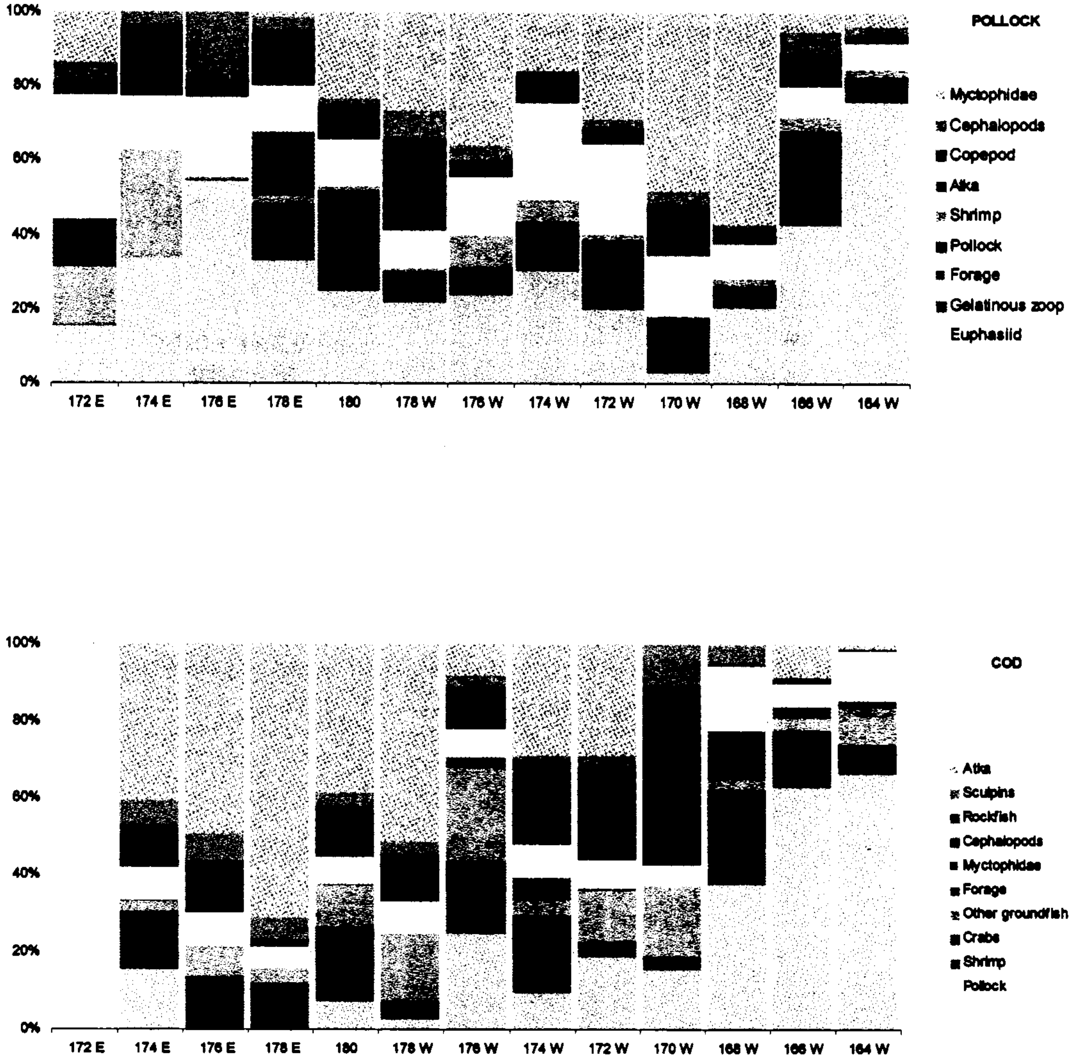

Figure 3. 11 Strong links of pollock (to) and Pacific cod (bottom).

Blank space represents weak links.

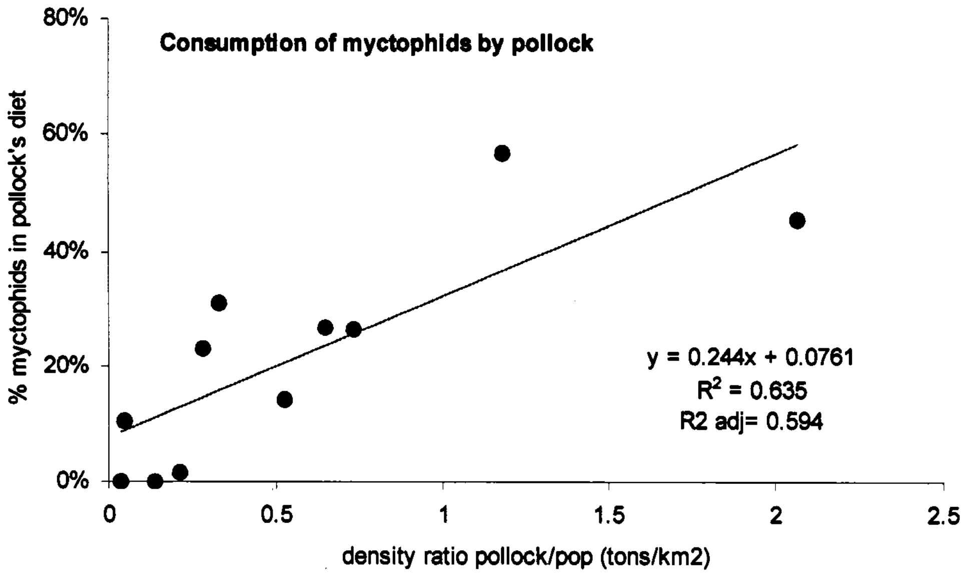

Figure 3. 12 Consumption of myctophids by pollock as a function of the density of pollock/pop. Data points are the consumption of myctophids at each of the 2-degree areas.

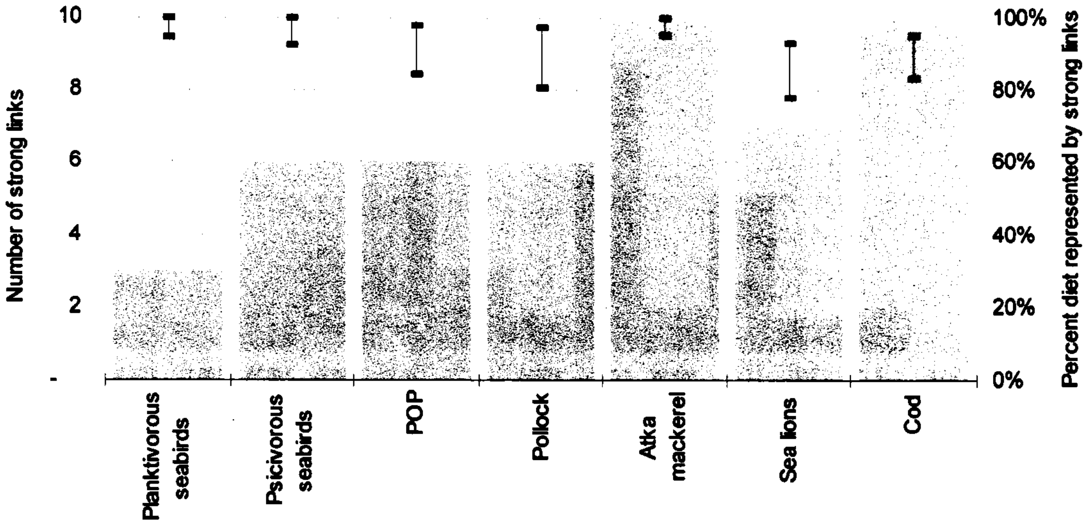

Figure 3. 13 Percent of predator's diet represented by strong links

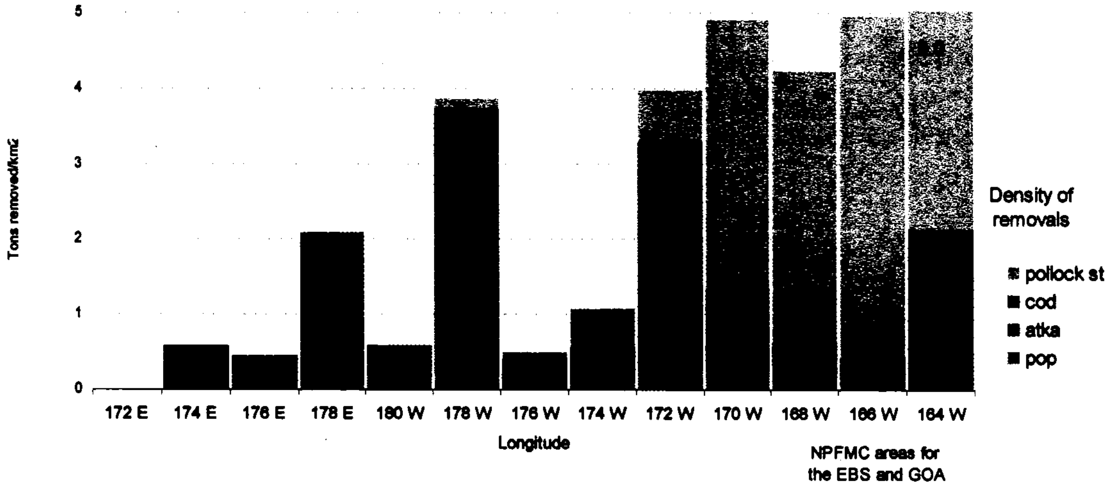

Figure 3. 14 Density of fisheries removals of Pacific cod, pollock, Atka mackerel, and Pacific Ocean perch in tons/km^2 during the early 1990s.

Removals are shown by two-longitudinal degree area. Areas 172E to170W are part of the NPFMC regulatory for the Aleutian Islands; areas 168W to 164W fall within the Eastern Bering Sea and Gulf of Alaska regulatory areas.

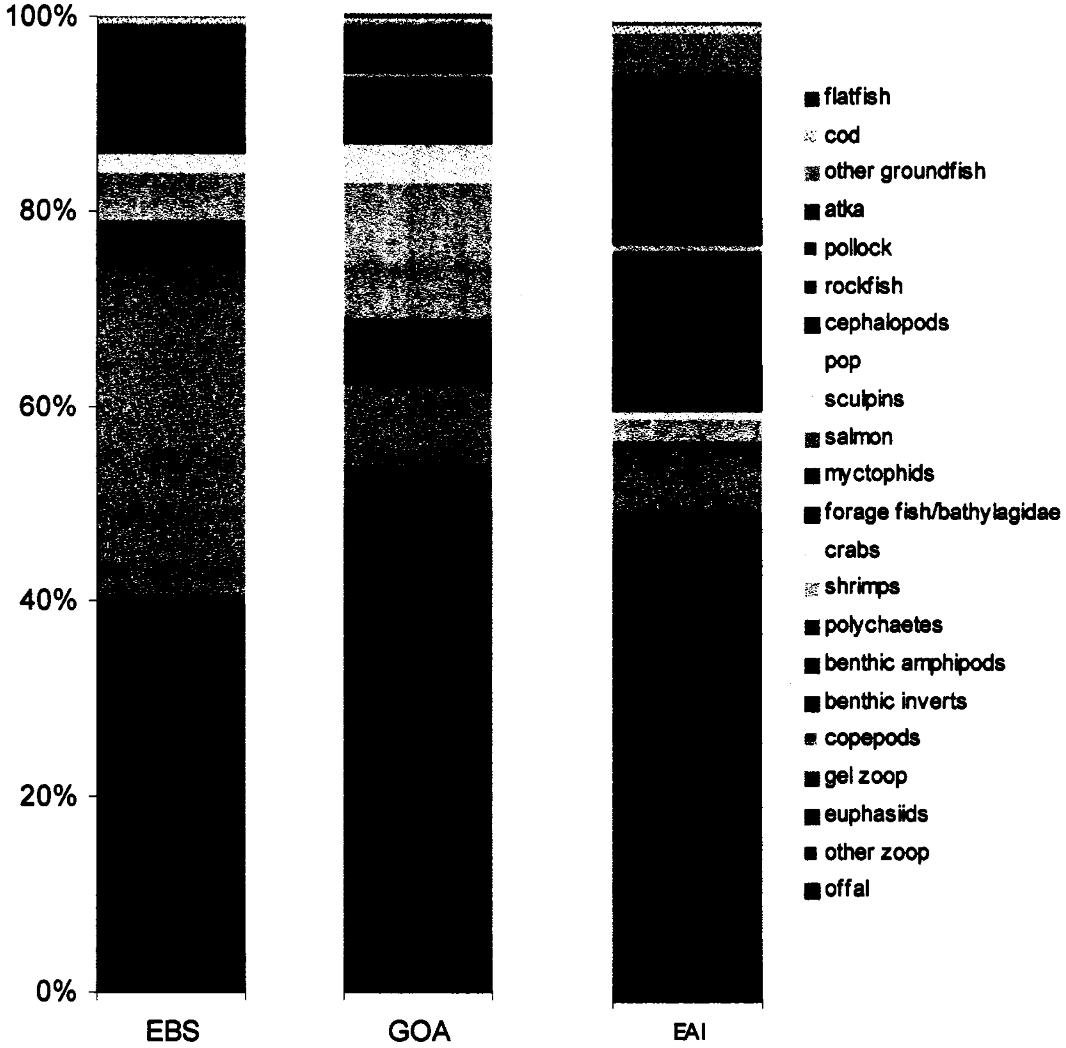

Figure 3. 15 Compared consumption of the seven predators in the Eastern Bering Sea (EBS), Gulf of Alaska (GOA) and eastern Aleutian Islands (EAI) (areas 164°W to 170°W).

The seven predators are piscivorous and planktivorous seabirds, Steller sea lions, Atka mackerel, Pacific Ocean perch, Pacific cod and walleye pollock.

Chapter 4. A multi scale food web modeling approach to fisheries effects in the Aleutian Islands

> *"One scale is a snapshot that is a slice of a much broader picture" Levin 1997*

> *"The world gets much prettier as it gets more complicated" Gregory Bateson*

4.1 SUMMARY

A multiple scale food web modeling approach was used to explore spatial ecosystem effects of fisheries removals during the early 1990s in the Aleutian Islands. Three aspects of fisheries removals are addressed: i) density as opposed to total amount removed, ii) density of removals with respect to production and removals by predation and iii) consumption of offal by groundfish. The Aleutian Islands extend over the three regulatory areas of the North Pacific Fisheries Management Council (NPFMC): the Aleutian Islands, the Eastern Bering Sea (EBS) and the Gulf of Alaska (GOA). One of the levels of spatial resolution used was that of the NPFMC regulatory areas, one food web model for each one. These models were introduced in the Chapter 2. The second level of spatial resolution is that of a food web model for each of thirteen 2-longitudinal degrees areas that cover the entire extent of the [American] Aleutian Islands. This series of models was introduced in Chapter 3.

The total amount of fisheries removals is highest in the EBS, followed by the GOA and Aleutian Islands. However, in terms of density, removals are highest in the EBS (4.1 t/km^2), followed by the Aleutian Islands (2.7 t/km^2) and the GOA (1.4 t/km^2).The density of removals varies across species and spatial scales. The ratio of production removed by fisheries and predation also varies across species and spatial scales. This implies stocks are harvested at different levels both across regulatory areas and 2-degree areas and opens the question regarding the ability of the management framework to detect local depletions and act upon them in a timely manner. The

proportion of fisheries mortality with respect to production and predation mortality has different implications in predators than prey species. While fisheries removals of prey species are in straight competition with other predators, the removal of predators decreases predation mortality on specific prey species. These prey species are given a competitive advantage, potentially modifying density dependent processes.

Total consumption of offal is proportional to the magnitude of the fisheries removals in each regulatory area. The general rule is the higher the density of removals, the higher the consumption of offal in the system. However at a species level there is not a strict proportionality. Areas where consumption of offal makes the most contribution to a species' diet are not necessarily where total removals are the highest. Changes in offal composition, live prey availability, and species interactions seem to be an important factor as well. The potential disruptive effect of offal moves management into an arena little addressed before, the relevance of location and amount of offal discharge by processing vessels. Spatial allocation can help prevent the potential adverse impacts of highly localized removals, fishing effort and discharges by ensuring they are diffused throughout the system.

4.2 INTRODUCTION

In 2002 the North Pacific Fisheries Management Council (NPFMC) convened an expert panel to provide an independent scientific review of the harvest strategy embodied in the NPFMC fisheries management plan (FMP) for the Bering Sea/Aleutian Islands/Gulf of Alaska groundfish fisheries (Goodman et al. 2002). In particular, the panel was charged to determine the appropriateness of the $F_{40\%}$ strategy and determine if the quota setting approach was considerate of ecosystem needs in the eastern Bering Sea (EBS), Aleutian Islands (AI) and Gulf of Alaska (GOA). $F_{40\%}$ is the full recruitment fishing mortality that would reduce the spawning biomass per recruit to 40% of what it would be under no fishing (NMFS 1998). The panel published an extensive report. Here, I highlight some of its main points:

- The NPFMC defines ecosystem-based management as a strategy to regulate human activity to maintain long-term system sustainability.
- The FMP may succeed in maintaining ecosystem health and sustainability; however it may fail to meet the needs of non-target species.
- An ecosystem approach may be implicit or explicit. The first does not quantify the production that must be reserved to satisfy ecosystem needs, nor does it modify fishing behavior to mitigate adverse impacts other than those on the target species. An explicit approach addresses ecosystem effects directly.
- Scale is important; fisheries can have effects spatially and temporally removed from the fishery itself.
- The harvest control rule [$F_{40\%}$] is generally applied at an aggregate level of the EBS, AI and GOA. An ecosystem approach may need finer spatial scales.
- Available data could support a decision system that is more protective of ecosystem considerations.

The report further noted that the NPFMC's overall cap on the annual North Pacific groundfish harvest of 2 million mt. could be taken as an implicit ecosystem approach based on safety margins, as this cap has limited the sum of TACs for all species to considerably less than the sum of all allowable biological catches (ABCs). Finally, the panel also concluded that the effectiveness of safety margins depended on how carefully the rules to set them were crafted.

Two issues are central to the panel's comments: the potential failure to meet ecosystem needs and the need to use spatial approaches at multiple scales to address needs of and impacts on the system.

Neglecting to both modify fishing behavior that has adverse unintended consequences to non commercial species and to quantify the amount of production the system requires, are two issues that may hamper the ability of the current harvest strategies to maintain the properties of natural communities in a way that they support populations as they did prior to modification by fisheries removals. Other aspects such as truncating the age structure of stocks or impacts on habitat structure are also important (Longhurst 1998; Goñi 2000). Food webs and species diversity can be used characterize natural communities. Both trophic structure and species diversity are tightly related to the way a community functions (Paine 1980; Yodzis 1981, Pimm 1982; Naeem et al. 1994; Tilman and Downing 1994; Tilman et al. 1996). Both fisheries removals and offal directly impact food web structure and species diversity.

Removals can be considered a recurrent disturbance by which the structure of marine systems can be changed (Dayton 1971; Gislason 1994; Fogarty and Murawski 1998). Within the NPFMC regulatory area of the Aleutian Islands, removals have averaged slightly over a 100,000 t since 2000 (NPFMC 2005). Concerns about potential localized depletions caused by fisheries removals within Steller sea lion's critical habitat has lead to extensive restrictions throughout the Aleutian Islands (NMFS 2001 2003). Serial depletion of local populations has been documented for crustaceans and bivalves within the state waters of Alaska (Orensanz et al. 1998; Kruse et al. 2001). It is important then to look at how catches are distributed across space.

Offal is a subsidy which supplies energy to the system otherwise unavailable (Polis 1996; Polis et al. 1997). It is nonexistent prior to fishing activities but with multiple trophic links when present (Livingston and deReynier 1996). Within the eastern Bering Sea and Aleutian Islands, 55% of the removals are done by catcher processor vessels (Hiatt et al. 2004). Quierolo et al. (1995) estimated that of the 2.2 x 106 tons removed by fisheries in the Bering Sea-Aleutian Islands and Gulf of Alaska combined, 1.3 x 106 t (58%) were offal (inshore and offshore combined). More recently, Crapo and Betchel (2003) estimated 403,585 t of offshore offal were produced by catcher or processor vessels in 2000, mostly in the southeastern Bering Sea. This amounts to 27% (1.8 x 106 t) of fisheries removals in Alaskan waters. One effect of dumping offal offshore is exemplified by the hoki fishery off New Zealand. The estimated 50,000 tons of offal discharged on the continental slope over two months, reached the sea floor (5800 m) in sufficient quantities to alter the benthic community composition and cause an oxygen depletion of 45-55% saturation near the seabed (Livingston and

Rutherford 1988, Grange 1993, Levin et al. 1994, Goñi 1998). Offal then, can be a non-negligible fisheries input in the marine ecosystems and food webs of Alaska.

To incorporate finer spatial scales into the assessment of adverse effects on the system, the location of removals must be evaluated beyond total allowable catches (TACs) by regulatory area and the 2 million ton cap for Alaska. In the Aleutian Islands regulatory area, catches for POP and Atka mackerel are commonly distributed across its three statistical areas (Figure 4.1, statistical areas 541, 542 and 543). This practice, however, is not extended or standard for allocating catches of all species. There is also no established way in which quota estimates address the intensity of removals per unit of area. Quantifying both removals and consumption of offal in terms of density can offer some insights in this respect.

Several studies on sustainability and ecosystems increasingly recognize the use of multiple scales as an imperative need to maintain a system's integrity ((Levin 1997; Allen and Hoekstra 1994; McCool and Haynes 1995; Fischer et al. 2004). It is an approach that enables the understanding of populations that live, move and are distributed across a variety of habitats, and a way to describe and identify local processes, interactions, and disturbances masked by large scale patterns.

In this chapter, I address the potential effects of offal and density of removals by using a multiple scale food web approach based on the models introduced in the previous chapters. The multiple scales refer both to the spatial extent of the models and the level of biological resolution of the functional groups. The geographic extension of the Aleutian Islands falls under the three regulatory areas of the North Pacific Fisheries Management Council (NPFMC): the Aleutian Islands, the eastern Bering Sea (EBS) and the Gulf of Alaska (GOA). Therefore one of the levels of spatial resolution needed is that of the NPFMC regulatory areas, one food web model for each one. These models depict a food web with 140 functional groups on average. The second level of spatial resolution is that of a food web model for each of thirteen 2-longitudinal degrees areas that cover the entire extent of the [American] Aleutian Islands. This series of models was introduced in Chapter 3. This level allows an intermediate resolution within the regulatory areas and is based on food webs around 6 predators (7 with fisheries) and their prey. I concentrate on comparing densities (t/km2) of harvest and production with those of production, and densities of offal consumption by predators (groundfish).

4.3 METHODS

Estimates of fisheries removals, production, predation and offal consumption were taken from the models developed in Chapters 2 and 3. The models and their methods have been described in detail in their respective chapters. Both sets of models were developed based on standardized procedures for the estimation of parameter values. The models for the NPFMC regulatory areas have approximately 140 groups each, include commercial and non commercial species in detail. Fisheries removals also include commercial and non commercial species; data was obtained from the NPFMC Blend Database and the Observer Database Program. Offal was estimated based on standard product recovery rates (NMFS, 50 CFR 679 Table 3) applied to the fisheries removals. The models for the 2-degree areas are simplified food webs of six predator groups and their detailed prey items. Four of the predator groups are commercial species: Atka mackerel, Pacific Ocean perch (POP), Pacific cod and pollock. Fisheries removals in the 2-degree area models are limited to these four commercial species. Models for the Aleutian Islands cover shelf areas from 0 to 500m depth; models for the regulatory areas of the Eastern Bering Sea and Gulf of Alaska go down to 1000 m depth. Figures 4.1 and 4.2 show the area covered by the different models for the NPFMC regulatory areas (4.1) and the 2-degree models for the Aleutian Islands (4.2).

The density of removals were evaluated at 3 increasingly smaller spatial and higher biological resolution scales: a) density of total fisheries removals in each NPFMC regulatory area; b) density of removals for Atka mackerel, POP, Pacific cod and pollock in the Aleutian Islands NPFMC regulatory area, c) density of removals of Atka mackerel, POP, Pacific cod and pollock in the 2-degree areas across the Aleutian

Archipelago. For each of these four species, the estimated density of production was compared to the density of removals by fisheries and predation at two scales: regulatory area and 2 degree areas.

The effects of offal were evaluated in three ways: i) the estimated percent of total fisheries removals consumed as offal in the NPFMC regulatory areas; ii) the partition of offal among the different groundfish groups in the NPFMC regulatory areas and iii) Pacific cod as a case study of the spatial variability in the consumption of offal across the 2-degree areas. For the purpose of this analysis, offal is defined as waste resulting from processed removals, and discards are unprocessed (whole fish) waste from removals. Offal can be readily identified from groundfish stomachs, as opposed to discards. There are no quantitative estimates available on offal/discard consumption by seabirds or marine mammals; hence they were not included in the analysis.

4.4 RESULTS

This section presents the results on the quantification of: i) the density of fisheries removals, ii) the comparison of production to removals by fisheries and predation and iii) offal production and consumption.

4.4.1 Density of removals

The density of removals differs across NPFMC areas. In absolute values, the removals from the Eastern Bering Sea are the highest (2,021,500 mt), followed by those from the Gulf of Alaska (419,707 mt) and the Aleutian Islands (152,940 mt). In all three regulatory areas, fisheries removed mostly target species which comprised 90% (GOA), 92% (AI), and 95% (EBS) of the total removals. However, in terms of density (Figure 4.3), the EBS supports the highest intensity of removals (4.1 t/km^2), followed by the Aleutian Islands where the density of removals is almost twice that of the GOA (2.7 and 1.4 t/km^2, respectively). So while in absolute values the Aleutian Islands are only 8% of the removals in the EBS, the density of the removals is 66% of the EBS.

Within the NPFMC regulatory areas, pollock, Pacific cod, Atka mackerel, and POP account for 80% of the total removals in the Aleutians Islands, 72% in the EBS and 43% in the GOA (Figure 4.4). Only pollock and Pacific cod make a substantial contribution in all three NPFMC regulatory areas. Within the Aleutian Islands NPFMC regulatory area, Atka mackerel supports the highest density of removals (0.9 t/km^2) followed by pollock, Pacific cod and POP (all >0.1 t/km^2). This pattern does not apply homogeneously across the Aleutian archipelago (Figure 4.5). Removals only extend to area 174°E; there were no removals in area 172°E. The density of removals of pollock decreased from east to west from a peak density of 9.0 in the easternmost area (164°W), catches dropped considerably west of area 170°W. The density of Pacific cod removals also peaked at the easternmost area (164°W) with catches relatively consistent throughout the archipelago. Removals of Atka mackerel were patchy, with a peak density of 3.1 t/km^2 at 178°W and decreasing densities to the east and west. Finally, the density of removals of POP are centered on areas 180°W and 172°W where the deep passes of Amchitka and Amukta are located (see Figure 4.2). These removals are low overall, as POP is under a stock rebuilding plan (Spencer et al 2004).

In summary, removals are unevenly distributed across the archipelago with localized high density removals for pollock, Pacific cod and Atka mackerel. High density removals may be of primarily one species as in areas 166°W or 178°W where the primary targets are pollock and Atka mackerel respectively. High density removals can also result from the aggregate removals of 2 or 3 species. In area 164°W the combined density of fishery removals of Pacific cod and pollock is 11 t/km^2. A similar case is observed in area 172°W where the density of removals for all four species is above the average estimated for the NPFMC regulatory area of the Aleutian Islands.

The impact of these removals at an ecosystem level is shown in the following results where the estimated production of pollock, Pacific cod, Atka mackerel and POP is compared to removals by fisheries and predation (Figures 4.6 through 4.9). These results highlight how production is partitioned between human and marine predators under current management policies.

4.4.1.1. Pollock

Across the NPFMC regulatory areas, removals by predation are greater than those by fisheries. Production satisfies the demand of predation and fisheries in the EBS and Aleutian Islands, but not in the GOA where the stock was assumed to be decreasing during the early 1990s (Aydin et al. *in review*) (Figure 4.6, top).

At a finer spatial scale, production could satisfy fisheries removals between 172°E and of 172°W but not the combined removals by fisheries and predation. The peak in predation removals at area 174 E are mostly due to predation by Atka mackerel on pollock juveniles. In contrast, the peak in predation removals at area 172°W is primarily the result of the combined predation by Atka mackerel, pollock and Pacific cod. From 170°W to 164°W, the production is not enough to satisfy removals by predation or by fisheries. The removals by fisheries are greater than or equal to the removals by predation (Figure 4.6, middle). Overall, pollock appears to be unbalanced as production is exceeded by removals through predation and fisheries across the archipelago.

4.4.1.2 Pacific cod

Pacific cod is a top predator and the production satisfies the removals of both predation and fisheries across NPFMC regulatory areas. Both production and removals are fairly even across the EBS, GOA and Aleutian Islands (Figure 4.7). The density of production across the archipelago is enough to satisfy the combined removals by fisheries and predation except at two locations: area 174°W and 164°W. In both areas, removals by fisheries exceed those of predation. As with pollock, the peak in the density of removals occurs at area 164°W. This case of Pacific cod shows the potential risk for localized depletion to go undetected. The estimates at the level of the NPFMC show there is ample productivity to support the removals by both fisheries and predation. Even combining the 2-degree areas into the NPFMC statistical areas for the

Aleutian Islands (from 170W to 177W, 177W to 177E and 177E to 172E), production and removals would be balanced. The unbalance at 174W would go unnoticed, masked by average values at larger spatial scales and excess production such as that of area 178 E, where production is expected to be high due to the high biomass density at that area (Figure 4.7, bottom). Similarly, the unbalance at 164 W is masked at the level of the NPFMNC areas of the EBS and/or GOA.

4.4.1.3 Atka mackerel

The highest density of Atka mackerel is found in the Aleutian Islands NPFMC regulatory area. As in pollock, predation removals are greater than those by fisheries (Figure 4.8, top). However, when removals by predation are estimated at finer scales, the production is exceeded by the joint removals of fisheries and predation at a majority of areas (Figure 4.8, middle). Although production could support removals by fisheries alone (except at area 170°W), it does not satisfy the requirements of fisheries and predation jointly, placing fisheries in strong competition with other predators.

4.4.1.4. Pacific Ocean perch

Across the NPFMC regulatory areas and the archipelago production of POP exceeds removals by fisheries and predation, except for area 170°W (Figure 4.9). Pacific Ocean perch is in recovery from excessive removals by the foreign fleet during the early 1960s. The surveyed peak biomass density of POP was located at area 172°E, where there were no fisheries recorded for any species during the early 1990s.

Figure 4.10 shows the density of removals by fisheries and predation for pollock, Pacific cod, Atka mackerel and POP. Overall, the density of fisheries removals is higher in the eastern areas (areas 172°W to 164°W), which would translate into an increased competition between predators and fisheries. The strength of the competition may vary depending on the diet of the predators. Those predators feeding mostly on pollock, Pacific cod, Atka mackerel, and POP would be expected to experience stronger competition with fisheries than those with a higher proportion of alternative prey. This implies that at an ecosystem level the competition between fisheries and predators should be estimated not only on a species by species basis, but in aggregate. The aggregate competition would be particularly important for species of concern or under special management programs (such as Steller sea lions). Based on the estimates from the models for the NPFMC regulatory areas, species for which Atka mackerel, pollock, Pacific cod and POP combined make up at least 50% of their diet include Steller sea lions, skates, halibut, arrowtooth flounder and Kamchatka flounder (Table 4.1). While fisheries removals of prey species are in direct competition with other predators, the removal of predators decreases predation mortality on specific prey species. Prey species are then given a competitive advantage, potentially modifying density dependent processes.

4.4.2 Effects of offal

The fate of fisheries removals across the Aleutian Islands, EBS and GOA NPFMC regulatory areas is shown in Figure 4.11 and summarized in Table 4.2. The percent of removals that ends as offal in the NPFMC regulatory areas varies from a high of 50% in the EBS to 33% in the Aleutian Islands and 29% in the GOA. This brings the total estimate of offal produced to over 1 million tons in the EBS, 50,000 tons in the Aleutian Islands and 120,000 tons in the GOA. During the early 1990s most (>90%) of the vessels in the Aleutian Islands NPFMC area were processors at sea (ADFG ticket database), so the offal between 170°W and 170°E was discharged at sea. In the Bering Sea and Aleutian Islands combined at least half of the total removals were processed at sea (Hiatt 2004). A large portion of the offal produced is estimated to be consumed by groundfish: 76% in the EBS, 88% in the Aleutian Islands and 61% in the GOA. The main routing of offal through the food webs is carried out by groundfish groups with large biomasses: Pacific cod and pollock in the Eastern Bering Sea and the Aleutian Islands; Pacific cod, sablefish and halibut in the Gulf of Alaska (Figure 4.12). These groups consume the largest portion of offal. However the percent of offal in their diets is not necessarily great. Overall, across all NPFMC areas, there are only

13 groups for which offal constitutes more than 1% of their diet (Figure 4.13). These groups are facultative scavengers that benefit the most from offal, which acts as a subsidy from fisheries. The main groups benefiting from offal as a subsidy include sleeper sharks, skates, halibut, Pacific cod and sablefish. For these groups offal contributes at least 5% of their diets.

Figure 4.14 shows Pacific cod as a case study, illustrating the spatial variability of offal consumption and its contribution to diet. For example, the average density of offal consumption in the NPFMC regulatory area of the Aleutian Islands is 0.34, but it can be as high as 1.2 t/km^2, as in area 178°W. Likewise the average proportion of offal in Pacific cod's diet is 5%, but it can be nil as in area 176°E or over 6% as in area 178°W. A higher density of removals does not necessarily translate into a higher consumption of offal. In the eastern areas, 168°W to 164°W, the density of removals is higher but there is also a larger biomass of other species eating offal (Figures 4.12-4.14).

4.5 DISCUSSION

In this section I discuss the implications of the density of removals by fisheries and its relation to production and predation first, followed by a discussion of the production and consumption of offal.

4.5.1 Implications of the density of fishery removals

Current management of the fisheries is based mostly on estimated total allowable catches (TAC), which have large spatial extent and the assumption of a stock-wide spatial scale as sufficient underlies most single species assessment models (Mangel et al. 2000). Spatial considerations and multiple scales do not necessarily have to be incorporated directly into the assessment models. Some studies have found that the production estimates from spatially explicit models do not differ in general from those based on non spatial assumptions (Roughgarden 1997). If so, then multiscale spatial considerations may be implemented in the allocation of the TAC, not the assessment models. The spatial variation in the density of removals and production shows the TAC could be distributed better based on the distribution of biomass and/or production. This would prevent the localized concentration of removals over small areas. The estimates for this study are based on the early 1990s, and some steps have been taken in this direction since then. The TAC for Atka mackerel and POP for the NPFMC area of the Aleutian Islands are routinely divided among its three statistical areas based on biomass distribution stemming from the trawl surveys. However, TAC allocation among the three statistical areas is not necessarily applied to bycatch species or all targets species in the Aleutian Islands (e.g., sharks and skates) (Gaichas et al. 2005; Courtney et la 2005). Diffusing the removals lowers the risk of spatially concentrated removals and potential localized depletions.

Although an improved spatial distribution of the TAC would aid lowering the risk of localized concentrations of removals, it does not imply that fisheries will not compete with other predators for local production. Changes in the estimation of the TAC itself could incorporate ecosystem needs by considering the production required in the system other than by fisheries. Current harvest strategies ensure there is enough production to satisfy the level of TAC only, and the production left may not be sufficient to satisfy the consumption by predators other than humans. Throughout the Aleutian Archipelago the competition between predators and fisheries is stronger towards the east (Figure 4.10). Regardless of the amount of production, the fact that the removals by fisheries and predation are almost the same density implies a stronger interaction among them than in the central or western areas. Competition strength between fisheries and predators may be stronger depending on the amount of production, the location and timing of the removals. For example, the density of Pacific cod removals by fisheries in the easternmost area 164°W, far exceeds the removals by predation and the level of local production. Even if the production deficit could be covered through biomass redistribution from adjacent areas, there could be some level of temporary depletion. In an independent study using recent data, Fritz and Brown (2005) found Pacific cod was locally depleted during the fishing season within the critical habitat area for Steller sea lions off Unimak Island in the EBS, which partially overlaps with area 164°W. Fritz and Brown observed that although the local abundance of Pacific cod gradually increased after the fishing season, the temporary local depletion of Pacific cod did decrease its availability to Steller sea lions during specific periods. One objective of ecosystem based fishery management (EBFM) is the minimization of competitive interactions between locally intense fisheries and other predators. Based on these potential localized depletions, the current strategy for the spatial allocation of TACs should be reviewed to ensure this objective is met.

Uncertainty in the production estimates may undermine the relevance of production deficits due to localized removals. However spatial deficits are hard to balance —even with total production in excess of the combined removals by fisheries and predation. To illustrate this case, I tried to balance the production deficits of pollock (Figure 4.6) adjusting the biomass estimate on which it was based. This was done by substituting the average biomass estimates for the upper 95% CI biomass estimate for the areas covered by the bottom trawl surveys (170°E to 164°W). The production in areas 168°W to 164°W was further increased by adding the biomass age 5+ of the Bogoslof stock. The Bogoslof, Bering and Aleutian Islands pollock stocks mix in an undetermined proportion (Ianelli et al. 2005). The increased production estimate is shown in Figure 4.15. The adjusted overall production is now enough to satisfy [in excess] both fisheries and predation removals. Yet, because all the additional biomass was allocated proportionately to the biomass estimates in each 2-degree area, it is not possible to balance production and removals in all areas without making further assumptions regarding the original biomass distribution or survey and movement estimates. Highly localized removals and strong production deficits are then relatively robust to uncertainty. In this case, a portion of the eastern areas (statistical area 518, northern portion of eastern Aleutian Islands, Figure 4.2) was closed (for political reasons) to direct pollock fishing in 1992. It is unknown what the effects would have been if the area had not been closed. Depletion at smaller scales or unmonitored local populations are at a higher risk of going undetected and having a delayed management response (if any).

4.5.2 Implications of offal

Most studies regarding discharges from seafood processing address discards, but not offal (Bluhm and Bechtel 2003). The potential impacts of offal are widespread and include adverse changes in water quality and community structure. Changes in water quality include increased oxygen demand, total dissolved solids, nutrient concentrations, and turbidity (Champ et al. 1981). Excess nutrients from offal can overwhelm the system, as exemplified by the hoki fishery off New Zealand where an oxygen depletion of 45-55% saturation near the seabed was registered subsequent to the discharge of 47, 800 tons of discards over a 60 day period (Goñi 1998). This decline in water quality prompted a ban on offshore offal discharge (New Zealand hoki management). Comparatively, the total offal produced in the NPFMC regulatory areas in the early 1990s is 50,000 tons in the Aleutian Islands, over 100,000 t in the GOA and over 1 million in the EBS. The total discharges are higher if discards (whole fish) are included: 85,000 tons in the Aleutian Islands, 197,000 tons in the GOA and 1.3 million tons in the EBS. Similar to the hoki case, fisheries in Alaska also usually concentrate over one or two months, so there is a risk of overwhelming the system if offal and/or discards are discharged in one concentrated area and they are allowed to settle and decay on the seabed. Catcher-processor vessels may stay at one location, fishing and processing fish (Figure 4.16) (Edwards 2006).

In terms of impacts on the community structure and energy flows, offal transfers energy from the sea bottom and water column to the surface, distinctly favoring scavengers. Before offal reaches the seafloor where it can be consumed by bottom dwellers, it becomes available to scavenging seabirds, whose reproductive success can be directly increased (Phillips et al. 1999; Furness 2003). In the North Pacific, shearwaters, Laysan albatross and black footed albatross are known to benefit from offal discharges (Gould et al. 1997; Gould 2000). Within the Aleutian Islands, fulmars, Laysan albatrosses and gulls consume offal as well (Edwards 2006). The consumption of offal may vary seasonally depending on the presence of migratory seabirds. As in the case of seabirds, offal consumption by marine mammals in waters off Alaska has not been systematically studied (Bluhm and Bechtel 2003). Offal [and discards] availability to both seabirds and marine mammals is limited by the amount of time that offal remains in the surface or midwater. A study off Chiniak Bay in Kodiak, Alaska showed fish offal settled down to depths of 150m within an hour (Bluhm and Bechtel 2003). Offal on the bottom becomes available to most groundfish and benthic organisms, particularly mobile scavengers, including large flatfish like black halibut and Kamchatka flounder in the western Bering Sea (Dayton et al. 1995, Orlov 2004). The results of this study for the regulatory areas of the NPFMC support this observation, where skates, sleeper sharks, Pacific cod, and flatfish, consume offal as a larger proportion of their diets (Figures 4.10 and 4.11). The case study of Pacific cod shows one species can consume varying portions of the offal available, even if offal is a relatively fixed portion of its diet across areas (Figures 4.12 and 4.13). Offal composition is not recorded in the feeding habits database from which the groundfish data for this analysis was taken, but seabirds studies show that while offal of gadoid and clupeid species is consumed in high percentages, flatfish offal is not (Garthe and Schep 2003). Offal composition then may partly explain why the consumption of offal by Pacific cod was not proportional to the density of the combined fisheries removals across the 2-degree areas. Total consumption of offal by all predators combined does increase as total removals increase, but the percent of offal consumed within the system varies among the NPFMC regulatory areas. Thus, there seems to be some level of partitioning of offal operating at smaller scales which is likely the combined result of offal composition, its availability with respect to other prey and interaction with other scavenging species at the surface, midwater and seafloor. The same is likely to apply to discards.

Operating as a subsidy, offal can help support higher abundances of the scavenging community that would be otherwise expected (Polis et al. 1997). Increasing abundances of dogfish and skates have been associated to increased food availability from discards. Offal may change the patchiness of the benthic communities favoring highly mobile fish and crabs compared to slow moving echinoderms (Goñi 1998). The effects of offal in the food web are not limited to the routing of energy in favor of scavengers; effects can spread through the food web via an increased predation on prey populations by scavengers and displacement of non scavenging species from shelter and feeding grounds. Changes in the ratio of scavenging and non scavenging populations and competitive exclusions have been amply documented for seabirds (Furness et al. 1992. 2003, 2005; Garthe and Schep 2003; Votier et al. 2004) and observed in hermit crabs (Kaiser et al. 1998).

The trade-off between impacts on water quality vs. community structure depends on the permanence and accumulation of offal within the system. The beneficial or adverse effect of offal offshore becomes a matter of judgment, partly based on the assumption of how much it is dispersed and subsequently incorporated into the marine food web (Bluhm and Bechtel 2003). The results presented here apply to waters <500 m deep, fate of offal at greater depths in the Aleutian Islands is poorly represented, as these removals were not included in the analysis. However, a review of the depth of observed catches from 1991 – 2003 shows the majority of catches for the main commercial species occurring within the 0-500 m depth layer since 1997. The assumption that offshore processing disperses offal throughout a large geographic area may not apply at times and areas where fisheries removals are concentrated, like in area 164°W, and direct studies on water quality subsequent to major fishing seasons (similar to that for hoki in New Zealand) are warranted.

Offal was addressed in 1998 with the establishment of the full retention and utilization program in Alaskan waters which requires that all harvest[xciii] be converted into primary products amounting to at least 15% of the round-weight catch[xciv]. A significant reduction of offal production also followed the creation of the Pollock Conservative Cooperative (PCC) in 1998 which allowed an optimization of the processing line, promoted secondary products and improved the match of offal flows to meal plants. In aggregate, these changes have increased the total product recovery rates of pollock from 19% in 1998 to 28% in 2002 which has also increased the value of the catch. While both the full retention/utilization program and the creation of the PCC have helped lower the overall production of offal, the spatial distribution of offal has yet to be addressed directly. Indirectly, offal is divided between inshore and offshore areas through TAC allocation among the inshore/offshore components and catcher/catcher processor vessels of each fishery. The offal discharges in Alaskan waters are regulated by the EPA under the National Pollutant Discharge Elimination System for Alaskan Seafood Processors (NPDES), which "limits the total annual load of settleable solid seafood processing waste". Violations in the nearshore area are not uncommon and several companies have been fined in the past 10 years for consistently exceeding the stipulated limits for offal discharge (EPA 2000 2006). The EPA proposes no limits on waste loads by offshore seafood processors discharging more than one nautical mile offshore (NPDES Seafood processing Fact sheet), so there are effectively no guidelines to prevent the localized discharge of offshore offal. The move towards an ecosystem based management approach opens a window of opportunity to address the gap on offshore offal regulation for water quality as well as potential impacts on community structure and food webs. Guidelines could be incorporated either through the FMPs for the regulatory areas of the NPFMC, the Fisheries Ecosystem Plan for the Aleutian Islands or industry oriented incentives to further improve recovery rates (Kirkpatrick 2003). Provisions on the spatial location

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[xciii] For species in the utilization/retention program: pollock, cod and shallow-water flatfish species complex in the GOA as defined in the annual harvest specifications for the GOA.

[xciv] Or round-weight delivery during the fishing trip.

and magnitude of offal discharges could be particularly relevant for areas of particular interest (e.g., coral gardens and Essential Fish Habitat). In areas where most of the fisheries removals are taken by catcher-processor vessels, the risk of having both localized depletions and localized offal discharge is compound. Spatial allocation can help prevent the potential adverse impacts of highly localized removals, fishing effort and discharges by ensuring they are diffused throughout the system.

In order to change fishing behavior and avoid or mitigate adverse impacts, feedbacks and incentives must be established to directly reward and motivate actions of fishermen that act for the common good (Levin 2000 and Hilborn 2002). Spatial information of fisheries removals and waste discharge can provide feedback to both management and industry regarding areas prone to localized depletions as well as the distribution of offal discharges. Such feedback loops must operate at multiple scales. At large scales they can provide information needed to achieve global goals that are similar to national objectives. At smaller scales they must be tailored to suit local needs and processes, preserving conditions for populations living in a variety of habitats and fishing fleets operating at a variety of spatial scales. Even when the relative magnitude of fisheries removals is low, the use of a single large spatial scale to assess the intensity of removals, resource partitioning and offal discharge, may fail to prevent localized effects if mechanisms are not set in place to diffuse the effects of fishing over space [and time]. Spatial allocation of quotas, fishing effort and processing discharges can help establish these feedbacks. Not doing so can have cumulative impacts, potentially: i) causing shifts in the trophic structure favoring scavengers such as sharks and skates; ii) inducing diet overlap in seabirds feeding on offal (Edwards 2006); and iii) fragmenting food webs with localized depletions along the Aleutian Archipelago.

Table 4. 1 Predators whose diet is at least 50% pollock, Pacific cod, Atka mackerel and POP.

	NPFMC regulatory area		
	AI	EBS	GOA
Steller sea lion	✓		✓
Alaska skate	✓		
Arrowtooth flounder		✓	
Kamchatka flounder		✓	
Pacific halibut		✓	✓
Bering skate		✓	

Table 4. 2 Fate of fisheries removals in the NPFMC regulatory areas of the Aleutian Islands, EBS and GOA.

	NPFMC regulatory area		
	Aleutian Islands	Eastern Bering Sea	Gulf of Alaska
Total removals*	152,940	2,021,449	419,708
Total discards	34,576	300,228	77,084
Total offal	50,712	1,020,627	120,122
Consumed offal	44,435	775,544	73,082
Km^2	56,936	495,218	291,840

*Removals include target and non-target species

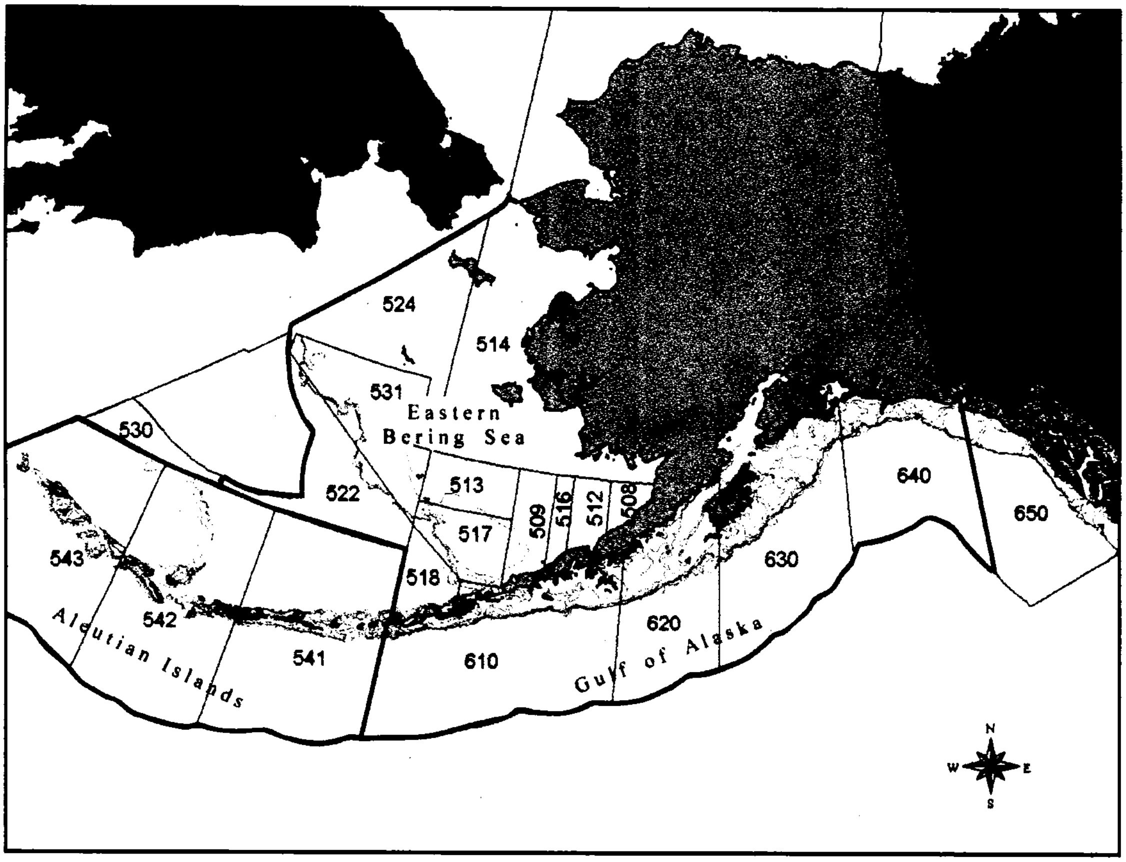


Figure 4.1 Geographical extent of the food web models for the NPFMC regulatory areas: Aleutian Islands (541, 542 and 543), Gulf of Alaska (610–640), and Eastern Bering Sea (500–529).

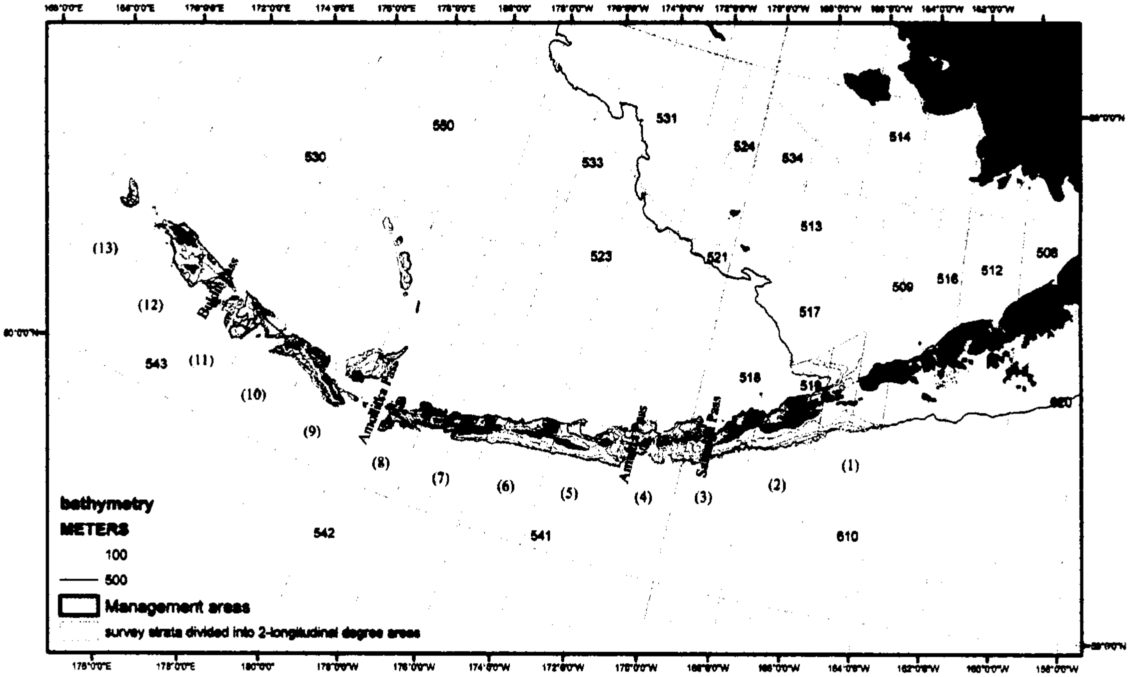


Figure 4. 2 Geographical extent of the [American] Aleutian Islands (shaded in green) 2-degree food web models and overlap with NPFMC regulatory areas

The islands west of Samalga Pass fall within the NPFMC regulatory area for the Aleutian Islands (statistical areas 541, 542 and 543). The south portion of the islands east of Samalga Pass falls within the statistical area 610 of the regulatory area of the Gulf of Alaska. The northern portion of the islands east of Samalga Pass are covered by the statistical areas 517, 518 and 519 of the regulatory area fort he Eastern Bering Sea. The meridians show the 2-longitudinal degree divisions, number in parenthesis show the thirteen 2-degree areas for which a food web model was constructed.

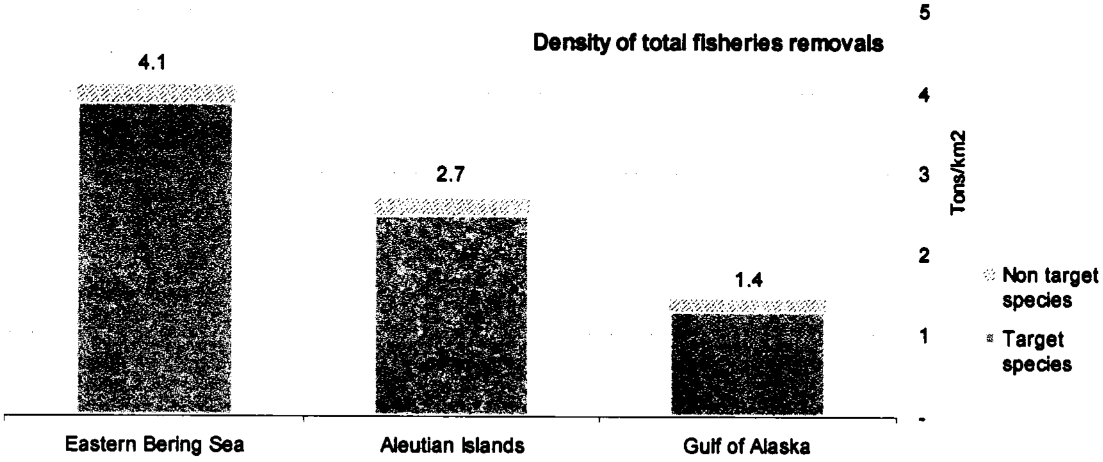


Figure 4.3 Density of total estimated fisheries removals of target (solid) and target (pattern) species in the three NPFMC regulatory area of the Eastern Bering Sea, Aleutian Islands and Gulf of Alaska during the early 1990s.

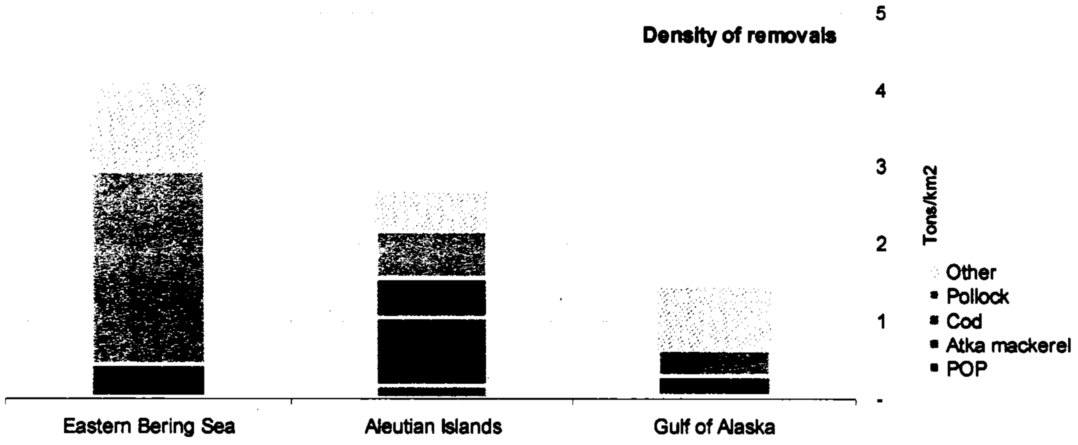


Figure 4.4 Estimated density of fisheries removals (t/km^2) of Pacific Ocean perch, Pacific cod, pollock and Atka mackerel and other target and non-target species in each of the NPFMC regulatory areas: Eastern Bering Sea, Aleutian Islands, and Gulf of Alaska during the early 1990s.

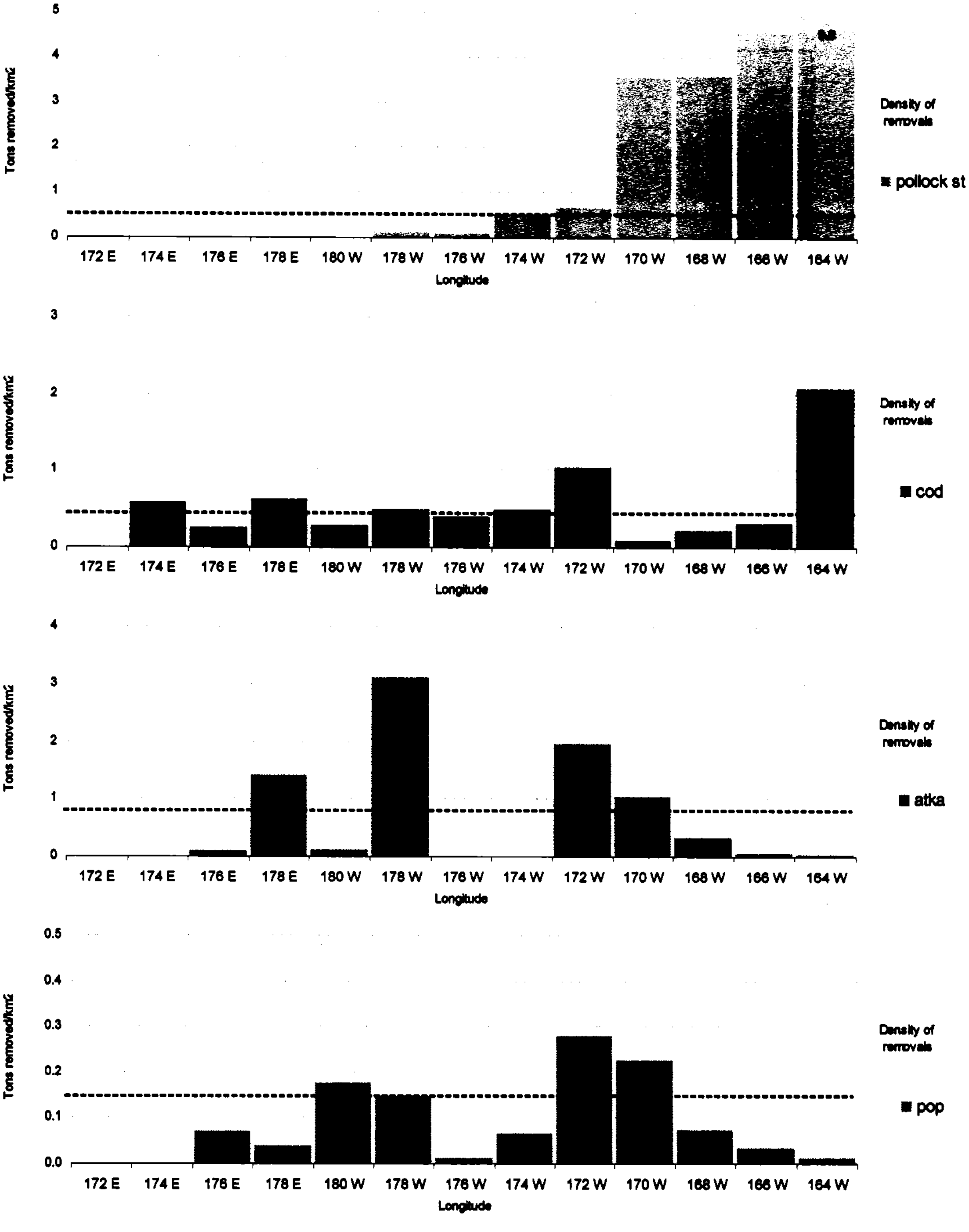


Figure 4.5 Density (t/km^2) of fisheries removals for pollock, Pacific cod (cod), Atka mackerel (atka) and Pacific Ocean perch (pop) throughout the American portion of the Aleutian Archipelago.

Dark dashed lines denote the density of removals in the NPFMC regulatory area of the Aleutian Islands. Areas 172°E to 170°W fall with in the NPFMC regulatory area of the Aleutian Islands. Areas 168°W to 164°W fall within the NPFMC regulatory areas of the Eastern Bering Sea and the Gulf of Alaska. Estimated removals correspond to the early 1990s.

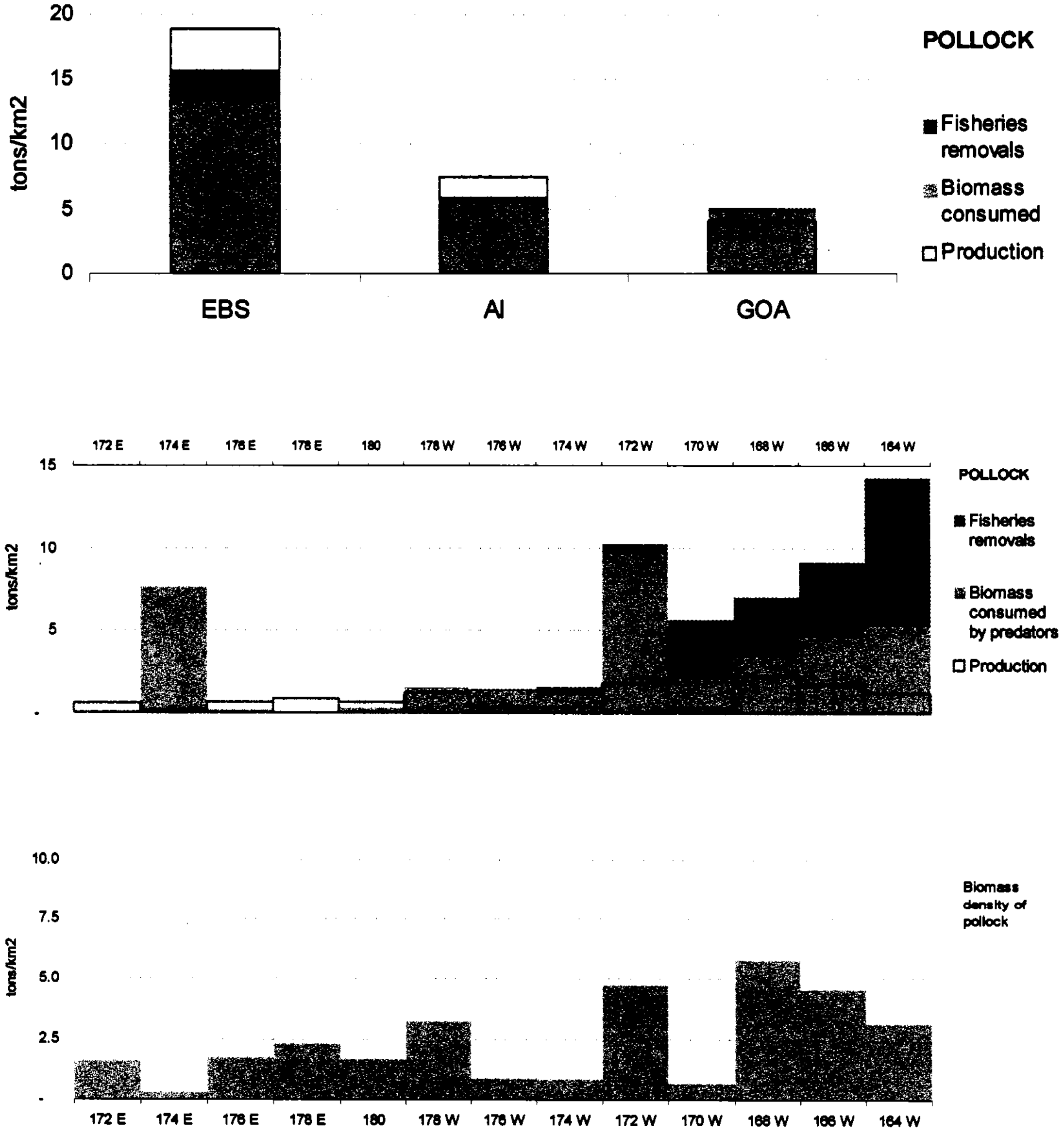


Figure 4.6 Density of production compared to removals by fisheries and predation of pollock.

Top: Across NPFMC regulatory areas; middle: across the Aleutian Archipelago shown by 2-degree areas; bottom: biomass density of pollock shown by 2-degree areas. Areas 172°E to 170°W fall within the Aleutian Islands NPFMC regulatory areas. Areas 168°W to 164°W fall within the EBS and GOA NPFMC regulatory areas.

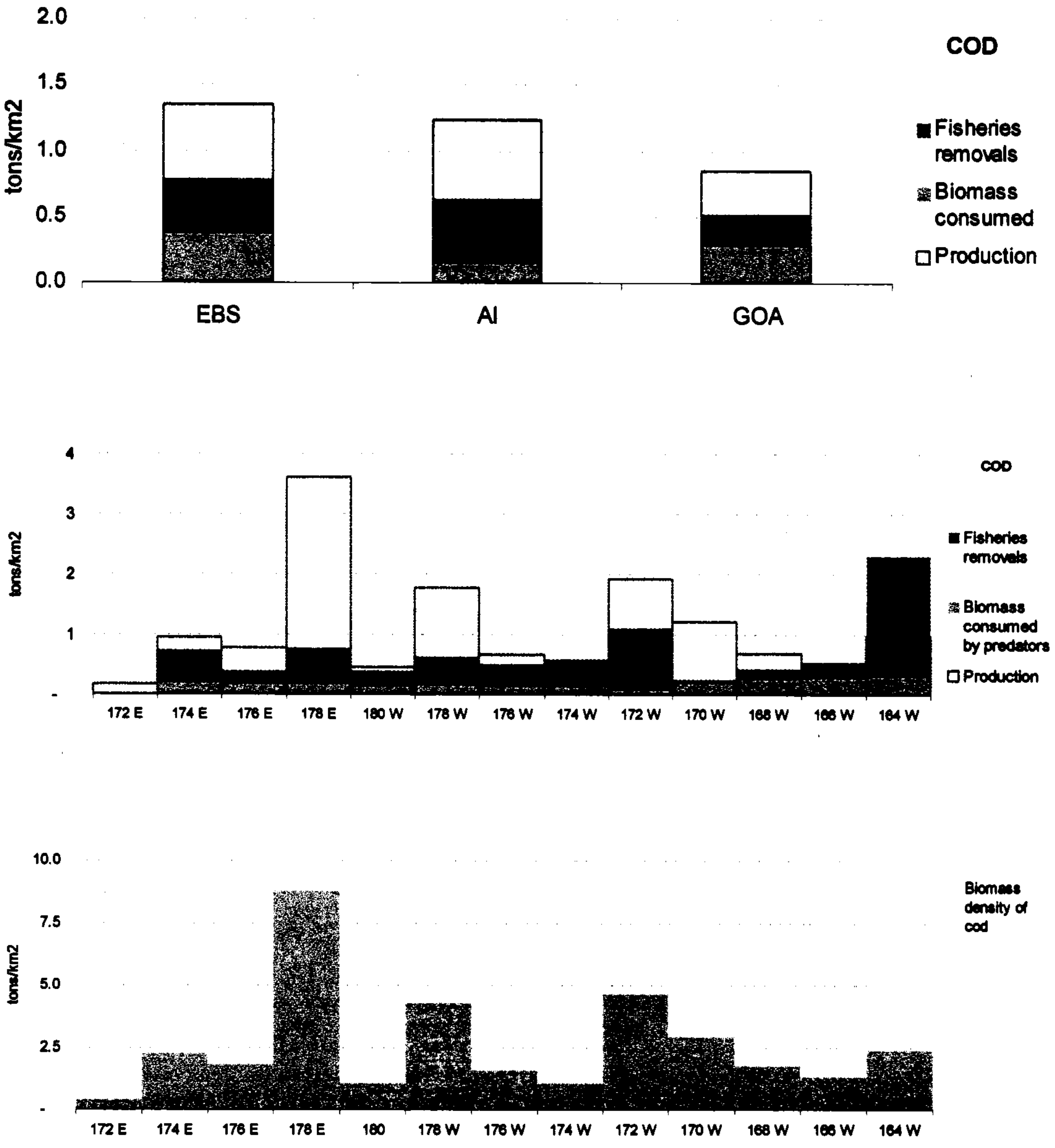


Figure 4.7 Density of production compared to removals by fisheries and predation of Pacificcod.

Top: Across NPFMC regulatory areas; middle: across the Aleutian Archipelago shown by 2-degree areas; bottom: biomass density of pollock shown by 2-degree areas. Areas 172°E to 170°W fall within the Aleutian Islands NPFMC regulatory areas. Areas 168°W to 164°W fall within the EBS and GOA NPFMC regulatory areas.

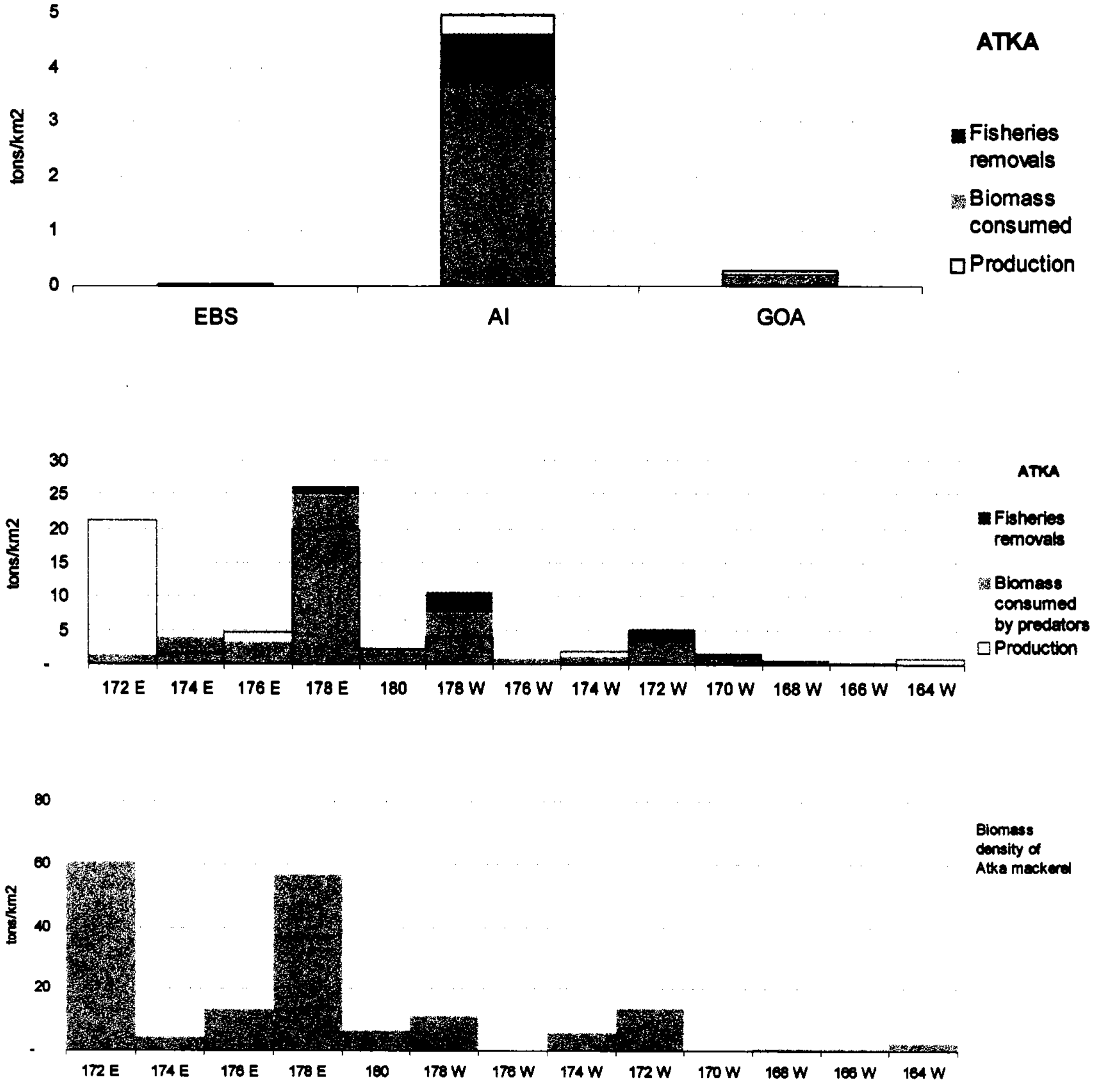


Figure 4.8 Density of production compared to removals by fisheries and predation of Atka mackerel.

Top: Across NPFMC regulatory areas; middle: across the Aleutian Archipelago shown by 2-degree areas; bottom: biomass density of pollock shown by 2-degree areas. Areas 172°E to 170°W fall within the Aleutian Islands NPFMC regulatory areas. Areas 168°W to 164°W fall within the EBS and GOA NPFMC regulatory areas.

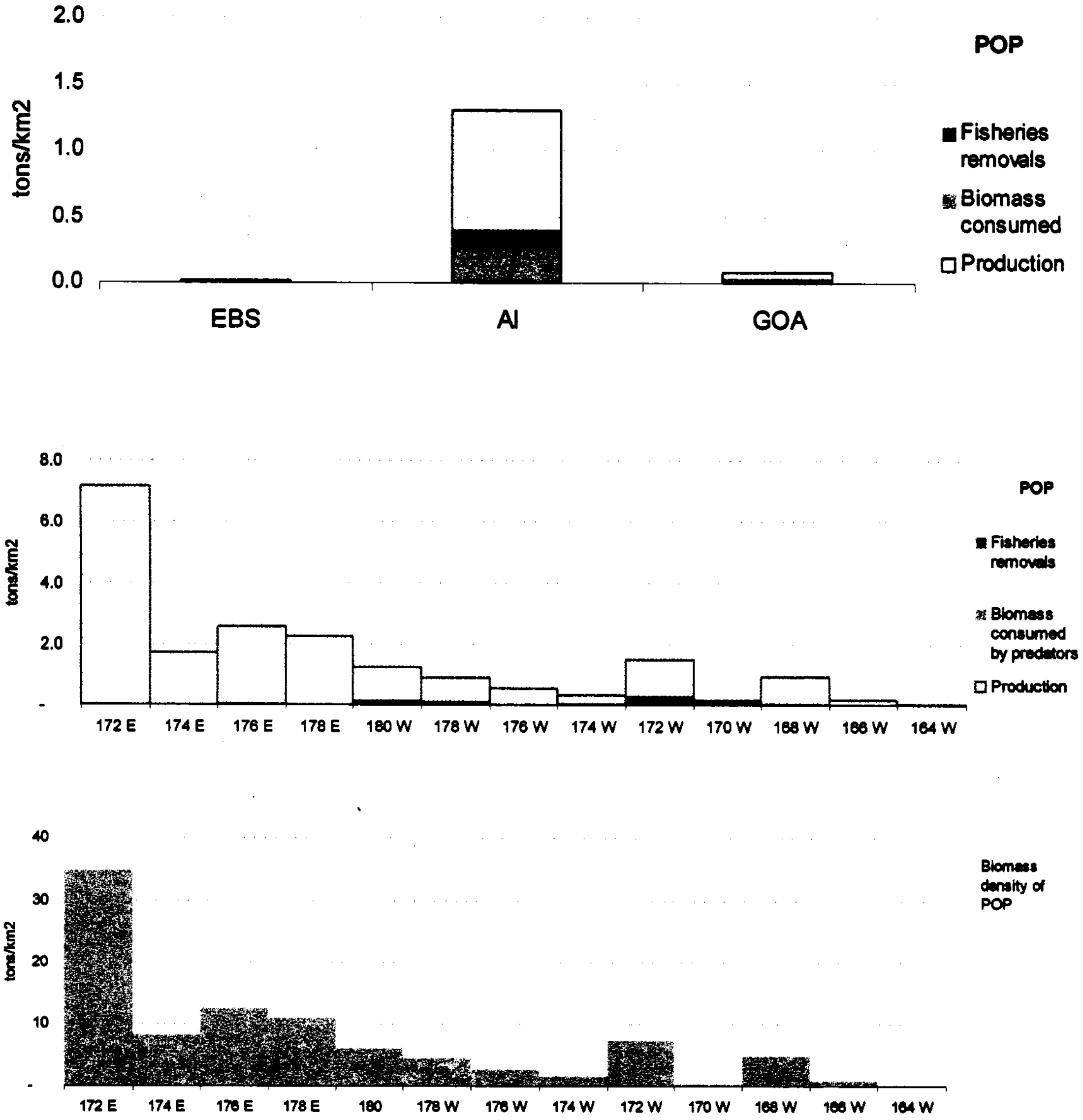


Figure 4.9 Density of production compared to removals by fisheries and predation of Pacific Ocean perch.

Top: Across NPFMC regulatory areas; middle: across the Aleutian Archipelago shown by 2-degree areas; bottom: biomass density of pollock shown by 2-degree areas. Areas 172°E to 170°W fall within the Aleutian Islands NPFMC regulatory areas. Areas 168°W to 164°W fall within the EBS and GOA NPFMC regulatory areas.

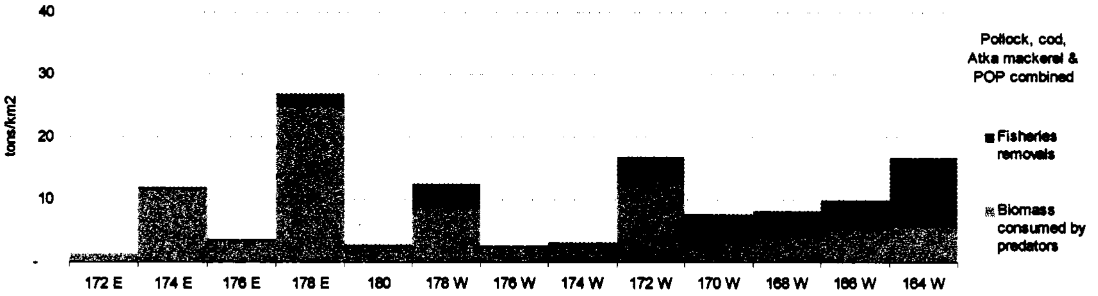


Figure 4.10 Density of removals by fisheries and predation of pollock, cod, Atka mackerel and POP combined shown by 2-degree areas.

Areas 172°E to 170°W fall within the Aleutian Islands NPFMC regulatory areas. Areas 168°W to 164°W fall within the EBS and GOA NPFMC regulatory areas.

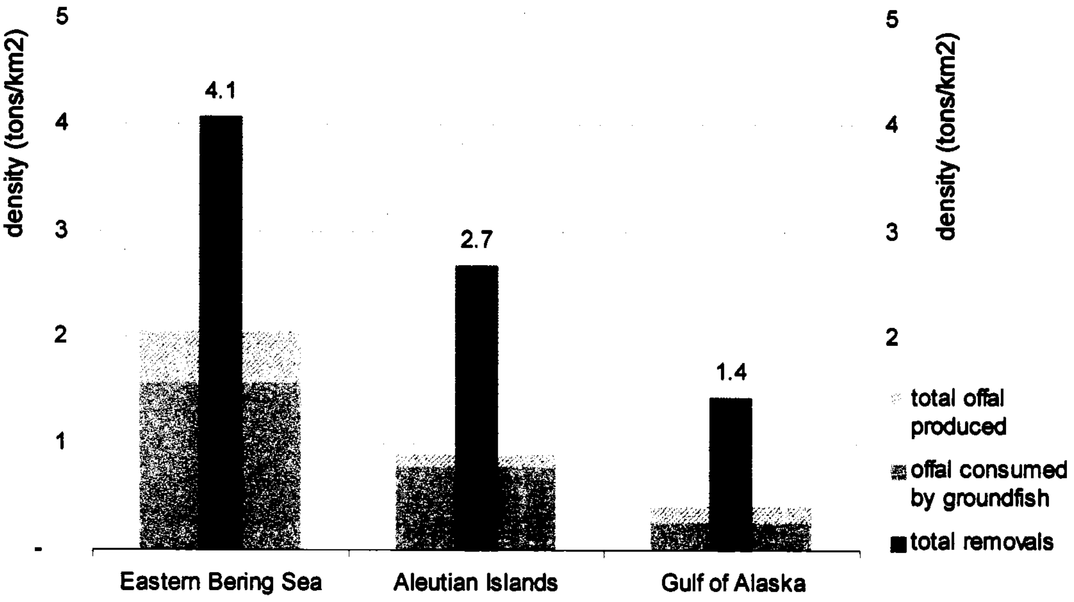


Figure 4.11 Percent of total removals consumed as offal and density of total removals in the NPFMC regulatory areas of the Eastern Bering Sea, Aleutian Islands and Gulf of Alaska (early 1990s).

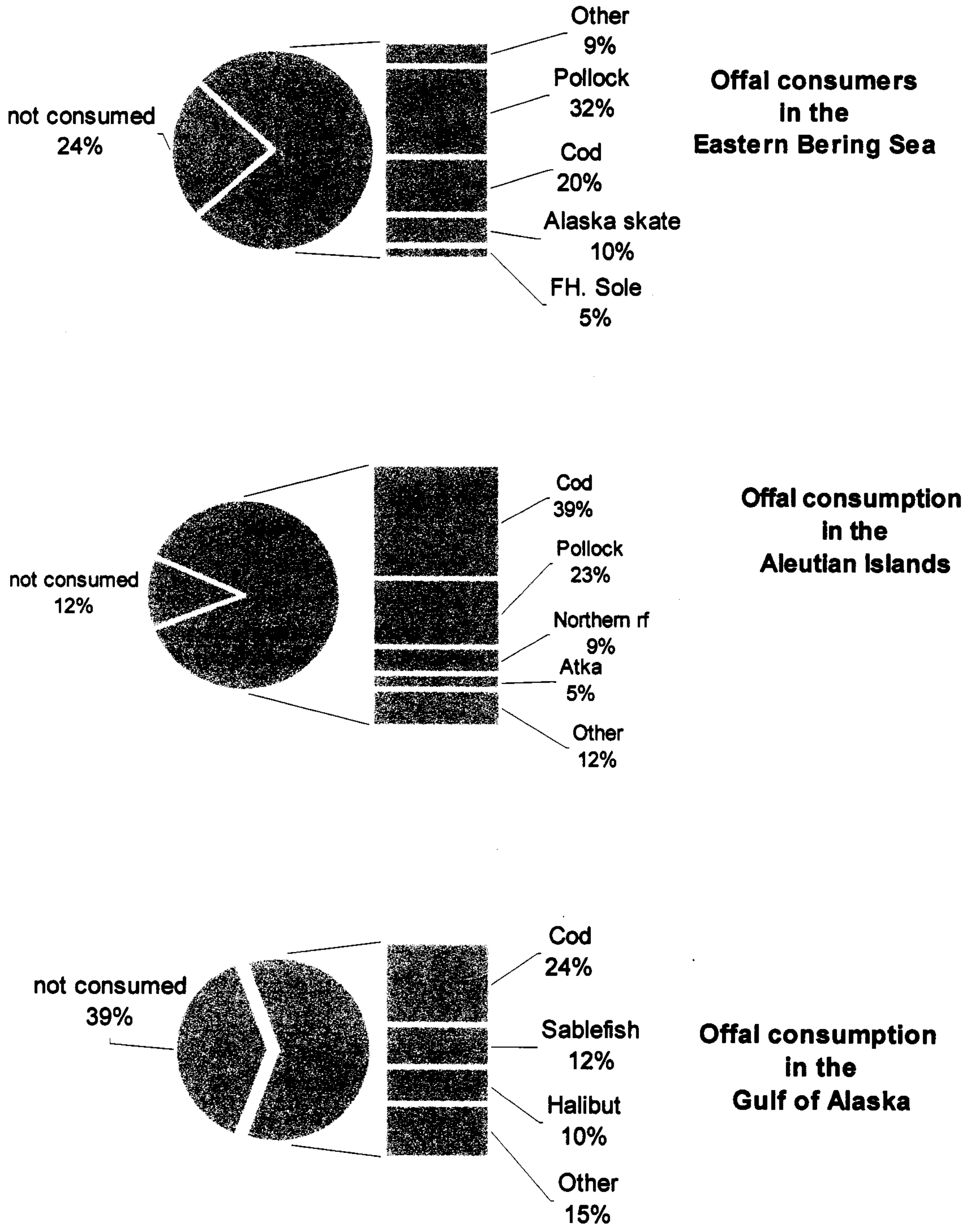


Figure 4.12 Offal consumers in the NPFMC regulatory areas of the Eastern Bering Sea (top), Aleutian Islands (middle) and Gulf of Alaska (bottom).

FH sole is Flathead sole, Northern rf is Northern rockfish and Atka is Atka mackerel.

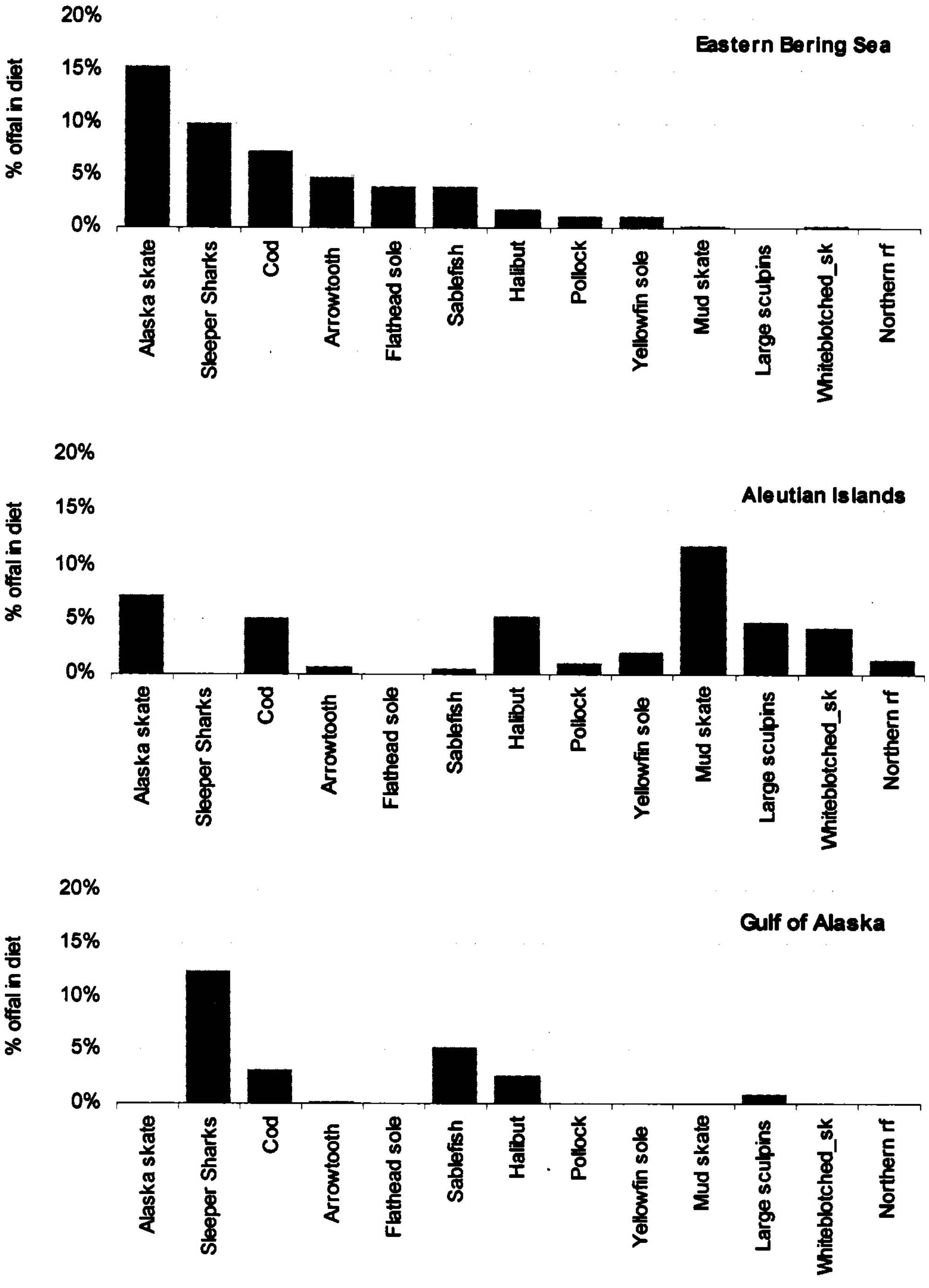
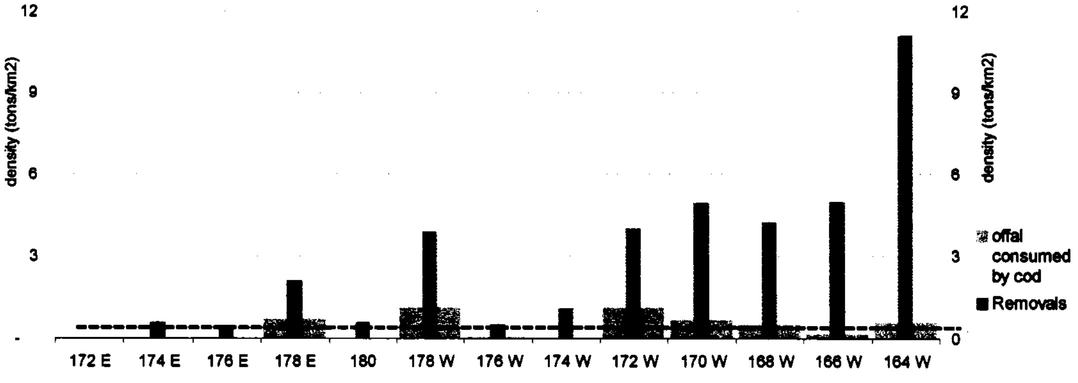


Figure 4.13 Percent of offal in the diet of groundfish and shellfish in the NPFMC regulatory area of the Eastern Bering Sea (top), Aleutian Islands (middle), and Gulf of Alaska (bottom).

Fish consuming offal are all adults. Groups shown are those where offal comprises more than 1% of their diet composition.



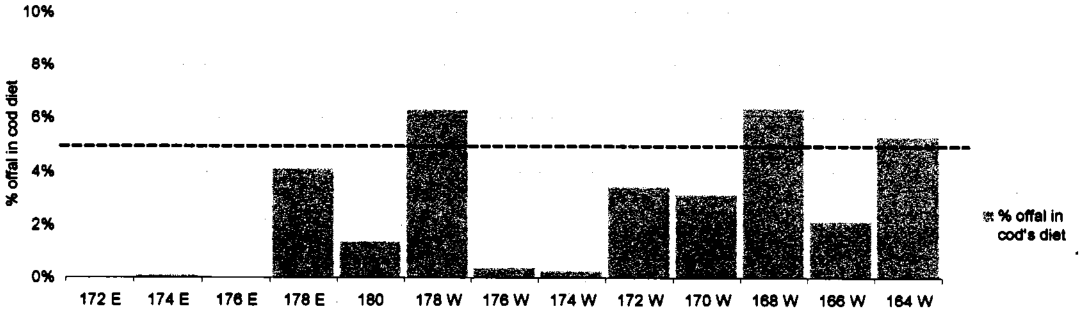


Figure4.14 Case study of Pacific cod: Spatial variability of the offal consumption by cod and density of removals across the Aleutian Islands shown per 2-degree area.

Dark dashed line denotes the density of offal consumed by Pacific cod in the regulatory area of the Aleutian Islands. Estimates of removals are for the early 1990s. Removals include those of Atka mackerel, Pacific Ocean perch, Pacific cod and pollock.

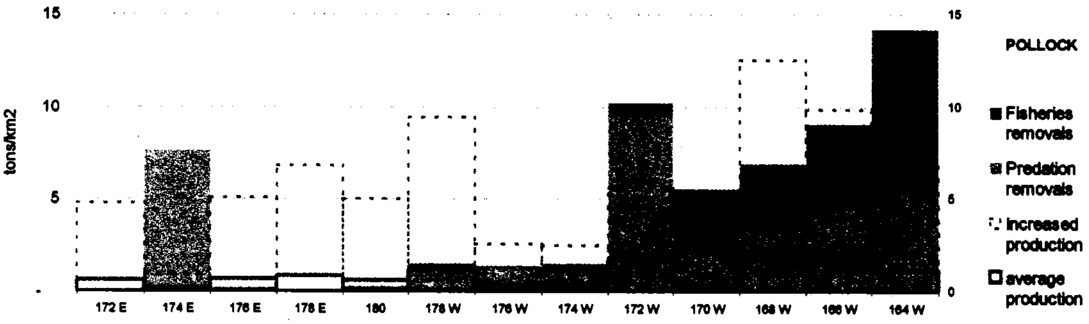


Figure 4. 15 Increased production to satisfy consumption and removals of pollock.

See text for details on modified parameters. Areas 172°E to 170°W fall within the Aleutian Islands NPFMC regulatory area. Areas 168°W to 164°W fall within the EBS and GOA NPFMC regulatory areas.

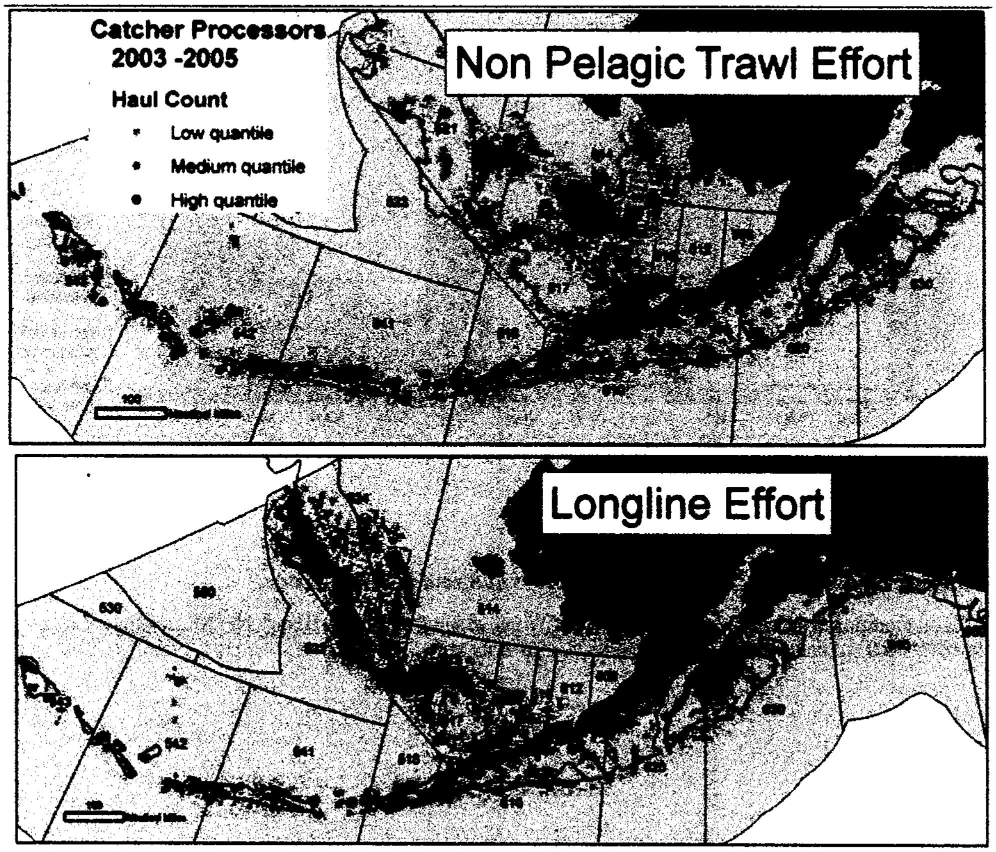


Figure 4. 16 Fishing locations of catcher-processor vessels during 2003-2005. Modified from Edwards 2006.

Chapter 5. Towards an FEP for the Aleutian Islands

> *"Unless someone like you cares a whole awful lot, nothing is going to get better. It's not." (Dr Seuss, The Lorax)*

> *"It is altering normative attitudes that changes can be implemented" (Ehrlich and Levin 2006)*

5.1 SUMMARY

Results from previous chapters are used to evaluate the Fisheries Management Plans (FMPs) for the Bering Sea – Aleutian Islands (BSAI) and Gulf of Alaska (GOA) within the context of the Fisheries Ecosystem Plan for the Aleutian Islands. Three aspects are evaluated: i) the validity of the current regulatory areas that cover the Aleutian Islands, ii) the resilience of the harvest strategies to different food web structures, and iii) the ability of the NPFMC policy framework to respond to effects of fisheries at different scales. An exercise to incorporate uncertainty into food web models is also presented.

The Action Plan for the Aleutian Islands FEP would better encompass ecosystem needs in the Aleutian Islands if it were to expand its proposed geographic coverage from 170°E to 170°W to go from 170°E to 164°W. This extension incorporates the eastern Aleutian Islands into the FEP. Incorporating this portion of the archipelago would allow a better representation of the food webs in these islands, currently managed in a split fashion, with the northern portion under jurisdiction of the BSAI FMP and the southern portion under that of the GOA FMP. Current harvest strategies do not address food web structure. Ecosystem needs could be incorporated by incorporating thresholds related to the partitioning of productivity between removals by predation and fisheries. The Action Plan for the FEP could also be more explicit on its intent to incorporate multiple scale approaches to maintain processes at various spatial scales as well as the spatial integrity of the archipelago.

5.2 INTRODUCTION

The Aleutian Islands are under the stewardship of the North Pacific Fishery Management Council (NPFMC). The NPFMC has jurisdiction over the 900,000 mi^2 Exclusive Economic Zone (EEZ) off Alaska and is responsible for the management of groundfish in the Gulf of Alaska (GOA) and Bering Sea – Aleutian Islands (BSAI). The current management set up is detailed in the Fishery Management Plans for the BSAI and GOA, which have been implemented since 1978 and 1982 respectively (NPFMC 2005a, NPFMC 2005b). The FMP for the BSAI encompasses two regulatory areas: the eastern Bering Sea (EBS) and the Aleutian Islands. Geographically, the [American] Aleutian Archipelago spans from 164°W to 170°E. From the NPFMC perspective, only the islands located between 170°W and 170°E fall within the Aleutian Islands regulatory area. The northern portion of the islands between 170°W and 164°W falls within the EBS regulatory area while the southern portion is part of the GOA regulatory area (Figure 5.1).

The NPFMC has been working towards the implementation of an ecosystem approach to fisheries (Witherell et al. 2000) well before the report of the Ecosystem Principles Advisory Panel and the appearance of the recent suite of reports on the status of marine resources (EPAP 1999, Pew Oceans Commission 2003, U.S. Commission on Ocean Policy 2004). Information and indicators on the Bering Sea-Aleutian Islands and Gulf of Alaska management regions have been incorporated into the annual reports on groundfish fisheries since 1995 as an independent chapter on ecosystem considerations, and since 2004 as a section within the stock assessment and fishery evaluation reports (SAFE reports) for the commercially important groundfish species (Livingston 2003; Boldt 2004; NPFMC 2004). Results from ecosystem models for the eastern Bering Sea (EBS) and Gulf of Alaska (GOA) contribute an important portion to the ecosystem considerations in the SAFE reports (NPFMC 2005). Prompted by the movement towards ecosystem based fisheries management (EBFM) and the recent unexplained declines of sea lions, sea otters and seabirds (Angliss and Lodge 2003, Doroff et al. 2003, Byrd et al. 2005), the NPFMC has started to develop a pilot FEP for the Aleutian Islands regulatory area (NPFMC 2005).

The pilot FEP is a guidance document only; it does not constitute a federal action and does not authorize any management actions or regulations. It is a strategic and planning document to guide the NPFMC. For the purposes of the FEP, the Aleutian Islands ecosystem area has been defined as the Aleutian Islands west of Samalga Pass (169°W) (Figure 5.1), although consideration can be given to species moving in and out of the area and/or external inputs. The NPFMC has defined five specific purposes for the Aleutian Islands FEP (NPFMC 2006):

- integrate information from across the Fishery Management Plans (FMPs) that involve the Aleutian Islands,
- identify indicators to evaluate the status of the Aleutian Islands ecosystem over time,
- provide a focal point to refine and evaluate management tools such as models and indicators,
- identify sources of uncertainty, determine research needs and data gaps, and finally,
- assist the NPFMC in setting management goals and objectives, and understanding the cumulative effect of management actions

In the subsequent sections I will integrate the results from previous chapters in a brief summary (Section 5.3) and then apply these results to evaluate the FMPs for the Bering Sea – Aleutian Islands (BSAI) and Gulf of Alaska (GOA) within the context of the FEP in three ways (Section 5.4): i) the validity of the current regulatory areas that cover the Aleutian Islands, ii) the resilience of the harvest strategies to different food web structures, and iii) the ability of the NPFMC policy framework to respond to effects of fisheries at different scales. These issues are in direct agreement with the purposes of the FEP as stated by the NPFMC.

5.3 FISHERIES AND FOOD WEBS ACROSS THE ALEUTIAN ARCHIPELAGO

5.3.1 Regions and baselines within the Aleutian Archipelago (Chapter 1)

The review of the marine environment showed evidence of three biogeographical boundaries. The first is located between 169°W and 170°W, coinciding with Samalga Pass (Figure 5.1). This biogeographical boundary is founded on oceanographic, ecological and climatological evidence. A second boundary might be located at 180°W (Amchitka Pass), and it is supported by ecological evidence from seabirds, sea lions and fish, with no oceanographic or climatological information available. The third potential boundary is at Buldir Pass, where evidence is available from nearshore seabirds linked to the relatively extensive shelf in the westernmost islands and declining fish species diversity west of the pass. There are then at least two moderately well defined biogeographical boundaries at Samalga and Amchitka, and a third weak or potential one at Buldir. The eastern portion of the Aleutian Archipelago, between Samalga Pass and Unimak Pass has been found to be a transition zone from the coastal/shelf environments of the Eastern Bering Sea on the north and the Gulf of Alaska on the south.

Historically, harvest records from the Aleutian Islands have been appended to those of either the Gulf of Alaska or the eastern Bering Sea. The grouping of catch statistics and records make it very difficult to reconstruct a time series exclusively for the Aleutian Archipelago, let alone further subdivisions. So even though there are distinct regions within the Aleutian Archipelago, there are no continuous long time series to inform us from past local responses and processes within these regions. This lack of global and regional records hinders our current ability to establish reference baselines and trends to quantify levels of depletion, recovery rates, and even historical distributions of whale and seabird populations. The baseline estimates on which current ecosystem assessments are founded are only as robust as their statistical assumptions. Two main management recommendations stem from this scarcity of historical records and baseline estimates. The first is that there is a need to establish baseline estimates of marine resources, preferably considering the regions within the marine environment, but at the very least globally for the entire archipelago. In this respect, surveys and stock assessments build a strong set of basic knowledge for the central and western Aleutian Islands, particularly for commercial species. The data for the northern portion of the eastern Aleutian Islands, although not reported separately, can be quantified using survey strata and statistical areas that cover this area exclusively. The southern portion of the eastern Aleutian Islands is harder to tease out from the data for the Gulf of Alaska and calls for some redesign of survey and statistical strata. The second management recommendation addresses resources which are directly impacted by fisheries removals but for which baseline estimates are not available or hard to produce. These resources, commonly non commercial species, would be better protected by an umbrella regulation that restricts incidental removals rather than allowing the removals to take place without any initial limitation (e.g., living substrates and seabirds with no nesting colonies in Alaska).

5.3.2 Food web structure of the central/western Aleutian Islands, Eastern Bering Sea and Gulf of Alaska (Chapter 2)

The central/western Aleutian Islands, Eastern Bering Sea and Gulf of Alaska comprise the three major management areas of the NPFMC. The static food web models for each management area not only provide a framework for fisheries, they improve our understanding of the basic structure and function within each system. In this respect, the western/central Aleutian Islands comprise an oceanic system driven by pelagic sources of energy where planktivorous species dominate the fish biomass, notably myctophids, Atka mackerel and Pacific Ocean perch. The eastern Bering Sea is a semi-enclosed shelf system fueled primarily by detrital sources of energy. Detritivorous and species feeding on benthic invertebrates are an important portion of the fish biomass, notably yellowfin sole and snow crabs. Finally the Gulf of Alaska is an intermediate coastal/oceanic system driven by similar pelagic and detrital pools of energy. Energy is transferred up the food web through coastal forage fish and shrimp, and the dominant fish biomass includes large flatfish such as Pacific halibut and arrowtooth flounder. Cod and pollock are common to the three systems and exemplify how distinct food web structures provide a unique context for a species. As the context varies, trophic interactions remain neither the same nor of the same strength. Hence, the impact of removals by predation or fishing spreads through the food web via different species and with different intensities.

Should the assessment of ecosystem goals be based on tracking the effect of fisheries removals through biomass changes on predators and prey of commercial species, then management can ill-afford to assume that these changes will be equally tractable for all commercial species or even for the same species across ecosystems. Likewise, management should be careful to assume that the removal (either by predation or fisheries) of any given species will have the same effect across systems. For example, sablefish is assumed to be one stock shared by the Aleutian Islands, EBS and GOA. However, sablefish feeds mostly on zooplankton in the Aleutian Islands (80% of diet), on adult pollock in the EBS (46%) and on adult pollock, squid and zooplankton in the GOA (18, 21, and 25% respectively). Likewise the leading source of mortality of sablefish is the longline fishery in the Aleutian Islands and the EBS (30 and 20% respectively) but predation by salmon sharks in the GOA (42%). Across ecosystems sablefish has very different predators and prey, some of which regularly monitored and some of which are not.

5.3.3 Changes in food web structure across the Aleutian Archipelago (Chapter 3)

Just as the food web structure changes across different regions of the Alaskan marine environment, food web structure can change within one region. Thirteen simplified food webs built for contiguous 2-longitudinal degree areas across the Aleutian Archipelago based on the detailed diets of 6 predators: Steller sea lions, planktivorous seabirds, piscivorous seabirds and 4 groundfish, pollock, Pacific cod, Atka mackerel and Pacific Ocean perch (POP). The food webs follow one of three general structures.

The first basic structure is observed in the eastern Aleutians from area 164°W to 170°W (Figure 5.1). In the eastern Aleutians seabirds biomass is above 300 tons on average and is mostly piscivorous; groundfish biomass is 40% pollock with the remainder made up of the other species and consumption of prey items has a strong east to west gradient: euphasiids and pollock decrease (80% to 30% combined), while copepods and myctophids increase (5% to 40% combined). The second basic structure is observed in the central Aleutians from areas 172°W to 178°W. In the central Aleutians seabird biomass is 50 tons on average and is mostly piscivorous; groundfish biomass is 40% Atka mackerel with the remainder made up of the other species and consumption has the same gradient of prey items but with the peak consumption of eupahsiids and pollocks centered at 174°W, decreasing to both east and west as consumption of copepods and myctophids increases. The third basic food web structure is observed in the western Aleutians from areas 180°W to 172°E. In the western Aleutians seabird biomass is over 100 tons on average and is mostly planktivorous; groundfish biomass is 80% Atka mackerel and POP and consumption has an east to west gradient of decreasing of euphasiids, increasing myctophids and cephalaopods and the proportion of copepods is the highest among all three food webs.

Large scale oceanographic processes determine longitudinal gradients of species abundance while local processes such as amount of shelf and species interactions influence depth gradients of species biomass. Both oceanography and habitat partitioning influence the structure of food webs. Habitat characteristics, whether in the form of physical structures or physical qualities encompass the space in which an organisms lives, feeds and reproduces. The location of an individual within a landscape determines access to prey, however the site selection is not necessarily a function of prey abundance. Other non trophic factors such as competition, shelter, space, light availability or flow speed may influence habitat selection. In the Aleutian Islands, living substrates (corals, sponges, sea whips) combine to provide a large variety of habitat types. There are 69 taxa of corals alone, many with distinct associations to groundfish (Heifetz et al. 2005). Rockfish and Atka mackerel are frequently associated with gorgonian, cup and hydrocorals, whereas flatfish and gadiids are found mostly with soft corals (Heifetz 2004). While corals are not well represented within the trophic flows of food webs, they are an influential factor in determining the distribution and diversity of fish and invertebrates.

Within the context of management, the existence of various food web structures implies there are some local processes that might not be detected by large scale models, and the removals by fisheries or predation will not have the same effects across the archipelago. For example, the eastern Aleutians are included in the food web model for the NPFMC regulatory of the EBS (northern portion) and the GOA (southern portion). The east to west gradient on the consumption of pollock, euphasiids, copepods and myctophids in the eastern Aleutians exemplifies a mesoscale process that can not be perceived with the system-wide food web models. Likewise cod's diet switches from pollock, cephalopods and Atka mackerel in the central Aleutians to shrimp and Atka in the western Aleutians. Both the central and western Aleutians are included in the NPFMC model for the Aleutian Islands regulatory area, however this model can not capture the different impact on the food web between removing cod from the central Aleutians than from the western Aleutians. The ability to capture structural changes in simplified food webs means fully detailed models are not necessary at all spatial scales. Major energy pathways can be captured by building the food webs on species with large biomasses and identifying their prey items in detail. Choosing species with large biomass ensure the model captures large flows of energy, and the detailed diet enables the identification of unagreggated prey categories. Focusing on species of primary interest such as commercial or endangered species can isolate relevant impacts of changes in abundance of prey or predators, and allows a more in depth assessment of the processes driving predator-prey interactions.

5.3.4 Effects of fisheries removals along the Aleutian Aechipelago (Chapter 4)

Three aspects of fisheries removals which impact the structure of the food webs in different ways are i) the density of the removals, ii) the proportion of fishery and predation removals with respect to production and iii) the amount of removals that are processed offshore and discharged as offal and discards. The density of removals differs from the total amount of removals in that it quantifies the removals per unit of area. A small amount can be an intense removal if it is taken from a highly localized area, potentially causing local depletion. Similarly, the effects of large removals can be diffused if they are spread over extensive areas. The relation of total removals with respect to predation and production addresses resource partitioning between humans and natural communities. Fishing competes with other predators for prey species and estimating the magnitude of removals based solely on production does not consider consumption by other species or the effects of increased competition for production.

Fisheries removals discharged offshore as offal act as a subsidy for scavenging communities and poses the risk of oxygen depletion at sea floor level. Offal is consumed by different species and in different proportions across space and can not be assumed to be processed at the same rate throughout the system. Offal consumption depends on local processes, and therefore the risk to locally overwhelm the system cannot be dismissed. Even when the relative magnitude of fisheries removals is low, the use of a single large spatial scale to assess the intensity of removals, resource partitioning and offal discharge, may fail to prevent localized effects if mechanisms are not set in place to diffuse the effects of fishing over space [and time].

5.4 EVALUATION OF THE NPFMC FISHERIES MANAGEMENT PLANS IN THE CONTEXT OF AN FEP FOR THE ALEUTIAN ISLANDS

5.4.1 Validity of current regulatory areas covering the Aleutian Islands for an FEP

One of the key recommendations stemming from the EPAP report (1999) was the definition of the ecosystem boundaries with specific consideration of hydrography, bathymetry, climate influences and trophic structure among other factors. The Aleutian Islands ecosystem as defined by the FEP recognizes the different nature of the central and western portion of the [American] Aleutian Archipelago as compared to that of the eastern Bering Sea or the Gulf of Alaska. However it does not i) improve the differentiation of the islands between 164°W and 169°W from the larger context in which they are currently considered, the eastern Bering Sea shelf and the Gulf of Alaska (Figure 5.1) or ii) explicitly recognize differences within the specified boundaries.

The FEP for the Aleutian Islands is being developed as a pilot document on which future FEPs for the EBS and GOA can be based. Under the current boundary delimitations, there is no vision to manage the northern and southern portion of the eastern Aleutian Islands as a unit, as opposed managing the northern portion as part of the EBS and the southern as part of the GOA. The split management of the northern and southern portions has gone unquestioned. What needs to be reconsidered is not the stock structure for the multiple species; rather it is the ability of management to assess the status of shelf resources, fishing effort and essential fish habitat as a whole in the eastern Aleutians. There are two main arguments to consider the eastern islands explicitly within the FEP for the Aleutian Islands. One is the potential misrepresentation of the eastern Aleutians by the ecosystem models for the EBS and GOA. The strong gradients in oceanographical features, water mass characteristics, species richness and feeding habits can not be aptly represented by averaged conditions (Dauvin and Vallet 2006) mostly for the shelf environment of the EBS or the GOA. In particular, the role of myctophids is poorly represented by the food webs of the EBS and GOA NPFMC regulatory areas (Chapter 3, section 3.5.3). Moreover, the eastern Aleutian Islands encompass the edge distribution of numerous fish species from the Oregonian province and marine mammals (Logerwell et al. 2005, Sinclair et al. 2005). Monitoring species response to changes in the environmental gradient in the eastern Aleutians facilitates an earlier detection of changes in distribution, which can provide useful information regarding fish movement and abundance in turn enhancing predictability and aiding management decisions (Austin, 2002). Monitoring the eastern Aleutians would also be in accordance with the recommendation of the Scientific Statistical Committee of the NPFMC which recommended that assessment teams differentiate stocks or portions of stocks at the periphery of their ranges (NPFMC 2003).

The second argument for explicitly including the eastern Aleutians in the FEP has to do with the recommendation of the EPAP to recognize and consider flows across ecosystems. The eastern Aleutian Islands are a crossroad for latitudinal flows between the EBS and GOA and longitudinal flows between the EBS-GOA and the central/western Aleutians. For example, the Alaska Coastal Current (ACC) dominates the Gulf of Alaska shelf system (Stabeno et al. 2004) and Unimak Pass (the first wide pass from east to west at 165°W) is considered the major connection between the shelves of the North Pacific Ocean and the EBS. The Gulf of Alaska is not the main source of nutrients to the Bering Sea shelf (Stabeno et al. 1998) but flow through Unimak Pass can influence processes in the EBS. For example, strong northward flow through Unimak Pass has been suggested as a mechanism that enhanced flux of nutrient rich water onto the shelf of the EBS, ultimately favoring feeding conditions for Tanner crab larvae and strong recruitment in those years (Bond 2005). Shimada and Kimura (1994) reported the BSAI stock of Pacific cod makes extensive seasonal migrations aggregating near the edge of the southeastern Bering Sea shelf in winter to spawn. Unimak Pass in the eastern Aleutians is a primary migratory route for gray whales and northern fur seals; and transient orcas frequent the pass during these migrations (Ragen et al. 1995; Matkin et al. 2006; Barret-Lennard et al. 2006). Fishing associated processes can also be magnified in the eastern Aleutians. Halibut bycatch has been reported to be highest in areas close to Unimak Pass (Alderstein and Trumble 1998). The eastern Aleutians can then be identified as a transition area located between Samalga Pass (to the west) and Unimak Pass (to the east). The extent to which fishing activities in the eastern Aleutians may impair the flow of species across ecosystems is unknown, but could be more easily addressed by having information readily available for the eastern Aleutians exclusively.

Regarding internal boundaries within an ecosystem, the action plan for the FEP (NPFMC 2006) makes no explicit mention of the need to recognize multiple spatial scales within the ecosystem and almost seems to consider one unique spatial scale as a default option. The action plan is not alone in this respect. The assessment of ecosystem impacts in Alaska has largely focused on individual aspects such as conservation of distinct habitats, species diversity and trophic relationships (Livingston et al. 2005). While this is a very comprehensive approach, it fails to explicitly recognize that indicators may need to be estimated at multiple scales, and that connectivity must be maintained not only within but across habitats and across food webs, not only within.

The changes observed in food web structure across the archipelago and regulatory areas (Chapter 2 and 3) imply that multiple scale processes (like vertical and longitudinal biomass density gradients) regulate the structure of a food web. If such processes are to be maintained, then spatial scales other than that of the regulatory areas must be introduced. In 1993 the BSAI FMP was amended to divide the Aleutian Islands regulatory area into three statistical areas (areas 541, 542 and 543 in Figure 5.1) (NPFMCb 2005). This recognition is a step towards the implementation of multiple scales in management, but could still be enforced in a stronger manner and extended to include the eastern Aleutians. The results presented in the previous chapters support the need to recognize meso-scale processes within the Aleutian Archipelago. Piatt (2006) for example proposes 25 marine eco-regions within Alaska. The need to include multiple habitats and scales in the FEP is backed by several studies that show these are needed in order to plan and achieve conservation goals for species with distributions at diverse spatial scales. In particular, the spatial integrity of the ecosystem must be preserved so that the movement of species with large home ranges and over large spatial scales continues uninterrupted (Forman 1995; Cushman and McGarigal 2002; McNally et al. 2002; Higgins et al. 2006). Stock-scale models and monitoring do not suffice to prevent or detect changes at smaller scales, such as local depletions (Chapter 4). For the Aleutians, scales and continuity should be considered for pelagic habitats, living substrates, gullies and shelf break regions among other.

The FEP for the Aleutian Islands opens the possibility to explicitly address the eastern Aleutian Islands in their totality and as a contiguous part of the archipelago. Future drafts of the FEP could incorporate a more explicit language in this respect. The FEP also offers a unique opportunity to move fisheries management in Alaska from large scales based on stock extent and regulatory areas to finer spatial approaches based on local populations, communities, and processes.

5.4.2 Resilience of harvest strategies to food web structure

The current NPFMC harvest strategies are generally based on proxies to a stock's maximum sustainable yield (MSY) and aim to ensure fisheries removals can be sustained by the estimated productivity of a stock. This general strategy does not consider ecosystem requirements of important prey species, such as Atka mackerel or walleye pollock, that are commercial targets. It also excludes the role of a predator within the ecosystem or the particular vulnerability of the ecosystem to different gear types. Additional considerations may be required to ensure removals by fisheries take into account both the structure of the food web and how the removals are processed through the system.

The interaction between Pacific cod and its prey was assessed across ecosystems. The strength of interaction between a predator and a prey depends on the amount of prey consumed by the predator (% in diet) and the amount of prey production removed by the predator (Figure 5.2). For example, Tanner crabs contribute less than 10% to cod's diet, but for tanner crabs this amounts to over 35% of its production. In contrast, pollock can comprise 5 to 25% of cods diet, which amounts to 15% in all cases. The same exercise can be conducted for cod fisheries (early 1990s) and the species caught (Figure 5.3). Cod fisheries are conducted with three gears hook and line fishery (longline), pots and trawl. The hook and line fishery for cod had the largest impact on skates in both the eastern Bering Sea and the Aleutian Islands. In the Aleutian Islands in particular, the hook and line fishery removed over 25% of the production of skates and between 15% an 25% of the production of sculpins.

The fisheries and stock assessments have changed since the early 1990s and these estimates may not reflect current impacts of fisheries removals. The estimates are intended to provide examples of different considerations that may be incorporated into management actions, assessments or quota estimates in the form of thresholds or adjustment factors. For example, cod fisheries (combined) in the Aleutians removed 61% of the production of sculpins, compared to 33% of the production of cod, its main target. The NPFMC could use this information to prioritize and limit sculpin bycatch reduction measures in the cod fisheries (note the NPFMC has taken action to reduce sculpin bycatch).

Ecosystem considerations are being used this year (2006) for the first time to adjust the Total Allowable Catch (TACs) of pollock in the eastern Bering Sea. A 10 percent reduction in the TAC of pollock has been proposed due to low productivity levels of large zooplankton (main pollock prey) and decreased spawning biomass (Ianelli et al. 2006). This first case on TAC reduction based on ecosystem considerations will serve as a case study to evaluate concerns, methods and approaches preferred by the NPFMC to incorporate ecosystem needs into fisheries management.

5.4.3 Ability of the NPFMC policy framework to respond to effects of fisheries at different scales

The NPFMC has taken action on issues related to stocks, such as Steller sea lions and sablefish, distributed across several NPFMC regulatory regions. I will focus here on the NPFMC response to effects of fisheries at finer scales than the regulatory areas. In 1993 the BSAI FMP was amended to divide the regulatory area of the Aleutian Islands into three statistical areas to allocate TACs (Figure 5.1, areas 541, 542, 543). Such action reflects the NPFMC's concern to diffuse the effect of fisheries removals throughout the extent of the regulatory area and the intent to keep track of fisheries activities at smaller spatial scales than the total regulatory area.

One of the current impediments to implement more spatially explicit approaches in Alaska is the restriction in the use and disbursement of vessel specific fishery data. Such restriction prevents the establishment of a reward system based on vessel specific best practices. This restriction however should not hamper the quantification of fisheries removals and biomass estimates at finer spatial scales than regulatory or statistical areas. By tracking removals at finer spatial scales, allocations can be set a priori in a way similar to how TACs are currently allocated among the three statistical areas. Set a priori, such limits would just restrict localized fishing operations while safeguarding vessel specific data.

The fishing grounds of the main commercial fisheries in the Aleutian Islands, sablefish, Pacific cod, pollock, Atka mackerel and Pacific Ocean perch, have changed during the last decade (Figures 5.4 and 5.5). Pollock catch was reduced drastically in 1999 due to concerns of the potential adverse impacts of pollock removals on the endangered Steller sea lions. Since 1999, catches have been restricted to areas outside critical habitat for Steller sea lions and have remained below 2,000 m tons. Highly localized removals like the removals in 2002 for cod, concentrated around 174°W are often a sign of temporal intensity. Cod is fished in the central Aleutians mainly during

February, March and April. During 2002, 70% of the observed catch was removed during March (Figure 5.6).

The potential risk of highly localized removals in both time and space is the temporary depletion of prey for other predators in the system, as well as the localized discharge of offal and discards discussed in chapter 4. The feasibility of dispersing catch effort is illustrated by POP for the year 2002. Like cod, the catch is highly concentrated in time, with 75% of the catch removed during July. However, POP catches during July are dispersed with a maximum of 20% within a one longitudinal degree block and hence removals are diffused over an extensive area from 175°E to 180°W. An economic analysis of selected case studies can better inform on the economic impact of a finer spatial allocation of fisheries removals or at least making the allocation of quotas among the three statistical areas of the Aleutian Islands regulatory area a standard practice. The improved feedback regarding fishing behavior and fleet composition should include the economic information provided in the economic chapter of the SAFE reports. Currently, the economic information is not readily available for the Aleutian Islands alone, as the report offers the economic status for the joint Bering Sea-Aleutian Islands region. Smaller scales for the NPFMC regulatory areas of the EBS and GOA are more problematic. The current statistical and survey areas do not readily allow for division of information regarding the eastern Aleutians, potentially the most relevant portion of these regulatory areas with respect to the development of an FEP for the Aleutian Islands.

Without feedbacks on the effect/intensity of removals at finer spatial scales the NPFMC lacks the basic information to implement restrictions or adjustments to modify fishing behavior that may affect local trophic structure and dynamics, putting at risk the spatial continuity of food webs and the spatial integrity of the ecosystem. These spatial considerations should be in addition to special provisions made to protect specific habitats such as living substrates, gullies and shelf break regions and ensure the continuity of prey availability across large spatial scales needed for highly mobile species (Forman 1995; McNally et al. 2002; Higgins et al 2002; Duavin and

Vallet 2006). Murawski (2000) observed that for ecosystem-based management to assume a greater role, the suite of indicators developed must address 1) biomass and production by the ecosystem and relationships among its parts, (2) diversity at different levels of organization, (3) patterns of resource variability, and (4) social and economic benefits. All this considerations would greatly benefit from a multiscale approach complementing current management strategies.

These set of recommendations in this section can be carried out without major changes to the current FMPs, they do not imply or require an FMP exclusive for the Aleutian Islands. The NPFMC has proven to have the flexibility to design measures for the EBS and AI independently, within the framework of the Bering Sea-Aleautian Islands FMP. The major change in terms of coverage the coverage of the regulatory and statistical areas in the FMPs would be the addition of a statistical area in the NPFMC regulatory area of the Gulf of Alaska. This would differentiate catches and fisheries activities in the eastern Aleutian Islands from the rest of the western GOA (NPFMC statistical area 610, Figure 5.1) improving the ability of the NPFMC to design actions and measures specific for the islands.

5.5 ADDRESSING UNCERTAINTY IN FOOD WEBS

The food webs developed at the scale of regulatory areas (Chapter 2) and 2-degree blocks (Chapter 3) provided multiple structures which represent how the system may reorganize itself given different spatial scales and boundaries. Here I develop alternative configurations for the food web model of the NPFMC regulatory area of the Aleutian Islands based on changes in groundfish biomass estimates.

The last 15 years have seen an increasing incorporation of uncertainty into fish and marine mammal stock assessments methods and management decisions, with new approaches continually developed (Hilborn 1992; Taylor et al. 2000; Punt and Hilborn 1997; Walters et al. 2006). These methods have extended from single species assessments to food web modeling. In Ecopath in particular, the resampling routine called Ecoranger is a Bayes like approach that allows entry of range, mean and mode values for all the basic parameters: biomasses, consumption rates, production rates, ecotrophic efficiencies and all elements of diet composition. Random input variables are then drawn, and a given combination is accepted if it complies with the mass balance constraints; rejected if it violates them. The results include probability distributions for both estimated parameters as well as input variables (Walters et al. 2002; Christensen and Walters 2004).

Maximum and minimum values are available for the biomass estimates of the main groundfish modeled in the food web presented in Chapter 2 for the NPFMC regulatory area of the Aleutian Islands. The results of this mass balanced model suggest the boundaries, as defined, are very loose. Moreover, various groundfish stocks are shared with the Eastern Bering Sea and the amount of movement of individuals from one system to the other is unknown. With this in mind, two extreme alternate food webs were developed to incorporate uncertainty into the model developed in Chapter 2. The first extreme case is a deflated food web, where all the mean values for groundfish biomass derived from bottom trawl surveys were substituted with the minimum values of their corresponding 95% CI. The second extreme case is an inflated food web, where all the mean values were substituted with the maximum values of their corresponding 95% CI. Table 5.1 shows the original and substitute values used. The models were left unbalanced, assuming the system is open and thus the aggregate production to satisfy fisheries and consumption demands on all groups does not have to be generated within the system. Even though the models are not balanced, it is still a valid question to ask how much biomass of any one given group would be necessary to support the fisheries and predation hypothesized under each extreme food web. The biomass required to satisfy fisheries and predation removals for any given group was calculated as:

$$B_i required = B_i * EE = \frac{\sum_j \left[B_j * \left(\frac{Q}{B}\right)_j * DC_{ij} \right] + C_i}{\left(\frac{P}{B}\right)_i}$$

where *i* is a functional group with predators *j*, *Bi* and *Bj* are biomasses; *P/Bi* is the production/biomass ratio; *EEi* is the fraction of total production (*B*(P/B)*) consumed within or caught from the system (*i.e.,* ecotrophic efficiency); *Ci* is the fisheries removals; *Q/Bj* the food consumption per unit biomass of *j*; *DCij* is the contribution of *i* to the diet of *j*. Because the scenarios are unbalanced, *EE* can be less or greater than 1.

In the modified version of Ecopath used in chapter one (Aydin et al. *in review*), changing the biomasses results in a different weighting scheme of the intermediate subareas-specific diet matrices for groundfish. Additionally, since diets calculated with the preference method are based on prey availability to the groundfish biomass, the partitioning of prey items within prey clusters gets modified accordingly. So, even though the diet input is never changed *per se* in the extreme food webs, the final diets matrices in these models are different.

Figure 5.7 (top) shows the biomass input used in the balanced model (bars), the estimated required biomass to satisfy removals by fisheries and predation in the balanced model (squares), and the estimated required biomass to satisfy removals by fisheries and predation in the [unbalanced] inflated and deflated food web models (dashed lines on vertical lines). The estimated required biomasses in the inflated and deflated food webs provide a range for the mean biomass input values used in the balanced model, giving some measure regarding the level of uncertainty around the estimates (height of vertical lines), and the risk of underestimating the amount of biomass required to satisfy both predation and fisheries removals (bar height with respect to vertical lines). For example, the biomass of adult Atka mackerel used in the balanced model was 663,000 tons, the required biomass in the balanced model was

636,000 tons, the required biomass in the inflated food web was 956,000 tons and required biomass in the deflated food web was 380,000 tons. Vertical lines extending above the bar height indicate groups potentially at risk of not satisfying fisheries and predation removals if the actual aggregate removals are higher than those estimated in the balanced model. Groups at risk include Atka mackerel, adult pollock, Greenland turbot, rougheye rockfish, sablefish (in decline during the early 1990s), flathead sole, Aleutian skates, dusky rockfish and dogfish. The risk is not necessarily posed by fisheries; it can also be that the increased predation by groundfish in the inflated food webs exceeds the estimated production. All the groups at risk had an estimated ecotrophic efficiency in the balanced model greater than 0.68 (EE>0.68) except for flathead sole which had an estimated EE of 0.37 (Figure 5.7, bottom). Flathead sole is not widely distributed in the Aleutian Islands, its biomass is low (~4400 tons) and hence any large variation in the biomass of predators can easily exceed its estimated production in the models.

In general, the potential variability of the estimated biomass of top down balanced groups increases at lower (<2.5) trophic levels and include zooplankton groups (right end of Figure 5.7). Non-zooplankton groups with highly variable estimates include squids, other sculpins, myctophids, shrimps and pandaliids (Figure 5.8). The increased biomass required from pelagics and lower trophic levels only reflects the increase in biomass of their immediate direct predators not cascading effects, as the inflated and deflated food webs are not mass balanced.

Finally, combining survey biomass estimates with required biomass estimates (from inflated and deflated food webs) can reduce the range of the original 95% CI. Several of the survey biomass estimates have a low biomass value of zero biomass. These values are highly unlikely and the estimated consumption and fisheries removals from the deflated food web can improve the low biomass estimates, making them non-zero values (e.g. adult Atka mackerel, giant grenadiers and dusky rockfish. (Figure 5.9).

Plaganyi and Butterworth (2004) recommend the use of probability distributions to encompass ranges of likely ecosystem responses. The approach presented here could easily be modified to sample from the probability distributions of the survey biomass estimates instead of just hypothesizing two extreme alternate food webs. Alternatively, the values obtained with these non-balanced models could be compared to those estimated with Ecoranger, which do require that the combination of parameters meet thermodynamic constraints.

5.6 CONCLUSIONS

Food web structure provides a unique context which result in distinct interactions among species. It is the result of multiple physical and biological processes, at multiple scales. Efforts to develop policies that maintain these processes should be encouraged, and harvest strategies robust to food web structure should be developed. A spatially explicit approach could greatly enhance the current policies and feedback loops to management (Botsford 1997; Pikitch 2004; Babcock et al. 2005; Freon 2005).

Variations in basic food web structure at large spatial scales result in differing routing of energy within an ecosystem and dominant feeding strategies. The role of species distributed across ecosystems changes as they move through the various food webs. For management this gives rise to potential changes in quota allocations of commercial and non commercial species across ecosystems as well as adjustments to conservation goals. Similar challenges are present within an ecosystem where spatial heterogeneity of habitats, species interactions, and fishing behaviors is common. The development of standardized methods and techniques for the construction of food web models has proven to be a useful approach to better understand the mechanisms behind food web structure and function as well as effects of fisheries removals. It has also provided a common platform to evaluate the robustness of policies to different food web structures and the feedback we obtain from models across systems, levels of biological resolution and multiple spatial scales.

Within an ecosystem context, the awareness of spatial heterogeneity is essential if the nature and characteristics of each ecosystem are to be maintained. Within the Aleutian Islands, the prevalence of fishing activities in offshore waters and the scarcity of local communities has favored a large scale approach to fisheries management. However conservation goals focused on average conditions or overall species richness are not enough to ensure the maintenance of the rich biodiversity that is palpable at multiple scales of organization (Higgins et al. 2006). Such biodiversity (like that of living substrates), far from being redundant, is what allows multiple combinations of resource partitioning that favor different species alternatively through space and time. It is the challenge of ecosystem based management to develop principles and methods that guide human behavior towards an equitable partitioning of resources and a coupling of the magnitude, frequency and location of our activities in accordance to evolutionary strategies (Naeem et al. 1994, Tilman and Kareiva 1997, Berlow 1999, Borvall et al. 2000, Chesson 2000, Loreau et al. 2001, Dunne et al. 2002, Longhurst 2006, Erlich and Levin 2005). The greatest challenge will be to forge a contagious ethic that promotes these new norms.

Table 5. 1 Parameters used for the high biomass and low biomass scenarios of the Ecopath model for the NPFMC regulatory area of the Aleutian Islands

Group	*Mean biomass estimates used in original model*	*Minimum 95% CI values used in high biomass scenario*	*Maximum 95% CI values used in low biomass scenario*
Atka mackerel	663,039	0	1,842,819
Pacific Ocean perch	357,497	7,505	901,911
Giant grenadier	289,010	0	289,010
Pollock adult	270,957	14,853	270,957
Pacific cod adult	166,965	14,516	361,589
Northern rockfish	153,553	24	306,815
Halibut	40,110	7,956	112,819
Northern rock sole	36,768	6,211	78,208
Arrowtooth adult	30,239	4,315	70,126
Kamchatka flounder	28,910	941	78,495
Shortraker rockfish	24,004	300	71,869
Greenland turbot	22,261	264	38,432
Rougheye rockfish	12,494	456	35,804
Sablefish	8,425	145	26,380
Alaska skate	8,400	304	25,704
Shortspine rockfish	6,203	321	14,107
Whiteblotched skate	5,853	245	14,945
Flathead sole	4,441	824	10,069
Aleutian skate	4,132	3,116	12,752
Herring adult	1004	88	2310
Mud skate	783	26	1,925
Dusky rockfish	340	0	1,089
Southern rock sole	319	0	1,587
Dover sole	193	0	564
Dogfish	69	0	206
Pacific grenadier		0	0

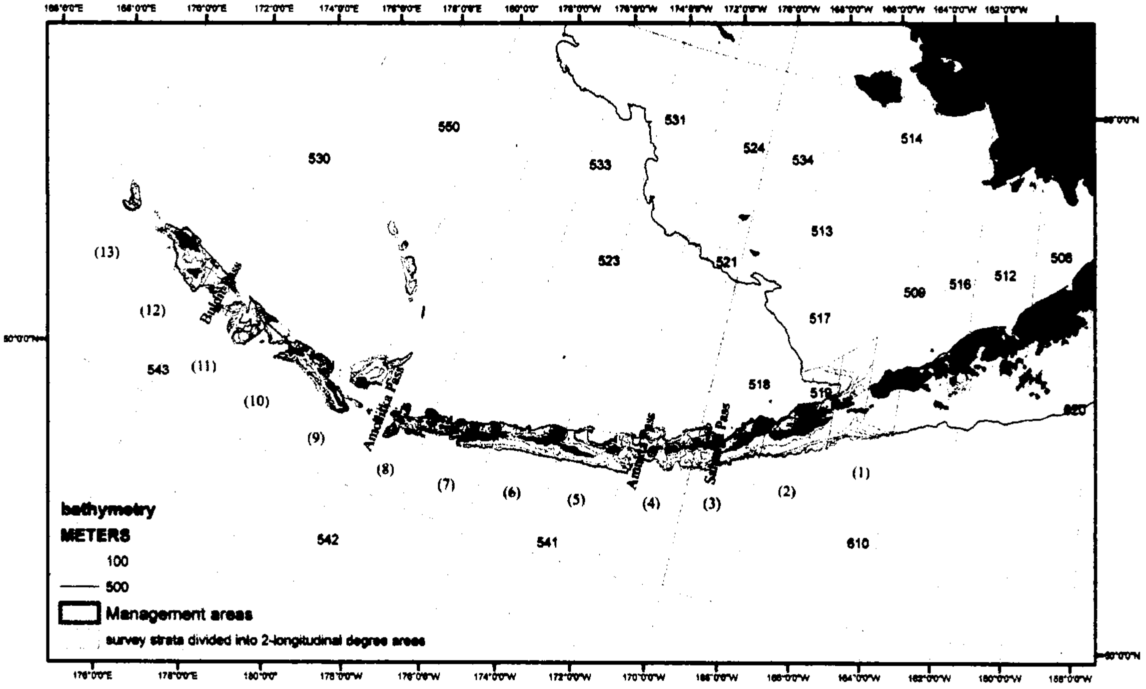


Figure 5. 1 Geographical extent of the [American] Aleutian Islands (shaded in green) 2-degree food web models and overlap with NPFMC regulatory areas.

The islands west of Samalga Pass fall within the NPFMC regulatory area for the Aleutian Islands (statistical areas 541, 542 and 543). The south portion of the islands east of Samalga Pass falls within the statisical area 610 of the regulatory area of the Gulf of Alaska. The northern portion of the islands east of Samalga Pass are covered by the statistical areas 517, 518 and 519 of the regulatory area fort he Eastern Bering Sea. The meridians show the 2-longitudinal degree divisions, number in parenthesis show the thirteen 2-degree areas for which a food web model was constructed

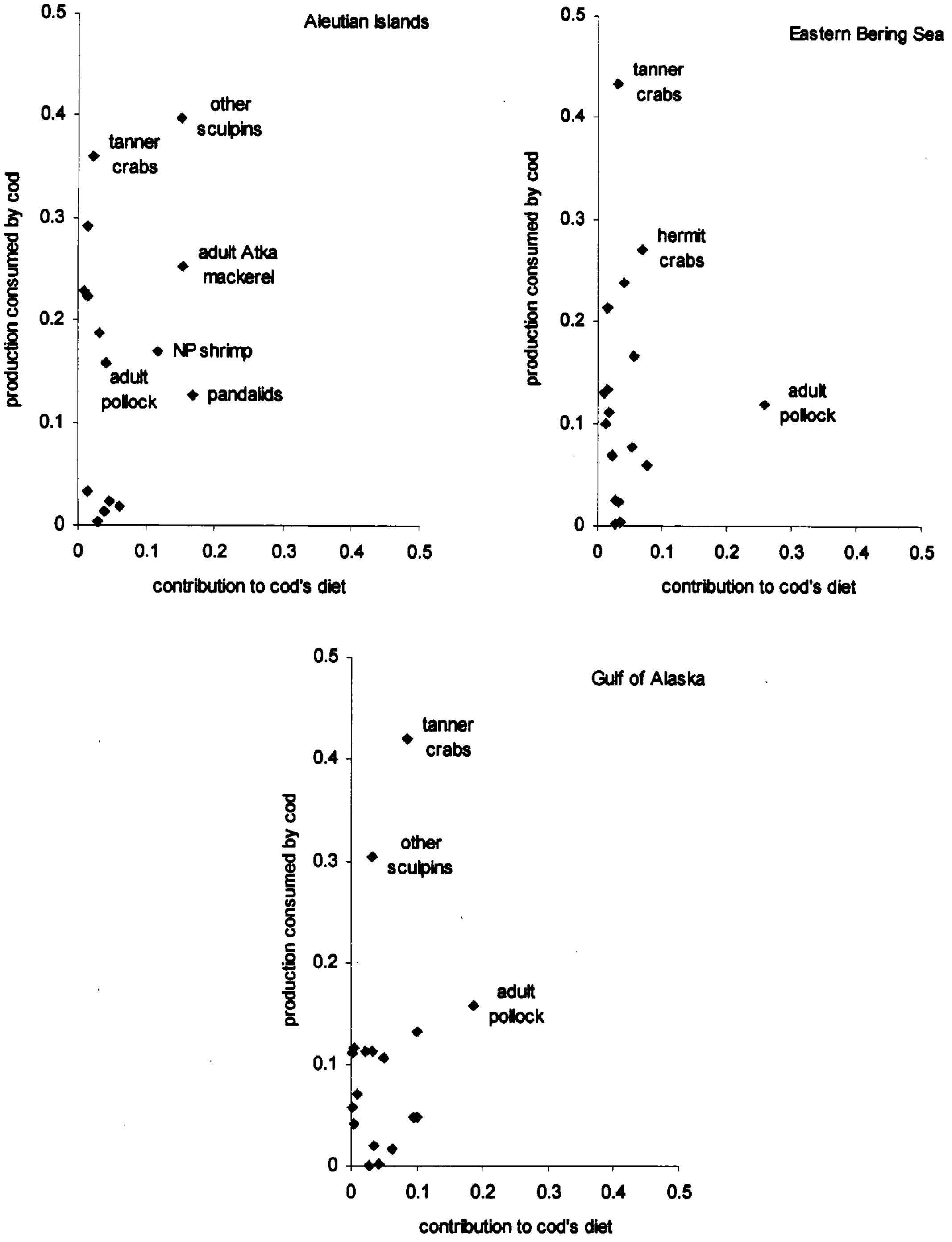


Figure 5. 2 Diet composition of Pacific cod vs. proportion of prey productivity consumed by Pacific cod in thr three regulatory areas of the NPFMC. From top to bottom: Aleutian Islands, Eastern Bering Sea and Gulf of Alaska.

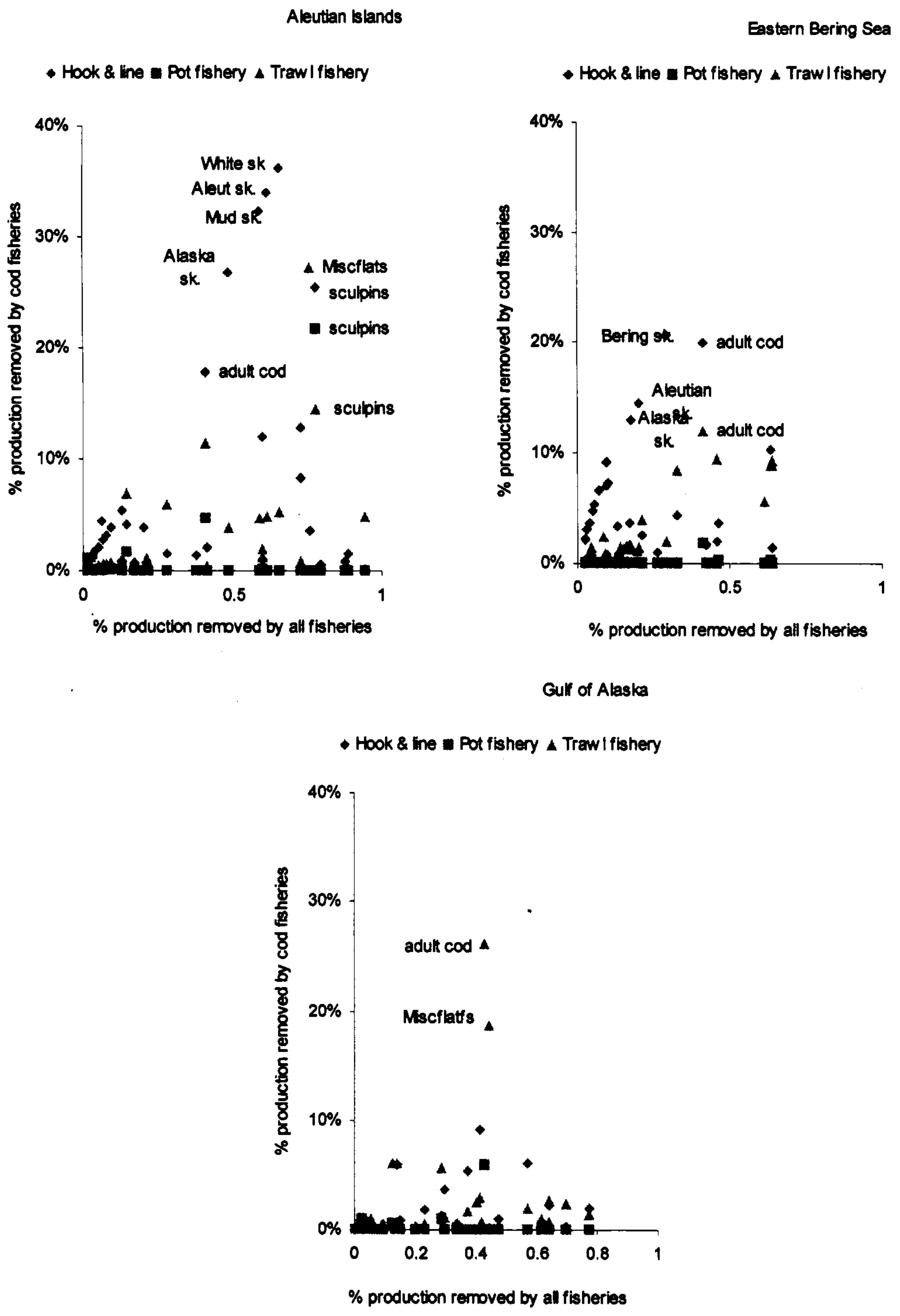
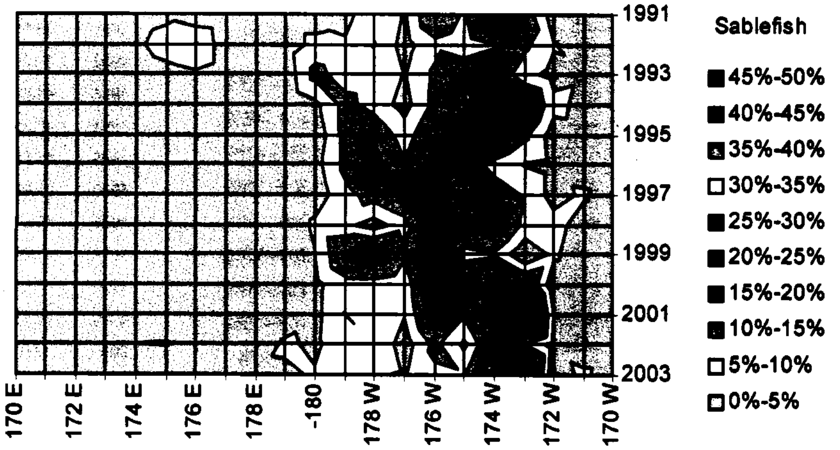
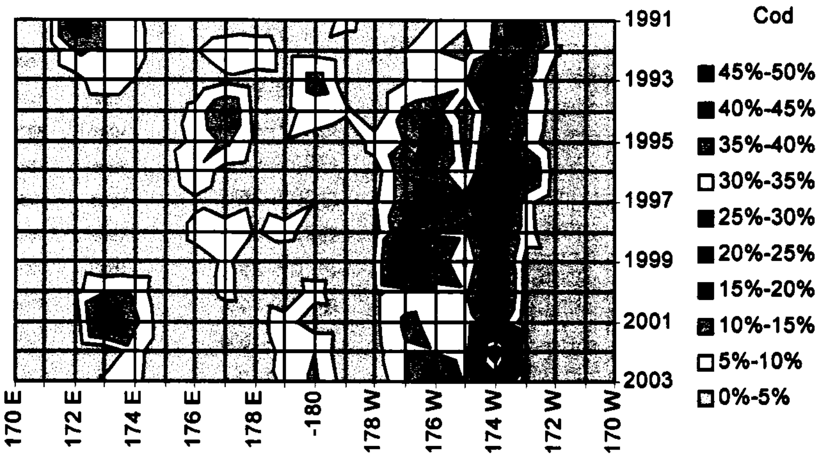


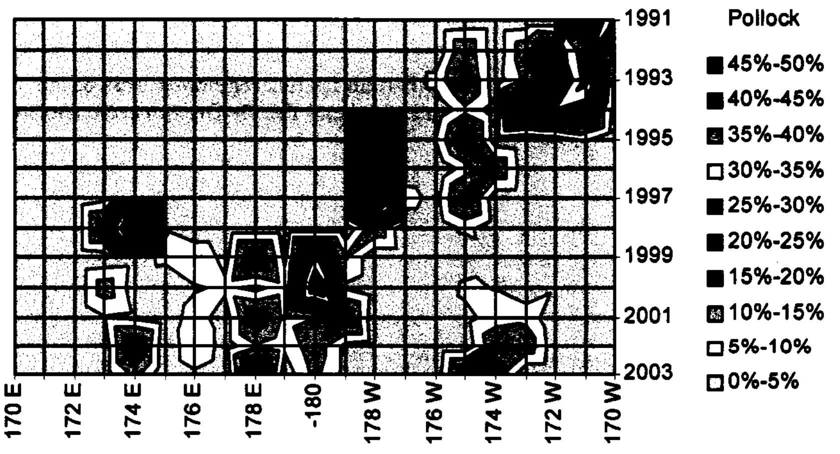
Figure 5. 3 Percent production removed by all fisheries vs. percent production removed by Pacific cod fisheries across the three regulatory NPFMC areas. Top to bottom: Aleutian Islands, Eastern Bering Sea and Gulf of Alaska



Observed catch	
1991	909
1992	422
1993	753
1994	543
1995	432
1996	231
1997	222
1998	176
1999	412
2000	445
2001	312
2002	353
2003	360

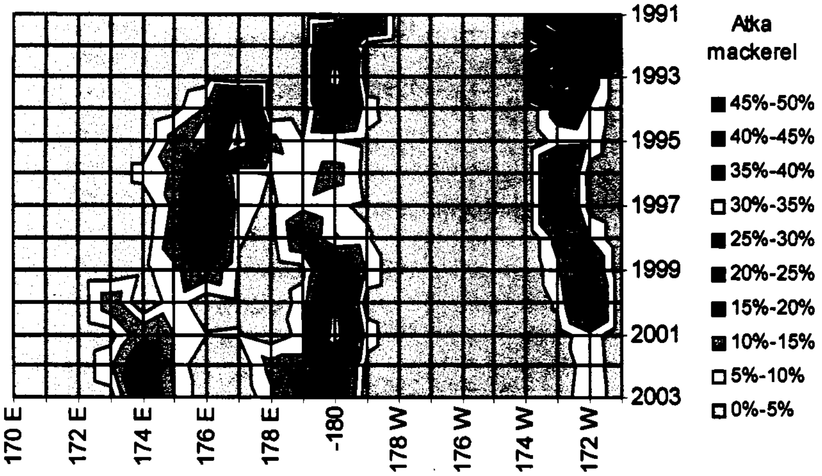


Observed catch (tons)	
1991	5,758
1992	27,665
1993	23,741
1994	15,383
1995	10,984
1996	18,231
1997	15,561
1998	23,358
1999	19,165
2000	23,682
2001	21,496
2002	20,528
2003	21,301

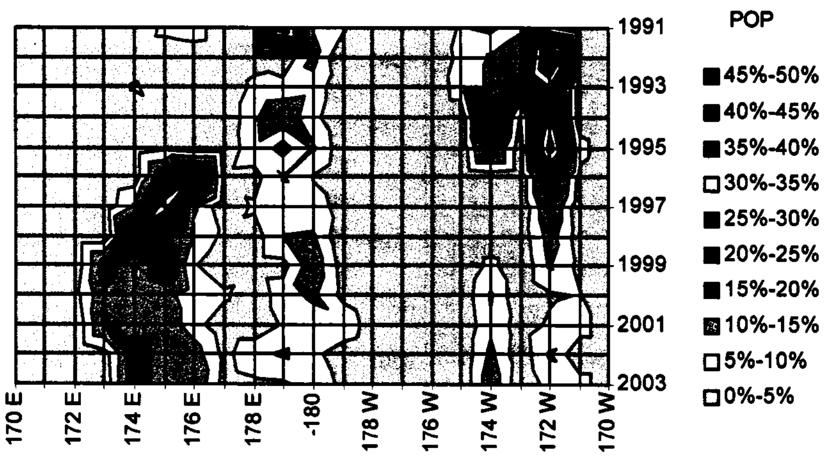


Observed catch	
1991	53,120
1992	36,581
1993	44,552
1994	43,430
1995	53,647
1996	23,482
1997	19,623
1998	21,032
1999	492
2000	573
2001	477
2002	519
2003	1,562

Figure 5. 4 Percent of total observed catch from 1991 to 2003 in the Aleutian Islands regulatory area of the NPFMC pooled in blocks of one longitudinal degree for sablefish, Pacific cod and pollock. Annual observed catches are in tons

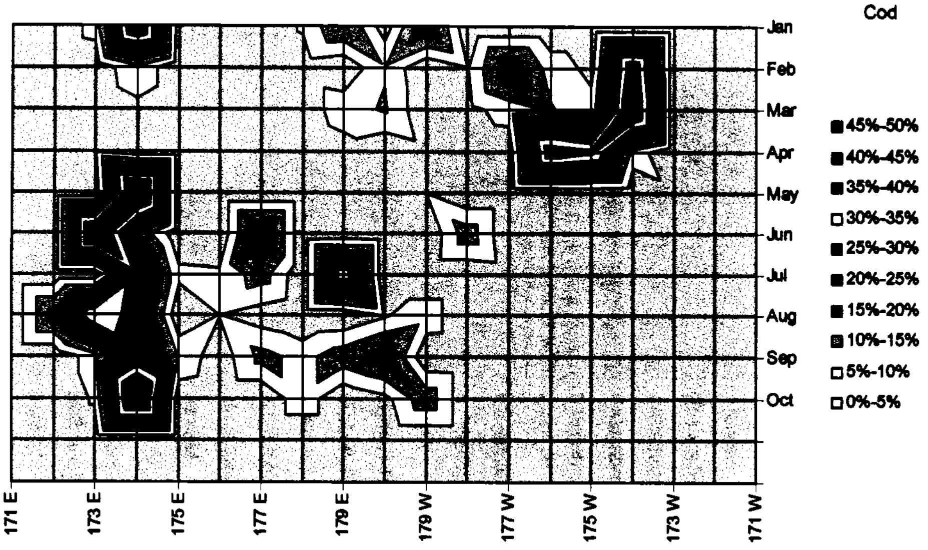


Observed catch	
1991	16,368
1992	30,723
1993	45,240
1994	45,234
1995	52,266
1996	69,919
1997	45,560
1998	42,078
1999	42,654
2000	39,269
2001	49,916
2002	42,724
2003	51,139

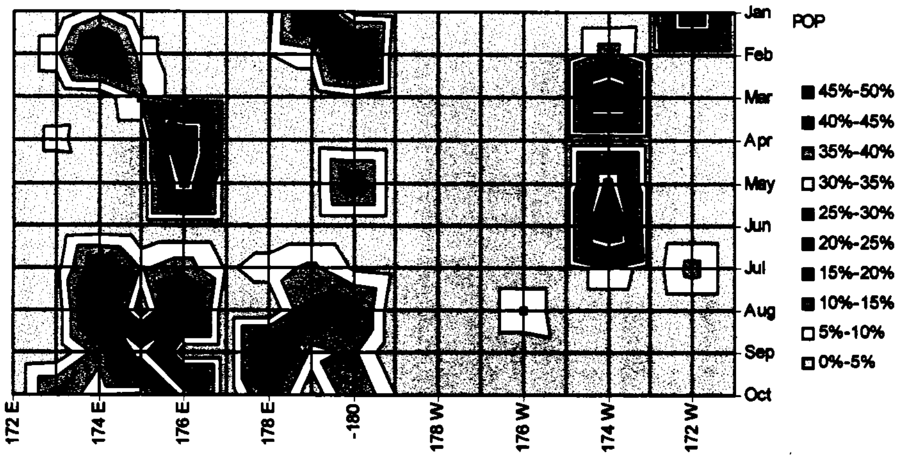


Observed catches	
1991	1589
1992	6912
1993	8877
1994	7564
1995	6155
1996	8547
1997	9321
1998	7380
1999	10369
2000	7457
2001	5680
2002	8124
2003	11267

Figure 5. 5 Percent of observed catch from 1991 to 2003 in the Aleutian Islands regulatory area of the NPFMC pooled in blocks of one longitudinal degree for Atka mackerel and Pacific Ocean perch. Annual observed catches are in tons.



2002 Observed catch	
Jan	446
Feb	4580
Mar	14089
Apr	433
May	42
Jun	29
Jul	81
Aug	202
Sep	589
Oct	37



2002 Observed catch	
Jan	123
Feb	133
Mar	95
Apr	109
May	123
Jun	173
Jul	6124
Aug	303
Sep	890
Oct	51

Figure 5. 6 Monthly observed catch for 2002 in the Aleutian Islands regulatory area of the NPFMC pooled in blocks of one longitudinal degree for Pacific cod. Observed 2002 catches are in tons.

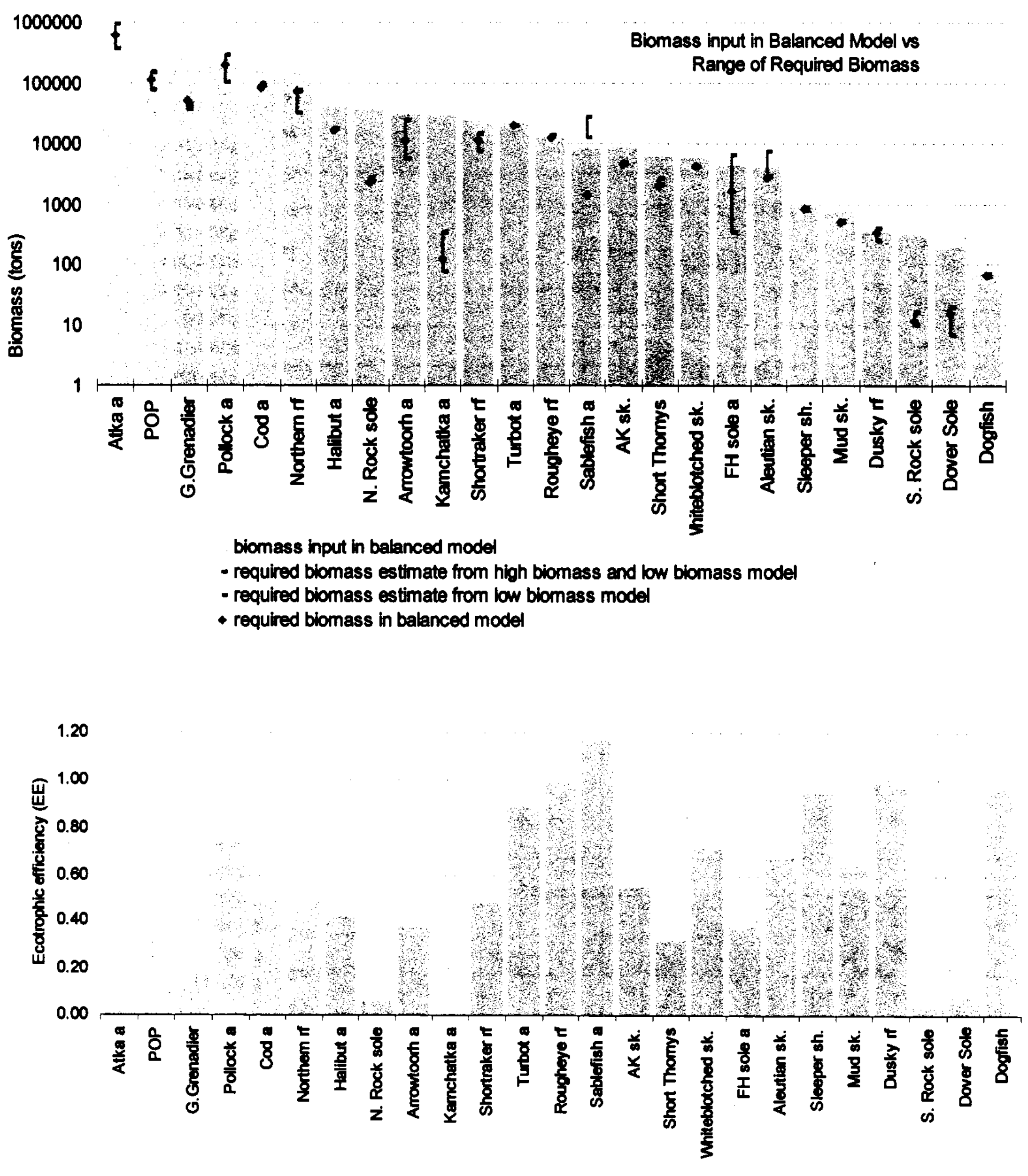


Figure 5. 7 Biomass input in Balanced Model (bar) vs Required Biomass estimates in inflated and deflated food webs (high-low lines) (top figure). Ecotrophic efficiency of main groundfish groups in balanced model (bottom figure).

The inflated and deflated food webs are unbalanced models where all groundfish biomass values were substituted for their corresponding maximum and minimum 95% CI values. Required biomass is the biomass estimated to satisfy fisheries removals and consumption within the system. Note sablefish stock was decreasing at the time (early 1990s) and hence the range of values is above the mean biomass used as input for the balance model.

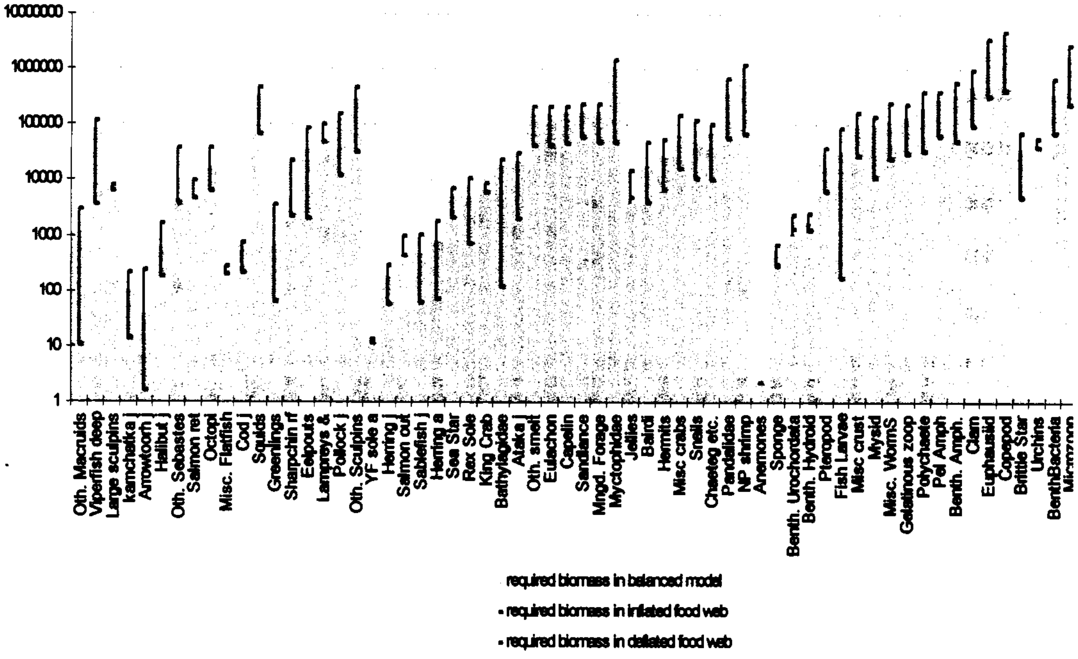


Figure 5. 8 Estimated required biomass in top-down balanced groups in the balanced food web model for the NPFMC regulatory area of the Aleutian Islands (rhomboids) and range of required biomass values in deflated and inflated food webs (high-low lines).

Groups are ordered (left to right) from highest to lowest trophic level

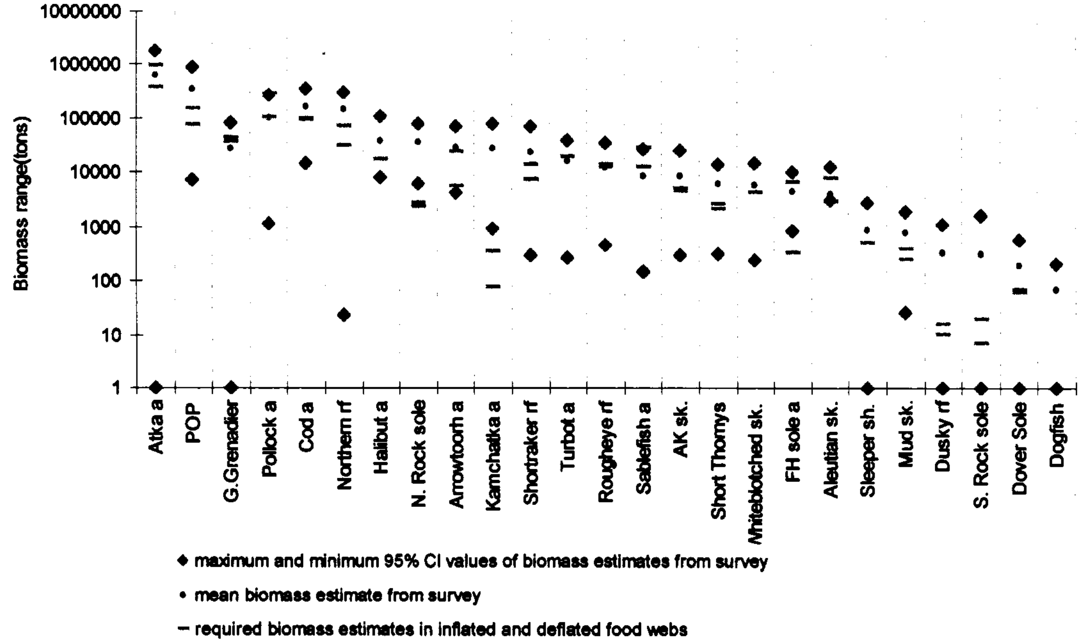


Figure 5. 9 Survey versus model derived biomass estimates for main groundfish in the Aleutian Islands NPFMC regulatory area.

Minimum and maximum survey biomass estimates within 95% CI (high and low dash) vs. estimates of required biomass from the inflated and deflated food webs (rhomboids). Dots denote mean survey biomass estimates. Required biomass is the biomass estimated to satisfy fisheries removals and consumption in the system.

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Appendix: Static food web model details

This section includes the description of functional groups (trophic species) included in the food web model for the Central and Western Aleutian Islands. This model was developed jointly with those for the Eastern Bering Sea and Gulf of Alaska, and much of the documentation below was extracted from Aydin et al. *in review*. When AI specific information was lacking, parameter values were estimated from those for the Gulf of Alaska or Eastern Bering Sea models. Where information was unavailable for all three systems, parameter values were agreed upon by consensus either based on data available for similar species or bibliographical sources. Some trophic species which are very infrequent in the Aleutian Islands were included in the model for comparison purposes with the Eastern Bering Sea and Gulf of Alaska models.

Dall's porpoise

Dall's porpoises (*Phocoenoides dalli*) are found in both nearshore and pelagic habitats throughout the North Pacific, Along the coast mostly distributed from 32 N to 62° N (Morejohn et al. 1973, Nishiwaki, 1967). It is unclear whether there is one stock in Alaskan waters, (Angliss and Lodge 2004) or two, should the Bering Sea prove to be a separate stock (Amano and Miyazaki 1993; Kasuya and Ogi 1987; Walker 1990; Walker and Sinclair 1990) based on genetics analyses (Winans and Jones 1988). The diet is composed mainly of cephalopods, fish and some crustaceans (Tomilin 1957; Crawford 1981; Frost and Lowry 1981; Lowry et al. 1982).

AI biomass was estimated at 3745 tons, PB was 0.05 and QB 11.16. The corresponding pedigree categories are 4, 6, and 6. For the diet, pedigree was 6.

Resident and transient Killer whales

Killer whales (*Orcinus orca*) have a cosmopolitan distribution (Leatherwood et al. 1982) and are found throughout Alaska waters from the Chukchi Sea to southeast Alaska (Braham and Dahlheim 1982). They inhabit coastal waters for the most part. (Heyning and Dahlheim 1988). There are two stocks in Alaska: the eastern North Pacific northern resident stock and the eastern North Pacific transient stock, denominated resident and transient in the model. Reliable data on population abundance trends for either stock are not available (Angliss and Lodge 2004). Diet preferences for esach stock differ, as each has specialized feeding techniques. Resident whales feed mainly on fish while transient whales have generally only been sighted eating other marine mammals, although it is uncertain if transients also eat fish (Bigg et al. 1987).

AI resident biomass was estimated at 223 tons, transients' biomass was 2.2.3 (10%). For both transients and residents PB was 0.02542 and QB 11.16. The corresponding pedigree categories for residents are 4, are 4, 3, and 6. For transients pedigree categories were 7, 3 and 6. Both diets had a pedigree of 6.

Sperm bk whales

Sperm whales (*Physeter macrocephalus*) are widely distributed throughout thr North Pacific in both tropical and temperate waters (Leatherwood et al. 1982). The population is divided into three management stocks, one of them the Alaska stock (Angliss and Lodge 2004). Within the Aleutians, they inhabit nearshore areas of the eastern islands but they are primarily found throughout deeper pelagic and continental shelf waters of the EBS, and nearshore habitat on the Gulf of Alaska and SE Alaska (Rice 1989). These individuals are thought to be mostly males as females and young sperm whales are believed to stay in tropical and temperate eaters year round. Sperm whales feed primarily on cephalopods, but consume other invertebrates and fish (Tomilin 1967; Berzin 1971), these last particularly near the continental shelf break and along the Aleutian Islands (Okutani and Nemoto 1964). The sperm whale is classified as endangered under the ESA and depleted under the MMPA, reliable abyundance ewstimates are not available (Angliss and Lodge 2004).

AI biomass was estimated at 8339.5 tons, PB was 0.047 and QB 6.61. The corresponding pedigree categories are 6, 6, and 6. For the diet, pedigree was 6.

Fin Whales

Fin whales (*Balaenoptera physalus*) are found during summer in the Bering Sea, Aleutians and the Gulf of Alaska. The Alaska stock is one of three recognized by NMFS. Fin whales are common occurrences south of the Aleutians (Forney and Brownell 1996); acoustic data showed fin whales calling in the western Aleutian Islands (Moore et al. 1998, Watkins et al. 2000). Neither reliable trends nor abundance estimate are currently available for fin whales. The best abundance estimate available is that of Zerbini et al. 2003, where abundance and distribution was estimated from the Kenai fjords to the Central Aleutians. In 1999, vessel surveys in the central Bering Sea yielded a provisional abundance estimate of 4,951 (95% C.I.: 2,833-8,653) fin whales (Moore et al. 2000). The fin whale is listed as endangered under the ESA and depleted under the MMPA. (Angliss and Lodge 2004).

AI biomass was estimated at 2502 tons, PB was 0.05 and QB 11.16. The corresponding pedigree categories are 4, 6, and 6. For the diet, pedigree was 6.

Humpbacks

Humpback whales (*Megaptera novaeangliae*) are distributed world wide; with historic summer ranges in Alaska encompassing the Bering Sea, Gulf of Alaska and west along the Aleutians all the way to the Kamchatka peninsula. Humpbacks tend to winter at latitudes ranging from 20-25° N in Japanese, Hawaiian and Mexican waters (Rice 1978). The western North Pacific stock winters in Japanese waters and is presumed to migrate to BSAI to feed (Omura and Ohsumi 1964; Ohsumi and Masaki 1975; Ivashin and Rovnin 1967). The central North Pacific stock (one of three) winters in Hawaiian waters and migrates in summer to localized feeding grounds in Alaskan and Canadian waters including the Aleutians, Prince William Sound, southeastern Alaska, British Columbia (Waite et al. 1999, Darling et al. 1996). There is no trend information for the western North Pacific stock. Abundance estimates for the North Pacific are available for the wintering areas, but not for the feeding areas, as these remain largely unknown. The best abundance estimate available is that of Zerbini et al. 2003, where abundance and distribution was estimated from the Kenai fjords to the Central Aleutians.The humpback whale is listed as endangered under the Endangered Species Act, and therefore designated as "depleted" under the MMPA (Angliss and Lodge 2004).

AI biomass was estimated at 8149 tons, PB was 0.0377 and QB 7.577. The corresponding pedigree categories are 4, 6, and 6. For the diet, pedigree was 6.

Minke whales

Minke whales (*Balaenoptera acutorostrata*) are distributed worldwide. The IWC recognizes three stocks, and minkes in Alaska belong to the stock east of 180 W (Donovan 1991). Within NMFS though, Minke whales in Alaska are managed as a separate stock from those in California, Oregon, and Washington (Angliss and Lodge 2004). Prey preferences of eastern North Pacific minke whales are unknown. Minke whales are known to feed on pelagic schooling fishes in the western North Pacific (Kasamatsu and Hana 1985; Kasamatsu and Tanaka 1992; Tamura et al. 1998); pollock, cod, sand lance, saury, sardines, anchovies, herring and small quantities of squid off the coast of Japan and in the Sea of Okhotsk (Omura and Sakiura 1956; Nemoto 1959). Stomach contents of a stranded minke whale in the Aleutian Islands contained walleye pollock (Frost and Lowry 1981). The best abundance estimate available is that of Zerbini et al. 2003, where abundance and distribution was estimated from the Kenai fjords to the Central Aleutians. No data exist on trends in abundance in Alaskan waters (Angliss and Lodge 2004).

AI biomass was estimated at 5555 tons, PB was 0.0511 and QB 7.78. The corresponding pedigree categories are 4, 6, and 6. For the diet, pedigree was 6.

Right whales

Northern right whales (*Eubalena japonicai*) within Alaska have a historical distribution encompassing the Gulf of Alaska (Rice and Wolman 1982), eastern Aleutina Islands and subcentral Bering Sea (Braham and Rice 1984; Scarff ,1986). Right whales in the North Pacific are known to feed on various zooplankton (*Calanus marshallae, Euphausia pacifica, Metridia* spp.), and copepods of the genus *Neocalanus* (Omura 1986). A reliable estimate of abundance for the North Pacific right whale stock is not available nor is there any estimate of population trend (Ferrero et al. 2000). Northern right whales are listed as depleted under the MMPA and endangered under the ESA (Angliss and Lodge 2004).

AI biomass was estimated at 202 tons, PB was 0.0328 and QB 8. The corresponding pedigree categories are 7, 6, and 6. For the diet, pedigree was 6.

Sei whales

Sei whales (*Balaenoptera borealis*) are found in all oceans, but tend to be restricted to more temperate waters (Mizroch et al. 1984b). The IWC recognizes only one stock in the North Pacific (Donovan 1991). Sei whales skim the surface for feeding but also engulf swarms of prey, typically copepods and krill (Mizroch et al. 1984b). Japanese pelagic whaling operations from 1952 to 1971 in the North Pacific showed that out of 21,713 sei whale stomachs examined, copepods were present in 82.7% of the stomachs containing food (Nemoto and Kawamura 1977). The next most common prey were euphausiids (present in 12.6% of the stomach samples). North and south of the Aleutian Islands chain, stomach contents were mostly copepods, with some containing squids, euphasiids and fish (Nemoto 1957). The dominant prey species for sei whales around the Aleutian Islands were the copepods *C. plumchrus*, *C. cristatus*, and *C. glacialis*, and the squid *Ommatostrephes sloanei-pacificus* (Klumov 1963). The sei whale is listed as endangered under the ESA and depleted under the MMPA.

AI biomass was estimated at 361 tons, PB was 0.0267 and QB 6.52. The corresponding pedigree categories are 7, 6, and 6. For the diet, pedigree was 6.

Resident seals

Resident seals in the Aleutian Islands are harbor seals (*Phoca vitulina richardsi*), and they are part of the Gulf of Alaska stock (the two others are SE Alaska and Bering Sea). These stocks are for management purposes only as scientific data is not conclusive on whether they are distinct biological stocks. The population would appear to be increasing, but the trend in the Aleutian Islands is unclear because the 1994 survey was the most complete census wheras previous census were conducted incidental to surveys designed to assess other species (i.e., sea otters or Steller sea lions). However, a subset of the 1994 survey in the eastern Aleutian Islands indicated a count of 1,600 in an area that had counts of approximately 1,000-2,500 seals during 1975-77 (Small 1996). Harbor seals are neither listed as depleted under the MMPA nor threatened/ endangered under the Endangered Species Act (Angliss and Lodge 2004).

AI biomass was estimated at 206.22 tons, PB was 0.0826 and QB 17.44. The corresponding pedigree categories are 5, 6, and 6. For the diet, pedigree was 5.

Sea Otters

The sea otter (*Enhydra lutis*) population in the Aleutian islands was estimated to decline at a rate of 17.5%/yr during the 1990s. (Doroff et al. 2003). Declines were not restricted to the Aleutian Islands, they extended to the Alaska Peninsula as well. Though the geographic extent of the decline is not known, some data show the Commander and far Western Aleutians with stable numbers, hence the westward extent of the decline would appear to be Attu Islland (Doroff et al. 2003). Sea otter diet changes radically between summer/autumn and winter/spring. Decadal changes have also been observed: instead of lumpsuckers, kelp forest fish were consumed (Estes 1981, Watt et al. 2000). However for the model, only summer diets were considered (jun- sep average): urchins were rounded off as 61.54%, other invertebrates (such as bivalve molluscs, rock jingles, mussels, sea stars, sea cucumbers, decapods, gastropods, octopus sp and annelids) are 8.31%, lumpsucker are 19.38%, and other fish (i.e. gunnel, sandlance and greenlings) are 10.77% (Watt et al. 2000).

AI biomass was estimated at 391.3394 tons, PB was 0.117 and QB 73. The corresponding pedigree categories are 4, 6, and 6. For the diet, pedigree was 5.

Steller sea lions

Two distinct stocks of Steller sea lions (*Eumetopias jubatus*) are recognized within U. S. waters: the eastern and western U. S. stocks. The first includes individuals east of Cape Suckling, Alaska (144°W), and the second includes those at and west of Cape Suckling (Loughlin 1997); the Aleutian Islands populations belong to this last stock. Between 1998 and 2000 the population was estimated to decline 10.2% in the Bering Sea/ Aleutian Island region (Angliss and Lodge 2004). There are some eight different hypotheses that have been proposed to explain the decline of Steller sea lions and they involve either bottom-up or top-down forcing. Bottom-up forcing hypotheses include nutritional limitation due to either 1) fisheries removals or 2) climate change/ regime shift. Top-down forcing hypotheses include increased mortality due to 3) predation, 4) purposeful killing, 5) subsistence uses, 6) bycatch, 7) infectious disease(s) and 8) toxic substances (this last one may be bottom-up as well). In all, the Committee on the Alaska Groundfish Fishery and Steller Sea Lions concluded the evidence is more consistent with a top-down forcing scenario. A combination of increased predation, illegal shooting in the early 1980's, bycatch mortality and subsistence harvest (NRC 2003). The decline of the western stock prompted the listing of Steller sea lions as endangered under the ESA criteria (up from "threatened"). NMFS responded to the listing by implementing some changes in the area, most notably: 1) a more precautionary rule for setting harvest limits, 2) extension of 3 nmi protective zones around rookeries and haulouts not currently protected, 3) closures of many areas around rookeries and haulouts to 20 nmi, 4) establishment of 4 seasonal catch limits inside critical habitat and two seasonal releases outside of critical habitat, and 5) establishment of a procedure for setting limits on removal levels in critical habitat based on the biomass of target species in critical habitat. A revised SEIS (Supplemental Environmental Impact Statement) was developed in 2001 and resulted in a preferred alternative that includes area-specific management measures designed to reduce direct and indirect interactions between the groundfish fisheries and Steller sea lions, particularly in waters within 10 nmi of haulouts and rookeries (Angliss and Lodge 2004).

AI biomass was estimated at 2964.1 for adults and 310.5 for juveniles.PB was 0.1098 for adults and 0.494 for juveniles; QB was 24.07 for adults and 108.32 for juveniles. The corresponding pedigree categories are 2, 4, and 5 for adults; 2, 4 and 7 for juveniles. For the diet, pedigree was 4 for both juveniles and adults.

Seabirds

Albatrosses

Three species of albatross occur in Alaska: Short tailed albatross, Laysan and Black-footed. Albatrosses are largest seabirds found in Alaska, but are small compared to many other albatrosses. Their wingspan of almost two meters, is half that of the largest albatrosses. Albatrosses do not nest in Alaska but they migrate here each year after having breeding in the

Northwestern Hawaiian Islands and Torishima Island in Japan. The biomass in the AI 4.68 tons; PB is 0.0676 and QB is 75. Pedigree is 4, 6, 6 respectively and 6 for the diet composition.

Short-tailed albatross (*Phoebastria albatrus*) is the largest seabird oin the North Pacific. Historically millions of birds nested in the western North Pacific . Only two breeding colonies remain active: Torishima Island and and Minami-kojima Island. They are long lived, upo to m40 years and begin breeding at about 7 or 8 years of age. During the late 1800s and early 1900s, feather hunters killed an estimated five million and the species became nearly extinct. The world population is about 1200 birds, hence bycacth in Alaskan fisheries (particulalry longline) is of great concern. Listed as endangered under the ESA.

Black footed albatross (*Phoebastria nigripes*) range farther north, penetrating the Gulf of Alaska and the Bering Sea. Common in the Bering Sea near the Aleutian Is. during summer, is the most common albatross in the e. North Pacific; Off the Aleutian Is., rockfish (*Pinnotheres* sp.) are an important dietary item. They feed mainly during the day by seizing prey at the surface described two methods of feeding: the duck-like "tip-up" method and complete submergence with wings extended. Flying-fish eggs are the principal component of the diet, followed by squid and crustacea.Flying-fish eggs are the principal component of the diet, followed by squid and crustacea. Some 50,000 pairs of Black-footed Albatross nest in the Northwestern Hawaiian Islands. (Whittow 1993)

Laysan albatross (*Phoebastria immutabilis*) Seen regularly in Gulf of Alaska during northern spring and the s. Bering Sea in summer Birds are farther north in summer than during the breeding season and nonbreeders concentrate near the Aleutians and in the Bering Sea. feeds largely on squid, the distribution of which is tied to abundance of shrimp-like euphausids. Larger euphausids occur in near-surface, eutrophic, cold waters. Feed by sitting on the water and seizing prey. Use their powerful beaks to shred large prey. Scavenge natural carrion or refuse from ships, but not as extensively as Black-footed Albatross does. Feed mainly at night; Laysans have high levels of rhodopsin, the visual pigment that enhances nocturnal vision. Squid are more plentiful in surface waters at night than during the day; they possess light organs and migrate to the surface at night. Laysans often feed in flocks with other albatross but rarely with other species. Squid make up the bulk of the diet. Fish eggs constitute the largest fraction of the "fish" part of the diet, followed by sunfish (*Ranzania laevis*;. Colonies on Johnston, Wake, and Marcus islands, and on the Izu Is., decimated by Japanese feather hunters at the turn of the century and have never recovered. Marcus once had an estimated population of one million birds. Midway and Laysan island (on Laysan I., more than 300,000 birds were killed in 1909 alone) populations also greatly reduced by feather hunters but have largely recovered. Lisianski population has remained depressed apparently because the vegetation was altered by introduced rabbits, destroying nesting habitat. Nearly all of the 400,000 breeding pairs nest in the Northwestern Hawaiian Islands. (Whittow 1993b)

Auklets

There are 5 species of auklets in the Aleutians, Least auklets, Crested, Cassin's, Parakeet and Whiskered. They are planktonic and nest in the Aleutians. The biomass estimate is 459 tons, PB is 0.169 and QB is 110. Pedigree is 4, 6, 6 respectively and 6 for the diet composition.

Least auklet (*Aethia pusilla*) The smallest alcid, total length 12–14 cm, wingspan 33–36 cm, mean adult mass about 85 g. This tiny alcid is one of the most abundant seabirds in North America, with a total population of about nine million. Least Auklets dive for plankton, nest in huge colonies in rock crevices, lay just one egg each year, and eat almost 90% of their weight per day—reflecting the high energetic demands of their flight and foraging. This species breeds on the Aleutian Islands and on remote islands in the Bering Sea, and winters at sea near. This is a socially monogamous species and mate choice is mutual, but there is relatively low mate fidelity between breeding seasons. Sperm competition may be an important aspect of the breeding system—males have by far the largest testis size relative to body size of any alcid. This species has a low survival rate relative to other alcids, with a predicted average life expectancy of about 4.5 years. Rats and foxes threaten some colonies. Population estimates for colonies have been difficult to obtain because colonies are often large, nests invisible, and colony attendance highly variable; thus estimates are for the most part based on anecdotal accounts Large breeding colonies are located at Kiska, Segula, and Gareloi islands in the Aleutians; St. Matthew I. These figures apparently based on estimated numbers of adults visible on colony site, undoubtedly a fraction of the total population. A total of 38 known colony sites have been described from Alaska. The total North American population may be about 9,000,000 individuals (USFWS 1988). Diet overlaps considerably with juvenile walleye pollack, and some pacific salmon (*Onchorhynchus*) species. Large numbers of Least Auklets killed by introduced foxes and rats in Aleutian Is. Effects on populations little studied, but likely to have been severe. Many birds destroyed when foxes were systematically introduced to Aleutians for fur-farming purposes Bailey 1993). Some large Aleutian auklet colonies have persisted with introduced foxes present (e.g.,, Sirius Point, Kiska I.), but many other island populations extirpated. Introduced arctic foxes are known to have eliminated auklets from several Aleutian islands (e.g.,, Uliaga, Kagamil). Populations are likely to recover if non-native foxes are removed but Introduced rats remain a threat because they are easily introduced accidentally, and are far more difficult to control once established. (Jones 1993).

Crested auklet (*A. cristatella*) Small, highly gregarious alcid; total length 18–20 cm, wingspan 40–50 cm, adult mass averages about 260 g.The Crested Auklet is a small, odd-looking seabird that breeds in colonies on remote islands and coastlines around the Bering Sea and winters in flocks on nearby waters. Breeding colonies are located on sea-facing talus slopes, cliffs, boulder fields, and lava flows, all of which provide abundant rock crevices suitable for nesting. This auklet dives for its food, primarily euphasiids, and lays but a single egg per clutch. Both male and female help to care for their semi-precocial young, which fledges at almost adult size after about 33 days in its nesting crevice. A large colony at Kagamil I. in the Aleutians is now extinct, probably due to predation by introduced arctic foxes (Bailey 1993). Introduced arctic foxes are known to have extirpated Crested Auklets from several Aleutian islands (e.g.,, Uliaga, Kagamil), and certainly eliminated or reduced many other islands' populations before they could be properly documented. Present Aleutian auklet populations are likely only a fraction of original populations prior to fox introductions. A large mixed auklet colony at Kiska I. apparently greatly increased in size by invasion of habitat created by a recent (1969) lava flow, but this population is now threatened by Norway rats, which have become abundant following removal of introduced arctic foxes. Little known about behavior at sea and foraging tactics. Forages on open ocean in deep water, often far from shore and at long distances from breeding colonies, particularly where the water column is vertically stratified and where dense layers of zooplankton are present. Also feeds in near shore areas where tidal currents and turbulence physically transport and concentrate prey, such as in narrow Aleutian Island passes. Nests in rock crevices; incubating bird seldom visible from outside. Suitable nesting habitat consists of talus slopes, cliffs, boulder fields, and porous lava flows near sea. Nests in rock crevices; not known to use earthen burrows. Nest spacing depends on rock size, crevice size, and talus depth. Compared to Least Auklet, prefers areas with larger boulders and crevices; Often forages in large flocks, suggesting foraging is socially facilitated. Individuals in feeding concentrations dive beneath sea surface and pursue prey in rapid wing-propelled underwater flight. (Jones 1993b).

Cassin's auklet (*Ptychoramphus aleuticus*) Small, rather nondescript alcid; overall length 23 cm, mass 150–200 g.. Cassin's Auklet is one of the most widely distributed of the Pacific alcids, and one of the best studied. A coastal, island-breeding species found from Alaska south to Baja California, this small, abundant auklet nests in shallow burrows, which the birds excavate with their sharp toe nails, and also in rock crevices or under trees or logs on the ground. During the nonbreeding season, this species spends most of its time at sea, sometimes lingering near nesting colonies but often traveling beyond the shallow waters of the continental shelf for its preferred food—small crustaceans, squid, and fish. Southern populations apparently sedentary, northern (Alaska and British Columbia) apparently migratory. In Alaska, they leave nesting islands after breeding and apparently move south to winter habitat. dive for food with aid of wings, often in small groups, occassionally in large assemblages. Both day and night feeding observed. Mean diving time beneath the sea surface is 42 s and diving depth is 20–80 km. Total estimated population at least 3.57 million individuals (Manuwal and Thorensen 1993).

Parakeet auklet (*A. psittacula*) A chunky alcid, 23–26 cm long (ILJ) and 238–347 g mass. Parakeet Auklets have the widest range of any of the Alaskan auklets, spanning the northern Gulf of Alaska, most of the Bering Sea, the north Pacific south of the Aleutian Islands, and the Sea of Okhotsk in Siberia. Their preferred breeding sites are in crevices along rocky cliff faces, although small breeding colonies may be located on rocky beaches, talus slopes, lava extrusions, and even grassy slopes with scattered boulders. This species is less gregarious and in most areas less abundant than sympatric Least (*Aethia pusilla*) and Crested (*A. cristatella*) auklets, and is never observed in large flocks at breeding colonies or at sea. Greater diversity of nesting habitat than other auklets. On islands without mammalian preda-tors, selects sites with rock crevices such as among beach boulders, talus slopes, scree slopes, and cliffs, on steep grassy slopes with scattered boulders where soft soil for burrowing is present, and on old talus slopes densely vegetated with grasses. Parakeet Auklets feed over stratified mixed and shelf waters, avoiding, or at least not concentrating at, areas of turbulence and upwelling, unlike other auklet species (Hunt et al. 1993 1998). Parakeet Auklets breed at 174 colonies in Alaska, compared to only 33 Least Auklet and 39 Crested Auklet colony sites, but populations at Parakeet Auklet colonies average much smaller (86% of Parakeet Auklet colonies contain <1,000 pairs breeding. Largest concentrations breed at St. George I., Pribilof Is. (250,000 pairs) and King I (Jones et al 2001).

Whiskered auklet (*A. pygmaea*) The Whiskered Auklet is a small alcid endemic to an arc of volcanic islands formed by the Aleutian, Commander, and Kuril island chains. Small alcid; only Least Auklet is smaller. Total length: 17–19 cm (GVB, JCW). About 5–7 cm smaller than Crested and Parakeet auklets (*Cyclorhynchus psittacula*), 3–4 cm smaller than Cassin's Auklet (*Ptychoramphus aleuticus*), 3–4 cm larger than Least Auklet. Mass of Whiskered Auklet (mean about 120 g) is about 40%–45% as large as Parakeet and Crested auklets, 70%

as large as Cassin's Auklet, and 39% larger than Least Auklet (GVB, JCW). Probably most remain near breeding areas throughout the year. Breeds in rock crevices on oceanic islands Feeds in nearshore marine waters, usually within 10 km of colonies. Feeding flocks associated with convergent tidal fronts year-round, usually within 16 km of islands, where zooplankton is apparently concentrated. This habitat characterized by well-mixed water with few gradients between surface and bottom. Dive depths unknown, but Whiskered Auklet mostly found in areas where water < 100 m deep. Like other alcids pursue prey by "flying" underwater. Probably concentrates on swarms of zooplankton, taking several organisms at a time. Able to store dozens of copepods in sublingual pouch to deliver to chicks.Phototrophic response can cause mortality by inducing collisions at night. (Byrd and Willliams 1993)

Cormorants

Two types of cormorants are found in the Aleutians, the Red faced cormorant and the Pelagic cormorant. Their combined biomass estimate is 61 tons, PB is 0.159 and QB is 73. Pedigree is 4, 6, 6 respectively and 6 for the diet composition.

Red faced cormorant (*Phalacrocorax urile*) The Red-faced Cormorant may be the least known of all North American species. It breeds in a narrow, latitudinally compressed band from the northern Sea of Japan, along the Kuril and Aleutian Island chain, and far east into the southeastern Gulf of Alaska. Possibly owing to its shy habits and inaccessible colony sites, it is one of the least studied and least known birds of the North Pacific: Little is known beyond distribution and rudiments of ecology. The Red-faced Cormorant is exclusively marine and ventures onto land only to breed or roost, never intruding more than a few meters from the edge of the sea. It sometimes is observed flying far out to sea, but is more commonly associated with the inshore and coastal waters of islands and continental shelves. Medium-sized cormorant. Length 75–100 cm; males larger than females: average mass for males, 2,400 g; females, 1,850 g (see Measurements, below). Not migratory, but postbreeding dispersal throughout range; never farther south than se. Alaska. In winter, adults and juveniles remain close to shore and feed in littoral and onshore waters near breeding colonies in the Aleutians and Pribilofs. Winter mortality is high, based on large number of carcasses seen after spring snowmelt. Commonly observed near islands and rocky shores; rarely seen far from land. Forages farther out to sea than does Pelagic Cormorant, however. Individuals rarely noted feeding in deep waters (>200 m) 20 km from shore, likely wandering or nonbreeding adults. Nesting colonies located on suitable cliffs of rocky islands and headlands; never noted on flat ground, pilings, or human-made structures, where Pelagic Cormorant known to nest. Colony size seems limited by availability of nest ledges, and actively growing colonies often invade kittiwake (*Rissa* spp.) and murre (*Uria* spp.) colonies Piscivorous; predominantly demersal fish, with little specialization. Prefers inshore areas often close to shore and near rocky bottoms. Like Pelagic Cormorant, usually swallows prey underwater. Considered in early times as "winter food" by native Aleut peoples. Arctic foxes were introduced onto many of the Aleutian Is. by the Russian-American Company in mid-eighteenth century; by late 1940s, all of the major islands and nearly all of the smaller ones were inhabited by foxes. Foxes substantially reduced breed-ing populations of all seabirds, including Red-faced Cormorants (Causey 2002)

Pelagic Cormorant (*P. pelagicus*) Small to medium-sized cormorant. Length 51–76 cm. Male larger than female (average mass: male, 1,750–2,034 g; female, 1,531–1,702 g;The Pelagic Cormorant, the smallest and most widely distributed of six cormor-ant species inhabiting the North Pacific, ranges from the Arctic waters of the Chukchi and Bering Seas south through temperate waters along the North American Pacific Coast to Baja California and along the Asian coast to southern China. It is among the least gregarious or social of the cormorants, nesting on steep cliffs along rocky and exposed shorelines, either in loose colonies or far from nearest neighbors. Migration occurs primarily in northern populations; in n. Bering Sea, likely as response to pack-ice cover, but migratory distances not generally known. Nesting colonies located on suitable cliffs of forested, grassy, and rocky islands and headlands. Also uses ledges of sea caves, beached driftwood logs, sand spits, and human-made structures such as navigation beacons, bridges, wharves, empty ship hulls, and abandoned towers. Forages in waters in Gulf of Alaska to about 36 m and around Pribilof Is. and coastal California; often found in waters up to 100 m deep, but foraging depths not confirmed in these waters. Food generalist; diet consists predominantly of medium-sized fish. Also consumes invertebrates, marine worms, and crustaceans. In Alaska, Black-legged Kittiwakes and cormorants compete for nest space. Red-faced Cormorants arrive early to occupy nesting cliffs and possibly dominate and exclude Pelagic Cormorants from the best nesting sites. Gulls and Double-crested Cormorants also compete with Pelagic Cormorants for nesting habitat (Hobson 1997).

Fulmar

Northern fulmar (*Fulamrus glacialis*) Medium-sized petrel (length 45–50 cm, wingspan 102–112 cm, mass 450–1,000 g). Pelagic dispersal; no true directed migrations, except possibly in high-arctic populations displaced by advancing sea ice in winter. On Pacific Coast, first arrivals off central California usually late Sep, peak mid-Nov; uncommon to abundant in different years. Occasional stragglers remain through summer in California; most depart by Mar–Apr. Peak numbers in Sep–Nov off British Columbia, but also common (immatures) along entire British Columbia coast in Jul. Prefers precipitous sea cliffs of small to large islands or mainland promontories. Often in mixed colonies with other cliff-breeders (murres [*Uria* spp.], kittiwakes [*Rissa* spp.], cormorants [*Phalacrocorax* spp.]), but differs in using upper, more densely vegetated portions of cliffs, canyons, and gullies with less severe slopes and greater soil accumulation. In Arctic or wherever ground predators exist, breeding sites usually restricted to inaccessible ledges of sheer cliffs. Omnivorous. Main foods are fish, cephalopods (mainly squids; zooplankton (especially amphipods, copepods, and other crustaceans), offal, and carrion. Offal includes fish refuse (livers, entrails, and whole fish discarded by trawlers and factory ships), as well as remains of whales, walruses (*Odobenus rosmarus*), and seals, especially blubber.

Observations suggest that most foraging during chick-rearing occurs closer to colonies, probably <100 km away. Fulmars obtain food by dipping, surface-seizing, surface-plunging, pursuit-diving, and scavenging; apparently unable to pick up prey while on the wing. In Alaska, foxes (*Alopex* and *Vulpes*), rats (*Rattus norvegicus*), ground squirrels (*Spermophilus* spp.), and other mammals widely introduced in late 1800s and early 1900s (Bailey 1993) reduced or eliminated some former colonies: Heavy predation by fox also likely in the West Pacific, particularly Kuril Is., from animals introduced by Japanese fur farmers in early twentieth century (Hatch and Nettleship 1998).

The biomass estimate for the Aleutian Islands is 278 tons. PB is 120 and QB 144. Pedigree is 4, 6, 6 respectively and 6 for the diet composition.

Gulls

Glaucus winged gull (*Larus glaucescens*) generally nests at high densities in large or small colonies on off-shore islands, although it has recently begun nesting on roofs of waterfront buildings. It is an abundant resident along the northwestern coast of North America; bold and omnivorous, it is a familiar sight in coastal cities and towns. Although generally an inshore species, it does venture away from the coast where it is often seen around fishing vessels at sea. This species has steadily increased in numbers in the last few decades, particularly around urban centers, mainly owing to environmental changes and to the availability of garbage and fish offal. Seizes food from water surface or just below it in flight or while swimming; also plunges from a floating position, by jumping into the air, to become partially or totally submerged. Chitons and limpets are pulled off rocks during ebbing tides while they are still submerged, and barnacles are grasped and broken off. Fish are obtained when stranded in tide pools, in shallow water along the shore, or when they come near the surface off shore. Steals food from its own species, and others. Kills and eats its own species' chicks, other birds. Rarely lives beyond 15 yr. The average life expectancy is 9.5 yr, starting at age 4 (Verbeek 1993).

The biomass estimate is 33 tons. Their estimated PB is 0.166 and the QB is 73. Pedigree is 4, 6, 6 respectively and 6 for the diet composition.

Kittiwakes

Two types of kittiwakes nest in the Aleutians, the Black-legged kittiwake and the Red-legged kittiwake. Their combined biomass estimate is 28 tons. PB is 0.076 and QB 110. Pedigree is 4, 6, 6 respectively and 6 for the diet composition.

Black-legged kittiwake (*Rissa tridactyla*) Like the Red-legged Kittiwake but unlike other gulls, the Black-legged Kittiwake usually nests on vertical sea cliffs, laying its eggs on narrow ledges—so narrow that most adults and chicks must face towards the cliff when on their nest, with their tails projecting over the edge. The Black-legged Kittiwake is one of the most widely distributed of our northern gulls, and one of the best studied. Ranging over the arctic, subarctic, and south, this species is also among the most pelagic of gulls. North American breeders winter offshore as far south as Florida and Baja California, and large numbers gather on the Grand Banks off Newfoundland and in ice-free waters off Alaska. During the breeding season, this species stays nearer the coast and its breeding colonies, often foraging at upwellings or oceanic fronts where its prey concentrate. It does not fly great distances to feed as does its close relative, the Red-legged Kittiwake (*Rissa brevirostris*). Small gull, length averages 380–410 mm with mean body weight of 365–400 g,. A cliff-nester on ledges of offshore islands, sea stacks, or inaccessible areas of coastal mainland. Also nests on steep earthen slopes or large boulders or in substitute-cliff man-made objects: shipwrecks, buildings; also on glaciers. In Gulf of Alaska, forages as close as 1–5 km to colonies, over the Shelf, or if Shelf narrow (e.g.,, Buldir I.), in more pelagic waters near colony. In the Bering

Sea, forages from < 1 to > 40 km from colonies and densities are as high over Continental Shelf as over the Shelf Break. Narrow shelf foragers consume more from oceanic food webs (e.g.,, euphausiids, zooplankton, pollock, lantern fish [Myctophidae]; opportunistic fish-eater. (Baird 1994).

Red legged kittiwake (*R. brevirostris*) Small gull. Total length: mean = 372 mm (SD = 12.1; *n* = 10 live birds unknown sex, Buldir I. 1992, JCW), range 353–392 mm; significantly shorter than Black-legged [mean = 405 mm]. Breeds on St. George, St. Paul, and Otter islands in the Pribilof Is. group, Bogoslof and Fire islands in the Bogoslof Is. group, and Buldir I. in the w. Aleutian Is. chain. Strictly accidental south of Alaska, but there are summer records for Oregon and one remarkable mid-summer occurrence in s. Nevada In summer, within 120–150 km of breeding islands. Pribilof Is. breeders concentrate south of islands near edge of continental shelf. Possible adaptation to night feeding when vertically migrating prey like lampfish (Myctophidae), and squid become available to surface-feeding kittiwakes. Red-legged classified as Endangered in Russia which gives special protective status, i.e., restricted public access to nesting cliffs in Commander Is. (A. Golovkin pers. comm.). Rat prevention program underway in Pribilof Is. (Byrd and Williams 1993).

Murres

Both thick billed and common murres are found throughout the Aleutians. Their combined biomass is 27.5 tons, derived from the Beringean Seabird Catalog colony counts for the western and central Aleutians multiplied by the average weight for each species to convert abundance to biomass estimates. Body weights were taken from Hunt et al. (2000). PB was estimated at 0.169, equi valent to Z (total mortality) at the Order level (Schreiber and Burger 2002) and QB was estimated at 72, from daily energetic requirements (Hunt et al. 2000). General diet was also from Hunt et al. (2000) but the final diet was obtained by using the preference method described in the methods section of the main paper. The pedigree of these estimates was 4 for the biomass, 6 for both PB and QB and 6 for the diet composition.

Thick billed murre (*Uria lomvia*) is one of the most numerous seabirds in the Northern Hemisphere. In Nortn America in particular, they range from Northern to west Alaska (Cape Lisburne to Diomede & Nunivak Islands), including the offshore islands (St. Lawrence I., St. Mathew I., and the Pribilofs), the Alaska Peninsula, and throughout the Aleutians (Buldir Island). Many individuals in the North Pacific remain within breeding range throughout year, but those in areas affected by ice may move towards the ice margin during winter. Found usually farther offshore than Common Murres, in water >30 m deep. Prefers proximity to deep, oceanic waters (Springer 1991). In the North Pacific, it is found far from the continental shelf, in subarctic waters of w. Subarctic Gyre, Alaskan Stream, and Subarctic Current In spring and early summer, strongly associated with margin of land-fast ice, especially where free-floating ice covered <50% of water adjacent to ice edge. Their distribution may be influenced by bottom topography and tidal phase, where strong tidal currents occur among islands and reefs (Cairns and Schneider 1990), also by the occurrence of oceanic fronts (Gaston and Hipfner 2000).

Their primary diet is comprised by midwater schooling fishes (cod, smelt, sandlance) and crustacea, especially pelagic amphipods and euphausiids; also benthic fishes (sculpins Cottidae, blennies Blennioidea, lumpsuckers), deepwater fishes (lanternfish), shrimps

(Crangonidae), squid, and annelids. Mean dive depths range from 7 to 33 m (n = 8), however the mean maximum depth 107 m ± 42 SD (n = 40); dives usually deeper dueimg day than during night (Croll et al. 1992). Murres do not build a nest. Rather, incubating birds shift pebbles or other debris. Numbers increased in 1980s at the Aleutians and Cape Lisburne (Gaston and Hipfner 2000).

Common murre (*Uria aalge*), aslo known as Thin-billed Murre, is very numerous in the Northern Hemisphere. It is a large alcid (body length 38–43 cm, wingspan 64–71 cm; 800–1,125 g) with Circumpolar distribution from 68–33°N in west coast of. North America. It is found msotly at sea with significant breeding grounds throughout Alaska, including the Aleutian Islands. The populations in high-latitude migrate to escape winter sea ice, especially those nesting on coasts of Chukchi and Bering Seas and off Labrador; midlatitude populations are partially migratory; and lower-latitude populations sedentary. Breeds on cliff ledges, sloping island surfaces, or flat areas on rocky headlands and islands in full ocean view. In nonbreeding season they are often found close to shore, even up inlets and sounds. However, during breeding season they are most common where prey gets concentrated by oceanographic fronts, tidal sheers, and similar oceanographic features that are located within flight range of colonies. Warmer climate (either by El Niño or PDO) common murres feed further inshore from shelf break (Ainley et al. 1990, Oedekoven et al. 2001). Common murres are skilled divers, capturing prey with their bill and using wings for propulsion at depths usually between 20-50 m but can dive as low as 180 m. It is likely more agile than Thick-billed Murre underwater, but slower and preferring shallower depths. More piscivorous than Thick-billed Murre. Predominance of one versus other murre species shifts: when North Pacific Pressure Index (PNI) anomalies consistently positive for a period, the Common Murre is more abundant, and conversely when negative. Murres have lost breeding grounds to sea lions (Ainley et al 2002). The oscillating pattern is typical of many other (but not all) Bering Sea and Aleutian Island colonies (Springer 1991, Byrd et al. 1993). With increasingly negative PNI (see Springer 1998), Common Murre at Bluff, Norton Sound, decreased markedly during 1970s, then stabilized in 1980s; conditions on wintering grounds in s. Bering Sea likely responsible (Murphy et al. 1986); a decline, too, observed at Cape Thompson, Chukchi Sea, AK, stabilizing by early 1980s (Byrd et al. 1993). PNI shifts bring food-web changes; with declines on Pribilof Islands. diets of lipid-poor juvenile walleye pollock (Theragra chalcogramma) switched with lipid-rich sandlance and capelin (Decker et al. 1996).

Predatory mammals, such as foxes cause major reductions in colonies or delays in breeding to later affect breeding success Foxes introduced historically (for fur farming) to 455 Alaskan islands still remained on 46 islands by 1990 (Bailey and Kaiser 1993).

Puffins

Both Tufted and Horned Puffin have breeding colonies in the Aleutian Islands. The biomass estimate is 234 tons; PB is 0.40 and QB 73. Pedigree is 4, 6, 6 respectively and 6 for the diet composition.

Tufted puffin (*Fratercula cirrhata*) Adult Tufted Puffins are the most pela-gic of the Alcidae, ranging widely from colonies in summer to find fish for their young, but feeding themselves largely on invertebrates, especially squid and euphausiids. During the nonbreeding season, adults migrate far south to oceanic waters of the Central North Pacific, where their diet consists largely of squid, euphausiids, and pelagic fish. Juveniles migrate south to the Central North Pacific after fledging and may not return to coastal breeding areas for several years. Thus, the Tufted Puffin, even more so than the Horned Puffin (Piatt and Kitaysky 2002), is a pelagic species that spends most of its life at great distances from land and has a diet more similar to shearwaters and petrels (*Pterodroma* spp.) than to most other alcids. Nests typically excavated in deep, vegetated turf on steep slopes or plateaus, well above shoreline. Where mammalian predators (e.g.,, foxes) are present, or normal habitat absent, breeding usually restricted to inaccessible cliff crevices or inside sea caves. Large feeding flocks are commonly observed near island passes in Aleutians where rip currents concentrate prey (JFP). Prey captured underwater using wing-propelled "flight". Often forages in small groups of 10–20 individuals in association with other fish-feeding seabirds such as shearwaters, Black-legged Kittiwakes (*Rissa tridactyla*), Glaucous-winged Gulls (*Larus glaucescens*), murres (*Uria* spp.), Horned Puffins, and Rhinoceros Auklets (Piatt and Kitaysky 2002)

Horned puffin (*F. corniculata*)Nests on coastline and offshore islands in British Columbia (rare), Gulf of Alaska, Aleutians, Sea of Okhotsk, Kurils, Bering and Chukchi Seas. Winters over a broad area of the central North Pacific, generally over deep oceanic waters. About 76% of colonies and 87% of world population found in Alaska. Largest colonies concentrated in Gulf of Alaska along Alaska Peninsula in Semidi, Shumagin, and Sanak Is. Population dispersed among Aleutian Is. and a few islands in Bering and Chukchi Seas Few remain as year-round residents in Aleutian passes. Some remain near breeding colonies in Aleutians and Gulf of Alaska, but most undergo general postbreeding dispersal to overwintering grounds in central North Pacific (see Distribution, above) where juveniles possibly remain for 1–2 yr before returning to breeding areas. Adults return to colonies en masse in spring. Breeds colonially on barren islands and mainland cliffs. Where mammalian predators (e.g.,, foxes) are present, breeding usually restricted to inaccessible cliff crevices; where predators absent, uses talus slopes, cliff crevices, and boulders along beaches. Forages in low densities (0.1–2.0 individuals/km^2) in bay, shelf, and shelf-edge habitats throughout Alaska, generally within 100 km of colonies. Few individuals found in coastal or shelf areas during winter. Whereas some may overwinter in passes among Aleutian Is., majority appear to inhabit deep, oceanic waters of central North Pacific. (Piatt and Kitaysky 2002a)

Shearwater

Both sooty shearwaters and short tailed shearwaters are found in Alaska. Their biomass estinate is an educated guess of the proportion flying through the Aleutian Passes, on their way to the Bering Sea. The estimated biomass is 103 tons, PB is 0.105 and QB 73. Pedigree is 4, 6, 6 respectively and 6 for the diet composition.

Short-tailed shearwater (*Puffinus tenuirostris)* as a group, shearwaters are known to form some of the largest flocks of any seabird in areas of high food abundance. Millions of short-tails breed near Tasmania during austral summer, and most of these migrate around the rim of the North Pacific during our summer. Huge rafts of short-tails may concentrate at various times in coastal and shelf waters from California to the Bering Sea of Alaska where they feed on dense aggregations of krill or schooling fish. The are many reports in the literature of large (10,000s), very large (100,000s) and even a few extraordinarily large (1,000,000s) flocks of shearwaters sometimes covering several square miles of sea surface. Flocks are known to gather regularly in certain key areas, and Unimak Pass in the eastern Aleutians is one of those locations owing to its rich abundance of krill (euphausiids) during summer. (Piatt 2004)

Storm Petrels

Leach's storm petresl and Fork-tailed storm petrels, both nest in the Aleutian Islands. Their combined biomass estimate is 201 tons, PB is 0.120 and QB is 144. Pedigree is 4, 6, 6 respectively and 6 for the diet composition.

Leach's storm petrel (*Oceanodroma leurcorhoa*) Alaska. Many colonies from Buldir I. (in Aleutian Is. at 52°22'N, 175°55'E), with 410,000 breeding pairs, to Petrel I. (in extreme se. Alaska at 54°45'N, 133°30'W), with 344,250 pairs. Many colonies off Alaska Peninsula; northernmost are small ones at Wooded Is., off Prince William Sound at 59°52'N, 147°25'W. Poorly known; larger colonies may still be undiscovered. Nesting habitat consists of islands far enough offshore to avoid predatory mammals; in Atlantic Ocean at latitudes 41°N (Penikese I., MA) to 69°N (Lofoten Is., Norway), in Pacific Ocean at latitudes 28°N (San Benito Is., Mexico) to 60°N (Wooded Is., off Prince William Sound, AK). Foraging habitat Wide-ranging in open sea, wherever zooplankton and nekton of suitable size are available. Feeds by pecking at individual organisms while hovering over surface, occasionally pattering on surface, as Wilson's Storm-Petrel commonly does, or sitting on water. No published reports of diving. Some surface fishes (e.g.,, rockfish [*Sebastes* sp.]) prominent in diet, but deep-water fish, especially myctophids, even more so. These and vertically migrant plankton in diet imply nocturnal feeding, but fish considered midwater species, e.g.,, *Vinciguerria lucetia*, come to surface often enough in daylight to be taken as prey, sometimes in great numbers. Vary geographically and seasonally, depending on available prey species, which include fishes (myctophids, cod, rockfish), cephalopods (squids, octopuses), crustaceans (euphausiids, decapods, amphipods, isopods, mysids, copepods), and jellyfish (Scyphozoa) (Huntington et al 1996).

Fork-tailed storm petrel (*O. furcata*) Second most abundant and widespread of storm-petrels breeding in n. Pacific. Core of distribution is offshore islands of Alaska, particularly e. Aleutian Is. Breeding range: in Alaska there are some 60 colonies of Fork-tailed Storm-Petrels, 39 of these in the Gulf of Alaska. Species breeds throughout the Aleutian Is. east to islands off w. Alaskan Peninsula. In the Aleutian group, Fork-tailed breeds on most islands; e.g.,, Buldir I. No records of mainland breeding. Islands vary in habitat; individuals use different breeding habitats, ranging from talus slopes to crevices under large trees or rocks. Nesting habitat of majority of populations characterized by subarctic maritime tundra, comprising grasses (*Elymus* sp., *Festuca* sp.), sedges (*Carex* sp.), and umbelliferae (*Heracleum* sp., *Angelica* sp.) among or under which burrows may be found. In general, nests are crevices among rocks, sod, or roots where birds can stay dry. Nests distributed from sea level to island tops. Generally found in colder waters of continental shelf and nearshore waters. In Gulf of Alaska during breeding season, seen both in deeper and inshore waters, although inshore waters more commonly explored. During Apr and May (approximately during prelaying exodus and beginning of laying), individuals congregate over continental shelf, most within 75 km of known colonies. Overall movement of birds nearer colonies during nestling period Surface feeders, seizing prey while hovering over, or landing briefly on, ocean surface. In eastern populations, amphipods. Myctophid and other deep-water fish, shallow-water fish, rockfish, greenling, sablefish, copepods, euphausiids, decapods, and squid comprise other main prey items (Boersma and Silva 2001)

Elasmobranchs

Pacific sleeper shark (*Somniosus pacificus*) are considered common in boreal and temperate regions of shelf and slope waters of the north Pacific; usually in relatively shallow waters at higher latitudes, and deeper habitats in temperate waters. Reproductive mode is unknown, although ovoviviparity is suspected. One individual mature female sleeper shark had 300 eggs. Sleeper sharks grow to large sizes; individuals have been measured to 4.3 m, and lengths to 7 m have been observed under water (Compagno 1984).

AI biomass is 96.45% of the average for years 1991 and 1994 (average estimate of 1991 and 1994 is 750 tons). This is because the total biomass for "sleeper sharks" was split between dogfish and sleeper sharks, based on the cumulative biomass percentage of each species from 1980-2002 trawl surveys (with 1986 excluded due to unusually high numbers of sleeper sharks). The total number of sharks reported in the trawl surveys is 22 and 33 for dogfish and sleeper sharks respectively with cumulative biomasses of 56.92 kg and 1420.29 respectively.

It seems likely that they have a slow growth and relatively low natural mortality rates, so a P/B of 0.1 was assumed for this and all other shark groups, until better information is available. Likewise, consumption rates are unknown, so a Q/B of 3.0 was adapted from a model of a nearby area, Prince William Sound (Hulbert 1999). Diet composition was based on stomach contents from 11 animals collected in the GOA during 1996 (Yang and Page 1999). The pedigree for the biomass estimate is 5, 7 for the PB and QB, 6 for the diets.

Salmon shark (*Lamnia ditropis*) Salmon sharks range in the north Pacific from Japan through the Bering Sea and Gulf of Alaska to southern California, USA and Baja California, Mexico. They are common in coastal littoral and epipelagic waters, both inshore and offshore. Like other lamnid sharks, salmon sharks are active and highly mobile, maintaining body temperatures well above ambient water temperatures (Anderson and Goldman 2001). Salmon sharks have been both considered a nuisance for eating salmon and damaging fishing gear (Macy et al. 1977; Compagno 1984) and investigated as potential target species in the Gulf of Alaska (Paust and Smith 1989), although little is known about their life history locally. In the western Pacific, females are estimated mature at 8-10 years and males at 5 years (Tanaka 1980). The reproductive mode for salmon sharks is ovoviviparous and with uterine cannibalism (Gilmore 1993); litter size in the western North Pacific is up to 5 pups, with a ratio of male to female of 2.2 (Tanaka 1980). Maximum size has been reported at 3.0 m, but average size range seems to be between 2.0 and 2.5 m. This species lives at least 25 years in the western North Pacific (Tanaka 1980). An investigation is currently underway to determine demographics and population parameters for salmon sharks in the eastern North Pacific (K. Goldman, VIMS, personal communication).

AI biomass was estimated by assuming a density of 0.003725 tons/Km^2 applied to shallow subareas only. Note this is not the density calculated by Ecopath as this last one calculates density based on the entire area, which includes the middle and deep strata where they are not really distributed. The calculation was as follows: The average minimum stock size of salmon sharks in the North Pacific (NP) during 1989 was estimated to be 1.92 million individuals (Nagasawa 1998). The mean body weight considered was 103 kg; the area of the NP was 26, 542,000 Km^2. Thus, ((1.92*10^6)*0.103)/ 26542000 = 0.007451 tons/Km^2. To account for migration, density was divided by 2, resulting in 0.003725 tons/Km^2. Because salmon sharks are found mainly in shallow waters, mostly 0-100m (Nagasawa 1998), it was assumed the density would only be applicable to shallow strata (but note Campagno 1984 mentions depth range may go down to 150m). Only two salmon sharks have been reported in the AI bottom trawl surveys between 1980 and 2002, probably due to the surveys poor performance for sampling large pelagic predators.

It seems likely that salmon sharks have a slow growth and relatively low natural mortality rates, so a P/B of 0.1 was assumed. Consumption rates are unknown, so a Q/B of 6.0 was adapted from a model for Prince William Sound, in southeast Alaska (Hulbert 1999).
Diet composition was estimated from 11 animals collected in Prince William Sound during 1998 (K. Goldman, pers. comm.). The percentage of spiny dogfish in salmon shark diet was lowered from 7% to 1% in order to balance spiny dogfish; the percentage of squid in salmon shark diet was increased to 7% to compensate; the rationale being that spiny dogfish may be more common prey for salmon sharks in Prince William Sound relative to the Aleutian Islands, where they are likely to encounter more squids.
The data pedigree was for biomass was considered 5 due to limited catchability in surveys. PB, QB, and diet data were all from general studies only and were all graded 7.

Spiny dogfish (*Squalus acanthius*) are demersal, occupying shelf and upper slope waters from the Bering Sea to the Baja Peninsula in the north Pacific, and worldwide in non-tropical waters; they are more common off the U.S. west coast and British Columbia than in Alaska (Hart 1973). The species is commercially fished worldwide, and may be the most abundant living shark. Complex population structure characterizes spiny dogfish stocks in other areas; tagging shows separate migratory stocks that mix seasonally on feeding grounds in the UK, and separate stocks in BC and Washington state, both local and migratory, that don't mix (Compagno 1984). Dogfish form large feeding aggregations, with schools often segregated by size, sex, and maturity stage. Male dogfish are generally found in shallower water than females, except for pregnant females which enter shallow bays to pup. The species is ovoviviparous with small litters of 1-20, and gestation periods of 18-24 months. While life history parameters often vary between populations, the female spiny dogfish in British Columbia are reported to mature at 23 years, while males mature at 14. Maximum age estimates range from 25-30 up to 100 years. Eastern north Pacific spiny dogfish stocks grow to a relatively large maximum size of 1.6 m (Compagno 1984). Directed fisheries for spiny dogfish are often selective on larger individuals (mature females), which results in a significant impact on recruitment (Hart 1973; Sosebee 1998).

The AI original biomass estimate was 3.5% of the average for years 1991 and 1994. However this estimate was insufficient to satisfy predation by salmon sharks and incidental mortality in fisheries, hence the biomass was doubled. The total biomass for "sleeper sharks" (750 tons) was split between dogfish and sleeper sharks based on the cumulative biomass percentage of each species from 1980-2002 trawl surveys (with 1986 excluded due to unusually high numbers of sleeper sharks). The total number of sharks reported in the trawl surveys is 22 and

33 for dogfish and sleeper sharks respectively with cumulative biomasses of 56.92 kg and 1420.29 respectively.

Stock assessments of Atlantic spiny dogfish use a natural mortality rate of 0.09 (Sosebee 1998), so a P/B of 0.1 was assumed for this group. Since consumption rates are unknown, a Q/B of 3.0 was adapted from a model for Prince William Sound, in SE Alaska (Hulbert 1999). Spiny dogfish diet compositions are absent in the AI, so diet preference was based on information from British Columbia collected in the 1970s (Jones and Geen 1977).
The data pedigree for biomass was considered 6, due to extremely limited catchability in surveys; PB, QB, and diet data were all from general studies only and were all graded 7.

Alaska skate (*Bathyraja parmifera*) In the AI, the skate now identified as *B. parmifera* is likely a separate species (J Orr, pers comm. 2004), however it is treated in the model as the same species inhabiting the Gulf of Alaska and Bering Sea. In the GOA, the maximum observed size of the Alaska skate is 135 cm (Gaichas et al. 2003). Using an empirical regression method (Frisk et al. 2001), length at maturity would be about 96 cm based on that maximum size. At present, there is no age and growth information for any skate species in Alaska. Age, growth, and maturity studies of the Alaska skate were initiated in the EBS in 2003, which may in the future provide information helpful to the management of skates in the GOA and AI.

AI biomass comes from AI bottom trawl survey estimates for 1991 and 1994. The estimates are a combined average of direct biomass estimates and the corresponding proportion of AK skates from the total biomass for "unidentified skates". Bycatch estimates were cut in half because the biomass of skates has doubled between the period of 1991-94 to that of 1997-2000 and so the bycatch extrapolated from 1997-2000 was considered to be too high.

Frisk et al. (2001) estimated that on average, medium sized (100-199 cm) elasmobranchs have a potential rate of population increase around 0.21. This was used as a proxy for Z or P/B = 0.20 for a population at equilibrium. A growth efficiency intermediate between sharks and large teleost predators (arrowtooth and halibut) seemed a reasonable assumption for skates; a GE of 0.1 was assumed, which led to a Q/B estimate of 2.0 for all skate species. Food habits information for the AI is currently lacking. Diet preference was based on information from the Kuril Islands and Kamchatka collected in the early 1990s (Orlov 1998, Orlov 1999). Pedigree for biomass was 2 (well-sampled by surveys, but downgraded from 1 due to species identification issues). PB and QB were considered 7 (general literature review from range of species). Diet AI were considered 6 (measured from same species, but in Russian waters).

Aleutian skate (*Bathyraja aleutica*) In the GOA, the maximum observed size of the Aleutian skate is 150 cm (Gaichas et al. 2003). Using an empirical regression method (Frisk et al. 2001), length at maturity would be about 107 cm based on that maximum size. At present, there is no age and growth information for any skate species in Alaska. Aleutian skate is the most common *Bathyraja* skate species in the GOA, and is dominant in deeper strata.
AI biomass comes from AI bottom trawl survey estimates for 1991 and 1994. The estimates are a combined average of direct biomass estimates and the corresponding proportion of AK skates from the total biomass for "unidentified skates". Bycatch estimates were cut in half

because the biomass of skates has doubled from 1991-1994 to 1997-2000. Thus we considered the bycatch extrapolated from 1997-2000 to be too high. The reduction by half reflects the fact that the biomass of skates was half at the time.

Frisk et al. (2001) estimated that on average, medium sized (100-199 cm) elasmobranchs have a potential rate of population increase around 0.21. This was used as a proxy for Z or P/B = 0.20 for a population at equilibrium. A growth efficiency intermediate between sharks and large teleost predators (arrowtooth and halibut) seemed a reasonable assumption for skates; a GE of 0.1 was assumed, which led to a Q/B estimate of 2.0 for all skate species
AI diet composition was estimated from less than 5 stomachs collected in 1994 and 1997during the AI bottom trawl survey. Biomass pedigree was considered 3: while surveys sampled the species, their deeper distribution had limited coverage by the surveys. PB and QB were considered 7 (general literature review from range of species). Diet was considered 4 (direct sampling but with low sample size).

Whiteblotched skate (*Bathyraja maculata*). The center of this species' abundance is in the AI. In the GOA, the maximum observed size of the whiteblotched skate is 121 cm (Gaichas et al. 2003). Using an empirical regression method (Frisk et al. 2001), length at maturity would be about 86 cm based on that maximum size.
AI biomass comes from bottom trawl survey estimates for 1991 and 1994. The estimates are a combined average of direct biomass estimates and the corresponding proportion of AK skates from the total biomass for "unidentified skates". Bycatch estimates were cut in half because the biomass of skates has doubled from 1991-1994 to 1997-2000. Thus we considered the bycatch extrapolated from 1997-2000 to be too high. The reduction by half reflects the fact that the biomass of skates was half at the time.

Frisk et al. (2001) estimated that on average, medium sized (100-199 cm) elasmobranchs have a potential rate of population increase around 0.21. This was used as a proxy for Z or P/B = 0.20 for a population at equilibrium. A growth efficiency intermediate between sharks and large teleost predators (arrowtooth and halibut) seemed a reasonable assumption for skates; a GE of 0.1 was assumed, which led to a Q/B estimate of 2.0 for all skate species
AI diet composition based on 30 stomachs collected during the 1994 abd 1997 AI bottom trawl surveys.
Biomass pedigree for all regions was considered 3: while surveys sampled the species, their deeper distribution had limited coverage by the surveys. PB and QB were considered 7 (general literature review from range of species). AI diets were considered 4 (direct sampling with low sample size).

Mud skate (Bathyraja taranetzi) AI biomass comes from AI bottom trawl survey estimates for 1991 and 1994. The estimates are a combined average of direct biomass estimates and the corresponding proportion of AK skates from the total biomass for "unidentified skates". Bycatch estimates were cut in half because the biomass of skates has doubled from 1991-94 to 97-00. Thus we considered the bycatch extrapolated from 1997-2000 to be too high. The reduction by half reflects the fact that the biomass of skates was half at the time.

Frisk et al. (2001) estimated that on average, medium sized (100-199 cm) elasmobranchs have a potential rate of population increase around 0.21. This was used as a proxy for Z or P/B = 0.20 for a population at equilibrium. A growth efficiency intermediate between sharks and large teleost predators (arrowtooth and halibut) seemed a reasonable assumption for skates; a GE of 0.1 was assumed, which led to a Q/B estimate of 2.0 for all skate species

Diet composition was estimated from 5 stomachs collected 1994 as part of the AI bottom trawl surveys.
Biomass pedigree was considered 3: while surveys sampled the species, their deeper distribution had limited coverage by the surveys. PB and QB were considered 7 (general literature review from range of species). AI diets were considered 4 (direct sampling with low sample size).

Bering skate (*Bathyraja interrupta*) Bering skates are rare in the AI and were assumed to have a biomass of 0 in this model.

Frisk et al. (2001) estimated that on average, medium sized (100-199 cm) elasmobranchs have a potential rate of population increase around 0.21. This was used as a proxy for Z or P/B = 0.20 for a population at equilibrium. A growth efficiency intermediate between sharks and large teleost predators (arrowtooth and halibut) seemed a reasonable assumption for skates; a GE of 0.1 was assumed, which led to a Q/B estimate of 2.0 for all skate species

The diet composition was derived from one stomach collected in the Eastern Aleutians during the 1995 bottom trawl survey for AI. Biomass pedigree was considered 3: while surveys sampled the species, their deeper distribution had limited coverage by the surveys. PB and QB were considered 7 (general literature review from range of species). Diet for AI was considered 4 (direct sampling but with low sample size).

Big skate (*Raja binoculata*) is dominant skate in the GOA in terms of biomass. It is a rare visitor to the EBS and AI. The big skate is the largest skate in the Gulf of Alaska, with maximum sizes observed over 200 cm in the directed fishery, and 192 cm on the survey (Gaichas et al. 2003). Using an empirical regression method (Frisk et al. 2001), length at maturity would be about 137 cm based on that maximum size. At present, there is no age and growth information for any skate species in Alaska. However, vertebrae were collected from the Gulf of Alaska in 2003 from commercial fisheries and during ADF&G and NMFS trawl surveys. Until these collections are processed, the only age and growth information available is from a study completed off the U.S. West Coast which was limited to a size range of skates smaller than that observed off British Columbia (King and McFarlane 2002) or in Alaska. According to that study, Californian female big skates mature at 12 years (1.3-1.4m), and males mature at 7-8 years (1-1.1 m), but the maximum sizes estimated were only 170 cm for females and 140 cm for males (Zeiner and Wolf 1993). Maximum size from fisheries off California is reported to be 2.4 m, with 1.8m and 90 kg common (Martin and Zorzi 1993). Information on fecundity in North Pacific skate species is extremely limited. There are one to seven embryos per egg case in locally occurring *Raja* species (Eschmeyer et al. 1983), but little is known about frequency of breeding or egg deposition for any of the local species.
In the AI, no biomass was considered to be present in the models.

Frisk et al. (2001) estimated that on average, medium sized (100-199 cm) elasmobranchs have a potential rate of population increase around 0.21. This was used as a proxy for Z or P/B = 0.20 for a population at equilibrium. A growth efficiency intermediate between sharks and large teleost predators (arrowtooth and halibut) seemed a reasonable assumption for skates; a GE of 0.1 was assumed, which led to a Q/B estimate of 2.0 for all skate species
Food habits data from fewer than 3 skates was used to calculate the EBS feeding habits. Food habits information specific to GOA skates is currently lacking. Diet preference for big skates was based on information from the U.S. west coast collected in the early 1980s (Wakefield 1984), with the modification that Dungeness crab in the west coast diet was replaced with equal parts sandlance and eelpouts to reflect qualitative personal observations from the 2003 NMFS GOA trawl survey.
Biomass pedigree for all regions was considered 3: while surveys sampled the species, their deeper distribution had limited coverage by the surveys. PB and QB were considered 7 (general literature review from range of species). Diet for EBS and AI were considered 5 (direct sampling but with extremely low sample size) while GOA diet were considered 6 (measured from same species, but in Russian waters).

Black Skates were included for comparison purposes to the NCC model, but they are not really found in Alaskan waters. This group will probably be omitted in future model updates.

Longnosed skate (*Raja rhina*) is one of the most abundant skates in the GOA, and second only to big skates (see below) in terms of biomass. Longnosed skates were rare in the AI and thus considered to have a biomass of 0 in both of these models.

In terms of maximum adult size, the *Raja* species are larger than the *Bathyraja* species found in the area. Observed sizes for the longnose skate, *Raja rhina*, are second largest in the GOA at about 165-170 cm (Gaichas et al. 2003). Using an empirical regression method (Frisk et al. 2001), length at maturity would be about 119 cm based on that maximum size. At present, there is no age and growth information for any skate species in Alaska. The longnose skate, *Raja rhina*, achieves a smaller maximum length of about 1.4 m in California, and matures between ages 6 (males) and 9 (females). Maximum age reported for the longnose skate was 13 years, but again the maximum estimated size seemed small at 107 cm for females and 95 cm for males (Zeiner and Wolf 1993). Information on fecundity in North Pacific skate species is extremely limited. There are one to seven embryos per egg case in locally occurring *Raja* species (Eschmeyer et al. 1983), but little is known about frequency of breeding or egg deposition for any of the local species.

Frisk et al. (2001) estimated that on average, medium sized (100-199 cm) elasmobranchs have a potential rate of population increase around 0.21. This was used as a proxy for Z or P/B = 0.20 for a population at equilibrium. A growth efficiency intermediate between sharks and large teleost predators (arrowtooth and halibut) seemed a reasonable assumption for skates; a GE of 0.1 was assumed, which led to a Q/B estimate of 2.0 for all skate species
Diet preference for longnose skates was based on information from the U.S. west coast collected in the early 1980s (Wakefield 1984).

Biomass pedigree was considered 3: while surveys sampled the species, their deeper distribution had limited coverage by the surveys. PB and QB were considered 7 (general literature review from range of species). Diets were considered 6 (sampling of same species in different area).

Fish

Pacific cod (*Gadus macrocephalus*) commonly reach lengths over 1 m and live up to 18 years, with females maturing between ages 5-7 and about 60-70 cm. Pacific cod are distributed throughout Bering Sea and the Aleutian Islands, from shoreline down to 500 m depth; they are managed as a single unit. (Thompson et al. 2003). Weight measurements taken since 1975 give an estimate of 15 kg. of maximum weight, and an average length at age 12 of 89 cm; 50 % of the population reaches maturity at 60-64 cm, with most of the population (94%) mature at lengths 80-85 cm. This group was modeled as two functional groups (juveniles and adults). The split between juveniles and adults was taken to be age 1, which was assumed to correspond to 20cm for calculating diets

Adults In the AI adult biomass is the average of 1991 and 1994 AI biomass estimates from the AI bottom trawl survey. The biomass was proportioned across the subareas according to survey estimates in each one.
The P/B and Q/B ratios of 0.41 and 2.28 were estimated using the age structure for 1991 (**need to check year w/ Kerim**) in the BSAI cod stock assessment (Thompson and Dorn 2003), and weight at age data collected on NMFS bottom trawl surveys for the EBS. Diet composition in the AI comes from stomachs collected in 1991 and 1994 as part of the bottom trawl surveys. Pedigree

Juveniles Juvenile were defined as fish less than 20 cm in length, which roughly corresponds to 0 and 1 year old fish. Biomass in the AI was estimated based on an EE of 0.8. The P/B in the AI was estimated using the same method and data as that for the adults.Likewise for the AI, which resulted in a Q/B of 5.58. Diet composition was estimated from food habits collections made during 1991 and 1994 as part of the bottom trawl surveys.

Walleye pollock (*Theragra chalcogramma*) are in the family Gadidae, and they display relatively high fecundity and rapid growth Pollock may reach maximum lengths of up to 1m and ages of 17 years, with fish maturing between 3-6 years and at 40+ cm (Dorn et al. 2003). Pollock are a schooling species distributed throughout the water column, and bottom trawl surveys might underestimate biomass. Due to the importance of juvenile pollock as a forage fish, this species was modeled as two functional groups (juveniles and adults). The split between juveniles and adults was taken to be age 2, which was assumed to correspond to 20cm for calculating diets.

Adults AI adult biomass is the average of 1991 to 1994 AI stock assessment biomass estimates for Age 3+ (Barbeaux et al 2003). Biomass was proportioned according to the percent in trawl survey biomass for each subarea. The biomass estimated from the trawl survey was not only about one third that of the stock assessment, it also has an opposite trend. So while the stock assessment estimates an increase in biomass between 1991 and 1994, the

survey estimates show a decline of about 40% between 1991 and 1994. Trawl surveys are limited to within the 500 m isobath, thus they exclude midwater pollock and pollock located offshore from the 500m isobath. This renders the estimates as an unknown proportion of the total biomass subject to annual variability in depth distribution, age composition, and others. The AI adult P/B ratio of 0.37 was derived from the estimated age structure for 1991 in the AI stock assessment. The Q/B of 4.4 was estimated using the generalized Von Bertalanffy growth function (Essington et al. 2001) fit to weight at age data from the AI and scaled to the 1991 age structure from the stock assessment. The diet composition was estimated from stomachs collected during the 1991 and 1994 bottom trawl surveys for the AI.
Pedigree for the biomass estimate is 3, 5 for the PB and QB, 1 for the diet, the NMFS fisheries data and 2 for the data quality of the indigenous fishery.

Juveniles Juvenile were defined as fish less than 20 cm in length, which roughly corresponds to 0 and 1 year old fish. With an initial estimate of juvenile P/B, the biomass was estimated by assuming that EE was .8 for the group. The same method described above for adults was used, resulting in an estimated ratio for P/B of 1.97 and a Q/B of 6.96. Diet composition for the AI was also estimated from stomachs collected during the 1991 and 1994 bottom trawl surveys.

The pedigree for the biomass estimate is 8 (top down balance), the PB and QB have a pedigree of 6 (based on Von Bertalanffy model); diet and fisheries data both come regularly maintained databases so their pedigree is 1. The pedigree for the data from the indigenous fisheries is 2.

Arrowtooth flounder (*Atherestes stomias*) are relatively large, piscivorous flatfish that inhabits continental shelf waters primarily until age 4, afterwards they are found both in the continental shelf and slope. They exhibit differential growth by sex; the slope survey in 1991 showed females 12 years old reached a maximum size of 85 cm and 9 year old males grow to 58 cm (Zimmermann and Goddard 1995); in the Gulf of Alaska individuals have been found of up to 23 years old. Females reach 50% maturity at 47 cm in the GOA, and display exponentially increasing fecundity with length, with large females producing over 2 million eggs annually (Zimmerman 1997). Arrowtooth from the AI are managed jointly with those from the EBS as a single stock (Wilderbuer and Sample 2003). The group was split in juveniles and adults to better represent their trophic relationships within the ecosystem.

Adults In the AI, the biomass is the average of 1991 and 1994 AI biomass estimates from the AI bottom trawl survey; it was proportioned across the subareas according to survey estimates in each one. Values for the AI P/B and Q/B ratios of 0.297 and 2.61 were estimated using the age structure for 1991 in the BSAI stock assessment for arrowtooth/ kamchatka flounder (Wilderbuer and Sample 2003), and weight at age data collected on NMFS bottom trawl surveys for the Gulf of Alaska. Diet composition w for the AI was based on stomachs collected in the AI during 1991 and 1994 as part of NMFS bottom trawl surveys. Pedigree for the biomass estimate is 2 (survey), for PB and QB is 5, Diet composition is 1 (based on feeding habits database), NMFS fishery data has a pedigree of one and the indigenous fisheries a pedigree of 2.

Juveniles were defined as fish less than 20 cm in length, which roughly corresponds to 0 through 2 year old fish. Biomass is based on an EE 0f 0.8. The juvenile P/B and Q/B were estimated using the same method as that described above for adults, resulting in 1.01 and 3.77. The diet composition was based on stomachs collected in the AI during 1991 and 1994 as part of NMFS bottom trawl surveys. Pedigree of the biomass estimate is 8 (top down balanced), PB and QB have a pedigree of 6, fisheries data and diet composition have a pedigree of 1 and the indigenous fishery a pedigree nof 2.

Kamchatka flounder (*Atheresthes evermanni*) is very similar in appearance to arrowtooth flounder they are typically not separated in commercial catches. The group was split into juveniles and adults

Adults Biomass is the average of 1991 and 1994 AI biomass estimates from the AI bottom trawl survey. The biomass was proportioned across the subareas according to survey estimates in each one. The P/B and Q/B ratios of 0.297 and 2.61 were estimated using the age structure for 1991 in the BSAI stock assessment for arrowtooth/ kamchatka flounder (Wilderbuer and Sample 2003), and weight at age data collected on NMFS bottom trawl surveys for the Gulf of Alaska. The diet composition was based on stomachs collects in the AI during 1991 and 1994 as part of NMFS bottom trawl surveys. Pedigree of biomass is 3, PB and QB have a pedigree of 5, the diet and NMFS fisheries data a pedigree of 2 and the indigenous fishery a data quality ranked 2.

Juvenile Juveniles are fish up to 20 cm which corresponds approximately to ages 0 to 2. The estimated biomass is based on an EE 0f 0.8. The juvenile P/B and Q/B ratios were estimated using the data and methods described above, the values were 1.01 and 3.77 respectively. No Kamchatka flounder juveniles were sampled for stomach contents; the diet composition was assumed to be the same as that of arrowtooth flounder juveniles sampled in the AI during 1991 and 1994 as part of NMFS bottom trawl surveys.

Greenland turbot (*Reinhardtius hippoglossoides*), also known as Greenland halibut, can be found as adults in the continental slope, having spent the first 3-4 years of their life in the continental shelf. Individuals taken from the commercial fishery have been aged as old as 21 years. Females reach 50% maturity at 60 cm (about 9 years old) and egg production varies from 60,000 to 80,000 eggs; spawning occurs in October through December (Witherell 2000). The group was split into juveniles and adults.

Adults Biomass estimates for the 1991 and 1994 bottom trawl surveys were averaged to obtain an AI biomass input. The biomass was proportioned across the subareas according to survey estimates in each one. The P/B and Q/B ratios, 0.18 and 1.16 respectively, were assumed to be the same as those estimated using the 1991 **(need to check year with Kerim)** stock assessment age structure for the arrowtooth flounder in the BSAI region and weight at age data for arrowtooth flounder in the EBS. These values were chosen to maintain consistency among the ecosystem models for the Alaska regions when there were no data available. Alternatively, one could use the values estimated for the arrowtooth flounder in the AI. The values for the AI arrowtooth flounder are higher, and the Greenland turbot estimates were chosen to keep more conservative values, given the turbot's lower abundance in the AI. The diet composition was based on stomachs collected in the AI during 1991 and 1994 as part of the bottom trawl surveys. Pedigree for the biomass is 2, for PB and QB 5, 1 for the NMFS fisheries and diet composition (from AFSC regularly managed databasees) and 2 for the data on the indigenous fishery.

Juveniles are fish no longer than 20 cm which corresponds approximately to fish ages 0 to 2. Juveniles are absent in the AI and it is thought the population originates from EBS or some other area . Rather than estimating biomass assuming an EE of 0.8, a biomass of 1 ton was assumed in each area, giving a total biomass of 9 tons [assuming a value of 0.8 for the EE gives a biomass estimate of less than 0.3 tons.] to lower the number of biommass estimates based on EE. P/B and Q/B ratios were estimated using the data and methods described above, the values were 1.58 and 3.31 respectively. No Greenland turbot juveniles were sampled in the AI for stomach contents; the diet composition was assumed to be the same as that of arrowtooth flounder juveniles sampled in the AI during 1991 and 1994 as part of NMFS bottom trawl surveys.

Pacific halibut (*Hippoglossus stenolepis*) is a flounder belonging to the family Pleuronectidae, they are the largest of all flatfish, up to 250 cm and weighing 227 kg. Females grow faster but mature slower than males; these last are mature by eight years old, whereas the average age of maturity for females is about 12 years. The eggs are usually found at depths between 90 to 183 m, but occur as deep as 450 meters; gradually moving towards the surface and shallower waters in the continental shelf. The postlarvae are transported by the Alaskan Stream in the Gulf of Alaska and westward along the Alaska peninsula and the Aleutian Islands, some into the Bering Sea. Halibut are demersal, living on or near the bottom in waters from 3 to 8°C. They have been caught as deep as 549 m, but are more commonly found 27 and 274 m. deep. Although halibut ocassionally migrate large distances, adults tend to return to the same feeding grounds each year (IPHC 1998)[xcv].

Adults in the AI adult biomass is the average of 1991 and 1994 biomass estimates from the AI bottom trawl survey. The biomass was proportioned across the subareas according to survey estimates in each one. The P/B ratio of 0.19 and Q/B ratio of 1.1 were estimated from the 1990-1993 age structure in the halibut stock assessment for IPHC Area 3A (Clark and Hare 2003) and weight at age data collected on IPHC longline surveys (and summarized on the IPHC website[xcvi]. Weight at age of Pacific halibut has varied significantly over time (Clark et al. 1999), hence only data from the early 1990s surveys was used to estimate the parameters for this model. The diet composition for the AI was estimated from stomachs collected during the 1991 and 1994 bottom trawl surveys for the AI. Pedigree for the biomass is 2 (from survey), both QB and PB have a pedigree of 5, the diet composition is 1 (from AFSC databse), NMFS fishery data has a pedigree of 2 (from IPHC), and so does the indigenous fishery.

Juvenile were defined as fish less than 20 cm in length, which roughly corresponds to 0 and 1 year old fish. No data was available to estimate AI specific values of PB and QB, so data for the Gulf of Alaska was used. An initial estimate of 0.5 for juvenile mortality (comparable to MSVPA estimates for the EBS (Jurado-Molina 2002)) was used to estimate the P/B ratio which resulted in 0.38 for 1990-1993 based on stock assessment age structure. Thise values were also used to estimate juvenile biomass given the numbers and weight at age estimated for those years. The same method estimated a Q/B of 1.42. Diet composition was estimated from food habits collections made during the 1990 and 1993 bottom trawl surveys of the GOA as no juvenile stomachs were available from the AI.

Small flatfish

[xcvi] http://www.iphc.washington.edu/halcom/research/sa/sa.html

In general are not very abundant in the AI. Stocks are managed jointly with the Eastern Bering Sea where the center of their abundances is. Whenever species specific data was unavailable, the P/B ratio of 0.2 and Q/B ratio of 2.0 were adapted from those estimated for the only small flatfish in the GOA with age structured stock assessment information, the Flathead sole. This P/B and Q/B values were assumed to be representative across Alaskan ecosystem models (AI, GOA, and EBS), of general small flatfish

Alaska plaice (*Pleuronectes quadrituberculatus*) are found mostly in the Western and Central GOA, but their center of abundance is in the continental shelf of the EBS with only a minor portion in the AI. It is not really distributed in the AI. In the EBS, plaice reach sizes of 46 cm and ages of over 22 years, with maturity estimated to occur at ages 8-9. Summer distribution moves to shallower waters (< 110 m deep); larger fish predominately in deep waters and smaller juveniles (<20 cm) in shallow coastal waters (Zhang et al. 1998). Though this species distribution overlaps with that of rock sole (*Lepidopsetta bilineata*) and yellowfin sole (*Limanda aspera*), the center of the distribution is north of these two species (Spencer et al. 2004). This species is not reported as bycatch from the fisheries in the AI, the group was kept for comparison purposes with the EBS.
AI value for biomass was estimated assuming an EE 0.8; though no biomass estimate is available, Alaska plaice is a prey item in the diets of several marine mammals, and sharks but mostly of adult yellowfin sole. The P/B ratio of 0.2 and Q/B ratio of 2.0 were adapted from GOA Flathead sole. Diet composition information was unavailable for GOA and AI Alaska plaice, so food habits collections made during the 1990-1993 EBS bottom trawl surveys were substituted. Pedigree for the biomass estimate is 8 (from survey), QB and PB have a pedigree of 6, diet composition is 5 (from other system), NMFS fishery data is ranked 1 and indigenous fishery has a pedigree of 2.

Dover sole (*Microstomus pacificus*) are medium sized flatfish which grow to over 60 cm and 54 years (Turnock and Amar 2004a), maturing 44 cm and 12-13 years of age (Abookire and Macewicz 2003).

AI biomass is the average of the 1991 and 1994 AI bottom trawl survey estimates
The P/B ratio of 0.2 and Q/B ratio of 2.0 were adapted from GOA Flathead sole. However, a stock assessment is in development for GOA Dover sole which may allow improvements in these parameters. Diet composition in the AI was assumed to be the average stomach content from samples collected in the GOA west shelf, gully, and slope subareas during 1990 and 1993 GOA bottom trawl surveys. Pedigree for the biomass estimate is 2 (from survey), QB and PB have a pedigree of 6, diet composition is 5 (from other system), NMFS fishery data is ranked 1 and indigenous fishery has a pedigree of 2.

Flathead sole (*Hippoglossoides elassodon*) grow to a size of 45 cm and a maximum age of 25 years, maturing at 27 cm or age 8. Growth in the GOA is somewhat faster than in the EBS (Turnock et al. 2003c).

Adult biomass was based on estimates from the AI bottom trawl surveys for 1991 and 1994. Flathead sole is managed as one stock for the joint BSAI region so in the AI the Q/B ratio was assumed to be the same as in the EBS, 1.97; the P/B was assumed slightly lower at 0.20, as the biomass is less than 1% of that in the EBS. AI diets were estimated from stomachs collected during AI bottom trawl surveys for 1994 (**check years, are the 80's surveys included here? Stomachs were collected in 1984 and 1986.** The biomass estimates are from the survey, so pedigree is 2, PB and QB estimates are ranked 5, diet and fisheries data is 1 (from regularly maintained databases, system specific), and the indigenous fishery has a pedigree of 2.

Juveniles were defined as fish less than 20 cm in length, which roughly corresponds to 0 through 2 year old fish. In the AI the biomass was estimated assuming all subareas had 1 (one) ton; therefore the total biomass was 9 ton. P/B and Q/B ratios were assumed to be the same as in the EBS 0.93 and 3.13 respectively. AI diets were estimated from stomachs collected during AI bottom trawl surveys for 1994. (**check years, are the 80's surveys included here?**

Miscellaneous flatfish is a composite group containing all remaining small flatfish species. In the AI, it includes butter sole (*Isopsetta isolepis*), starry flounder (*Platichthys stellatus*) and English sole (*Parophrys vetulus*).

In the AI biomass estimates from the AI bottom trawl surveys were only available for English sole in 1994 (~1.9 tons). This biomass was not enough to satisfy the consumption of miscellaneous flatfish within the ecosystem and was therefore an EE of 0.8 was used to estimate the final biomass in the model
The P/B ratio of 0.2 and Q/B ratio of 2.0 were adapted from GOA Flathead sole. Miscellaneous flatfish diet composition in the GOA was estimated from food habits collections made during the 1990 and 1993 bottom trawl surveys of the GOA Diet composition in the AI was assumed to be the same as GOA. Pedigree for the biomass is 8 (top-down balanced), PB and QB are 6, the diet composition is 5 and both fisheries data is 2.

Northern rock sole (*Lepidopsetta polyxystra*) are distributed primarily on the southeastern Bering Sea continental shelf and in much lesser amounts in the Aleutian Islands region. This species overlaps with the southern rock sole in the Gulf of Alaska, but the northern species dominates the Bering Sea and Aleutian Islands populations where they are managed as a single stock. The adults are benthic and, in the eastern Bering Sea, occupy separate winter (spawning) and summertime feeding distributions on the continental shelf (Wilderbuer and Walters 2003). There are no sihnificant differences between males and females, Northern rock sole grows to about 43 cm in the GOA and lives over 20 years, maturing at 33 cm and 7 years of age (Turnock et al. 2003b).

Prior to 1997, northern & southern rock sole AI biomass was estimated as "general rock sole" in the bottom trawl surveys. Starting 1997 onwards, the two species have been addressed separately. The average proportion of northern to southern rock sole in 1997 and 2000 was used to proportion the biomass of 1991 and 1994 of "general rock sole" biomass. According to these data, 99% of the rock sole biomass corresponds to northerns. Values for the P/B and Q/B ratios were estimated by fitting a von Bertalanffy growth function to data from the 1991 age structure in the BSAI stock assessment, and weight at age data from the AI. The P/B and Q/B values are 0.25 and 1.70, respectively. Northern rock sole diet composition was estimated from food habits collections made during the 1990 and 1993 bottom trawl surveys of the GOA.The AI diet composition was an average from GOA subareas west shelf, gully, and slope. Pedigree is 3 for the biomass estimate, 5 for the QB, PB and diet composition, 2 for the fisheries informmation.

Southern rock sole (*Lepidopsetta bilineata*) reach a slightly larger maximum length, 52 cm, and matures at 35 cm or 9 years old (Turnock et al. 2003b). Southern rock sole are a minor portion of the rock sole population in the Bering Sea-Aleutian Islands area and are managed jointly as one stock. Prior to 1997, northern & southern rock sole AI biomass was estimated as "general rock sole" in the bottom trawl surveys. Starting 1997 onwards, the two species have been addressed separately. The average proportion of northern to southern rock sole in 1997 and 2000 was used to proportion the biomass of 1991 and 1994 of "general rock sole" biomass. The biomass for southern rock sole is much lower, ~ 1% that of northerns.

AI values for the P/B and Q/B ratios were estimated by fitting a von Bertalanffy growth function to data from the 1991 age structure in the BSAI stock assessment, and weight at age data from the AI. The P/B and Q/B values are 0.25 and 1.70, respectively. Southern rock sole diet composition was estimated from food habits collections made during the 1990 and 1993 bottom trawl surveys of the GOA.The diet composition was an average from GOA subareas west shelf, gully, and slope. Pedigree for the biomass is 3, 6 for QB and PB estimates, 5 for the diet composition and 2 for the fisheries data.

Rex sole (*Glyptoephalus zachirus*) are medium sized flatfish reaching sizes exceeding 45 cm and a maximum age of 27 years. Size and age at maturity are still being studied, but may be 35 cm and 5-6 years (Turnock and Amar 2004b).

AI biomass was estimated assuming an EE.8 for balancing purposes; the average of 1991-1994 biomass estimates from the AI bottom trawl surveys was not enough to satisfy assumed consumption within the ecosystem. The P/B ratio of 0.2 and Q/B ratio of 2.0 were adapted from GOA Flathead sole. However, an age structured stock assessment is in development for GOA rex sole which may allow improvements in these parameters. The AI diet composition was assumed to be the average stomach content from samples collected in the GOA west shelf, gully, and slope subareas during 1990 and 1993 GOA bottom trawl surveys. Pedigree of the biomas estimate is 8 (top down balanced), 6 for PB and QB estimates, 5 for the diet composition, 1 for the NMFS fishery data and 2 for the indigenous fishery.

Yellowfin sole (*Limanda aspera*) are managed as one stock covering the EBS and AI, primarily the EBS. Rarely caught on surveys in the AI, they are part of the bycatch of fisheries. Yellowfin sole migrate annualy from shelf-slope break areas where they spend the winter, to nearshore waters where they spawn during spring and summer. Based on data from 1979 to 1990, the maximum length and weight have been estimated at 35 cm and 508 grams, respectively. Fifty percent of the female population is mature by the time they are 11 years old, and they live over 26 years (Wilderbuer and Nichol 2004). Yellowfin juvenile and adult groups were kept in model for comparison purposes with the EBS.

Adult biomass was estimated by assuming an EE of 0.8. Biomass estimates based on the AI bottom trawl surveys are only available for those strata north of Umak and Unalaska (which fall within the EBS model). In the rest of the Aleutians, biomass is estimated as "zero", and considered negligible for stock assessment purposes. However, yellowfin sole is reported as bycatch in several fisheries in the AI; particularly those trawling for "other groundfish". It was therefore assumed that yellowfin biomass was too low to be sampled adequately by the survey. The P/B and Q/B ratios were assumed to be the same as those estimated for the Eastern Bering Sea stock, 0.174 and 0.93 respectively. AI diets were estimated from stomachs collected in the EBS during surveys in 1991 **(check years of survey with Kerim. AI diets was the sum of all partial diets in the EBS)**. Pedigree is 8 for the biomass estimate (top-down balanced), 5 for the PB and QB estimates as well as for the diet composition; 1 for the NMFS fishera data and 2 for the indigenous fishery.

Juveniles were kept to maintain the same structure as in the EBS model, where the data for the AI was taken from. Juveniles are part of the diets for some marine mammals and sharks – albeit these diets are based on literature reviews. The ratios for P/B and Q/B are the same as those estimated for the EBS, 0.6 and 1.74 respectively. Diet composition was assumed to be the same as in the EBS.

Rockfish

Whenever site specific data was not available for to estimate values for PB and/ or QB, the values etsimated for POP in the GOA were used as a default. The P/B ratio of 0.09 and Q/B ratio of 1.99 were estimated from the 1990-1993 age structure in the POP stock assessment (Hanselman et al. 2003) and weight at age data collected on NMFS bottom trawl surveys. In the EBS, these estimates (P/B and Q/B are 0.21 and 1.8, respectively) are less conservative, hence the ones for the GOA were preferred for general reference.

Dusky rockfish (*Sebastes ciliatus* and *S. variabilis*) were considered one species in the early 1990s so the aggregate biomass is reported here. Light dusky rockfish (still called *Sebastes ciliatus*) are most common in the habitats sampled by the trawl survey, while Dark dusky rockfish (*Sebastes variabilis*) are more common in shallower nearshore areas (Orr and Blackburn 2004). Little is known about the life history dark duskies; light duskies grow to a maximum size of 53 cm, a similar size to POP (Orr et al. 1998), and a maximum age of 59 (Clausen et al. 2003b).

AI biomass was the average of the 1991 and 1994 bottom trawl survey estimates for the AI, increased in a minimal amount just to bring it into balance (EE was 1.005). This adjustment still falls well within the range given for the original estimate. Based on the bottom trawl surveys, the highest biomass is located in the central Aleutians. A P/B of 0.10 and a Q/B of 2.0 were applied based on the values calculated for adult POP in the GOA. Diet composition in the AI was based on stomachs collected as part of the AI bottom trawl surveys. Pedigree for the biomass is 2 (from survey with good catchability), 6 for the PB and QB estimates, 2 for the diet from the AFSC database and 1 for the NMFS fishera data and 2 for the indigenous fishery.

Northern rockfish (*Sebastes polyspinis*) grow to a maximum size of 40 cm, a similar size as POP (Orr et al. 1998), and reach a maximum age of 67 years (Courtney et al. 2003).
AI biomass was the average of the 1991 and 1994 bottom trawl survey estimates for the AI. The values for P/B and Q/B were 0.1 and 2.0 were applied based on the values calculated for adult POP in the GOA. These same values respectively. The diet composition in the AI was based on stomachs collected during btoom trawl surveys in the AI for 1991 and 1994. pedigree for the biomass estimate is 2 (from survey), QB and PB have a pedigree of 6, diet a pedigree of 2 (from database, from the AI), 2 for the NMFS fishera data and 2 for the indigenous fishery.

Other *Sebastes* is a composite group containing the remaining rockfish (*Sebastes*) species found in the Alaska. The complex varies is dominated by harlequin (*S. variegatus*), and redbanded (*S. babcocki*). The first in particular has been observed as bycatch in commercial fisheries.
Biomass was estimated assuming an EE of 0.8 because although this is a composite group, the only biomass estimate available was for harlequin and redbanded rockfish (*Sebastes variegates* and *S. babcocki*, respectivelt) at 19 tons, which was insuffiecient to satisfy consumption within the ecosystem. Values for P/B of 0.10 and a Q/B of 2.0 were applied based on adult POP in the GOA. No stomachs from the AI are available for any of the *Sebastes* species included in this group, therefore diet composition was estimated from stomachs collected in the western GOA as part of the GOA bottom trawl surveys. The biomass pedigree is 8 (top down balanced), 6 for the QB and PB, 5 for the diet and 2 for the NMFS and indigenous fishery data.
pedigree

Pacific Ocean perch, POP, (*Sebastes alutus*) are schooling fish which have historically been the most abundant rockfish in this region and constitute the primary commercial rockfish species. During the 1960's this species supported a major trawl fishery, as Japanese and Societ fisheries actively sought POP; the catch in the AI peaked at 109,100 t. in 1965. POP inhabits the outer continental shelf and the upper slope region. They are relatively small fish but long-lived fish, reaching 40 cm and 90 years of age (Spencer and Ianelli 2003). The stock is managed as a unit with the EBS, though catches are higher in the AI and historically, higher abundances have been estimated in the western and central Aleutians.

AI biomass estimate comes from the average of the 1991 and 1994 AI bottom trawl surveys. The P/B and Q/B ratios in the AI were estimated by fitting a von Bertalanffy growth function to data from the 1991 age structure in the BSAI stock assessment, and weight at age data from the AI. The P/B and Q/B values are 0.21 and 1.8, respectively. Diet composition was based on stomachs collected in AI bottom trawl surveys during 1991 and 1994. Pedigree of the POP biomass estimate is 2, 3 for the PB and QB estimate and 1 for the diet composition; 1 for the NMFS fishera data and 2 for the indigenous fishery.

Rougheye rockfish (*Sebastes aleutianus*) are thought to be composed of two separate species which are only distinguishable genetically. Like shortrakers, rougheye rockfish achieve a large maximum size (97 cm) and very old age, but age is difficult to determine with estimates varying from 95 to 205 years of age (Clausen et al. 2003a). Within the AI rougheyes are found mostly within the deep strata (200-500m) during bottom trawl surveys (where surveys only go as deep as 500 m).

AI biomass was the average of the 1991 and 1994 bottom trawl survey estimates for the AI, increased in a minimal amount just to bring it into balance (EE was 1.008). Specific PB and QB rtes could not be calculated for rougheyes; instead values calculated for adult POP in the GOA were used. Diet composition was estimated from food habits collections made during bottom trawl surveys in the AI. Pedigree for the biomass estimat is 2, 6 for the QB and PB estimates, 2 for the diet, NMFS fishery data and indigenous fishery data.

Sharpchin rockfish (*Sebastes zacentrus*) live over 58 years and reach a maximum size of 39 cm, a similar size to that of POP (Clausen et al. 2003a, Orr et al. 1998). In the AI, the only biomass estimate available was from the eastern Aleutians (0.65 tons) and was insufficient to satisfy the consumption within the ecosystem. Therefore an EE of 0.8 was assumed to estimate the biomass. The PB and QB values were assumed to be 0.1 and 2.0 respectively, a modification of GOA adult POP estimates. No stomachs were available from either the AI or the western GOA, so the diet composition was assumed to be an average of all rockfish diets (except POP) based on stomachs collected in the AI during bottom trawl surveys. This rationale is the same as in the EBS model. Pedigree for the biomass estimat is 8, 6 for the QB and PB estimates, 5 for the diet, and 2 for the NMFS fishery data and indigenous fishery data.

Shortraker rockfish (*Sebastes borealis*) are among the largest rockfish in the Aleutians, growing to a size of 108 cm (Orr et al. 1998). Ageing is uncertain, however it is recognized they are longlived with maximum age estimates varying from 120-157 years (Clausen et al. 2003a). Within the AI they are found mostly within the deep strata (200-500m) during bottom trawl surveys (where surveys only go as deep as 500m). Biomass was the average of the 1991 and 1994 bottom trawl survey estimates for the AI. Values for P/B of 0.10 and a Q/B of 2.0 calculated for adult POP in the GOA were applied due to lack of more specific data on energetics. The feeding habits were based on stomachs collected in the Aleutian Islands during the bottom trawl surveys for 1991 and 1994. Pedigree for the biomass estimat is 2, 6 for the QB and PB estimates, 2 for the diet, NMFS fishery data and indigenous fishery data.

Shortspine thornyhead (*Sebastolobus alascanus*) reach maximum sizes of 77 cm and mature at 22 cm; maximum age ranges from a low of 62 years to highs over 150-200 years depending on methodology (Gaichas et al. 2003). Within the AI they are found mostly within the deep strata (200-500m) during bottom trawl surveys (where surveys only go as deep as 500m). AI biomass was the average of the 1991 and 1994 bottom trawl survey estimates for the AI. The production and consumption values in the AI wer rounded off from those estimated for juveniles and adults in the GOA (P/B 0.13 and Q/B 0.44 for adults; P/B of 0.21 and Q/B of 0.57 for juveniles), which are based the 1990-1993 age structure in the thornyhead assessment (Gaichas et al. 2003) and weight at age data collected on NMFS bottom trawl surveys (in this case, only U.S. west coast surveys had any shortspine thornyhead weight at age data). The resulting values were a PB of 0.15 and a QB of 0.5. Diet composition was based on food habits collections made during bottom trawl surveys of the AI. Pedigree for the biomass estimat is 2, 6 for the QB and PB estimates, 2 for the diet, 1 for the NMFS fishery data and 2 indigenous fishery data.

Hexagrammids and deep fish

Atka mackerel (*Pleurogrammus monopterygius*) are not mackerel at all, but Hexagrammids. These fish are most abundant in the AI, with the population apparently expanding to occupy the GOA intermittently. Atka mackerel grow rather quickly to a maximum size of about 55 cm and an age of 13-15 years (the highest age being observed at the center of the population's abundance in the AI, Lowe and Lauth 2003). They mature at about 38 cm and 3-4 years of age in the GOA (McDermott and Lowe 1998). The group was split into adults and juveniles.

Adult biomass was based on the average estimates from 1991 and 1994 bottom trawl surveys. The P/B and Q/B ratios were estimated by fitting a von Bertalanffy growth function to data from the 1991 age structure in the BSAI stock assessment, and weight at age data from the AI. The resulting rates were a PB of 0.348 and QB of 5.647 respectively. The AI diet composition was estimated directly from stomachs collected during 1991 and 1994 as part of the AI bottom trawl surveys. Pedigree for the biomass estimat is 1 (from survey), 3 for the QB and PB estimates (from stock assessment data with Von Bertalanffy curve fit to data of the AI), 1 for the diet (from AI stomachs of the period, NMFS fishery data has 1 (AFSC databse) and indigenous fishery data has a pedigree of 2..

Juveniles are fish less than 20 cm in length, which roughly corresponds to 0 through 2 year old fish. Biomass for this juvenile group was estimated by assuming that EE was 0.8 for the group. Juveniles have a P/B of 1.9 and Q/B of 8.9, which were estimated by the same method and using the same information from the AI as for adults. Information on diet composition was based on analyzed stomachs collected during 1991 and 1994 as part of the bottom trawl surveys. Check years with Kerim

Eelpouts (family *Zoarcidae*) is a composite group which includes representatives of the genera *Lycodes*, *Lycodapes*, and *Gymnelis*. Eelpouts are a diverse family; the trawl surveys throughout Alaska primarily catch the larger *Lycodes* species, particularly the marbled eelpout (*L. raridens*), the wattled eelopout (*L. palearis*) and the shortfin eelpout (*L. brevipes*). Data on smaller eelpout species is limited due to limited trawl catchability. Eelpouts are small, narrow, eel-like fishes which are extremely poorly sampled by bottom trawl survey gear designed for groundfish.

Eelpout biomass was estimated by assuming that EE was 0.8 for the group. They are assumed to have similar productivity to other groundfish such as pollock, cod, and herring, so P/B was set to 0.40 (this was used as the default groundfish P/B if no other information was available). Default growth efficiency was assumed to be 0.2, so default Q/B was set to 2.0 in the absence of other information (again, similar to groundfish such as Pacific cod). Diet composition was estimated from food habits collections made during the EBS bottom trawl surveys, with the modification that juvenile crabs in the EBS diet which have no equivalent in the other models were called miscellaneous crabs. Eelpout biomass pedigree was 8 (estimated by Ecopath) while PB and QB were 7 (average values across a wide range of groundfish) and diets were 6 (limited data but within modeled areas and time period).

Greenlings (family *Hexagrammidae*) is a composite group containing all remaining members of this family aside from Atka mackerel, including the kelp greenling (*Hexagrammos decagrammus*), the rock greenling (*H. lagocephalus*), the masked greenling (*H. octogrammus*), and the white spotted greenling (*H. stelleri*).

No biomass estimates were available, thus an EE of 0.8 was assumed. There is little to no life history information available for species in this group, so P/B was assumed to be 0.4 and Q/B was assumed to be 2.0 (similar to adult Pacific cod). The diet composition was based on stomachs collected during the AI bottom trawl surveys during 1991 and 1994. Pedigree is 8 for the biomass (Ecopath estimate), 7 for both the PB and QB and 2 for the diet composition. The data from NMFS is ranked 7 and the indigenous fishery data has a pedigree of 2.

Giant grenadier (*Albatrossia pectoralis*) are the most common grenadier in Alaska, and are the largest of all macrourid species (Nelson 1994) reaching a maximum size of 150 cm (not including the long, whiplike tail). Because grenadiers dominate the biomass in many deep-sea habitats, they are suspected to play an important ecological role in energy transfer, either as pelagic predators, benthic predators, and/or as scavengers on detritus (McLellan 1977). Research in Russian waters shows giant grenadiers form sex-specific aggregations with females found shallower than males, and they migrate seasonally between shallower and deeper waters according to the timing of ovarian maturation and spawning (Novikov 1970, as referenced in Burton 1999). Concentrations of giant grenadiers peak during the summer months in Russian waters (Tuponogov 1986 1997, as referenced in Burton 1999). Giant grenadiers have a pelagic juvenile stage, with settlement to benthic habitats thought to coincide with the onset of maturity (Noikov 1970). This life history strategy may protect immature giant grenadiers from fishing pressure (Burton 1999), to which they are rather vulnerable. They are a very slow growing species which lives at least 30 to 50 years, maturing at 10-15 years and 50-56 cm TL (Burton 1999) and so would have a slower recovery from heavy fishing pressure, similar to rockfish and elasmobranch populations.

AI biomass was originally based on the averaged 1991 and 1994 AI bottom trawl survey estimates. However the biomass was not sufficient to satisfy consumption within the ecosystem: the maximum depth of the survey is considerably shallower than the main concentrations of grenadiers in other ecosystems. The survey estimate was increased by one order of magnitude based on the information from the 1996 SAFE Bering Sea Aleutian Islands chapter 13 (Lowell 1996), in which the biomass of giant grenadiers for 1986 is over 600,000 tons (compared to 28,900 from the survey). There is no direct information to estimate production or consumption rates for this group so values comparable to those for other relatively low productivity groups were used, a P/B of 0.15 and a Q/B of 2.0. Diet composition was based on stomachs collected during bottom trawl surveys in the AI. Biomass pedigree was 6 (limited information from surveys). P/B and Q/B pedigree was 7 (average values across a wide range of groundfish). Diet pedigree was 3 in the AI, with direct sampling although with incomplete depth coverage.

Pacific grenadier (*Coryphaenoides pacificus*) are very slow growing species which reach a size of 84 cm TL and ages of up to 73 years, maturing at 20-40 years and 46-65 cm TL off the

U.S. west coast (Andrews et al. 1999). These life history traits suggest grenadier populations may be more vulnerable to and slower to recover from heavy fishing pressure.

AI biomass is not believed to be sampled adequately. There are indications that the maximum density of Pacific grenadiers occurs around 1500 m depth (Andrews et al 1999), whereas the maximum depth during bottom trawl surveys is 500m. This problem is also exemplified with the giant grenadier, above. Because there is no direct information to estimate production or consumption rates for this group, we used values comparable to those for other relatively low productivity groups, a P/B of 0.15 and a Q/B of 2.0.

Pacific grenadier diet composition is unknown, instead the feeding habits in the AI for the giant grenadier were used as substitute. AI biomass pedigree was 6 (limited information from surveys). P/B and Q/B pedigree was 7 (average values across a wide range of groundfish). Diet pedigree was 5 in all systems: it was taken from system-specific diet studies of the same family (giant grenadiers).

Other macrourids (family *Macrouridae*) is a composite group which includes the remaining major grenadier species found in Alaska, primarily the popeye grenadier *Coryphaenoides cinereus* and an additional 8 species which are known from the Pacific Ocean, and may be present in the North Pacific.

The AI biomass estimate from the 1991 and 1994 AI trawl surveys was for popeye grenadier only, a mere 1.5 tons. Thus the biomass was estimated by assuming an EE of 0.8 for balance purposes. Values comparable to those for other groups with relatively low productivity were used, those being a P/B of 0.15 and a Q/B of 2.0. No data on feeding habits was available for any of the species in this group, so giant grenadier diet composition was used instead. Pedigree for biomass was considered 8 (estimated by Ecopath). P/B and Q/B pedigree was 7 (average values across a wide range of groundfish). Diet pedigree was 5, it was taken from system-specific diet studies of the same family (giant grenadiers).

Large sculpins (suborder Cottoidei) includes several common species that achieve large sizes in Alaska, and are thought to be most likely encountered in the commercial fisheries (Gaichas 2003): *Myoxocephalus* spp. (eg, the great sculpin), *Hemilepidotus* spp. (Irish lords), and the bigmouth sculpin, *Hemitripterus bolini*. Despite their abundance and diversity, sculpin life histories are not well known in Alaska. Sculpins lay adhesive eggs in nests, and many exhibit parental care for eggs (Eschemeyer et al 1983). Bigmouth sculpins, *Hemitripterus bolini*, lay eggs in vase sponges–however, it is unknown whether they are completely dependent on finding a particular type of sponge to reproduce. Some larger sculpin species such as the great sculpin, *Myoxocephalus polyacanthocephalus*, reach sizes of 70 cm and 8 kg in the western North Pacific. In the western Pacific, great sculpins are reported to have relatively late ages at maturity (5-8 years, Tokranov 1985) despite being relatively short-lived (13-15 years), which suggests a limited reproductive portion of the lifespan relative to other groundfish species. Mean fecundities for great sculpin were 60,000 to 88,000 eggs per gram body weight (Tokranov 1985).

In the AI no biomass estimate was available for any of the species in this complex and hence an EE of 0.8 was assumed to estimate biomass. P/B was assumed to be 0.4 and Q/B was assumed to be 2.0, a modification of those for Pacific cod. The feeding habits in the AI were based on stomachs collected as part of the AI bottom trawl surveys. Pedigree for the biomass estimate is 8 (Ecopath estimate), the PB and QB were 7 (modified from similar species) diet composition was 2; the NMFS fishery data was 4 and the indigenous data had a pedigree of 2.

Other sculpins (suborder Cottoidei) includes all other sculpin species in Alaska not found in the large sculpin group (see above). These species are thought to be less likely to comprise much commercial fishery bycatch, due to small size, inaccessible habitat, or both (Gaichas 2003). This category includes sculpins in the genera *Icelus*, *Triglops*, *Artediellus*, *Enophrys*, *Gymnocanthus*, *Icelinus*, *Leptocottus*, *Malacocottus*, *Blepsias*, *Dasycottus*, and *Rhamphocottus*, among others. Limited life history information on related species from other areas suggests that other sculpins have broadly similar life history to the better studied large sculpins, with maximum ages on the order of 10 years or less and ages at maturity ranging from 4-6 (Gaichas et al. 2004).

The original biomass estimate, from the average of the 1991 and 1994 AI bottom trawl survey estimates (~13,800 tons), was not sufficiently high to satisfy consumption within the ecosystem, thus an EE of 0.8 was used to estimate a minimum biomass. P/B was assumed to be 0.4 and Q/B was assumed to be 4.0. The AI diet was based on the stomach contents of samples collected in the AI as part of the bottom trawl surveys; the diet was modified to avoid cannibalism, the fraction corresponding to "other sculpins" moved to the category "size unknown". Pedigree for biomass was considered 8 (estimated by Ecopath). P/B and Q/B pedigree was 7 (average values across a wide range of groundfish). Diet pedigree was 2, it was taken from system-specific stomach samples,.

Prickly deep is a composite group containing a variety of less common deeper-dwelling fishes, including dragonfishes and viperfishes (*Stomiidae*), hatchetfishes (*Sternoptychinae*), tubesnouts (*Aulorhynchidae*), slickheads (*Alepocehpalidae*), pearleyes (*Scopelarchidae*), and bigscale fishes or ridgeheads (*Melamphaidae*). No biomass estimate is available for any of these taxa, so biomass for this group was estimated by assuming EE was 0.8. Likewise, no information on production or consumption is available for these taxa. Because they are generally deep-sea dwellers, the standard P/B ratio was lowered to 0.2 to account for generally lower productivity in this habitat. The standard Q/B ratio of 4.0 was applied. The diet was assumed to be mainly squids and shrimp, a simplification of the grenadier's diet. Pedigree for these species is 8 for biomass (estimated by Ecopath) and 7 for P/B, Q/B, and Diet (general information from wide ranging species in similar habitats).

Prickly gadids is a group containing a variety of demersal fishes, including poachers (Agonidae), lumpsuckers (Cyclopteridae), snailfishes (Liparidae), Arctic and saffron cod (Gadidae), ronquils (Bathymasteridae), wolffishes (Anarhichadidae), prowfish (Zaproridae), lampreys (Petromyzodontidae), hagfish (Myxinidae), and others.

In the AI the original biomass estimate, from the average of 1991 and 1994 AI bottom trawl surveys was 3255.65 tons and corresponded to prowfish. This estimate proved to be too low and since most other species are either rarely encountered to estimate biomass, small for effective catch by the gear, or inhabit untrawlable areas, we assumed an EE of 0.8 to estimate the biomass for this complex. P/B was assumed to be 0.4 and Q/B was assumed to be 4.0, because of the lack of more specific data. The AI diet was originally based on prowfish stomachs collected in the AI as part of the bottom trawl surveys. It was later modified to reproportion the prey items and make jellyfish a minor component of the diet (as opposed to the dominant one). This modification was thought to better represent the diet of the other species and prowfish. Pedigree for biomass was considered 8 (estimated by Ecopath). P/B and Q/B pedigree was 7 (average values across a wide range of groundfish). Diet pedigree was 5, it was taken from system-specific diet studies of the same family (prowfish).

Sablefish (*Anoplopoma fimbria*) grow to a size of 83 cm and a maximum age of 94 years, maturing at 57-65 cm or age 5-7 (Sigler et al. 2004). Adults occur along the continental slope, shelf gullies, and in deep fjords, commonly deeper than 200m and very near the bottom. They are highly migratory and move between the Bering Sea-Aleutian Islands and the Gulf of Alaska. Spawning is pelagic at depths of 300-500 m near the edges of the continental slope; after two years they begin gradually moving offshore to the upper continental slope, reaching their adult habitat at 4 to 5 years (Sigler et al. 2004).

Adults biomass was originally that average of that estimated directly from the AI bottom trawl surveys (~6000 tons). This abundance was not enough to satisfy consumption within the ecosystem and so it was corrected using catch data. Survey estimates were only available for the deep strata going from 200 to 500 m depth. However catches come both from deeper areas and shallower areas. The biomass for the deep strata was thus increased to account for catches deeper than 500 m and then shallow and middle biomass estimates were added to reflect the proportion of catches occurring between depths 0-100 and 100-200 m respectively. This was still not enough, but rather than increasing the abundance further, it was assumed that this imbalance was a reflection of the reduction in abundance seen in the stock during that period. To balance the model a negative biomass accumulation of 0.0329 was added; this rate was based on a linear regression of the biomass estimates of age 4+ between 1990 and 1996. The P/B ratio of 0.19 and Q/B ratio of 1.03 were estimated from the 1990-1993 age structure in the sablefish stock assessment, which applies to all areas of Alaska (Sigler et al. 2004) and weight at age data collected on NMFS bottom trawl surveys. AI diet composition was based on stomachs from both the AI and the west GOA collected during 1991-1994. Pedigree is 3 for the biomass, 5 for the QB and PB (same period overall stock), diet composition is 4.

Juveniles were defined as fish less than 20 cm in length, which roughly corresponds to 0 through 2 year old fish. Biomass was estimated by assuming that EE was 0.8 for the group. The P/B of 1.65 and Q/B of 3.32 were estimated by the same method and using the same information as for adults. Diet composition was based on stomachs from both the AI and the west GOA. Pedigree is 3 for the biomass

Cephalopods and forage fish

Species specific information for these is almost non-existent, particularly in terms of their production and consumption rates. To retain consistency among groups, the default values were set at a PB of 0.8 and of 3.65; these values represent a relatively productive species, and are based on a non-age structured estimate for Pacific herring (Trites et al. 1999). Likewise for the diet data, the smaller forage species had very little or no information at all, hence a simplified version of the myctophids diet was used as default: 90% euphasiiids and 10% copepods.

Octopi (Order Octopoda) are cephalopod molluscs with a wide size range (from a few centimeters to well over a meter), and one of the largest species in the world inhabiting Alaskan waters. The North Pacific giant octopus, *Enteroctopus dofleini*, is the largest of all octopods. While this species may dominate our image of the octopus species complex in the Alaska, there are many more octopus species found in the area, many of which are currently being described (E. Jorgenson 2004 pers comm). In general, short lifespans of 1 to 5 years with a single reproductive period are reported for octopod species (Boyle 1983). In Japan, where giant Pacific octopus support directed fisheries, seasonal inshore-offshore migrations are reported, with mating occurring during autumn inshore in less than 100 m depth. Male octopus migrate back offshore and die, while females remain inshore, spawning 18,000 to 74,000 eggs in shallow water nests (< 50 m) on rocky or sandy bottom between May and July. Eggs are brooded for 6-7 months; female octopi do not feed during this period, and die soon after the eggs hatch. Hatchlings are about 10 mm long, and are planktonic until growing to 20 - 50 mm, settling out to benthos in about March of the year following hatching (Roper et al. 1984). Life history in the eastern North Pacific is not as well known, but spawning may be more common in winter months (Hartwick 1983). It is thought that giant octopus require 3 years to grow to an adult (mature female) size of 10kg, and that they live 3-5 years. Because at least some octopus species migrate seasonally inshore and offshore, the sexes are often found in separate habitats.

Trawl surveys do not produce reliable biomass estimates for most octopus species (Gaichas et al. 2004), so biomass for this group was estimated by assuming EE was 0.8. The original estimate was too low to satisfy consumption within the ecosystem (estimate was 1341 tons). For lack of better information the P/B was assumed to be 0.8, and Q/B 3.65, the default assumption for productive forage species. Diet information is not available for the AI, so EBS diet compositions were substituted with the modification that juvenile crabs in the EBS diet were called miscellaneous crabs as they have no equivalent in the AI. Pedigree for the octopi biomass is 8 as it was estimated by the model without better information. The rest of the estimates (QB, PB and diet) have a pedigree of 7 (average of several species).

Squids (Order Teuthoidea) are cephalopod molluscs; active predators which swim by jet propulsion, reaching swimming speeds of up to 40 km/hr, the fastest of any aquatic invertebrate. The 18 squid species found in the mesopelagic regions of the Bering Sea represent 7 families and 10 genera (Sinclair et al. 1999). Little is known about squid species in the AI, but the species are likely to represent EBS species and a combination of Oregonian species towards the east, Kurile species towards the west. Squid are distributed throughout the North Pacific, but are common in large schools in pelagic waters surrounding the outer continental shelf and slope (Sinclair et al 1999). The most common squid species in the Eastern Bering Sea are all in the family Gonatidae. Near the continental shelf, the more common species are *Berryteuthis anonychus* and *Berryteuthis magister*. Further offshore, the likely common species are *Gonatopsis borealis*, *Gonatus middendorfi* and several other *Gonatus* species, according to survey information collected in the late 1980's (Sinclair et al. 1999). The predominant species of squid in commercial catches in the EBS is believed to be the red squid, *Berryteuthis magister*, while the boreal clubhook squid, *Onychoteuthis borealijaponicus*, is likely the principal species encountered in the Aleutian Islands region (Gaichas 2003). In addition, marine mammal food habits data and recent pilot studies indicate that *Ommastrephes bartrami* may also be common, in addition to *Berryteuthis magister* and *Gonatopsis borealis* (B. Sinclair, ASFC, personal communication). The best studied squid in the north Pacific is *Berryteuthis magister*. This species is distributed from southern Japan throughout the Bering Sea, Aleutian Islands, and Gulf of Alaska to the U.S. West coast as far south as Oregon (Roper et al. 1984). The maximum size reported for *B. magister* is 28 cm mantle length (Arkhipkin et al. 1995). *B. magister* from the western Bering Sea are described as slow growing (for squid) and relatively long lived (up to 2 years). Males grew more slowly to earlier maturation than females (Arkhipkin et al. 1995).

The NMFS bottom trawl surveys are directed at groundfish species, and therefore do not employ the appropriate gear or sample in the appropriate places to provide reliable biomass estimates for the generally pelagic squids (Gaichas et al. 2004). Biomass for this group was estimated by assuming EE was 0.8 both in the AI. Squids are highly productive and voracious predators, so a P/B of 3.2 and a Q/B of 10.62 were adapted from Trites (**need ref from Kerim**). **Sarah has Trites written down, but in the EBS model (the xls file) you have Radchenko 1992. Which one is correct?** Diet information is not available for the AI, so EBS feeding habits were substituted. However, the diet from Radchenko 1992, reflects primarily that of *Berryteuthis magister* so the diet of small pelagic squids is underrepresented. The biomass has a pedigree of 8 as it was estimated with Ecopath; PB and QB were from other system, so the pedigree is 7; so was the diet which also has apedigree of 7.

Pacific salmon (Genus *Oncorhyncus*) is a composite group which includes the ocean going adults and juveniles of pink, chum, coho, sockeye, and Chinook. Within the Aleutian Islands salmon are mainly pink and chum. Pacific salmon were divided into functional groups representing the large mature salmon returning through continental shelf environments on the way back to freshwater spawning grounds (**Salmon Returning**), and the small outmigrating smolts entering the oceanic habitat (**Salmon Outgoing**). Because these groups represent multiple species with different life histories and abundances, these two groups are treated separately and are not parameterized to interact as adult and juvenile groups comparable to groundfish.

Returning biomass was estimated assuming a density of 0.14 throughout all strata. This gave a biomass estimate of 7982 tons. Age specific production and consumption rates for each of the five Pacific salmon species were estimated in the field (Aydin 2000) and were weighted by the relative biomass of each species in the AI, mainly pink and chum (from tag data Myers et al. 1996). The resulting PB of 1.8 is the average of the PB of returning chum age 2 & 3 and pink age 1 (age/species specific rates from Aydin 2000). The same holds for the calculation of QB, which resulted in a value of 12.12. Salmon diet information was not available for the AI, so diet composition for EBS was substituted.

Outgoing was assumed that outgoing salmon were found in a density 10% that of returning salmon. The resulting biomass in the AI is 798 tons. The PB and QB rates were calculated using the method described above resulting in a PB of 1.77 and a QB, of 16. AI specific diet information was not available, so EBS feedeing habits were substituted. Biomass has a pedigree of 7; PB and QB is 6 (weighted average of species in complex), the diet is also 7.

Pacific herring (*Clupea pallasi*) Herring are small, relatively short-lived fish that reach sizes of 30-40 cm and live up to 8 years, reaching maturity at 3-4 years (Hart 1980). Herring are known for their large spring spawning aggregations in nearshore coastal waters, where eggs are laid on submerged aquatic vegetation and milt turns nearby waters white.

Adult biomass was estimated assuming an EE of 0.8. The P/B and Q/B ratios of 0.32 and 3.52 respectively, were assumed calculated using the Pacific herring stock assessment for the Eastern Bering Sea (**need ref from Kerim**) and were assumed to be the same for the AI. There is no data on herring for the AI that allows any improvements on these estimates. Diet composition information was unavailable for GOA and AI Pacific herring, so diet composition estimated from food habits collections made during the 1990-1993 EBS bottom trawl surveys were substituted. Biomass has a pedigree of 8 (top-down balanced), PB and QB were taken from an Alaskan system but not the AI so the pedigree is 7; diet composition comes from nearby system, the EBS. The diet pedigree is 5.

Juvenile were defined as fish less than 20 cm in length, which roughly corresponds to 0 through 3 year old fish. Biomass was estimated assuming an EE of 0.8; the P/B ratio of 2.37 comes from the estimate for the EBS; the same QB as that for the EBS was assumed, 7.24. No diet data is available from the AI, so the diet composition was based on stomachs collected in the Eastern Bering Sea middle northwest area. Pedigree of biomass was 8 (ecopath estimated), PB and QB have a pedigree of 6 (general proxy from data on the GOA); the diets are 7 (outside the area, they're for the EBS).

Bathylagidae (deep sea smelt) is a composite taxonomic group containing all members of this family of deep-sea smelts found in Alaska. Maximum lengths for common North Pacific bathylagids range from 12-25 cm (Nelson 2003). No biomass estimate exists for this group of small mesopelagic schooling fishes (Nelson 2003), so biomass for this group was estimated by assuming EE was 0.8. Similarly, energetics information is not available for this group. Until better information is available, P/B is assumed to be 0.8, and Q/B is assumed to be 3.65. No diet composition available so the deafault 90% euphausiids and 10% copepods was applied. The data pedigree for species Biomass was 8 (estimated by Ecopath), while PB, QB, and Diets were 7 (general literature review for a wide range of species).

Capelin (*Mallotus villosus*) are small, densely schooling smelts found throughout the shallow nearshore waters of Alaska. They reach a maximum size of 25 cm and an age of 4 years, with maturity arriving at 3-4 years. Spawning takes place in intertidal sand and gravel, and most capelin die after spawning once (Nelson 2003).

No biomass estimate is available, so an EE of 0.8 was assumed. Energetics information is not available for this group; hence default values were assumed, a P/B of 0.8, and a Q/B of 3.65. Similarly a default diet composition of 90% euphausiids and 10% copepods was applied. The data pedigree for species biomass was 8 (estimated by Ecopath), while PB, QB, and diets were 7 (general literature review for a wide range of species).

Eulachon (*Thaleichthys pacificus*) are anadromous smelts which achieve a maximum size of 25 cm and age of 5, but like capelin, they most often do not survive past one spawning, which may happen as early as age 3 (Nelson 2003).

No biomass estimate exists so it was estimated by assuming EE was 0.8. P/B is assumed to be 0.8, and Q/B is assumed to be 3.65, the default values for forage species. Diet composition information was also unavailable hence a diet 90% euphausiids and 10% copepods was applied. The data pedigree for species biomass was 8 (estimated by Ecopath), while PB, QB, and diets were 7 (general literature review for a wide range of species).

Myctophidae is a composite taxonomic group containing all members of this family of lanternfishes found in Alaska. Myctophids are a key prey item for both fish and marine mammals in the Aleutian Islands, particularly towards the west. In a global context, they are among the most abundant group of mesopelagic fishes. Within Alaska the dominant species are the California headlightfish (*Diaphus theta*), lampfish (*Lampanyctus* sp, *Stenobrachius* sp, *Protomyctophum* sp), broken line myctophid (*L. jordani*), lanternfish (*L. tenuiformes*), northern lampfish (*S. leucopsarus*), garnet myctophid (*S. nannochirI*), bigfin lanternfish (*Symbolophorus californiense*), and blue lanternfish (*Tarletonbeania crenularis*). All members of the family have photophores on the head and body (hence the name lanternfish/ lampfish). Most myctophids are less than 10 cm long, but some reach about 30 cm. They are oviparous, with planktonic eggs and larvae (Moser and Ahlstrom 1996). Diurnal migration is exhibited by many: most species have peak abundance between 300 and 1200 m by day and between 10 and 100 m at night. (Nelson 1994).

No biomass estimate is available, (Nelson 2003) so biomass for this group was estimated by assuming EE was 0.8. Similarly, energetics information is lacking so default values were assumed, P/B is 0.8, and Q/B is 3.65. Some food habits information was available for the AI based on stomachs collected (northern lampfish, *Stenobrachius leucopsarus* and broken line myctophid *Lampanyctus jordani*) during bottom trawl surveys.
The data pedigree for species Biomass was 8 (estimated by Ecopath), while PB, QB, and Diets were 7 (general literature review for a wide range of species).

Sandlance (*Ammodytes hexapterus*) are small, eel-like benthic fish which reach a maximum size of 17 cm and an age of 6 years (Robards et al. 1999), maturing at 2-3 years and 10-15 cm (Nelson 2003).

No biomass estimate exists thus an EE of 0.8 was assumed to estimate the biomass. The default values for PB and QB were applied for lack of better information; the P/B is 0.8, and Q/B is 3.65. Likewise the default diet composition was assumed 90% euphausiids and 10%

copepods. The data pedigree for species Biomass was 8 (estimated by Ecopath), while PB, QB, and Diets were 7 (general literature review for a wide range of species).

Managed forage is a composite group which includes other members of a North Pacific management category known as "forage fish" aside from the separately grouped and more common capelin, eulachon, sandlance, bathylagids, and myctophids (see above). Managed forage includes the Pacific sandfish (*Trichodon trichodon*), gunnels (Pholidae), bristlemouths and anglemouths (Gonatostomatidae), and pricklebacks, warbonnets, eelblennys, cockscombs, and shannys (Sticheidae).

Biomass was estimated by assuming EE was 0.8. Default values were assumed for the energetics, P/B is assumed to be 0.8, and Q/B is assumed to be 3.65. Diet composition was unavailable so it was assumed to be 90% euphausiids and 10% copepods. The data pedigree for species biomass was 8 (estimated by Ecopath), while PB, QB, and diets were 7 (general literature review for a wide range of species).

Other pelagic smelts is a composite group which includes herring smelts or argentines (Argentinidae), surf smelts (*Hypomesus pretiosus*), whitebait smelts (*Allosmerus elongatus*), and rainbow smelts (*Osmerus mordax*).

Biomass was estimated by assuming EE was 0.8. Production and consumption were estimated assuming default values, P/B is assumed to be 0.8, and Q/B is assumed to be 3.65. A default diet composition of 90% euphausiids and 10% copepods was applied. The data pedigree for species biomass was 8 (estimated by Ecopath), while PB, QB, and diet were 7 (general literature review for a wide range of species).

Shellfish, motile/sessile epifauna and infauna

These groups, except for Bairdi, King crabs and shrimps lacked adequate estimates of QB. Therefore, a common assumption of a conversion efficiency of 0.20 (a rounded average for benthic groups documented in Trites et al. 1999) was made to give different QBs for each PB.

Bairdi refers to the tanner crab *Chinoecetes bairdi.* Tanner crabs are found throughout the continental shelf North Pacific Ocean and Bering Sea from Hokkaido to Oregon; their strongholds are around the Pribilof Islands and immediately north of the Alaska Peninsula though they are found in lower abundance in the GOA. Sexual maturity is reached at about age six with an average carapace width of 110-115 mm for males and 80-110 mm for females (Tyler and Kruse 1997). The maximum size for males is 190 mm of carapace width and they live up to 14 years (Donaldson et al. 1981). Females form high-density mating aggregations consisting of hundreds of crabs per mound. These mounds are thought to provide protection from predators and attract males for mating. Females have been observed to retain viable sperm in spermathecae for up to two years; they carry clutches ranging from 50,000 to 400,000 eggs for one year after fertilization (EIS 2004)

Biomass was estimated assuming an EE of 0.8. The PB was 0.6 based on averaged juvenile and adult mortality rates from various studies and for a mix of years (Trites et al. 1999). QB is 3 and it based on size-specific ration studies from late 1970s (OCEAP 1981); the values from combined adult/juvenile values were pooled and rounded. Diet composition was taken from russian surveys in 1972. Biomass has a pedigree of 8 (estimated with Ecopath), PB was 6 (based on same species, different within perdiod, QB is 6, diets taken from surveys in adjacent system [redacted]

King crab are either red or golden king crabs, *Paralithodes camtschaticus and Lithodes aequispina* respectively. Golden kings (or brown kings) support most of the fishery in the Aleutian Islands, with 5.7 million pounds for the 2003-04 quota vs half a million pounds for red kings. The King crab fisheries in the Aleutians are reported off Adak. Both fisheries were open during 1991 and 1994, the one for red was closed in 1996 and opened recently. Red king crabs are found in the western Aleutian Islands (Adak or Petrel Bank) and eastern Aleutian Islands (Dutch Harbor). Larvae are planktonic, they follow a basic life history pattern where adults occur up current from juvenile nursery grounds and juveniles show a migration to the adult habitat. Adults have a seasonal pattern of offshore-onshore migration that is apparently mediated by temperature and photoperiod. Male and females when adult, generally inhabit separate grounds during feeding, with males migrating farther. A spring spawning migration occurs during the molting and mating season. Golden kings are found from British Columbia to Japan, with the center of abundances located in the Aleutian Islands; they are generally in waters between 200–1000 m, generally in high relief habitat with strong currents prevailing such as in inter-island passes. Golden generally inhabit separate grounds during feeding, with males migrating farther. A spring spawning migration occurs during the molting and mating season. There are few records of golden king crab larvae in upper water plankton tows and it is possible that these larvae are demersal (EIS 2004).

Biomass was roughly estimated based on catches and a logistic model. No population sampling is available for a better estimate. Biomass was estimated at 7,691 tons and is probably an underestimate. The PB was 0.6 based on averaged juvenile and adult mortality rates from various studies and for a mix of years (Trites et al. 1999). QB is 3 and it based on size-specific ration studies from late 1970s (OCEAP 1981); the values from combined adult/juvenile values were pooled and rounded. Diet composition was taken from russian surveys in 1972. The pedigree for the biomass is 7 (based on system specific catch, but poor fit to data). PB has a pedigree of 6 (general life-history proxy), QB was 5 (same species, historical period); diet pedigree is 7 (general literature review, outside region).

Non-Pandalid shrimp groups all other (generally non-commercial) shrimp species outside the family Pandalidae. At least seven families comprise this group, including Penaeidae, Sergestidae, Caridea, Oplophoridae, Pasiphaeidae, Hippolytidae, and Crangonidae. The most representative genera are Spirontocaris sp.(6 species), Eualus sp. (11 species), Crangon sp. (8 species), Argis sp. (6 species), and Metacrangon sp.(4 species) but multiple other genera are also included Metapenaeopsis sp, Sergestes sp, Bentheogennema sp, Hymenodora sp, Pasiphaea sp (glass shrimp), Parapasiphae sp. (grooved-back shrimp), Lebbeus sp., Heptacarpus sp, Sclerocrangon sp, Rhynocrang sp. Non pandalid shrimps have a wide depth range, though most of them are generally found in the mesopelagic zone, located roughly around at 200 meters depth. None of them support a commercial fishery in Alaskan waters, though they do in some other areas of the North Pacific. Hyppolytids (cleaner shrimps) are known to associate with anemones; within Alaska (around Kodiak), the pink sea anemone *Cribrinopsis fernaldi* was observed surrounded by several species of Caridean shrimp. These were aggregated in a radial pattern beneath or just beyond the anemone's tentacle canopy. The caridean species observed included *Eualus suckleyi*, *Spirontocaris* sp., *Lebbeus grandimanus*, *L. groenlandicus* and *Pandalus tridens*, but not *Pandalus borealis*, although it was probably also present. The number of shrimps per anemone increased with depth from 61 to 115m; more shrimp were observed on silty-sand than on sandy-gravel substrates. (Stevens & Anderson 2000).

Biomass was estimated by assuming EE was 0.8. The P/B of 0.57 and Q/B of 2.4 was based on growth and longevity studies of pink shrimp in Prince William Sound, Alaska.
Biomass pedigree was 8 (estimated by Ecopath), while P/B and Q/B were 6 (ranking of 5 were appropriate for Pandalidae, this was downgraded for non-pandalid shrimp due to species differences). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Pandalid shrimp is a composite group constitued by commercial shrimp species in the family Pandalidae, including the pink shrimp (*Pandalus borealis*), the humpy shrimp (*Pandalus goniurus*), the sidestripe shrimp (*Pandalopsis dispar*), the coonstripe shrimp (*Pandalus hypsinotis*), and the spot prawn (*Pandalus platyceros*). Pandalid shrimps are opportunistic feeders and have a boreo-artic distribution in both the Pacific and Atlantic Oceans, inhabiting varying depths and habitat types. Spots and coonstripes are generally associated with rock piles, coral, and debris-covered bottoms, whereas pinks, sidestripes, and humpies typically occur over muddy bottom. Pink or northern shrimp can occur anywhere between 30-1460 m; humpies and coonstripes usually inhabit shallower waters, 10-370 m; spot shrimp (or spot prawn) range from 5 to 450 m, and sidestripes can be found somewhat deeper, 45 to 640 m though most concentrations occur at depth greater than 70 m. Most pandalids have seasonal migrations, from deep to shallow waters and up the water column. For example, pink shrimp, may move off the bottom towards the evening, occupy the whole water column through the night, and return to the bottom in early morning. Pandalids are protandric hermaphrodites, they mature as males and then become females. The females carry anywhere between a few hundred to up to 4,000 eggs until they hatch; clutch size is generally proportional to the size of the female. Pandalids tend to spawn in fall and hatch in spring, but this may vary among species and range. Pandalid shrimps have been used as ecosystem indicators in the Gulf of Alaska, their abundance declined quickly following water column warming caused by an abrupt climate change after 1977 (Anderson 2000).

Due to the low catchability of shrimps in bottom trawl surveys, Pandalids in the in the AI was estimated by assuming an EE of 0.8. The P/B of 0.57 and Q/B of 2.4 was based on growth and longevity studies of pink shrimp in Prince William Sound, Alaska. Shrimp diets were estimated from information found in Feder (1978) and Rice (1981).
Pedigree for biomass was 8 (estimated by Ecopath), while P/B and Q/B were 5 (Alaskan area reference for appropriate species, but covering limited species in this functional group). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Hermit crabs (Family Paguridae). Approximately 28 species of hermit crabs have been identified in Alaskan waters. Both polychaetes (annelids) and/or amphipods (crustaceans) have been found to be comensals with pagurids from the Alaska shelf, namely *Pagurus aleuticus, P. capillatus, P. confragosus, P ochotensis , P. rathbuni, P. setosus, P. trigonocheirus, Elassochirus cavimanus* , and *Labidochirus splendescens.*

Biomass was estimated by assuming an EE of 0.8. A P/B of 0.82 is reported for hermit crabs by Volvenko (1995) and Dulepov (1995) and thus value was used for all models. Q/B was calculated assuming a growth efficiency of 0.2 which resulted in a QB of 4.1. Hermit crabs were assumed to consume infauna and detritus; for lack of better data, diet proportions were assumed to be equally split between clams, polychaetes, miscellaneous worms, and detritus. Biomass pedigree was 8 (estimated by Ecopath). The P/B pedigree was considered 6 (estimate from related species in other ecosystems) and Q/B pedigree considered 7 (growth efficiency averaged over wide range of species). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Miscellaneous crabs is an aggregate of all non commercial species of crabs, except for hermit crabs, which comprise a separate group (see above). Within Alaskan waters the group is an assemblage of some 50 species, including about 14 stone crabs (Family Lithodidae), 14 spider crabs (Family Majidae) and 6 pea crabs (Family Pinnotheridae). Though not crabs per se, mud shrimps are also included in this group (Family Axiidae).

Biomass in the AI was estimated by assuming an EE of 0.8. The P/B estimate for misc. crabs in all models was assumed to be the same as for hermit crabs, 0.82, above. Q/B was calculated assuming a growth efficiency of 0.2 which resulted in a QB of 4.1. Miscellaneous crabs were assumed to consume infauna and detritus; for lack of better data, diet proportions were assumed to be equally split between clams, polychaetes, miscellaneous worms, and detritus in all ecosystems.

Biomass pedigree was 8 (estimated by Ecopath). The P/B pedigree was considered 6 (estimate from related species in other ecosystems) and Q/B pedigree considered 7 (growth efficiency averaged over wide range of species). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Miscellaneous Crustaceans is a group which consolidates most of the arthropods not found in any of the other groups. It is hence an assemblage of barnacles, ostracods, cladocerans, isopods, cumaceans and sea spiders. Cumaceans can be found either in the intertidal zone or in deep seas. They are generally smaller than 8mm in size, but can reach up to 25mm. As a rule they burrow in the surface sediments and become active swimmers in open waters at night. Sea spiders (or picnogonids) feed on soft-bodied invertebrates, particularly cnidarians, nudibranchs, and other small gastropods; larval pycnogonids often live as parasites within cnidarian tissues. Most are very small but some of the largest ones can be up to 20 inches across. Sea spiders have been found at depths of up to 2,850 m off Newport, Oregon.

Biomass was estimated assuming an EE of 0.8. Dulepov (1995) calculated a P/B ratio specific to benthic amphipods of 7.4 (compared to pelagic amphipod P/B of 1.5) and this higher value

was assumed to apply to miscellaneous crustaceans. Q/B was calculated assuming a growth efficiency of 0.2 which resulted in a QB of 37. Miscellaneous crustaceans were assumed to consume detritus; however, detritus consumption was assumed to be split evenly between detritus and benthic bacteria, to make trophic levels comparable between benthic and pelagic secondary consumers (e.g., copepods).
Biomass pedigree was 8 (estimated by Ecopath). The P/B pedigree was considered 6 (estimate from related species in other ecosystems) and Q/B pedigree considered 7 (growth efficiency averaged over wide range of species). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Benthic Amphipods groups at least ten families: Caprellidae, Gammaridae, Ampeliscidae, Corophiidae, Eusiridae, Haustoriidae, Isaeidae, Ischyroceridae, Lysianassidae, and Pardaliscidae. Benthic amphipods may be facultative predators when they compete for space with other organisms such as the northern sand dollar *Echinarachnius parma*. This in part, may explain alternative benthic communities in the eastern Bering Sea. In general though, benthic amphipods are scavengers and are important in recycling organic material (Schmitt 1968, Griffiths & Stenton-Dozey 1981). Studies on northern Bering Sea benthic amphipod show that high latitude species grow slowly, require 2 to 4 years to mature, reach a large size, and have long lifespans. Amphipod growth rates and molting rates appear to be decoupled, resulting in small adults at warm temperatures and large adults at lower temperatures. It is believed that at warm temperatures molting occurs rapidly irrespective of tissue growth, and that sexual maturity is reached after a fixed number of molts. Alternatively, gonad development is also temperature-dependent and may drive maturation, regardless of the number of molts experienced. Amphipods have linear or exponential growth rates, as opposed to the familiar asymptotic curve (they do not reach a maximum size). Consequently, secondary production is highly dependent upon the proportion of large individuals in the population as opposed to the proportion of young, which is the pattern prevailing in populations of species with maximum size. Production is correlated with standing stock but not the P:B ratios. This may be the case for other organisms with non asymptotic growth, and thus seems to be only comparable only as an index of generation time (Highsmith & Coyle 1991). Benthic amphipods are common in the diet of juvenile skates (Orlov 1998).

Biomass was estimated assuming an EE of 0.8. Dulepov (1995) calculated a P/B ratio specific to benthic amphipods of 7.4 (compared to pelagic amphipod P/B of 1.5) and this higher value was used in all three models. Q/B was calculated assuming a growth efficiency of 0.2 which resulted in a QB of 37. Benthic Amphipods were assumed to consume detritus; however, detritus consumption was assumed to be split evenly between detritus and benthic bacteria, to make trophic levels comparable between benthic and pelagic secondary consumers (e.g., copepods).
Biomass pedigree was 8 (estimated by Ecopath). The P/B pedigree was considered 6 (estimate from related species in other ecosystems) and Q/B pedigree considered 7 (growth efficiency averaged over wide range of species). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Brittle Star is a composite group which represents members of the class Ophiura, that is brittle and basket stars. The basket star *Gorgonocephalus eucenemis* has been reported in

Alaska. Three families of brittle stars are found in Alaska, Ophiuridae, Ophiocomidae and Amphiuridae. Species include *Ophiurida chilophiurina, Amphiophiura megapoma, Opniura leptocteni, O. maculata, O. sarsi, Ophiocantha normani, Ophiopholis aculenta, Amphiodia euryaspis, Amphiopholis pugetana* and *A squamata.* Ophiurids or brittle stars (snake stars) have a well marked central disc and usually five arms. The arms are long and flexible, which allows them to move rapidly (by wriggling them) as they have no tube feet like the sea stars. The basket stars (Order Euryalida) have a similar structure to that of snake stars, but are usually larger. The arms are very distinct, highly forked and branched, and even more flexible than those of brittle stars. Snake and basket stars can be found in shallow water, and a few species can adapt to brackish water (unusual in echinoderms) but they are also found in deeper waters; brittle stars in particular can be dominant in many parts of the deep sea. Most ophiuroids are either scavengers or detritus feeders, however they also prey on small live animals like crustaceans and worms. Basket stars on the other hand, filter-feed on plankton with their arms, for the most part.

Biomass in the AI was estimated by assuming an EE of 0.8. The P/B of 1.21 for brittlestars was calculated for intertidal species by Asmus (1987). Little information exists for consumption rates of invertebrate benthic predators in the model regions. Q/B was calculated assuming a growth efficiency of 0.2 which resulted in a QB of 6.05. Diet compositions were obtained from the Alaska-wide OCSEAP invertebrate studies summarized by Feder and Jewett (1981), these diets are not specific to the Aleutians though.
Biomass pedigree was 8 (estimated by Ecopath). The P/B pedigree was considered 6 (estimate from related species in other ecosystems) and Q/B pedigree considered 7 (growth efficiency averaged over wide range of species). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Sea Star is a composite group that includes all members of the class Asteriodea, particularly the Family Asteriidae. One of the most common species in Alaska, and especially the GOA, is *Ctenodiscus crispatus*, the mud sea star, but the family is well represented and varied. Other common species include: blackspined sea star *Lethasterias nanimensis*, cookie star *Ceramaster patagonicus*, crested sea star *Lophaster furcilliger*, cushion sea star *Pteraster tesselatus*, fish-eating star *Stylasterias forreri*, northern sea star *Dipsacaster borealis*, redbanded sea star *Leptasterias coei*, rose sea star *Crossaster papposus*, scarlet sea star *Pseudarchaster parelii*, spiny red star *Hippasteria spinosa* and sunflower sea star *Pycnopodia helianthoides*. Sea stars do not have a sharp demarcation between the arms and central body; they move along the sea floor using their tube feet. Most sea stars are predators, feeding on either sessile or slow-moving prey such as mollusks and barnacles; sea stars turn a portion of their stomachs out through the mouth, which enables them to digest exogenously.

Biomass in the AI was estimated by assuming an EE of 0.8. The P/B of 1.21 for sea stars was calculated for intertidal species by Zaika (1983) and Asmus (1987). Little information exists for consumption rates of invertebrate benthic predators in the model regions. Q/B was calculated assuming a growth efficiency of 0.2 which resulted in a QB of 6.05. Diet compositions were obtained from the Alaska-wide OCSEAP invertebrate studies summarized by Feder and Jewett (1981). Biomass pedigree was 8 (estimated by Ecopath). The P/B pedigree was considered 6 (estimate from related species in other ecosystems) and Q/B pedigree considered 7 (growth efficiency averaged over wide range of species). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Snail (Class Gastropoda) includes all gastropods except for pteropods. Their life histories and ecology are very diverse, which allows them to fill in a number of niches. Within Alaska, the group encompasses both shallow (intertidal to 200m) and deep species (200-300m) such as *Bathybembix* sp. They may also be pelagic, such as the heteropods, which have a finlike foot and reduced shells. Whelks, false tritons (Family Buccinidae) and moonshells (Family Naticidae) are also found in Alaskan waters. While most gastropods are herbivores, many feed on organic debris and others are carnivores. Predatory snails commonly drill holes into the shells of their preys which includes other snails as well as skate egg cases, worms, sea urchins and fish.

Biomass was estimated by assuming an EE of 0.8. A P/B value of 1.81 for intertidal snails was calculated by Asmus (1987). Q/B was calculated assuming a growth efficiency of 0.2 which resulted in a QB of 9.05. Feder and Jewett (1981) report that *Neptunea* and *Solariella* snails feed on polychaetes, other infauna, and detritus in the eastern Bering Sea: for lack of information, diets of snails were equally proportioned between representatives of these groups and macroalgae.
Biomass pedigree was 8 (estimated by Ecopath). The P/B pedigree was considered 6 (estimate from related species in other ecosystems) and Q/B pedigree considered 7 (growth efficiency averaged over wide range of species). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Urchins dollars cucumbers is an assemblage of the echinoderms within the Echinoidea (sea urchins and dollars) and the Holothuroidea (sea cucumbers). Species found in Alaska include *Echinacea* sp., *Strongylocentrotus* sp (sea urchin); Family Clypeasteridae (sand dollars); Family Cucumariidae, and *Pentamera* sp. (sea cucumber).

Biomass in the AI was estimated by assuming an EE of 0.8. Rough estimates of P/B for the western Bering Sea urchins averaged 0.61 as calculated by Banse and Mosher (1980) and this value was used for this functional group in all models. Q/B was calculated assuming a growth efficiency of 0.2 which resulted in a QB of 3.05. Diet compositions were obtained from the Alaska-wide OCSEAP invertebrate studies summarized by Feder and Jewett (1981): identical diets were assumed for all three models. However, since macroalgae grazing was not quantified in these results, 25% of diet was assumed to be macroalgae. Biomass pedigree was 8 (estimated by Ecopath). P/B pedigree was considered 6 (estimate from related species in other ecosystems) and Q/B pedigree considered 7 (growth efficiency averaged over wide range of species). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Anemones (Class Anthozoa, Order Actiniaria) is a group comprised by sea anemones. Anemones are found anywhere from the intertidal zones down to trenches (to 6000 m). Within Alaska, they are relatively more abundant in the Eastern Bering Sea, though are commonly found throughout both the Gulf of Alaska and the Aleutian Islands. Species occurrence is not very well documented, as many sea anemones are only identified as actiniarians on trawl surveys (some 80%). Some of the most frequent species include *Liponema brevicornis*, *Meridium* sp, and *Uricina* sp.

Biomass in the AI was estimated using data from the Gulf of Alaska as surrogate, keeping density depth specific. So shallow and middle have a higher density than deep areas. The density estimates were taken from the 1993 ADFG surveys around Kodiak for the deep areas, and around the Alaska Peninsula for the shallow and middle areas.
There was no data on anemone growth rates so they were assumed to have a seasonal generation time, with a P/B of 1/year. Q/B was calculated assuming a growth efficiency of 0.2 which resulted in a QB of 5. These species were initially assumed to be 100% detritivores; however, detritus consumption was split between detritus (60%), benthic bacteria (15%) and benthic crustaceans/amphipods (25%) to make trophic levels comparable with pelagic tertiary consumers (e.g., euphausiids). GOA estimates as a surrogate for biomass so the pedigree was downgraded to 5. The P/B pedigree was considered 6 (estimate from related species in other ecosystems) and Q/B pedigree considered 7 (growth efficiency averaged over wide range of species). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Benthic Hydroid (Class Hydrozoa) includes some 200 species which have been identified in Alaskan waters (O'Clair and O'Clair 1998). Hydroids are mostly colonial, either erect, tree-like, or prostrate encrustations on mollusk shells (live or dead), rock, or other hard surfaces. Tree like species are usually not taller than 15 cm. Some hydroids have alternating benthic and pelagic generations. The pelagic medusae are like tiny jellyfish. Reproduction in the group is varied and complex, with many species having a free-swimming planula larva that spends hours/ days in the water column before settling to the bottom (Barnes 1980). The family Sertulariidae, identified as a food item in Alaskan diets, has been identified as part of the epifaunal community of deep sea corals (Henry 2001). On the west Kamchatka Shelf, a rich assemblage dominated by hydroids, bryozoans, and sponges was the favored habitat of young-of-the-year red king crab (*Paralithodes camtschaticus*), and hydroids were considered to be their main food. In the EBS hydroids are also part of the sessile invertebrate communities where young-of-the-year red king crab are found (McMurray et al. 1984, Stevens and MacIntosh 1991). In the SE Bering Sea, the hermit crab *Labidochirus splendescens* (splendid hermit) is typically found in a moon snail shell encrusted with the velvet textured hydroid *Hydractinia* sp. (Kessler 1985).

Biomass was estimated assuming an EE of 0.8. There was no data on benthic hydroid growth rates so they were assumed to have a seasonal generation time, with a P/B of 1/year. Q/B was calculated assuming a growth efficiency of 0.2 which resulted in a QB of 5. These species were initially assumed to be 100% detritivores; however, detritus consumption was split between detritus (60%), benthic bacteria (15%) and benthic crustaceans/amphipods (25%) to make trophic levels comparable with pelagic tertiary consumers (e.g., euphausiids).
Biomass pedigree was 8 (estimated by Ecopath). The P/B pedigree was considered 6 (estimate from related species in other ecosystems) and Q/B pedigree considered 7 (growth efficiency averaged over wide range of species). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Benthic Urochordata (Phylum Urochordata) or tunicates, includes ascidians also known as sea squirts, sea potatos, sea onions and sea peaches. The body of an adult tunicate is essentially a sack with two siphons through which water enters and exits. Water is filtered inside the body. Adults are sessile, but the larvae of many tunicates are free-swimming. Ascidians are most frequent in the EBS, though they are also found in GOA and AI. Common genera include *Aplidium* sp. *Boltenia* sp, *Styela* sp, *Halocynthia* sp. (Malecha et al).

Biomass density in the AI was estimated using Northern GOA surveys conducted in the 1970s as surrogate. A P/B value of 3.58 for intertidal Ascidians was calculated by Asmus (1987). Q/B was calculated assuming a growth efficiency of 0.2 which resulted in a QB of 17.9. These species were initially assumed to be 100% detritivores; however, detritus consumption was split between detritus (60%), benthic bacteria (15%) and benthic crustaceans/amphipods (25%) to make trophic levels comparable with pelagic tertiary consumers (e.g., euphausiids). Biomass pedigree was considered 5 as values came from literature results from non-modeled time periods. The P/B pedigree was considered 6 (estimate from related species in other ecosystems) and Q/B pedigree considered 7 (growth efficiency averaged over wide range of species). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Corals is a group composed of Cnidarians and includes soft corals, cup corals, soft corals, sea fans, hydrocorals and black corals. In Alaska, corals form gardens, as opposed to reefs like those in the tropics. These gardens can be quite extensive, as those found around the Aleutian Islands, and in very localized areas of the GOA. Main species in the AI include the bubble gum coral *Paragorgia* sp, *Fanellia* sp, *Primnoa* sp (gorgonians), *Thouarella superba* (white gorgonian), *Stylantheca petrograpta* (pink hydrocoral) and *Stylaster* sp (hydrocoral). *Paragorgia* is a long lived cold water gorgonian (gorgonians include the sea fans, bamboo and tree corals) (Wing & Barnard 2003). Within the Aleutians Islands, gorgonians prevail, followed by cup corals, hydrocorals and soft corals. They create a habitat that can be occupied by a diversity of life and provides shelter for numerous organisms, as in Adak Canyon; dead coral maybe covered with gooseneck barnacles, sponge, pink octocoral and bryozoan colonies.

In terms of frequency, all corals are more numerous in the AI, except for the soft corals in the EBS. Within the AI, the highest abundance of gorgonian corals, was found in the vicinity of Attu and Kiska Islands. Specific associations were observed between groups of fish and types of coral. Rockfish, sablefish, Atka mackerel, and arrowtooth flounder were rarely found with soft coral (compared to the other types), whereas gadids, Greenland turbot, greenlings, and other flatfish were found more frequently around them. The branches of *Primnoa* are used for suspension feeding by crinoids, basket stars, anemones, and sponges, mostly at depths greater than 300m. *Primnoa* provides shelter for six rockfish species, as well as crabs and shrimp, and is therefore a key component of the deepwater ecosystem (Krieger & Wing 2002).

Biomass in the AI was estimated based on the average of the 1990-1993 NMFS survey highest density estimates for the Gulf of Alaska; highest density of coral occurred in the central gulf shelf (0.011); since this would not satisfy the demand in the ecosystem it was multiplied by 8, which is how much more bycatch of coral there is in the AI compared to GOA (7.8333, rounded to 8). A lifespan of 100 years is reported for Aleutian Islands Gorgonians by Andrews et al. 2002. Assuming it takes this amount of time for 99% of mortality to occur results in a P/B equal to the mortality rate of 0.046/year. Q/B was calculated assuming a growth efficiency of 0.2 which resulted in a QB of 0.23. These species were initially assumed to be 100% detritivores; however, detritus consumption was split between detritus (60%), benthic bacteria (15%) and benthic crustaceans/ amphipods (25%) to make trophic levels comparable with pelagic tertiary consumers (e.g., euphausiids). Biomass pedigree was 5, as GOA estimates were used as a surrogate. The P/B pedigree was considered 6 (estimate from related species in other ecosystems) and Q/B pedigree considered 7 (growth efficiency averaged over wide range of species). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Sea Pens (Octocorallia: Pennatulacea) group the benthic cnidarians commonly known as sea pens and sea whips. Age and growth estimates for the sea pen *H. willemoesi* have been based on the ring couplets in the axial rod which were considered as annuli. The ring couplet counts indicate growth in length is slow at first, fastest at medium size, and slows toward maximum size, with an estimated longevity approaching 50 yr. They can form large colonies of over 150 cm. (Wilson, et al. 2002). Sea pens are most frequently found in the Gulf of Alaska, but they also occur in the EBS and the AI. Species identified belong to the genera *Halipteris* sp, *Stylatula* sp, *Virgularia* sp, and *Ptilosarcus* sp. Cod and pollock are most commonly caught with sea anemones, sea pens and sea whips (Malecha et al).

Biomass density in the AI was estimated using the data from the Gulf of Alaska trawl surveys as surrogate. A lifespan of 50 years is reported for sea pens in Alaska (Wilson et al. 2002). Assuming during this time 99% of mortality occurs, the resulting P/B equals to the mortality rate of 0.092/year. Q/B was calculated assuming a growth efficiency of 0.2 which resulted in a QB of 0.46. These species were initially assumed to be 100% detritivores; however, detritus consumption was split between detritus (60%), benthic bacteria (15%) and benthic crustaceans/amphipods (25%) to make trophic levels comparable with pelagic tertiary consumers (e.g., euphausiids). Biomass pedigree is 5, as GOA estimates were used as a surrogate. The P/B pedigree was considered 6 (estimate from related species in other ecosystems) and Q/B pedigree considered 7 (growth efficiency averaged over wide range of species). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Sponge (Phylum Porifera) is a varied group, well represented throughout Alaskan waters. In the Aleutians the most frequent species are *Halichondria* cf *sitiens, Polymastia* sp, *Tethya* sp, and *Micale loveni.* Several sponges are classified by their common names only, these include club sponges, cat-o-nine tail sponges, and the hairy lemon sponge (Malecha et al). Sponges are important live substrates; the stalks of glass sponges (hexactinellids) provide hard substrate and act as habitat islands for deep-sea fauna (Beaulieu 2001). They also seem to play some role in halibut habitat. When given the choice between bare sand or sand with 16% sponge coverage, halibut demonstrated strong preference for sponge. Sponges also tend to provide shelter from predation; their emergent structure, in otherwise low-relief benthic habitats, may play an important role in the ecology of some juvenile flatfishes. Removal of emergent structure by towed fishing gear and other anthropogenic and/or natural disturbance may influence patterns of distribution for juvenile halibut, as fish redistribute to less preferred habitat, and may decrease survival rates through increased losses to predation (Ryer et al. 2004).

Biomass in the AI was estimated using sponge data from the Gulf of Alaska. Data for the shallow and middle areas in the AI comes from the 1990 and 1993 NMFS GOA survey estimates for the west GOA shelf (660.4 tons). Data for the deep areas in the AI comes from the 1999 NMFS GOA slope survey estimates for the west GOA (20011.43). There was no data on sponge growth rates so they were assumed to have a seasonal generation time, with a P/B of 1/year. Q/B was calculated assuming a growth efficiency of 0.2 which resulted in a QB of 5. These species were initially assumed to be 100% detritivores; however, detritus consumption was split between detritus (60%), benthic bacteria (15%) and benthic crustaceans/amphipods (25%) to make trophic levels comparable with pelagic tertiary consumers (e.g., euphausiids).
Biomass pedigree was 6, as GOA estimates were used as a surrogate. The P/B pedigree was considered 6 (estimate from related species in other ecosystems) and Q/B pedigree considered 7 (growth efficiency averaged over wide range of species). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Clams (Class Bivalvia) is a group comprised by all bivalves and clams. Bivalves are the second largest class of mollusks following gastropods. The group includes mussels, scallops, cockles and scaphopods. Within Alaskan waters there are at least eight families of bivalves that are important as prey: Nuculidae, Nuculanidae, Mytilidae, Pectinidae, Lucinidae, Cardiidae, Tellinidae, Myidae.

Biomass in the AI was estimated by assuming an EE of 0.8. An estimate of P/B= 1.3/year for clams was obtained from Evans (1984), which is comparable to the value 1.47 cited from various sources in the western Bering Sea (Aydin et al. 2002). Q/B was calculated assuming a growth efficiency of 0.2 which resulted in a QB of 6.5. These species were initially assumed to be 100% detritivores; however, detritus consumption was split between detritus (60%), benthic bacteria (15%) and benthic crustaceans/amphipods (25%) to make trophic levels comparable with pelagic tertiary consumers (e.g., euphausiids). Bivalves had a biomass pedigree of 8 (estimated by Ecopath). The P/B pedigree was considered 6 (estimate from related species in other ecosystems) and Q/B pedigree considered 7 (growth efficiency averaged over wide range of species). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Miscellanous Worm Etc. is a composite assemblage containing annelid worms (including oligochaetes, leeches, flatworms), sipunculids (peanut worms), bryozoans (moss animals), and brachiopods (lampshells). For the AI, most of the prey items in this group were either either bryozoans (Ectoprocta) or marine worms (Echiuridae).

Biomass was estimated assuming an EE of 0.8. An average P/B of 2.23 for polychaetes in multiple ecosystems was calculated from sources cited in Aydin et al. (2002); this is neither species nor system specific. Q/B was calculated assuming a growth efficiency of 0.2 which resulted in a QB of 11.15. Diet was assumed to composed of detritus; which was split evenly between detritus and benthic bacteria, to make trophic levels comparable between benthic and pelagic secondary consumers (e.g., copepods). Biomass pedigree was 8 (estimated by Ecopath). The P/B pedigree was considered 6 (estimate from related species in other ecosystems) and Q/B pedigree considered 7 (growth efficiency averaged over wide range of species). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Polychaete (Class Polychaeta) includes most marine segmented worms. Polychaetes are well represented within Alaskan fish diets, and numerous families have been identified: Alciopidae, Aphroditidae, Chaetopteridae, Eunicidae, Flabelligeridae, Glyceridae, Lumbrineridae, Maldanidae, Nephtyidae, Nereidae, Onuphidae, Opheliidae, Phyllodocidae, Polynoidae, Sabellidae, Terebellidae, Tomopteridae, Trichobranchidae, Sigalionidae, Euphrosinidae, Syllidae, Sphaerodoridae, Goniadidae, Arabellidae, Orbiniidae, Paraonidae, Spionidae, Cirratulidae, Scalibregmidae, Sternaspidae, Capitellidae, Oweniidae, Sabellaridae, Pectinariidae, Ampharetidae, Serpulidae, Spirorbidae. However, groundfish prey items are often unidentifiable beyond class Polychaeta. For the AI, out of the 37 familes listed above, only the first 18 have been identified among stomach contents.

The bristles, or setae, of polychaetes project from side flaps called parapods. Polychaete feeding habits vary from detritus feeding to suspension feeding (filtering plankton and detritus from the water using feathery feeding tentacles) to active predation. On hard substrates such as rocks or corals, polychaetes may build temporary or permanent tubes, where they lead stationary lives by filtering the water for suspended food. A few polychaete species, such as scale worms, have taken up a symbiotic lifestyle, living in association with sea stars and limpets or other marine animals. Reproduction is generally through dispersal of gametes directly into the sea. Once fertilized, eggs develop into ciliated larvae called trochophores. These larvae live in the plankton, feeding on suspended algae, until they develop into juvenile worms that settle to the benthos to become adults.

Biomass was estimated by assuming an EE of 0.8. An average P/B of 2.97 for polychaetes in multiple ecosystems was calculated from sources cited in Aydin et al. (2002); this is neither species nor system specific. Q/B was calculated assuming a growth efficiency of 0.2 which resulted in a QB of 14.85. Polychaetes were assumed to consume detritus; however, detritus consumption was assumed to be split evenly between detritus and benthic bacteria, to make trophic levels comparable between benthic and pelagic secondary consumers (e.g., copepods). Biomass pedigree was 8 (estimated by Ecopath). The P/B pedigree was considered 6 (estimate from related species in other ecosystems) and Q/B pedigree considered 7 (growth efficiency averaged over wide range of species). Diet estimates were considered poor (7) due to extrapolation of primarily qualitative data.

Pelagic Zooplankton

Suitable biomass estimates were not available for the AI, thus for all groups comprising the pelagic zooplankton, biomass was estimated assuming an EE of 0.8. For several functional groups within this category, adequate PB, QB and diet estimates were also lacking. For the PB and QB rates, euphasiids were thought to provide a good approximation. Thus the PB ratio of 5.475 was used as surrogate and QB was estimated using a growth efficiency (GE) of 35%

which represents temperature-specific 3% growth scenarios in euphasiids (Smith 1991, Parsons et al. 1984). This allowed QB ratios to be commensurate to PB rates. Finally, when diets were not available for specific groups, were assumed to be 25% copepods, 15% microzooplankton, 50% large phytoplankton and 10% small phytoplankton, which yields a trophic level of 2.5. [redacted]

Chaetognaths etc. (Phylum Chaetognatha) includes arrow worms and the acorn worms (Hemichordata: Enteropneusta). Arrow worms range in size from 3mm to 12cm., are transparent or translucent, and are covered by a cuticule. All species are hermaphroditic, carrying both eggs and sperm. A few species are known to use neurotoxins to subdue prey. *Sagitta* sp has been identified in Alaskan waters. For the Aleutian Islands, they comprise common food items for walleye pollock, Atka mackerels, Pacific Ocean perch, northern rockfish, arrowtooth, spectacled sculpin and northern lampfish.

Biomass was estimated by assuming an EE of 0.8. PB and QB values were taken from euphasiids resulting in a PB of 5.475 and a QB of 15.64 based on a GE of 35%. Diet composition was taken from an model in an adjacent area, the EBS ([redacted]). pedigree

Copepods (Order Copepoda) are a major zooplankton group worldwide. Most Alaskan species belong to the superfamily Calanoida, which is not surprising as calanoids are the most successful copepods in colonizing pelagic environments. Several families are well represented: within the Family Calanoidae, common genera include *Calanus, Neocalanus,* and *Mesocalanus.* Within the Family Eucalanidae are the genera *Ecucalanus, Rhincalanus,* and *Paracalnus.* Within Family Pseudocalanidae are the genera *Clausocalanus, Ctenocalanus,* and *Pseudocalanus.* Family Aetideidae contains the genera *Aetideopsis, Aetideus, Chiridius, Euchirella,* and *Gaetanus,* and Family Euchatetidae contains genus *Euchaeta.* Family Metridiidae contains genera *Metridia, Pleuromamma, Centropages, Pachyptilus, Candacia, Epilabidocera,* and *Acartia.* Superfamily Harpacticoida contains genera *Oncaea, Corycaeus, Oithona,* and *Copepoda monstrilloida,* and Superfamily Caligoida is also found in Alaska. Though the list of species is extensive, within the Aleutians, only a few of these species have been found as prey, namely: *Candacia columbiae, Candacia* sp, *Neocalanus cristatus.* Though the list of species is extensive, within the Aleutians, only a few of these species have been found as prey, namely: *Candacia columbiae, Candacia* sp, *Neocalanus cristatus* as most prey can only be identified as copepods.

Biomass in the GOA and AI was estimated by assuming an EE of 0.8. PB is assumed to be 6 (Trites et al. 1999); QB of 27.74 (Cooney 1982). This value is between those proposed by Daggs et al. and Trites et al. 1999, 33 and 26.2 for Trites. Diet composition was taken from an adjacent area, the EBS.

Euphausiid (Family Euphasiidae) is a dominant group within the zooplankton in high latitude seas worldwide. Twenty three species have been identified in the NE Pacific, from northern California to northern Alaska (Kathman, et al. 1986); at least fourteen of these have been identified in Alaskan diets. Common Alaskan genera include *Euphausia* sp, *Nematoscelis* sp, *Stylocheiron* sp, *Tessarabrachia* sp, *Thysanoessa* sp. In the Aleutian Islands the most common species are *Thysanoessa spinifera, T.inermis, T. longipes, Euphasia pacifica,* and *Tessarabrachia oculatum.*

Biomass was estimated by assuming an EE of 0.8. The PB value was adapted from Smith Smith 1991. PB values Ranged from 2% to 6% per day during spring-late summer for *T. inermis* and *T. raschi* during 1980-81 (warm and cold years). The higher estimates include egg production in females only. A value of 3%/day was chosen to account for euphasiids being highly productive for only half the year. QB resulted in 15.64 based on a GE of 35% (Smith 1991, Parsons et al. 1984). Diet composition was assumed to be the same as that in an adjacent area, the EBS (see above).

Fish larvae is an aggregate of all fish planktonic larvae.

Biomass was estimated by assuming an EE of 0.8. PB and QB values were taken from euphasiids resulting in a PB of 5.475 and a QB of 15.64 based on a GE of 35%. Diet composition was assumed to be the same as the default diet for all pelagic zooplankton (see above).

Mysid is a group comprised mostly by the Order Mysidacea, however unidentified malacostraca (which includes decapods, amphipods, and isopods among others) are also within this group. Represented in Alaskan diets are at least 24 of the 48 mysid species reported for the NE Pacific (Kathman et al. 1986). The most representative families are Mysidae and Eucopiidae, with well represented genera such as *Acanthomysis,* sp., and *Neomysis* sp. In the AI however, these are not main prey items, rather the most commonly consumed species are *Gnathophausia gigas,* and *Meterythrops sp.* Mysids are shrimp-like crustaceans, sometimes referred to as opposum shrimps because the females carry their developing young in a bulging pouch or marsupium formed by at the base of their legs. Females can carry broods of up 30 fry in their pouches, although 6 or 7 is the normal brood size. Young mysids are only released once they are well-developed juveniles. Mysids, cumaceans, amphipod and shrimps and can be found in swarms and these swarms are important in describing the geographic patterns of grey whales feeding from the Chukchi Sea to Baja California (Kim & Oliver 1989, Kathman et al. 1986).

Biomass was estimated by assuming an EE of 0.8. PB and QB values were taken from euphasiids resulting in a PB of 5.475 and a QB of 15.64 based on a GE of 35%. Diet composition was assumed to be the same as the default diet for all pelagic zooplankton (see above).

Pelagic Amphipods groups a minimum of 9 families which have been identified in Alaskan waters : Melphidippidae, Oedicerotidae, Phoxocephalidae, Pleustidae, Podoceridae, Stenothoidae, Synopiidae, Hyperiidae, Phronimidae. Within the Aleutians, the most common family is Hyperiidae followed by Stenothoidae, and only 3 genera have been identified: *Themisto* sp, *Phromina* sp, and *Primno* sp. Hyperiids are primarily nektonic amphipods are mostly commensals and parasitoids of gelatinous zooplankton like medusas, salps, and coelenterates; gammarid and hyperiid amphipods, along with mysids, and euphausiids can prey on eggs and yolk-sac larvae of walleye pollock (Bailey et al. 1993).

Biomass was estimated by assuming an EE of 0.8. A PB of 2.5 was assumed based on Russian averages for the wester Bering Sea (Aydin et al. 2002). The QB of 15.64 was based on a GE of 35%. Diet composition was assumed to be the same as the default diet for all pelagic zooplankton (see above).

Pelagic Gelatinous Filter Feeders is a composite group which includes the salps and larvaceans (the only free-swimming pelagic urochordates), and ctenophores. Ctenphores are also known as gooseberries, sea walnuts or Venus's girdles. Both *Salpa* sp and *Thaliacea* sp are salps found in diets within the AI, but it is the larvaceans of the Order Copelata that are found most frequently as prey items. There are about 70 species of larvaceans; they can filter particles as small as 1 micron, which enables them to feed on coccolithophorid phytoplankton. Larvaceans reproduce sexually and are mostly hermaphrodites; they are small, typically not longer than 5mm across, but can reach up to 100 mm. They secrete a temporary gelatinous house (they lack a tunic) which they replace several times a day, as it becomes clogged with particles. Salps have the inlet siphon at one end and the outlet at the other end (as opposed to ascidians which have both on the same side). Rather than having cilia to move the water, they contract rhythmically to pump water through the body. They have no larval stage as they develop directly into adult organisms. They commonly form swimming colonies and are bioluminescent. Ctenophores are mainly composed of inert mesoglea, which causes them to have a low rate of metabolism. Many species are bioluminescent. Ctenophores are also known as comb jellies because of the eight "comb rows" of fused cilia. The ctenophores are hermaphroditic, and some species can reproduce asexually. Unlike cnidarians, with which they share several superficial similarities, they lack stinging cells. Instead, in order to capture prey, ctenophores possess sticky cells called colloblasts.

Biomass was estimated by assuming an EE of 0.8. PB and QB values were taken from euphasiids resulting in a PB of 5.475 and a QB of 15.64 based on a GE of 35%. Diet composition was assumed to be the same as the default diet for all pelagic zooplankton (see above).

Pteropods (Order Pteropoda) are pelagic mollusks also known as sea butterflies, as their anterior portion of the foot has expanded to form swimming fins. Genera include *Thecosomata* sp, *Lumacina* sp and *Clione* sp. Within Alaskan waters, both *Thecosomata* and *Gymnosomata* are found as part of fish diets. Due to their specific environmental requirements, most single-species populations, as well as species assemblages, characterize various water masses and circulation patterns. Ecological biogeographers have mapped the limits of ranges of numerous taxa and have drawn broad ecological inferences. Being planktonic, both foraminifera and pteropods float passively, or nearly so, with currents (Herman & Andersen 1989).

Biomass was estimated by assuming an EE of 0.8. PB and QB values were taken from euphasiids resulting in a PB of 5.475 and a QB of 15.64 based on a GE of 35%. Diet composition was assumed to be the same as the default diet for all pelagic zooplankton (see above).

Scypho Jellies Scyphozoa (jellyfish) are generally just identified as such and in the AI they are generally consumed by Atka mackerel and prowfish.

Biomass in the AI was estimated by assuming an EE of 0.8. PB was assumed to be 0.88 (Trites et al. 1999) and QB was assumed to be 3, based on a summer ration of 3 taken from Brodeur et al. 2002. Pedigree for the biomass estimate is 7 (selected density value from Prince William Sound by Purcell). Both PB and QB have a pedigree of 6 (historical/ single study not overlapping with the AI). Diet is 7, based on a literature review, outside the region.

Microzooplankton, Microbial loop and primary producers

Unfortunately no reliable estimates suitable for the entire geographic range of the islands were available for microzooplankton or primary producers. Some estimates are available for areas north, fronts in the Aleutians (Kern and Coyle 1992). These estimates were tried in the model despite being both outside the geographic range of the model and uncharacteristic of the Aleutian chain. They proved to be too low, insufficient to satisfy system requirements, particularly for euphasiids and copepods. All biomass estimates have a pedigree of 8, as all values were estimated using Ecopath. The PB has a value of 6 for euphasiids,pelagic amphipods and phytoplankton, as their values were derived from studies ata different time but on same species or same species different area GOA for the phytoplankton). The rest has 7 as the values were derived from those for euphasiids (lit review outside region). QB estimates have the same pedigree as the PBs. Diets were 7 as they come from a general literature review.

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Vita

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