ISSN 1198-6727

Fisheries Centre Research Reports

2005 Volume 13 Number 1

Food web models and data for studying fisheries and environmental impacts on Eastern Pacific ecosystems

Fisheries Centre, University of British Columbia, Canada

Food web models and data for studying fisheries and environmental impacts on Eastern Pacific ecosystems

edited by
Sylvie Guénette
Villy Christensen

Fisheries Centre Research Reports 13 (1)
237 pages © published in 2005 by

the Fisheries Centre, University of British Columbia
2259 Lower Mall
Vancouver, B.C., Canada

ISSN 1198-6727

Fisheries Centre Research Reports 13(1)
2005

FOOD WEB MODELS AND DATA FOR STUDYING FISHERIES AND ENVIRONMENTAL IMPACTS ON EASTERN PACIFIC ECOSYSTEMS

edited by
Sylvie Guénette and Villy Christensen

Contents

A Research Report from the Fisheries Centre at UBC
237 pages © Fisheries Centre, University of British Columbia, 2005

FISHERIES CENTRE REPORTS ARE ABSTRACTED IN THE FAO AQUATIC SCIENCES AND FISHERIES ABSTRACTS (ASFA)
ISSN 1198-6727

Director's foreword

There are various ways ecosystem "control", and two of these are 'top-down control' and 'bottom-up control', usually set as alternatives. This dichotomy has various incarnations; in the Pacific Northwest it is referred to as the 'Thompson-Burkenroad debate', with the former associated with top-down control (here: of halibut biomass, by fishing), and the latter bottom-up control (with environmental variability responsible for changes in the recruitment, and eventually, the biomass of halibut). When applied to ecosystems, more often than not, the 'bottom-up' part of this dichotomy has more evidence in its favour, particularly in the Pacific Northwest, where 'regime shifts' tend to be invoked almost exclusively to explain ecosystem changes. The main reason for this asymmetry, however, is that it is easier to measure temperature and its variability, or chlorophyll and its variability, than to construct and fit ecosystem models and test how much they explain of the variability at hand. However, it has now become possible to straightforwardly construct models of ecosystems, and to fit them with time-series data, and thus to test top-down control hypotheses, i.e., to separate out top-down from bottom-up effects. These tests, which required ecosystem models such as documented in this report, have not shown regime shifts to be unimportant. Rather, they have shown, at least for the North Pacific, that bottom-up and top-down processes occur simultaneously, and that both must be taken in account when modelling these ecosystems. Thus, this document is part of what will take us beyond the dichotomy, toward the complex hypotheses that these complex ecosystems deserve.

Daniel Pauly
Director, Fisheries Centre, UBC

Fisheries, the environment, or what? An introduction

Sylvie Guénette and Villy Christensen

The North Pacific is a hot-bed for understanding how marine populations are impacted by humans as well as by environmental conditions. The "Thompson-Burkenroad debate" has been ongoing since the late-1940s: what drives the marked fluctuations in Pacific halibut that has been observed over the past century? Dr William Thompson, who started up the work of the International Pacific Halibut Commission, IPHC, argued that the changes in halibut abundance could be fully explained by changes in fishing pressure, i.e. that they were the result of successful management on the part of IPHC, while his adversary, Dr Martin Burkenroad questioned if the populations trends could be accounted for by fishing pressure on its own, or if wasn't rather a question of environmental factors impacting halibut recruitment. While Thompson and Burkenroad actually never debated the relative role of fisheries and the environment – indeed it may well be that they would actually agree that one factor in itself would not suffice to give us the full explanation their debate has lived on, and both sides still have proponents arguing for one over the other. Examining the Pacific halibut trends now, nearly 60 years after the debate started, still yields inconclusive answers only. We cannot name the culprit.

The debate has widened since Thompson and Burkenroad's days, and we regularly hear about regime shifts in connection with the North Pacific. A notable debate in this context has emerged, seeking explanations for why the Steller sea lions have declined to become threatened in major parts of their North Pacific distribution area, while increasing in others. A multitude of explanations have been brought forward, and considerable research has been aimed at understanding the importance of nutritional conditions, of predators and of prey, of competition with commercial fisheries, of parasites and diseases, of the Pacific Decadal Oscillation Index, and of the potential impact of incidental culls, to mention some. As for the halibut, no conclusive explanation has emerged.

Asking then, if the non-emergence of a single clear explanation may be due to the Steller sea lion being impacted by a combination of factors the North Pacific Universities Marine Mammal Research Consortium and the North Pacific Marine Science Foundation initiated a project "Ecosystem analysis of Steller sea lion dynamics and their prey" through NOAA funding. The project, which was the brain child of Andrew Trites (Director of the Marine Mammal Research Unit, Fisheries Centre), employs ecosystem modelling of North Pacific ecosystems (Southeast Alaska, the Central Gulf of Alaska and the Western Aleutian Islands) in an attempt to evaluate (quantify!) the relative role the various factors may have played in determining population trends. The methodologies applied for the modelling along with some of the preliminary findings from the study are described in this report. Notably, the models indicate that no single factor by itself can explain the population trends of Steller sea lion, several have to be invoked.

In parallel to the work centred on Steller sea lion, the UBC 'Sea Around Us' project (www.seaaroundus.org) through funding from the Pew Charitable Trusts initiated a series of workshops aimed at evaluating the relative role of fisheries and environmental factors for North Pacific ecosystems. Bringing together researchers from the Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo; the NOAA Alaska Fisheries Science Center, Seattle; the University of Washington, School of Fisheries, Seattle; and the University of British Columbia, Fisheries Centre, Vancouver, to analyse a series of ecosystems ranging from the Bering Sea to the Northern California Current, and coordinate the methodologies. We present descriptions of some studies in this report, while most of the findings are published separately. The present report also includes a reconstruction of North Pacific whale catches for the 20th century, which served to estimate the whale population at different periods in Southeast Alaska and the Western Aleutians. Finally, in the interest of preparing future work related to evaluating nutritional aspects of North Pacific ecosystems we have included a compilation of the energy content of invertebrates, fish and mammals in the Gulf of Alaska.

The present report is freely available at the website of the Fisheries Centre of the University of British Columbia (www.fisheries.ubc.ca/publications/reports/fcrr.php).

Ecosystem models of the Western and Central Aleutian Islands in 1963, 1979 and 1991[1]

Sheila J.J. Heymans

Fisheries Centre, UBC, Vancouver, BC; s.heymans@fisheries.ubc.ca

ABSTRACT

This paper describes the data and methodology used to construct three models for the Aleutian Islands for 1963, 1979 and 1991 as well as how the 1963 model was fitted to time series data. The models were built to examine the decline in the western stock of Steller sea lions, *Eumetopias jubatus*, and reflect that purpose in the breakdown of groups, e.g. it includes 4 different groups for Steller sea lions. The models also include 5 other mammal groups and there were 21 groups of fish, 6 invertebrate, 2 primary producers, sea birds and detritus for a total of 40 groups.

INTRODUCTION

The reasons for the Steller sea lion decline in the Aleutian Islands were investigated by using three models of the system from the early 1960s (1963), the late 1970s (1979), and the early 1990s (1991) and fitting the 1963 model to time series data to obtain the best fit of the model parameters to the time series data. The models consist of 40 compartments, of which 1 is detritus, 2 primary producers (phytoplankton and macrophytes), 6 invertebrates, 9 marine mammals, 1 seabird and 21 fish. A brief overview of the fisheries is given below, followed by the description of each compartment and their specific time series of biomass and catches, model balancing and finally model fitting.

Various hypotheses for the decline in Steller sea lion have been given: disease, orca predation, junk food hypothesis, entanglement in marine debris, climate change, pollution and fisheries interactions (Alverson 1992). The interactions between fisheries and Steller sea lions include competition for food sources, bycatch mortalities, interruption of normal feeding patterns, shooting in defence of gear, as well as indiscriminate shooting (Alverson 1992). Fishermen have been observed killing adult sea lions at rookeries, haul-outs and in the water near boats and trawl fishermen commonly shoot sea lions during haul back operations (Merrick et al. 1987). Sea lions were also used as bait for crab traps and Merrick et al. (1987) suggested that it is not a coincidence that the sea lions declined during the peak landing for Bering Sea king, *Lithodes* spp., and snow crabs, *Chionoecetes opilio*. Sea lions tend to sink when shot, and Fiscus and Baines (1966) found that 68% of the sea lions killed sank when they were collecting them at sea. Thus, the shooting of sea lions in defence of gear or indiscriminately would not be noticeable as stranding.

STUDY SITE

The Aleutian Island chain is 1,100 miles (1,770 km) long and stretches from the Alaskan Peninsula to close to Siberia (Figure 1A) (Murie 1959). It consists of 70 named islands, and the southernmost island (Amatignak) lies not far north of 51˚N, which is the same latitude as the northern tip of Vancouver Islands (Murie 1959). Very few of the islands are flat and have lakes (Amchitka, Agattu ans Semichi), and many of the islands are volcanic (Murie 1959). The waters of the Aleutian Islands are generally sea ice free, and the weather is usually cloudy or foggy with an abundance of rain in the summer (Murie 1959).

The specific area of this model covers administrative areas 541, 542 and 543 in the western and central Aleutian Islands, from 170˚W to 170˚E around the Aleutian Islands, to the 500 metre depth contour, and it encompasses an area of 56,936 km² (Figure 1B). The westernmost island in the model area is Attu Island in the "Near Islands" group, and the eastern cutoff to the model is Carlisle Island, halfway through the "Islands of Four Mountains" group (Figure 1B). Most of the fish species are managed for the Bering Sea and Aleutian Islands combined (BSAI), while very few species, such as Atka mackerel, *Pleurogrammus monopterygius*, are managed specifically for the Aleutian Islands (170˚W to 170˚E).

---

[1] Cite as: Heymans, Sheila J.J., 2005. Ecosystem models of the Western and Central Aleutian Islands in 1963, 1979 and 1991. In: Guénette, S., and V. Christensen (editors). 2005. Food web models and data for studying fisheries and environmental impacts on Eastern Pacific ecosystems Fisheries Centre Research Reports 13(1): 8-82.

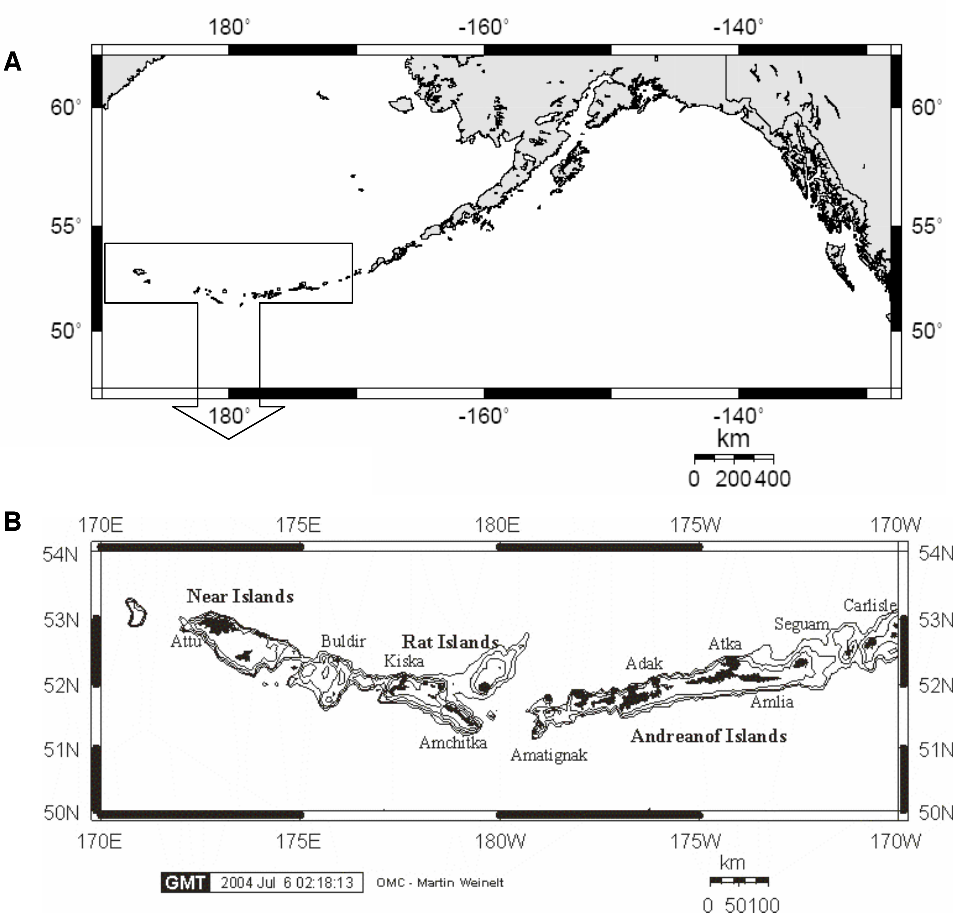


Figure 1. A. Map of the North Pacific showing the Aleutian Islands, Bering Sea and Gulf of Alaska. B. Study area for the Western and Central Aleutian Islands models showing the approximate area of the model down to the 500 m depth contour.

FISHERIES

Human activity in the north Pacific can be divided into four distinct periods (Figure 2): the subsistence period from 28,000 years ago to present, the northern fur seal period (1786–1984), the whaling period (1845–1914) and the commercial fishing period which started in 1952 in the Bering Sea (Loughlin et al. 1999) and in 1960 in the Aleutians. During the subsistence period aboriginal fishermen fished from large dugout canoes to capture abundant flatfish, dogfish, *Squalus acanthias*, rockfish, *Sebastes* spp., lingcod, *Ophiodon elongatus*, Pacific cod, *Gadus macrocephalus*, herring, *Clupea pallasii,* and blackcod or sablefish, *Anoplopoma fimbria* (Forrester et al. 1978). Faunal analyses of archaeological sites throughout the Aleutian chain confirmed the heavy use of sea lion and other marine mammal species by prehistoric Aleuts (McCartney (1984) in Wolfe et al. 2002). From four well-preserved sites on southwest Umnak Island in the eastern Aleutians, about 70% of the archaeological biomass (meat weight) was represented by sea lions, compared to only 12% by fur seals, *Callorhinus ursinus*, and 3% by sea otters, *Enhydra lutris* (Yesner (1981) in Wolfe et al. 2002). The primary uses for sea lions were for food and clothing, and sea lion whiskers were sold to the Chinese in San Francisco (Wolfe et al. 2002). In addition to marine mammals, native fishing also included seabirds and fish (Loughlin et al. 1999). In the recent time, sea lion hunting was done primarily from skiffs along the coast of Atka and Amlia Islands during the early 1980s (Wolfe et al. 2002).

Sealing started when northern fur seals were discovered on the Probilof Islands by the crew of a Russian ship, and from 1786 to 1984 they were commercially harvested for their fur (Figure 2) while at present there is only a subsistence fishery by Native fishers for meat (Loughlin et al. 1999). The harvest of northern fur seals was the sole commercial activity until 1845, when whaling ships moved from whaling grounds near Kodiak and south of the Aleutian Islands into the Bering Sea Hunt (1975 in Loughlin et al. 1999). Between 1889 and 1907, predominantly blue whales, *Balaenoptera musculus,*

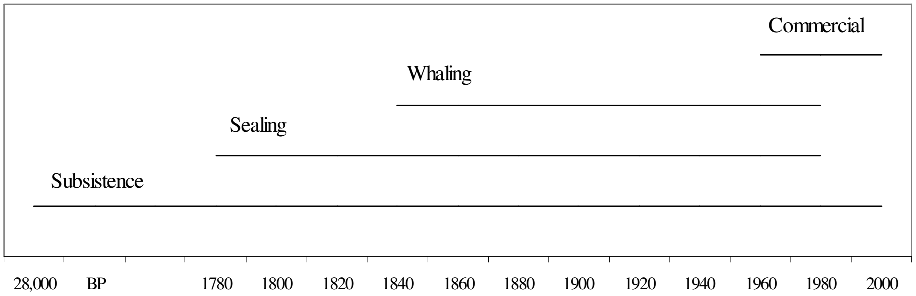


Figure 2. The four periods of human exploitation in the Aleutian Islands adapted from Loughlin et al. (1999).

were taken (Mackintosh 1965) and by 1914 whaling became uneconomical in the Bering Sea. However, whaling continued in the northeast Pacific until 1974 (Figure 2) when the last fin whale, *Balaenoptera physalus,* was caught and gray whales, *Eschrichthius robustus,* are still taken as subsistence (Guénette and Salter, this volume). By the late 1960s, only Japan and the USSR were whaling and they were only catching sperm, *Physeter macrocephalus*, fin and sei whales, *Belaenoptera borealis* (Merrell 1977).

In the Aleutian Islands, the commercial fishery started in 1960-1962 when Canada and the USA began fishing for halibut, *Hippoglossus stenolepis* (Figure 2) (Forrester et al. 1978). The Japanese fishery for Pacific Ocean perch (POP), *Sebastes alutu*s, started in 1962 (Forrester et al. 1978) and the USSR conducted experimental fisheries for both sablefish and halibut from 1962-1964 (USFWS 1965). The Japanese longline fisheries for Pacific halibut, cod and sablefish started in the 1960s and increased their effort in the 1970s (Figure 3). The target species off the Aleutian Islands was mainly POP and other rockfish through the 1960s and early 1970s, but POP and rockfish ceased to be important after the mid-1970s (Alverson 1992). In 1974, South Korea expanded their fleet into the central Aleutian Islands where they fished for pollock, *Theragra chalcogramma*, arrowtooth flounder, *Reinhardtius stomias*, POP, cod and halibut (USFWS 1967; 1974). The foreign trawl fishery depleted stocks of POP in the 1960s and 1970s, with peak landings in 1965 (115,000 tonnes (t), Figure 3) (National Research Council 2003).

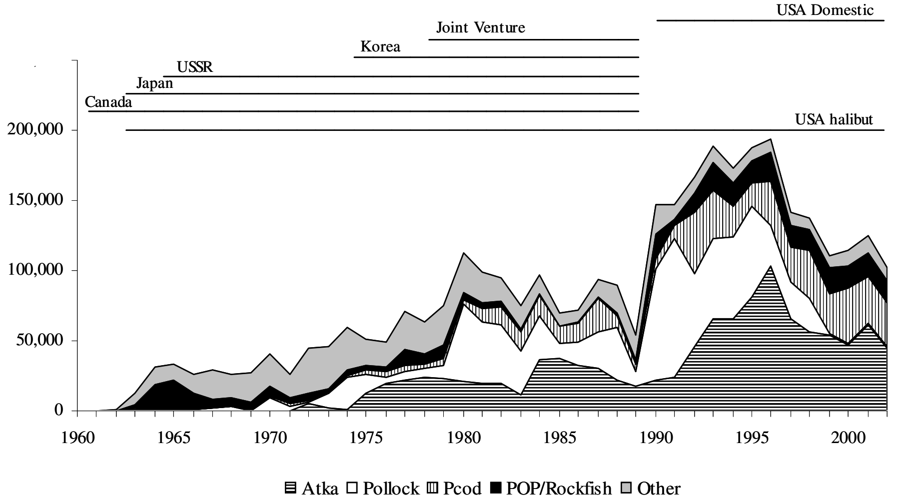


Figure 3. Catches (tonnes) made in the Aleutian Islands from 1960-2002 and time-frame of fishing nations that took those catches. The category "other" includes marine mammals, sablefish, all flounders, halibut, cephalopods and bycatch/discards of sharks, skates, sculpins, etc.

From 1960, the freezer fleets began to catch halibut, sablefish, POP, herring etc. and together with the longline and gillnet fleets, they extended operations to the continental slope in the Aleutians (Forrester et al. 1978). Pollock dominated the Japanese catches after 1964, when the surimi production was introduced to factory trawlers and by 1970 it constituted 88% of the Japanese total groundfish catch (Forrester et al. 1978). A foreign fishery for Atka mackerel developed in the 1970s with mean annual landings of 13,000 tonnes (t) during 1972-1979 (National Research Council 2003). By 1975, the USSR catch for Atka mackerel and other rockfish (Figure 3) had increased significantly and the effort in the Aleutians was increasing although the overall effort in the Bering Sea/Aleutian Island (BSAI) area had decreased (USFWS 1975). The BSAI groundfish fishery in 1971-1976 consisted of mostly Japanese and USSR fishers, with Japan taking 80% of the catch and the USSR taking the remaining 20% (Forrester et al. 1983). The Japanese groundfish fishery included mothership-type groundfish fisheries, trawl fisheries, longline gillnet fisheries and land based dragnet fisheries (Forrester et al. 1983).

USA commercial fishery operations were instituted in 1978 and increased rapidly as 'joint venture' fisheries (Alverson 1992). Joint venture fisheries dominated in the 1980s with average landings of 24,000 tonnes (Figure 3), and by 1990 the USA domestic fishery took over. At present, the main fisheries are for Atka mackerel, pollock, and flatfish, which are mainly caught by trawl gear (National Research Council 2003). Atka mackerel landings increased from 47,000 tonnes in 1992 to 103,000 tonnes in 1996 (Fritz (1993) in National Research Council 2003) and decreased to approximately 45,000 tonnes in 2002 (Figure 3), while total catches (including discards) were approximately 200,000 tonnes in 1996 and had been reduced to about 100,000 tonnes in 2002.

Since the inception of the fishery, large amounts of undesirable groundfish were discarded and estimates of these discards were included in “other” in Figure 3. The species most often discarded include skates (Rajidae), sharks, sculpins (Cottidae) and squids (Gaichas 2003). Most of the shark bycatch occurred in the midwater trawl pollock fishery and in the hook and line fisheries for sablefish, Greenland turbot, *Reinhardtius hippoglossoides*, and Pacific cod along the outer continental shelf and slope of the Bering Sea (Gaichas 2003). While skates were caught in almost all fisheries and areas, most of the skate bycatch were taken in the hook and line fishery for Pacific cod, with trawl fisheries for pollock, rock sole, *Lepidopsetta bilineata*, and yellowfin sole, *Limanda aspera*, also caught in significant amounts. Sculpins were caught by a wide variety of fisheries, but trawl fisheries for yellowfin sole, Pacific cod, pollock, Atka mackerel and rock sole had the biggest impact (Gaichas 2003). Squids were mainly caught as bycatch in the midwater trawl pollock fishery primarily over the shelf break and slope or in deep waters of the Aleutian basin, while octopuses were mostly caught by bottom trawlers for pollock and all three of the Pacific cod fisheries (pots, longlines and trawls) (Gaichas 2003).

MODEL DESCRIPTION

For most fish and invertebrate groups, time series data on biomass and catches were obtained from stock assessment reports or from the literature, while diets, estimates of annual P/B and Q/B ratios were obtained from a preliminary model obtained from NMFS (Yvonne Ortiz, University of Washington and NOAA, Seattle, Wa, *pers. comm.*) for the Aleutian Islands (NMFS model). The NMFS diet database included diet data specifically for the Aleutians, which would be better than the literature in most cases. As the NMFS model consisted of ~ 150 groups, with most species being split into adult and juvenile groups, I combined most of the prey groups for adults and juveniles, as well as combining the different prey groups as defined in my model. For the predator compartments, I usually used the adult diet only, as most of the biomass estimates that I had were only for the spawning stock or adult biomass; thus juvenile diets were excluded if they were not considered in the biomass. Similarly, the annual P/B and Q/B ratios of adult fish only were mostly used. For most top predators the diets, annual P/B and Q/B ratios, etc., were obtained from the literature, although in some cases, I had to revert to those given in the NMFS model.

1. Transient killer whales

Killer whales, *Orcinus orca,* in the Aleutian Islands are divided into transient and resident killer whales. Resident killer whales were grouped with toothed whales, while transients were placed in their own group as they feed on Steller sea lions. There are two proposed communities of transients; the West Coast community (from California to SE Alaska) and the Gulf of Alaska community, which includes the transients in our model (Ford and Ellis 1999). According to Rice (1968), killer whales were seen frequently in the Aleutian Islands, where there are many large rookeries of Steller sea lions.

Murie (1959) found that killer whales were common along the Aleutians in the late 1930s (1936-1938) and they generally found them in small groups (average size 3 per group), although they did see a pod of 25 animals. He quoted various unpublished notes and recordings made by captains and others of large groups of 500-1,500 killer whales in the early

1900s (1913-1922) that were apparently migrating northward (p. 336 in Murie 1959), and Turner (1886 in Murie 1959) saw as many as 150 killer whales at one time in the Aleutian Islands. Murie (1959) also reported that there were "a great deal of fighting accompanied by leaping at a remarkable assemblage of various whales, seals and other {sea} life".

Fiscus et al. (1981) counted 63 killer whales in the central Aleutian Islands (from the Rat Islands to the Fox Islands), which includes the Fox Islands (east of the study area) where 6 animals were counted, and exclude the Near Islands. They stated that their records may underestimate the number of cetaceans because their emphasis was on surveying close to shore for pinnipeds (Fiscus et al. 1981). They reported groups of 30 and 11 killer whales, two groups of 7 and one group of 2 killer whales, which could indicate that the group of 30 and 11 were residents, while the groups of 2 and 7 might be transients. They found that a group of 27 killer whales near Seguam pass was feeding with minke whales on a common food source (probably fish), thus this group was definitely not transients (Fiscus et al. 1981). They also found that there was no close association between killer whales and sea lion haul out sites (Fiscus et al. 1981). I assumed that the estimate of killer whales in 1979 would probably be similar to the 63 counted by Fiscus et al. (1981), or 0.0003 $t{\cdot}km^{-2}$ transients and 0.002 $t{\cdot}km^{-2}$ resident killer whales, using a 1:9 ratio. These could be underestimates, but I also used them for the 1963 model.

For the 1990s, Waite et al. (2002) gave an estimate of 391 killer whales in the Eastern Bering Sea, and by assuming that 25% of this population is in the Aleutian Islands, that 10% of that population is actually transient killer whales (approximately 10 animals), and that the average body weight is 2,435 kg, a biomass of 0.0004 $t{\cdot}km^{-2}$ was obtained. This is similar to using the 60 animals suggested by Ford and Ellis (1999) for the Gulf of Alaska population (from just north of SE Alaska to the Aleutians), and the area of the Gulf of Alaska (429,000 km² in Aydin et al. 2003) minus that of SE Alaska (91,351 km², S. Guénette, Fisheries Centre, UBC, *pers. comm.*), which also gave a biomass of 0.0004 $t{\cdot}km^{-2}$.

The annual P/B estimate for transient killer whales (0.025) was obtained from NMFS, and is marginally higher than the 0.02 used by Guénette (this volume) i.e. 50% of r_{max}. The annual Q/B ratio (7.5) was estimated by using the average daily requirement of 73 $kg{\cdot}day^{-1}$ for transient orcas feeding on mammals and an average weight of 3,550 kg (Barrett-Lennard et al. 1994). This estimate was used for the 1991 and 1979 models. For 1963, I increased the estimate to 10.83 as the annual food requirements were only for captive animals (see Guénette, this volume).

Killer whales are known to feed on fur seals, walrusses, sea lions, elephant seals, harbour porpoises, Dall's porpoise, minke whales, cod, flatfishes and salmon (Parsons 1987), while the diet of the British Columbia community of transient killer whales also includes sea otters, harbour seal, seabirds, Steller sea lions, California sea lion and Pacific white-sided dolphin (Ford and Ellis 1999), and some baleen whales (gray and minke whales) have also been reported (Ford et al. 1998). Additionally, in a study by Heise et al. (2003), stomach content analysis showed that harbour seals were the predominant prey item in all killer whale stomachs that contained marine mammals, and that they were likely a more important prey item for killer whales than Steller sea lions.

Barrett-Lennard et al. (1994) suggested that the proportion of Steller sea lions in the diet of transients was between 10-15% (mean 12.5%). In a survey of fishers, tour operators and others, Heise et al. (2003) found that of the 492 killer whale/sea lion interactions, only 32 attacks were fatal, and that the ratio of pups, sub-adults, adults and unknown in the attacks were 6% pups, 16% sub-adults, 50% adults (mostly young adults) and 9% not stated. However, the high percentage of adults in the diet could be due to the fact that attacks on adults would be more visible and last longer (Heise et al. 2003), and is probably an overestimate. Harbour seals, which are about the same size as a small sea lion, are usually attacked and killed under water, with blood, oil and fragments of blubber being the only evidence of a fatal attack (Heise et al. 2003). However, the observed kills would not necessarily represent the diet, as many of the smaller mammals (juvenile Steller sea lions and harbour seals) would not necessarily be observed. I therefore adapted the diet used by Guénette (this volume) to include 78% small mammals, 1% birds, 4% sea otters, 16% Steller sea lions and 1% baleen whales. I reduced the baleen whales from 3% (in Guénette, this volume) to 1% and used the 2% she had as import in her model to get a value of 4% for sea otters. The 16% of sea lions in the diet was broken down into 1% pups, 9% juveniles and 6% adults.

The fishing mortality of transient killer whales was reported at 0.4 and 0.2 killer whales respectively by the groundfish and longline fisheries (Angliss and Lodge 2002), out of a population of 346 animals, which gave a catch of 0.0000005 $t{\cdot}km^{-2}{\cdot}year^{-1}$ and 0.0000002 $t{\cdot}km^{-2}{\cdot}year^{-1}$ respectively for those fisheries. I used this value for the 1991 model. Mackintosh (1965) suggested that killer whales were captured in small numbers, and that killer whales were a nuisance to whalers as they attacked the carcasses of larger whales before they were hauled out of the water. However, as no quantitative information on catches were available or the 1979 and 1963 models, I did not include any catches for those two models.

2. Toothed whales

The toothed whales that occur in the Aleutian Islands include resident killer whales, sperm whales, *Physeter macrocephalus*, Baird's beaked whales, *Berardius bairdii*, Cuvier's beaked whales, *Ziphius cavirostris* and Stejneger's beaked whales, *Mesoplodon stejnegeri.* Belugas, *Delphinapterus leucas,* are rare visitors to the Aleutian Islands (Abegglen 1977) and were not included in our estimates. The only species for which relatively good estimates were available are sperm whales, with the estimates of resident killer whales (see section above) and the beaked whales being marginal. The estimates of Baird's, Cuvier's and Stejneger's beaked whales were obtained from Trites et al. (1997) and their average weight from Trites and Pauly (1998) (Table 1A). The calculation of biomass of these whales in the Northeast Pacific (area 7,503,000 km²) is given in Table 1B, and was used for all three time periods (1991, 1979 and 1963).

Waite et al. (2002) estimated the killer whale population in the Eastern Bering Sea at approximately 391 animals, and assuming that 25% of the population occurs in the Aleutians, and that 90% of the population were resident killer whales, the biomass was estimated at 0.004 t·km^{-2} for the Aleutian Islands. For the 1979 model, estimates of 63 killer whales were made by Fiscus et al. (1981), and 90% of that population was assumed to be resident killer whales. This estimate (0.002 t·km^{-2}) was also used for the 1963 model.

The North Pacific sperm whales are divided into the NE and NW stocks and both stocks migrate to the Aleutian Islands (Gosho and Rice 1984). The NE Pacific (Eastern temperate) stock currently consists of approximately 24,000 whales and the NW Pacific stock 29,674 whales (Whitehead 2002). Perry et al. (1999) suggested that only the mature male sperm whales move north into the Aleutian Islands waters in the summer, although Nishiwaki (1966) did find that a few females were caught in years when the water temperature was above normal, and they caught females around Attu and Kiska Islands in 1961. However, Nishiwaki (1966) also stated that the presence of females is very rare, so I assumed that only large males go that far north. Using a ratio of 72% adults (from Guénette, this volume), the male to female ratios for NE and NW Pacific from Gosho and Rice (1984), and assuming that the population is in the North Pacific for 120 days a year (Calkins 1987), yielded an estimate of about 9 large male sperm whales in the Aleutian Islands. Using the average weight of large males (26,939 kg) the biomass of sperm whales in the Aleutian Islands in 1999 was 0.004 t·km^{-2}. The global population had decreased from 1963 to 1979 and increased thereafter (Whitehead 2002), and using the same ratio of decrease and increase as in the global population, gave a biomass of 0.004 t km^{-2} in 1991 and 0.0036 t·km^{-2} in 1979 and 0.007 t·km^{-2} for 1963 (Table 1B). The total biomass for toothed whales was estimated at 0.012, 0.010 and 0.013 t·km^{-2} for 1991, 1979 and 1963 respectively.

Estimates of the annual P/B ratio for sperm whales in the western sub-Arctic region were obtained from Aydin et al. (2003) and that of resident killer whales from NMFS, and prorated by biomass to give average estimates of 0.029 year^{-1} for the 1991 model, 0.028 year^{-1} for 1979 and 0.036 year^{-1} for 1963. The annual Q/B estimates for sperm whales (9.4) and Stejneger's beaked whales (14.4) were calculated from the energy requirements, energetic values of their food, and average weight acquired from Perez and McAllister (1993). The annual Q/B ratio for resident killer whales was estimated by using the average daily requirement of 84.3 kg·day^{-1} for resident killer whales feeding on fish and an average weight of 3,550 kg (Barrett-Lennard et al. 1994), to give an annual Q/B of 10.8. These Q/B estimates were then prorated by biomass to give annual Q/B ratios for the group of 10.1, 11.7 and 11.1 respectively for the 1991, 1979 and 1963 models.

Table 1A. Biomass estimates for beaked whales in the Aleutian Islands obtained from Trites et al. (1997).

Beaked whales	**Avg. body weight (t)**	**Pacific population**	**Proportion in area 67**	**Biomass (t·km^{-2})**
Baird's	3.1365	30,000	0.3	0.00376
Cuvier's	0.8285	16,500	0.1	0.00018
Stejneger's	0.455	3,000	0.5	0.00009

Table 1B. Biomass of toothed whales in the Aleutian Islands in 1963, 1979 and 1991 (t·km^{-2}).

Species	**Avg. body weight (t)**	**1963**	**1979**	**1991**
Resident killers	2.435	0.002	0.002	0.004
Sperm whale	18.519	0.007	0.004	0.004
Beaked whales		0.004	0.004	0.004
Total		0.013	0.010	0.012

The diet of resident killer whales in the West Coast Community (SE Alaska and south) included chinook, pink, coho, chum and sockeye salmon, as well as steelhead and other fish such as herring, rockfish and halibut (Ford and Ellis 1999). Perez (1990) and Ford et al. (1998) suggested that resident killer whales consume herring, salmon, capelin, smelts, Pacific cod, Arctic cod, saffron cod, Atka mackerel, Pacific halibut, other flatfish, sharks, skates, cephalopods, euphausiids, copepods, amphipods, other invertebrates, and rockfish. Deep-water cephalopods are the main food for sperm whales (Okutani and Nemoto 1964; Gosho and Rice 1984), but their diet also included salmon, lanternfish, lancetfish, Pacific cod, pollock, saffron cod, rockfish, sablefish, Atka mackerel, sculpins, lumpsuckers, lamprey, skates, rattails, cephalopods, amphipods and other invertebrates (Perez 1990). The diet of Stejneger's beaked whales is not well known, except that they fed predominantly on squids (Loughlin and Perez 1985). The diet of all toothed whales combined was estimated by using the diets of the various species in proportion of their biomass and the proportion of biomass of the prey species where available (Table 2). For the different models, different biomass estimates of both whales and fish were used to calculate different diets, specifically for 1991 and 1979, while the 1979 diet was also used for 1963 as very little data was available on prey density (Table 2). In addition, the proportion of small pelagics (5%), small demersals (3%) and myctophids (2%) in the diet of toothed whales were assumed as no biomass values were available for these groups. The different biomass estimates for both toothed whales and fish in 1979 and 1991 were used to estimate different diets for toothed whales, while the diet in 1963 was estimated using the 1979 fish biomass and the 1963 toothed whale estimates as no data were available of fish biomass in that time period.

Table 2. Diet composition of toothed whales of the Aleutian Islands in 1991 and 1979.

	Resident killer whales (%)		**Sperm whale (%)**		**Toothed whale (proportion)**		
Species/group	**1991**	**1979**	**1991**	**1979**	**1991**	**1979**	**1963**
Skate	0.04	0.08	0.04	0.08	0.0004	0.0008	0.0008
Salmon	61.75	61.75			0.2882	0.2468	0.1591
Capelin, sand lance, smelts	?	?					
Arctic cod	?	?					
Pelagic small invertebrate feeders					0.0500	0.0500	0.0500
Atka mackerel	1.767	1.587	1.704	1.520	0.0173	0.0155	0.0154
Herring	?	?			0.0080	0.0076	0.0076
pollock	0.734	1.152	0.71	1.104	0.0072	0.0112	0.0112
Pacific ocean perch			0.08	0.04	0.0004	0.0002	0.0003
Rockfish	0.05	0.11	0.05	0.09	0.0005	0.0009	0.0009
Sablefish			0.12	0.17	0.0006	0.0010	0.0012
Pacific cod	0.57	0.26	0.55	0.25	0.0056	0.0025	0.0025
Pacific halibut	0.08	0.08			0.0004	0.0003	0.0002
Saffron cod	?	?	?	?			
Sculpin			?	?			
S & M demersals					0.0300	0.0300	0.0300
Deep-sea smelt /lanternfish	?	?	?	?			
Myctophids					0.0200	0.0200	0.0200
Cephalopods	20	20	82	82	0.5307	0.5722	0.6603
Euphausiids	1	1			0.0100	0.0100	0.0100
Copepods	1	1			0.0100	0.0100	0.0100
Other invertebrates	2	2	2	2	0.0200	0.0200	0.0200

Catches, obtained from the International Whaling Commission for the Northeast Pacific, the coastal Northwest Pacific and the pelagic whaling fleet (Guénette and Salter, this volume), were used to prorate catches in the Aleutian Islands. In 1963, 15,548 sperm whales were caught in the North Pacific, but I only used 8% of this catch as the biomass of sperm whales in the Aleutian Islands was only 8% of the biomass in the North Pacific (72% adults, and 30% males in the western stock and 40% males in the eastern stock, prorated by area). Thus, the catches taken from the sperm whales in this area were 0.0006 $t\cdot km^{-2}\cdot year^{-1}$ in 1963, 0.00012 $t\cdot km^{-2}\cdot year^{-1}$ in 1979, and there were no commercial catches in 1991. However, the fishery catches of resident killer whales was reported to be 1.4 killer whales out of a population of 723 animals (0.6 by the groundfish fishery and 0.8 by the longliners) (Angliss and Lodge 2002), which amounted to catches of 0.000003 $t\cdot km^{-2}\cdot year^{-1}$ and 0.000004 $t\cdot km^{-2}\cdot year^{-1}$ respectively for the groundfish and longline fisheries in 1991. The time series of catches for baleen whales (blue, fin, humpback and sei) and toothed whales (sperm) for the whole North Pacific are given in Figure 4 and were used as proxy for catch time series in the Aleutian Islands.

3. Baleen whales

The baleen whales of the area include minke, *Balaenoptera acutorostrata*, fin, *B. physalus*, sei, *B. borealis*, blue, *B. musculus*, and humpback whales, *Megaptera novaeangliae*. Gray whales, *Eschrichtius robustus*, were not included as they do not occur in the central and western Aleutian Islands (Murie 1959), but pass through the eastern part of the islands (Abegglen 1977). Pacific right whales, *Eubalaena glacialis glacialis,* were recorded in the waters of the Aleutian Islands and two were killed at the Akutan whaling station in 1914 (Murie 1959), but Perry et al. (1999) found that they did occur south of the Aleutian Islands in the summer. Similarly, bowhead whales, *Baelaena mysticetus*, used to visit the Aleutians (Murie 1959), but neither of these species are known to frequent the Aleutians anymore (Nishiwaki 1967). I therefore did not include any information on gray whales, Pacific right whales or bowhead whales in these models.

Humpback, fin and right whales feed in both the Gulf of Alaska and the Bering Sea during the summer and early fall, while blue, sei and sperm whales are more restricted to the North Pacific or deeper western Bering Sea (Brueggeman et al. 1987). Nishiwaki (1966) suggested that there were many humpbacks in the Aleutians, but that the number of them taken was rather small. Humpback whales migrate between the Aleutians and the warm waters of the western North Pacific (Mackintosh 1965). Most humpback whales (69%) were observed on the continental shelf, while 30% are seen in waters > 2000 m deep and only 1% on the slope (Brueggeman et al. 1987). Most of the humpbacks observed by Brueggeman et al. (1987) were seen in the Shumagin Planning Area (from 156˚W to 165˚W south of the Alaskan peninsula). Angliss and Lodge (2002) estimated that there were 1,175 humpback whales in the central Bering Sea during the summer, and also found that the majority of the sightings for humpbacks were close to the Aleutian Islands, while the minimum population estimated for the area was 367 humpbacks, assuming that they only stay in the area for the summer (25% of the time). This estimate is closer to that obtained from Trites et al. (1997) (220 animals), although NMFS, quoting estimates made by Zerbini et al. (2003), calculated 268 humpbacks staying for the whole year, thus giving an estimate of 0.14 t·km^{-2}, which is the estimate I used for the 1991 model. Calkins (1987) estimated the total North Pacific population of humpbacks at approximately 1,200 animals (0.001 t·km^{-2}), which was similar to those of Johnson and Wolman (1984 in Perry et al. 1999) and I used this estimate for the 1979 model. For 1963, I used an estimate of 1,000 animals (or 0.0008 t·km^{-2}) obtained from Rice (1978 in Perry et al. 1999).

The estimates for fin whales (0.01 t·km^{-2}) obtained from Perez (1990) were lower than the estimates obtained by NMFS (0.044 t·km^{-2}) based on Zerbini et al. (2003), but when a more appropriate estimate of body weight (37 vs. 56 tonnes, Nancy Friday pers. comm.) was used, the latter biomass was drastically reduced to 0.03 t·km^{-2}. The 1970s biomass was estimated as 0.048 t·km^{-2} by Perry et al. (1999) and the 1963 estimate for the North Pacific was 27,788 fin whales (Guénette and Slater, this volume) or 0.03 t·km^{-2}.

I used the sei whale abundance (21 animals, 0.006 t·km^{-2}) obtained from NMFS quoting Zerbini et al. (2003) for 1991, which is higher than that given by Perez (1990). Calkins (1987) estimated that the total North Pacific population of sei whales in the 1970s was approximately 8,600, which is similar to the 9,110 sei whales estimated by Perry et al. (1999), giving a biomass of 0.004 t·km^{-2}. Calkins (1987) also estimated that the number of sei whales in the North Pacific in the 1960s was approximately 42,000 (0.018 t·km^{-2}), which is similar to the total unfished population given by Perry et al. (1999).

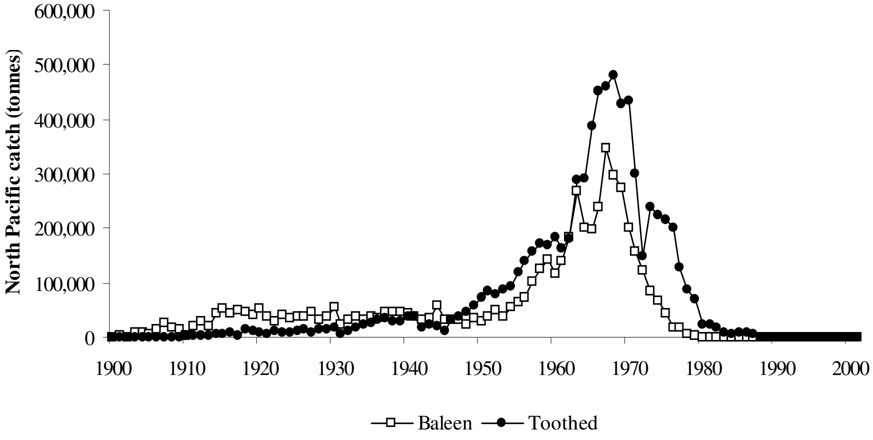


Figure 4. Catch (tonnes) of baleen and toothed whales in the North Pacific from 1900 to 2000.

Minke whales are divided into two stocks in the North Pacific and the boundary between these stocks runs through the Amchitka Pass (Gosho and Rice 1984; Parsons 1987) and through the middle of this study site. The estimates for minke whales obtained from Perez (1990) where lower than the estimate of 846 minkes obtained from NMFS (0.09 t·km^{-2})

calculated based Zerbini et al. (2003). According to Perry et al. (1999), the numbers of minke whales have stayed fairly constant over time, thus I assumed that the biomass in all three time periods were 0.09 $t{\cdot}km^{-2}$.

Blue whales have been recorded in both the central and western Aleutian Islands and have been protected since 1966 (Abegglen 1977). The biomass of blue whales (0.003 $t{\cdot}km^{-2}$) were estimated from Trites et al. (1997) and their average weight from Trites and Pauly (1998). This estimate was used for both the 1991 and 1979 model. According to Mackintosh (1965), only about 2,000 blue whales and 40,000 fin whales existed globally by 1964. If we assumed that the ratio of blue whales in the North Pacific vs. the global population was similar to that of fin whales, the total North Pacific blue whale population in 1963 would be approximately 1,032 blue whales, or 0.0026 $t{\cdot}km^{-2}$. This is probably an upper limit, as fewer blue and fin whales frequent the northern hemisphere than the south, and blue whales in particular do not go north of the Aleutians according to Mackintosh (1965).

Thus, the total biomass for baleen whales were 0.28, 0.153 and 0.145 $t{\cdot}km^{-2}$ for 1991, 1979 and 1963 respectively. Current best estimates of baleen whales were given by Perry et al. (1999) as 6,000-8,000 humpbacks, 3,300 blue whales, 14,620-18,630 fin whales and 9,110 sei whales in the North Pacific. According to Perry et al. (1999) the numbers of minke whales have stayed fairly constant over time, thus I assumed that the current minke biomass is similar to that of 1991, which gives a biomass estimate for baleen whales in 1999 of around 0.13 $t{\cdot}km^{-2}$. However, the estimates given by Perry et al. (1999) of fin and humpback whales are less than those calculated by NMFS from Zerbini et al. (2003), which would increase the best 1999 estimate to 0.282 $t{\cdot}km^{-2}$.

The annual P/B and Q/B estimates of fin, sei and minke whales were given by Aydin et al. (2003) and prorated by biomass to give average annual P/B and Q/B ratios for baleen whales over time. The annual P/B ratios stayed constant at 0.02 as all three whale species had an annual P/B of 0.02, while the annual Q/B ratios differed over time, from 6.99 in 1991, to 6.7 in 1979 and 6.99 in 1963. Perry et al. (1999) quoted various authors that give annual natural mortality rates of 0.04 for blue and fin whales, 0.07 for sei whales, and survival of 0.95 for humpbacks, and prorating these ratios by their biomass estimates for the three time periods gave annual natural mortalities of 0.06, 0.04 and 0.05 for the 1963, 1979 and 1991 models. Adding to that the annual fishing mortality for each time period (0.04, 0.0003 and 0 for 1963, 1979 and 1991) gave annual P/B estimates of 0.1, 0.04 and 0.05 respectively.

The diet of this group was obtained by using the average minke, fin, sei and humpback whale diets. The different abundances of fish and whales between 1991 and 1979 were incorporated into the diet of baleen whales in those two models. For 1963, the proportion of fish in 1979 was used as proxy for the proportion of fish in 1963 (Table 3). Minke whales feed on fish (60%), cephalopods (1%), euphausiids (30%) and copepods (9%) (Perez 1990). Tamura et al. (1998) suggested that minke whales in the central Pacific consumed salmon (1%), pomfrets and other large pelagics (4.5%), saury (80.6%), northern anchovy (7.1%) and some zooplankton (~7%). I used this information to estimate the diet of minke whales using 30% of the fish from those species for which I had biomass estimates (Atka mackerel and pollock) and assumed that the other 30% of the fish comes from capelin and Arctic cod (10% each), sand lance and saffron cod (5% each). Fin whales consumed fish (16%), cephalopods (2%), euphausiids (55%), copepods (27%) and other invertebrates (1%) (Perez 1990). For fin whales, I assumed that the 16% fish consisted of 9% Atka mackerel, rockfish and Pacific cod in the ratio of their biomass, and the other 7% was divided equally between salmon, capelin, Arctic cod, sand lance, herring, juvenile pollock, and saffron cod. The diet of sei whales consisted of 3% fish, 1% cephalopods, 13% euphausiids, 83% copepods, with the 3% fish split equally between smelts, capelin, sand lance, Arctic cod, sardine, pollock, rockfish and greenling (Calkins 1987). Lowry et al. (1989) suggested that the favourite food of humpback whales in the Aleutian Islands is Atka mackerel, but they also consumed other fish (29%), cephalopods (1%), euphausiids (69%) and copepods (1%) (Perez 1990). The 29% fish was divided into 19% Atka mackerel, pollock and rockfish (in the ratio of their biomass), and 2% each of salmon, capelin, Arctic cod, sand lance and saffron cod. No diet estimates were available for blue whales, but Nemoto (1957) suggested that they feed nearly exclusively on euphausiids and Perry et al. (1999) found that they feed extensively on krill, euphausiids and red crabs.

Mackintosh (1965) gave estimates for the average annual global catch of blue, fin, sei and humpback whales and also stated that 90% of the worlds catch of fin, blue and humpback whales were made in the southern hemisphere, thus giving a catch of 3,133 fin whales, 651 sei whales, 172 blue whales and 360 humpback whales in the northern hemisphere. These estimates were only made by the pelagic whaling fleet. From the IWC whaling data (Guénette and Salter, this volume), the total catches of whales in the North Pacific in 1963 were 2,140 fin whales, 4,291 sei whales, 2,339 humpbacks and 404 blue whales, giving a total catch of 263,946 tonnes in the North Pacific, which included the Northeast Pacific catch, the pelagic catch in the North Pacific and the coastal catch in Northwest Pacific, and gave a catch of 0.006 $t{\cdot}km^{-2}{\cdot}year^{-1}$

for the whole North Pacific (Areas 61, 67 and ¼ of 77 = 40,203,750 km²). The time series of catches for baleen whales are shown in Figure 4 above. In 1979, 43 fin whales were caught by the northwest Pacific fishery, with no catch of sei, humpback or blue whales in that year, giving a catch of 0.00004 $t{\cdot}km^{-2}{\cdot}year^{-1}$. By 1991 no commercial catches were made, but the mean annual catch of humpback whales in the western north Pacific stock by the groundfish trawl fishery was 0.4 animals from a population of 367 (Angliss and Lodge 2002), which gave a catch of 0.0002 $t{\cdot}km^{-2}{\cdot}year^{-1}$. The annual catch of fin whales by the groundfish fishery was 0.6 animals (Angliss and Lodge 2002) or 0.0006 $t{\cdot}km^{-2}{\cdot}year^{-1}$, for a total fishery mortality of baleen whales by the groundfish fishery of 0.0007 $t{\cdot}km^{-2}{\cdot}year^{-1}$.

Table 3. Diet compositions of baleen whales in the Aleutian Islands in 1991, 1979 and 1963. Note that the diet for sei whales did not change in the model between 1979 and 1991.

	Minke whale (%)		**Fin whale (%)**		**Sei (%)**	**Humpback (%)**		**Baleen whale (proportion)**		
Species/group	**1991**	**1979**	**1991**	**1979**		**1991**	**1979**	**1991**	**1979**	**1963**
Salmon			1	1		2	2	0.01	0.01	0.002
Capelin, sand lance,					0.4	2	2			
Capelin	10	10	1	1	0.4					
Arctic cod	10	10	1	1	0.4	2	2			
Sardine/saury					0.4					
Pelagic invertebrate feeders								0.09	0.094	0.15
Atka mackerel	23.9	20.3	6.6	7.4		14.8	12.4	0.15	0.124	0.137
Sand lance	5	5	1	1	0.4	2	2	0.03	0.029	0.038
Herring			1	1				0	0	0.001
Juv pollock			1	1				0	0	0.001
pollock	6.1	9.7			0.4	3.8	5.9	0.06	0.09	0.092
Rockfish			0.2	0.4	0.4	0.5	0.7	0	0.004	0.001
Pacific cod			2.1	1.2				0	0.001	0.002
Saffron cod	5	5	1	1		2	2			
Greenling					0.4					
S & M demersals								0.03	0.029	0.038
Cephalopods	1	1	2	2	1	1	1	0.011	0.011	0.01
Euphausiids	30	30	55	55	13	69	69	0.524	0.524	0.315
Copepods	9	9	27	27	83	1	1	0.09	0.09	0.211

4. Steller sea lions (embryo, pups, juveniles and adults; Groups 4-7)

Steller sea lions, *Eumetropias jubatus*, are found throughout southwestern Alaska from Attu Island east to Carlisle Island (Murie 1959). They have been caught for consumption by native fishermen as well as being taken as bycatch by the domestic and foreign trawl and longline fisheries. According to Alverson (1992), the fisheries that had the greatest impact on Steller sea lions were the Japanese and US salmon fisheries, Japanese, Soviet and US herring fisheries, foreign and US groundfish, shrimp, longline and crab operations. The average catch by the groundfish trawl and longline fisheries from 1979-2000 were estimated from Perez and Loughlin (1991), Perez (2003) and Berger et al. (1986). The bycatch for 1989-1991 was estimated at approximately 6.6 animals by trawlers and 1.8 animals by longliners respectively, assuming that the unidentified pinnipeds consisted of both harbour seals and Steller sea lions. The estimates of sea lion shootings in defense of fish gear from 1960-1990 and harvest are not really well known, but the government was seeking ways to reduce the number of Steller sea lions and other marine mammals and had put a bounty on harbour seals (Alverson 1992). Commercial harvests of sea lions were authorized and cannery operators provided ammunition to fishermen. Even marine and wildlife biologists were known to have joined in the shooting, as there was no dishonour in shooting sea lions or using them for crab bait (Alverson 1992).

Alverson (1992) suggested that approximately 150 animals were taken annually statewide as subsistence harvest. Losses from entanglement in marine debris were not assumed to be a major factor, with fewer than 100 animals (he used 97 animals) killed each year (Alverson 1992). The average subsistence take was given by Wolfe et al. (2002) for Atka Island (the only community that they studied in the Western Aleutian Islands) from 1992-2002 by sex and for adults, juveniles and pups (Table 4). The average weight for adult males (430 kg) and females (229 kg), unknown adults (286 kg), juvenile males (152 kg), juvenile females (123 kg), unknown juveniles (132 kg), male pups (22 kg), female pups (20 kg) and unknown age and sex (162 kg), obtained from the age-structured model (Guénette, this volume), were used to calculate the average weight of the adult, juvenile and pup catch by year. The number of animals discarded (struck and lost) were assumed to be in the same proportion as the adults and juveniles (assuming that no pups were lost), and using the average weight for adults and juveniles. For 1999, no estimate of subsistence catch was available and I assumed that it was the average of 1998 and 2000.

Table 4. Subsistence catch (in numbers) of Steller sea lions by Western Aleutian Island communities obtained from Wolfe et al. (2002).

Group	1992	1993	1994	1995	1996	1997	1998	2000	2001	2002
Adult male	8.8	4.4	2.2	10	6.5	7.6	6.1	6.1	10.0	46.5
Adult female	9.9	10.9	20.6	12.5	6.5	0	3.1	3.1	1.7	6.0
Unknown adults	0	0	5.4	0	0	0	3.1	3.1	0	3.0
Juvenile male	2.2	2.2	14.1	2.5	3.2	1.5	3.1	3.1	0	13.5
Juvenile females	4.4	2.2	3.3	5	0	3.1	0	0	0	1.5
Unknown juv	1.1	0	0	0	1.1	0	1.5	1.5	0	0
Male pups	1.1	0	0	0	0	0	0	0	0	0
Female pups	1.1	0	0	0	0	0	0	0	0	0
Unknown	0	5.5	0	10	0	0	0	0	21.7	3.0
Total Harvest	28.6	25.1	45.5	40	17.3	12.2	16.8	16.8	33.3	73.5
Struck & Lost	9.9	0	8.7	0	0	0	0	0	11.7	12.0

Note: No data available for 1999

For the 1979 model, the subsistence estimate of between 15 to 25 animals from Veltre and Veltre (1983) was used. They stated that sea lions were hunted throughout the year and that adult and juvenile males were preferred. Veltre and Veltre (1983) also estimated that only 60% of sea lions killed were retrieved, and 40% discarded. Thus, using the breakdown of adults, juveniles and pups from the 1994 subsistence fishery on Atka Island, Wolfe and Mishler (1995) gave a subsistence catch for 1979 of about 20 harvested and 12 struck and lost (Table 5). I assumed that all subsistence catches prior to 1992 were similar to the estimates given by Veltre and Veltre (1983).

Table 5. Steller sea lions caught and lost (discards) by First Nations in the 1979 model of the Aleutian Islands (in kg·km^{-2}·year^{-1}).

	Harvest	Discards
Pup	0	0.0001
Juvenile	0.023	0.014
Adult	0.06	0.036

Thus, the subsistence catch of Steller sea lions prior to 1992 can be estimated at 32 killed per year (Table 6) and the numbers for 1992-2002 are given in Table 4. Incidental and intentional kills by the trawl fleet, salmon fisheries and other fisheries as well as entanglements in marine debris were obtained from Trites and Larkin (1992) and were prorated by the area of the Aleutian Islands (56,936 km²) to that of the Gulf of Alaska (348,776 km²). Salmon catches were also weighted by the ratio of salmon caught in the Aleutians vs. the whole Gulf of Alaska. For intentional shootings I used the estimates given by Alverson (1992) prorated by area. Alverson (1992) estimated on average 290 shootings per year and gave estimates of between 100 and 1,455 animals shot annually by the salmon fisheries between 1960 and 1990. For 1991-2002 the kills by the trawl fleet was obtained from Perez (2003) and I assumed that kills by the other fleets, marine debris and indiscriminate shooting did not change from 1990-2002, except for the salmon fleet which I assumed did not kill any Stellers as they hardly caught any salmon in that time. The bycatch of Steller sea lions by the fishery was assumed to be juveniles and young adults (years 1-12) in the ratio of the abundances in the general population (Table 6). The catches were prorated for adults and juveniles for each year and gear type, with all incidental harvest by other fleets, indiscriminate shooting and marine debris being attributed to other gear in the model.

The population estimates given by Trites and Larkin (1996) were multiplied with the average weight of the animals to obtain the biomass and stanza information given in Table 7. The annual P/B estimates were calculated for each of the years by calculating the slope of the natural log of numbers at age for pups, juveniles and adults respectively and were used in conjunction with the annual Q/B estimates to calculate the biomass of the other stanzas in the three models (Table 7). The Q/B ratio was calculated from the energy requirements, energetic values of their food, and average weight given by Perez and McAllister (1993) as 27.4 year^{-1}, which is marginally higher than the 24.1 year^{-1} estimated by NMFS. I therefore used a value somewhere in between (25.6 year^{-1}), which is similar to that given by Guénette (this volume) for the SEAK model. The juvenile rate was estimated at between 39.3 year^{-1}and 39.6 year^{-1} (Table 7) per year which is in the range of 1.4-1.8 times the Q/B of adults given by Innes et al. (1987).

Table 6. Known and estimated Steller sea lion kills in the Aleutian Islands by subsistence and commercial fisheries.

Year	**Sub-sistence**	**Incidental harvest / shooting**			**Indiscriminate shooting**	**Marine debris**	**Total Deaths**	**Total (t)**	
		Trawlers	**Salmon**	**Other**				**Juveniles**	**Adults**
1960	32	0	52	15	65	8	172	9	29
1961	32	0	15	15	65	9	137	7	23
1962	32	0	198	19	82	10	340	18	57
1963	32	3	16	21	82	11	164	9	28
1964	32	17	24	18	114	11	217	12	36
1965	32	24	0	18	114	12	200	11	34
1966	32	15	20	21	131	13	232	13	39
1967	32	20	5	22	131	14	223	12	37
1968	32	21	138	22	131	15	358	20	60
1969	32	22	41	22	147	16	279	15	47
1970	32	29	77	24	147	16	325	18	54
1971	32	43	6	27	163	16	287	16	48
1972	32	23	1	34	163	16	270	15	45
1973	32	46	1	35	196	16	327	18	55
1974	32	46	0	33	196	16	323	18	54
1975	32	42	38	47	229	16	404	22	68
1976	32	42	0	55	229	16	374	20	63
1977	32	20	0	54	229	16	351	19	59
1978	32	16	5	71	261	16	402	22	67
1979	32	20	44	73	261	16	447	24	75
1980	32	23	122	72	261	16	526	29	88
1981	32	21	21	90	261	16	443	24	74
1982	32	56	67	92	294	16	557	30	93
1983	32	28	3	104	294	16	478	26	80
1984	32	49	96	96	294	16	583	32	98
1985	32	42	0	81	294	16	466	26	78
1986	32	17	3	135	278	16	480	26	80
1987	32	6	0	80	278	16	413	23	69
1988	32	3	3	53	114	16	221	12	37
1989	32	1	0	25	33	16	107	6	18
1990	32	1	2	17	16	16	84	5	14
1991	32	10	0	17	16	16	91	5	15
1992	39	0	0	17	16	16	88	5	15
1993	25	0	0	17	16	16	75	4	12
1994	54	2	0	17	16	16	106	6	18
1995	40	2	0	17	16	16	91	5	15
1996	17	2	0	17	16	16	69	4	12
1997	12	3	0	17	16	16	65	4	11
1998	17	4	0	17	16	16	70	4	12
1999	17	5	0	17	16	16	71	4	12
2000	17	1	0	17	16	16	67	4	11
2001	45	0	0	17	16	16	94	5	16
2002	86	0	0	17	16	16	135	7	23

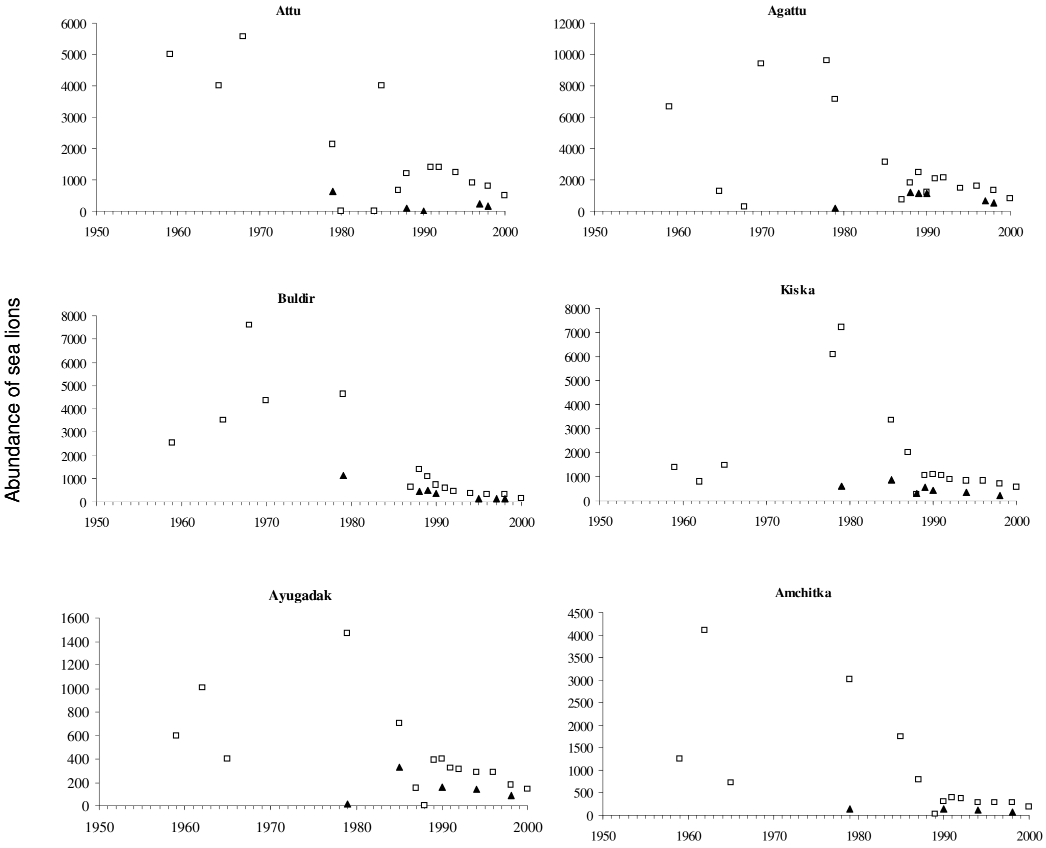


Figure 5. Counts of non-pups (open squares) and pups (closed triangles) on the rookeries of the Western Aleutian Islands.

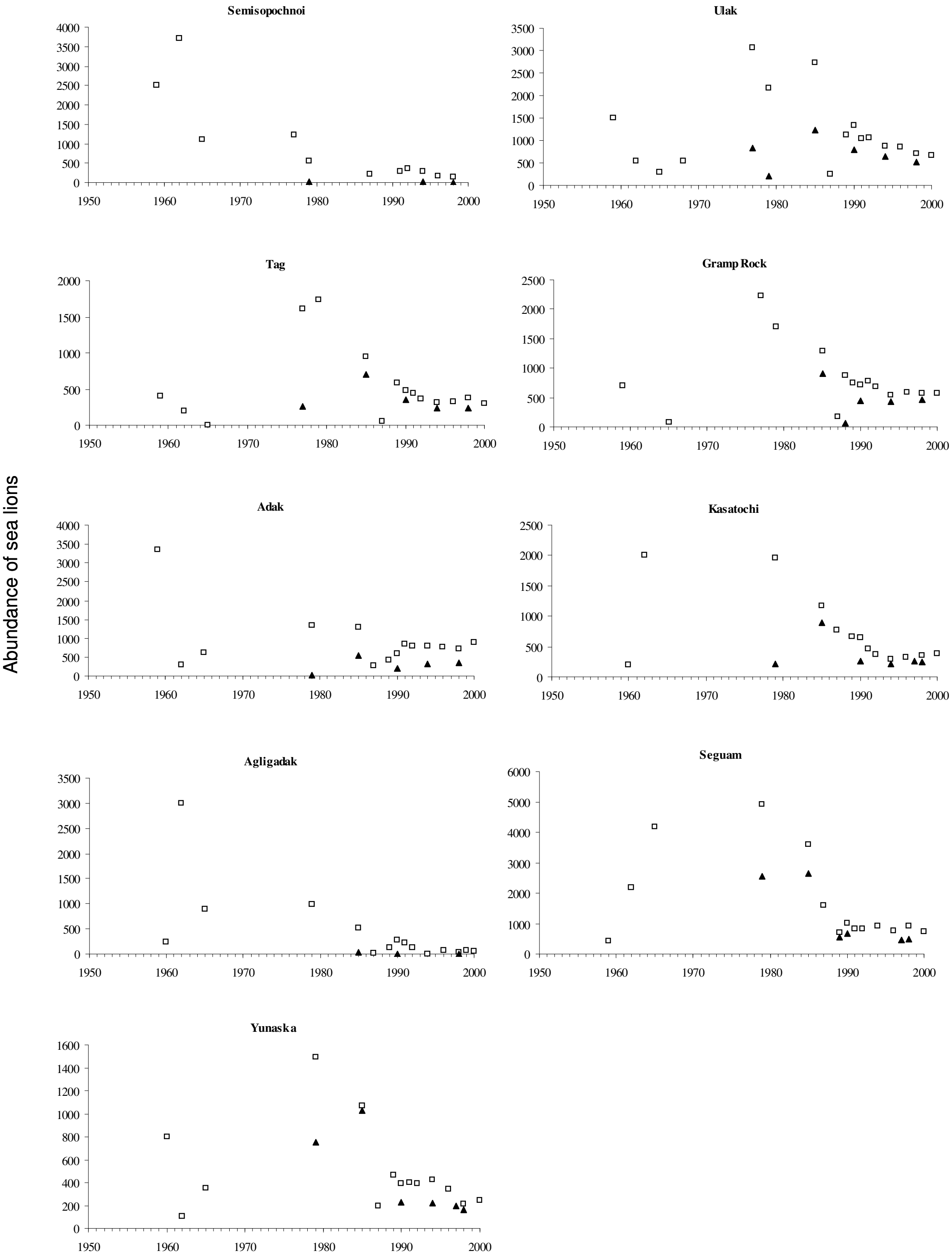


Figure 6. Counts of non-pups (open squares) and pups (closed triangles) on the rookeries of the Central Aleutian Islands.

There was no evidence to suggest that either growth or body condition was worse for western stock animals than it is for juveniles from SEAK (Pitcher 2002). On the contrary, although mass at birth were similar between pups in SEAK and the west, growth rates appeared higher in the west, and body composition estimates suggested better conditions in western stocks (Pitcher 2002). Andrews et al. (2002) suggested that adult female Stellers found suitable prey more quickly and were able to ingest prey at a much higher rate in the central Aleutians than in SEAK. They suggested that this might be the reason why the growth rate for pups measured at the central Aleutian Islands was double that in SEAK (Andrews et al. 2002). Unfortunately, no data was available for the western Aleutians, thus to be conservative, I used a K of 0.282 year^{-1} and a W_{max}/W_{∞} of 0.00001, (see Guénette, this volume).

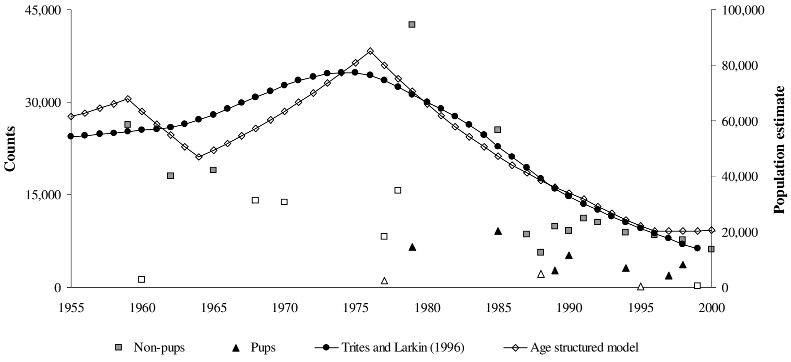


Figure 7. The total counts and population estimates of non-pups (squares) and pups (triangles) in the western and central Aleutian Islands. Open squares and open triangles are respectively non-pups and pups not included in the model.

Table 7. Stanza information used in the 1991 and 1979 models. Note values in Italics were estimated by Ecopath.

Stanza	**time**	**Biomass t·km^{-2}**			**P/B (year^{-1})**			**Q/B (year^{-1})**		
	(months)	**1991**	**1979**	**1963**	**1991**	**1979**	**1963**	**1991**	**1979**	**1963**
Embryo	0-6	*0*	*0*	*0.00005*	0	0	0.02	219.614	219.237	220.786
Pup	7-19	*0*	*0.003*	*0.002*	0.52	0.51	0.52	82.955	82.822	83.413
Juvenile	20-56	*0.018*	*0.042*	*0.030*	0.23	0.24	0.24	39.313	39.279	39.562
Adult	57-	0.083	0.184	0.148	0.19	0.18	0.17	25.550	25.550	25.55

The diet of Steller sea lions were obtained as % frequency of occurrence from scat samples (Sinclair and Zeppelin 2002) for region 4 (which is mostly the central and western Aleutian Islands), and used as the best representation of their diet in weight. The diet estimates were given for summer and winter, and the average of these two seasons were taken for adult diet (Table 8), while the winter diet was assumed to be more representative for juveniles, as juveniles are not really present on the rookeries much during the summer (Sinclair and Zeppelin 2002). The diet used in this study was probably mostly those of female and young-of-the-year Steller sea lions (Sinclair and Zeppelin 2002). There is no data available on the diet of Steller sea lions in the 1970s or 1960s in the Central and Western Aleutians and I therefore used this diet for all three models, although there might have been changes over time. Merrick (1996) found that in the EasternAleutians (around Kodiak Island) the diet consisted of 1.7-42.7 cm fork length (FL) fish, with the average mean FL for juveniles being 20.8 cm and that of adults 27.9 cm, thus I could have both juveniles and adult Steller sea lions feeding on both juvenile and adult pollock. Using the average length for 2 year old pollock of 28 cm, the number of prey in each length class from Merrick (1996) and the von Bertalanffy equation, Guénette (this volume) found that juvenile sea lions would consume 65% juvenile pollock and 35% adult pollock, while adult sea lions would consume 21% juvenile pollock and 79% adult pollock.

The diet (Table 8) therefore consisted of sharks and rays (0.7% for both juveniles and adults), salmon (12% juveniles, 11% adults), Atka mackerel (33 and 43% respectively), adult and juvenile pollock (1% each for adult and juveniles eaten by adult and juvenile Stellers respectively), rockfish (2%), Pacific cod (9 and 6% respectively), arrowtooth (1% each), flatfish (4% and 3% respectively), small demersals (25% and 16%), large demersals (6% and 5%), myctophids (1% and 2%), cephalopods (6% and 8% respectively for juvenile and adults Stellers).

Table 8. Diet for Steller sea lion adults and juveniles (using the winter diet) used for the 1979 and 1991 models.

Prey	**Summer**	**Winter (Juveniles)**	**Average (Adults)**
Mammal	*		*
Skates & sharks	0.006	0.007	0.007
Salmon	0.0934	0.119	0.106
Atka mackerel	0.561	0.327	0.427
Sand lance	0.006		0.005
Pacific herring	*		*
Pollock	0.058	0.014	0.033
Rockfishes	0.014	0.017	0.016
Pacific cod	0.039	0.085	0.063
Halibut	*	*	*
Arrowtooth	0.006	0.014	0.010
Flatfish	0.012	0.039	0.027
Demersals S & M	0.050	0.246	0.162
Large demersals	0.027	0.064	0.047
Myctophids	0.015	0.010	0.016
Cephalopods	0.110	0.058	0.081

* <1 Frequency of occurrence

8. Small mammals

This group contains both pinnipeds and cetaceans. The pinnipeds include northern fur seals, *Callorhinus ursinus*, ribbon seals, *Phoca fasciata*, spotted seals, *P. largha*, and harbour seals, *P. vitulina stejnegeri*. The harbour seals in the Aleutian Islands is a different sub species from those in the rest of the Gulf of Alaska (*P.v. richardii*), as the boundary between the two subspecies are in the eastern Aleutian Islands (Burns 2002). Murie (1959) suggested that harbour seals were not particularly abundant in the Aleutians, and they sighted single animals or small groups only, but in 1925 they were abundant and hauled out on kelp covered boulders near the beaches of Adak Island.

Fur seals are not normally found in the Aleutian Islands in great numbers (Veltre and Veltre 1983). They generally migrate between their breeding grounds in the Pribilof Islands and their wintering territories south of the Aleutians through the passes of the eastern Aleutians but as fur seal females can travel up to 800 km between successive nursing periods (Scheffer et al. 1984), they could feed in the Aleutian Islands. Archaeological information showed that their bones were found throughout the archipelago, while historic and contemporary reports indicated that they were regularly spotted in low numbers near Atka Island (Veltre and Veltre 1983) and the Aleuts told that fur seals hauled out on Buldir Island and even bred there (Murie 1959).

The cetaceans include Dall's porpoise, *Phocoenoides dalli*, and harbour porpoise, *Phocoena phocoena*. Buckland et al. (1993) did not observe Pacific white-sided dolphins, *Lagenorhynchus obliquidens*, anywhere near the Aleutian Islands, so I did not include them in the estimates. There are no estimates of harbour porpoise in the Aleutian Islands and so they were not included in this model. Dall's porpoise is the most abundant cetacean (>10,000 inidviduals) in the BSAI area (Loughlin et al. 1999).

By 1990, there were approximately 400,000 northern fur seals in the summer BSAI population (with an average mass of 30 kg) and a tenth of that in winter (70 kg) (Perez 1990), giving a total biomass of 14,785 tonnes or 0.001 t·km^{-2} if we assumed that they only stay in the Aleutian Islands for 2 months. This estimate is similar to the 33,100 fur seals in the area between 45N:170E and 55N:170W obtained from the North Pacific Marine Mammal sighting database for 1990 (Buckland et al. 1993), which estimated a biomass of 0.0006 t·km^{-2} using an average adult body weight of 28 kg (Trites and Pauly 1998). The northern fur seal population in the Eastern Pacific had declined from 1.25 million in 1974 at a rate of 6.5-7.8% per year into the 1980s (York (1987) in Angliss and Lodge 2002). Using this decrease, the total population in 1979 was estimated at approximately 900,000 (Angliss and Lodge 2002), or a biomass of 0.0005 t·km^{-2}. This is similar to the estimate I used of 0.0007 t·km^{-2} obtained from Anonymous (2001) and using the ratio between 1979 and 1990 with the 1990 biomass from Buckland et al. (1993). For 1963, I used the ratio of 1963 to 1991 biomass in the time series obtained from Anonymous (2001), to give a biomass of 0.0008 t·km^{-2}.

Harbour seal abundance was estimated at 3,437 for the Aleutian Islands in 1994 (Withrow and Loughlin (1995) in Angliss and Lodge 2002) and that included 1,600 animals in a smaller area that had approximately 1,000-2,500 animals in a count in 1975-77 (Small (1996) in Angliss and Lodge 2002). I scaled up this estimate for the smaller area in 1975-77 to the whole area for an estimate of 3,759 seals. I used the number estimated by the trawl survey for the Aleutian Islands (Small (1996) in Angliss and Lodge 2002), the total area of 56,938 km^2 and an average body weight of 115 kg for the western subspecies, to get a biomass of 0.007 t·km^{-2} and 0.008 t·km^{-2} for 1994 and 1979 respectively. According to Kenyon, quoted by Sekora (1973 in Veltre and Veltre 1983) the total harbour seal population in 1959 was 11,600 animals, which is close to the 15,000 reported by Fiscus et al. (1981) in 1979. However, for the early 1960s, Abegglen (1977) suggested that the 1965 estimate of harbour seals from Cold Bay (~163˚E) to Attu was 4,868 animals and the 1962 census was more than 6,000 animals. I used an estimate of 5,623 harbour seals for 1963, which was the difference between the 6,000 animals in 1962 and the 4,868 in 1965 given by Abegglen (1977), or a biomass of 0.011 t·km^{-2}.

The biomass of Dall's porpoise was estimated by Buckland et al. (1993) from the North Pacific Marine Mammal sighting database for 1990, and using the abundances for the area between 45N:170E and 55N:170W which gave an abundance of 227,098 porpoises in that area. Using an average adult weight of 61 kg (Trites and Pauly 1998) a biomass of 0.01 t·km^{-2} was estimated. This is substantially lower than the 0.07 t·km^{-2} estimated by NMFS, but I used the 0.01 t·km^{-2} estimate to be conservative. No estimates were available for Dall's porpoise in 1979 or 1963, thus I used the 1991 biomass for those two models. The best estimates of total biomass for small mammals in the three time periods were thus 0.017 t·km^{-2} in 1991, 0.018 t·km^{-2} in 1979, and 0.022 t·km^{-2} in 1963. The biomass time series available for small mammals and sea otters are given in Figure 8.

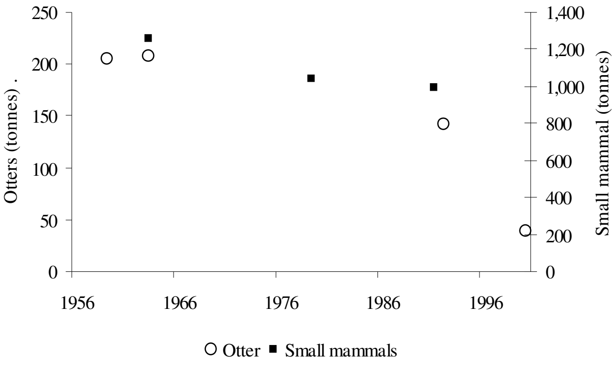


Figure 8. Biomass (in tonnes) of sea otters and small mammals available from 1959 to 2000.

The annual P/B (0.24) and Q/B (39.0) estimates of northern fur seals were obtained from Aydin et al. (2003) for the western sub-Arctic region. For harbour seal, the annual P/B (0.08) and Q/B (17.4) ratios given in the NMFS model (AI) were used at first, but had to be modified to fit the 1963 model. The annual P/B (0.1) and Q/B (27.5) ratios of Dall's porpoise were obtained from Aydin et al. (2003), while Guénette (this volume) had an estimate of 0.22 year^{-1} for the P/B of Dall's porpoise, which I used and prorated by biomass to get a P/B for small mammals of 0.166 year^{-1} for 1991, 0.164 year^{-1} for 1979 and 0.150 year^{-1} for 1963. The annual Q/B estimates were also prorated by biomass for a Q/B of 23.9 year^{-1} in 1991, 23.7 year^{-1} in 1979 and 22.7 year^{-1} in 1963.

Harbour seals feed in nearby coastal locations on cephalopods, pollock, sculpins, Atka mackerel, Pacific cod, greenling, capelin, herring, eulachon, sand lance, rockfish, shrimp, crabs, other invertebrates, salmon, Arctic cod and eelpouts (Perez 1990) (Table 9). Northern fur seals mainly feed on the shelf-break and offshore waters on pollock, cephalopods, capelin, herring, deep-sea smelts, salmon and Atka mackerel (Perez 1990). The diet of Dall's porpoise was reported to consist of 50% cephalopods and 50% fish (salmon, capelin, Arctic cod, atka mackerel, sand lance, herring, pollock, rockfish, sablefish, flatfish, eelpouts, deep-sea smelts and lanternfish (Perez 1990). The 50% fish was divided into 25% for species for which the biomass estimates were available (Atka mackerel, pollock, rockfish, sablefish, flatfish), in the ratio of their biomass estimates and 25% species for which no biomass was available in equal proportions (salmon, capelin, Arctic cod, sand lance, herring, eelpouts, deep-sea smelts and lanternfish). The diet of Dall's porpoise was prorated by the biomass of the fish they consumed for the 1979 and 1991 models, and the 1979 ratio of fish was used in the 1963 model. These diets were then combined and prorated by the biomass estimates of the mammals and fish (for Dall's porpoise) for each model, to calculate the overall diet (Table 9).

Of all the small mammals, the only species that are taken regularly by First Nations for subsistence are harbour seals, and Wolfe et al. (2002) estimated that 29 harbour seals were taken in 1992, while 10 were struck and lost. The average subsistence take given by Wolfe et al. (2002) for Atka Island (the only community that they studied in the Western Aleutian Islands) from 1992-2002 by sex and for adults, juveniles and pups, was used in our model (Table 10). The average body weight for adult male *P. v. stejnegeri* (128.5 kg), female (101 kg) and pups (19 kg) were obtained from Ridgeway and Harrison (1981) while the juvenile males and females were assumed to be about 50% of adult weights (similar to Steller sea lion females as the males get larget). The average weights used for unknown adults (115 kg), juvenile males (69 kg), juvenile females (54 kg), unknown juveniles (61 kg) and unknown age and sex (65 kg) were used to calculate the average adult, juvenile and pup catches by year. The number of animals discarded (struck and lost) were assumed to be in the same proportion as the adults and juveniles (assuming that no pups were lost), and using the average weight for adults and juveniles (Table 10).

Table 9. Diet composition of small marine mammals in the Aleutian Islands. Note that only Dall's porpoise diet is different between 1991 and 1979.

Prey	**Harbour seal (%)**	**Northern fur seal (%)**	**Dall's porpoise (%)**		**Total small mammals**		
			1991	**1979**	**1991**	**1979**	**1963**
Salmon	1	2	3.1	3.1	0.022	0.022	0.019
Capelin, sand lance, smelts			3.1	3.1			
Capelin	5	16					
Arctic cod	1		3.1	3.1			
Eulachon	4						
Pelagic invertebrate feeders					0.081	0.082	0.085
Atka mackerel	9	2	18.2	13.5	0.140	0.112	0.101
Sand lance	4		3.1	3.1	0.033	0.034	0.035
Herring	5	6	3.1	3.1	0.040	0.040	0.042
Pollock	12	34	4.6	6.4	0.085	0.098	0.113
Rockfish	2		0.6	0.8	0.011	0.013	0.014
Sablefish			1.2	1.5	0.007	0.008	0.006
Pacific cod	8				0.032	0.033	0.041
Flatfishes	3		0.4	2.8	0.014	0.028	0.026
Saffron cod	3						
Sculpin	9						
Eelpouts	1		3.1	3.1			
Greenling	8						
S & M demersals					0.101	0.104	0.122
Deep-sea smelt/lanternfish		4	3.1	3.1			
Lanternfish/myctophids			3.1	3.1			
Myctophids					0.037	0.036	0.030
Cephalopods	19	33	50	50	0.372	0.365	0.335
Shrimps	2				0.008	0.008	0.010
Euphausiids			0.3	0.3	0.002	0.002	0.001
Other invertebrates	2				0.008	0.008	0.010
Epibenthic carnivores	2				0.008	0.008	0.010

Table 10. Subsistence catch of small mammals (mainly harbour seals) by Western Aleutian Island communities.

Group	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**2000**	**2001**	**2002**
Adult male	4.4	1.1	8.7	27.5	3.2	.0	1.5	1.5	13.3	4.5
Adult female	4.4	4.4	20.6	2.5	2.2	.0	3.1	3.1	0	1.5
Unknown adults	0	0	8.7	0	1.1	.0	7.6	7.6	0	1.5
Juvenile male	6.6	8.7	7.6	2.5	6.5	4.6	0	0	25.0	10.5
Juvenile females	8.8	2.2	5.4	0	2.2	4.6	0	0	5.0	12.0
Unknown juv	0	0	16.3	0	3.2	.0	0	0	0	1.5
Male pups	2.2	0	2.2	0	0	.0	0	0	0	0
Female pups	2.2	5.5	1.1	0	0	3.1	0	0	0	0
Unknown pups	0	0	3.3	0	0	.0	0	0	0	0
Unknown	0	10.9	0	10.0	4.3	13.8	4.6	4.6	20.0	4.5
Total Harvest	29	32.7	73.7	42.5	22.7	26.0	16.8	16.8	63.3	36.0
Struck & Lost	9.9	0	8.7	0	2.2	1.5	0	0	6.7	0

Note: No data available for 1999

The bycatch of small mammals in 1992 consisted of 1 northern fur seal and 1 Dall's porpoise caught by trawlers, 1 harbour seal caught by the pot fishery and 3 unidentified pinnipeds caught by the longline fishery (Perez and Loughlin 1991). In 1990, 28 Dahl's porpoises were caught by the Aleutian Islands-Alaska Peninsula salmon driftnet fishery and assuming that 20% of that catch was made in the Aleutian Islands, gave a bycatch of 0.000006 $t{\cdot}km^{-2}{\cdot}year^{-1}$ for the salmon driftnet fishery (Angliss and Lodge 2002). The Japanese high seas squid driftnet fishery (20°N-46°N and 170°E-145°W) caught 2,405 fur seals or 1.1% of the population in 1990 (Baba et al. 1993), which gave a bycatch from the squid driftnet fishery of 0.00001 $t{\cdot}km^{-2}{\cdot}year^{-1}$. Thus, I assumed that for the 1991 model the total bycatch of small mammals was 0.000016 $t{\cdot}km^{-2}{\cdot}year^{-1}$ by the driftnet fishery, 0.000002 $t{\cdot}km^{-2}{\cdot}year^{-1}$ by the domestic trawl fishery, 0.000004 $t{\cdot}km^{-2}{\cdot}year^{-1}$ by the longline fishery and 0.000001 $t{\cdot}km^{-2}{\cdot}year^{-1}$ by the pot fishery.

The bycatch of small mammals by the domestic trawl, longline and pot fisheries for the 1979 model was obtained from Perez (1991), who indicated that no small mammals were caught in that year. However, for the salmon drift net fishery, I assumed that their catch of Dahl's porpoise would be in the same ratio as for the 1990 catch, giving a catch of 0.002 t·km^{-2}·year^{-1} made by the salmon driftnet fishery. For the subsistence catch in the 1970s, Veltre and Veltre (1983) estimated that approximately 30 harbour seals were caught annually and that only 10% was lost, giving a total catch of 33 animals. By using the average weight from Ridgeway and Harrison (1981), a total catch of 0.000067 t km^{2} year^{-1} was estimated and a discard estimate of 0.000006 t·km^{-2}·year^{-1}.

For 1963, I assumed that the fleets fishing in 1963 would have had similar catch rates of small mammals as they did in 1991, and using the total catch made by each fleet, I calculated the catch of small mammals to be approximately 39 kilograms by the pot fishery, 1 kilogram by the trawl fishery, 283 kilograms by the longlines and 18.3 tonnes by the salmon driftnet fishery. This large catch by the driftnet fishery is due to the fact that salmon was one of the highest catches in that year, and it estimated a large fishing mortality for small mammals in 1963 (Figure 9). No estimates of subsistence catch was available for the 1963 model, but I assumed that it was similar to the average catch from 1992-1999 and 1979 for a catch of 0.000052 t·km^{2}·year^{-1} and discards of 0.000006 t·km^{-2}·year^{-1}. These estimates of catch and biomass were used to calculate the fishing mortality for each of the three models and the estimated fishing mortality from 1963-1990 (Figure 9).

9. Sea otters

The range of the northern sea otter, *Enhydra lutris*, included the entire southern Alaskan coast and the Aleutian chain before they were hunted (Murie 1959). The sea otter population was heavily exploited from 1741 to 1911, but after near extinction it recovered and recolonised unexploited habitat in its native range in the Aleutians Islands (Palmisano 1975). The Rat Islands were the first to be recolonised in the 1950s, while the Near Island population was only re-established in the mid-1960s but the population grew rapidly through the 1970s and 1980s (Konar 1998).

The 1911 population estimate was as low as 1,000 - 2,000 animals, but by 1965 the population included approximately 25,000 animals (Palmisano 1975). Murie (1959) suggested that the total Aleutian Island population was estimated conservatively at 2,000 animals and Doroff et al. (2003) indicated that the population increased from 1911 to the 1980s. Doroff et al. (2003) gave estimates of the populations in the Near, Rat, Delarof, Andreanof and Four Mountain Island groups for 1959, 1965, 1992 and 2000 (Table 11). For the Islands of the Four Mountains, only the populations on Amukta, Yunaska, Herbert and Carlisle Islands were included in my estimate (Table 11), with the populations on Chuginadak, Kagamil and Uliaga Islands being in the Eastern Aleutian area (<170°W). These estimates gave a biomass in 1992 of approximately 0.0025 t·km^{-2} and for 1965 the estimate was 0.0036 t·km^{-2}. Assuming a linear increase over the time period 1959 to 1965, the 1963 population was approximately 9,620 otters or 0.00363 t·km^{-2}. For the 1979 model, I assumed that the biomass was similar to that in 1965 (0.0036 t·km^{-2}). The decline of the sea otter population in the Aleutians started around 1988 at Adak Island, 1991 for Amchitka Island and 1986 for Kagalska in the Andreanof Group (Doroff et al. 2003) but the population was still increasing in Attu by 1986 (Estes 1990). The population declined by approximately 17.5% per year in the 1990s (Doroff et al. 2003) and the cause of the decline in the central Aleutian Islands was found to be elevated adult mortality (Estes et al. 1998).

The annual sea otter reproduction rate was about 16%, with the annual rate of population change between 4-5% in dense populations and 10-12% in unexploited habitat (Palmisano 1975), which confirmed that the P/B of approximately 0.12 year^{-1} given by NOAA was realistic for a declining population. Perez and McAllister (1993) suggested that the daily energy requirements for

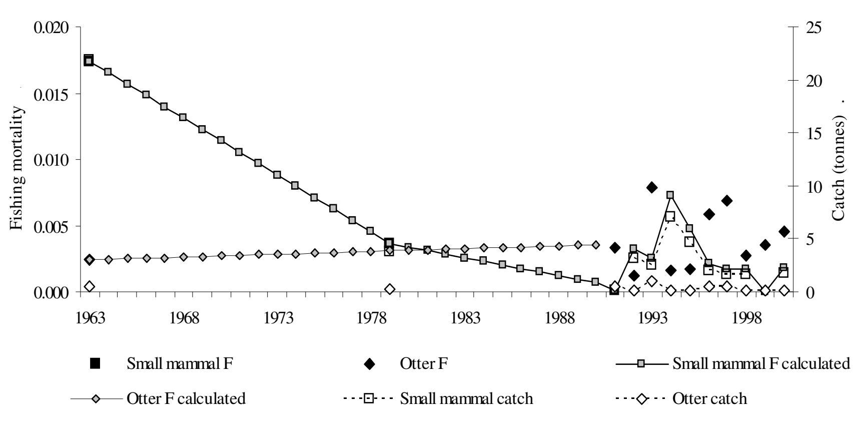


Figure 9. Fishing mortality (F, year^{-1}) and catch (t·year^{-1}) of small mammals and sea otters in the Aleutian Islands.

otters were 4.9 10^3 kcal, and that the energy value of their food was 0.9 kcal·g^{-1}, which gave a daily food consumption of 5.4 kg and an annual Q/B of 86.4.

Sea otters are fed on by transient orcas in the central Aleutian Islands, with the decline in otters from the mid-1980s to the mid-1990s possibly being caused by only a few transients (Ford and Ellis 1999). Murie (1959) reported that, in the 1930s, killer whales were seen cruising the outer edge of a kelp bed close to sea otter population, but he could not verify that they were catching otters. They were also preyed on by sharks and according to Estes (1980) by Steller sea lions, but I have not added them to the diet of Stellers.

The diet (by volume) of sea otters was estimated at 6% greenlings, 86% sea urchins and 8% other invertebrates (Wilke 1957), while Estes et al. (1981) gave the frequency of occurrence in the diet as: 60% sea urchins, 29% other invertebrates, 2.5% epibenthic carnivores (crabs), 1% macrophytes, 0.1% octopi, and 6% greenlings, and Yang (1999) suggested that Atka mackerel has been found in the stomach of sea otters. Watt et al. (2000) calculated the diet of sea otters during winter and summer at Amchitka Island in both % frequency and % volume and we used the average % volume for our diet in 1991. Thus the diet of sea otters was assumed to be approximately 13.2% greenling/lumpsucker etc. (small demersals), 78.9% invertebrates (mostly urchins), 3.9% epibenthic carnivores, 0.3% cephalopods, 1.2% Atka mackerel and 1.2% sand lance.

Table 11. Estimates of sea otter populations in the Aleutian islands obtained from Doroff et al. (2003).

Island group	**1959**	**1960**	**1965**	**1992**	**2000**
Near Islands	0		27	995	368
Rat Islands	3480		3147	1461	192
Delarof Islands	4178		2798	995	343
Andreanof Islands	1889		3685	3107	847
4 Mountains		0		31	30
Total	**9547**		**9657**	**6589**	**1780**
Density (t·km^{-2})	0.0036		0.0036	0.0025	0.0007

Estes (1990) suggested that sea otters start off by eating large sea urchins, eventually reducing the number and size of sea urchins to such an extent that the habitat goes from urchin barren to kelp bed. In response to these changes (lack of large urchins and the increase in kelp associated species) the diet would change from one dominated by invertebrates to one dominated by fish (Estes 1990). Monson et al. (2000) also indicated that by 1993 the body condition of the remaining sea otters at Amchitka Island had improved, because the decline in otters increased the sea urchin population, and they were also feeding on smooth lumpsuckers (small demersal species from the epipelagic zone) which increased their body condition. Thus, the above mentioned diet would probably be good for the 1991 model, but the 1979 model would include more fish (greenlings, lumpsuckers and Atka mackerel). Watt et al. (2000) suggested that by the early 1970s kelp-forest fishes were the single most important prey of otters at Amchitka and most fish eaten by otters were inshore, kelp-associated species such as greenlings, rockfishes, gunnels, pricklebacks and sculpins. Thus, for the 1979 model I included more fish (30% small demersals, 4% Atka mackerel and 4% sand lance). I also used this diet for the 1963 model.

Sea otters were caught as bycatch by the Aleutian Islands black cod pot fishery in 1992 (Angliss and Lodge 2002), and Berger et al. (1986) estimated that 18 sea otters were taken that year, giving a bycatch of 0.000007 t·km^{-2}·year^{-1} for that fishery, which I used in the 1991 model. No sea otters were caught by the pot fishery in 1979, and as I have no estimate of catch for the 1963 fishery, I assumed that the bycatch by the pot fishery was proportional to the catch, giving a catch of 0.000009 t·km^{-2}·year^{-1}.

Table 12. Catch of sea otters by First Nations in the Aleutians.

Year	**Number**	**kg·km^{-2}·year^{-1}**
1989	50	0.003
1990	50	0.003
1991	25	0.002
1992	50	0.003
1993	180	0.011
1994	52	0.003
1995	50	0.003
1996	150	0.009
1997	150	0.009
1998	50	0.003
1999	52	0.003
2000	50	0.003

The estimated catch by First Nations from 1989-2000 were obtained from Angliss and Lodge (2002). The average catch by First Nations for the western stock (from the Western Gulf of Alaska to the Aleutian Islands and including the Pribilof Islands) for 1996-2000 was 97 animals (Angliss and Lodge 2002). The total number of otters in the western stock consisted of 33,203 otters, of which 7,309 animals were in the Aleutian Islands (Angliss and Lodge 2002). I used this ratio (33,203:7,309) to calculate the First Nations catch in the Aleutian Islands. Thus, in 1991 approximately 25 otters (or 0.002 kg·km^{-2}·year^{-1}) were caught in the western stock (Table 12). There were no estimates of subsistence catches for 1979 or 1963, but the population was higher, therefore I used the average catch from 1989 to 2000 in the total Western Gulf of 76 animals or 0.005 kg·km^{-2}·year^{-1} for both time periods (Angliss and Lodge 2002). Thus, the total catch of sea otters amounted to 0.000008 in 1991, 0.000005 in 1979 and 0.000014 t·km^{-}

^{2}·year^{-1} in 1963. The estimates of catch and biomass were used to calculate a fishing mortality rate for each of the three models and the extrapolated fishing mortality from 1963-1990 (Figure 9).

10. Birds

The various bird species of of the Aleutian Islands are given in Table 13 and consist of invertebrate feeders and piscivorous birds. In addition to the species for which biomass estimates were available (Table 13), invertebrate feeding birds also include ancient murrelet, *Synthliboramphus antiquus,* short-tailed albatross, *D. albatrus,* Cassin's auklet, *Ptychoramphus aleuticus,* whiskered auklet, *A. pygmaea* and parakeet auklet, *Cyclorrhynchus psittacula* (Anonymous 2001). Similarly, additional piscivorous bird species include the Aleutian tern, *Sterna aleutica,* Arctic tern, *S. paradisaea,* black guillemot, *Cepphus grille,* red-legged kittiwake, *R. brevirostris,* Bonaparte's gull, *Larus Philadelphia,* glacous gull, *L. hyperboreus,* glaucous-winged gull, *L. glaucescens,* herring gull, *L. argentatus,* Mew gull, *L. canus,* ivory gull, *Pagophila eburnean,* common murre, *Uria aalge,* Kittlitz's murrelet, *Brachyearamphus brevirostris,* marbled murrelet, *B. marmoratus,* pigeon guillemot, *Cepphus columba,* rhinoceros auklet, *Cerorhinca monocerata,* Sabine's gull, *Xema sabini* (Anonymous 2001).

The species for which biomass estimates were available in the Western Sub-Arctic (USA), their residency (92 days), body mass and occupancy (Table 13) were obtained from Hunt et al. (2000). The total area of the WSA (2,168,000 km²) was used to calculate the total biomass per unit area (0.09 t·km^{-2}) for the 1991 model. I assumed that the Aleutian Island bird biomass was similar to that of the western sub-arctic region and this estimate was then a lower limit to the biomass as not all the species were represented. For the 1979 and 1963 models no biomass was available and they were estimated by Ecopath. The annual P/B estimate (0.113) was obtained from the NMFS model, while the annual Q/B ratio (65.4) was estimated by using the daily ration (R), the average weight (W) for each species, and the empirical equation:

$$\log R = -0.293 + 0.85 \quad \log W(g)$$

obtained from Nilsson and Nilsson (1976) in Wada (1996).

Table 13. Estimates of invertebrate feeding and piscivorous bird numbers, mean weight and biomass in the Western Sub-Arctic region; all birds have a residency time of 92 days (Hunt et al. 2000).

Common name	Species	Abundance	Body mass (kg)	Weight (t)
Invertebrate feeders				
Black-footed albatross	*Diomedea nigripes*	5,000	3.148	1,448
Crested auklet	*Aethia cristatella*	380,000	0.264	9,229
Fork-tailed storm petrel	*Oceanogroma furcata*	3,600,000	0.055	18,315
Leach's storm petrel	*Oceanogroma leucorrhoa*	3,500,000	0.040	12,816
Least auklet	*Aethia pusilla*	47,000	0.084	363
Northern fulmar	*Fulmarus glacialis*	600,000	0.544	30,029
Red phalarope	*Phalaropus fulicaria*	87,000	0.056	446
Short-tailed shearwater	*Puffinus tenuirostris*	430,000	0.543	21,481
Thick-billed murre	*Uria lomvia*	47,000	0.964	4,168
Piscivorous birds				
Black-legged kittiwake	*Rissa tridactyla*	610,000	0.407	22,841
Buller's shearwater	*Puffin bulleri*	5,000	0.380	175
Cormorants	*Phalacrocorax spp.*	1,000	2.822	260
Horned puffin	*Fratercula corniculata*	85,000	0.619	4,841
Laysan albatross	*Diomedea immutabilis*	1,100,000	3.042	307,850
Long-tailed jaeger	*Sterocorarius longicaudus*	38,000	0.297	1,037
Parasitic jaeger	*Sterocorarius parasiticus*	76,000	0.465	3,248
Pomarine jaeger	*Sterocorarius pomarinus*	190,000	0.694	12,131
Sooty shearwater	*Puffinus griseus*	3,100,000	0.787	224,452
South polar skua	*Stercorarius maccormicki*	150,000	1.156	15,953
Tufted puffin	*Fratercula cirrhata*	892,000	0.779	63928

The diet of birds were obtained from NMFS data for shearwaters, murre, kittiwakes, auklets, puffins, fulmars, storm petrels, cormorants and albatrosses. The diets of all other species were prorated by the biomass of each group. A diet for gulls was given but not used in my calculation, as I had no biomass to prorate their diet. For many species a preference diet was given, and was either prorated by the biomass of their prey (if those were available) or by taking a straight percentage of the preference given, so for instance, for albatrosses 50% of the diet consisted of salmon, small pelagics, sand lance, herring, myctophids, juvenile pollock and Pacific cod, and that 50% was divided equally (7.1% each) between these species. For cormorants 45% of their diet was divided between myctophids and small pelagics (22.5%). The contribution of shrimp, benthic invertebrates and epibenthic carnivores were 2.5% combined or 0.8% each. The 3% preference for Atka mackerel, juvenile pollock, Pacific Ocean perch, rockfish and Pacific cod was divided based on the biomass of these species, and the 2.5% small and large zooplankton was prorated on their biomass. Finally the remaining 27% of the diet was divided equally between small pelagics and myctophids.

For storm petrels, the 32% allocated to zooplankton was prorated by their biomass, the 1.7% allocated to Atka mackerel, juvenile pollock, Pacific Ocean perch, rockfish and Pacific cod was prorated by their biomass and the 4.2% allocated to small pelagics and sand lance was divided equally between them. For fulmars the 3.4% allocated to zooplankton and the 30.6% allocated to Atka mackerel, juvenile pollock, Pacific Ocean perch, rockfish and Pacific cod was prorated by their biomasses, and the 7.15% allocated to small pelagics and sand lance was divided equally between them. The NMFS data also had fulmars eating 0.15% transient killer whales, toothed whales, juvenile and adult Steller sea lions, small mammals, sea otters and birds. I redirected this portion of the diet to Steller sea lion pups, although it could also be redirected to detritus, as this could be dead mammals.

For puffins, the 7% allocated to zooplankton and the 11.6% allocated to Atka mackerel, juvenile pollock, Pacific Ocean perch, rockfish and Pacific cod was prorated by their biomass, and the 71% allocated to small pelagics and sand lance was divided equally between them. For auklets, the 93% allocated to zooplankton and the 0.3% allocated to Atka mackerel, juvenile pollock, Pacific Ocean perch and Pacific cod was prorated by their biomasses, and the 5.4% allocated to small pelagics and sand lance was divided equally between them. For kittiwakes, the 8.2% allocated to zooplankton and the 23.3% allocated to Atka mackerel, juvenile pollock, Pacific Ocean perch, rockfish and Pacific cod was prorated by their biomasses. The 50.9% allocated to small pelagics and sand lance, and the 12.2% allocated to herring and myctophids were divided equally between them. For murres, the 11.3% allocated to zooplankton and the 20% allocated to Atka mackerel, juvenile pollock, Pacific Ocean perch, rockfish and Pacific cod was prorated by their biomass. The 37.4% allocated to small pelagics and sand lance and the 0.2% allocated to herring and myctophids were divided equally. For shearwaters, the 1.7% allocated to zooplankton was prorated by their biomass and the 29% allocated to herring and myctophids were divided equally. The diet of birds in 1991 and 1979 were prorated for the biomass of their prey where possible and are given in Table 14 and 15 respectively. For the 1963 model, I used the same diet as for the 1979 model as no biomass estimates were available for fish during that time.

Table 14. Diet composition of birds (% weight) in the Aleutian Islands in 1991.

Group	**Shear water**	**Murre**	**Kitti-wake**	**Auklet**	**Puffin**	**Fulmar**	**Storm Petrel**	**Cormo-rant**	**Albatross Jaeger**	**Total**
Biomass	0.114	0	0.011	0.004	0.032	0.014	0.01	0	0.15	
SSL Pups	0	0	0	0	0	0.2	0	0	0	0
Salmon	0	0	0	0	0	0	0	0	7.1	3.1
Small Pelagics	41.6	18.7	25.4	2.7	35.7	3.6	2.1	13.5	7.1	21.5
Atka mackerel	0	13.4	15.6	0.2	7.8	20.4	1.1	2	0	2.2
Sand lance	14.5	18.7	25.4	2.7	35.7	3.6	2.1	50	7.1	12.5
Herring	0	0.1	6.1	0	0	0	0	15	7.1	3.3
Juv. pollock	0	27.1	1.5	0	0.8	2	0.1	0.2	7.1	3.5
A. pollock	0	0	0	0	0	0	0	0	0	0
POP	0	0.6	0.7	0	0.4	0.9	0.1	0.1	0	0.1
Rockfish	0	0.4	0.5	0	0.2	0.6	0	0.1	0	0.1
Pcod	0	4.3	5	0.1	2.5	6.6	0.4	0.6	7.1	3.8
Myctophids	14.5	0.1	6.1	0	0	0	0	13.5	7.1	8.2
Shrimp	0	0	0	0	0	0	0	0.8	0	0
Benthic inverts	1	0.6	4.7	0.9	6.3	0.1	1.4	0.8	0	1.1
Epi.carnivores	0	0	0	0	0	0	0	0.8	0	0
Cephalopods	26.6	3.5	0.7	0.1	3.8	58.6	60.7	0	50	36.3
L zooplankton	1.2	8.1	5.9	66.4	5	2.4	22.8	1.8	0	3
S Zooplankton	0.5	3.2	2.3	26.6	2	1	9.2	0.7	0	1.2

Both piscivorous and invertebrate feeding birds were taken as bycatch in the longline and trawler fisheries(Anonymous 2001). Bycatch by the BSAI longline fleet and the BSAI and GOA trawl fleets were given for 1993-1999 by Anonymous (2001). The area of the Bering Sea and Aleutian Islands is approximately 552,000 km², while the BSAI and Gulf of Alaska combined is approximately 844,000 km² giving a bycatch in 1993 of 0.00013 t·km^{-2} year^{-1} by the longline fleet and 0.000002 t·km^{-2} year^{-1} by the trawlers in 1993, which was used for bycatch in the 1991 model. Estimates of bycatch for the 1979 and 1963 models were not available, and I used the ratio of the total catch by trawlers and longlines in 1979 and 1963 compared to 1993 to get the proportion of bycatch in 1979 and 1963. The total catch made by trawlers for 1979 was 83,000 tonnes, or 63% of the 1993 catch (~ 132,000 tonnes), resulting in a bycatch of 0.000001 t·km^{-2}·year^{-1}. Similarly, the total catch made by trawlers and longlines in 1963 were 12,325 tonnes and 664 tonnes respectively, indicating catches of 0.0000005 and 0.0000004 t·km^{-2}·year^{-1} made by the longliners and trawlers respectively.

Table 15. Diet composition of birds (% weight) in the Aleutian Islands in 1979.

Group	Shear-water	Murre	Kitti-wake	Auklet	Puffin	Fulmar	Storm petrel	Cormo-rant	Albatross Jaeger	Total
Biomass*	0.114	0	0.011	0.004	0.032	0.014	0.01	0	0.15	
SSL Pups	0	0	0	0	0	0.2	0	0	0	0
Salmon	0	0	0	0	0	0	0	0	7.1	3.1
Small Pelagics	41.6	18.7	25.4	2.7	35.7	3.6	2.1	13.5	7.1	21.5
Atka mackerel	0	13.5	15.7	0.2	7.8	20.6	1.1	2	0	2.2
Sand lance	14.5	18.7	25.4	2.7	35.7	3.6	2.1	50	7.1	12.5
Herring	0	0.1	6.1	0	0	0	0	15	7.1	3.3
Juv. pollock	0	27.1	3.7	0	1.8	4.8	0.3	0.5	7.1	3.8
Ad.pollock	0	0	0	0	0	0	0	0	0	0
POP	0	0.4	0.4	0	0.2	0.6	0	0.1	0	0.1
Rockfish	0	0.8	1	0	0.5	1.2	0.1	0.1	0	0.1
Pcod	0	2.2	2.6	0	1.3	3.4	0.2	0.3	7.1	3.5
Myctophids	14.5	0.1	6.1	0	0	0	0	13.5	7.1	8.2
Shrimp	0	0	0	0	0	0	0	0.8	0	0
Benthic inverts	1	0.6	4.7	0.9	6.3	0.1	1.4	0.8	0	1.1
Epi.carnivores	0	0	0	0	0	0	0	0.8	0	0
Cephalopods	26.6	3.5	0.7	0.1	3.8	58.6	60.7	0	50	36.3
L zooplankton	1	6.9	5	56.9	4.3	2.1	19.6	1.5	0	2.6
S Zooplankton	0.7	4.4	3.2	36.1	2.7	1.3	12.4	1	0	1.6

* Assuming that biomass has the same ratio as in 1991.

11. Mammal eating sharks

Mammal eating sharks include the Pacific sleeper shark, *Somniosus pacificus*, the great white shark, *Carcharodon carcharias*, and the bluenose sixgill shark, *Hexanchus griseus*. There are some indications that salmon sharks, *Lamna ditropis*, also feed on sea lions (Loughlin and York 2000), but this species was not added to the mammal eating shark group. Little biological information was available for Pacific sleeper sharks, although they were considered common in boreal and temperate regions of shelf and slope waters of the North Pacific (Hare et al. 2003). Sleeper sharks are found in relatively shallow waters at higher latitudes, and in deeper habitats in temperate waters and large concentrations of sleeper sharks were found during the 2000 pilot Bering Sea slope survey, but hardly any were found in the Eastern Bering Sea shelf survey (Hare et al. 2003). Orlov and Moiseev (1998) found that they occurred in depths from 85 m to 717 m (average about 450 m) in the Western Bering Sea and the Northwestern Pacific (close to the Kuril Islands and Kamchatka). Great whites have been reported off the Aleutians Islands (http://www.sharkresearch committee.com/dist.htm) but very little other information is available.

No data was available on the biomass of mammal eating sharks in the Aleutians for any of the models (1963, 1979 or 1991). The annual P/B (0.1) and Q/B (3.0) ratios of Pacific sleeper sharks were obtained from the NMFS model and used for the 1979 and 1991 models (and the Q/B in 1963). The annual P/B ratio in 1963 of 0.13 was obtained from the natural mortality given by Guénette (this volume). The diet of Pacific sleeper sharks included harbour seals and cetaceans (Hulbert et al. 2002), although the diet estimates obtained from NMFS for sleeper sharks did not include any mammals. I therefore used the initial diet used by Guénette (this volume) for mammal eating sharks (including white and sixgill sharks), which included 3.5% Steller sea lion juveniles, and added the percentage of slope and shelf rockfish into my rockfish group, as well as adding the small demersals to myctophids (see Table A1). This diet was used for all three models.

According to the Predator Conservation Network website, sleeper sharks were caught year-round on commercial sablefish long-line gear in Alaska, with tagged sharks were usually recaptured near where they were originally caught. Fishermen reported few catches of sleeper sharks in the late 1980's but catches have increased since the early 1990's (http://www.conservationinstitute.org/pcnpacificsleepershark.htm). According to Orlov and Moiseev (1998), Pacific sleeper sharks were more abundant in the western Bering Sea than in the Kuril Islands, with bottom trawl catches in the Bering Sea usually being represented by 1-10 (maximum 25) specimens and caught at a frequency of 42.7%. Off the northern Kuril Islands and southestern Kamchatka they were caught mostly as single specimens with frequency of occurrence in bottom trawl catches of about 3.5% (Orlov and Moiseev 1998). However, there was no clear estimate of the catch of sharks and therefore I estimated the catch from the "other groundfish" group given by Gaichas (2003). This estimate for other groundfish was divided using the proportion of sharks, skates, sculpins and octopuses in the 1999 catch obtained from Anonymous (2001). The proportion of the catch allotted to sharks was then divided equally between mammal eating and other sharks, and the other shark catch was added to the skate and shark group (Table 16). The domestic catches for sharks and skates were divided into trawl, pot and longline gear (Anonymous 2001) and I assumed that all of these catches were discarded. For 1963-1976, no estimates of catches or discards were available, and I assumed that the bycatch of sharks (both mammal eaters and sharks and skates) were in the same ratio of the bycatch to catch ratio for the 1979 model.

Table 16. Catch (t) of mammal eating sharks and sharks and skates in the Aleutians.

	Mammal eating sharks				**Sharks and skates**			**Total**
Year	**Pot**	**Trawl**	**Longline**	**Total**	**Pot**	**Trawl**	**Longline**	
1963	0	56	1	57	0	4262	82	4,345
1964	0	223	2	225	0	17061	151	17,211
1965	0	270	1	271	0	20631	97	20,728
1966	0	220	8	228	0	16823	633	17456
1967	0	154	14	168	0	11800	1,070	12,870
1968	0	125	9	134	0	9553	682	10,236
1969	0	109	14	123	0	8327	1,066	9,393
1970	0	198	14	212	0	15167	1,061	16,228
1971	0	72	7	79	0	5489	544	6,033
1972	0	115	17	132	0	8829	1,303	10,132
1973	0	75	16	91	0	5727	1,216	6,943
1974	0	129	16	145	0	9863	1,196	11,060
1975	0	115	7	122	0	8797	567	9,364
1976	0	88	8	96	0	6726	615	7,341
1977	0	134	0	134	0	10,234	38	4,319
1978	0	101	2	103	0	7,719	181	7,900
1979	0	104	4	107	0	7,931	285	8,216
1980	0	108	0	108	0	8,243	32	8,276
1981	0	60	0	60	0	4,587	34	4,621
1982	0	42	1	43	0	3,230	53	3,282
1983	0.02	30	1	31	0	2,265	70	2,334
1984	0.00	14	0	14	0	1,037	24	1,061
1985	0.01	17	0	17	0	1,269	33	1,302
1986	0.03	12	0	13	0	941	18	959
1987	0.00	10	0	10	0	731	3	734
1988	0.06	3	0	4	0	236	42	278
1989	0.04	1	0	1	0	40	29	69
1990	1.92	34	3	39	0.13	1,720	1,261	2,981
1991	0.38	7	1	8	0.03	344	252	596
1992	1.26	22	2	26	0.08	1,129	828	1,957
1993	1.34	23	2	27	0.09	1,201	881	2,082
1994	0.45	8	1	9	0.03	403	295	698
1995	0.53	9	1	11	0.03	473	347	819
1996	0.70	12	1	14	0.05	625	458	1,084
1997	0.62	11	1	13	0.04	557	408	966
1998	1.01	18	2	20	0.07	900	660	1,559
1999	0.69	12	1	14	0.05	615	451	1,066
2000	1.23	22	2	25	0.08	1,103	809	1,912
2001	1.65	29	3	33	0.11	1,477	1,083	2,559
2002	0.81	14	1	16	0.05	726	532	1,258

12. Sharks and skates

All sharks and skates, excluding the three mammal eating shark species above are given in this group. The sharks include salmon sharks, *Lamna ditropis*, and spiny dogfish, *Squalus acanthias*, while skates include the white skate, *Bathyearaja* *spinosissima*, deepsea skate, *B. abyssicola*, big skate, *Raja binoculata*, Bering skate, *B. interrupta*, longnose skate, *R. rhina*, starry skate, *R. stellulata*, mud skate, *B. taranetzi / Rhinoraja longii*, black skate, *B. trachura*, Alaska skate, *B. parmifera*, Aleutian skate, *B. aleutica*, commander skate, *B. lindbergi*, whiteblotched skate, *B. maculate*, whitebrow skate, *B. minispinosa*, golden skate, *B. smirnovi* and Okhotsk skate, *B. violacea* (Hare et al. 2003). The skate community in the Aleutian Islands appeared to be different from that of the Eastern Bering Sea (Hare et al. 2003). The most abundant species in the 1997 survey of the Aleutian Islands was the whiteblotched skate, while Alaska and Aleutian skates were also common (Hare et al. 2003). The mud skate was relatively common but represented a lower proportion of total biomass because it is a smaller skate and all seven other skate species identified in the 1997 survey made up about 7% of aggregate skate complex biomass (Hare et al. 2003).

The biomass for sharks and skates (Figure 10) for 1991 (0.31 t·km^{-2}) was obtained from the survey (Gaichas 2002), but no estimates were available for either the 1979 or 1963 model so they were estimated by Ecopath. The annual P/B (0.18) and Q/B (2.5) ratios for this group were obtained by using the average of the ratios given in the NMFS model for salmon sharks, dogfish, Alaska skate, Bering skate, Aleutian skate, whiteblotched skate, mud skate, longnosed skate, big skate and black skate, and were used for all three models. For 1963, an average annual P/B of 0.16 was calculated based on the natural mortality of sharks and skates given by Gaichas (2003).

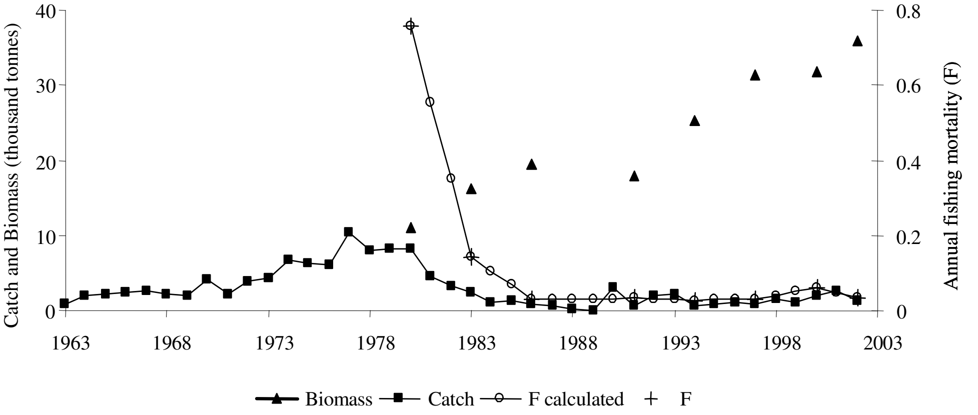


Figure 10. Catch (tonnes), biomass (tonnes) and fishing mortality (year^{-1} observed and interpolated) for sharks and skates in the Aleutian Islands.

The diet for sharks and skates was obtained from NMFS for salmon sharks, dogfish, Alaska skate, Aleutian skate, Bering skate, whiteblotched skate, mud skate, big skate, longnose skate and black skate. In the NMFS database, when no information was available about the proportion in the diet of the different prey, it was assumed that prey were consumed in proportion to their abundance. As with birds, only preference diet was given for some prey species, and these prey were either prorated by their biomass (if those were available, and I used the different biomass for 1979 and 1991 to get different diets for those time periods) or by taking a straight percentage of the preference given.

The diet of salmon sharks (Table 17) included a preference of 1% for all rockfish, and 4% for greenlings, sculpins, etc. which were all grouped into the small demersal group. Dogfish diet had a preference of 9% for small zooplankton and some large zooplankton species (viz. mysids, chaetognaths, pelagic amphipods), and I prorated this preference between the large and small zooplankton based on the biomass small and large zooplankton (adding the value to the 16.3% already given for euphausiids and jellies). The invertebrate portion of the diet included non-pandalid shrimps (shrimps), anemones, hydroids, clams, polychaetes (benthic invertebrates), snails and sea stars (carnivorous epibenthos), and as no biomass estimates existed for shrimp and carnivorous epibenthos, I divided the 2.9% equally into these three groups, adding it to the 7.6% shrimps, 2.2% benthic invertebrates and 6.7% epibenthic carnivores already consumed. A preference of 15.4% was divided between Pacific cod, juvenile and adult pollock in the ratio of their biomass estimates and 11.1% was divided between halibut, arrowtooth and flatfish in the ratio of their biomass, while the 2.8% preference for all rockfish was allocated to the one rockfish group, and the 1.9% preference for dogfish and skates was allocated to the shark and skate group.

Table 17. Diet composition for sharks and skates (in % weight) in the Aleutian Islands for 1991. Data from NMFS except for Alaska skate, which was adapted from Guénette (this volume). Diets for longnose, big and black skates were prorated to get proportions.

Group	**Salmon sharks**	**Dog-fish**	**Alaska skate**	**Bering skate**	**Aleutian skate**	**White-blotch**	**Mud skate**	**Long nose**	**Big skate**	**Black skate**	**Total**
Sharks/skates	1	2	0	0	0	0	0	0	0	0	0.3
Salmon	39.6	0	0	0	0	0	0	4.8	1.7	0	4.4
Small Pelagics	0	3.7	1	0	0	0	0	4.8	1.7	1	0.9
Atka mackerel	0	0	5	0	0	27.8	0	4.8	1.7	34.9	4.1
Sand lance	0	1.1	1	0	0	0	0	4.8	12.1	1	0.9
Herring	0.4	14.4	1	0	0	0	0	4.8	1.7	1	2
Juv. pollock	0	6.3	1	0	25.6	0	0	4.8	1.7	1	3.7
A. pollock	0	4	0	0	0	10.2	0	4.8	1.7	94.8	3
POP	0	0	0	0	0	0	0	0	0	1	0.01
Rockfish	1	2.8	0	0	0	0	0	0	0	22.7	0.7
Sablefish	36	0	5	0	0	0	0	0	0	1	4.1
Pcod	0	5.1	5	0	0	0	0	4.8	1.7	1	1.5
Halibut	11	1.7	1.7	0	0	0	0	8.3	5.8	1	2.3
Arrowtooth	0	4	1.7	0	0	0	0	8.3	5.8	1	1.4
L demersals	0	0	0	0	0	0	0	0	0	1	0.01
Flatfish	0	5.5	1.7	0	0	0	0	33.7	5.8	1	3.7
S demersals	4	0	10	0	0	8.8	0	4.8	103.3	59.1	5.8
Large deep	0	0	0	0	0	0	0	0	0	15.5	0.2
Myctophids	0	0	10	0	0	0.1	1.2	4.8	0	101.4	2.8
Shrimp	0	8.5	4	8.7	74.4	32.2	0	21	44.1	171.2	17.6
Benthic inverts	0	3.1	12	90.3	0	0.6	1.9	0	76.7	106.8	13.8
Epi.carnivores	0	7.6	8	0	0	12.4	0	0	10	90.3	4.1
Cephalopods	7	4.7	24	0	0	2.4	83.4	0	51.7	55.3	14
Lzooplankton	0	22.8	8	1	0	0.1	1.7	0	95	43.6	6.1
SZooplankton	0	2.6	0	0	0	0	0	0	0	0	0.3
Detritus	0	0	0	0	0	5.4	11.8	0	13.2	26.6	2.3
Import	0	0	0	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	119	435	833	100

The diet of Alaska skates included 79% small pelagics, sand lance, herring, sablefish, Pacific cod, halibut, arrowtooth and flatfish, and the total diet summed to >1, so I adapted the diet used by Guénette (this volume) for Alaska skates, to include 5% Atka mackerel instead of rockfish, 5% sablefish and Pacific cod, and the 5% allocated to flatfish I divided between halibut, arrowtooth and flatfish. The diet also consisted of 1% each for sand lance, herring, small pelagics and juvenile pollock, 10% each for small and medium demersals and myctophids, 4% shrimps, 12% benthic invertebrates, 8% epibenthic carnivores, 24% cephalopods and 8% large zooplankton.

For big skates, the diet preference for small pelagics, salmon, Atka mackerel, herring, juvenile pollock, adult pollock and Pacific cod was divided equally between these species, while the preference for halibut, arrowtooth flounder and flatfish was also divided equally. Similarly, for longnose skates the preference for halibut, arrowtooth and flatfish was divided between these three groups, and the value added to the consumption of rex sole by longnose skates and the preference for salmon, small pelagics, Atka mackerel, sand lance, herring, pollock adult and juveniles, Pacific cod, myctophids and small and medium demersals was divided equally between these groups. Likewise, the preference by black skates for small pelagics, sand lance, herring, adult and juvenile pollock, Pacific Ocean perch, rockfish, sablefish, Pacific cod, halibut, arrowtooth, demersal large predators, flatfish, demersal small/medium predators and large deep water fish were divided equally between the groups. This proportion was added to the known percentage for shortraker rockfish in the rockfish group, to the known percentages for Irish lord and sculpins in the demersal small/medium group and to the other macrourids in the large deep group. The total 1991 and 1979 diet breakdowns for sharks and skates are given in Tables 17 and 18 respectively. For 1963 very few estimates of fish biomass were available, thus I used the 1979 diet for this model. Spiny dogfish were commonly taken by the pelagic pollock trawl fishery and in the longline fisheries for sablefish, halibut, Greenland turbot, and Pacific cod, and their catch rates have increased five-fold in Prince William Sound and

Table 18. Diet composition for sharks and skates (% weight) in the Aleutian Islands for 1979. Data from NMFS except for Alaska skate, which was adapted from Guénette (this volume). Diets for longnose, big and black skates were prorated to get proportions.

Group	**Salmon sharks**	**Dog-fish**	**Alaska skate**	**Bering skate**	**Aleutian skate**	**White-blotch**	**Mud skate**	**Long nose**	**Big skate**	**Black skate**	**Total**
Sharks and skates	1	2	0	0	0	0	0	0	0	0	0.3
Salmon	39.6	0	0	0	0	0	0	4.8	1.7	0	4.4
Small Pelagics	0	3.7	1	0	0	0	0	4.8	1.7	1	0.9
Atka mackerel	0	0	5	0	0	27.8	0	4.8	1.7	34.9	4.1
Sand lance	0	1.1	1	0	0	0	0	4.8	12.1	1	0.9
Herring	0.4	14.4	1	0	0	0	0	4.8	1.7	1	2
Juv. pollock	0	8.3	1	0	25.6	0	0	4.8	1.7	1	3.9
A. pollock	0	5.3	0	0	0	10.2	0	4.8	1.7	94.8	3.1
POP	0	0	0	0	0	0	0	0	0	1	0.01
Rockfish	1	2.8	0	0	0	0	0	0	0	22.7	0.7
Sablefish	36	0	5	0	0	0	0	0	0	1	4.1
Pcod	0	1.8	5	0	0	0	0	4.8	1.7	1	1.1
Halibut	11	1.6	1.7	0	0	0	0	8.3	5.8	1	2.3
Arrowtooth	0	2.8	1.7	0	0	0	0	8.3	5.8	1	1.3
L demersals	0	0	0	0	0	0	0	0	0	1	0.01
Flatfish	0	6.8	1.7	0	0	0	0	33.7	5.8	1	3.8
S demersals	4	0	10	0	0	8.8	0	4.8	103.3	59.1	5.8
Large deep	0	0	0	0	0	0	0	0	0	15.5	0.2
Myctophids	0	0	10	0	0	0.1	1.2	4.8	0	101.4	2.8
Shrimp	0	8.5	4	8.7	74.4	32.2	0	21	44.1	171.2	17.6
Benthic inverts	0	3.1	12	90.3	0	0.6	1.9	0	76.7	106.8	13.8
Epiben.carnivores	0	7.6	8	0	0	12.4	0	0	10	90.3	4.1
Cephalopods	7	4.7	24	0	0	2.4	83.4	0	51.7	55.3	14
Lzooplankton	0	21.8	8	1	0	0.1	1.7	0	95	43.6	6
SZooplankton	0	3.5	0	0	0	0	0	0	0	0	0.4
Detritus	0	0	0	0	0	5.4	11.8	0	13.2	26.6	2.3
Import	0	0	0	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	119	435	833	100

twenty-fold in the central Gulf of Alaska since 1994 (http://www.conservationinstitute.org/spinydogfish.htm). The bycatch of sharks and skates were estimated from the stock assessment of "other groundfish" (Gaichas 2003) using the breakdown of other groundfish in the 1999 estimates from Anonymous (2001). From 1963-1976 no estimates of catches or discards were available, and I assumed that the bycatch of sharks and skates were in the same ratio of the bycatch to the catch ratio in the 1979 model (Table 16).

13. Salmon

The salmon present in the Aleutian Islands area are mostly part of the western Alaska stock, of the Bering Sea from the Yukon River to Unimak Island (Rogers 1987). These stocks migrate through the Aleutians from the Bering Sea to the Gulf of Alaska as smolts, and back into the Bering Sea as adults (Rogers 1987). According to Scheffer (1959), all five species of salmon were found in the Aleutians in the 1930s, with pink, *Onchorhynchus gorbuscha,* and silver or coho, *O. kisutch*, being the most common. Chum salmon, *O. keta*, was only collected once at Atka Island, while king/spring/chinook salmon, *O. tshawytscha,* was only collected as fingerlings, and sockeye salmon, *O. nerka*, was running into a lake on Attu Island in early June 1937 (Scheffer 1959).

Unfortunately, there was no biomass estimate for the salmon population in the Aleutian Islands and therefore I let Ecopath estimate the biomass. The catch of salmon in the whole Alaskan peninsula and Aleutian Islands were obtained from Byerly et al. (1999) and used as a proxy for salmon biomass time series (Figure 11). The annual P/B (0.9) and Q/B (4.33) ratios were obtained from the average outgoing and returning salmon from the NMFS model and used in the 1979 and 1991 models (as well as Q/B for 1963). For 1963 an annual P/B ratio of 1.17 was estimated based on the natural mortalities of

Table 19. Diet composition (in proportion) for salmon in the Aleutian Islands obtained from the NMFS model.

Groups	**Returning salmon**	**Outgoing salmon**	**Average**
Cephalopods	0.2	0	0.1
Large zooplankton	0.4	0.25	0.325
Small zooplankton	0.2	0.25	0.225
Algae	0.2	0.5	0.35
Import	0	0	0
Total	1	1	1

the various salmon stocks (Huato 1996; Orsi et al. 2003). The diet obtained from the NMFS model is given in Table 19. This diet was used for all three models.

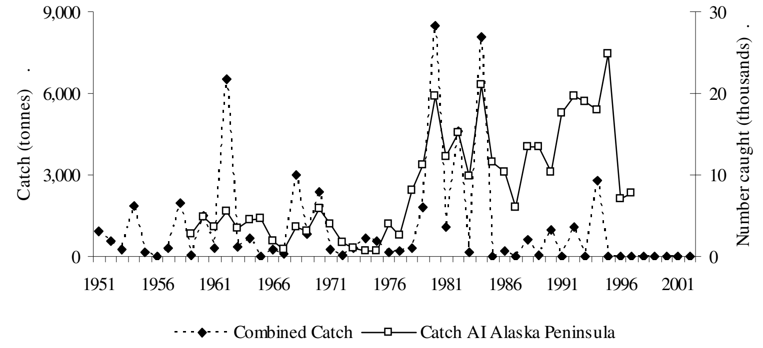


Figure 11. Catch (tonnes) of all salmon species combined in the Aleutian Islands and numbers of salmon caught in the Alaskan peninsula and Aleutian Islands combined used as proxy for a biomass time series.

The catch of salmon in the state waters of the Aleutian Islands is very small, and consists mostly of subsistence fishing (1988-2002, Table 20), although there was a directed commercial fishery from 1992 to 1994 (Joseph Dinnocenzo, Alaska Fish and Game, pers.comm), which was added to the data in Table 21. No data was available for subsistence fishing prior to 1988, and I assumed that it was similar to 1988 (3.7 tonnes) from 1963 to 1987. Salmon was also caught as bycatch in the BSAI groundfish fishery (area 522,154 km²), with estimates for 1990 to 1999 obtained from Anonymous (2001) (Table 20). Unfortunately, no estimates of salmon bycatch is available prior to 1990, but as Heard et al. (1998) proposed that the salmon bycatch was usually made by the pollock fleet, I assumed the bycatch was in the same proportion to the trawl catch as it was from 1990-1998 (approximately 3%). Catches of chinook, sockeye, coho, pink and chum salmon from 1911 to 1997 (Table 21) were reported by Byerly et al. (1999) and it seems that no salmon catches were made since 1994 in the Aleutian Island (west of 170˚) (Figure 11). The three years of commercial fishing from the state fishery was added into the catches obtained from Byerly et al. (1999).

Table 20. Subsistence catch of salmon (in numbers) by species, average body weight of each species in kg and total subsistence catch in tonnes, obtained from the Alaska Department of Fish and Game. Bycatch (tonnes) of salmon obtained from Anonymous (2001) for the BSAI groundfish fishery.

Year	**Chinook**	**Sockeye**	**Coho**	**Pink**	**Chum**	**Subsistence catch**
Average weight (kg)	*17.04*	*6.03*	*7.14*	*3.23*	*8.85*	tonnes
1988	0	503	23	150	0	3.68
1989	0	382	0	117	0	2.68
1990	0	800	47	41	0	5.30
1991	0	281	6	34	0	1.85
1992	0	572	30	4	0	3.68
1993	0	156	0	0	0	0.94
1994	0	0	0	0	0	0
1995	0	156	0	0	0	0.94
1996	0	91	0	0	0	0.55
1997	0	229	0	0	4	1.42
1998	0	399	0	25	0	2.49
1999	0	164	4	0	0	1.02
2000	0	265	4	78	0	1.88
2001	0	474	19	17	0	3.05
2002	0	150	0	0	0	0.91

14. Large pelagics

Large pelagic predators include the ocean sunfish, *Mola mola*, King-of-the-salmon, *Trachipterus altivelis*, and the Pacific pomfret, *Brama japonica*. No data were available on these species in the Aleutian islands, so I let Ecopath estimate their biomass and used the annual P/B (0.22), Q/B (1.47) and diets obtained from the SEAK model (Guénette, this volume) for all three models. There was also no known catch for this group.

15. Small pelagics

The small pelagic species include capelin, *Mallotus villosus*, eulachon, *Thaleichthys pacificus*, other pelagic smelts (Osmeridae) such as the night smelt *Spirinchus starksi*, longfin smelt *S. thaleichthys*, surf smelt, *Hypomesus pretiosus*, Arctic rainbow smelt, *Osmerus mordax,* sardine, *Engraulis mordax*, and chub mackerel, *Scomber japonicus*. There was no estimate of biomass available for this group, but scales in the sediments of Skan Bay on the north side of Unalaska

Table 21. Commercial salmon catch in the Aleutian Islands by species and year in thousands of fish (Byerly et al. 1999), and total catch and estimated bycatch (t) from the trawl fleet.

Year	Chinook	Sockeye	Coho	Pink	Chum	All salmon	Catch (t)	Bycatch (t)
1911		9				9	54	
1916		76	1	180		257	1048	
1917		70	4	1	23	98	658	
1918		55	4	76		135	606	
1919		4	1	4		9	44	
1920		10	3			13	82	
1921						0	0	
1922		14				14	84	
1923						0	0	
1924		25		674		699	2331	
1925		19		4	9	32	207	
1926		1		522	8	531	1765	
1927		17		335		352	1186	
1928-50	*							
1951		12		1	95	108	916	
1952		43		32	26	101	593	
1953		4	1	69	1	75	263	
1954		6	1	566		573	1874	
1955		13		31		44	179	
1956				5		5	16	
1957	2	27			14	43	321	
1958				613		613	1983	
1959		6		12		18	75	
1960		8		445		453	1488	
1961		3		94		97	322	
1962		5		2002	1	2008	6515	41
1963		5		90		95	321	17
1964				194	2	196	645	21
1965						0	0	39
1966		1		63	1	65	219	56
1967				8		8	26	41
1968		3		894	1	898	2919	81
1969				242		242	783	16
1970				642	3	645	2103	293
1971				45		45	146	97
1972				3		3	10	44
1973				2		2	6	317
1974						0	0	686
1975		19		1	2	22	136	417
1976						0	0	130
1977						0	0	206
1978		2		38		40	135	181
1979		12		539		551	1816	280
1980		9		2597	5	2611	8499	1,682
1981		5		303	7	315	1072	1,319
1982		3		1405	6	1414	4616	1,253
1983		6		3	10	19	134	947
1984		67	2	2271	32	2372	8048	963
1985		2				2	12	293
1986		6		41	2	49	187	528
1987						0	0	794
1988		4		183		187	616	1,116
1989		8		7		15	71	320
1990		12		283	1	296	997	344
1991		1				1	6	1,332
1992		3		320	2	325	1071	977
1993					1	1	9	2,319
1994				860	1	861	2791	1,365
1995								531
1996								1,569
1997								1,282
1998								1,442
1999								681

* Data only included in the South Peninsula catch)

Island indicated that some small forage fish (probably capelin) disappeared from the area in about 1978 and from seabird diets in the Pribilof Islands beginning around 1978, while eulachon also disappeared from the bycatch in the Eastern Bering Sea around that time (Merrick 1996). The average annual P/B (0.8) and Q/B (3.65) ratios for capelin, eulachon, other pelagic smelts and a group called "managed forage fish" from the NMFS model were used. The diet of small pelagics was obtained from the NMFS database.

The BSAI pollock and yellowfin sole fishery had an average bycatch of 31.8 – 292.1 tonnes of pelagic smelts in 1990-1993, giving an average bycatch of 162 tonnes, or 0.0003 $t{\cdot}km^{-2}{\cdot}year^{-1}$ (Anonymous 2001). As there are no estimates of small pelagic catches for 1979, I used the same value and assumed that all catches were discarded. No estimates of catches were available for the 1963 models and I assumed that they were probably not a big part of the bycatch of the pollock fishery at that time.

16. Atka mackerel

Atka mackerel, *Pleurogrammus monopterygius*, occurs along the Aleutian chain but is most abundant near the western end (Scheffer 1959). They are important in the diet of many larger predators in the Aleutian Islands. The stock assessment for Atka mackerel gave total biomass estimates in 1991 and 1979 of 724,820 tonnes (12.7 $t{\cdot}km^{-2}$) and 353,130 tonnes (6.2 $t{\cdot}km^{-2}$) respectively (Lowe et al. 2003). The annual P/B (0.18) and Q/B (5.6) ratios for adult Atka mackerel and diet estimates were obtained from the NMFS model and used for the 1991 and 1979 models. For 1963, I used the natural mortality obtained from the stock assessment report (Lowe et al. 2003) of 0.34 $year^{-1}$ as an estimate of P/B. No estimate of Atka mackerel biomass was available for 1963. The biomass and catch time series (Figure 12) for Atka mackerel were obtained from the stock assessment report (Lowe et al. 2003).

Atka mackerel was mainly caught by bottom trawl, general trawl and non-pelagic trawl fisheries, with minor catches being made by the longline fishery. The catch estimates for Atka mackerel from 1977-1990 were obtained from the stock assessment (Lowe et al. 2003), while the catch from 1991 to 2001 came from the NMFS database and the catch from 1970–1976 were obtained from Forrester et al. (1983). In the early 1970s, most Atka mackerel catches were made in the western Aleutian Islands (west of 180˚W longitude), while in the late 1970s and 1980s, the effort moved eastward (Lowe et al. 2003). In the Aleutians, the Atka mackerel fishery started in 1972, with 4,907 tonnes being caught by the USSR (Forrester et al. 1983). This was prorated between catch and discards by using the average ratio from 1991 to 2002. In 1979, the catch of 23,264 tonnes obtained from the stock assessment report (Lowe et al. 2003) was assumed to be mainly taken by the trawl fishery and I used the average % discards in the 1991-2002 data (12.8% discards) to estimate the breakdown of discards (2,986 tonnes) and landings (20,278 tonnes). This ratio was also used for the breakdown of discards and landings in the time series data (Table 22). The fishing mortality calculated as catch/age 1+ biomass from the stock assessment report (Lowe et al. 2003) was used to drive the Ecosim simulations (Figure 12).

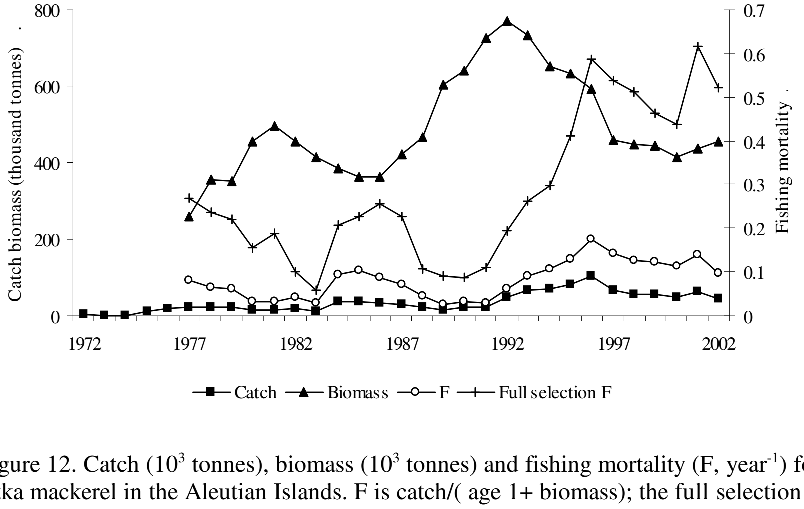


Figure 12. Catch (10^3 tonnes), biomass (10^3 tonnes) and fishing mortality (F, $year^{-1}$) for Atka mackerel in the Aleutian Islands. F is catch/(age 1+ biomass); the full selection F is the annual fishing mortality of fish fully selected by the fishing gear.

Table 22 Landings and discards of Atka mackerel (tonnes) in the Aleutian Islands taken by the various fleets.

Year	Landings				Discards				Total
	Pot	Trawl	Longline	Total	Pots	Trawl	Longline	Total	catch
1972		4,277		4,277		630		630	4,907
1973		1,398		1,398		206		206	1,604
1974		1,200		1,200		177		177	1,377
1975		10,528		10,528		1,550		1,550	12,078
1976		17,513		17,513		2,579		2,579	20,092
1977		18,970		18,970		2,793		2,793	21,763
1978		21,137		21,137		3,112		3,112	24,249
1979		20,278		20,278		2,986		2,986	23,264
1980		17,859		17,859		2,629		2,629	20,488
1981		17,161		17,161		2,527		2,527	19,688
1982		17,323		17,323		2,551		2,551	19,874
1983		10,221		10,221		1,505		1,505	11,726
1984		31,428		31,428		4,627		4,627	36,055
1985		33,001		33,001		4,859		4,859	37,860
1986		27,884		27,884		4,106		4,106	31,990
1987		26,203		26,203		3,858		3,858	30,061
1988		19,250		19,250		2,834		2,834	22,084
1989		15,685		15,685		2,309		2,309	17,994
1990		19,355		19,355		2,850		2,850	22,205
1991	0.000	22,015	0	22,015	0	2,122	3	2,125	24,140
1992	0.001	36,542	26	36,567	2	9,337	30	9,369	45,937
1993	0.000	50,150	4	50,154	0	15,635	17	15,652	65,805
1994	0.000	56,006	2	56,008	0	9,139	38	9,177	65,184
1995	0.125	66,652	0	66,652	1	14,519	42	14,562	81,214
1996	0.672	86,473	0	86,474	1	16,651	31	16,684	103,158
1997	0.183	59,244	1	59,245	0	6,381	39	6,421	65,665
1998	0.025	51,030	4	51,034	0	5,068	93	5,160	56,195
1999	0.179	49,105	4	49,109	1	4,753	67	4,822	53,931
2000	0.186	44,249	4	44,253	1	2,589	147	2,737	46,990
2001	0.063	56,709	135	56,844	1	4,312	138	4,452	61,296
2002	0.011	37,316	1	37,318	0	7,364	40	7,404	44,722

17. Sand lance

The biomass for Pacific sand lance, *Ammodytes hexapterus*, was not available and was estimated by Ecopath using the annual P/B (0.8) and Q/B (3.6) ratios obtained from NMFS. The diet obtained from NMFS was 90% large zooplankton and 10% algae, which I allocated to phytoplankton. There was no estimate of sand lance catches in the Aleutian Islands.

18. Herring

Herring, *Clupea pallasii*, does not seem to be very prevalent in the western and central Aleutian Islands, but it was abundant in the 1930s in the eastern Aleutians around Unalaska and Dutch harbour (Scheffer 1959). In addition, most of the Aleutian Island herring food and bait fishery was part of the Eastern Bering Sea herring biomass (Duesterloh and Burkey 2003). There was no estimate for herring biomass but the annual P/B (0.16) and Q/B (0.97) ratios for adult herring were obtained from NMFS and used to calculate a biomass in all models. Hirons (2001) found that the δ^{15}N for adult herring in the Aleutians was 2‰ higher than the same species from the Bering Sea, indicating that herring have a different diet in the Aleutians than in the Bering Sea. However, the diet estimates obtained for adult herring from the NMFS diet database came from a general diet database and included mostly large zooplankton. Small quantities of herring were taken by the foreign trawl fleet in the late 1970s, with 6 tonnes taken in 1979 and 14 tonnes in 1986 (foreign observer database, Berger, NMFS, Seattle, Wa., *pers. comm.*). Very few other catches were made of herring and no catch estimates were available for the 1991 and 1963 models.

Table 23. Von Bertalanffy growth curve parameters for pollock obtained from Barbeaux et al. (2003) and Ronholt et al. (1994).

Parameter	1980	1986
L_{inf} (cm)	54.01	53.41
a	0.02	0.0134
b	2.853	2.845
W_{inf} (g)	1,639	1,102
W_{inf} (kg)	1.64	1.10
W_{mat} (kg)	0.55	0.51
W_{mat}/W_{inf}	0.34	0.46
K (year^{-1})	0.374	0.34

19. Juvenile pollock

The annual P/B (1.99) ratio for juvenile Pollock, *Theragra chalcogramma*, were obtained from the NMFS model and used for the 1991 and 1979 models. The natural mortality of pollock juveniles (1.2 year^{-1}) given by Guénette (this volume) was used for the 1963 model. The Q/B was reduced to 4.6 year^{-1} when the adult Q/B was reduced to 1.9 year^{-1} (see section below) and the juvenile biomass was estimated by the multistanza Ecopath algorithm. The diet of juvenile pollock came for the NMFS diet database.

20. Adult pollock

From the Aleutian Island stock assessment report (Barbeaux et al. 2003), the age-3+ biomass for pollock in the Aleutian Islands were estimated at 267,152 tonnes in 1991 and 244,822 tonnes in 1979, and no estimates were available for 1963. The split between adults and juveniles were made at 25 months (2+), thus I used the numbers at age for the Aleutian Island population and the weight at age from the observer database in the stock assessment report (Barbeaux et al. 2003) to calculate the biomass for age 3+ while for age 2. I used an average length of 28 cm taken from Guénette (this volume) and the length-weight parameters (Table 23) from Ronholt et al. (1994) to calculate an average weight of 170 grams. This yielded a total biomass of 301,158 tonnes (5.3 t·km^{-2}) in 1991 and 256,459 tonnes (4.5 t·km^{-2}) in 1979 using the area for the Aleutian Islands. The time series of age 2+ pollock is given in Figure 13A. Even though these estimates are made for the NRA area (Near, Rat and Andreanof area) of 82,700 km^2 (Barbeaux et al. 2003), Ivonne Ortiz (University of Washington and NMFS, pers. comm.) suggested that I used the Aleutian Island area as the population is mainly concentrated in that area. To get an estimate of biomass in 1963, I compared the stock assessment biomass of age 3+ animals in the Aleutian Islands to that of the Gulf of Alaska obtained from Dorn et al. (2003) and for the Bering Sea obtained from Ianelli et al. (2003a) in Figure 13B. As the pollock biomass estimates for the Gulf seems to show the opposite trend to that of the Aleutians, while the biomass in the Bering Sea seems to be quite similar to that of the Aleutians, and the trend in the Bering Sea was that the biomass in 1963 was similar to that in 2000, I used the 2000 estimate for pollock in the Aleutians for 1963 (6.1 t·km^{-2}).

The von Bertalanffy growth curve parameters (Table 23) for 1980 and 1986 obtained from Barbeaux et al. (2003) and Ronholt et al. (1994) were used for the 1979 and 1991 models and I used the values for 1980 for the 1963 model. Thus, the W_{mat}/W_{inf} was calculated at 0.34 for 1979 and 0.46 for 1991 and I used the 1979 value for 1963. The annual P/B (0.366) and Q/B (3.65) ratios obtained from NMFS were used for both the 1991 and 1979 models. The annual P/B for adult pollock for the 1963 model (0.304) was estimated by using the natural mortality obtained from Barbeaux et al. (2003) and adding the fishing mortality estimated for that time. The diet of adult pollock was obtained from the NMFS diet database.

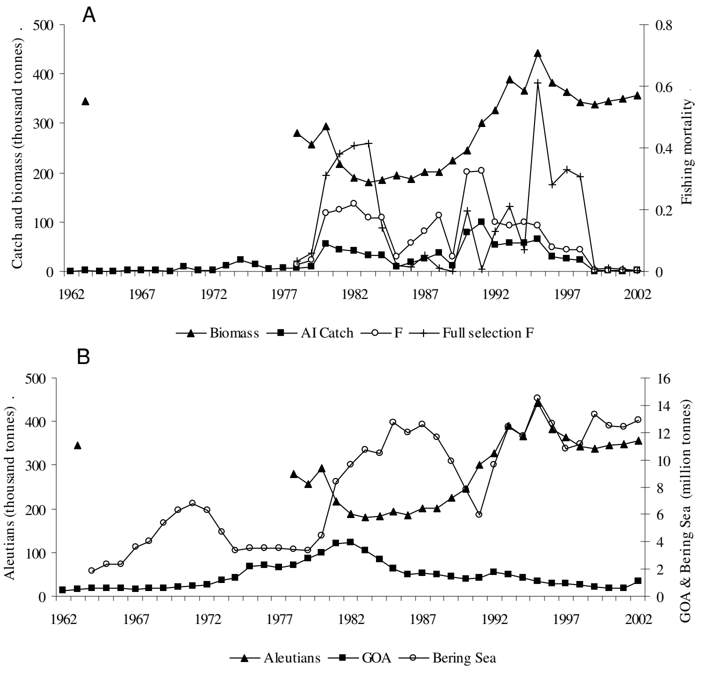


Figure 13. A. Catch (10^3 tonnes), biomass (10^3 tonnes) and fishing mortality (year^{-1}) for pollock in the Aleutian Islands. F is catch/(age 2+ biomass), and full selection F is the fishing mortality on only the fish that are fully selected by the fishing gear. B. Comparison of age-3+ biomass estimates for the Aleutian Islands (10^3 tonnes), the Gulf of Alaska (Dorn et al. 2003) and the Bering Sea (10^6 tonnes) (Ianelli et al. 2003a).

The pollock fishery in the Aleutian Islands started in 1962, and was relatively small until the late 1970s (Figure 13B). The data for pollock by the joint venture and foreign fleet was combined in Barbeaux et al. (2003), and included observer data and reported catches. The joint venture/foreign fleet and domestic fleet data obtained from Barbeaux et al. (2003) were used for catch estimates from 1977 to 1991, and the breakdown of these catches between trawlers and longlines (Table 24) were obtained from the NMFS observer database (J. Berger, NMFS Seattle, Wa., *pers. comm.*). From 1991-2002 the breakdown of the catch (Table 24) into longline, trawl and pot gear, as well as the breakdown between landings and discards, came from the NMFS database (Kerim Aydin, NMFS, Seattle, Wa. *pers. comm.*). Catches from 1962 to

1976 were obtained from Ronholt et al. (1994) and were assumed to be taken by the trawl fleet. The average distribution of landings and discards from the observer database were used to estimate the breakdown of the total catch between landings and discards for 1963-1990. The discards by gear were subtracted from the catches obtained from the NMFS observer database (Berger, NMFS Seattle, Wa., *pers. comm.*). However, from 1983 onwards the discards estimated for longlines were more than the minor catches, so longline discards were set to 0 and all discards were taken from the trawl fishery from 1983-1989. The time series of catch, biomass and fishing mortality is shown in Figure 13A.The 1970 pollock catch seemed to only be from the Japanese fleet, with the extra 9,490 tonnes taken by the USSR (Merrell 1977) added here (Figure 13A).

Table 24. Landings and discards (tonnes) of pollock in the Aleutian Islands from the observer data (1977-1989) and the NMFS database (Barbeaux et al. 2003).

Year	**Landings**				**Discards**				**Total catch**
	Pot	**Trawl**	**Longline**	**Total**	**Pot**	**Trawl**	**Longline**	**Total**	
1963		1304		1,304				55	1,359
1964		537		537				23	560
1965		669		669				28	697
1966		1225		1,225				52	1,277
1967		1758		1,758				75	1,833
1968		2568		2,568				109	2,677
1969		491		491				21	512
1970		9275		9,275				394	9,669
1971		3067		3,067				130	3,197
1972		1383		1,383				59	1,442
1973		10048		10,048				427	10,475
1974		21737		21,737				924	22,661
1975		13223		13,223				562	13,785
1976		4115		4,115				175	4,290
1977		7,067		7,067		297	3	300	7,367
1978		6,027		6,027		254	2	256	6,283
1979		9,058	4	9,061		381	4	385	9,446
1980		55,709	78	55,786		2,347	23	2,370	58,157
1981		53,250	4	53,254		2,241	22	2,263	55,517
1982		55,397	2	55,399		2,331	23	2,354	57,753
1983		56,604	12	56,616		2,406		2,406	59,021
1984		74,421	11	74,432		3,163		3,163	77,595
1985		55,768	9	55,778		2,370		2,370	58,147
1986		43,587		43,587		1,852		1,852	45,439
1987		27,311		27,311		1,160		1,160	28,471
1988		39,523		39,523		1,679		1,679	41,203
1989		10,138		10,138		431		431	10,569
1990		75,804		75,804		3,221		3,221	79,025
1991		93,368	5	93,373	0.006	5,229	2	5,231	98,604
1992		49,369		49,369	0.013	2,968	15	2,982	52,352
1993		55,398	1	55,399		1,692	41	1,733	57,132
1994		57,286		57,286	0.002	1,368	5	1,373	58,659
1995		63,539	6	63,545		1,358	23	1,380	64,925
1996		28,067		28,067	0.023	984	10	994	29,062
1997		25,302	20	25,323	0.077	596	22	617	25,940
1998		23,629	28	23,657	0.010	156	8	164	23,821
1999	0.017	521	8	529	1.700	475	4	480	1,010
2000	0.261	424	30	455	2.541	772	15	790	1,244
2001	0.005	391	54	445	4.376	357	19	380	824
2002	0.196	393	4	398	0.021	777	2	779	1177

21. Pacific Ocean perch

Until 1990, Pacific Ocean perch, *Sebastes alutus*, was part of the Pacific Ocean perch (POP) complex with four associated species including northern rockfish, *S. polyspinis*; rougheye rockfish, *S. aleutianus*; shortraker rockfish, *S. borealis*; and sharpchin rockfish, *S. zacentrus* (Spencer and Ianelli 2002). These five species were managed as a single entity with a single TAC (total allowable catch) but in 1991 the North Pacific Fishery Management Council separated Pacific Ocean perch from the rockfish complex in order to provide protection from possible overfishing (Spencer and Ianelli 2002). Of the five species in the former POP complex, Pacific Ocean perch has historically been the most abundant rockfish in this region and has contributed most to the commercial rockfish catch (Spencer and Ianelli 2002). Historically, the Aleutian Island survey indicated higher abundances in the western and central Aleutian Islands, and this pattern was repeated in the 2002 survey (Spencer and Ianelli 2002).

The stock assessment for Pacific Ocean perch was done for BSAI and the biomass for 1991, 1979 and 1963 were 321,639 tonnes, 92,616 tonnes and 612,325 tonnes respectively (Spencer and Ianelli 2003a). Using a total area of 552,154 km² yielded a biomass of 0.58 t·km^{-2}, 0.17 t·km^{-2} and 1.11 t·km^{-2} respectively for 1991, 1979 and 1963 (Figure 14). The annual P/B (0.1) and Q/B (1.8) ratios for Pacific Ocean perch were obtained from the NMFS model and used for the 1991 and 1979 models. For 1963, I used the natural mortality from the stock assessment report (Spencer and Ianelli 2003a) and the fishing mortality to calculate a P/B of 0.08 year^{-1}. The diet of adult Pacific Ocean perch was obtained from the NMFS diet database and used for all models.

The catch estimates for POP were obtained from the stock assessment report (Spencer and Ianelli 2003a) which showed that POP were highly sought by Japanese and Soviet fisheries and supported a major trawl fishery throughout the 1960s, with a peak catch in the Aleutian Islands in 1965 at 109,100 tonnes. Soviet catches of Pacific Ocean perch (complex) in the Aleutians started in 1963, and fishing effort increased and areas of operation expanded annually (USFWS 1965). Catches declined throughout the 1960s and 1970s, reaching their lowest levels in the mid 1980s (Spencer and Ianelli 2003a). Catch estimates prior to 1977 (Figure 14) were obtained from Ronholt et al. (1994) and Anonymous (2001), and included other rockfish, so this could be an overestimate of catches of POP. The average proportion of Pacific Ocean perch in the total rockfish catch was 80% and I therefore prorated the catches for POP and other rockfish. I used the total catch for the Bering Sea and Aleutian Islands, and the total biomass for that area to calculate an exploitation rate, which I then used to calculate a catch for the Aleutians from 1963-1976 (Figure 14). The breakdown between longline and trawl fisheries and the breakdown of catch into landings and discards from 1991-2000, obtained from the NMFS observer database (J. Berger, NMFS Seattle, Wa., *pers. comm.*), were used to calculate the catch and discards made by the longline and trawl fisheries in the 1963-1990 period (Table 25). The fishing mortality rate (catch/biomass) for 1962-2002 in Figure 14 was used to drive the Ecosim model.

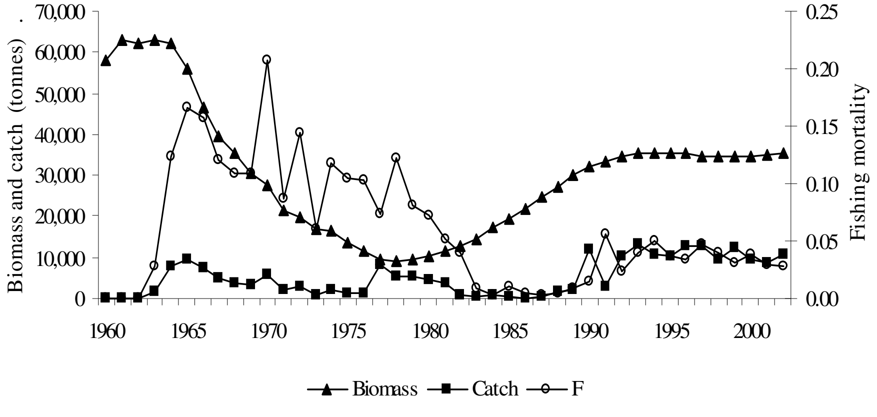


Figure 14. Catch (tonnes), biomass (tonnes) and fishing mortality (year^{-1}) for Pacific Ocean perch in the Aleutian Islands.

Table 25. Landings and discards (tonnes) of Pacific Ocean perch in the Aleutian Islands by pot, trawl and longline gear.

Year	**Landings**				**Discards**				**Total catch**
	Pot	**Trawl**	**Longline**	**Total**	**Pot**	**Trawl**	**Longline**	**Total**	
1963		1511		1511		262		262	1,773
1964		6559		6559		1137		1137	7,696
1965		7924		7924		1374		1374	9,298
1966		6239		6239		1082		1082	7,321
1967		4060		4060		704		704	4,764
1968		3261		3261		565		565	3,827
1969		2818		2818		489		489	3307
1970		4859		4859		843		843	5,702
1971		1583		1583		275		275	1,858
1972		2411		2411		418		418	2,830
1973		857		857		149		149	1,006
1974		1627		1627		282		282	1,909
1975		1206		1206		209		209	1,415
1976		1017		1017		176		176	1,193
1977		6,868	18	6,886		1,186	8	1194	8080
1978		4,490	15	4,505		776	5	781	5,286
1979		4,667	9	4,676		805	6	811	5,487
1980		3,997	9	4,005		690	5	695	4,700
1981		3,080	6	3,087		532	4	535	3,622
1982		861	3	864		149	1	150	1,014
1983		237	2	239		41		41	280
1984		534	2	536		92	1	93	629
1985		183	1	183		32		32	215
1986		136		136		23		24	160
1987		426		426		73	1	74	500
1988		1,289		1,289		222	2	224	1,513
1989		1,791		1,791		308	2	310	2,101
1990		10089		10,089		1,737	12	1,749	11,838
1991		1774	41	1,815		969	1	970	2,785
1992		8650	16	8,666	0.022	1,510	104	1,613	10,280
1993		11478	1	11,479		1,891	4.759	1,896	13,375
1994		9489	2	9,491		1,374	0.871	1,374	10,866
1995		8603		8,603	0.191	1,700	0.371	1,701	10,303
1996	0.005	9831		9,831	0.003	2,994	0.896	2,995	12,827
1997		10854		10,854		1,794	0.224	1,794	12,648
1998		8282		8,282		1,016	0.340	1,016	9,299
1999		10984		10,985	0.036	1,499	0.157	1,499	12,484
2000		8586		8,586		734	8.634	743	9,328
2001	0.013	7195		7,195	0.017	1,359	3.043	1,362	8,557
2002	0.016	9315		9,315		1,260	0.414	1,260	10575

22. Other rockfish

Of all the rockfish species described in the SEAK model (Guénette, this volume) only sharpchin, *Sebastes zacentrus*, northern, *Sebastes polyspinis*, dusky, *S. ciliatus*, shortraker, *S. borealis*, rougheye *S. aleutianus*, and shortspine thornyheads *Sebastolobus alascanus*, are prevalent in the surveys off the Aleutian Islands. Stock assessments are done on northern rockfish (Spencer and Ianelli 2003b), shortraker and rougheye rockfish (Spencer and Reuter 2003) for the BSAI area, and these biomass estimates were used as a lowest estimate of rockfish biomass and prorated for the Aleutian Islands area (Figure 15). The 1991 biomass was 215,853 tonnes or 0.39 $t{\cdot}km^{-2}$ using the total area for BSAI, while the 1980 biomass of 207,808 tonnes (0.38 $t{\cdot}km^{-2}$) was used for 1979, as the stock assessment for shortraker and rougheye only started in 1980. No biomass estimate was available for 1963. The annual P/B (0.1) and Q/B (2.0) ratios for sharpchin, northern, dusky, shortraker and rougheye were all the same in the NMFS model and was used here for all rockfish. The diet for northern, dusky, shortraker, rougheye, shortspine thornyheads were taken from the NMFS database, while that of sharpchin and other rockfish were obtained from the general diet proposed by NMFS. The average of these diets was taken as the rockfish diet in our model.

Rockfish have been identified to species level in fishery catches by U.S. observers since 1977 (Reuter and Spencer 2003), providing a means of estimating annual harvests of individual species. The catches for northern rockfish (Spencer and Ianelli 2003b), shortraker and rougheye rockfish (Spencer and Reuter 2003) and other rockfish (Reuter and Spencer 2003) made by the foreign, joint venture and domestic fleets were combined for the total rockfish catch (Figure 15). The catches prior to 1979 were reported in the POP complex, and I used the ratio of POP to total rockfish to estimate the catches of other rockfish from the estimates given by USFWS (1965) and Forrester et al. (1978; 1983). The ratio between longline and trawl fisheries from 1977-1990 were obtained from the NMFS observer database (Berger, NMFS Seattle, Wa., *pers. comm.*) and applied to the combined catch from the stock assessment reports (Table 26). The breakdown of the catches into discards and landings from 1991-2001 also came from the NMFS database, and the average breakdown of catch into landings and discards from this period was used to estimate the discards by gear type in the 1963-1990 period. I assumed that all catches prior to 1977 were made by the trawl fleet. The fishing mortality rate (F) in Figure 15 was used to drive rockfish in the Ecosim simulations.

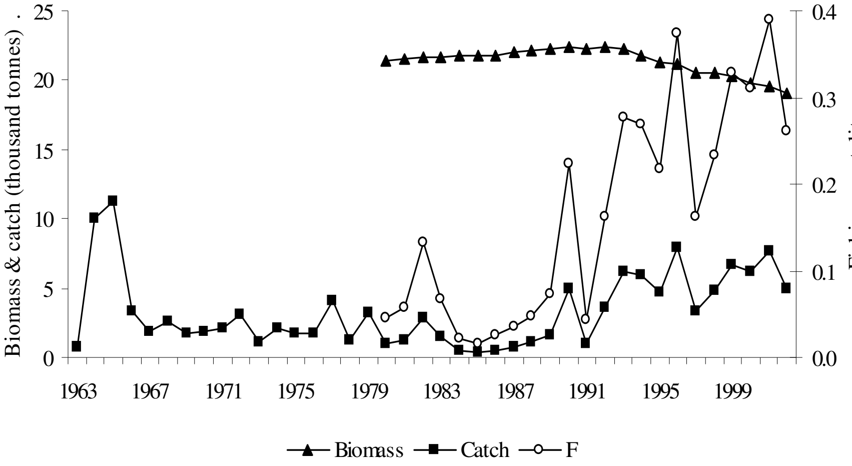


Figure 15. Biomass, catch (10^3 tonnes) and fishing mortality rate (F, $year^{-1}$) of rockfish in the Aleutian Islands.

Table 26. Landings and discards (tonnes) of rockfish in the Aleutian Islands by the pot, trawl, longline and other gear (jigging, gillnetting, etc.).

Year	**Landings**					**Discards**					**Total catch**
	Other	**Pot**	**Trawl**	**Longline**	**Total**	**Other**	**Pot**	**Trawl**	**Longline**	**Total**	
1963			199		199			521		521	721
1964			2,761		2,761			7,221		7,221	9,981
1965			3,101		3,101			8,110		8,110	11,211
1966			926		926			2,422		2,422	3,348
1967			500		500			1,307		1,307	1,806
1968			704		704			1,842		1,842	2,546
1969			469		469			1,227		1,227	1,696
1970			499		499			1,305		1,305	1,804
1971			571		571			1,492		1,492	2,063
1972			866		866			2,264		2,264	3,129
1973			322		322			844		844	1,166
1974			587		587			1,536		1,536	2,123
1975			463		463			1,210		1,210	1,672
1976			463		463			1,210		1,210	1,673
1977			1,134	3	1,137			2,801	173	2,974	4,111
1978			346	1	347			856	53	909	1,256
1979			886	2	888			2,187	135	2,322	3,210
1980			270	1	271			668	41	709	980
1981			338	2	340			837	52	888	1,228
1982			785	6	791			1,948	120	2,068	2,859
1983			337	6	409			1,008	62	1,071	1,480
1984			85	1	133			328	20	349	482
1985			57		95			233	14	247	342
1986			58		150			370	23	393	543
1987			71		214			528	33	561	775
1988			141		295			726	45	771	1,066
1989					453			1,116	69	1,185	1,638
1990					1,380			3,399	210	3,609	4,989
1991		0.026	347	323	670		0.306	249	36	286	956
1992	0.61	0.006	1,133	575	1,709	0.240	1.787	1,602	313	1,917	3,627
1993			997	418	1,414		0.000	4,431	327	4,758	6,173
1994	0.05	4.843	1,417	318	1,740		3.647	4,044	96	4,144	5,884
1995		1.68	1,629	177	1,808		0.235	2,774	69	2,843	4,651
1996		0.067	2,988	186	3,175		0.823	4,568	151	4,719	7,894
1997			921	110	1,031	0.034	0.032	2,154	160	2,314	3,345
1998			870	180	1,050		0.007	3,432	334	3,765	4,815
1999	0.3	0.233	1,218	113	1,331		0.755	5,110	224	5,336	6,667
2000	0.609	0.074	1,036	210	1,246		1.016	4,570	349	4,919	6,166
2001	0.043	0.391	995	218	1,213		0.274	6,063	365	6,428	7,641
2002		0.687	803	175	979		0.281	3,786	207	3,993	4,972

23. Sablefish

Sablefish, *Anoplopoma fimbria*, is managed as a single stock from SE Alaska to the Aleutian Islands. They migrate from SE Alaska as young fish (immature), to the edge of the Aleutian Islands, then back as mature fish south of the Aleutian Islands (Maloney 2002). Tag and release studies of this population showed that the Aleutian Islands have mostly small and medium sized sablefish (ages 3-4 and 5-6) and not too many large sablefish in those age classes (Maloney 2002). In the age classes 7-8 and 9-10, and >10 most of the sablefish found in the Aleutian Islands were medium and large, with no small fish of those age classes found (Maloney 2002).

The stock assessment of sablefish (Sigler et al. 2003) gave the biomass trajectory (Figure 16) from 1979 to 2002 and a biomass of 49,000 tonnes (0.86 t·km^{-2}) and 39,000 tonnes (0.68 t·km^{-2}) in 1991 and 1979 respectively for the Aleutian Islands. For the period 1963-1978, the biomass was estimated by prorating the BSAI-GOA population to the Aleutian Islands in the same proportion as that found in 1979 (Figure 16). The resulting biomass amounted to 71,000 tonnes (0.93 t·km^{-2}) in 1963, although the biomass increased dramatically to 1.8 t·km^{-2} in 1964. The annual P/B (0.19) and Q/B (1.03) estimates for adult sablefish were obtained from the NMFS model and used for the 1991 and 1979 models. For 1963, the natural mortality of 0.1 year^{-1} (Sigler et al. 2003) was added to the fishing mortality for a P/B of 0.113 year^{-1}. According to the NMFS diet database, which was based on stomach samples in the Aleutian Islands, sablefish adults consume mainly large zooplankton (88%), cephalopods (9.7%) and benthic invertebrates (2%).

Sablefish have been caught in the Aleutian islands since 1962 (USFWS 1965). The total catch for the Aleutian Islands were obtained from Sigler et al. (2003), who also gave the breakdown by fixed (longline) and trawl gear for this species in the whole area (Table 27). Discards were 2.9% for the fixed gear and 26.9% for the trawl gear (Sigler et al. 2003). The catch from 1991-2001 obtained from the NMFS database also included small catches in the pot and other (jigging etc.) fisheries (Table 27). The fishing mortality rate of catch/biomass (age 4+) in the Aleutian Islands (Figure 16) was used to drive the Ecosim model.

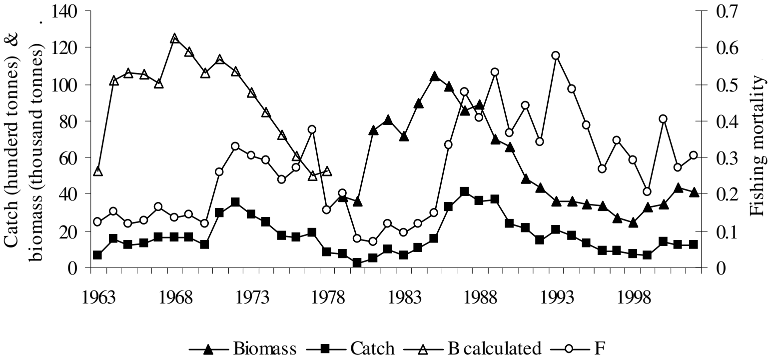


Figure 16. Catch (10^2 tonnes), biomass (10^3 tonnes) and fishing mortality (F, year^{-1}) of sablefish in the Aleutian Islands.

24. Pacific cod

Pacific cod, *Gadus macrocephalus,* availability has fluctuated in the Aleutian Islands. They have the ability to react quickly to nearshore cooling of the water column by redistributing away from nearshore bay habitats (Anderson and Blackburn 2002). The biomass estimates of 1.02 t·km^{-2} for 1979 and and 4.11 t·km^{-2} for 1991 respectively for Pacific cod was obtained from the stock assessment (Thompson and Dorn 2003). However, according to Kerim Aydin (NMFS, Seattle, Wa. *pers. comm.*), the stock assessment estimates seemed to be very high and the authors of the stock assessment report had problems with the catchability estimates, thus I used the survey estimates for 1980-1986 from Ronholt et al. (1994) and for 1991-2002 from Zenger (2002) (except for 2000, as it does not seem to follow the same trajectory as the stock assessment values). These biomass time series were used to estimate a fishing mortality rate to drive the model (Figure 17). No biomass estimates were available for 1963. The annual P/B (0.41) and Q/B (2.28) ratios for Pacific cod were obtained from NMFS and used for the 1991 and 1979 models. For 1963, the natural mortality (0.37 year^{-1}) obtained from the stock assessment report (Thompson and Dorn 2003) was used as an estimate of annual P/B as no estimate of fishing mortality was available. The diet of adult Pacific cod was obtained from the NMFS diet database and used for all three models.

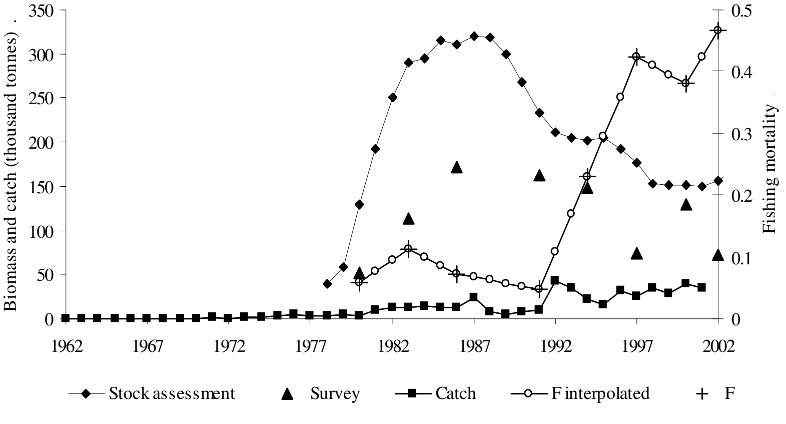


Figure 17. Catch (10^3 t), biomass from stock assessment and surveys estimates (10^3 t) and fishing mortality (observed and interpolated, year^{-1}) of Pacific cod obtained from the stock assessment and surveys.

The Japanese longline fishery harvested Pacific cod for the frozen fish market from the early 1960s (Thompson and Dorn 2003). Cod constituted a bycatch to the walleye pollock fishery, but was also targeted if high concentrations were detected (Thompson and Dorn 2003). By 1977, foreign catches of Pacific cod had consistently been between 30,000-70,000 tonnes for a full decade (Thompson and Dorn 2003). A USA domestic trawl fishery started in 1981 and several joint venture fisheries began operations in the BSAI at that time (Thompson and Dorn 2003). The catch estimates of Pacific cod from 1963 to 1976 were obtained from Ronholt et al. (1994), for 1977-1980 from the NMFS observer database (Berger, NMFS Seattle, Wa., *pers. comm.*), while the estimates from 1981-2002 were obtained from the stock assessment report for the foreign vessels, joint venture and domestic fisheries by gear (Thompson and Dorn 2003). The breakdown of landings to discards from 1991-2002 also obtained from the NMFS database were used to calculate discards prior to 1991 (Table 28). The fishing mortality estimated from the surveys and the catches were interpolated for the years where no biomass estimates were available and used to drive the Ecosim model (Figure 17).

Table 27. Landings and discards of sablefish in the Aleutian Islands by the longline, trawler, pot and other fleets (in tonnes).

Year	Landings					Discards					Total catch
	Other	Pot	Trawl	Longline	Total	Other	Pot	Trawl	Longline	Total	
1963			196	403	599			53	12	65	664
1964			661	683	1,343			178	20	198	1,541
1965			880	129	1,009			237	4	240	1,249
1966			802	314	1,116			216	9	225	1,341
1967			1,041	322	1,363			280	9	289	1,652
1968			842	588	1,429			226	17	244	1,673
1969			766	682	1,447			206	20	226	1,673
1970			393	728	1,121			106	21	127	1,248
1971			1,094	1,503	2,598			294	44	338	2,936
1972			1,287	1,845	3,131			346	54	400	3,531
1973			849	1,773	2,622			228	51	280	2,902
1974			513	1,775	2,288			138	51	189	2,477
1975			305	1,321	1,627			82	38	120	1,747
1976			259	1,292	1,552			70	37	107	1,659
1977			178	1,624	1,802			48	47	95	1,897
1978			77	703	780			21	20	41	821
1979			76	666	742			21	19	40	782
1980			42	215	257			11	6	18	275
1981			54	452	505			14	13	28	533
1982			116	793	910			31	23	54	964
1983			72	576	648			19	17	36	684
1984			226	752	978			61	22	83	1061
1985			123	1,355	1,479			33	39	72	1,551
1986			655	2,384	3,040			176	69	245	3,285
1987			697	3,136	3,833			188	91	279	4,112
1988			677	2,679	3,356			182	78	260	3616
1989			613	2,843	3,457			165	82	247	3704
1990			327	1,941	2,268			88	56	144	2,412
1991			249	1,800	2,049			67	52	119	2,168
1992	1	1	157	1,261	1,421	0.09	0	42	37	79	1,500
1993			162	1,821	1,983			44	53	97	2,080
1994	3	22	170	1,468	1,662		2.065	46	43	90	1,752
1995		16	131	1,134	1,281		0.025	35	33	68	1,349
1996			89	770	859		0.043	24	22	46	905
1997			80	804	884			22	23	45	929
1998		0	60	639	699			16	19	35	734
1999	2	10	77	557	646		0.271	21	16	37	683
2000		103	131	1,115	1,349		0.265	35	32	68	1,417
2001		110	121	912	1,143			33	26	59	1,202
2002		104	155	916	1,175		0.870	42	27	69	1,244

Table 28. Landings and discards (tonnes) of Pacific cod in the Aleutian Islands made by the pot, trawl, longline and other fleets.

Year	**Landings**					**Discards**					**Total catch**
	Other	**Pot**	**Trawl**	**Longline**	**Total**	**Other**	**Pot**	**Trawl**	**Longline**	**Total**	
1963			353	208	560			28	13	41	601
1964			163	96	259			13	6	19	278
1965			269	158	428			21	10	31	459
1966			100	59	159			8	4	12	171
1967			220	129	349			17	8	25	374
1968			173	102	274			14	6	20	294
1969			130	77	207			10	5	15	222
1970			167	98	265			13	6	19	284
1971			1,224	720	1,944			97	44	141	2,085
1972			257	151	408			20	9	30	438
1973			570	335	905			45	20	66	971
1974			793	466	1,259			63	28	91	1,350
1975			1,658	975	2,633			132	59	191	2,824
1976			2,449	1,440	3,889			194	87	282	4,171
1977			2,045	1,024	3,069		4	153	65	222	3,292
1978			2,242	923	3,165		4	158	67	229	3,394
1979			4,355	687	5,042		6	252	107	365	5,407
1980			2,644	165	2,810		3	140	60	204	3,013
1981			6,688	1,874	8,563	1	10	428	181	620	9,183
1982			7,386	4,435	11,820	1	14	591	250	857	12,677
1983			7,486	4,757	12,243	1	15	612	259	887	13,130
1984			6,692	6,708	13,400	1	16	670	284	971	14,371
1985			5,695	6,030	11,725	1	14	586	248	850	12,575
1986		1	6,438	5,703	12,141	1	15	607	257	880	13,021
1987		82	12,212	9,750	22,045	2	27	1,102	467	1,597	23,642
1988		28	4,660	3,205	7,893	1	10	395	167	572	8,465
1989		18	3,953	270	4,241		5	212	90	307	4,548
1990		7	6,464	561	7,031	1	9	351	149	510	7,541
1991		3,034	3,121	3,116	9,271	0	146	293	88	526	9,797
1992	70	6,265	12,789	21,708	40,832	14	52	1,770	400	2,236	43,068
1993	33		13,619	14,664	28,316		0	3,693	2,196	5,888	34,204
1994		147	11,120	6,788	18,055		0	3,263	221	3,484	21,539
1995		978	8,702	3,674	13,354		47	1,872	1,261	3,180	16,534
1996		4,511	18,613	5,348	28,472	0.45	100	2,566	471	3,137	31,609
1997	76	560	15,920	6,502	23,057	13	15	1,429	649	2,107	25,164
1998		423	20,603	13,277	34,302		2	155	505	662	34,964
1999	69	3,729	16,150	7,669	27,617		22	287	205	513	28,130
2000	33	3095	20,193	15,671	38,992		12	168	512	692	39,684
2001	19	544	15,608	17,565	33,736		0.06	219	252	471	34,207
2002		6	27,344	2,717	30,067		0.2	585	148	734	30,801

25. Pacific halibut

Pacific halibut, *Hippoglossus stenolepis*, is managed by the International Pacific Halibut Commission. For the Aleutian Islands (IPHC Area 4B) the stock assessment (Clark 1999) estimated the 2002 exploitable biomass at 0.52 t·km^{-2}, but did not give estimates prior to 1999. Figure 11 in Clark and Hare (2003) showed that the exploitable biomass of halibut in area 4B had decreased nearly linearly from 1999 to 2003. Thus, I used the halibut survey estimates (Figure 18) obtained from Ronholt et al. (1994) for 1980-1986 and from Zenger (2002) for 1991-2002 giving estimates of 0.29 t·km^{-2} for 1979 and 0.58 t·km^{-2} for 1991 repectively. No estimates of biomass were available for 1963. The annual P/B and Q/B ratios for halibut given by the NMFS model were 0.19 and 1.1 respectively, but Yang (1999) suggested a Q/B of 2.0 year^{-1}, which is what I used. The diet of adult halibut came from the NMFS diet database and consisted of data obtained from stomachs sampled in the Aleutian Islands.

Catches made by Japan, the U.S.S.R, Canada and the USA from 1963-1970 were obtained from Forrester et al. (1978) while those for 1971-1973 came from Forrester et al. (1983). Commercial catches from 1981-2003 were obtained from the stock assessment (Clark and Hare 2003) for area 4B, and for 1974-1980 the 4B catch was assumed to be in the same ratio as it was in 1981-1982 (Table 29A and Figure 18). The catch made for personal use and by sports fishermen, and the discards by the longline fleet for area 4 were obtained from the IPHC's webpage (http://www.iphc.washington.edu/halcom/research/sa/sa.data/rem.y.txt) and prorated by ratio of the commercial catch in area 4B to the total catch in area 4. The areal extent of Area 4B (55,564 km²) is marginally smaller than the area used for this model and I used area 4B to calculate the catches in t·km^{-2}·year^{-1}.

The greatest amount of the bycatch mortality of halibut occurred in the groundfish fisheries off Alaska and until the early 1980s, most of the bycatch was taken by foreign fisheries with bycatch mortality generally decreasing during the transition to entirely domestic fisheries (Hare et al. 2003). Fishery observers sampled the catch on each bottom trawler, collecting data to estimate bycatch while the bycatch from gear such as shrimp trawl, sablefish pot, and rockfish hook-&-line fisheries was largely unknown but believed to be relatively low (Williams 2004). The bycatch for Area 4 was obtained from Williams (2004), and prorated by the commercial catch for area 4B. For 1990-2003 the bycatch in BSAI were divided into trawl gear, hook and line and pot gear (Williams 2004), and the bycatch obtained from Williams (2004) were prorated using the BSAI proportions from 1990 to 2003, while for 1974-1989 the average percentage bycatch for each gear from 1990-2003 was used to estimate the bycatch by gear. The total bycatch by the longline fleet was added to the commercial catch by the halibut longline fleet to give the total catch made by the longline fleet (Table 29B).

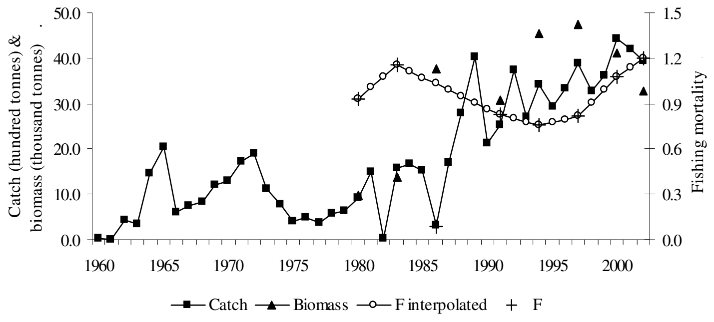


Figure 18. Catch (10^2 tonnes), biomass (10^3 tonnes) and fishing mortality (F, observed and interpolated, year^{-1}) for Pacific halibut in the Aleutian Islands.

The biomass and catch estimates described above were used to estimate fishing mortality (C/B) for the years that biomass estimates were available, and projected for the years that they were not. The one exception is that the 1986 catch was very low compared to the adjacent years, and I therefore projected the F's from 1983 to 1991 instead of using the 1986 catch (Figure 18).

Table 29A. Catch (tonnes) of Pacific halibut made by Japan, USSR, Canada and the USA in the Aleutian Islands from 1960-1973.

Year	**Japan**	**USSR**	**Canada**	**USA**	**Total dressed weight**	**Total round weight**
1960			19		19	25
1961			2		2	3
1962	1			41	42	56
1963	67		42		109	145
1964	893		1	4	898	1,197
1965	1,266		22	33	1,321	1,761
1966	163		48		211	281
1967	215			20	235	313
1968	219		6		225	300
1969	330		3	56	389	519
1970	351		38	31	420	560
1971	387			1	388	517
1972	723	1	9	24	757	1,009
1973	245	4	29		278	371

Table 29B. Catches (tonnes) of Pacific halibut made in the Aleutian Islands for personal use (combined with the First Nations fishery), sports fishermen (other fisheries), commercial longline fisheries and bycatch in the pot, trawl and longline fisheries, as well as discards from the longline fishery.

Year	Personal use	Sport	Bycatch			Commercial	Discards	Total
	First Nations	Other	Pot	Trawl	Longline	Longline	Longline	Catch
1974			1.17	573	128	66		767
1975			0.56	274	61	58		394
1976			0.70	343	77	66		487
1977			0.45	219	49	113		381
1978			0.77	377	84	125		587
1979			1	407	91	126		626
1980			1.41	694	155	66		916
1981		2	2.11	1,034	231	236		1,505
1982			0.03	16	4	6		26
1983		1	1.30	637	142	810		1,591
1984		3	1.64	804	179	665		1,653
1985		1	1.22	599	134	750	26	1,511
1986		1	0.26	128	28	157	8	323
1987		4	1.25	616	137	907	34	1,699
1988		7	3.01	1,478	330	961	14	2,794
1989		8	3.93	1931	431	1,602	42	4,019
1990		6	0.61	1155	115	804	32	2,112
1991	32	19	1	1,294	229	913	37	2,526
1992	23	9	4.69	1,660	604	1,403	27	3,731
1993	23	11	0.00	1,299	169	1,185	21	2,709
1994	27	10	1.95	1,690	456	1,221	24	3,431
1995	20	12	5.55	1,474	386	1,016	5	2,918
1996	22	18	7.37	1,625	379	1,252	18	3,321
1997	22	16	1.99	1,426	375	2,008	18	3,867
1998	18	19	2.34	1,201	285	1,754	10	3,289
1999	30	17	2.19	1,165	229	2,159	17	3,619
2000	34	15	4.93	1,157	356	2,836	14	4,417
2001	33	6	2.78	1,126	299	2,703	18	4,187
2002	32	7	3.35	1,158	250	2,467	7	3,924

26. Arrowtooth flounder

The stock assessment for arrowtooth flounder, *Reinhardtius stomias*, (Wilderbuer and Sample 2003) estimated the biomass in BSAI at 741,748 tonnes (1.34 t·km^{-2}) and 284,965 tonnes (0.52 t·km^{-2}) in 1991 and 1979 respectively (Figure 19). No biomass estimate was available for 1963. The average annual P/B (0.18) and Q/B (2.6) ratios for adult arrowtooth flounder obtained from NFMS were used. For 1963, I used the natural mortality of 0.3 year^{-1} (Wilderbuer and Sample 2003) as an estimate of P/B. Hirons (2001) found that the δ^{15}N for arrowtooth flounder in the Aleutians was significantly different (4‰ lower) from those found around Kodiak Island (Central GOA), indicating that they feed on significantly different food in those two areas. Both these areas had enriched δ^{13}C values indicating that they probably fed more on benthic organisms such as sole and octopus (Hirons 2001). The diet estimates for adult arrowtooth flounder were therefore obtained from the NMFS database which included stomach content for the Aleutian Islands specifically.

The stock assessment report for arrowtooth flounder gave catches from 1970–2002 which peaked at ~6,500 tonnes in 1979 (Figure 19) and again at ~5,000 tonnes in 1991

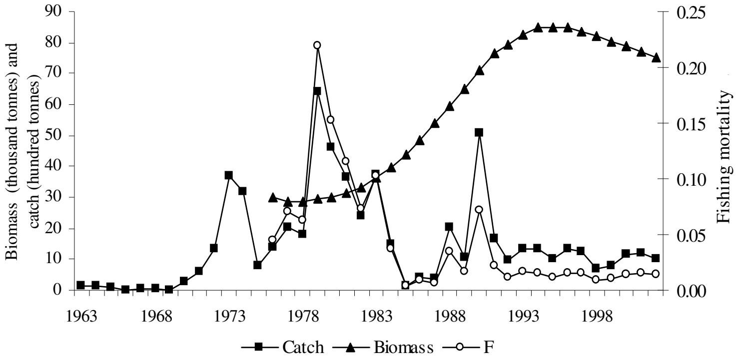


Figure 19. Biomass (·10^3 tonnes), catch (·10^2 tonnes) and fishing mortality of arrowtooth flounder in the Aleutian Islands.

(Wilderbuer and Sample 2003). After 1997, catches decreased due to restrictions placed on the Greenland turbot fishery and phasing out of the foreign fishery, and the resource has remained lightly exploited with catches averaging 12,300 tonnes from 1977-2003. Arrowtooth had a low commercial value and were mostly discarded in various trawl and longline target fisheries, with the largest discards being in the Pacific cod and flatfish fisheries (Wilderbuer and Sample 2003). Prior to 1970, catches of all flounders combined were given by Ronholt et al. (1994) and I prorated these by the ratio of arrowtooth to other flounder given by Anonymous (2001). The catch estimates obtained from these sources for 1963-1990 (Wilderbuer and Sample 2003) were assumed to be discarded in the same ratio as the landing:catch ratio for the 1991-2002 catches (Table 30, Figure 19) obtained from the NMFS fishery database (Kerim Aydin, NMFS Seattle, Wa., *pers. comm.*). The landings and discards for the 1970-1990 were also prorated to the gear given in later data (Table 30).

Table 30. Landings and discards (tonnes) in the Aleutian Islands of arrowtooth flounder made by the pot, trawl and longline fleets.

Year	**Landings**				**Discards**				**Total Catch**
	Pot	**Trawl**	**Longline**	**Total**	**Pot**	**Trawl**	**Longline**	**Total**	
1963	0.1	23	2	25	0.213	66	27	93	118
1964	0.124	30	2	32	0.270	84	34	118	150
1965	0.08	19	1	20	0.173	54	22	76	96
1966	0.02	4	0	4	0.034	10	4	15	19
1967	0.06	13	1	14	0.119	37	15	52	66
1968	0.03	6	0	7	0.058	18	7	25	32
1969	0.02	4	0	4	0.037	11	5	16	20
1970	0.227	54	4	58	0.495	153	62	216	274
1971	0.482	115	8	123	1.050	325	131	458	581
1972	1.097	262	18	281	2.391	741	299	1,042	1,323
1973	3.072	733	49	786	6.695	2,074	838	2,919	3,705
1974	2.649	632	43	678	5.774	1,789	723	2,517	3,195
1975	0.650	155	10	166	1.417	439	177	618	784
1976	1.136	271	18	291	2.476	767	310	1,079	1,370
1977	1.687	403	27	432	3.677	1,139	461	1,603	2,035
1978	1.478	353	24	378	3.220	998	403	1,404	1,782
1979	5.337	1,274	86	1,365	11.630	3,603	1,457	5,071	6,436
1980	3.817	911	61	976	8.318	2,577	1,042	3,627	4,603
1981	3.018	720	49	772	6.578	2,038	824	2,868	3,640
1982	2.003	478	32	512	4.364	1,352	547	1,903	2,415
1983	3.112	743	50	796	6.782	2,101	849	2,957	3,753
1984	1.221	291	20	312	2.660	824	333	1,160	1,472
1985	0.132	31	2	34	0.287	89	36	125	159
1986	0.344	82	6	88	0.750	232	94	327	415
1987	0.291	69	5	74	0.634	196	79	277	351
1988	1.694	404	27	433	3.692	1,144	462	1,610	2,043
1989	0.864	206	14	221	1.883	583	236	821	1,042
1990	4.215	1,006	68	1,078	9.185	2,845	1,150	4,005	5,083
1991	0.000	307	17	324	0.055	1,252	100	1,352	1,676
1992	0.003	13	12	25	0.352	726	195	922	947
1993	0.000	91	11	103	0.000	934	310	1,243	1,346
1994	0.000	58	1	59	13.192	996	252	1,261	1,320
1995	0.000	67	9	76	0.004	722	204	926	1,001
1996	0.060	445	0	446	0.066	690	210	899	1,345
1997	0.000	352	13	365	0.086	479	395	875	1,240
1998	0.000	160	0	160	0.000	281	252	534	694
1999	0.231	204	66	270	2.141	250	260	512	782
2000	0.812	508	25	533	3.937	175	444	624	1,157
2001	4.969	286	14	305	2.894	555	357	915	1,220
2002	5.334	233	16	253	2.136	643	134	779	1,032

27. Flatfish

Flatfish other than halibut were combined into this group and include turbot, *Reinhardtius hippoglossoides,* flathead sole, *Hippoglossoides elassodon*, Arctic flounder, *Liopsetta glacialis*, butter sole, *Isopsetta isolepis*, curlfin sole *Pleuronectes decurrens*, deepsea sole, *Embassichths bathybus*, Dover sole, *Microstomus pacificus*, English sole, *Parophrys vetulus*, longhead dab *Limanda proboscidea*, Pacific sanddab, *Citharichthys sordidus*, petrale sole, *Eopsetta jordani*, rex sole, *Glyptocephalus zachirus*, roughscale sole, *Clidodoerma asperrimum*, sand sole, *Psettichthys melanostictus*, slender sole, *Lyopsetta exilis*, starry flounder, *Platichthys stellatus* and sakhalin sole, *Pleuronectes sakhalinensis* (Hare et al. 2003). Yellowfin sole and northern and southern rocksole were not included in this group as most of their biomass was located in the Bering Sea.

Stock assessment biomass estimates were only available for turbot (Ianelli et al. 2003b) and flathead sole (Spencer et al. 2003a) for BSAI and no other stock assessments were available. I used the survey time series (Figure 20) for turbot (Ianelli et al. 2003b), rocksole (Wilderbuer and Walters 2003), flathead sole (Spencer et al. 2003a) and other flatfish (Spencer et al. 2003b), giving a total biomass of 1.26 $t{\cdot}km^{-2}$ in 1979 and 1.84 $t{\cdot}km^{-2}$ in 1991. The average annual P/B (0.19) and Q/B (1.72) ratios and diets for adult Kamchatka flounder, Greenland turbot, flathead sole, Alaska plaice, Dover sole, rex sole, and other miscellaneous flatfish were obtained from the NMFS model and used for all three models.

Catch estimates for rock sole (Wilderbuer and Walters 2003), Greenland turbot (Ianelli et al. 2003b), flathead sole (Spencer et al. 2003a) and other flatfish (Spencer et al. 2003b) from 1977-2002 were obtained from the stock assessment reports. Catches for all flatfish from 1962–1976 made by the Japanese, USSR, Canadian and USA fleets were obtained from Forrester et al. (1978; 1983). Catches made by the USSR for 1966-1970 were only reported for the BSAI area, and were prorated by area to obtain catches for the Aleutian Islands (Figure 20). From 1962-1976 catches of turbot, Kamchatka flounder and arrowtooth flounder were divided into arrowtooth and other turbot by using the ratio of arrowtooth to turbot in the 1977-2000 catches. From 1977 the estimates were usually reported for the BSAI area, and they were therefore prorated by area (56,936 km²/552,154 km²) to estimate the catches for the Aleutian Islands. The breakdown of landings and discards and between the different gear types from 1991-2002 were used to estimate landings by gear for the 1963-1990 period (Table 31). Fishing mortality was calculated as following a linear relationship between the various point estimates of F calculated using the survey biomass (Figure 20).

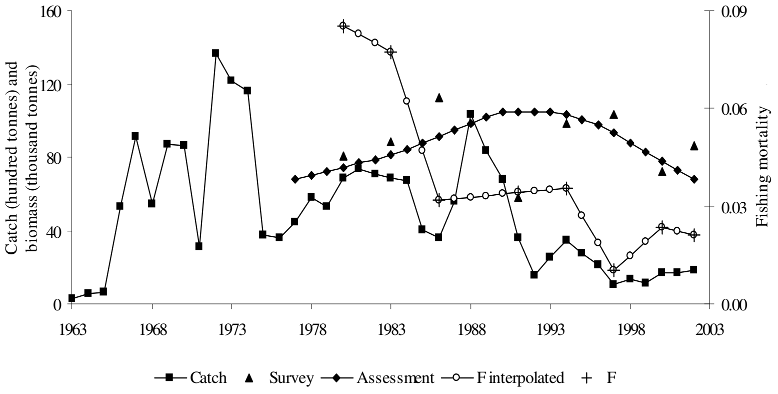


Figure 20. Catch (10^2 tonnes) and biomass (10^3 tonnes) estimated by survey and stock assessment, as well as fishing mortality (F, observed and interpolated, $year^{-1}$) for flatfish in the Aleutian Islands.

28. Small demersals

Small demersal fish included the Pacific tomcod, *Microgadus proximus*, saffron cod, *Eleginus gracilis*, red brotula, *Brosmophycis marginata*, bigmouth sculpin, *Hemitripterus bolini*, Pacific sandfish, *Trichodon trichodon*, padded sculpin, *Artedius fenestralis*, shortfin eelpout, *Lycodes brevipes* and sailfin sculpin, *Nautichthys oculofasciatus.* The number of small demersal species in the SE Alaska model was very large (see Guénette, this volume) and included many sculpins as well as greenlings. Sculpins (Cottidae) are relatively small, benthic-dwelling predators, with many species in the North Pacific, but they are not well known in Alaska (Hare et al. 2003). Of all these species, only the greenlings were of any importance in the Aleutian Islands, and the average annual P/B (0.6) and Q/B (3.0) ratios obtained from the NMFS model for eelpouts, greenlings and other sculpins were used here for all three models. There were no estimates of biomass and I let Ecopath estimate the biomass in all three models. The average diet of eelpouts, greenlings and various sculpins were obtained from the NMFS diet database.

Table 31. Landings and discards (tonnes) of flatfish in the Aleutian Islands made by the pot, trawl and longline fleets.

Year	**Landings**				**Discards**				**Total Catch**
	Pot	**Trawl**	**Longline**	**Total**	**Pot**	**Trawl**	**Longline**	**Total**	
1963	0.342	99	55	155	0.332	72	71	144	298
1964	0.682	198	110	309	0.664	143	143	287	595
1965	0.748	217	121	339	0.728	157	156	314	653
1966	6.089	1,766	985	2,757	5.925	1,278	1,274	2,558	5,315
1967	10.468	3,036	1,694	4,740	10.184	2,197	2,190	4,397	9,137
1968	6.207	1,800	1,004	2,811	6.039	1,303	1,298	2,607	5,418
1969	9.980	2,895	1,615	4,519	9.710	2,095	2,088	4,192	8,711
1970	9.881	2,866	1,599	4,475	9.614	2,074	2,067	4,150	8,625
1971	3.540	1,027	573	1,603	3.445	743	741	1,487	3,090
1972	15.684	4,549	2,538	7,102	15.260	3,292	3,281	6,588	13690
1973	13.981	4,055	2,262	6,331	13.603	2,934	2,924	5,872	12,204
1974	13.308	3,860	2,153	6,026	12.948	2,793	2,784	5,590	11,616
1975	4.281	1,242	693	1,939	4.165	898	895	1,798	3,737
1976	4.142	1,201	670	1,876	4.030	869	866	1,740	3,615
1977	4.497	1,304	728	2,037	5.646	1,218	1,214	2,438	4,474
1978	5.806	1,684	939	2,629	7.330	1,581	1,576	3,164	5,793
1979	5.406	1,568	875	2,448	6.663	1,437	1,432	2,876	5,324
1980	6.828	1,980	1,105	3,092	8.745	1,886	1,880	3,775	6867
1981	7.388	2,143	1,195	3,346	9.343	2,015	2,009	4,033	7,379
1982	6.690	1,940	1,083	3,030	9.338	2,014	2,008	4,031	7,061
1983	6.237	1,809	1,009	2,825	9.322	2,011	2,004	4,024	6,849
1984	3.258	945	527	1,475	12.170	2,625	2,616	5,254	6,729
1985	2.406	698	389	1,090	6.820	1,471	1,466	2,944	4,034
1986	1.781	516	288	806	6.417	1,384	1,380	2,770	3,576
1987	1.557	452	252	705	11.266	2,430	2,422	4,863	5,568
1988	1.641	476	266	743	22.226	4,794	4,778	9,595	10,338
1989	1.468	426	238	665	17.889	3,859	3,846	7,723	8,387
1990	3.596	1,043	582	1,628	11.919	2,571	2,563	5,146	6,774
1991	0.000	2,750	110	2,860	0.344	182	604	786	3,645
1992	0.002	224	225	449	1.818	365	764	1,131	1,580
1993	0.000	502	820	1,322	0.000	511	700	1,211	2,533
1994	0.000	1,305	507	1,812	1.966	410	1,270	1,682	3,494
1995	0.000	1,002	403	1,406	0.010	467	875	1,342	2,747
1996	0.000	716	361	1,078	0.271	504	562	1,066	2,144
1997	0.000	234	136	370	0.006	279	409	689	1,059
1998	3.890	85	643	731	0.556	473	121	595	1,326
1999	11.843	75	305	393	10.491	628	82	720	1,113
2000	1.697	237	681	920	7.071	559	205	771	1,692
2001	4.652	648	321	973	3.614	491	230	725	1,698
2002	6.391	481	97	584	1.562	1,108	134	1,244	1828

29. Large demersals

Large demersals include the great sculpin, *Myoxocephalus polyacanthocephalus*, plain sculpin, *Myoxocephalus jaok*, yellow Irish lord, *Hemilepidotus jordani*, wolf-eel, *Anarrhichthys ocellatus*, spotted ratfish, *Hydrolagus colliei*, cabezon, *Scorpaenichthys marmoratus*, prowfish, *Zaprora silenus*, Pacific lamprey, *Lampetra tridentate*, American river lamprey, *Lampetra ayearesii*, skilfish, *Erilepis zonifer*, and lingcod, *Ophiodon elongates*. After consultation with Yvonne Ortiz and Kerim Aydin (NMFS, Seattle Wa.), the average annual P/B (0.4) and Q/B (2.0) ratios and diet estimates for two aggregated groups ("Bigmouth, myox, Irish Lord, Sculpins" and "Pricklies, Squishies, gadids, junk") obtained from the NMFS model were used as the ratios for the whole group. Estimates of sculpin biomass made by the trawl surveys (Gaichas 2003) consisted of mainly great sculpin (Sarah Gaichas, NMFS Seattle Wa. pers. comm.) and were used as lower estimates for large demersal biomass in 1979 ($0.6\ t{\cdot}km^{-2}$) and 1991 ($0.3\ t{\cdot}km^{-2}$), as well as a proxy time series for Ecosim fitting (Figure 21). No biomass estimates were available for the 1963 model. ratios and diet estimates for two aggregated groups ("Bigmouth, myox, Irish Lord, Sculpins" and "Pricklies, Squishies, gadids, junk") obtained from the NMFS model were used as the ratios for the whole group. Estimates of sculpin biomass made by the trawl surveys (Gaichas 2003) consisted of mainly great sculpin (Sarah Gaichas, NMFS Seattle Wa. pers. comm.) and were used as lower estimates for large demersal biomass in 1979 ($0.6\ t{\cdot}km^{-2}$) and 1991 ($0.3\ t{\cdot}km^{-2}$), as well as a proxy time series for Ecosim fitting (Figure 21). No biomass estimates were available for the 1963 model.

Table 32. Catch (tonnes) of sculpins in the Aleutian Islands by pot, trawl and longline gear.

Year	Pot	Trawl	Longline	Total
1963	4,665	2,090	113	6,868
1964	5,522	8,366	206	14,094
1965	3,365	10,116	132	13,614
1966	1,533	8,249	867	10,649
1967	3,682	5,786	1,465	10,933
1968	4,195	4,684	934	9,814
1969	4,694	4,083	1,460	10,237
1970	4,184	7,437	1,453	13,074
1971	4,032	2,691	745	7,469
1972	4,879	4,329	1,785	10,993
1973	2,557	2,808	1,665	7,030
1974	739	4,836	1,639	7,214
1975	114	4,314	777	5,204
1976	1	3,298	843	4,142
1977	278	4,862	488	5,628
1978	214	3,739	376	4,328
1979	222	3,889	391	4,502
1980	224	3,917	394	4,534
1981	125	2,187	220	2,532
1982	89	1,554	156	1,798
1983	63	1,105	111	1,279
1984	29	502	50	581
1985	35	616	62	714
1986	26	454	46	525
1987	20	347	35	402
1988	8	131	13	152
1989	2	32	3	38
1990	81	1,411	142	1,633
1991	16	282	28	326
1992	53	926	93	1,072
1993	56	985	99	1,141
1994	19	330	33	383
1995	22	388	39	449
1996	29	513	52	594
1997	26	457	46	529
1998	42	738	74	854
1999	29	505	51	584
2000	52	905	91	1,048
2001	69	1,211	122	1,402
2002	34	595	60	689

The bycatch of sculpins (mainly great sculpins) were estimated from the stock assessment of "other groundfish" (Gaichas 2003) by using the breakdown of other groundfish in the 1999 estimates from Anonymous (2001), which showed that 35% of the "other groundfish" group are sculpins. According to Gaichas (2003) the larger sculpin species were assumed to be the major contributor to bycatch, which is why the catch was assumed to come from the large demersals as oppose to the small demersal species (Figure 21). For catches prior to 1977, I assumed that the bycatch of large demersals were in the same ratio of the bycatch to catch ratio for the 1979 model. The breakdown of sculpin catch by pot, trawl and longline gear obtained from the observer database was used to break down the catch from 1963 to 2002 (Table 32). It is assumed that all of this catch was discarded. The fishing mortality of sculpins was then used as proxy for large demersals, and was interpolated between survey biomass years (Figure 21). For 1963 no estimate of catches or discards were available, and I assumed that the bycatch of large demersals were in the same ratio of the bycatch to catch ratio for the 1979 model.

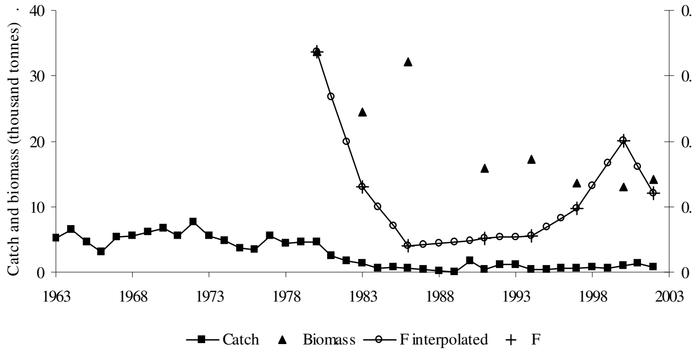


Figure 21. Catch (10^3 tonnes), biomass (10^3 tonnes) and fishing mortality (F, observed and interpolated, year^{-1}) for large demersals in the Aleutian Islands.

30. Large deep water fish

Large deep water fish (Large deep) species included the Pacific grenadier, *Coryphaenoides acrolepis,* giant grenadier, *Albatrossia pectoralis*, popeye grenadier, *C. cinereus*, longnose lancetfish, *Alepisaurus ferox*, daggertooth, *Anotopterus pharaoh*, ragfish, *Icosteus aenigmaticus* and opah, *Lampris guttatus*. The only species for which any information was available in the Aleutians were the grenadiers, which I used as a proxy for the group. Prior to 1990 the trawl surveys were done down to 900 metres, and in 1980 the biomass of all grenadiers was 322,409 tonnes (Gaichas 2002), of which most were giant grenadiers (313,480 tonnes), and most (98.5%) of the biomass was found in the area from 500-900 metres (Ronholt et al. 1994). I used the ratio of giant grenadier in the 1-500 m vs 1-900 m depth (on average 5%) to calculate the biomass of all grenadier in the 1-500 m area for the 1980, 1983 and 1986 surveys and the average for 1980 and 1983 as a biomass for 1979 (21,642 tonnes or 0.38 t·km^{-2}, Figure 22). For the 1991-2002 trawl surveys, I used the total grenadier biomass (24,597 tonnes, 0.43 t·km^{-2}) (Gaichas 2002) and this was a lower limit to the biomass estimate (Figure 22). The biomass (>500m depth) was used for time series fitting and no estimates were available for 1963. The average annual P/B (0.15) and Q/B (2.0) ratios from NMFS for grenadiers were used and the diet estimates for Pacific grenadier, giant grenadier, "prickle, squish, deep" and "other macrourids" from the NMFS diet database was averaged for this group. No estimates of catches were available for this group.

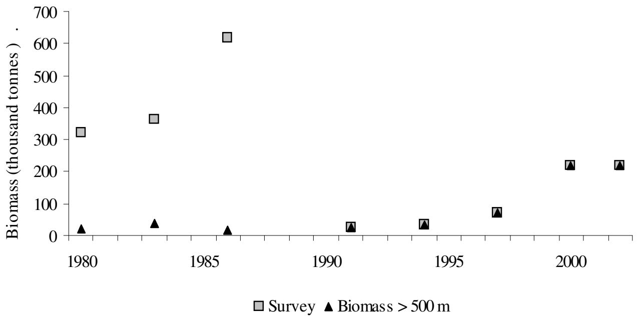


Figure 22. Biomass (10^3 tonnes) for grenadiers for the Aleutian Islands obtained from trawl surveys for 1980-1986 (1-900 m) and for 1991-2002 (1-500 m) and biomass estimated for 1980-1986 using the ratio of giant grenadier in 1-500 m to 1-900 m.

31. Myctophids / small deep water fish

There were 61 species of mesopelagic fish in the Bering Sea, with Myctophidae (89% lanternfishes) and Bathylagidae (8% deepsea smelts) being the most highly represented in trawl surveys and diet studies (Sinclair et al. 1999). However, six species comprised over 91% of the fish biomass in the western Bering Sea, namely: garnet lanternfish, *Stenobrachius nannochir*, northern lampfish, *Stenobrachius leucopsarus*, slender blacksmelt, *Bathylagus pacificus,* eared blacksmelt, *B. ochotensis*, northern smoothtongue, *Leuroglossus schmidti*, *Pseudobathylagus milleri* and *Chauliodus macouni* (Sinclair et al. 1999). Other myctophids included the northern pearleye, *Benthalbella dentate*, barreleye, *Macropinna microstoma*, bulb-fish, *Oneirodes bulbosus*, pinpoint lampfish, *Nannobrachium regale*, California headlightfish, *Diaphus theta*, blue lanternfish, *Tarletonbeania crenularis*, brokenline lanternfish, *Lampanyctus jordani*, highfin dragonfish, *Bathophilus flemingi*, bluethroat argentine, *Nansenia candida*, highsnout melamphid, *Melamphaes lugubris*, crested bigscale, *Poromitra crassiceps*, showy bristlemouth, *Cyclothone signata*, tan bristlemouth, *C. pallida*, deep-water bristlemouth, *C. atraria*, *Oneirodes thompsoni,* and *Tarletonbeania taylori* (Guénette, this volume).

Across the regions in the Bering Sea, the greatest concentration of myctophid and bathylagid fishes occurred near the continental slope, underwater elevations and canyons (Sinclair et al. 1999). There was no biomass estimate for this group in the Aleutian Islands, but the biomass in the Bering Sea was given as 9.3 million tonnes in the 1980s and 10.5 million tonnes in the 1990s (Shuntov and Radchenko 1999) giving a biomass of approximately 4.0 t km^{-2} and 4.6 $t \cdot km^{-2}$ respectively, when using an area of 2,300,000 km^2 (Perez and McAlister 1993). The 1990s and 1980s biomass for the Bering Sea was used in the 1991 and 1979 Aleutian Island models respectively in conjunction with the annual P/B (0.8) and Q/B (3.65) ratios and diets for Myctophidae and Bathylagidae obtained from NMFS. No estimates of biomass in 1963 or catches for any time period were available for this group.

32. Shrimps

The shrimp group includes both pandalid and non-pandalid species and the most important commercial shrimp species was the northern shrimp, *Pandalus borealis* (Bowers et al. 2003), while non-pandalid species included *Argis, Crago, Spirontocaris* and *Heptacarpus*, with *Crago alaskensis* and *Spriontocaris dalli* being represented from more locations than any other species (Scheffer 1959). No biomass estimate for shrimps existed for the Aleutian Islands, but the annual P/B (2.04) and Q/B (10.2) ratios, as well as their diets were obtained from the NMFS model. Hirons (2001) found that the $\delta^{15}N$ for shrimp in the Aleutians was significantly different from those found around Kodiak Island (Central GOA), indicating that they feed on different food in those two areas although the NMFS diet database only give a general diet.

Shrimps as well as scallops, sea cucumbers, clams, octopuses, squids and sea urchins are managed by the Alaska Department of Fish and Game (Kruse et al. 2000). The catch time series for these species are given in Table 33. The USSR and Japanese started a commercial shrimp fishery in the 1960s northwest of the Pribilof Islands but the Aleutian Island shrimp fishery only started in 1972, when the domestic trawl fishery targeted northern shrimp in the vicinity of Unalaska Islands, and catches increased to a peak in 1977-78 (Bowers et al. 2003). The Japanese fishery caught 4 tonnes of shrimp in 1972 and 1 tonne in 1973 (Forrester et al. 1983). As the fishery developed the catch peaked at 3,085 tonnes in 1977-78, but a precipitous decline in shrimp since 1978 resulted in a reduction in the season and closures between 1983 and 1992, with commercial harvests only occurring in 1992 and 1999 (Kruse et al. 2000).

Table 33. Catch of shrimp (in lbs and tonnes), octopus and urchins (lbs) in the Aleutian Islands (Bowers et al. 2003). C = closed, CF = confidential, NF = No fishery , NL = no landings.

Year	Shrimp (lbs)	Shrimp (tonnes)	Octopus	Urchin
1972	CF	CF*		
1973	CF	CF*		
1974	5,749,407	2,608		
1975	467,196	212		
1976	3,670,609	1,665		
1977	6,800,393	3,085		
1978	4,946,350	2,244		
1979	3,292,049	1,493		
1980	2,454,829	1,113		
1981	2,185,326	991		
1982	CF	CF		
1983	NL	NL		
1984	NL	NL		
1985	NL	NL		
1986	NL	NL		
1987	NL	NL		
1988	NL	NL		
1989	NL	NL		
1990	NL	NL		
1991	NL	NL		
1992	72,133	33		
1993	NL	NL		
1994	NL	NL		
1995	NL	NL		
1996	NL	NL	62,214	3,701
1997	NL	NL	73,472	NL
1998	NL	NL	29,360	NL
1999	CF	CF	115,322	NL
2000	FC	FC	21,265	NL
2001			13,097	NL

* Japanese trawlers caught 4 tonnes and 1 tonne of shrimp in 1972 and 1973 respectively.

33. Benthic invertebrates

Intertidal invertebrate species included barnacles, *Balanus cariosus* and *B. glandula*, mussels, *M. edulis*, isopods, *Idothea wosneseskii*, amphipods, *Parallorchestes ochotensis*, chitons, *Katharina tunicate*, mussels, *Mytilus edulis*, limpets, *Collisella pelta*, littorines, *Littorina aleutica, L. atkana, L. sitkana*, green sea urchins, *Strongylocentrotus polyacanthus, S. drobachiensis* (Palmisano 1975), brittle stars, *Gorgonocephala eucnemis* var. *caryi, Ophiopholis aculeate* and *Ophiura sarsi*i, sand dollars, *Echinarachnius parma*, sea cucumbers, *Cucumaria populifer*, anemones, benthic hydroids, sea pens, sponges, clams, polychaetes and other miscellaneous worms (Scheffer 1959). Abalone, *Haliotis spp.* were not prevalent in the Aleutians, probably because of predation by sea otters (Palmisano 1975).

In the 1950s the vase sponge, *Esperiopsis quatsinoensis*, was common throughout the Aleutian Islands, hydroids such as *Abietinaria filicula* was often washed up on the seaweed and *Thuaria robusta* was collected in sea otter scats (Scheffer 1959). Gorgonian corals (sea fans, bamboo corals and tree corals) of the genera *Callogorgia, Primnoa, Paragorgia, Fanellia, Thouarella* and *Arthrogorgia* were the most common corals, and the Aleutian Islands had the highest abundance and diversity of corals compared to the Gulf of Alaska and the Bering Sea (Heifetz 2000). Soft corals were less frequently encountered than gorgonians and gorgonian corals were most vulnerable to fishing impacts due to their size (3 m high and 7 m wide) and longevity (Heifetz 2000). Cup corals had the highest CPUE in the western Aleutians, near Attu and Amchitka islands while hydrocorals were found throughout the Aleutians with high CPUE near Kiska, Agattu and Amchitka Islands (Heifetz 2000).

Within the Aleutian, some islands (Shemya, Attu) had dense populations of large sea urchins, chitons, mussels, barnacles, amphipods and isopods in the 1970s, while other islands (Amchitka) had sparse populations and small individuals of these species (Palmisano 1975). The most important invertebrates that were available to the Aleuts of Atka Island included sea urchins, chitons, limpets, mussels, clams, sea cucumbers and octopuses (Veltre and Veltre 1983). I used estimates of urchin biomass was obtained from Estes and Duggins (1995) and Konar (1998) for the area > 60 m for 1972 (52 $t{\cdot}km^{-2}$), 1987 (64 $t{\cdot}km^{-2}$), 1994 (70 $t{\cdot}km^{-2}$) and 1997 (76 $t{\cdot}km^{-2}$) as a minimum estimate, and using the average area of the Aleutians > 60 m (3,600 km^2) from Palmisano (1975), I prorated for the total area. I used the value for 1972 as proxy for 1979 and 1994 for 1991 and there was no estimate of biomass for 1963. The average annual P/B (1.3) and Q/B (8.4) ratios and the average diet for brittle stars, urchins, sand dollars, sea cucumbers, snails, anemones, corals, benthic hydroids, sea pens, sponges, clams, polychaete worms, benthic amphipods, and other miscellaneous crustaceans and worms were obtained from the NMFS model. A fishery for sea urchins started in 1996 and no catches were available for either the 1963, 1979 or 1991 models (Table 33).

34. Epibenthic predators and commercial crabs

Epibenthic predators included predacious snails, *Thais lima*, hermit crabs, *Pagurus hirsuitiusculus*, predacious sea stars, *Leptasterias alaskensis* and the commercial crabs such as red, *Paralithodes camtschatica*, scarlet, *Lithodes couesi*, and golden king crabs, *L. aequispina*, as well as dungeness crab, *Cancer magister*, tanner crab, *Chionecetes bairdi*, grooved tanner crab, *C. tanner*, triangle tanner crab, *C. angulatus*, and Korean horsehair crabs, *Erimacrus isenbeckii* (Bowers et al. 2003). Scheffer (1959) collected the largest starfish species in the Aleutian Islands: *Aleutiaster shefferi, Henricia leviuscula, H. sanguinolenta* and *Asterias amurensis*. No biomass was available for this group. The average annual P/B (1.3) and Q/B (5.0) ratios of hermit crabs, sea stars and other miscellaneous crabs were obtained from the NMFS model. The P/B ratio is very similar to the 1.4 $year^{-1}$ obtained for the Southwestern Bering Sea from Shiomoto (1999). The average diet of snails, sea stars, king crabs, hermit crabs and other miscellaneous crabs were obtained from the NMFS diet database.

The Japanese pioneered the Alaskan crab fisheries with tanglenets in the 1930s, and the Russians entered in the 1950s, while the Japanese also caught crabs with pots in the late 1960s and early 1970s (National Research Council 2003). Domestic fisheries for red king crab developed in 1961 in Adak and Dutch harbour (Kruse et al. 2000), but the fishery plummeted in the early 1980s and have been closed since 1983 (National Research Council 2003). The golden king crab fishery developed in the Aleutians after the collapse of the red king crab fishery in the 1980s, and the harvest from Adak Island peaked at 5,800 tonnes by 62 vessels in 1981-82 (National Research Council 2003). The Aleutian Island fishery peaked in 1986 with 5,805 tonnes (Table 34) and between 1981 and 1995 an average of 49 vessels in Adak participated in the fishery (Kruse et al. 2000). The crab fishery at Adak (Table 34) in 1963 caught only red king crabs, while in 1979 and 1991 both red and golden king crab as well as tanner crab were caught (Bowers et al. 2003). The Adak fishery encompassed the area west of 172˚W so I prorated the catch by using the average area from the halibut fishery (4B = 55,564 km^2), and the area of the model (56,936 km^2).

35. Cephalopods

The cephalopods of the western sub-arctic include large gonatid squid of the family Gonatidae, neon flying squid, *Ommastrephes bartrami*, armhook squid *Berryteuthis magister magister, B. anonychus,* boreopacific armhook squid, *Gonatopsis borealis, G. makko, G. okutanii*, *Gonatus* spp., and micronectonic squid (Aydin et al. 2003). Boreal clubhook squid, *Onychoteuthis borealijaponica*, robus clubhook squid, *Moroteuthis robusta*, clawed armhook squid, *Gonatus onyx*, eastern Pacific bobtail, *Rossia pacifica* and California market squid, *Loligo opalescens*, are also part of the squid species of the BSAI area (Hare et al. 2003), while *Chiroteuthis* spp. and *Japetella heathi* were found in the salmon gillnet investigations of the North Pacific (Fiscus and Mercer 1982). The octopods included the North Pacific giant octopus, *Enteroctopus dofleini,* flapjack devilfish, *Opisthoteuthis californiana*, and smoothskin octopus, *Octopus leioderma* (Hare et al. 2003) and *Octopus apollyon* (Scheffer 1959). The most frequently occurring mesopelagic cephalopods in the Bering Sea were *Galiteuthis phyllura*, *Belonella borealis, Bonatopsis borealis, G. octopedatus* and *G. middendorffi* (Sinclair et al. 1999). From the trawl surveys (Gaichas 2002), the biomass for 1991 and 1980 were 61,756 tonnes (1.08 t·km^{-2}) and 17,218 tonnes (0.3t·km^{-2}) respectively and no estimates were available for 1963 (Figure 23). The average annual P/B (2.0) and Q/B (7.16) for squids and octopuses obtained from the NMFS model were used. For the 1963 model, I used the average natural mortality of octopus and squid from the stock assessment report (Gaichas 2003), which gave an annual P/B of 0.41.

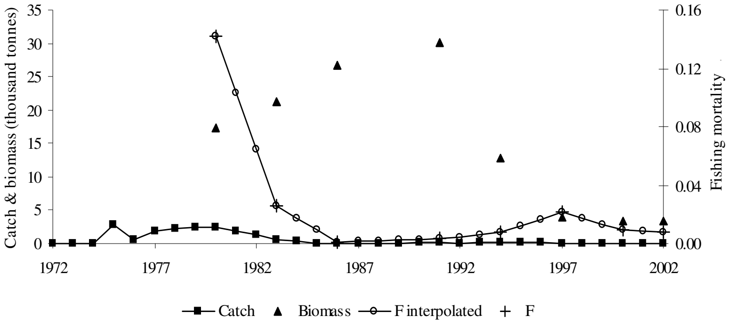


Figure 23. Catch (10^3 tonnes), biomass (10^3 tonnes) and fishing mortality (F, observed and interpolated, year^{-1}) for cephalopods in the Aleutian Islands.

Squids were important food for toothed whales, pinnipeds, porpoises and larger pelagic fish such as salmon, while offshore pelagic fish such as tuna, salmon and pomfret, as well as some seabirds (sooty shearwaters) fed on smaller squids (Rogers 1987). Juvenile squids fed on planktonic crustaceans such as euphausiids, while adults fed on myctophids and the juveniles of other fish such as rockfish, with cannibalism being common among squids (Rogers 1987). Hirons (2001) found that the $\delta^{15}N$ for squids in the Aleutian Islands was significantly different from those found around Kodiak Island, indicating that they feed on different food in those two areas. The average diet for cephalopods was obtained from the NMFS database for squid and octopuses.

The boreal clubhook squid was the main commercial cephalopod species in the Aleutian Islands (Kajimura 1984; Hare et al. 2003). Squids were targeted by Japanese and Republic of Korea trawl fisheries and were generally taken incidentally in target fisheries for pollock, but have been comparatively lightly exploited in recent years and discard rates of squids (discards/total squid catch) by the BSAI groundfish fisheries have ranged between 40% and 85% in 1992-1998 (Gaichas 2003). The squid and octopus catches from 1972 to 1976 were obtained from Forrester et al. (1983), and there were no catches reported before 1972 (Forrester et al. 1978) (Table 35). Catches from 1977 to 1990 were obtained from the stock assessment report (Gaichas 2003), while the catches from 1991 onwards came from the NMFS observer database (Figure 23). The breakdown of catches into discards and landings for squids in 1991-2002 was used to estimate their breakdown prior to 1991. Octopus bycatch was estimated from the stock assessment of "other groundfish" (Gaichas 2003) using the breakdown of other species in the groundfish survey in the 1999 estimates from Anonymous (2001), and I assumed that all octopuses were discarded. The fishing mortalities were calculated for years that survey estimates were available and estimated between the survey biomass years (Figure 23).

Table 34. Catch of crabs in the Adak fishery, in pounds (lbs) with total in tonnes. C = closed, CF = confidential, NF = No fishery, NL = no landings.

Year	**Red king crab**	**Golden king crab**	**Scarlet king crab**	**Tanner crab**	**Grooved tanner**	**Dungeness crab**	**Total (lbs)**	**Total (tonnes)**
1960	2,074,000						2,074,000	941
1961	6,114,000						6,114,000	2,773
1962	8,006,000						8,006,000	3,631
1963	17,904,000						17,904,000	8,121
1964	21,193,000						21,193,000	9,613
1965	12,915,000						12,915,000	5,858
1966	5,883,000						5,883,000	2,668
1967	14,131,000						14,131,000	6,410
1968	16,100,000						16,100,000	7,303
1969	18,016,000						18,016,000	8,172
1970	16,057,000						16,057,000	7,283
1971	15,475,940						15,475,940	7,020
1972	18,724,140						18,724,140	8,493
1973	9,741,464			71,887			9,813,351	4,451
1974	2,774,963			CF		60,517	2,835,480	1,286
1975	411,583	25,490		CF		CF	437,073	198
1976	C	2,285		NL		NL	2,285	1
1977	905,527	47,445		237,512		NL	1,190,484	540
1978	807,195	NF		197,244		CF	1,004,439	456
1979	467,229	23,485		337,297		CF	828,011	376
1980	1,419,513	58,914		220,716		NL	1,699,143	771
1981	1,648,926	1,194,046		838,697		NL	3,681,669	1,670
1982	1,701,818	8,008,274		488,399		CF	10,198,491	4,626
1983	1,981,579	8,128,029		384,146		CF	10,493,754	4,760
1984	1,367,672	3,180,095		163,460		91,739	4,802,966	2,179
1985	908,293	11,124,759		206,814		17,830	12,257,696	5,560
1986	712,243	12,798,004		42,761		CF	13,553,008	6,148
1987	1,213,933	8,001,177		141,390		26,627	9,383,127	4,256
1988	1,567,314	9,080,196		148,997		22,634	10,819,141	4,907
1989	1,118,566	10,162,400		48,746		11,124	11,340,836	5,144
1990	828,105	5,250,687		14,779		17,365	6,110,936	2,772
1991	951,278	6,254,409		7,825		7,412	7,220,924	3,275
1992	1,266,424	4,916,149		CF		5,649	6,188,222	2,807
1993	698,077	4,635,683		NL	CF	7,531	5,341,291	2,423
1994	196,967	6,378,030	21,308	NL	NL	NL	6,596,305	2,992
1995	38,941	4,896,926	49,126	CF	CF	NL	4,984,993	2,261
1996	C	2,591,720	24,076	C	145,795	NL	2,761,591	1,253
1997	C	2,444,628	6,720	C	CF	NL	2,451,348	1,112
1998	5,900	1,691,385		C	NL	NL	1,697,285	770
1999	C	2,768,902		C	NL	NL	2,768,902	1,256
2000	76,792	2,884,682		C	C	NL	2,961,474	1,343
2001	153,961				C	CF	153,961	70

Table 35. Landings and discards (tonnes) of cephalopods in the Aleutian Islands.

Year	**Landings**			**Discards**				**Total catch**
	Pot	**Trawl**	**Total**	**Pot**	**Trawl**	**Longline**	**Total**	
1972					4		4	4
1973					2		2	2
1974		1	1		7		7	8
1975		225	225		2,505		2,505	2,730
1976		46	46		511		511	557
1977		200	200	111	1,624	9	1,744	1,944
1978		230	230	86	1,867	7	1,959	2,190
1979		249	249	89	2,016	7	2,112	2,361
1980		258	258	90	2,087	7	2,184	2,442
1981		195	195	50	1,575	4	1,629	1,824
1982		133	133	36	1,073	3	1,112	1,244
1983		56	56	25	457	2	485	541
1984		38	38	11	307	1	319	357
1985		1	1	14	10	1	25	26
1986		2	2	10	19	1	30	33
1987		3	3	8	22	1	31	34
1988				3	3		6	7
1989		1	1	1	5		6	7
1990		10	10	32	88	3	123	134
1991		13	13	6	76	1	82	95
1992		2	2	21	62	2	83	85
1993				23	75	2	97	98
1994		6	6	8	82	1	89	96
1995		4	4	9	92	1	101	105
1996		6	6	12	79	1	91	97
1997		21	21	10	52	1	62	83
1998		8	8	17	19	1	36	44
1999	0.005	5	5	12	6	1	17	22
2000				21	11	2	32	32
2001		1	1	28	8	2	36	37
2002	0.136	1	1	14	11	1	25	26

36-37. Zooplankton

Zooplankton is divided into small and large groups in the models. The large zooplankton included scyphozoan jellies, fish larvae, chaetognaths, euphausiids, mysids, pelagic amphipods, pelagic gelatinous filter feeders and pteropods while small zooplankton consisted of copepods and microzooplankton. The crystal jellyfish, *Aequorea aequorea*, was observed daily from July in the Aleutians and *Cyanea capillata* was seen frequently in bays from July to September, *Aurelia aurita* was not as prevalent, while *Aegina, Hybocodon, Mitrocoma, Rathkea, Sarsia* and *Stomotoca* were caught in plankton hauls (Scheffer 1959). The most dominant euphausiid collected by plankton nets in the Aleutian Islands was *Thysanoëssa longipes* and it was also the main species of euphausiids fed on by baleen whales in the area along with *T. spinifera* and *Euphausia pacifica* (Nemoto 1957).

The main copepods (small zooplankton) in the system were *Calanus cristatus, C. plumchrus, C. finmarchicus, C. helgolandicus, Eucalanus bungi bungi, Pseudocalanus elongates, P. gracilis, Centopages adbominalis, Aetideus armatus, Euchaeta japonica, Gaidius brevispinus, G. tenuispinus, Scolecithricella minor, Heterorhabdus papilliger, Candacia columbiae, Metridia lucens, Pleuromamma robusta, Acartia clause* and *Oithona similis* (Nemoto 1957).

Data of zooplankton dry mass, obtained from Steve Romaine (IOS, DFO, Sidney, BC, *in. litt*), was converted from dry mass to wet mass using conversion ratios for copepods, euphausiids and gelatineous zooplankton of 0.186 (dry weight = 0.186 wet weight), 0.225 and 0.041 respectively (Brey 1999, http://www.awi-bremerhaven.de/Benthic/Ecosystem/FoodWeb/Handbook/enflow/efconvers.html). The estimates were grouped into small zooplankton and large zooplankton (including jellies) and their biomass were estimated at 13.5 t·km^{-2} and 33.7 t·km^{-2} for respectively (Table 36). Data obtained from McAlister (1971) were used to obtain zooplankton estimates of 500 g·1000m^{-3}, or 50 t·km^{-2} (over 100 m depth) for the 1970s.

Table 36. Biomass (t·km^{-2}) estimates used for small and large zooplankton in the Aleutian Islands.

Group	**1970**	**1999**
Large zooplankton	30.60	33.67
Small zooplankton	19.40	13.48

McAlister (1971) also suggested that copepods comprised 85.2% of the numbers, but I used the biomass ratios obtained from Romaine (IOS, DFO, Sidney, BC, *in. litt.*) to divide between small (19.4 t·km^{-2}) and large zooplankton (30.6 t·km^{-2}) (Table 36). Unfortunately, no estimates were available for the 1963 model and I used the same estimated as in the 1970s.

The annual P/B and Q/B ratios of small zooplankton (23.7 and 112 respectively) were obtained from Aydin et al. (2003), while that of large zooplankton, large jellyfish, salps and ctenophores, obtained from Aydin et al. (2003) were prorated by the biomass of these groups in that model to give P/B and Q/B ratios of 5.9 year^{-1} and 38 year^{-1} respectively. The diets of jellyfish, chaetognaths, euphausiids, mysids, pelagic amphipods and other large zooplankton from the NMFS diet database were averaged for the diet of large zooplankton, while the diet of fish larvae, pteropods, copepods and microzooplankton were averaged for the diet of small zooplankton in the Aleutian Islands. A zooplankton biomass time series from 1955 to 1994 was obtained from Sugimoto and Tadokoro (1997), who reported mean and standard deviation of zooplankton biomass (in mg·m^{-3}) in the central subarctic Pacific, from 160°W to 170°E and 40°N to the Aleutian chain. I used it as a proxy for large zooplankton biomass time series (Figure 24).

38. Phytoplankton

The waters of the Aleutian Islands are unusually rich in plankton (Murie 1959). Phytoplankton in the Pacific Ocean was exposed to a favourable light regime during winter and was able to maintain a moderate level of biomass and production, thus about 80% of the biomass was in the form of small flagellate cells that were grazed by protozoa, which were preyed on by relatively large copepods that had only one generation per year (Mann and Lazier 1991). Parsons (1987) suggested that there is an area south of the Aleutian Islands (closer to the Aleutian Trench) that showed relatively larger oceanic chlorophyll-a concentrations than the rest of the Gulf of Alaska and that water movement through the Aleutian passes produced local upwelling.

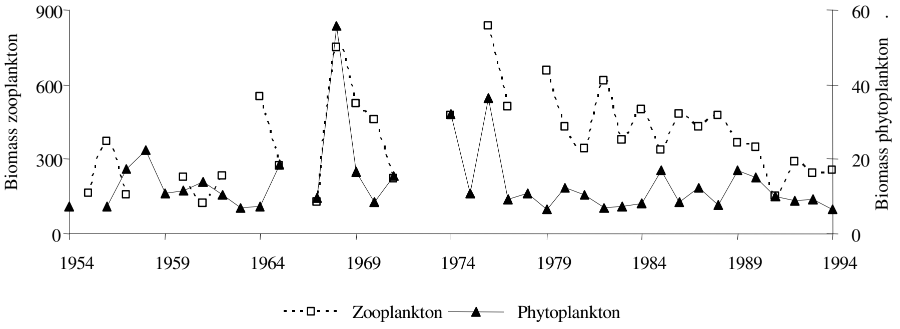


Figure 24. Zooplankton and phytoplankton biomass (in mg·m^{-3}) estimates used in time series fitting.

Primary productivity data (gC·m^{-2}·year^{-1}) were provided by the Joint Research Centre (JRC), of the European Commission Space Applications Institute (SAI) Marine Environment Unit (ME) (www.me.sai.jrc.it/me-website /contents/ shared_ utilities /frames /index_windows.htm) and it was developed using the Behrenfeld and Falkowski (1997) model that includes NOAA's satellite data on sea temperatures, chlorophyll-a levels and light irradiance (Reg Watson, UBC Fisheries Centre, pers. comm.). The data was available on a spatial scale of approximately 0.176 degree and was averaged into ½ degree spatial cells. The area used for data extraction was cells < 500m deep, although very few cells around the Aleutian Islands were that shallow. The average depth of the total area was 2,068 m and the total area sampled was 257,983 km², while the area up to 500 m depth was 54,134 km². The average primary production was 248 gC·m^{-2}·year^{-1}, which translated into 2,236 g wet weight·m^{-2}·year^{-1}, using a carbon:wet weight ratio of 9 (Strathmann 1967). The 248 gC·m^{-2}·year^{-1} was similar to the 200-400 gC·m^{-2}·year^{-1} estimated by Schumacher and Alexander (1999) for the southeastern and western Bering Sea. Using the average P/B ratio (91 year^{-1}) of large and small phytoplankton obtained from the western sub-Arctic model (Aydin et al. 2003) resulted in a biomass of 24.6 t·km^{-2} for the 1991 model.

For 1979, I used the average chlorophyll-a, and daily production estimates for 1958 to 1974 obtained from Anderson et al. (1977). The conversion from chlorophyll-a to carbon was obtained from Zeitschel (1970), whose data on chlorophyll-a and carbon gave a regression equation:

$$\text{Carbon} = (43.749 \cdot \text{chlorophyll-a}) - 1.7107$$

Using the conversion from carbon to wet weight of 9 obtained from Strathmann (1967) and a growing season of 200 days (Parsons 1987), rendered a biomass of 17 t·km^{-2} and a P/B ratio of 130 year^{-1} for the 1979 model which were also used for the 1960s model. This value of phytoplankton biomass was used in conjunction with the time series of chlorophyll-a biomass estimates given by Sugimoto and Tadokoro (1997) from 1954 to 1994 for the central sub-arctic Pacific. They reported mean and standard deviation of chlorophyll concentration (in mg·m^{-3}) in the central subarctic Pacific, from 160°W to 170°E and 40°N to the Aleutian chain (Figure 24). These estimates were prorated by using the average for 1958-1974 and assuming that it would be the same as the average for that time period obtained from Anderson et al. (1977) to get a time series used in the Ecosim fitting (Figure 24).

39. Macrophytes

The marine vegetation of the Aleutian Islands was represented by the kelp beds that disappeared in the winter (Murie 1959). Scheffer (1959) suggested that the genus *Alaria* was the most abundant and found along the entire archipelago, with masses of *Alaria* seen floating detached at sea and piled on the beaches in August. Similarly, *Ulva* (sea lettuce) were on every beach, while *Halosaccion* occurred in clumps on spray covered rocks (Scheffer 1959). Lime-secreting marine algae called *Lithothamnion* were also conspicuous on Aleutian beaches (Scheffer 1959).

The nearshore subtidal habitat in the Aleutian Islands had been described by Konar (2000) as sea urchin barrens, that are devoid of foliose macroalgae, or kelp beds. The macroalgal populations depended on the sea otter consumption of sea urchins, and therefore sublittoral macroalgae at Attu and Shemya were essentially absent because of intense overgrazing by sea urchins (Estes et al. 1978). In contrast, at Amchitka Island, the sublittoral fringe showed competitive interactions between *Agarus* and *Alaria fistulosa*, while 3 species of *Laminaria* co-existed (Estes et al. 1978). At Adak Island, the majority of the community consisted of *L. longipes* and *Alaria crispa* (Estes et al. 1978).

The macrophytes of Amchitka Islands consisted of the Rhodophyta and macroalgae such as *Laminaria longipes, L. groenlandica, L. yezoensis, L. dentigera, Agarum cribrosum, Thalassiophyllum clathrus* and *Desmarestia spp* (Estes et al. 1978). *L. longipes* was most abundant from the sublittoral fringe to 3 m, while *L. grounlandica, L. dentigera* and *L. yezoensis* grew between mean low water to depths > 24 m. *Hedophyllum sessile* predominated the lower midlittoral region in protected areas and *Alaria crispa* occupied the lower midlittoral region on exposed areas, while *Halosaccion glandiforme, Irideae cornucopiae* and *Fucus distichus* covered the higher zones of the mid-littoral region (Palmisano 1975). Rhodophytes were continuously abundant from the sublittoral fringe to depths > 24 m (Estes et al. 1978). Subtital kelp beds were extensive in Amchitka but less so at Adak Island (Palmisano 1975). At islands with no or few sea otters (Shemya, Attu) there was a definite browse line at the low water level, and *L. longipes* did not form a complete mat in the sublittoral fringe, with areas of *Thallasiophyllum clathrus* and *Laminaria groenlandica* (Palmisano 1975).

The brown algal community at Shemya Island included *Alaria fistulosa, Desmarestia ligulata, D. viridis, Laminaria dentigera, Agarum cribrosum* and *Thalassiophyllum clathrus* and were mainly found on the tops of pinnacles, while the bases and sides of the pinnacles were colonized by encrusting coralline algae (Konar 2000). The average wet weight of drift algae at Shemya Island was approximately 0.3 t·km^{-2} (Konar 1998), while the weight of other macrophytes (*Laminaria* spp., *L. longipes, Agrarum cribrosum, Thalassiophyllum clathrus, Desmarestia* and Foloise Rhodophytes) amounted to 2,109 t·km^{-2} (Estes et al. 1978). This estimate was very high, and I let Ecopath estimate the biomass for this group. For an annual P/B ratio I used the average wet weight of *Laminaria* given by Estes et al. (1978) and the production given by Palmisano (1975) as 7,842 kcal·m^{-2}·year^{-1}, with a conversion of 0.65 kcal·g^{-1} wet weight, to give an annual P/B of 8.1, which I used for all three models.

40. Detritus

The NMFS model had various groups of detritus, including discards, offal, pelagic detritus, benthic detritus and benthic bacteria, which were grouped here as it is part of the benthic microbial loop. No estimates of detritus mass were available.

BALANCING THE MODELS

1991 model

The unbalanced model for 1991 is given in Table 37. To balance the model, I started by making sure all the P/Q's were within the 0.1-0.3 range. I let Ecopath estimate the Q/B's for mammal eating sharks and sharks and skates by assuming a P/Q of 0.1. Similarly, I changed the P/Q of Atka mackerel, halibut and arrowtooth to 0.2 and let Ecopath estimate their Q/B's. For large deep water fish I assumed a P/Q of 0.2 and let Ecopath estimate a P/B. For Pacific Ocean perch, I assumed a P/Q of 0.1 and estimated their Q/B's (1.1 year^{-1}) as Kerim Aydin (NMFS) suggested that their P/Q would be lower. Similarly, for rockfish I assumed a P/Q of 0.15 and estimated a P/B (0.3 year^{-1}), as the P/B obtained from NMFS was only for some species of rockfish. In this model, I generally did not want to estimate the P/B's as the estimates of P/B were obtained from NMFS for this specific year. However, as for rockfish, the flatfish group did not include all species and therefore I assumed a P/Q of 0.2 and estimated a P/B of 0.34 year^{-1}.

1. The biomass of sharks and skates (0.315 t·km^{-2}) came from the trawl survey, and probably did not include all species, so I let Ecopath estimate a biomass (0.68 t·km^{-2}) for this group.
2. To balance Atka mackerel, decreased the Atka mackerel in the diet of adult Steller sea lions from 42.7% to 20% and added 12.7% small pelagics and 10% sand lance. This reduced the consumption by Steller sea lions, but still did not balance the Atka mackerel. I then decided to estimate the P/B but retained the Q/B ratios for this group, which estimated a P/B of 1.1 year^{-1}, similar to the average of adult and juvenile Atka mackerel in the NMFS model.
3. For adult pollock I used the average biomass for pollock in 1991 and 1994, as suggested by Ivonne Ortiz (University of Washington, *pers. comm.*). Thus the adult pollock biomass was increased to 5.8 t·km^{-2}, which reduced the EE but still did not balance adult pollock. One of the main predators of adult pollock was Pacific cod, so I also used the average biomass for 1991 and 1994 for Pacific cod (3.8 t·km^{-2}) as their EE was quite low (0.7) and they consumed large quantities of prey. This reduced the EE of adult pollock to 1.3. I reduced the adult pollock in the diet of adult Steller sea lions (their main predator) from 2.6% to 1% and added 1.6% as import, which reduced the EE to 1.2. Finally, using the P/B and Q/B ratios given by NMFS estimated a P/Q of only 0.1, so I increased the P/B to 0.45 year^{-1} (from 0.37 year^{-1}), which balanced the adult pollock.
4. I reduced the juvenile pollock in the diet of Atka mackerel from 6.1% to 4% and added the 2.1% to import to balance that group.
5. Pacific Ocean perch was reduced in the diet of both Pacific cod and flatfish to 0.1% for balancing purposes, and I added other rockfish (0.1% for Pacific cod and 0.5% for flatfish). In the model the diet of adult Stellers included only rockfish and no Pacific Ocean perch, although Pacific Ocean perch was part of the rockfish from the diet. Thus, the diet of Stellers was changed to include 1.48% rockfish and 0.02% POP, which was all the POP could accomodate. The biomass estimate I had for rockfish (0.39 t·km^{-2}) was only for northern, shortraker and rougheye rockfish, so it did not include all the other species. I therefore let Ecopath estimate a biomass of 1.0 t·km^{-2}.
6. To balance large demersals I reduced the cannibalism in medium demersals from 3.6% to 1%, as the eelpouts in that group consumed juvenile large demersals. I added the remaining 2.6% to import. In addition, I reduced the consumption of juvenile large demersals by eelpouts from 2.3 to 0.1% and added 2.2% to import. The consumption of adult Steller sea lions was 4.7% and I reduced it to 2.4% adding 0.2% to halibut and 0.1% to sablefish. I then let Ecopath estimate the biomass of large demerals (3.6 t·km^{-2}).
7. To balance the large deep water fish, I let Ecopath estimate their biomass (0.6 t·km^{-2}) as their biomass (0.432 t·km^{-2}) was only for grenadiers.
8. For myctophids, I let Ecopath calculate the P/B (was 0.8 year^{-1}) by assuming a P/Q of 0.28, which resulted in a P/B of 1.02 year^{-1}, similar to Guénette (this volume)'s, and then let Ecopath calculate a biomass of 8.3 t·km^{-2}.
9. I checked the P/B and Q/B estimates for cephalopods and decided to use the estimates from Aydin et al. (2003) instead, excluding the micronectonic squid from that estimate, which gave a P/B of 2.55 year^{-1} (similar to Guénette, this volume) and a Q/B of 6.9 year^{-1}. I let Ecopath estimate the biomass (5.1 t·km^{-2}), which is very high, so I changed the diet of Atka mackerel, which fed extensively on cephalopods from 10.4% to 1% and added an import of 9.4% to their consumption, assuming that they consume large quantities of cephalopods from outside the system. This reduced the biomass to 2.3 t·km^{-2}.

Table 37. Input data for 1991 model. Values estimated by Ecopath are shown in bold.

#	Group	Biomass ($t \cdot km^{-2}$)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	P/Q
1	Transient orca	0	0.025	7.506	0.072	0.003
2	Toothed whales	0.012	0.029	10.094	0.108	0.003
3	Baleen whales	0.279	0.020	6.996	0.120	0.003
4	SSL embryo	**0**	0.020	219.613	0.000	0.000
5	SSL pups	**0.001**	0.518	82.955	0.063	0.006
6	SSL juveniles	**0.018**	0.234	39.313	0.105	0.006
7	SSL adults	0.083	0.186	25.550	0.023	0.007
8	Small mammals	0.017	0.166	23.880	0.985	0.007
9	Sea otters	0.002	0.117	86.401	0.549	0.001
10	Birds	0.09	0.113	65.353	**0.006**	0.002
11	Shark mammal eater	**0.001**	0.100	3.000	0.950	**0.033**
12	Sharks and skates	0.315	0.180	2.500	**0.590**	**0.072**
13	Salmon	**0.722**	0.900	4.325	0.950	0.208
14	Large pelagics	**0.001**	0.220	1.467	0.950	0.150
15	Small pelagics	**5.384**	0.800	3.650	0.950	0.219
16	Atka mackerel	12.73	0.178	5.647	**2.267**	**0.032**
17	Sand lance	**1.495**	0.800	3.650	0.950	0.219
18	Herring	**4.485**	0.160	0.970	0.950	0.165
19	pollock juveniles	1.246	1.992	9.851	**2.084**	0.202
20	pollock adult	5.29	0.366	3.650	**1.313**	**0.100**
21	POP	0.583	0.109	1.802	**1.453**	**0.060**
22	Rockfish	0.391	0.100	2.000	**2.173**	**0.050**
23	Sablefish	0.861	0.190	1.030	0.908	0.184
24	Pacific cod	4.107	0.412	2.280	0.382	0.181
25	Halibut	0.579	0.190	2.008	0.576	**0.095**
26	Arrowtooth	1.343	0.180	2.609	0.303	**0.069**
27	Flatfish	1.844	0.188	1.718	**0.627**	0.109
28	Small demersals	**6.471**	0.600	3.000	0.950	0.200
29	Large demersals	0.279	0.400	2.000	**8.304**	0.200
30	Large deep	0.432	0.150	2.000	**4.964**	**0.075**
31	Myctophids	4.565	0.800	3.650	**2.332**	0.219
32	Shrimps	**4.336**	2.040	10.200	0.950	0.200
33	Benthic invertebrates	69.549	1.317	8.429	0.766	0.156
34	Epibenthic carnivores	**6.999**	1.283	5.000	0.950	0.257
35	Cephalopods	1.085	2.000	7.160	**5.945**	0.279
36	Large zooplankton	33.672	5.866	37.937	**1.307**	0.155
37	Small zooplankton	13.484	23.725	112.420	**3.154**	0.211
38	Phytoplankton	24.559	91.061	-	0.643	-
39	Marine plants	**1.876**	8.119	-	0.950	-
40	Detritus	-	-	-	**1.045**	-

10. I increased the P/Q of benthic invertebrate feeders to 0.2 and let Ecopath estimate their P/B at 1.7 $year^{-1}$, which balanced this group.
11. To balance small and large zooplankton, I changed the diet I had of large and small zooplankton to that of the aggregated Gulf of Alaska model (Heymans, this volume). For large zooplankton the diet changed to 0.6% large zooplankton, 40% small zooplankton and 59.4% phytoplankton, and for small zooplankton the diet changed to 14.7% small zooplankton, 57.9% phytoplankton and 27.4% detritus. This balanced the large zooplankton but not the small zooplankton. I also changed the P/B of small zooplankton to 36.3 $year^{-1}$ (the average for copepods and microzooplankton from the NMFS data) and changed the Q/B of large zooplankton to be more similar to that of Guénette (this volume) and the Gulf of Alaska model (16.0 $year^{-1}$), which balanced the model.
12. Finally, these changes reduced the EE of Atka mackerel to 0.5, so I increased them in the diet of adult Steller sea lions to 41.6% by reducing the small pelagics to 2.7%, sand lance to 0.5% and adding the 1.6% that was imported. This increased the EE of Atka mackerel to 0.68, and I then reduced the P/Q to 0.15, which estimated a P/B of 0.85 $year^{-1}$ and increased the EE to 0.91. The balanced model is given in Table 38 and the balanced diet in Table A1.

Table 38. Balanced model for 1991 model. Parameters estimated by Ecopath are shown in bold.

#	Group	Biomass ($t \cdot km^{-2}$)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	P/Q
1	Transient orca	0	0.025	7.506	**0.072**	**0.003**
2	Toothed whales	0.012	0.029	10.094	**0.050**	**0.003**
3	Baleen whales	0.279	0.020	6.996	**0.109**	**0.003**
4	SSL embryo	**0**	0.020	219.184	**0.000**	**0.000**
5	SSL pups	**0.001**	0.518	82.792	**0.054**	**0.006**
6	SSL juveniles	**0.018**	0.234	39.236	**0.081**	**0.006**
7	SSL adults	0.083	0.186	25.500	**0.023**	**0.007**
8	Small mammals	0.017	0.166	23.880	**0.899**	**0.007**
9	Sea otters	0.002	0.117	86.401	**0.549**	**0.001**
10	Birds	**0**	0.113	65.353	0.950	**0.002**
11	Shark mammal eater	**0.001**	0.100	**1.000**	0.950	0.100
12	Sharks and skates	**0.185**	0.180	**1.800**	0.950	0.100
13	Salmon	**0.485**	0.900	4.325	0.950	**0.208**
14	Large pelagics	**0**	0.220	1.467	0.950	**0.150**
15	Small pelagics	**2.295**	0.800	3.650	0.950	**0.219**
16	Atka mackerel	12.73	**0.847**	5.647	**0.429**	0.150
17	Sand lance	**0.592**	0.800	3.650	0.950	**0.219**
18	Herring	**2.651**	0.160	0.970	0.950	**0.165**
19	pollock juveniles	1.852	1.990	**9.514**	**0.862**	**0.209**
20	pollock adult	5.8	0.450	3.650	**0.915**	**0.123**
21	POP	0.583	0.109	**1.090**	**0.963**	0.100
22	Rockfish	**0.343**	**0.300**	2.000	0.950	0.150
23	Sablefish	0.861	0.190	1.030	**0.587**	**0.184**
24	Pacific cod	3.8	0.412	2.280	**0.264**	**0.181**
25	Halibut	0.579	0.190	**0.950**	**0.515**	0.200
26	Arrowtooth	1.343	0.180	**0.900**	**0.281**	0.200
27	Flatfish	1.844	**0.344**	1.718	**0.309**	0.200
28	Small demersals	**5.429**	0.600	3.000	0.950	**0.200**
29	Large demersals	**1.286**	0.400	***2.000***	0.950	**0.200**
30	Large deep	**0.581**	**0.400**	2.000	0.950	0.200
31	Myctophids	**8.254**	**1.022**	3.650	0.950	0.280
32	Shrimps	**4.349**	2.040	10.200	0.950	**0.200**
33	Benthic invertebrates	69.549	**1.686**	8.429	**0.612**	0.200
34	Epibenthic carnivores	**7.508**	1.283	5.000	0.950	**0.257**
35	Cephalopods	**1.526**	2.550	6.900	0.950	**0.370**
36	Large zooplankton	33.672	5.866	16.000	**0.523**	**0.367**
37	Small zooplankton	13.484	36.300	112.420	**0.981**	**0.323**
38	Phytoplankton	24.559	91.061	-	**0.536**	-
39	Marine plants	**1.944**	8.119	-	0.950	-
40	Detritus	-	-	-	**0.565**	-

1979 model

The unbalanced model for 1979 is given in Table 39 in conjunction with the diets and catches given in the model description above. To balance the model I confirmed that the P/Q's of all species were in the range of 0.1-0.3. I added a P/Q of 0.1 for mammal eating sharks and sharks and skates, and let Ecopath estimate their Q/B. Similarly, I changed the P/Q of Atka mackerel, halibut, arrowtooth, and deep demersals to 0.2 and let Ecopath estimate their P/B's. For Pacific Ocean perch and rockfish I added a P/Q of 0.15 and let Ecopath estimate their P/B's as NMFS suggested that their P/Q's were not that high.

1. As I did not have estimates for all small mammals, I let Ecopath estimate the biomass (0.04 $t \cdot km^{-2}$) by assuming an EE of 0.5. Similarly, I let Ecopath estimate the biomass for sharks and skates, as the estimate I had from the trawl survey (0.192 $t \cdot km^{-2}$) was not very representative of this group. I used an EE of 0.95, which estimates a biomass of 2.3 $t \cdot km^{-2}$, which was too high, as the 1963 biomass was only 1.8 $t \cdot km^{-2}$. I added a negative biomass accumulation of

15%, as the biomass was too high and Ecopath estimated a biomass of 1.2 t·km^{-2}, which would be realistic if the fishery had discarded sharks and skates caught since the induction of the fishery in 1963.

2. For Pacific cod, I increased their P/Q to 0.2 and let Ecopath estimate their P/B, which reduced their EE to 5.5. I reduced the Pacific cod in the diet of Steller sea lion adults from 0.063 to 0.01, and added 0.005 to halibut and 0.01 to herring, both of which were assumed to be less than 1% in their diets (Sinclair and Zeppelin 2002), and had the last 3.8% be import, as it could be juveniles of these species (Pacific cod etc.), or consumed outside the system. I also reduced the Pacific cod in the diet of juvenile Steller sea lions from 0.085 to 0.05 and added 0.035 to small pelagics. This reduced their EE to 1.7 and I let Ecopath estimate the biomass (1.9 t·km^{-2}).
3. The P/B of rockfish calculated when assuming a P/Q of 0.15 was quite low (0.3 year^{-1}), and I increased the P/Q to 0.2 which gave a P/B of 0.4 year^{-1}. I let Ecopath estimate the rockfish biomass (1.5 t·km^{-2}) as the biomass estimates I had is only for northern, shortraker and rougheye rockfish, so it did not include all the other species.
4. To balance flatfish I let Ecopath estimate their biomass, as I did not have a good estimate of their biomass. The biomass of flatfish was only for turbot and flathead sole (1.26 t·km^{-2}), with no estimates for yellow fin sole or rock sole. Ecopath estimated a biomass of 6.5 t·km^{-2}. However, the P/Q for flatfish was 0.11 which was low, so I assumed a P/Q of 0.2 and estimated a P/B of 0.34 year^{-1}, which reduced the biomass to 3.6 t·km^{-2}.
5. For Pacific Ocean perch the annual P/B calculated when assuming a P/Q of 0.15 was very low (0.27), much lower than the fishing mortality and therefore I increased it to 0.75 year^{-1}, as Guénette (this volume) had 0.51 year^{-1}, and POP was highly exploited in the Aleutians at that time. I also used Guénette's (this volume) Q/B of 2.55 year^{-1} instead of the 1.8 year^{-1} given by NMFS. The diet of Steller sea lions did not include any Pacific Ocean perch, but only rockfish, so I included 0.01% POP. The EE of POP was then 1.1, and I reduced POP in the diet of flatfish (from 0.006 to 0.001), their main predator flatfish, and added 0.005 to shrimp to balance the POP.
6. Large demersals were unbalanced due to consumption of their juveniles and eelpouts by small demersals. The cannibalism in small demersals had to be reduced from 3.6% to 1%. I added the remaining 2.6% to import. In addition I reduced the consumption of juvenile large demersals by eelpouts from 2.3 to 0.1% and added 2.2% to import. This reduced the EE but not enough, and as the only other predator that caused this large imbalance is Stellers, I let Ecopath estimate the biomass (7.1 t·km^{-2}).
7. To balance Atka mackerel, I increased their P/Q to 0.3 and let Ecopath estimate a new annual P/B of 1.7, which reduced the EE to 1.6. I had to decrease the Atka mackerel in the diet of adult Steller sea lions from 42.7% to 20% and added 12.7% small pelagics and 10% sand lance. Similarly, I reduced the Atka mackerel in the diet of juvenile Steller sea lions from 32.7% to 20% and added 12.7% sand lance, which balanced the Atka mackerel.
8. Juvenile pollock was reduced in the diet of Atka mackerel from 6.1% to 4% and I added the 2.1% to import.
9. Sablefish was reduced in the diet of sharks and skates from 4.1% to 3% and I added 1.1% to the large pelagics, which increased their biomass to 0.12 t·km^{-2}.
10. To balance halibut, I let Ecopath estimate their biomass (0.47 t·km^{-2}) as the estimate I had is very uncertain.
11. I reduced the arrowtooth in the diet of adult Steller sea lions from 1% to 0.3% and add 0.2% to halibut and 0.5% to flatfish. Similarly, I reduced arrowtooth in the diet of juvenile Steller sea lions from 1.4% to 0.4% and add 1% to herring, which balanced the arrowtooth.
12. To balance the "large deep" group I let Ecopath estimate a biomass (0.53 t·km^{-2}) as I did not have a good estimate.
13. For myctophids I let Ecopath calculate the P/B (was 0.8 year^{-1}) by assuming a P/Q of 0.28, which calculated a P/B of 1.02 year^{-1}, similar to Guénette's (this volume), and then let Ecopath calculate a biomass of 7.4 t·km^{-2}.
14. The P/Q of benthic invertebrate feeders was increased to 0.2 and Ecopath estimated their P/B at 1.7 year^{-1} and their biomass at 62.5 t·km^{-2}.
15. The biomass of cephalopods was estimated to be rather high (6.0 t·km^{-2}), so I checked the P/B and Q/B estimates and decided to use the estimates from Aydin et al. (2003) instead, excluding the micronectonic squid from that estimate, which gives a P/B of 2.55 year^{-1} similar to Guénette (this volume), and a Q/B of 6.9 year^{-1}, which reduced the biomass to 4.7 t·km^{-2}. To reduce the biomass even further, I changed the diet of Atka mackerel that fed extensively on cephalopods from 10.4% to 1% and added an import of 9.4% to their consumption, assuming that they consumed large quantities of cephalopods from outside the system. This reduced the biomass to 3.3 t·km^{-2}.
16. To balance small and large zooplankton I changed their diets to that of the aggregated Gulf of Alaska model (Heymans, this volume). For large zooplankton the diet changed to 0.6% large zooplankton, 40% small zooplankton and 59.4% phytoplankton, and for small zooplankton the diet changed to 14.7% small zooplankton, 57.9% phytoplankton and 27.4% detritus. I also changed the P/B of small zooplankton to 36.3 year^{-1} (the average for copepods and microzooplankton from the NMFS data), and changed the Q/B of large zooplankton to be more similar to that of Guénette (this volume) and the Gulf of Alaska model (16.0 year^{-1}), which balanced the zooplankton.
17. The biomass of sharks and skates estimated in this model (1.2 t·km^{-2}) was much higher than the biomass estimated for the 1991 model (0.47 t km^{-2} see above), which is the opposite of what the trawl survey was showing (0.192 t·km^{-2},

see Figure 10 above). In 1980, the catch was very high and the biomass very low, thus I assumed that the P/B of 0.18 year^{-1} was too low, and estimated a new P/B by using a P/Q of 0.2 and the Q/B (2.5 year^{-1}) given by NMFS. I also reduced the shark and skates in the diet of adult Steller sea lions from 0.7% to 0.2% and assumed that the remaining 0.5% was imported, i.e. that Stellers consumed this outside the system. I then let Ecopath estimate a biomass of 0.4 t·km^{-2}. Similarly, the biomass of benthic invertebrates was much too high (74.4 t·km^{-2}), when the original estimate was 52.3 t·km^{-2}, thus I increased the P/Q to 0.25 and estimated a biomass of 59 t·km^{-2}. The balanced model is given in Table 40 and the balanced diet in Table A2.

Table 39. Input data for 1979 model, unbalanced parameters and biomass estimated by Ecopath are shown in bold.

#	Group	Biomass (t·km^{-2})	P/B (year^{-1})	Q/B (year^{-1})	EE	P/Q
1	Transient orca	0	0.025	7.510	0.000	0.003
2	Toothed whales	0.01	0.028	11.660	**1.841**	0.002
3	Baleen whales	0.153	0.020	6.700	0.532	0.003
4	SSL embryo	**0**	0.020	219.236	0.000	0.000
5	SSL pups	**0.003**	0.520	82.822	0.098	0.006
6	SSL juveniles	**0.042**	0.240	39.279	0.232	0.006
7	SSL adults	0.184	0.190	25.550	0.039	0.007
8	Small mammals	0.018	0.160	23.730	**2.354**	0.007
9	Sea otters	0.004	0.120	86.400	0.198	0.001
10	Birds	**0.002**	0.110	65.350	0.950	0.002
11	Shark mammal eater	**0.02**	0.100	3.000	0.950	**0.033**
12	Sharks and skates	**1.211**	0.180	2.500	0.950	**0.072**
13	Salmon	**1.041**	0.900	4.330	0.950	0.208
14	Large pelagics	**0.008**	0.220	1.470	0.950	0.150
15	Small pelagics	**2.472**	0.800	3.650	0.950	0.219
16	Atka mackerel	6.202	0.180	5.650	**4.228**	**0.032**
17	Sand lance	**0.31**	0.800	3.650	0.950	0.219
18	Herring	**2.919**	0.160	0.970	0.950	0.165
19	pollock juveniles	1.212	1.992	9.418	**1.066**	0.212
20	pollock adult	4.5	0.366	3.650	0.443	**0.100**
21	POP	0.168	0.110	1.800	**6.175**	**0.061**
22	Rockfish	0.376	0.100	2.000	**5.098**	**0.050**
23	Sablefish	0.685	0.190	1.030	1.309	0.184
24	Pacific cod	1.017	0.410	2.280	**1.431**	0.180
25	Halibut	0.289	0.190	2.010	1.538	**0.095**
26	Arrowtooth	0.516	0.180	2.610	**2.527**	**0.069**
27	Flatfish	1.264	0.190	1.720	**1.766**	0.110
28	Small demersals	**5.16**	0.600	3.000	0.950	0.200
29	Large demersals	0.591	0.400	2.000	**4.301**	0.200
30	Large deep	0.38	0.150	2.000	**2.309**	**0.075**
31	Myctophids	4.043	0.800	3.650	**1.771**	0.219
32	Shrimps	**2.828**	2.040	10.200	0.950	0.200
33	Benthic invertebrates	52.263	1.320	8.430	**0.670**	0.157
34	Epibenthic carnivores	**4.136**	1.280	5.000	0.950	0.256
35	Cephalopods	0.302	2.000	7.160	**11.257**	0.279
36	Large zooplankton	30.6	5.870	37.940	**1.145**	0.155
37	Small zooplankton	19.4	23.730	112.420	**2.402**	0.211
38	Phytoplankton	17.186	129.555	-	0.803	-
39	Marine plants	**1.609**	8.120	-	0.950	-
40	Detritus	-	-	-	**1.347**	-

Table 40. Balanced model for 1979 model. Values in bold were estimated by Ecopath.

#	Group	**Biomass (t·km^{-2})**	**P/B (year^{-1})**	**Q/B (year^{-1})**	**EE**	**P/Q**
1	Transient orca	0	0.025	7.510	**0.000**	**0.003**
2	Toothed whales	0.01	0.028	11.660	**0.852**	**0.002**
3	Baleen whales	0.153	0.043	6.700	**0.115**	**0.006**
4	SSL embryo	**0**	0.020	219.761	**0.000**	**0.000**
5	SSL pups	**0.003**	0.510	82.969	**0.047**	**0.006**
6	SSL juveniles	**0.039**	0.240	39.373	**0.100**	**0.006**
7	SSL adults	0.184	0.180	25.500	**0.041**	**0.007**
8	Small mammals	**0.043**	0.160	23.730	0.500	**0.007**
9	Sea otters	0.004	0.120	86.400	**0.198**	**0.001**
10	Birds	**0.001**	0.110	65.350	0.950	**0.002**
11	Shark mammal eater	**0.02**	0.100	**1.000**	0.950	0.100
12	Sharks and skates	**0.271**	**0.500**	2.500	0.950	0.200
13	Salmon	**0.917**	0.900	4.330	0.950	**0.208**
14	Large pelagics	**0.039**	0.220	1.470	0.950	**0.150**
15	Small pelagics	**2.592**	0.800	3.650	0.950	**0.219**
16	Atka mackerel	6.202	**1.695**	5.650	**0.331**	0.300
17	Sand lance	**1.368**	0.800	3.650	0.950	**0.219**
18	Herring	**2.698**	0.160	0.970	0.950	**0.165**
19	pollock juveniles	1.212	1.992	**9.418**	**0.733**	**0.212**
20	pollock adult	4.5	0.366	3.650	**0.399**	**0.100**
21	POP	0.168	0.750	2.550	**0.807**	**0.294**
22	Rockfish	**0.474**	**0.400**	2.000	0.950	0.200
23	Sablefish	0.685	0.190	1.030	**0.500**	**0.184**
24	Pacific cod	**0.628**	**0.456**	2.280	0.950	0.200
25	Halibut	**0.158**	**0.402**	2.010	0.950	0.200
26	Arrowtooth	0.516	**0.522**	2.610	**0.542**	0.200
27	Flatfish	**1.116**	**0.344**	1.720	0.950	0.200
28	Small demersals	**4.085**	0.600	3.000	0.950	**0.200**
29	Large demersals	**1.855**	0.400	2.000	0.950	**0.200**
30	Large deep	**0.245**	**0.400**	2.000	0.950	0.200
31	Myctophids	**6.107**	**1.022**	3.650	0.950	0.280
32	Shrimps	**2.458**	2.040	10.200	0.950	**0.200**
33	Benthic invertebrates	23.436	**2.108**	8.430	0.950	0.250
34	Epibenthic carnivores	**5.475**	1.280	5.000	0.950	**0.256**
35	Cephalopods	**1.254**	2.550	6.900	0.950	**0.370**
36	Large zooplankton	30.6	5.870	16.000	**0.431**	**0.367**
37	Small zooplankton	19.4	36.30	112.420	**0.767**	**0.323**
38	Phytoplankton	17.186	129.555	-	**0.698**	-
39	Marine plants	**1.158**	8.120	-	0.950	-
40	Detritus	-	-	-	**0.512**	-

1963 model

The unbalanced 1963 model is given in Table 41 in conjunction with the diets and catches given in the model description above. The P/Q's of all species should be between 0.1 and 0.3. I added a P/Q of 0.2 for mammal eating sharks, sharks and skates and Atka mackerel, and let Ecopath estimate their Q/B ratios. Similarly, I changed the P/Q of halibut and deep demersals to 0.15 and 0.2, respectively and let Ecopath estimate their P/B's as no estimates of fishing mortalities were available for these groups. For rockfish, I added a P/Q of 0.1 and let Ecopath estimate their Q/B.

1. To balance juvenile pollock, I changed the annual Q/B of adult pollock from the 3.65 given by NMFS, to 2.0 as the P/Q ratios of both adult and juvenile pollock were too low. These changes and those to Atka mackerel Q/B reduced the EE of juvenile pollock to 1.8. The diet of Atka mackerel contained only juvenile pollock, but as the breakdown between juvenile and adult pollock was at 25 months, I added 4.1% adult pollock and reduced the juvenile pollock in their diet to 2%. This balanced the juvenile pollock.
2. To balance toothed whales, I added a negative biomass accumulation rate of -0.01 year^{-1}, as their fishing mortality rate was higher than production in the early 1960s.

3. To balance phytoplankton I reduced the annual P/B of large zooplankton from 37.9 to 16 to be similar to the Gulf of Alaska and Southeast Alaska models. I also changed the diet of large and small zooplankton to be similar to that of the aggregated Gulf of Alaska model (Heymans, this volume). For large zooplankton the diet changed to 0.6% large zooplankton, 40% small zooplankton and 59.4% phytoplankton, and for small zooplankton the diet changed to 10% small zooplankton, 65% phytoplankton and 25% detritus.
4. The benthic invertebrate feeder P/Q (0.15) was very low, thus I let Ecopath estimate a P/B and assumed a P/Q of 0.3, which estimated a P/B of 2.5 year^{-1} and reduced the biomass of that group.

Table 41. Input data for 1963 model, unbalanced parameters and those estimated by Ecopath shown in bold.

#	Group	Biomass ($t \cdot km^{-2}$)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	P/Q
1	Transient orca	0	0.025	10.830	0.000	0.002
2	Toothed whales	0.013	0.036	11.073	**1.247**	0.003
3	Baleen whales	0.145	0.099	6.990	0.472	0.014
4	SSL embryo	**0**	0.020	220.786	0.000	0.000
5	SSL pups	**0.002**	0.521	83.413	0.040	0.006
6	SSL juveniles	**0.03**	0.241	39.562	0.079	0.006
7	SSL adults	0.148	0.174	25.550	0.045	0.007
8	Small mammals	0.022	0.150	22.741	**1.007**	0.007
9	Sea otters	0.004	0.117	86.400	0.296	0.001
10	Birds	**0**	0.113	65.350	0.950	0.002
11	Shark mammal eater	**0.002**	0.125	3.000	0.950	**0.042**
12	Sharks and skates	**0.351**	0.159	2.500	0.950	**0.064**
13	Salmon	**0.562**	1.168	4.330	0.950	0.270
14	Large pelagics	**0.001**	0.220	1.470	0.950	0.150
15	Small pelagics	**48.06**	0.800	3.650	0.950	0.219
16	Atka mackerel	**13.004**	0.340	5.650	0.950	**0.060**
17	Sand lance	**6.482**	0.800	3.650	0.950	0.219
18	Herring	**2.241**	0.160	0.970	0.950	0.165
19	pollock juveniles	0.674	1.200	8.541	**5.963**	0.141
20	pollock adult	6.078	0.304	3.650	0.283	0.083
21	POP	1.109	0.078	1.800	0.559	0.043
22	Rockfish	**1.138**	0.100	2.000	0.950	**0.050**
23	Sablefish	0.932	0.113	1.030	0.642	0.110
24	Pacific cod	**1.116**	0.370	2.280	0.950	0.162
25	Halibut	**0.149**	0.190	2.010	0.950	**0.095**
26	Arrowtooth	**0.244**	0.300	2.610	0.950	0.115
27	Flatfish	**1.174**	0.188	1.720	0.950	0.109
28	Small demersals	**4.31**	0.600	3.000	0.950	0.200
29	Large demersals	**2.702**	0.400	2.000	0.950	0.200
30	Large deep	**0.667**	0.150	2.000	0.950	**0.075**
31	Myctophids	**22.141**	0.800	3.650	0.950	0.219
32	Shrimps	**5.539**	2.040	10.200	0.950	0.200
33	Benthic invertebrates	**201.706**	1.317	8.430	0.950	0.156
34	Epibenthic carnivores	**43.793**	1.283	5.000	0.950	0.257
35	Cephalopods	**26.652**	0.410	7.160	0.950	**0.057**
36	Large zooplankton	**447.82**	5.870	37.940	0.950	0.155
37	Small zooplankton	**469.882**	23.730	112.420	0.950	0.211
38	Phytoplankton	17.186	129.555	-	**21.168**	-
39	Marine plants	**9.463**	8.120	-	0.950	-
40	Detritus	-	-	-	0.000	-

FITTING TO TIME SERIES DATA

The balanced 1963 model was then fitted to time series data. To fit the model, I changed the w_{max}/w_{inf} ratio for Steller sea lions, as it did not give a flatline in the first run of Ecosim. This does not seem to work for mammals, and I reduced the ratio to very small (0.00001), to be close to zero. Additionally, the feeding time adjustment rates for transient orcas, toothed whales, baleen whales and Steller sea lion adults and juveniles were set to 0.5, while for all other groups the parameter was set to 0.

The model was driven by fishing mortalities where available, and forced to fit to the catch and biomass time series as given in the model description above. Where no time series information on biomass or fishing mortality was available the catches were used to force the model (similar to a simple stock reduction model). This was the case for toothed whales, mammal eating sharks, salmon, Atka mackerel (prior to 1977), pollock (< 1978), rockfish (< 1983), Pacific cod (< 1980), halibut (< 1983), arrowtooth flounder (< 1976), flatfish (< 1983), large demersals (< 1983), shrimp, crab and cephalopods (< 1983).

To fit the data, I changed the diet of mammal eating sharks to include 8% cannibalism, and decreased their consumption of small mammals to 0.4%. I also had to assume a biomass of 0.05 $t \cdot km^{-2}$ to fit the catch time series, as I had large bycatch by trawlers from 1964 to 1977. This caused the toothed whales to become unbalanced, but I increased their negative biomass accumulation rate to -0.025% to balance them. To fit the sharks and skate catch series, I assumed a biomass of 2.6 $t \cdot km^{-2}$, which unbalanced the sablefish. The biomass of sablefish calculated for 1963 (0.93 $t \cdot km^{-2}$) was nearly half that of 1964 (1.8 $t \cdot km^{-2}$), thus the 1964 value was used instead and a negative biomass accumulation of - 0.02 $year^{-1}$ was added.

To fit the catch of flatfish, I had to increase their biomass by reducing their EE to 0.5, to estimate a higher initial biomass in the Ecopath model. Similarly, I had to increase the biomass of salmon by assuming an EE of 0.5. I was unable to fit the catch of large demersals. The F series I obtained for large demersal predators were only for sculpins, and as the biomass of sculpins were not well estimated, I decided to force the catch for the whole time series for this group.

Similarly, to fit the catch of cephalopods, it was obvious that the biomass of this group was too high due to the much lower P/B (0.41 $year^{-1}$) I had assumed from the natural mortality of some squid species. By contrast, the average P/B for squids given by Aydin et al. (2003) was 2.94 $year^{-1}$, which fitted the catch better. However, similar to large demersals, the trawl surveys used for the calculation of biomass of cephalopods was very uncertain, as the survey method and depth changed in 1980. I therefore decided to force the catch of cephalopods for the whole time series.

To fit halibut, a biomass accumulation of 0.03 $year^{-1}$ was added, while the P/B of 0.19 $year^{-1}$ was used and the Q/B ratio was estimated using a P/Q ratio of 0.15. Similarly, for arrowtooth flounder, a P/Q of 0.15 was used to estimate their Q/B ratio. It was also necessary to assume a biomass 0.5 $t \cdot km^{-2}$ to fit arrowtooth, which was higher than the 0.3 $t \cdot km^{-2}$ estimated using an EE ratio of 0.95.

As the biomass of Atka mackerel was estimated by the model it increased every time a change was made, and as it was an important predator and prey in this system, the biomass of Atka mackerel was therefore assumed to be 13.5 $t \cdot km^{-2}$, rather than having it estimated. However, this unbalanced the juvenile pollock, which was then balanced by assuming that they contributed 1% to the diet of Atka mackerel and the contribution of adult pollock was increased to 5.1%.

To fit baleen whale and small mammal data, biomass accumulations of -0.02 $year^{-1}$ and -0.01 $year^{-1}$ were added to those groups respectively. In addition, the P/B of small mammals was much lower than that given for the Southeast Alaska model, because I used a P/B ratio for harbour seals of 0.08 $year^{-1}$ (obtained from NMFS). The P/B ratio used by Guénette (this volume) for harbour seals was 0.23 $year^{-1}$, thus the P/B for small mammals was increased to 0.2 $year^{-1}$ which fitted the small mammal biomass data.

Finally, the diet of orcas that was used for all the models included only 16% Steller sea lions in their diet, but to fit Steller sea lions better, the diet was increased to include 10% pups, 40% juveniles and 30% adult Steller sea lions, 15% small mammals, 3% sea otters and 1% birds.

The model was fitted to time series by changing the vulnerabilities of transient orcas, toothed and baleen whales, adult and juvenile Steller sea lions, small mammals, mammal eating sharks, sharks and skates, salmon, Atka mackerel, herring, adult pollock, POP, rockfish, sablefish, Pacific cod, halibut and arrowtooth. The fitting algorithm fitted the model to only the biomass of toothed and baleen whales, Steller sea lion adults, small mammals, otters, sharks and skates, salmon, Atka mackerel, pollock, POP, rockfish, sablefish, Pacific cod, halibut and arrowtooth.

The balanced and fitted model is given in Table 42, the diet in Table A3 and the fits of the catch and biomass time series to the model in Figures 25 and 26. A forcing function (Figure 27) and vulnerabilities (Table 43) were estimated to fit the data using 40 spline points. The environmental forcing function (Figure 27) was compared to the Pacific Decadal Oscillation, a long-lived El Niño–Southern Oscillation (ENSO)-like pattern of Pacific climate variability (Hare and Mantua 2000). The PDO is defined as the leading principal component of monthly SST anomalies in the North Pacific Ocean, poleward of 20˚N. The monthly mean global SST anomalies were removed to separate this pattern of variability from any "global warming" signal that may be present in the data (Mantua et al. 1997) (http://www.iphc.washington. edu /Staff/hare/html/decadal/post1977/pdo1.html).

Table 42. Balanced and fitted model for 1963. Values in bold were estimated by Ecopath.

#	**Group**	**Biomass (t·km^{-2})**	**P/B (year^{-1})**	**Q/B (year^{-1})**	**EE**	**P/Q**	**BA (year^{-1})**
1	Transient orca	0	0.025	10.830	**0.000**	**0.002**	
2	Toothed whales	0.013	0.036	11.073	**0.947**	**0.003**	-0.03
3	Baleen whales	0.145	0.099	6.990	**0.310**	**0.014**	-0.02
4	SSL embryo	**0**	0.020	220.786	**0.000**	**0.000**	
5	SSL pups	**0.002**	0.521	83.413	**0.368**	**0.006**	
6	SSL juveniles	**0.03**	0.241	39.562	**0.345**	**0.006**	
7	SSL adults	0.148	0.174	25.550	**0.075**	**0.007**	
8	Small mammals	0.022	0.200	22.741	**0.177**	**0.009**	-0.01
9	Sea otters	0.004	0.117	86.400	**0.227**	**0.001**	
10	Birds	**0.001**	0.113	65.350	0.950	**0.002**	
11	Shark mammal eater	0.05	0.125	**0.625**	**0.431**	0.200	
12	Sharks and skates	2.6	0.159	**0.795**	**0.147**	0.200	
13	Salmon	**1.161**	1.168	4.330	0.500	**0.270**	
14	Large pelagics	**0.004**	0.220	1.470	0.950	**0.150**	
15	Small pelagics	**2.715**	0.800	3.650	0.950	**0.219**	
16	Atka mackerel	13.5	0.340	**1.700**	**0.997**	0.200	
17	Sand lance	**0.774**	0.800	3.650	0.950	**0.219**	
18	Herring	**2.765**	0.160	0.970	0.950	**0.165**	
19	pollock juveniles	0.674	1.200	4.680	**0.781**	**0.256**	
20	pollock adult	6.078	0.304	2.000	**0.997**	**0.152**	
21	POP	1.109	0.078	1.800	**0.824**	**0.043**	
22	Rockfish	**1.231**	**0.100**	**1.000**	0.950	0.100	
23	Sablefish	1.8	**0.113**	1.030	**0.458**	**0.110**	-0.02
24	Pacific cod	2.4	0.370	2.280	**0.549**	**0.162**	0.03
25	Halibut	**0.372**	**0.190**	1.267	0.950	0.150	0.03
26	Arrowtooth	**0.5**	0.300	2.000	**0.603**	**0.150**	
27	Flatfish	**2.827**	0.188	1.720	0.500	**0.109**	
28	Small demersals	**5.07**	0.600	3.000	0.950	**0.200**	
29	Large demersals	**3.259**	0.400	2.000	0.950	**0.200**	
30	Large deep	**0.494**	**0.400**	2.000	0.950	0.200	
31	Myctophids	**7.641**	0.800	3.650	0.950	**0.219**	
32	Shrimps	**3.228**	2.040	10.200	0.950	**0.200**	
33	Benthic invertebrates	**26.208**	**2.529**	8.430	0.950	0.300	
34	Epibenthic carnivores	**8.105**	1.283	5.000	0.950	**0.257**	
35	Cephalopods	**2.09**	2.940	7.160	0.950	**0.411**	
36	Large zooplankton	**14.127**	5.870	16.000	0.950	**0.367**	
37	Small zooplankton	**9.517**	23.730	112.420	0.950	**0.211**	
38	Phytoplankton	17.186	129.555	-	**0.373**	-	
39	Marine plants	**1.368**	8.120	-	0.950	-	
40	Detritus	1	-	-	**0.283**	-	

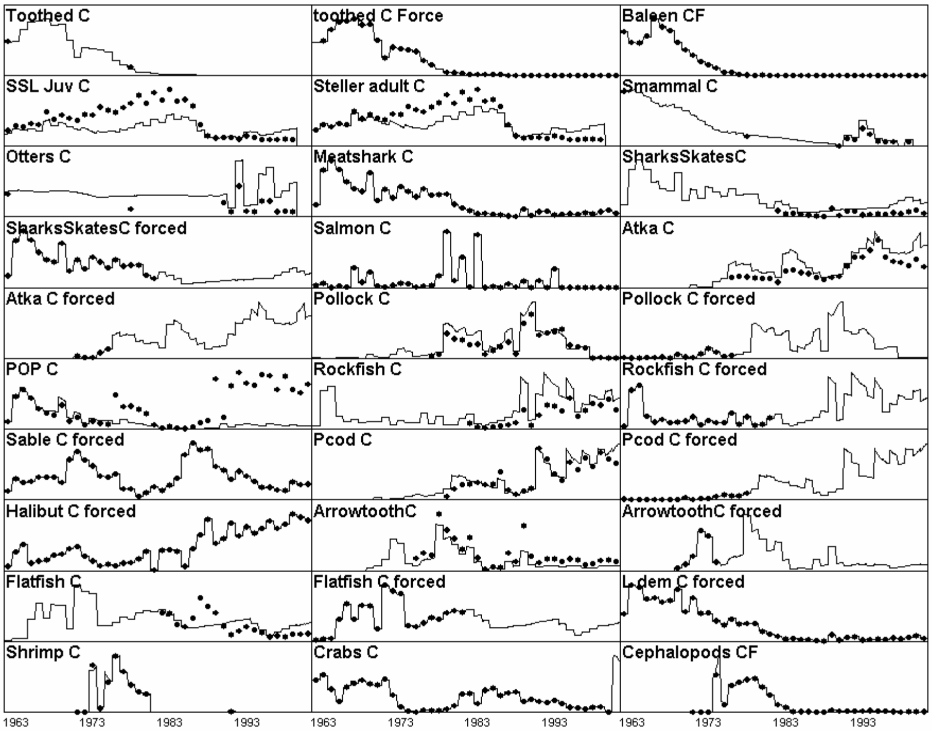


Figure 25. Fit of catch estimates (dots) to the model predictions (lines). Graphs with headings C forced indicate where the model was forced to fit the catches.

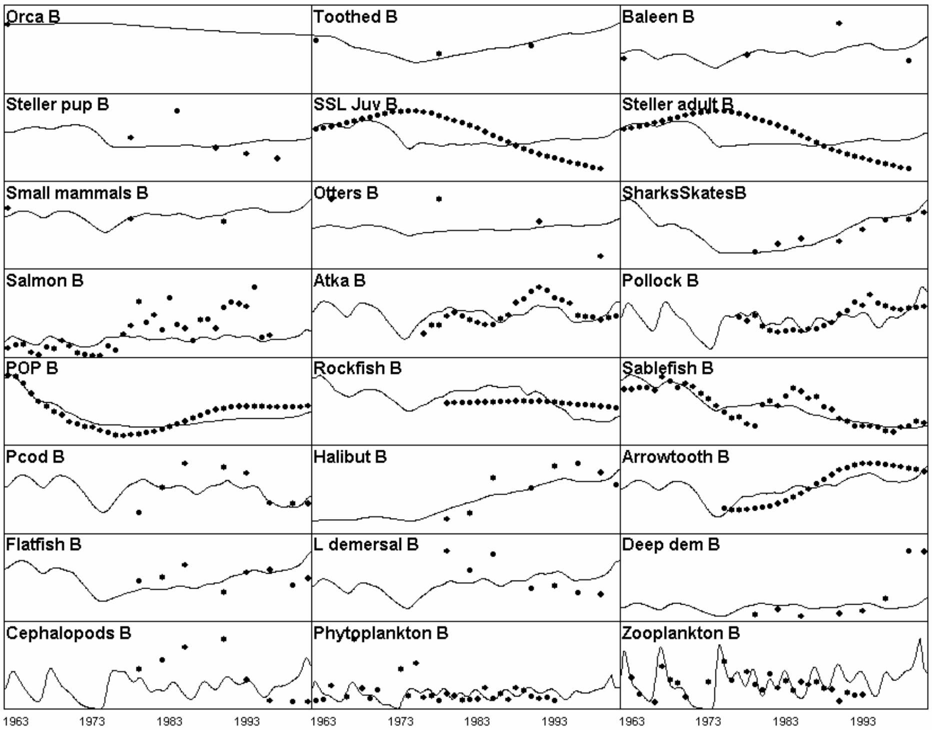


Figure 26. Fit of biomass estimates (dots) to the model predictions (lines).

FUTURE WORK

The large drop in Steller sea lion biomass (Figure 26) around 1973 was probably due to the large drop in Atka mackerel biomass at that time. The biomass of Atka mackerel should be constrained in the model, as no data were available to do so, and there were no data pointing to such a large biomass of Atka mackerel in 1963 (Table 42). The large Atka mackerel biomass estimated by Ecopath was caused by the diet of Steller sea lions which contained 42.7% Atka mackerel. This diet was obtained from Sinclair and Zeppelin (2002), but was really mainly for the 1990s. Fiscus and Baines (1966) found that diet of Steller sea lions in the Eastern Aleutians in 1962 consisted mostly of capelin and other small schooling fish, as well as sand lance, sculpins, rockfishes and flatfishes. Similarly, Thorsteinson and Lensink (1962) found that the main species of importance in the Eastern Aleutians and Western Gulf of Alaska in 1959 were cephalopods, sand lance and clams, snails or mussels, rockfish and crabs. Even though these diets do not represent the Central and Western Aleutians it could be used as an indication of the change in diet that might have occurred since the early 1960s. It would therefore be important to test what difference a decrease the proportion of Atka mackerel in the diet of Steller sea lions and increase small pelagics, sand lance and herring would make to the model predictions.

Table 43. Vulnerabilities (Vuln) of predators on prey used to fit the model.

#	Group	Vuln.
1	Transient orca	>100
2	Toothed whales	1.09
3	Baleen whales	1
6	SSL juveniles	5
7	SSL Adults	25
8	Small mammals	1
9	Sea otters	1
11	Mammal eating sharks	1
12	Shark and skates	1.52
13	Salmon	1
16	Atka mackerel	1.1
19	Juvenile Pollock	2
20	Adult Pollock	1
21	POP	5
22	Rockfish	1
23	Sablefish	>100
24	Pacific cod	1
25	Halibut	25
26	Arrowtooth	1

In addition, estimates of transient killer whales obtained from Springer et al. (2003) suggested that there were 3,888 killer whales in an area of 1,080,000 km^2 surrounding the Aleutian Islands, and that 7% (or 14 in the area of our model) of these killer whales were transients, thus estimating a biomass of 0.0006 t·km^{-2}, which is double the present estimate. This needs to be incorporated if the effects of killer whale predation are to be taken into consideration.

Finally, the estimated forcing function does not fit the PDO, but is actually more similar to its inverse. It would be useful to look at the correlation of the forcing function with the inverse of the PDO and to examine if the model fits better when the inverse of the PDO is used as a forcing variable.

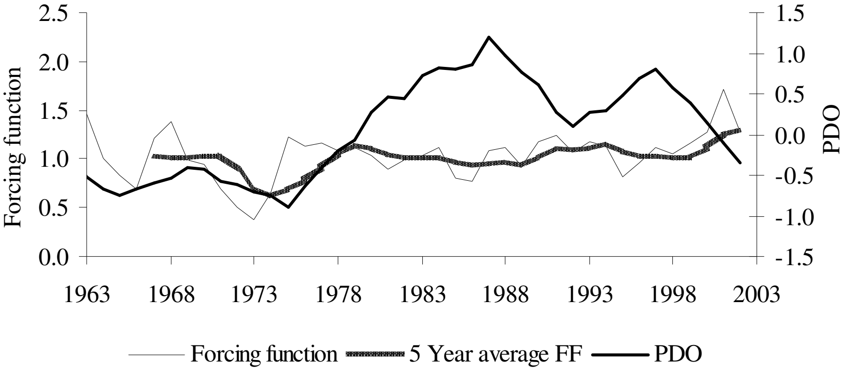


Figure 27. Forcing function and five year running average of the forcing function (FF) estimated to fit the 1963 model to time series data and for comparison the 5 year running average of the Pacific Decadal Oscillation (PDO).

ACKNOWLEDGEMENTS

This report was prepared under Award Number NA16FX0124/NA16FX2629 from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, through the North Pacific Universities Marine Mammal Research Consortium and the North Pacific Marine Science Foundation. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration or the Department of Commerce. I want to acknowledge and thank Sylvie Guénette, Villy Christensen, Kerim Aydin, Sarah Gaishas, Ivonne Ortiz, Andrew Trites and Carl Walters for their help with the construction and collection of data for these models. In addition, data were obtained from the National Marine Fisheries Service (NOAA) in Seattle, the Alaska Department of Fish and Game, the North Pacific Marine Mammal Consortium and the USGS.

REFERENCES

Abegglen, C. E., 1977. Sea mammals: Resources and population. *In*: The Environment of Amchitka Island, Alaska. *Edited by* M. L. Merritt and R. G. Fuller, Energy Research and Development Administration. Division of Military Application, Springfield, Va. pp. 493-510.

Alverson, D. L. 1992. A review of commercial fisheries and the Steller sea lion (*Eumetopias jubatus*): The conflict arena. Reviews in Aquatic Sciences, 6(3-4):203-256.

Anderson, G. C., Lam, R. K., Booth, B. C., and Glass, J. M., 1977. A description and numerical analysis of the factors affecting the processes of production in the Gulf of Alaska. *In*: Environmental Asssessment of the Alaskan Continental Shelf. Annual Reports of Principal Investigators for the year ending March 1977, NOAA Special Report No. 76. University of Washington, Seattle, Wa. Vol. VII. Receptors - Fish, Littoral, Benthos pp. 477-798.

Anderson, P. J., and Blackburn, J. E., 2002. Status of demersal and epibenthic species in the Kodiak Island and Gulf of Alaska region. *In*: Steller Sea Lion Decline: Is It Food II. *Edited by* D. P. DeMaster and S. Atkinson, University of Alaska Sea Grant College Program AK-SG-02-02, Fairbanks Alaska. pp. 57-60.

Andrews, R. D., Calkins, D. G., Davis, R. W., Norcross, B. L., Peijnenberg, K., and Trites, A., 2002. Foraging behavior and energetics of adult female Steller sea lions. *In*: Steller Sea Lion Decline: Is It Food II. *Edited by* D. P. DeMaster and S. Atkinson, University of Alaska Sea Grant College Program AK-SG-02-02, Fairbanks Alaska. pp. 19-22.

Angliss, R. P., and Lodge, K. L., 2002. Alaska marine mammal stock assessments. NMFS Department of Commerce, NOAA Technical Memorandum, NMFS-AFSC-133. 119 pp.

Anonymous, 2001. Alaska Groundfish Fisheries: Draft programmatic supplemental environmental impact statement. US. Dep. of Commerce, NOAA, National Marine Fisheries Service, Alaska Region, Juneau, Alaska.

Aydin, K. Y., McFarlane, G. A., King, J. R., and Megrey, B. A., 2003. PICES-GLOBEC International program on climate change and carrying capacity. The BASS/MODEL report on trophic models of the Subarctic Pacific Basin Ecosystems. North Pacific Marine Science Organization, Sidney BC, PICES Scientific Report, 25. 93 pp.

Baba, N., Kiyota, M., Hatanaka, H., and Nitta, A. 1993. Biological information and mortality of northern fur seals (*Callorhinus ursinus*) by the high seas Japanese squid driftnet fishery. International North Pacific Fisheries Commission Bulletin, 53(III):461-471.

Barbeaux, S., Ianelli, J., and Brown, E., 2003. Aleutian Islands walleye pollock SAFE: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, AK, NPFMC Bering Sea/Aleutian Island SAFE, 839-888 pp.

Barrett-Lennard, L. G., Heise, K., Saulitis, E., Ellis, G. M., and Matkin, C., 1994. The impact of killer whale predation on Steller sea lion populations in British Columbia and Alaska. North Pacific Universities Marine Mammal Research Consortium, Fisheries Centre UBC, Vancouver, BC, 66 pp.

Berger, J. D., Smoker, J. E., and King, K. A., 1986. Foreign and joint venture catches and allocations in the Pacific Northwest and Alaska fishing area under the Magnuson Fishery Conservation and Management Act, 1977-84. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-F/NWC-99. 53 pp.

Bowers, F. R., Soong, J., Granath, K., Cavin, M., and Lillo, C., 2003. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands. Dutch Harbor.

Brueggeman, J. J., Green, G. A., Grotefendt, R. A., and Chapman, D. G., 1987. Aerial surveys of endangered cetaceans and other marine mammals in the Northwestern Gulf of Alaska and Southeasterns Bering Sea. OCSEAP Research Unit 673, Contract No. 85-ABC-00093.

Buckland, S. T., Cattanach, K. L., and Hobbs, R. C. 1993. Abundance estimates of Pacific white-sided dolphin, northern right whale dolphin, Dall's porpoise and northern fur seal in the North Pacific, 1987-1990. International North Pacific Fisheries Commission Bulletin, 53(III):387-407.

Burns, J. J., 2002. Harbor seal and spotted seal - *Phoca vitulina* and *P. largha*. *In*: Encyclopedia of Marine Mammals. *Edited by* W. F. Perrin, B. Würsig, and J. G. M. Thewissen, Academic Press, pp. 552-560.

Byerly, M., Brooks, B., Simonson, B., Savikko, H. M., and Geiger, H. J., 1999. Alaska commercial salmon catches, 1878 - 1997. Alaska Department of Fish & Game, Division of Commercial Fisheries, Juneau, Regional Information Report, 5J99-05.

Calkins, D. G., 1987. Marine mammals. *In*: The Gulf of Alaska: Physical Environment and Biological Resources. *Edited by* D. W. Hood and S. T. Zimmerman, US Government Printing Office, Washington DC. pp. 527-558.

Clark, W. G. 1999. Effects of an erroneous natural mortality rate on a simple age-structured stock assessment. Canadian Journal of Fisheries and Aquatic Sciences, 56:1721-1731.

Clark, W. G., and Hare, S. R., 2003. Assessment of the Pacific halibut stock at the end of 2003. Pacific Halibut Commission.

Dorn, M., Barbeaux, S., Guttormsen, M., Megrey, B., Hollowed, A., Wilkins, M., and Spalinger, K., 2003. Assessment of walleye pollock in the Gulf of Alaska. North Pacific Fishery Management Council, Anchorage, AK, NPFMC Bering Sea/Aleutian Island SAFE, 33-148 pp.

Doroff, A. M., Estes, J. A., Tinker, M. T., Burn, D. M., and Evans, T. J. 2003. Sea otter population declines in the Aleutian archipelago. Journal of Mammalogy, 84(1):55-64.

Duesterloh, S., and Burkey, C. J., 2003. Alaska peninsula - Aleutian islands management area herring sac roe and food and bait fisheries annual management report, 2003. Alaska Department of Fish and Game, Kodiak, Alaska, Regional Information Report, 4K03-63. 58 pp.

Estes, J. A. 1980. *Enhydra lutris*. Mammalian Species, 133:1-8.

Estes, J. A. 1990. Growth and equilibrium in sea otter populations. Journal of Animal Ecology, 59:385-401.

Estes, J. A., and Duggins, D. O. 1995. Sea otters and kelp forests in Alaska: generality and variation in a community ecological paradigm. Ecological Monographs, 65(1):75-100.

Estes, J. A., Smith, N. S., and Palmisano, J. F. 1978. Sea Otter predation and community organization in the Western Aleutian Islands, Alaska. Ecology, 59(4):822-833.

Estes, J. A., Jameson, R. J., and Johnson, A. M., 1981. Food selection and some foraging tactics of sea otters. *In*: Worldwide Furbearer Conference, *Edited by* J. A. Chapman and D. Pursley, Frostburg, MD, 3-11 August, 1980, The Worldwide Furbearer Conference, Inc. pp. 606-641.

Estes, J. A., Tinker, M. T., Williams, T. M., and Doak, D. F. 1998. Killer whale predation on sea otters linking oceanic and nearshore ecosystems. Science, 282:473-476.

Fiscus, C. H., and Baines, G. A. 1966. Food and feeding behavior of Steller and California sea lions. Journal of Mammalogy, 47(2):195-200.

Fiscus, C. H., and Mercer, R. W., 1982. Squids taken in surface gillnets in the North Pacific Ocean by the Pacific Salmon Investigations Program, 1955-1972. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS F/NWC-28. 32 pp.

Fiscus, C. H., Rugh, D. J., and Loughlin, T. R., 1981. Cencus fo northern sea lion (*Eumetopias jubatus*) in central Aleutian Islands, Alaska, 17 June - 15 July 1979. With notes on other marine mammals and birds. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS F/NWC-17. 109 pp.

Ford, M. T., and Ellis, G. M., 1999. Transients: Mammal-hunting killer whales of British Columbia, Washington, and Southeastern Alaska. UBC Press, Vancouver. 96 pp.

Ford, M. T., Ellis, G. M., Barrett-Lennard, L. G., Morton, A. B., Palm, R. S., and Balcomb, K. C. I. 1998. Dietary specialization in two sympatric populations of killer whales (*Orcinus orca*) in coastal British Columbia and adjacent waters. Canadian Journal of Zoology, 76:1456-1471.

Forrester, C. R., Beardsley, A. J., and Takahaski, Y., 1978. Groundfish, shrimp, and herring fisheries in the Bering Sea and Northeast Pacific - Historical catch statistics through 1970. International North Pacific Fisheries Commission, Vancouver, Canada, INPRC Bulletin, 37. 100 pp.

Forrester, C. R., Bakkala, R. G., Okada, K., and Smith, J. E., 1983. Groundfish, shrimp, and herring fisheries in the Bering Sea and Northeast Pacific - Historical catch statistics, 1971-1976. International North Pacific Fisheries Commission, Vancouver, Canada, INPRC Bulletin, 41. 100 pp.

Gaichas, S., 2002. Summary of changes in the Bering Sea-Aleutian Islands squid and other species assessment. NMFS, Stock assessment report, 32 pp.

Gaichas, S., 2003. Summary of changes in the Bering Sea-Aleutian Islands squid and other species assessment: Stock assessment and fishery evaluation report for the Groundfish Resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, AK, NPFMC Bering Sea/Aleutian Island SAFE, 777-808 pp.

Gosho, M. E., and Rice, D. W. 1984. The sperm whale, *Physeter macrocephalus*. Marine Fisheries Review, 46(4):54-64.

Hare, S. R., and Mantua, N. J. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Progress in Oceanography, 47:103-145.

Hare, S. R., Williams, G. H., and Chen, D., 2003. Bycatch mortality and size distribution extrapolation methodology. International Pacific Halibut Commission, 1-18 pp.

Heard, B., Helle, J., Koshi, K., Lorenz, M., Murphy, M., Taylor, J., and Wertheimer, A., 1998. Essential fish habitat assessment report for the Salmon Fisheries in the EEZ off the Coast of Alaska. Alaska Department of Fish & Game, NMFS, North Pacific Fishery Management Council, Anchorage, AK, 1-64 pp.

Heifetz, J. 2000. Coral in Alaska: Distribution, abundance, and species associations. Proceedings of the Nova Scotia Institute:1-9.

Heise, K., Barrett-Lennard, L. G., Saulitis, E., Matkin, C., and Bain, D. 2003. Examining the evidence for killer whale predation on Steller sea lions in British Columbia and Alaska. Aquatic Mammals, 29(3):325-334.

Hirons, A. C., 2001. Trophic dynamics of pinniped populations in Alaska using stable carbon and nitrogen isotope ratios. PhD thesis, University of Alaska, Fairbanks, Alaska, 143 pp.

Huato, L., 1996. Salmon in the ocean (in the Alaska Gyre). *In*: Mass-Balance Models of North-eastern Pacific ecosystems, *Edited by* D. Pauly, V. Christensen, and N. Haggan, University of British Columbia, Fisheries Centre. Vol. 4 (1) 129 pp. pp. 21-23.

Hulbert, L., Sigler, M. F., and Lunsford, C. R., 2002. Pacific sleeper shark predation on Steller sea lions. *In*: Steller Sea Lion Decline: Is It Food II. *Edited by* D. P. DeMaster and S. Atkinson, University of Alaska Sea Grant College Program AK-SG-02-02, Fairbanks Alaska. pp. 67-69.

Hunt, G. L. J., Kato, H., and McKinnell, S. M., 2000. Predation by marine birds and mammals in the subarctic North Pacific Ocean. North Pacific Marine Science Organization, Sidney, BC, PICES Scientific Report, 14. 168 pp.

Ianelli, J., Barbeaux, S., Walters, G. E., and Williamson, N., 2003a. Eastern Bering Sea walleye pollock stock assessment. NMFS, 1-88 pp.

Ianelli, J. N., Wilderbuer, T. K., and Sample, T. M., 2003b. Assessment of Greenland turbot in the Eastern Bering Sea and Aleutian Islands: Stock assessment and fishery evaluation report for the Groundfish Resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, AK, NPFMC Bering Sea/Aleutian Island SAFE, 339-366 pp.

Innes, S., Lavigne, D. M., Earle, W. M., and Kovacs, K. M. 1987. Feeding rates of seals and whales. Journal of Animal Ecology, 56:115-130.

Kajimura, H., 1984. Opportunistic feeding of the northern fur seal, *Callorhinus ursinus*, in the Eastern North Pacific Ocean and Eastern Bering Sea. U.S. Department of Commerce, NOAA Technical Report, NMFS SSRF-779. 49 pp.

Konar, B., 1998. Mechanisms that structure marine benthic communities at the Semichi Islands, Alaska. PhD thesis, University of California, Santa Cruz, California, 178 pp.

Konar, B. 2000. Seasonal inhibitory effects of marine plants on sea urchins: structuring communities the algal way. Oecologia, 125:208-217.

Kruse, G. H., Funk, F. C., Geiger, H. J., Mabry, K. R., Savikko, H. M., and Siddeek, S. M., 2000. Overview of state-managed marine fisheries in the central and western Gulf of Alaska, Aleutian Islands, and Southeastern Bering Sea, with feference to Steller sea lions. Alaska Department of Fish & Game, Division of Commercial Fisheries, Juneau, Regional Information Report, 5J00-10.

Loughlin, T. R., and Perez, M. A. 1985. *Mesoplodon stejnegeri*. Mammalian Species, 250:1-6.

Loughlin, T. R., and York, A. E. 2000. An accounting of the sources of Steller sea lion, *Eumetopias jubatus*, mortality. Marine Fisheries Review, 62(4):40-45.

Loughlin, T. R., Sukhanova, I. N., Sinclair, E. H., and Ferrero, R. C., 1999. Summary of biology and edosystem dynamics in the Bering Sea. *In*: Dynamics of the Bering Sea: A summary of the Physical, Chemical, and Biological Characteristics, and a Synopsis of Research on the Bering Sea. *Edited by* T. R. Loughlin and K. Ohtani, University of Alaska Sea Grant, Fairbanks, Alaska. pp. 387-407.

Lowe, S., Ianelli, J. N., Zenger, H., and Lauth, R., 2003. Stock assessment of Aleutian Islands Atka mackerel: Stock assessment and fishery evaluation report for the Groundfish Resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, AK, NPFMC Bering Sea/Aleutian Island SAFE, 711-775 pp.

Lowry, L. F., Frost, K. J., and Loughlin, T. R., 1989. Importance of walleye pollock in the diets of marine mammals in the Gulf of Alaska and Bering Sea, and implications for fishery management. *In*: Proceedings fo the International Sympoisum on the bioogy and management of walleye pollock, Anchorage, Alaska, November 14-16 1988, Alaska Sea Grant and University of Alaska. Vol. 89-1. pp. 701-726.

Mackintosh, N. A., 1965. The stocks of whales. Coward & Gerrish, Ltd., Bath, England. 232 pp.

Maloney, N. E., 2002. Report to industry on the Alaska sablefish tag program, 1972-2001. U.S. Department of Commerce, AFSC Processed Report, 2002-01. 44 pp.

Mann, K. H., and Lazier, J. R. N., 1991. Dynamics of marine ecosystems: Biological-physical interactions in the oceans. Blackwell Scientific Publications, Boston.

Mantua, N. J., Hare, S. R., Zhang, Y., Wallace, J. M., and Francis, R. C. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society, 78(6):1069-1079.

McAlister, W. B. 1971. Oceanography in the vicinity of Amchitka Island, Alaska. BioScience, 21(12):646-651.

Merrell, T. R. J., 1977. Fishery fesources of the Western Aleutians. *In*: The Environment of Amchitka Island, Alaska. *Edited by* M. L. Merritt and R. G. Fuller, Energy Research and Development Administration. Division of Military Application, Springfield, Va. pp. 315-330.

Merrick, R. L., 1996. Importance of juvenile walleye pollock, *Theragra chalcogramma*, in the diet of Gulf of Alaska Steller sea lions, *Eumetopias jubatus*. U.S. Department of Commerce, NOAA Technical Report, NMFS 126. 153-166 pp.

Merrick, R. L., Loughlin, T. R., and Calkins, D. G. 1987. Decline in abundance of the northern sea lion, *Eumetopias jubatus*, in Alaska, 1956-1986. Fishery Bulletin, 85(2):351-365.

Monson, D. H., Estes, J. A., Bodkin, J. L., and Siniff, D. B. 2000. Life history plasticity and population regulation in sea otters. Oikos, 90:457-468.

Murie, O. J. 1959. Fauna of the Aleutian Islands and Alaska Peninsula. North American Fauna, U.S. Fish and Wildlife Service, 61:1-406.

National Research Council, 2003. Decline of the Steller sea lion in Alaskan waters: untangling food webs and fishing nets. The National Academies Press, Washington, DC. 204 pp.

Nemoto, T. 1957. Foods of baleen whales in the northern Pacific. Scientific Report of the Whale Research Institute, Tokyo, 12:33-89.

Nishiwaki, M., 1966. Distribution and migration of the larger cetaceans in the North Pacific as shown by Japanese whaling results. *In*: Whales, Dolphins, and Porpoises. *Edited by* K. S. Norris, University of California Press, Berkeley. pp. 171-191.

Nishiwaki, M. 1967. Distribution and migration of marine mammals in the North Pacific area. Bulletin of the Ocean Research Institute of University of Tokyo, 1(1):1-64.

Okutani, T., and Nemoto, T. 1964. Squids as the food of sperm whale in the Bering Sea and Alaskan Gulf. Scientific Report of the Whale Research Institute, Tokyo, 18:111-122.

Orlov, A. M., and Moiseev, S. I. 1998. Some biological features of Pacific sleeper shark, *Somniosus pacificus* (Bigelow et Schroeder, 1944) (Squalidae) in the Northwestern Pacific Ocean. Oceanological Studies, 28(1-3):3-16.

Orsi, J. A., Weirtheimer, A. C., Sturdevant, M. V., Fergusson, E. A., Mortensen, D. G., and Wing, B. L. 2003. Hatchery and wild stock interactions of juvenile chum salmon in marine waters of southeastern Alaska: a bioenergetic approach.manuscript (comm pers).

Palmisano, J. F., 1975. Sea otter predation: Its role in rocky intertidal community structure at Amchitka and other Aleutian Islands. PhD thesis, University of Washington, Seattle, Wa, 207 pp.

Parsons, T. R., 1987. Ecological relations. *In*: The Gulf of Alaska: Physical Environment and Biological Resources. *Edited by* D. W. Hood and S. T. Zimmerman, US Government Printing Office, Washington DC. pp. 561-570.

Perez, M. A., 1990. Review of marine mammal population and prey information for Bering Sea ecosystem studies. U.S. Department of Commerce, NOAA Technical Memorandum, NFMS F/NWC-186. 81 pp.

Perez, M. A., 2003. Compilation of marine mammal incidental take data from the domestic and joint venture groundfish fisheries in the U.S. EEZ of the North Pacific, 1989-2001. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-AFSC-138. 145 pp.

Perez, M. A., and Loughlin, T. R., 1991. Incidental catch of marine mammals by foreign and joint venture trawl vessels in the U.S. EEZ of the North Pacific, 1973-88. U.S. Department of Commerce, NOAA Technical Report, NMFS-104. 57 pp.

Perez, M. A., and McAlister, W. B., 1993. Estimates of food consumption by marine mammals in the Eastern Bering Sea. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-AFSC-14. 44 pp.

Perry, S. L., DeMaster, D. P., and Silber, G. K. 1999. The great whales: History and status of six species listed as endangered under the U.S. Endangered Species Act of 1973. Marine Fisheries Review, 61(1):1-74.

Pitcher, K. W., 2002. Nutritional limitation? An alternative hypothesis. *In*: Steller Sea Lion Decline: Is It Food II. *Edited by* D. P. DeMaster and S. Atkinson, University of Alaska Sea Grant College Program AK-SG-02-02, Fairbanks Alaska. pp. 15-18.

Reuter, R. F., and Spencer, P. D., 2003. 2003 BSAI other rockfish: Stock assessment and fishery evaluation report for the Groundfish Resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, AK, NPFMC Bering Sea/Aleutian Island SAFE, 681-709 pp.

Rice, D. W. 1968. Stomach contents and feeding behavior of killer whales in the Eastern North Pacific. Norsk Hvalfangst-Tidende, 57(2):35-38.

Ridgeway, S. H., and Harrison, R. J., 1981. Handbook of Marine Mammals. Volume 2: Seals. Academic Press, London. 235 pp.

Rogers, D. E., 1987. Pacific salmon. *In*: The Gulf of Alaska: Physical Environment and Biological Resources. *Edited by* D. W. Hood and S. T. Zimmerman, US Government Printing Office, Washington DC. pp. 461-477.

Ronholt, L. L., Teshima, K., and Kessler, D. W., 1994. The groundfish resources of the Aleutian Islands region and Southern Bering Sea 1980, 1983, and 1986. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-AFSC-31. 358 pp.

Scheffer, V. B. 1959. Invertebrates and fishes collected in the Aleutians, 1936-1938. In: Murie, O.J. Fauna of the Aleutian Islands and Alaska Peninsula. North American Fauna, U.S. Fish and Wildlife Service, 61:365-406.

Scheffer, V. B., Fiscus, C. H., and Todd, E. I., 1984. History of scientific study and management of the Alaskan fur seal, *Callorhinus ursinus*, 1986-1964. U.S. Department of Commerce, NOAA Technical Report, NMFS SSRF-780. 70 pp.

Schumacher, J. D., and Alexander, V., 1999. Variability and role of the physical environment in the Bering Sea ecosystem. *In*: Dynamics of the Bering Sea: A summary of the Physical, Chemical, and Biological Characteristics, and a Synopsis of Research on the Bering Sea. *Edited by* T. R. Loughlin and K. Ohtani, University of Alaska Sea Grant, Fairbanks, Alaska. pp. 147-160.

Shiomoto, A., 1999. Effects of nutrients on phytoplankton size in the Bering Sea basin. *In*: Dynamics of the Bering Sea: A summary of the Physical, Chemical, and Biological Characteristics, and a Synopsis of Research on the Bering Sea. *Edited by* T. R. Loughlin and K. Ohtani, University of Alaska Sea Grant, Fairbanks, Alaska. pp. 323-340.

Shuntov, V. P., and Radchenko, V. I., 1999. Summary of TINRO ecosystem investigations in the Bering Sea. *In*: Dynamics of the Bering Sea: A summary of the Physical, Chemical, and Biological Characteristics, and a Synopsis of Research on the Bering Sea. *Edited by* T. R. Loughlin and K. Ohtani, University of Alaska Sea Grant, Fairbanks, Alaska. pp. 771-776.

Sigler, M. F., Lunsford, C. R., Fujioka, J. T., and Lowe, S. A., 2003. Alaska sablefish assessment for 2004: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, AK, NPFMC Bering Sea/Aleutian Island SAFE, 223-291 pp.

Sinclair, E. H., and Zeppelin, T. K. 2002. Seasonal and spatial differences in diet in the western stock of Steller Sea Lions (*Eumetopias jubatus*). Journal of Mammalogy, 83(4):973-990.

Sinclair, E. H., Balanov, A. A., Kubodera, T., Radchenko, V. I., and Fedorets, Y. A., 1999. Distribution and ecology of mesopelagic fishes and cephalopods. *In*: Dynamics of the Bering Sea: A summary of the Physical, Chemical, and Biological Characteristics, and a Synopsis of Research on the Bering Sea. *Edited by* T. R. Loughlin and K. Ohtani, University of Alaska Sea Grant, Fairbanks, Alaska. pp. 485-508.

Spencer, P., and Ianelli, J., 2002. Pacific Ocean perch. NMFS, Stock assessment report, 44 pp.

Spencer, P. D., and Ianelli, J. N., 2003a. Pacific Ocean perch: Stock assessment and fishery evaluation report for the Groundfish Resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, AK, NPFMC Bering Sea/Aleutian Island SAFE, 563-610 pp.

Spencer, P. D., and Ianelli, J. N., 2003b. Northern rockfish: Stock assessment and fishery evaluation report for the Groundfish Resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, AK, NPFMC Bering Sea/Aleutian Island SAFE, 611-652 pp.

Spencer, P. D., and Reuter, R. F., 2003. Shortraker and rougheye rockfish: Stock assessment and fishery evaluation report for the Groundfish Resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, AK, NPFMC Bering Sea/Aleutian Island SAFE, 653-680 pp.

Spencer, P. D., Walters, G. E., and Wilderbuer, T. K., 2003a. Flathead sole: Stock assessment and fishery evaluation report for the Groundfish Resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, AK, NPFMC Bering Sea/Aleutian Island SAFE, 463-510 pp.

Spencer, P. D., Walters, G. E., and Wilderbuer, T. K., 2003b. Other flatfish: Stock assessment and fishery evaluation report for the Groundfish Resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, AK, NPFMC Bering Sea/Aleutian Island SAFE, 553-562 pp.

Springer, A. M., Estes, J. A., van Vliet, G., Williams, T. M., Doak, D. F., Danner, E. M., Forney, K. A., and Pfister, B. 2003. Sequential megafaunal collapse in the North Pacific Ocean: An ongoing legacy of industrial whaling? Proceedings of the National Academy of Sciences of the USA, 100(21):12223-12228.

Strathmann, R. R. 1967. Estimating the organic carbon content of phytoplankton from cell volume or plasma volume. Limnology and Oceanography, 12(3):411-418.

Sugimoto, T., and Tadokoro, K. 1997. Interannual-interdecadal variations in zooplankton biomass, chlorophyll concentration and physical environment in the subarctic Pacific and Bering Sea. Fisheries Oceanography, 6(2):74-93.

Tamura, T., Fujise, Y., and Shimazaki, K. 1998. Diet of minke whales *Balaenoptera acutorostrata* in the northwestern part of the North Pacific in summer, 1994 and 1995. Fisheries Science, 64(1):71-76.

Thompson, G. G., and Dorn, M. W., 2003. Assessment of the Pacific cod stock in the Eastern Bering Sea and Aleutian Islands area: Stock assessment and fishery evaluation report for the Groundfish Resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, AK, NPFMC Bering Sea/Aleutian Island SAFE, 127-222 pp.

Thorsteinson, F. V., and Lensink, C. J. 1962. Biological observations of Steller sea lions taken during an experimental harvest. Journal of Wildlife Management, 26(4):353-359.

Trites, A., and Larkin, P. A., 1992. The status of Steller sea lion populations and the development of fisheries in the Gulf of Alaska and Aleutian Islands. Pacific States Marine Fisheries Commission, Vancouver, BC, NOAA Report, Award No. NA17FD0177. 134 pp.

Trites, A., and Pauly, D. 1998. Estimating mean body masses of marine mammals from maximum body lengths. Canadian Journal of Zoology, 76:886-896.

Trites, A. W., and Larkin, P. A. 1996. Changes in the abundance of Steller sea lions (*Eumetopias jubatus*) in Alaska from 1956 to 1992: how many were there? Aquatic Mammals, 22:153-166.

Trites, A. W., Christensen, V., and Pauly, D. 1997. Competition between fisheries and marine mammals for prey and primary production in the Pacific ocean. Journal of Northwest Atlantic Fisheries Science, 22:173-187.

Trites, A. W., Miller, A. J., Maschner, H. D. G., Alexander, M. A., Bograd, S. J., Calder, J. A., Capotondi, A., Coyle, K. O., Di Lorenzo, E., Finney, B. P., Fritz, L., Gregr, E. J., Grosch, C. E., Hare, S. R., Hunt, G. L., Jahncke, J., Kachel, N. B., Kim, H.-J., Ladd, C., Mantua, N. J., Marzban, C., Maslowski, W., Mendelssohn, R., Neilson, D. J., Okkonen, S., Overland, J. E., Reedy-Maschner, K. L., Royer, T. C., Schwing, F. B., Wang, J. X. L., and Winship, A. J. 2004 in press. Bottom-up forcing and the decline of Steller sea lions in Alaska: Assessing the ocean climate hypothesis. Fisheries Oceanography:1-62.

USFWS, 1965. Foreign fishing activities: Bering Sea and Gulf of Alaska, 1965. Office of Enforcement and Surveillance, Bureau of Commercial Fisheries, Region 5 U.S. Fish and Wildlife Service, Juneau, Alaska, 100 + 69 pp.

USFWS, 1967. Foreign fishing activities: Bering Sea and Gulf of Alaska, 1967. Office of Enforcement and Surveillance, Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service, Juneau, Alaska, 85 + 82 pp.

USFWS, 1974. Foreign fishing activities: Bering Sea and Gulf of Alaska, 1974. National Oceanic and Atmospheric Administration. National Marine Fisheries Service, Law Enforcement Division, Juneau, Alaska, 64+58 pp.

USFWS, 1975. Foreign fishing activities: Bering Sea and Gulf of Alaska, 1975. National Oceanic and Atmospheric Administration. National Marine Fisheries Service, Law Enforcement Division, Juneau, Alaska, 54 pp.

Veltre, D. W., and Veltre, M. J., 1983. Resource utilization in Atka, Aleutian Islands, Alaska. Alaska Department of Fish & Game, Division of Subsistence, Technical Paper, No. 88. 222 pp.

Wada, Y., 1996. Marine mammals and birds. *In*: Mass-Balance Models of North-eastern Pacific Ecosystems: Proceedings of a Workshop held at the Fisheries Centre University of British Columbia, Vancouver, B.C., Canada, November 6-10, 1995. *Edited by* D. Pauly, V. Christensen, and N. Haggan, The Fisheries Centre, University of British Columbia, Vancouver, BC. Vol. 4(1) pp. 69-73.

Waite, J. M., Friday, N. A., and Moore, S. E. 2002. Killer whale (*Orcinus orca*) distribution and abundance in the central and southeastern Bering Sea, July 1999 and June 2000. Marine Mammal Science, 18(3):779-786.

Watt, J., Siniff, D. B., and Estes, J. A. 2000. Inter-decadal patterns of population and dietary change in sea otters at Amchitka Island, Alaska. Oecologia, 124:289-298.

Whitehead, H. 2002. Estimates of the current global population size and historical trajectory for sperm whales. Marine Ecology Progress Series, 242:295-304.

Wilderbuer, T. K., and Sample, T. M., 2003. Arrowtooth flounder: Stock assessment and fishery evaluation report for the Groundfish Resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, AK, NPFMC Bering Sea/Aleutian Island SAFE, 367-407 pp.

Wilderbuer, T. K., and Walters, G. E., 2003. Rock sole: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, AK, NPFMC Bering Sea/Aleutian Island SAFE, 409-462 pp.

Wilke, F. 1957. Food of sea otters and harbor seals at Amchitka Island. Journal of Wildlife Management, 21(2):241-242.

Williams, G. H., 2004. Incidental catch and mortality of Pacific halibut, 1962-2003. International Pacific Halibut Commission, 1-11 pp.

Wolfe, R. J., and Mishler, C., 1995. The subsistence harvest of harbor seal and sea lion by Alaska natives in 1994. Alaska Department of Fish & Game, Division of Subsistence, Juneau, Technical Paper, No. 236. 118 pp.

Wolfe, R. J., Fall, J. A., and Stanek, R. T., 2002. The subsistence harvest of harbor seal and sea lion by Alaska natives in 2001. Alaska Department of Fish & Game, Division of Subsistence, Juneau, Technical Paper, No. 273. 124 pp.

Yang, M.-S. 1999. The trophic role of Atka mackerel, *Pleurogrammus monopterygius*, in the Aleutian Islands area. Fishery Bulletin, 97(4):1047-1057.

Zeitschel, B. 1970. The quantity, composition and distribution of suspended particulate matter in the Gulf of California. Marine Biology, 7:305-318.

Zenger, H., 2002. 2002 groundfish assessment survey, Aleutian Islands region. Resource Assessment and Conservation Engineering (RACE) Division., 4 pp.

Zerbini, A. N., Wade, P. R., and Waite, J. M., 2003. Abundance and distribution of fin, humpback and minke whales from the Kenai Fjords to the Central Aleutian Islands, Alaska: Summer 2001-2002. International Whaling Commission, Scientific Committee Report, SC/55/O9. 14 pp.

Appendix A:

Table A1 continued…

	Prey \ Predator	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
1	Transient orca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	Toothed whales	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	Baleen whales	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	SSL embryo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	SSL pups	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	SSL juveniles	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	SSL Adults	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	Small mammals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	Sea otters	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	Birds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	Shark mammal eater	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	Shark and skates	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	Salmon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	Large pelagics	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	Small pelagics	-	-	-	-	1.50	0.10	3.80	-	1.40	-	-	-	-	-	-	10.00	-	-
16	Atka mackerel	3.5	-	-	-	15.10	15.70	19.60	0.50	-	11.30	-	-	-	-	-	-	-	-
17	Sand lance	-	-	0.70	-	0.60	2.30	-	0.90	-	-	-	-	-	-	-	2.50	-	-
18	Herring	-	-	-	-	-	-	0.20	-	2.30	-	-	-	-	-	-	-	-	-
19	Juvenile pollock	0.1	-	0.70	-	-	0.30	9.60	-	0.50	1.20	-	-	-	-	-	-	-	-
20	Adult pollock	0.4	-	-	-	4.10	8.90	1.40	0.30	-	-	-	-	-	-	-	-	-	-
21	POP	-	-	-	-	0.10	-	-	0.10	-	-	-	-	-	-	-	-	-	-
22	Rockfish	-	-	-	-	0.10	-	-	0.50	-	-	-	-	-	-	-	-	-	-
23	Sablefish	-	-	-	-	0.20	1.70	1.10	-	-	-	-	-	-	-	-	-	-	-
24	Pacific cod	-	-	-	-	0.20	0.70	0.20	-	-	-	-	-	-	-	-	-	-	-
25	Halibut	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	Arrowtooth	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	Flatfish	-	-	-	-	0.30	0.40	-	-	-	-	-	-	-	-	-	-	-	-
28	Dem S M	0.1	-	0.60	-	16.20	4.80	4.00	0.90	1.00	0.20	-	-	-	-	-	-	-	-
29	Large demersals	-	-	-	-	1.50	1.90	3.20	-	0.10	5.40	-	-	-	-	-	-	-	-
30	Deep L	-	0.30	-	-	1.70	1.90	3.20	0.70	-	-	-	-	-	-	-	-	-	-
31	Myctophids	25.1	2.50	0.10	-	3.90	2.60	25.80	21.00	0.20	0.10	0.60	0.20	-	-	-	5.00	-	-
32	Shrimps	4.1	0.10	37.50	-	27.90	1.90	18.00	13.10	5.70	3.30	65.50	-	-	-	0.10	2.50	-	-
33	Benthic inverts	8.2	2.40	23.60	2.00	7.70	1.80	3.70	41.10	61.20	8.80	8.30	2.80	40	0.80	68.20	25.00	-	-
34	Epiben carnivores	0.2	-	5.70	-	6.20	17.70	-	4.00	12.80	25.00	-	-	-	-	4.50	20.00	-	-
35	Cephalopods	2.7	0.50	1.20	9.70	7.10	32.40	0.50	8.20	1.30	0.60	25.60	-	-	-	-	-	-	-
36	Large zooplankton	35.6	17.70	18.30	88.30	0.40	-	5.30	7.10	8.80	41.70	-	86.20	20	-	12.90	30.00	0.60	-
37	Small zooplankton	19	76.50	11.50	-	0.10	-	-	1.50	-	-	-	5.80	-	-	1.40	-	40.00	14.70
38	Phytoplankton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	59.40	57.90
39	Macrophytes	-	-	-	-	-	-	-	-	-	-	-	5.00	-	1.90	2.90	5.00	-	-
40	Detritus	0.9	-	0.20	-	5.10	5.10	0.60	-	-	2.40	-	-	40	97.30	10.00	-	-	27.40
	Import	-	-	-	-	-	-	-	-	4.80	-	-	-	-	-	-	-	-	-

Table A2: Diet matrix (%) for the balanced 1979 model of the Aleutian Islands.

	Prey \ Predator	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
1	Transient orca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	Toothed whales	-	-	-	-	-	-	-	-	-	-	0.70	-	-	-	-	-	-	-	-
3	Baleen whales	1	-	-	-	-	-	-	-	-	-	2.20	-	-	-	-	-	-	-	-
4	SSL embryo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	SSL pups	1	-	-	-	-	-	-	-	-	-	0.20	-	-	-	-	-	-	-	-
6	SSL juveniles	9	-	-	-	-	-	-	-	-	-	3.50	-	-	-	-	-	-	-	-
7	SSL Adults	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	Small mammals	78	-	-	-	-	-	-	-	-	-	8.40	-	-	-	-	-	-	-	-
9	Sea otters	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	Birds	1	-	-	-	-	-	-	-	-	-	0.40	-	-	-	-	-	-	-	-
11	Shark mammal eater	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	Shark and skates	-	0.10	-	-	-	0.70	0.20	-	-	-	15.50	0.30	-	-	-	-	-	-	-
13	Salmon	-	28.80	1.10	-	-	11.90	10.60	2.20	-	3.10	2.20	4.40	-	1.70	-	-	-	-	-
14	Large pelagics	-	-	-	-	-	-	-	-	-	-	2.60	1.10	-	0.30	-	-	-	-	-
15	Small pelagics	-	5.00	9.40	-	-	3.50	12.70	8.20	-	21.50	0.70	0.90	-	7.60	-	-	-	-	-
16	Atka mackerel	-	1.80	12.40	-	-	2-	2-	11.20	4.00	1.60	-	4.10	-	-	-	-	-	-	-
17	Sand lance	-	-	2.90	-	-	12.70	10.50	3.40	4.00	12.50	-	0.90	-	4.50	-	-	-	-	-
18	Herring	-	0.80	0.10	-	-	1.00	1.00	4.00	-	3.30	0.70	2.00	-	9.30	-	-	-	-	-
19	Juvenile pollock	-	-	0.10	-	-	0.90	0.70	3.20	-	4.50	0.40	3.70	-	1.00	-	4.00	-	-	-
20	Adult pollock	-	0.70	8.50	-	-	0.50	2.60	6.60	-	-	2.10	3.00	-	1.00	-	-	-	-	-
21	POP	-	-	-	-	-	-	0.01	-	-	-	0.20	-	-	-	-	-	-	-	-
22	Rockfish	-	0.10	0.40	-	-	1.70	1.60	1.30	-	0.10	1.80	0.70	-	-	-	-	-	-	-
23	Sablefish	-	0.10	-	-	-	-	-	0.80	-	-	0.70	3.00	-	-	-	-	-	-	-
24	Pacific cod	-	0.50	0.10	-	-	5.00	1.00	3.30	-	3.40	0.80	1.10	-	-	-	-	-	-	-
25	Halibut	-	-	-	-	-	-	0.70	-	-	-	1.50	2.40	-	-	-	-	-	-	-
26	Arrowtooth	-	-	-	-	-	0.40	0.30	-	-	-	15.80	1.40	-	-	-	-	-	-	-
27	Flatfish	-	-	-	-	-	3.90	3.20	2.80	-	-	1.10	3.90	-	-	-	-	-	-	-
28	Dem S M	-	3.00	2.90	-	-	24.60	16.20	10.40	3-	-	4.90	2.60	-	-	-	0.20	-	-	3.40
29	Large demersals	-	-	-	-	-	6.40	4.70	-	-	-	2.40	3.40	-	0.80	-	-	-	-	-
30	Deep L	-	-	-	-	-	-	-	-	-	-	2.60	0.70	-	-	-	-	-	-	-
31	Myctophids	-	2.00	-	-	-	1.00	1.60	3.6	-	8.20	1.50	2.30	-	1.90	-	0.90	-	-	0.10
32	Shrimps	-	-	-	-	-	-	-	0.80	-	-	0.20	17.60	-	3.10	-	0.50	-	-	9.90
33	Benthic inverts	-	2.00	-	-	-	-	-	0.80	6-	1.10	0.60	13.80	-	13.40	-	5.30	-	-	11.00
34	Epiben carnivores	-	-	-	-	-	-	-	0.80	2.00	-	0.40	4.10	-	-	-	2.30	-	-	0.40
35	Cephalopods	-	53.10	1.10	-	-	5.80	8.10	36.50	-	36.40	22.00	14.00	10	9.90	-	1.00	-	-	-
36	Large zoopl.	-	1.00	52.50	-	-	-	-	0.20	-	2.60	-	6.00	45	33.00	90	35.60	90	96.8	36.1
37	Small zoopl.	-	1.00	8.50	-	-	-	-	-	-	1.60	-	0.40	10	12.60	-	38.60	-	3.20	39.10
38	Phytoplankton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39	Macrophytes	-	-	-	-	-	-	-	-	-	-	-	-	35	-	10	-	10	-	-
40	Detritus	-	-	-	-	-	-	-	-	-	-	4.10	2.30	-	-	-	0.10	-	-	-
	Import	-	-	-	100.	100	-	4.30	-	-	-	-	-	-	-	-	11.50	-	-	-

Table A2 continued…

	Prey \ Predator	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
1	Transient orca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	Toothed whales	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	Baleen whales	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	SSL embryo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	SSL pups	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	SSL juveniles	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	SSL Adults	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	Small mammals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	Sea otters	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	Birds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	Shark mammal eater	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	Shark and skates	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	Salmon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	Large pelagics	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	Small pelagics	-	-	-	-	1.50	0.10	3.80	-	1.40	-	-	-	-	-	-	10.00	-	-
16	Atka mackerel	3.5	-	-	-	15.10	15.70	19.60	0.50	-	11.30	-	-	-	-	-	-	-	-
17	Sand lance	-	-	0.70	-	0.60	2.30	-	0.90	-	-	-	-	-	-	-	2.50	-	-
18	Herring	-	-	-	-	-	-	0.20	-	2.30	-	-	-	-	-	-	-	-	-
19	Juvenile pollock	0.1	-	0.70	-	-	0.30	9.60	-	0.50	1.20	-	-	-	-	-	-	-	-
20	Adult pollock	0.4	-	-	-	4.10	8.90	1.40	0.30	-	-	-	-	-	-	-	-	-	-
21	POP	-	-	-	-	0.20	-	-	0.10	-	-	-	-	-	-	-	-	-	-
22	Rockfish	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	Sablefish	-	-	-	-	0.20	1.70	1.10	-	-	-	-	-	-	-	-	-	-	-
24	Pacific cod	-	-	-	-	0.20	0.70	0.20	-	-	-	-	-	-	-	-	-	-	-
25	Halibut	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	Arrowtooth	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	Flatfish	-	-	-	-	0.30	0.40	-	-	-	-	-	-	-	-	-	-	-	-
28	Dem S M	0.1	-	0.60	-	16.20	4.80	4.00	0.90	1.00	0.20	-	-	-	-	-	-	-	-
29	Large demersals	-	-	-	-	1.50	1.90	3.20	-	0.10	5.40	-	-	-	-	-	-	-	-
30	Deep L	-	0.30	-	-	1.70	1.90	3.20	0.70	-	-	-	-	-	-	-	-	-	-
31	Myctophids	25.1	2.50	0.10	-	3.90	2.60	25.80	21.00	0.20	0.10	0.60	0.20	-	-	-	5.00	-	-
32	Shrimps	4.1	0.10	37.50	-	27.90	1.90	18.00	13.70	5.70	3.30	65.50	-	-	-	0.10	2.50	-	-
33	Benthic inverts	8.2	2.40	23.60	2.00	7.70	1.80	3.70	41.10	61.20	8.80	8.30	2.80	40	0.80	68.20	25.00	-	-
34	Epiben carnivores	0.2	-	5.70	-	6.20	17.70	-	4.00	12.80	25.00	-	-	-	-	4.50	20.00	-	-
35	Cephalopods	2.7	0.50	1.20	9.70	7.10	32.40	0.50	8.20	1.30	0.60	25.60	-	-	-	-	-	-	-
36	Large zooplankton	35.6	17.70	18.30	88.3	0.40	-	5.30	7.10	8.80	41.70	-	86.10	20	-	12.90	30.00	0.60	-
37	Small zooplankton	19	76.50	11.50	-	0.10	-	-	1.50	-	-	-	5.80	-	-	1.40	-	40.0	14.70
38	Phytoplankton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	59.4	57.90
39	Macrophytes	-	-	-	-	-	-	-	-	-	-	-	5.00	-	1.90	2.90	5.00	-	-
40	Detritus	0.9	-	0.20	-	5.10	5.10	0.60	-	-	2.40	-	-	40	97.30	10.00	-	-	27.40
	Import	-	-	-	-	-	-	-	-	4.80	-	-	-	-	-	-	-	-	-

Table A3: Diet matrix (%) for the balanced and fitted 1963 model of the Aleutian Islands.

	Prey \ Predator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Transient orca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	Toothed whales	-	-	-	-	-	-	-	-	-	-	0.70	-	-	-	-	-	-	-	-
3	Baleen whales	1	-	-	-	-	-	-	-	-	-	2.20	-	-	-	-	-	-	-	-
4	SSL embryo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	SSL pups	10	-	-	-	-	-	-	-	-	-	0.20	-	-	-	-	-	-	-	-
6	SSL juveniles	40	-	-	-	-	-	-	-	-	-	3.50	-	-	-	-	-	-	-	-
7	SSL Adults	30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	Small mammals	15	-	-	-	-	-	-	-	-	-	0.40	-	-	-	-	-	-	-	-
9	Sea otters	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	Birds	1	-	-	-	-	-	-	-	-	-	0.40	-	-	-	-	-	-	-	-
11	Shark mammal eater	-	-	-	-	-	-	-	-	-	-	8.00	-	-	-	-	-	-	-	-
12	Shark and skates	-	0.10	-	-	-	0.7	0.7	-	-	-	15.5	0.30	-	-	-	-	-	-	-
13	Salmon	-	15.9	0.2	-	-	11.9	10.6	2	-	3.1	2.2	4.40	-	1.70	-	-	-	-	-
14	Large pelagics	-	-	-	-	-	-	-	-	-	-	2.6	-	-	0.30	-	-	-	-	-
15	Small pelagics	-	5	14.4	-	-	-	-	8.50	-	21.5	0.7	0.90	-	7.60	-	-	-	-	-
16	Atka mackerel	-	1.5	13.4	-	-	32.7	42.7	10.1	4	2.20	-	4.10	-	-	-	-	-	-	-
17	Sand lance	-	-	3.7	-	-	-	0.50	3.5	4	12.5	-	0.90	-	4.50	-	-	-	-	-
18	Herring	-	0.8	0.2	-	-	-	-	4.2	-	3.3	0.7	2.00	-	9.30	-	-	-	-	-
19	Juvenile pollock	-	-	0.2	-	-	0.9	0.70	3.7	-	3.8	0.4	3.30	-	1.00	-	1.00	-	-	-
20	Adult pollock	-	1.10	8.8	-	-	0.5	2.60	7.6	-	-	2.1	3.30	-	1.00	-	5.10	-	-	-
21	POP	-	-	-	-	-	-	-	-	-	0.1	0.2	-	-	-	-	-	-	-	-
22	Rockfish	-	0.10	0.1	-	-	1.7	1.60	1.4	-	0.1	1.8	0.70	-	-	-	-	-	-	-
23	Sablefish	-	0.10	-	-	-	-	-	0.60	-	-	0.7	4.10	-	-	-	-	-	-	-
24	Pacific cod	-	0.30	0.2	-	-	8.5	6.30	4.1	-	3.5	0.8	1.10	-	-	-	-	-	-	-
25	Halibut	-	-	-	-	-	-	-	-	-	-	1.5	2.40	-	-	-	-	-	-	-
26	Arrowtooth	-	-	-	-	-	1.40	1.00	-	-	-	15.8	1.4	-	-	-	-	-	-	-
27	Flatfish	-	-	-	-	-	3.9	2.70	2.6	-	-	1.10	3.9	-	-	-	-	-	-	-
28	Dem S M	-	3.00	3.7	-	-	24.6	16.2	12.2	30	-	4.90	2.6	-	-	-	0.20	-	-	3.40
29	Large demersals	-	-	-	-	-	6.40	4.7	-	-	-	2.40	3.4	-	0.8	-	-	-	-	-
30	Deep L	-	-	-	-	-	-	-	-	-	-	2.60	0.70	-	-	-	-	-	-	-
31	Myctophids	-	2.00	-	-	-	1.00	1.60	3.00	-	8.20	1.50	2.3	-	1.9	-	0.90	-	-	0.10
32	Shrimps	-	-	-	-	-	-	-	1.00	-	-	0.20	17.6	-	3.1	-	0.50	-	-	9.90
33	Benthic inverts	-	2.00	-	-	-	-	-	1.00	60	1.10	0.60	13.8	-	13.4	-	5.30	-	-	11.00
34	Epi. carnivores	-	-	-	-	-	-	-	1.00	2	-	0.40	4.1	-	-	-	2.30	-	-	0.40
35	Cephalopods	-	66	1.2	-	-	5.80	8.1	33.5	-	36.3	22	14	10	9.9	-	10.40	-	-	-
36	L zooplankton	-	1.00	32.6	-	-	-	-	0.10	-	2.6	-	6.00	45	33	90	35.60	90	96.7	36.10
37	S zooplankton	-	1.00	21.4	-	-	-	-	-	-	1.6	-	0.40	10	12.6	-	38.60	-	3.20	39.10
38	Phytoplankton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39	Macrophytes	-	-	-	-	-	-	-	-	-	-	-	-	35	-	10	-	10	-	-
40	Detritus	-	-	-	-	-	-	-	-	-	-	4.10	2.30	-	-	-	0.10	-	-	-
	Import	-	-	-	100	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table A3 continued…

	Prey \ Predator	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
1	Transient orca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	Toothed whales	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	Baleen whales	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	SSL embryo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	SSL pups	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	SSL juveniles	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	SSL Adults	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	Small mammals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	Sea otters	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	Birds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	Shark mammal eater	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	Shark and skates	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	Salmon	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	Large pelagics	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	Small pelagics	-	-	-	-	1.50	0.10	3.80	-	1.40	-	-	-	-	-	-	10.00	-	-
16	Atka mackerel	3.5	-	-	-	15.10	15.70	19.60	0.50	-	11.30	-	-	-	-	-	-	-	-
17	Sand lance	-	-	0.70	-	0.60	2.30	-	0.90	-	-	-	-	-	-	-	2.50	-	-
18	Herring	-	-	-	-	-	-	0.20	-	2.30	-	-	-	-	-	-	-	-	-
19	Juvenile pollock	0.1	-	0.70	-	-	0.30	9.60	-	0.50	1.20	-	-	-	-	-	-	-	-
20	Adult pollock	0.4	-	-	-	4.10	8.90	1.40	0.30	-	-	-	-	-	-	-	-	-	-
21	POP	-	-	-	-	0.20	-	-	0.60	-	-	-	-	-	-	-	-	-	-
22	Rockfish	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	Sablefish	-	-	-	-	0.20	1.70	1.10	-	-	-	-	-	-	-	-	-	-	-
24	Pacific cod	-	-	-	-	0.20	0.70	0.20	-	-	-	-	-	-	-	-	-	-	-
25	Halibut	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	Arrowtooth	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	Flatfish	-	-	-	-	0.30	0.40	-	-	-	-	-	-	-	-	-	-	-	-
28	Dem S M	0.1	-	0.60	-	16.20	4.80	4.00	0.90	3.60	0.20	-	-	-	-	-	-	-	-
29	Large demersals	-	-	-	-	1.50	1.90	3.20	-	2.30	5.40	-	-	-	-	-	-	-	-
30	Deep L	-	0.30	-	-	1.70	1.90	3.20	0.70	-	-	-	-	-	-	-	-	-	-
31	Myctophids	25.1	2.50	0.10	-	3.90	2.60	25.80	21.00	0.20	0.10	0.60	0.20	-	-	-	5.00	-	-
32	Shrimps	4.1	0.10	37.50	-	27.90	1.90	18.00	13.10	5.70	3.30	65.50	-	-	-	0.10	2.50	-	-
33	Benthic inverts	8.2	2.40	23.60	2.00	7.70	1.80	3.70	41.10	61.20	8.80	8.30	2.80	40.00	0.80	68.20	25.00	-	-
34	Epiben carnivores	0.2	-	5.70	-	6.20	17.70	-	4.00	12.80	25.00	-	-	-	-	4.50	20.00	-	-
35	Cephalopods	2.7	0.50	1.20	9.70	7.10	32.40	0.50	8.20	1.30	0.60	25.60	-	-	-	-	-	-	-
36	Large zooplankton	35.6	17.70	18.30	88.20	0.40	-	5.30	7.10	8.80	41.70	-	86.10	20.00	-	12.90	30.00	0.60	-
37	Small zooplankton	19	76.40	11.50	-	0.10	-	-	1.50	-	-	-	5.80	-	-	1.40	-	40.00	10.00
38	Phytoplankton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	59.40	65.00
39	Macrophytes	-	-	-	-	-	-	-	-	-	-	-	5.00	-	1.90	2.90	5.00	-	-
40	Detritus	0.9	-	0.20	-	5.10	5.10	0.60	-	-	2.40	-	-	40.00	97.30	10.00	-	-	25.00
	Import	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Ecosystem model of the eastern Aleutians and central Gulf of Alaska in 1963

Sheila J.J. Heymans [1]

Fisheries Centre University of British Columbia, Vancouver BC; *s.heymans@fisheries.ubc.ca*

ABSTRACT

This report describes a model of the Eastern Aleutians and central Gulf of Alaska constructed for 1963. The model consists of 40 compartments, and was specifically parameterized to be similar to the models of the Aleutian Islands and Southeast Alaska. It was built for comparison with the Aleutian Islands and Southeast Alaska models to study the decline in the western stock of Steller sea lions. However, the present model is still preliminary and was constructed based on an unpublished model for the area in 1991. It needs to be updated before it is used. As the data presently available lack in detail, and the fit to the time series is deficient, the results are not conclusive.

INTRODUCTION

This report describes the 1963 model of the central Gulf of Alaska and eastern Aleutian Islands for comparison with the models of the western and central Aleutian Islands and Southeast Alaska models constructed by Heymans (this volume) and Guénette (this volume), respectively. The model was built for the purpose of studying the decline in the western stock of Steller sea lions, *Eumetopias jubatus*, in the Gulf of Alaska. The model consists of 40 compartments, and was specifically parameterized to be similar to the models of the Aleutians and Southeast Alaska. Preliminary data on P/B and Q/B ratios as well as biomass and catches from the area in 1991 were obtained from Sarah Gaichas (NMFS, Seattle, Wa. *pers. comm.*) and used to aggregate the more detailed NMFS model into the model described below.

STUDY AREA

The central Gulf of Alaska and eastern Aleutian Islands model (henceforth called the Gulf of Alaska model) is bound by the North Pacific Fishery Management Council (NPFMC) management areas 610, 620, 630, and 640 (Figure 1), which coincide roughly with International Pacific Halibut Commission (IPHC) management areas 3A and 3B. The model spans the area from the 50 m depth contour to the 500 m depth contour, and the aerial extent is approximately 291,840 km².

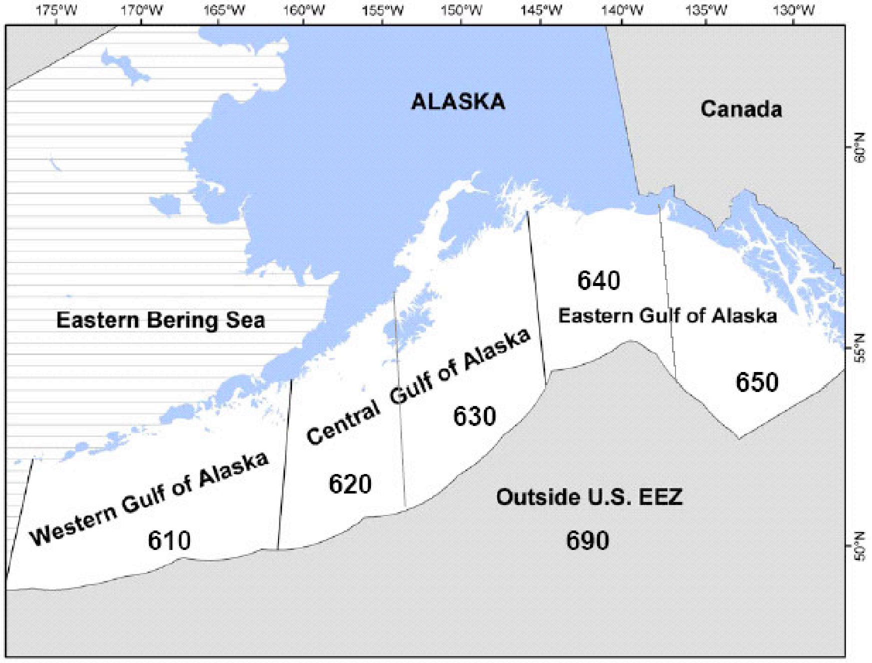


Figure 1. Map showing the Western Gulf of Alaska (Area 610), Central Gulf of Alaska (Areas 620 and 630) and Eastern Gulf of Alaska (640 only) encompassed in this model.

---

[1] Cite as: Heymans, Sheila J.J., 2005. Ecosystem model of the eastern Aleutian and central Gulf of Alaska in 1963. In: Guénette, S., and V. Christensen (editors). 2005. Food web models and data for studying fisheries and environmental impacts on Eastern Pacific ecosystems Fisheries Centre Research Reports 13(1):83-105.

FISHERY

There has been three periods to the Gulf of Alaska fishery; 1) the development of the cod, *Gadus macrocephalus*, halibut, *Hippoglossus stenolepis,* and sablefish, *Anoplopoma fimbria,* fisheries by North American fishers from 1867 to after World War II; 2) the development of the U.S. crab and shrimp fisheries and the foreign bottomfish fisheries in the 1960s; and 3) the present fisheries, which started with the declaration of the U.S. 200 miles EEZ in 1976 (Alton 1981). Cod, halibut and sablefish catches declined in the 1930s, and since 1941 the annual catch of cod has been very small (Alton 1981). The Alaskan herring, *Clupea pallasii,* fishery started as early as 1882, when the first reduction plant was built, and continued through 1942 (Forrester et al. 1978). The halibut fishery only started after World War I and the domestic sablefish fishery was relatively unimportant until 1934 when catches started to increase (Alton 1981).

In the early 1950s, Japan developed a large high-sea salmon (*Oncorhynchus* spp.) fishery in the North Pacific using drift gillnets (Figure 2), catches declined through the 1970s and in 1988 the fishery ended at the U.S. EEZ (National Research Council 2003). The USSR fleet started fishing for Pacific Ocean perch (POP, *Sebastes alutus*) in 1962, followed by a Japanese fleet the next year that also fished for POP and sablefish (Alton 1981). These two fleets increased rapidly in the 1960s, and from 1973 vessels from the Republic of Korea, Poland and Taiwan also entered the bottomfish fishery (Alton 1981). By 1979, pollock, *Theragra chalcogramma*, Pacific cod (Pcod), flounders, POP, other rockfish, Atka mackerel, *Pleurogrammus monopterygius*, sablefish, halibut, Dungeness crab, *Cancer magister*, king crab, (*Lithodes* spp.), snow crab, *Chionoecetes opilio,* and shrimp were being fished (Alton 1981). At present, the main fisheries include salmon, pollock and Pacific cod (Figure 2).

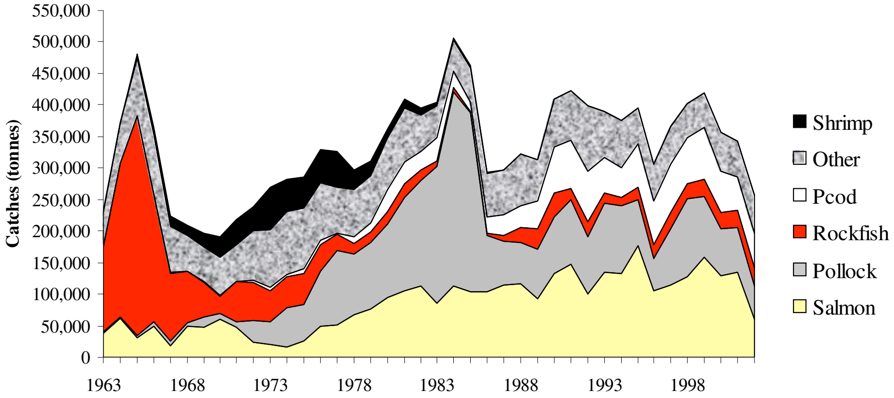


Figure 2. Catches (tonnes) made in the Gulf of Alaska from 1963 until the 2002. Other species include all marine mammals, halibut, arrowtooth, Atka mackerel, herring, sablefish and crabs.

MODEL DESCRIPTION

A preliminary model that consisted of 137 compartments was obtained from NMFS (Sarah Gaichas, *pers. comm.*). This model was aggregated into 40 functional groups to be similar to the models for the Aleutian Islands (Heymans, this volume) and Southeast Alaska (Guénette, this volume) and described in Table 1 below.

The "SIZEUNK", "MISC", "UNID", outside production and outside detritus groups used by NMFS were excluded. I also excluded the juveniles of Atka mackerel, herring, POP, Pacific cod, sablefish, Pacific halibut, arrowtooth, *Reinhardtius stomias*, shortsphine thornyheads, *Sebastolobus alascanus,* and flathead sole, *Hippoglossoides elassodon*, as none of these groups were included in the models for SEAK and the Aleutian Islands. The diets were rebalanced to 1, which caused the herring and adult pollock to be unbalanced, thus I reduced herring and adult pollock in the diet of their predators to what they were in the original model, and re-calculated the rest of the diet to 1, to balance these two groups.

A large pelagic predator group was added, using the same P/B, Q/B and diet estimates as given in the SEAK model (Guénette, this volume). To estimate a biomass for this group the diet of sharks and skates were adjusted from 4.8% small pelagics to 4% and large pelagics were added (0.8%), which estimates a biomass of 0.03 $t \cdot km^{-2}$ for large pelagics.

Table 1. Correspondence between the original and condensed model.

Condensed model		**Original model**		**Condensed model**		**Original model**	
1	Transient orca	1	Transient Killer			38	Arrowtooth juveniles
2	Toothed whales	2	Sperm beaked whales	26	Arrowtooth	39	Arrowtooth adults
2	Toothed whales	3	Resident Killers	27	flatfish	42	Yellowfin sole
3	Baleen whales	5	Gray whales			43	Flathead sole juveniles
3	Baleen whales	6	Humpbacks	27	flatfish	44	Flathead sole adults
3	Baleen whales	7	Fin whales	27	flatfish	45	Northern rock sole
3	Baleen whales	8	Sei whales	27	flatfish	46	Southern rock sole
3	Baleen whales	9	Right whales	27	flatfish	47	Alaska plaice
3	Baleen whales	10	Minke whales	27	flatfish	48	Dover sole
6	Sea lion juveniles	14	Central sea lion juv.	27	flatfish	49	Rex sole
7	Sea lion adults	15	Central sea lion ad.	27	Flatfish	50	Miscellaneous flatfish
6	Sea lion juveniles	16	West sea lion juv.	28	Small Demersals	61	Eelpouts
7	Sea lion adults	17	West sea lion adults	28	Small Demersals	78	Greenlings
8	Small mammals	4	Porpoises	28	Small Demersals	80	Other sculpins
8	Small mammals	12	Fur seal juveniles	29	Large Demersals	79	Bigmouth myox Sculpin
8	Small mammals	13	Fur seal adults	29	Large Demersals	81	Pricklies Squishies gadids
8	Small mammals	18	Resident seals	30	Large deep fish	62	Giant grenadier
9	Sea otters	11	Sea otters	30	Large deep fish	63	Pacific grenadier
10	Birds	19	Shearwater	30	Large deep fish	64	Other macrouids
10	Birds	20	Murre	30	Large deep fish	65	Prickle squish deep
10	Birds	21	Kittiwake	31	Small deep fish	86	Bathylagidae
10	Birds	22	Auklet	31	Small deep fish	87	Myctophidae
10	Birds	23	Puffin	32	Shrimps	96	Pandalidae
10	Birds	24	Fulmar	32	Shrimps	97	Non pandalid shrimp
10	Birds	25	Storm petrel	33	Benthic inverts	99	Brittle Star
10	Birds	26	Cormorants	33	Benthic inverts	100	Urchins, dollars, cucumbers
10	Birds	27	Gulls	33	Benthic inverts	104	Misc. crustacean
10	Birds	28	Albatross jaeger	33	Benthic inverts	105	Benthic amphipods
11	Mammal-eating sharks	29	Sleeper sharks	33	Benthic inverts	106	Anemones
12	Sharks and skates	30	Salmon sharks	33	Benthic inverts	107	Corals
12	Sharks and skates	31	Dogfish	33	Benthic inverts	108	Benthic hydroid
12	Sharks and skates	51	Alaska skate	33	Benthic inverts	109	Benthic Urochordata
12	Sharks and skates	52	Bering skate	33	Benthic inverts	110	Sea Pens
12	Sharks and skates	53	Aleutian skate	33	Benthic inverts	111	Sponge
12	Sharks and skates	54	Whiteblotched skate	33	Benthic inverts	112	Clam
12	Sharks and skates	55	Mud skate	33	Benthic inverts	113	Polychaete
12	Sharks and skates	56	Longnosed skate	33	Benthic inverts	114	Misc. Worm. Etc.
12	Sharks and skates	57	Big skate	34	Benthic carniv.	101	Snail
12	Sharks and skates	58	Black skate	34	Benthic carniv.	102	Hermit crabs
13	Salmon	84	Salmon returning	34	Benthic carniv.	103	Misc crabs
13	Salmon	85	Salmon outgoing	34	Benthic carniv.	93	Bairdi
14	Large pelagics			34	Benthic carniv.	94	King Crab
15	Small pelagics	88	Capelin	34	Benthic carniv.	95	Opilio
15	Small pelagics	90	Eulachon	34	Benthic carniv.	98	Sea Star
15	Small pelagics	91	Managed forage	35	Cephalopods	82	Octopi
15	Small pelagics	92	Other pelagic smelts	35	Cephalopods	83	Squids
-	--	76	Atka mackerel juv.	36	Large zoopl..	115	Scypho Jellies
16	Atka mackerel	77	Atka mackerel adults	36	Large zoopl.	117	Chaetognates etc.
17	Sand lance	89	Sand lance	36	Large zoopl.	118	Euphausiids
-	--	36	Herring juveniles	36	Large zoopl.	119	Mysids
18	Herring	37	Herring adults	36	Large zoopl.	120	Pelagic amphipods
19	Juvenile pollock	32	West pollock juv.	36	Large zoopl.	121	Pel. gelatin.filter feeder
20	Adult pollock	33	West pollock adults	36	Large zoopl.	122	Pteropods
-	--	66	POP juveniles	36	Large zoopl.	116	Fish larvae
21	POP	67	POP adults	37	Small zoopl.	123	Copepods
22	Rockfish	68	Sharpchin rockfish	37	Small zoopl.	124	Microzooplankton
22	Rockfish	69	Northern rockfish	38	phytoplankton	127	Large phytoplankton
22	Rockfish	70	Dusky rockfish	38	phytoplankton	128	Small phytoplankton

Condensed model		**Original model**		**Condensed model**		**Original model**	
22	Rockfish	71	Shortraker rockfish	39	marine plants	126	Algae
22	Rockfish	72	Rougheye rockfish	40	Detritus	125	Benthic bacteria
22	Rockfish	73	Shortspine rockfish	40	Detritus	133	Discards
22	Rockfish	74	Shortspine rockfish thornyhead adults	40	Detritus	134	Offal
22	Rockfish	75	Other Sebastes	40	Detritus	135	Pelagic detritus
-	--	59	Sablefish juveniles	40	Detritus	136	Benthic detritus
23	sablefish	60	Sablefish adults		n.a..	129	Outside production
-	--	34	Pacific cod juveniles		n.a.	130	SIZEUNK
24	Pacific cod	35	Pacific cod adults		n.a.	131	MISC
25	Halibut	40	Halibut juveniles		n.a.	132	UNID
25	Halibut	41	Halibut adults		n.a.	137	Outside Detritus

The western and central Steller sea lion groups were combined into adults and juveniles, and then two new groups for embryos and pups were added. The groups were converted into multistanza groups in Ecopath and the estimates of P/B, Q/B, K and W_{inf}/W_{mat} obtained from the SEAK model (Guénette, this volume) were used. Pollock was also converted to a multistanza group, with juveniles and adults split at 24 months and I used the same parameters for growth as for the SEAK model (Guénette, this volume). In the original model, pollock had a negative biomass accumulation of -1.25 year^{-1}, which was converted to a negative biomass accumulation rate (BA/B) of -0.2251 year^{-1}. The balanced 40 group model built for 1991, was used as a starting point for P/B and Q/B ratios as well as diets for the 1963 model described here. To calculate the biomass, catch, etc. for the 1963 model, time series data were obtained from the literature and stock assessment reports. This time series data is explained below as well as any other assumptions made with regards to biomass, etc. for the 1963 model.

TIME SERIES DATA

For mammals, the bycatch of all species by the trawl fleet between 1989 and 2001 were obtained from Perez (2003), the bycatch of all species but Steller sea lions for the time period 1973 to 1988 were obtained from Perez and Loughlin (1991). For species with no time series data, I tried to obtain at least three estimates, for 1963, 1977 and 1999. The time series of biomass and catch data are given in Tables 4 and 5 respectively, at the end of the document.

Transient orcas

Brueggeman et al. (1987) estimated the total number of killer whales in 1985 for the southern Alaska Peninsula (Shumagin area) at 244, which would give an estimate of 24 transients. John Durban (NMML, Seattle, Wa., pers. comm.) proposed that approximately 250 transient orcas used the coastal waters between the Kenai Fjords and the central Aleutians (Amchitka Pass) at present, but how this would translate into values for 1963 is not clear. The estimate used in this model included 53 animals west of Seward (Shumagin area), 21 in the Gulf of Alaska, and 11 in Prince William Sound estimated by the stock assessment report (Angliss and Lodge 2002), which equates to 85 animals (0.0007 t·km^{-2}). Angliss and Lodge (2002) suggested that the minimum mortality rate due to commercial fisheries was 0.6 animals year^{-1} from 1994-1998.

Toothed whales

Toothed whales include beaked whales (Baird's, Cuvier's and Stejneger's), sperm whales and resident killer whales. The biomass of beaked whales (0.004 t·km^{-2}) was assumed to be similar to that estimated for the Aleutian Islands (Heymans, this volume) and there was no trend information for beaked whales. The abundance of resident killer whales was given by Angliss and Lodge (2002) as 68 whales in unassigned pods (west of Seward) and 341 whales in Prince William Sound, for a total biomass of 0.003 t·km^{-2}. An increase of 2% per year from 1985-1991was recorded in Prince William Sound by Matkin and Saulitis (1994 in Angliss and Lodge 2002) however, no trend was available for the whole area or the whole time period. Killer whales are affected by groundfish trawlers, longlines and pot fisheries, with an annual average of 1.4 kills recorded for 1995-1999 (Angliss and Lodge 2002), similar to the 2 animals killed by the groundfish fishery in 1990 (Perez 2003), which I used for the bycatch of killer whales in 1963.

Sperm whale corrected abundance was taken from Whitehead (2002) as 24,000 animals in the Eastern temperate North Pacific, which was prorated by the area of the Gulf of Alaska (291,840 km²) and Area 67 (7,503,000 km²). Calkins (1987) suggested that they stay in the Gulf for about 120 days, and that only the large males go up there to feed, so using the ratio of males to females in the eastern population (Gosho and Rice 1984) and the proportion of adults (72% from Guénette, this volume) gave an estimate of 90 animals year round, or 2,412 tonnes. Using the population trajectory for the world given in Whitehead (2002) the biomass was estimated at 3,919 tonnes in 1963. Without other information I used the same biomass for resident killer and beaked whales for 1963 and calculated a total biomass estimate of 0.0207 t·km^{-2}.

Perez (2003) showed that 6 sperm whales were taken in 1996 and 4 in 1999, giving an average of 1 year^{-1} sperm whale taken for the 10 years of his data. I assumed that the bycatch would be the average (1 sperm whale) for 1963, and that the bycatch equalled 4 killer whales in 1999. For sperm whales caught by commercial whaling, I used the same estimate as for the Aleutian Islands (Heymans this volume), or 0.0006 t·km^{-2} ·year^{-1} for 1963, giving a total catch of toothed whales of 0.0006 t·km^{-2}·year^{-1} for 1963.

Baleen whales

Baleen whales include gray, fin, sei, humpback and blue whales. Gray whale abundance estimates were given by Angliss and Lodge (2002) at 26,635 in the Eastern North Pacific, while Wade (2002) estimated the same population at 17,127 and 13,012 animals in 1977 and 1963 respectively. Prorating by area and assuming that they are only in the Gulf of Alaska for 45 days (Calkins 1987) indicated that there were 62, 82 and 128 gray whales in the Gulf year round. Gray whales were incidentally killed by gillnet and salmon purse seine fisheries (Angliss and Lodge 2002).

There are two stocks of humpback whales that migrate to the Gulf of Alaska to feed, the Hawaiian stock and the western North Pacific stock (Perry et al. 1999). Calkins (1987) suggested that they stay in the Gulf for 210 days. Angliss and Lodge (2002) proposed that there were 394 humpbacks in the western North Pacific stock, or 190 in the Gulf year round. Similarly, Rice and Wolman (1981 in Calkins 1987) estimated the western stock to be 306, or 176 year round in the late 1970s. Using the ratio of the total population in 1963 to that in the 1999 (Guénette and Salter, this volume) gave an estimate of 176 western humpbacks in the Gulf in 1963. For the central Pacific stock, the estimate in the late 1990s was 200 whales in Prince William Sound and 651 in the Kodiak area (Waite et al. 1999 in Angliss and Lodge 2002), or a total of 714 humpbacks year round in the late 1990s, using the same residence time. The ratio of the north Pacific stock in 1963 and 1999 (Guénette and Salter, this volume) were used to calculate the ratio of the central stock in 1963 at 411. Thus the total population of humpbacks in the Gulf of Alaska in 1963 was 601 animals. The average weight of a humpback whale is 30,408 kg (Trites and Pauly 1998) and there were no estimated bycatch for the western stock of humpback in the Gulf of Alaska (Angliss and Lodge 2002). Bycatch in the central Pacific stock included 1.2 whales annually by the Southeast Alaska salmon drift gillnet, purse seine and crustacean pot fisheries.

Fin whales of the Northeast Pacific stock range from California to the Gulf of Alaska in summer (Angliss and Lodge 2002). The population model constructed by Guénette and Salter (this volume) for the whole of the North Pacific estimated the abundance at 27,788 in 1963, 12,934 in 1977 and 23,897 in 1999. Calkins (1987) found that they stay in the Gulf of Alaska for 150 days, and using the ratio of the Gulf vs. the whole North Pacific yielded estimates of 83, 39 and 71 respectively for the Gulf of Alaska in 1963, 1977 and 1999.

Minke whales in Alaska are considered a separate stock from those in California, Oregon, and Washington (Angliss and Lodge 2002). Zerbini et al. (2003) estimated the abundance of minke whales in the Gulf of Alaska and Aleutian Islands, and Sarah Gaichas (NMFS, Seattle, Wa. pers. comm.) estimated the population in the central Gulf of Alaska at 105 whales. Minke whales have never been exploited commercially in the Gulf, and I assumed that the population has been stable over time.

Thus, the total biomass estimates for baleen whales were 0.08 t·km^{-2} in 1963, 0.06 t·km^{-2} in 1977 and 0.07 t·km^{-2} in 1999. Total catches included bycatch of fin, gray and humpback whales and the total catch of baleen whales made by the whaling industry on a per area basis. The catches made of fin, sei, humpback and gray whales were obtained from Guénette and Salter (this volume) while the catches made of blue whales were obtained from Heymans (this volume). I used the same exploitation rate as was used by Guénette (this volume).

Steller sea lions

Steller sea lion bycatch estimates were obtained from Trites and Larkin (1992) for 1956 to 1990, and was assumed to be augmented by indiscriminate shooting estimates obtained from Alverson (1992). The bycatch estimates given in Trites and Larkin (1992) were prorated by area for the Aleutian Islands and the Gulf of Alaska. Estimates of Steller sea lion bycatch from 1990-2002 by the trawl fleet was obtained from Perez (2003) and I assumed that during that time the incidental catches by other fleets including the salmon fleet, indiscriminate shooting and marine debris entanglement were the same as in 1990. The directed harvest of pups also came from Trites and Larkin (1992) and subsistence catches of both Steller sea lions and harbour seals for 1992-2001 were obtained from Wolfe et al. (2002). These catch estimates were used in conjunction with the age-structured population model (Guénette, this volume) to calculate the changes in population structure over the past 40 years. The model reproduced the population trend given by Trites and Larkin (1996) relatively well (Figure 3) by using one multiplier of survival for both the adult and pup populations (Figure 4). However, the initial population was much higher than that given by Trites and Larkin (1996) as they did include all the catches in their model. The initial population calculated by the Solver routine (in Microsoft Excel ©) was 176,340 sea lions. The breakdown of pups, adults and juveniles in the population was used to estimate what proportion of the catch were juveniles or adults (Figure 5).

The total mortality of adults, pups and juveniles were estimated as the slope of the regression line between the age classes and the numbers at age, giving a total annual mortality rate of 0.17 for adults, 0.24 for juveniles, 0.52 for pups, and I used 0.02 similar to that used in both the SEAK and AI models for the embryo stanza.

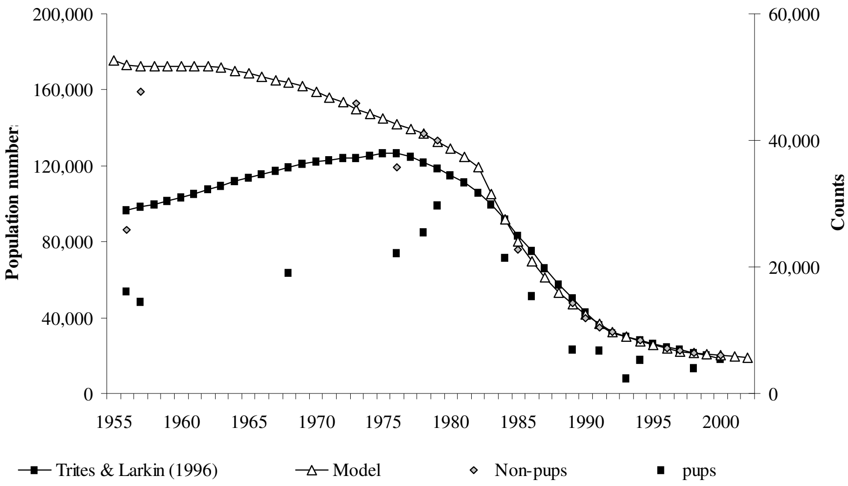


Figure 3. Counts of non-pups (diamonds) and pups (squares) in the Gulf of Alaska and population estimates given by Trites and Larkin [, 1996 #17] and estimated by the age structured model.

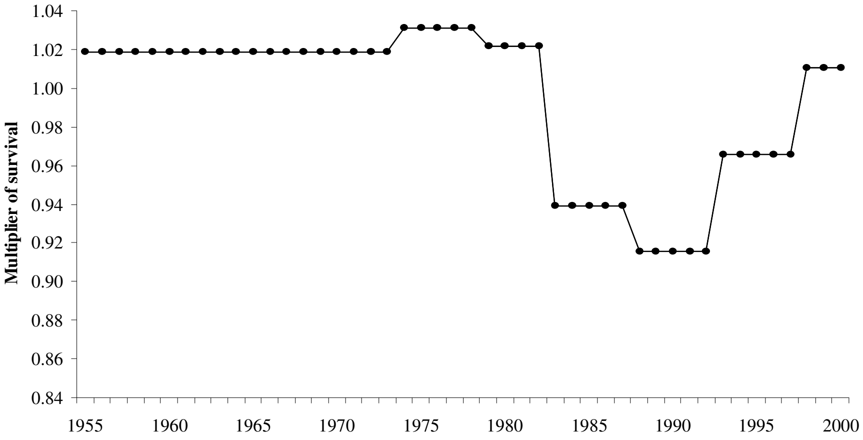


Figure 4. Multiplier of survival used on both adult and pups of Steller sea lions.

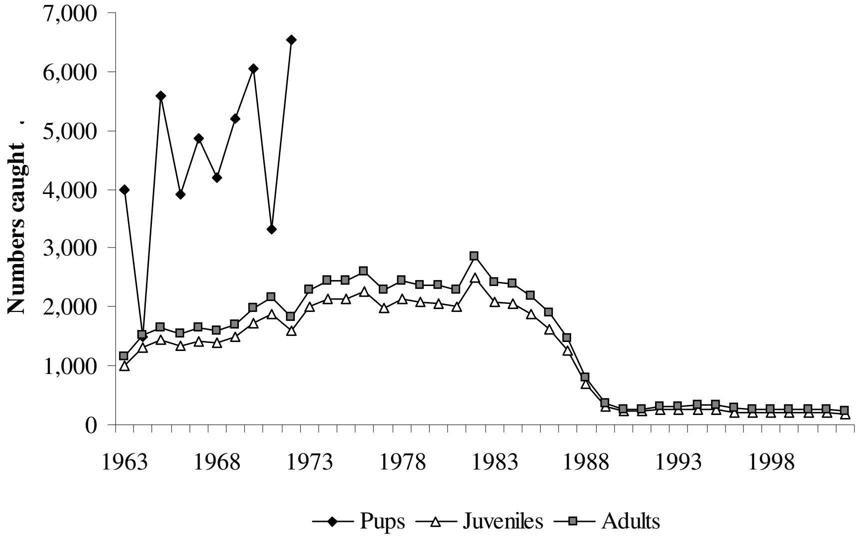


Figure 5. Catch (numbers) of Steller sea lion pups, juveniles and adults in number from 1963-2002.

Small marine mammals

Harbour seal kills were made by fishermen and hunters even as early as the 1940s (Imler and Sarber 1947). Pitcher (1977) reported that 30,250 harbour seals were killed from 1951-1958, and I distributed those catches equally between the years. Pitcher (1977) also found that the peak catch was 50,000 animals killed in southern Alaska in 1965 after which the harvest dropped due to low prices and stabilized at 10,000 animals by 1971-72. I assumed that 66% of the catch was taken in the Gulf of Alaska and 33% in Southeast Alaska. Thus, 33,333 animals were shot in 1965 and 6,667 in 1972. I linearly increased the catch from the 3,781 in 1958 to 33,333 in 1965 and used the ratio of kills made in Tugidak Island from 1966-1972 (Pitcher 1990) to estimate the total catch in the Gulf of Alaska. The total harvest of harbour seals ceased (except for native subsistence catches) after 1972 when the Marine Mammal Protection Act was instituted (Pitcher 1977). The bycatch of harbour seals was estimated at 35 animals per year by Angliss and Lodge (2002). This is similar to the estimates of between 0 and 38 given by the mammal bycatch database of the joint venture and domestic trawlers, and I used it as an average estimate of bycatch for the whole time period (Perez 2003).

Estimates of harbour seal stock size ranged from 6,000 in Copper River Delta in 1945 (Imler and Sarber 1947), through 17,000 in Tugidak area in 1956 (Mathisen and Lopp 1963 in Pitcher 1990). The Tugidak Island population was only rivalled by the counts made in the Bering Sea (Pitcher 1990), so I assumed that this would be the largest haulout. Pitcher (1990) found a 27% decline from 1964 to 1972, mainly due to the large harvest, but his simulation model was unable to reproduce the 72-85% decline seen in the counts made from 1976-1988. Small (1997 in Angliss and Lodge 2002) suggested that the Tugidak population had increased from 769 in 1992 to 1,420 in 1996 and I assumed that they increased in the same proportion as the Kodiak Island (Small et al. 2003) population from 1997-2000. For the 1963 biomass, I used the 20,622 estimated for Tugidak by Pitcher (1990), added to the 4,000 estimated for Prince William Sound in 1973 by Pitcher and Vania (1973 in Pitcher 1977), the 3,157 seals in Kodiak in 1993 (Small et al. 2003), the 6,000 estimated for the Copper river delta in the 1940s by Imler and Sarber (1947), and the 2,244, 713 and 3,200 seals in Cooke, Kenai and Southern Peninsula populations estimated by Angliss and Lodge (2002), giving an estimate of 39,936 harbour seals in 1963. In 1977 the abundance would have been reduced to 31,666 due to the decline in Tugidak, and by 1999 the abundance was down to 17,180 due to a decrease in the Prince William Sound and Tugidak populations.

The stock size of Pacific white sided dolphins was estimated by Buckland et al. (1993 in Angliss and Lodge 2002) at 26,880 dolphins in the area north of 45˚N (area 67). The minimum total annual mortality was 3 dolphins from 1990-1998 (Angliss and Lodge 2002). Harbour porpoise stock size was estimated at 21,451 animals in an area of 119,183 km² or 52,526 in the total Gulf of Alaska, and the total bycatch by the fishery was 24.7 animals from 1990-98 (Angliss and Lodge

2002). Dall's porpoise population estimates given by Angliss and Lodge (2002) were 106,000 animals in the Gulf of Alaska, but when corrected for vessel attraction (Turnock and Quinn 1991 in Angliss and Lodge 2002) it was reduced to 21,200 animals. Their reported annual bycatch in the Gulf of Alaska, Bering Sea and Aleutian Islands was 42 animals or 11 animals in the Gulf of Alaska alone for 1990-1998, which was consistent with the 4-6 year^{-1} animals caught by domestic trawlers from 1990-1997 (Perez 2003).

The total abundance of small mammals in 1963 was therefore 39,936 harbour seals, 32,857 fur seals, 344 Pacific white sided dolphins, 52,526 harbour porpoises and 21,200 Dall's porpoises, giving a total biomass of 0.022 t·km^{-2}. The changes in harbour and fur seals decreased the biomass to 0.02 t·km^{-2} and 0.016 t·km^{-2} in 1977 and 1999 respectively. Catches of small mammals in 1963 included 1,634 tonnes of harbour seal, 72 tonnes of northern fur seal (Guénette, this volume) and 1.7 tonnes for harbour porpoise, Dall's porpoise and Pacific white-sided dolphin, for a total catch of 1,708 tonnes.

Sea otters

Doroff and Gorbics (1998 in Angliss and Lodge 2002) estimated that there were 645 sea otters in the northern Gulf of Alaska in 1996, while the estimates in Prince William Sound (13,234) and Cooke Inlet/Kenai Fiords (2,673) were made by the USGS (Unpublished data in Angliss and Lodge 2002). In the western stock, the USFWS estimated the otter population at 2,392 offshore on the South Peninsula, 5,212 on the South Peninsula shoreline, 964 on the South Peninsula islands, 100 at Unimak Island, 5,893 on the Kodiak Archipelago and 6,918 in Kamishak Bay in 2001-2002 (Unpublished data in Angliss and Lodge 2002). Thus the total population in the Gulf of Alaska was 38,031 sea otters in 2000.

Historic estimates of the population was available from Bodkin et al. (1999) but only in logarithmic graph format. The only population for which any information was available prior to the 1980s is that of Fox Island which showed an increase. I assumed that all the populations had the same magnitude of increase over the early period. The western population had declined since the early 1990s, with the Fox Island population declining from 1458 in 1992 to 640 in 2000 (Doroff et al. 2003), the Peninsula and Kodiak populations declining from 27,000 and 13,200 in 1994 (U.S.F.W.S. 1994) to 6,176 and 5,893 in 2001 (Angliss and Lodge 2002) respectively. In contrast, the Kenai population had increased over that time, with Prince William Sound showing a reduction after the oil spill (U.S.F.W.S. 1994) and a quick recovery to 1999 (Angliss and Lodge 2002). Estimates of the different population trajectories are given in Figure 6, with points being estimates and lines indicating interpolation.

Estimates of subsistence harvest for 1989-2000 in south-central Alaska and western Alaska were used to calculate the average subsistence catch from 1963-1988 (Angliss and Lodge 2002). The estimates for the Aleutian Islands were prorated and subtracted from that of Western Alaska (Heymans, this volume).

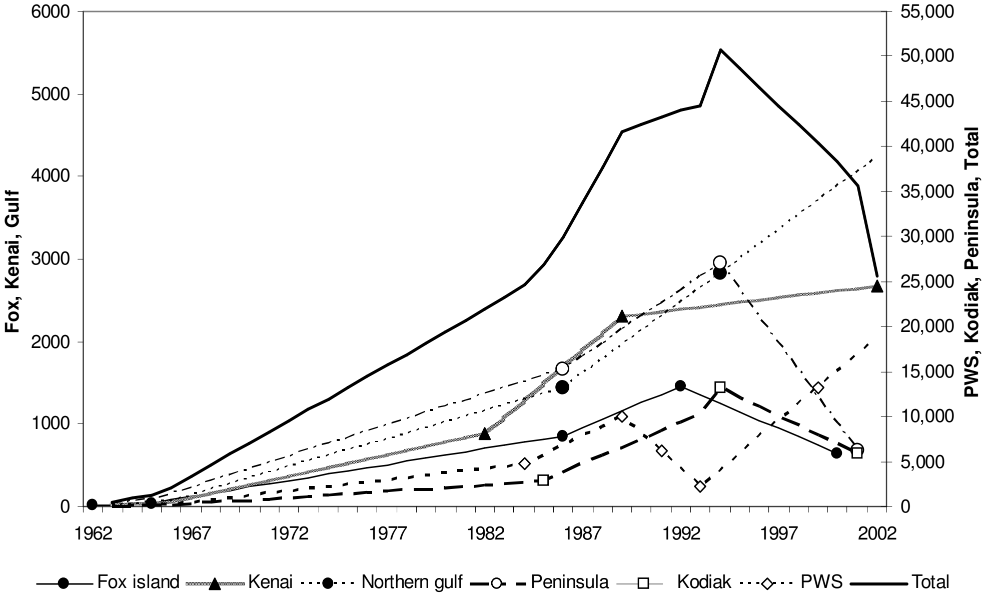


Figure 6. Population trajectories estimated for the six sea otter populations in the Gulf of Alaska. Note lines are interpolation, and marks are estimates obtained from the literature. The total estimate is the sum of the individual estimates.

Fish

Groundfish time series catch and biomass estimates were obtained from the SAFE stock assessment documents for the Gulf of Alaska where available (NOAA 2003). For pollock, arrowtooth flounder, Pacific Ocean perch and sablefish catch and biomass estimates were available from the early 1960s to present, while for Atka mackerel, Pacific cod and slope rockfish catches were only available from 1979 onwards (NOAA 2003). Historic catches for these and other species were obtained from Forrester et al. (1978; 1983), while the groundfish landings table in the introduction to the SAFE document (NOAA 2003) also gave historic catches for some species, viz. Pacific cod.

Salmon catches prior to 1997 were obtained from a report on historical catches by Byerly et al. (1999), while catches for 1998-2002 were obtained from various sources: Prince William Sound catches were obtained from Gray et al. (2002) until 2001; the lower Cook Inlet catches and average weight were obtained from Hammarstrom and Dickson (2004); the upper Cook Inlet catches and average weight were obtained from Fox and Shields (2003); Kodiak and Chignik catches and average weights were obtained from the internet (http://www.cf.adfg.state.ak.us/geninfo/finfish/salmon/catchval/blusheet/02exvesl.php); South Peninsula catches and average weights were obtained from for the season summaries (Shaul et al. 2000; Shaul et al. 2001; Shaul et al. 2002), while 1998 and 1999 catches were obtained from Arnie Shaul (State of Alaska, Department of Fish and Game, *pers. comm.*). No estimates of biomass or fishing mortality of salmon were available for the Gulf of Alaska, thus I used the F and u (Catch/biomass) calculated by Gu ette (this volume) for Southeast Alaska, to calculate the probable biomass in the Gulf of Alaska.

The Atka mackerel stock assessment report (Lowe and Lauth 2003) gave no indication of stock size, but did give estimates of catches from 1977-2002, while the catches prior to 1977 were obtained from Forrester et al. (1978; 1983).

Herring catches and biomass estimates for the Prince William Sound (1979-1999) were obtained from Johnson et al. (2002), while catches for the Kodiak region (1964-2002), the South Peninsula (1979-2002) and the Upper Cooke river (1973-2002) were obtained from Gretsch (2004), Duesterloh and Burkey (2003) and Fox and Shields (2003), respectively. No estimates of biomass were available for these areas, but guideline harvest levels of 20% were given for the Kodiak region from 1979 to 2003 (Gretsch 2004). The guideline levels and biomass estimates in Prince William Sound were used as the minimum biomass estimate for this group.

For pollock, the age 2+ biomass from 1969-2002 and the catch from 1964-2002 were obtained from Dorn et al. (2003), while the catch for 1963 came from Forrester et al. (1978). Pollock biomass was estimated as 349,728 tonnes for 1962 (Ronholt et al. 1978 in Dorn et al. 2003), and that was used as an estimate of biomass for 1963.

The Pacific Ocean perch stock assessment data (Hanselman et al. 2003) was used for catch and biomass estimates from 1963-2002, and the catch used by Guénette (this volume) for the Southeast Alaska model was subtracted from the total catch.

The various rockfish assessments (Clausen et al. 2003a; Clausen et al. 2003b; Courtney et al. 2003; Gaichas and Ianelli 2003; Lunsford et al. 2003; O'Connell et al. 2003) gave estimates of biomass, but stock assessments were not done for all the species. The northern rockfish assessment was only performed from 1977 onwards (Courtney et al. 2003), and the thornyhead assessment (Gaichas and Ianelli 2003) from 1967 onwards, thus no estimates of biomass were used in this model. The total catch of slope rockfish was obtained from NOAA (2003).

Sablefish biomass and catch estimates came from the stock assessment for the whole Gulf of Alaska (Sigler et al. 2003) from which the SEAK biomass was subtracted (13%, Guénette, this volume) to obtain the biomass for the central Gulf of Alaska. Similarly, catch estimates for SEAK (Guénette, this volume) was subtracted from the total catch in the Gulf of Alaska to obtain the catch in the central Gulf of Alaska.

For Pacific cod, the age 3+ biomass for 1978-2002 obtained from Thompson et al. (2003) was assumed to be 95% in the Gulf of Alaska and 5% in Yakutat/Southeast Alaska (Guénette, this volume). Pacific cod catches from 1963-1977 were obtained from NOAA (2003), and catches for 1978-2002 came from the stock assessment report (Thompson et al. 2003). The catch used by Guénette (this volume) for the SEAK model was subtracted from the total catch given above.

Halibut catches for areas 3A and 3B were obtained from Clark and Hare (2003) for 1974-2003 and from Forrester et al. (1978; 1983) prior to 1974. Biomass estimates and fishing mortality was only available for area 3A (from Kodiak to

Southeast Alaska), and were obtained from Clark and Parma (1999). I estimated the biomass in area 3B by assuming a similar F to that in area 3A.

Arrowtooth biomass and catch estimates came from the stock assessment report (Turnock et al. 2003) and it was assumed that 13% of the biomass was part of the SEAK model (Guénette, this volume). Similarly, catches estimated for SEAK (Guénette, this volume) was subtracted from the total catch in the Gulf of Alaska for the present model.

The catch for shrimp was obtained from the Alaska Department of Fish and Game reports (ADFG 2002; Trowbridge and Bechtol 2003) for the westward region (Kodiak, Chignik and the Peninsula) and for the lower Cooke Inlet. Estimates of CPUE were obtained from Anderson et al. (1997).

Zooplankton and phytoplankton

Estimates of zooplankton and chlorophyll-a biomass were obtained for the eastern subarctic Pacific from 1960-1994 in mg m^{-3} (Sugimoto and Tadokoro 1997). These values were taken for selected areas only, and did not always encompass the inshore areas, thus they were only used as an index of change.

Production and consumption ratios

The preliminary P/B and Q/B ratios obtained from Sarah Gaichas (NMFS, Seattle, Wa., *pers. comm.*) did not necessarily relate to the 1963 model, and I therefore used the natural mortality plus fishing mortality where possible to estimate P/B ratios. For most fish species and large mammals, I used this formulation, but for some species, where there was a catch but no biomass was available (viz. salmon, rockfish, sablefish and Pacific cod), I used the average P/B ratio obtained from the Aleutian Islands (Heymans, this volume) and Southeast Alaska (Guénette, this volume) models for 1963 on the assumption that the Gulf would be somewhere between those two models. For sea otters and birds, the assumption was that their P/Bs would be similar to that of the Aleutian Islands, while for Steller sea lions, I used the population model data (see above). For some species, such as pollock, herring, shrimp, benthic invertebrates, epibenthos, large and small zooplankton, phytoplankton and macrophytes, I assumed that the P/B was similar to that obtained for Southeast Alaska, because herring, shrimp and epibenthos were not caught in the Aleutian Islands at that time and I assumed that the zooplankton, phytoplankton and macrophytes were similar to that in Southeast Alaska.

The Q/B ratios for all mammals, birds and Atka mackerel were assumed to be similar to that of the Aleutian Islands, while all other Q/B ratios were set to be similar to the Southeast Alaska model with the exception of Pacific Ocean perch, where the P/Q ratio was set to 0.2 to estimate a Q/B of 0.95 $year^{-1}$. The input data and values estimated by Ecopath for the 1963 model are given in Table 2.

BALANCING THE MODEL

The major imbalance in the model was sea otters (which probably had too high a catch for 1963), small mammals and baleen whales. To balance sea otters, I re-evaluated the catch and biomass estimates of otters as their fishing mortality was too high. I had assumed that the 1963 catch would be similar to the average First Nations catch for 1989-2000, but the catch over that time had increased substantially, so I used the average catch for the first four years (0.000008 $t{\cdot}km^{-2}{\cdot}year^{-1}$). Also, the diet of transient orcas included 0.6% sea otters, as it was taken from the preliminary model from NMFS, but if there really were so few otters in 1963, their contribution to orca diet would be much less. I therefore decreased their contribution to the orca diet to 0.1% and increased that of juvenile Steller sea lions to 0.7% and added 0.1% to seabirds, as orcas are known to feed on seabirds. The EE was then reduced to 3.1, and I let Ecopath estimate the biomass of sea otters (0.000132 $t{\cdot}km^{-2}{\cdot}year^{-1}$). I then used that biomass as a starting biomass for the time series of sea otters.

Small mammals catches were very high with large numbers of harbour seals being caught leading up to 1965. Thus, I increased the P/B from the natural mortality of $0.17{\cdot}year^{-1}$ to be similar to the P/B in SEAK (0.22 $year^{-1}$) and let Ecopath estimate a negative biomass accumulation (-0.0016 $t{\cdot}km^{-2}{\cdot}year^{-1}$) by entering an EE of 0.95.

Baleen whales were unbalanced due to the high predation by transient killer whales. The diet of transient killer whales obtained from NMFS consisted of 10% gray whales, 32% humpbacks and 48% fin whales, which all added up to 91% for baleen whales in our model. This was not realistic, and caused the imbalance of baleen whales. I therefore modified the diet which now consisted of 10% baleen whales, 0.8% Steller sea lion pups, 43% juveniles, 45% adult, 1% small mammals and 0.1% each of sea otters and birds.

Table 2. Input data for the 1963 model of the Gulf of Alaska. Values in bold were estimated by Ecopath.

	Group name	Biomass t·km^{-2}	P/B year^{-1}	Q/B year^{-1}	EE	P/Q	Catch t·km^{-2} ·year^{-1}
1	Transient orca	0.0007	0.03	10.00	**0.22**	**0.003**	0.000005
2	Toothed whales	0.021	0.06	11.07	**0.51**	**0.005**	0.000632
3	Baleen whales	0.081	0.10	7.11	**1.63**	**0.014**	0.006340
4	Steller embryo	0.00003	0.02	217.31	**0.00**	**0.000**	
5	Steller pup	0.001	0.52	82.10	**0.46**	**0.006**	0.000288
6	Steller juveniles	0.018	0.24	38.93	**0.12**	**0.006**	0.000482
7	Steller adult	0.088	0.17	25.55	**0.09**	**0.007**	0.001090
8	Small mammals	0.022	0.17	22.74	**1.65**	**0.007**	0.005850
9	Sea otters	0.00004	0.12	86.40	**12.81**	**0.001**	0.000021
10	Birds	**0.015**	0.11	65.35	0.95	**0.002**	
11	Sharks mammal eater	**0.0007**	0.13	1.30	0.95	**0.100**	
12	Sharks and skates	**0.236**	0.11	1.20	0.95	**0.092**	
13	Salmon	**0.622**	1.31	7.30	0.95	**0.180**	0.131000
14	Large pelagics	**0.011**	0.22	1.10	0.95	**0.200**	
15	Small pelagics	**2.746**	0.89	4.45	0.95	**0.200**	
16	Atka mackerel	**0.238**	0.34	5.65	0.95	**0.060**	
17	Sandlance	**1.007**	0.73	5.75	0.95	**0.127**	
18	Herring	**0.034**	1.10	5.50	0.95	**0.200**	0.003010
19	Juvenile pollock	0.099	1.20	3.73	**3.12**	**0.322**	
20	Adult pollock	1.198	0.30	1.50	**4.46**	**0.200**	0.003910
21	POP	3.256	0.19	**0.95**	**0.03**	0.200	
22	Rockfish	**0.112**	0.20	0.54	0.95	**0.380**	
23	Sablefish	0.653	0.11	0.55	**0.73**	**0.200**	0.005000
24	Pacific cod	**0.236**	0.37	1.85	0.95	**0.200**	0.000569
25	Pacific halibut	**0.064**	0.42	2.15	0.95	**0.193**	
26	Arrowtooth	1.020	0.20	1.00	**1.93**	**0.200**	
27	Flatfish	**0.457**	0.19	1.32	0.95	**0.144**	
28	Small demersals	**0.125**	1.07	4.28	0.95	**0.250**	
29	Deep demersals	**0.032**	0.26	1.34	0.95	**0.195**	
30	Large demersals	**0.400**	0.45	2.25	0.95	**0.200**	
31	Small deep	**0.646**	0.56	4.00	0.95	**0.140**	
32	Shrimp	**1.120**	1.00	6.67	0.95	**0.150**	0.015727
33	Epibenthic carnivores	**9.256**	2.00	17.00	0.95	**0.118**	
34	Benthic invertebrates	**1.146**	0.98	6.53	0.95	**0.150**	
35	Cephalopods	**0.662**	2.55	10.00	0.95	**0.255**	
36	Large zooplankton	**8.190**	4.30	16.90	0.95	**0.254**	
37	Small zooplankton	**23.389**	20.00	112.00	0.95	**0.179**	
38	Phytoplankton	**16.843**	100.00	-	0.95	-	
39	Algae	**0.182**	4.40	-	0.95	-	
40	Detritus	-	-	-	**1.24**	-	

For pollock, the diet of the predators of both adults and juveniles had to be changed, as this species was probably not as prevalent in the ecosystem in the early 1960s as it was in 1991. Juvenile pollock contributed 16.7% to the diet of birds in this model, and I reduced it to 3.7% (similar to the Aleutians model) and added 7% herring, 3% Atka mackerel and 3% juvenile Pacific cod, which reduced the EE to 2.2. Adult pollock was consumed mostly by juvenile (37.9%) and adult (40.4%) Steller sea lions and I revisited the diet of Stellers by using the estimates obtained from Fiscus and Baines (1966) for juvenile (1-2 years old) and adult (> 2 years) in the Gulf of Alaska region. The diet consisted of mainly capelin and sand lance for both adults and juveniles (Table 3) and I assumed that the Pleuronectidae was equally divided into flatfish, halibut and arrowtooth flounder while Cottidae was equally distributed between small and large demersals, rockfish into Pacific Ocean perch and other rockfish, and unidentified fish included all the species found in the 1990s diets (Trites et al. 2004 in press).

The diet in Table 3 excluded birds for the diet of Stellers, which were included in the 1990s diet obtained from NMFS, reducing the consumption of birds to such low estimates that Ecopath was unable to estimate biomass for herring, which was one a prey species for birds. Thus, I included birds in the diet of sharks and skates, by reducing the adult pollock in the diet of sharks and skates to 4.6% and include 1% birds. This estimated a biomass of 0.02 t·km^{-2} for birds, but still left the pollock unbalanced.

Table 3. Diet of adult and juvenile Steller sea lions obtained from Fiscus and Baines (1966).

Diet	Juvenile	Adult
Rockfish (and POP)	5	0
Cottidae (Small and large demersals)	6	23
Cyclopteridae (Small demersals)	3	0
Unidentified fish	3	3
Capelin (Small pelagics)	64	25
Sand lance	17	23
Pleuronectidae	1	25

One of the main predators of adult pollock was halibut, but as pollock was not as prevalent in the system in the 1960s, I reduced it to 5% (from 48.4%) which was more similar to the Aleutians halibut diet. I added 33.4% of the halibut diet to cephalopods and 10% to POP, which had a low EE. The next most important predator of adult pollock was arrowtooth flounder, whose diet contained 13.9% adult pollock. I reduced that to 5% and added the 8.9% to the deep small group (Myctophids) which was important in the Aleutian Islands model. This balanced the adult pollock with an EE of 0.995. Similarly, arrowtooth was also one of the main predators on juvenile pollock, and I reduced juvenile pollock in their diet from 11.3% to 2% and added 4.3% to the small deep (Myctophid) group and 5% to POP. I then reduced juvenile pollock in the diet of birds once more, from 3.7% to 1% and added the 2.7% to salmon (similar to Aleutian Islands), which balanced the juvenile pollock with an EE of 0.939.

The next species to balance was arrowtooth flounder, with an EE of 1.5 and whose main predator was adult Steller sea lions. As I had allocated the Pleuronectidae in the diet of Steller sea lions evenly to halibut, flatfish and arrowtooth, I reduced the arrowtooth in their diet from 8.5% to 4% and added the remaining 4.5% to other flatfish, which balanced the arrowtooth flounder with an EE of 0.919. The only other group that was unbalanced was detritus, whose main consumer was small zooplankton. I reduced the detritus in the small zooplankton diet to 20% (from 27.4%) and added the remainder to the phytoplankton, which increased phytoplankton to 65.3% and balanced the detritus.

Finally, the P/Q of rockfish was too high, so I used a P/Q of 0.2 and estimated a P/B. There were also some instances where the 1990s diet obtained from NMFS was unrealistic, although it did not cause the model to be unbalanced: I increased the proportion of POP and rockfish in the diet of Pacific cod to 0.1% by reducing the detritus to 5.7% (they were both very low <0.0001) as that would not have been realistic in a system with large numbers of POP and rockfish. The diet of mammal eating sharks in the NMFS model did not contain any mammals, as the only species for which any diet information was available was sleeper sharks. Thus, I decreased the detritus consumed by that group and added 0.1% toothed whales, 2% baleen whales, 0.2% Steller sea lion pups, 2% Steller juveniles and 4% small mammals, which was similar to the estimates in the Aleutians (Heymans, this volume). In addition, the P/B I used for small mammals did not take into consideration the full fishing mortality for that species, so I increased it to 0.43 year^{-1} (F+M) and added an Ecotrophic efficiency of 0.5 to get the model to estimate a negative biomass accumulation (0.001 t·km^{-2}·year^{-1}).

FITTING THE MODEL

The balanced model was then fitted to time series data for biomass (Table 4) and catch (Table 5). To fit the model, I had to change the W_{max}/W_{inf} ratio for Steller sea lions, as it did not give a flatline in the first run of Ecosim. The W_{max}/Ww_{inf} ratio does not apply to mammals as their fecundity does not increase with age once maturity is reached, thus I reduced the ratio to be very small (0.000001). The model was driven by fishing mortalities where available, and where no fishing mortalities and/or biomass were available, the model was forced to fit to the catch time series (similar to a simple stock reduction model). In addition, for species where the biomass estimates were very uncertain (e.g. pollock), I forced the model to follow the catch trajectory, which gave some indications of where the initial biomasses estimated by Ecopath were too low. The species that were driven by catch include toothed whales, baleen whales, small mammals, salmon, Atka mackerel, herring (< 1979), pollock (1964-1969), rockfish, Pacific cod (< 1978), halibut (< 1974), shrimp and crabs. In addition, herring, pollock, Pacific cod, sablefish and halibut were also forced to fit all catches, as their initial biomasses were not well known, and the biomass estimated by the model caused the stocks to collapse.

To fit the catches for salmon, Atka mackerel, herring, rockfish, halibut and Pacific cod I reduced their EE's to 0.1, 0.5, 0.5, 0.2, 0.2 and 0.1 respectively. However, this increase in biomass (of mostly Pacific cod and halibut) caused the adult and juvenile pollock, arrowtooth flounder and detritus to be unbalanced. Adult pollock was contributing 18.8% to the diet of Pacific cod, and I reduced it to 1%, adding 5% to Atka mackerel, 8.3% to shrimp and 4% as import, which is similar to the Aleutians diet. Halibut consumed 5% adult pollock, which was further reduced to 1% and 4% POP added to the halibut diet. The consumption of juvenile pollock by Pacific cod was reduced to 0.1% and 0.9% added as import. In addition, the annual P/B of adult and juvenile pollock were increased to 0.335 and 1.6 respectively, which is the average estimated for SEAK and Aleutians. The P/Q of pollock was not in the 0.1-0.3 range, so I changed the Q/B of adult pollock to 2.575 year^{-1}. In addition, arrowtooth was predated on by halibut, so I decreased their contribution in the diet from 3.5%

to 0.1% and add 3.4% to other flatfish. Finally, to reduce the EE of detritus, I reduced the small pelagics (main predator or large zooplankton, which consumes small zooplankton that affects detritus) in the diet of cephalopods to 10% and added 6.4% to shrimps. This reduced the EE of detritus, but not enough. The diet of benthic invertebrates were then changed from mostly detritivores (94.9% detritus reduced to 69%) to include more herbivores (26.1%).

To fit pollock catches, I increased their biomass to 1.5 t·km^{-2} and added biomass accumulation rate of 7%, and similarly, to fit sablefish I had to increase the biomass. Sablefish biomass was estimated at 0.653 t·km^{-2} in 1963 and 1.26 t·km^{-2} in 1964, so I used 0.9 t·km^{-2} to fit sablefish catches. It was only possible to reproduce sea otter catches by increasing their P/B to 0.2 year^{-1} and adding a biomass accumulation rate of 8%.

Table 4a. Biomass of toothed whales, baleen whales and small mammals (tonnes), Steller pups (number), capelin and shrimp CPUE (kg·km^{-1}), zooplankton and chlorophyll-a (mg·m^{-3}) used to fit the model.

Year	Toothed whales (t)	Baleen whales (t)	Small mammals (t)	Steller pups (number)	Capelin CPUE kg·km^{-1}	Shrimp CPUE kg·km^{-1}	Zoo-plankton mg·m^{-3}	Chloro-phyll-a mg·m^{-3}
1963	6029	22,096	5,497					
1964							348	
1965								
1966								
1967								
1968				19174			381	1.83
1969								
1970							1671	4.37
1971								
1972					23.8	605		
1973					10.13	259		
1974					12.11	513		
1975					12.37	379		2.5
1976				22186	21.31	435		
1977	4,321	15,894	6,317		2.34	217		
1978				25414	1.09	163		
1979				29728	9.67	195		
1980					15.96	149	201	0.73
1981					2.08	91	214	1.49
1982					0.26	19	215	1.18
1983						24	453	1.17
1984				21518	0.05	28	246	2.44
1985					0.1	14	175	2.15
1986				15339	0.21	8		
1987						14	227	1.14
1988						1	227	0.98
1989				6947		11	187	1.13
1990						4	194	0.95
1991				6766	0.1	12	144	2.13
1992					0.1	27	229	1.02
1993				2371		2	182	0.90
1994				5396			196	1.47
1995						19		
1996								
1997								
1998				4058				
1999	4,522	25,233	4,624					
2000								
2001								
2002								

Table 4b. Biomass of Steller sea lion adults, otters, salmon, herring, pollock, Pacific Ocean perch, sablefish, Pacific cod, halibut and arrowtooth flounder (all in tonnes) used to fit the model.

Year	SSL adult	Otter	Salmon	Herring	Pollock	POP	Sablefish	Pacific cod	Halibut	Arrow-tooth
1963	30,637	39	77,824		349,728	950,343	190,530			297,629
1964	31,239	65	118,567			933,858	368,010			300,066
1965	31,824	91	85,023			811,199	380,190			300,441
1966	32,301	117	78,365			582,311	377,580			299,979
1967	32,784	143	85,974			467,186	361,050			297,028
1968	33,318	170	70,985			409,749	448,920			294,527
1969	33,753	196	255,730		690,000	361,486	421,950			293,749
1970	34,099	222	165,813		751,000	331,002	380,190			295,652
1971	34,384	248	149,469		840,000	318,075	408,900			299,270
1972	34,608	274	59,087		1,035,000	272,470	385,410			312,150
1973	34,761	301	72,385		1,259,000	221,902	341,910			335,685
1974	35,001	327	63,739		1,797,000	184,455	305,370		74,528	375,674
1975	35,319	353	165,658		2,199,000	148,553	261,000		88,419	441,094
1976	35,435	379	211,743		2,293,000	111,130	219,240		92,517	493,033
1977	34,877	405	104,750		2,322,000	76,678	180,960		102,192	553,227
1978	33,985	432	154,938		2,589,000	62,002	187,920	420,850	100,378	601,287
1979	33,190	458	235,006	65,690	3,049,000	59,792	174,000	475,950	101,328	642,725
1980	32,179	484	262,676	79,290	3,670,000	57,604	161,820	579,500	105,820	683,860
1981	31,017	510	241,703	66,766	4,082,000	53,644	274,920	604,200	126,811	737,509
1982	29,600	536	260,776	71,153	4,023,000	51,425	312,330	647,900	184,631	795,828
1983	27,821	563	166,412	85,437	3,425,000	54,186	309,720	677,350	220,610	838,951
1984	25,575	589	277,932	106,434	2,741,000	59,945	384,540	690,650	200,000	881,441
1985	23,292	615	178,250	87,943	2,074,000	66,466	420,210	686,850	213,186	940,757
1986	20,970	641	197,608	78,581	1,869,000	76,442	404,550	698,250	193,593	1,014,229
1987	18,456	726	531,725	134,273	1,763,000	86,037	377,580	734,350	214,774	1,099,706
1988	16,144	811	565,771	121,302	1,609,000	98,155	364,530	736,250	226,455	1,155,525
1989	14,086	896	164,835	102,198	1,496,000	116,276	327,120	739,100	209,524	1,212,371
1990	11,943	913	369,401	81,360	1,491,000	133,604	293,190	741,950	206,363	1,271,122
1991	10,036	931	313,601	99,370	1,514,000	150,399	257,520	714,400	210,794	1,312,708
1992	8,951	946	274,551	27,593	1,734,000	170,660	248,820	719,150	178,382	1,357,844
1993	8,347	957	305,173	20,084	1,559,000	188,183	227,070	719,150	154,195	1,431,202
1994	7,834	1,091	276,849	22,654	1,298,000	205,758	234,030	716,300	123,961	1,490,014
1995	7,361	1,047	405,462	32,389	1,092,000	219,960	225,330	695,400	129,766	1,523,962
1996	6,915	1,002	212,177	42,105	962,000	229,166	216,630	660,250	128,358	1,565,991
1997	6,467	957	326,251	41,824	928,000	234,479	201,840	635,550	135,853	1,616,147
1998	6,028	913	313,908	30,392	828,000	237,228	206,190	616,550	123,826	1,681,867
1999	5,571	868	311,003	25,482	668,000	239,142	213,150	578,550	107,634	1,744,959
2000	5,141	823			606,000	238,680	202,710	523,450	95,321	1,794,218
2001		767			713,000	237,617	247,950	501,600	104,116	1,860,982
2002		552			995,000	235,393	234,030	486,400	111,152	1,989,864

Table 5. Catches (t) by functional group used to fit the the Gulf of Alaska model.

Year	Tooth	Baleen	Steller pup	Steller juv.	Steller adult	Small mammal	Otters	Salmon	Atka	Herring	Pollock	POP
1963	164	2,008	84	138	324	1,708	2	38,123	0	0	1,141	136,300
1964	166	1,871	32	181	422	1,959	2	62,469	0	878	1,126	243,336
1965	219	1,575	117	198	462	2,237	2	31,202	0	692	2,749	348,500
1966	255	1,503	82	184	430	979	2	48,299	0	2,967	8,932	200007
1967	260	1,537	102	196	460	399	2	18,674	0	1,962	6,276	107,944
1968	271	1,384	88	191	443	411	2	48,909	0	2,016	6,164	80,306
1969	242	1,155	109	203	472	440	2	46,910	0	1,488	17,553	53,138
1970	245	786	127	237	552	549	2	59,502	0	1,112	9,343	27,614
1971	170	664	70	258	602	520	2	46,821	0	4,325	9,458	61,390
1972	86	657	137	219	514	522	2	23,904	6,282	4,444	34,081	58,566
1973	136	519	0	278	650	95	2	20,510	10,993	9,240	36,836	42,327
1974	128	449	0	306	717	95	2	16,976	17,531	9,642	61,880	38,544
1975	123	275	0	300	702	96	2	24,628	26,563	9,541	59,512	41,348
1976	116	177	0	309	727	98	2	49,532	19,157	4,535	86,527	34,944
1977	74	175	0	273	641	91	2	51,313	19,455	4,290	118,445	16,797
1978	52	177	0	293	683	59	2	66,741	19,588	3,323	97,035	6,546
1979	42	172	0	285	662	56	2	77,090	10949	8,093	105,800	5,593
1980	16	168	0	284	660	56	2	95,524	13,166	12,101	114,851	8,200
1981	16	163	0	275	642	55	2	105,495	18,727	17,716	148,177	8,873
1982	12	166	0	341	795	56	2	112,220	6,760	11,503	168,850	7,976
1983	8	166	0	287	676	55	2	85,763	1,260	7,178	215,821	2,583
1984	7	166	0	283	667	56	2	112,170	1,153	9,467	307,712	4,449
1985	7	166	0	258	613	56	2	103,029	1,848	10,670	284,993	931
1986	7	166	0	223	531	56	2	103,133	4	14,095	89,011	1,336
1987	7	165	0	173	413	56	2	114,862	1	10,017	69,978	3,180
1988	3	164	0	95	226	56	2	116,685	0	13,626	65,758	9,710
1989	3	150	0	44	103	56	2	92883	0	3,116	78,465	13,528
1990	5	148	0	32	75	55	1	132,118	1,416	14,153	90,902	15,993
1991	3	149	0	31	72	56	2	148,125	3,258	18,892	100504	5,571
1992	3	130	0	36	85	64	4	100,326	13,834	27,582	90,897	5,940
1993	3	130	0	36	89	62	8	135,294	5,146	9,524	109,024	1,993
1994	3	135	0	35	90	58	10	133,280	3,538	6,729	107,405	1,842
1995	3	140	0	36	93	49	8	176,467	701	5,174	72,662	5,666
1996	3	135	0	29	76	50	9	105,255	1,580	4,154	51,410	8,271
1997	3	139	0	28	72	52	8	114,124	331	9,372	90,186	9,390
1998	3	366	0	26	69	56	10	126,763	317	6,215	125,162	8,961
1999	3	144	0	28	72	54	5	158,455	262	1,710	95,625	10,472
2000	3	143	0	29	75	52	8	130,212	170	1,385	73,136	10,155
2001	3	143	0	29	75	49	2	134,432	76	1,819	72,153	10,816
2002	3	0	0	25	64	45	2	60,906	84	1,830	52,015	11,728

Table 5 (cont.). Catches (t) by functional grous used to fit the the Gulf of Alaska model.

Year	Rock-fish	Pacfic cod	Halibut	Arrowtooth	Sablefish	Shrimp	Crab
1963	32	166	22,241	404	2,302	4,590	23,729
1964	0	194	22,856	407	2,187	197	33,742
1965	0	594	22,677	499	2,642	6,270	59,750
1966	0	1,373	22,612	2,447	4,705	10,930	59,326
1967	58	2,185	19,965	1,586	4,194	17,757	40,911
1968	609	855	18,626	902	9,312	15,635	23,461
1969	794	1,270	20,859	615	12,305	20,514	18,007
1970	458	1,755	20,399	429	16,534	33,288	18,812
1971	1,643	629	17,502	899	17,895	39,351	15,871
1972	2,015	3,440	15,888	2,094	26,802	37,677	20,529
1973	5,226	5,804	11,300	5,307	20,719	67,041	32,122
1974	9,540	4,977	5,962	4,714	21,150	50,323	39,142
1975	7,964	6,590	7,958	2,548	19,188	48,765	29,970
1976	7,428	6,554	8,327	2,659	21,039	53,850	34,169
1977	8,259	2,098	7,153	5,018	12,005	56,197	23,766
1978	9,090	11,933	7,026	5,350	5,670	29,611	32,856
1979	9,921	14,082	7,093	4,708	6,379	24,246	35,920
1980	12,471	34,597	7,407	5,753	6,126	14,608	35,589
1981	12,184	35,261	8,877	5,016	6,444	14,671	26,964
1982	7,991	28,736	11,078	4,491	5,731	10,220	18,370
1983	7,405	35,849	13,237	6,086	6,477	5,315	15,633
1984	4,452	23,865	16,000	3,336	7,504	2,896	11,508
1985	1,087	14,363	19,187	1,413	10,459	2,127	10,522
1986	2,981	24,859	25,167	1,028	21,347	919	7,712
1987	4,981	32,585	23,625	4,716	26,146	30	5,271
1988	13,779	33,565	27,175	4,915	30,767	11	5,507
1989	19,002	43,121	25,143	2,484	29,609	9	5,328
1990	21,114	72,376	22,700	7,505	27,067	4	3,741
1991	13,994	75,886	21,079	9,832	23,497	6	2,258
1992	16,910	80,203	21,406	15,475	22,707	52	2,543
1993	14,240	55,895	18,503	15,176	22,685	104	1,763
1994	11,266	47,241	17,354	23,224	21,340	15	1,918
1995	15,023	68,781	12,977	18,027	18,631	0	1,144
1996	14,288	67,927	14,119	22,387	15,975	0	891
1997	15,304	76,599	20,378	15,510	13,264	5	894
1998	14,402	72,114	22,289	12,787	12,760	0	665
1999	18,057	81,280	23,680	15,962	12,227	0	785
2000	15,683	66,204	20,971	23,977	13,777	0	675
2001	16,479	51,358	22,906	19,756	12,127	0	443
2002	17,128	54,460	24,454	21,108	12,484	0	0

Table 7. Balanced and fitted 1963 model of the Gulf of Alaska. Values in bold were estimated by Ecopath.

	Group name	**Trophic level**	**Biomass t·km^{-2}**	**P/B year^{-1}**	**Q/B year^{-1}**	**EE**	**P/Q**	**Catch t·km^{-2}·year^{-1}**
1	Trans killer whales	5.35	0.001	0.032	10.000	**0.220**	**0.003**	0.000005
2	Toothed whales	4.68	0.021	0.060	11.073	**0.513**	**0.005**	0.000632
3	Baleen whales	3.62	0.081	0.099	7.110	0.951	**0.014**	0.006880
4	Steller sea lion embryo	1.00	0.00003	0.020	221.191	**0.000**	**0.000**	
5	Steller sea lion pup	1.00	0.001	0.520	83.561	**0.567**	**0.006**	0.000288
6	Steller sea lion juveniles	4.44	0.017	0.240	39.629	**0.803**	**0.006**	0.000482
7	Steller sea lion adult	4.47	0.088	0.170	25.550	**0.273**	**0.007**	0.001090
8	Small mammals	4.56	0.022	0.430	22.741	0.500	**0.019**	0.005850
9	Sea otters	3.66	**0.0001**	0.200	86.400	0.955	**0.002**	0.000008
10	Birds	4.3	**0.020**	0.113	65.350	0.950	**0.002**	
11	Mammal eating sharks	4.92	**0.001**	0.130	1.300	0.950	**0.100**	
12	Sharks and Skates	4.27	**0.172**	0.110	1.200	0.950	**0.092**	
13	Salmon	3.65	**1.873**	1.314	7.300	0.100	**0.180**	0.131000
14	Large pelagics	3.88	**0.008**	0.220	1.100	0.950	**0.200**	
15	Small pelagics	3.45	**6.794**	0.890	4.450	0.950	**0.200**	
16	Atka mackerel	3.44	**1.438**	0.340	5.650	0.500	**0.060**	
17	Sand lance	3.45	**2.736**	0.730	5.750	0.950	**0.127**	
18	Herring	3.46	**0.290**	1.100	5.500	0.500	**0.200**	0.003010
19	Juvenile pollock	3.43	0.265	1.595	6.568	**0.484**	**0.243**	
20	Adult pollock	3.55	1.500	0.335	2.575	**0.816**	**0.130**	0.003910
21	POP	3.45	3.256	0.190	**0.950**	**0.928**	0.200	
22	Rockfish	3.49	**1.572**	0.107	0.535	0.200	**0.200**	
23	Sablefish	3.99	0.900	0.110	0.550	**0.461**	**0.200**	0.005000
24	P. Cod	3.72	**1.454**	0.370	1.850	0.200	**0.200**	0.000569
25	P. Halibut	4.25	**1.514**	0.416	2.150	0.200	**0.193**	
26	Arrowtooth	4.17	1.020	0.250	1.000	**0.931**	**0.250**	
27	Flatfish	3.25	**2.847**	0.190	1.315	0.950	**0.144**	
28	Small demersals	3.25	**0.605**	1.070	4.280	0.950	**0.250**	
29	Large deep fish	3.93	0.032	0.260	1.335	0.950	**0.195**	
30	Large demersals	3.51	**0.958**	0.450	2.250	0.950	**0.200**	
31	Small deep fish	3.45	**1.893**	0.560	4.000	0.950	**0.140**	
32	Shrimp	2.72	**2.823**	1.000	6.670	0.950	**0.150**	0.015700
33	Epibenthic carnivores	2.05	**35.601**	2.000	17.000	0.950	**0.118**	
34	Benthic invertebrates	2.74	**5.194**	0.980	6.533	0.950	**0.150**	
35	Cephalopods	3.69	**1.933**	2.550	10.000	0.950	**0.255**	
36	Large zooplankton	2.48	**21.986**	4.300	16.900	0.950	**0.254**	
37	Small zooplankton	2.17	**63.318**	20.000	112.000	0.950	**0.179**	
38	Phytoplankton	1.00	**51.070**	100.000	-	0.950	-	
39	Algae	1.00	**38.236**	4.400	-	0.950	-	
40	Detritus	1.00	1.000	-	-	**0.543**	-	

The model was then fitted to time series by changing the vulnerabilities of 14 groups (Table 6) and by reducing the sum of squares of the difference between the predicted biomass and the time series data. The model was fitted to the biomasses of toothed and baleen whales, Steller sea lion adults and pups, small mammals, otters, salmon, capelin, herring, pollock, POP, sablefish, Pacific cod, halibut, arrowtooth and shrimp, and was forced to fit the catches of all species for which catches were available: toothed whales, baleen whales, Steller sea lion adult, juvenile and pup, small mammals, salmon, Atka mackerel, herring, Pollock, rockfish, sablefish, Pacific cod, halibut and arrowtooth. The model was fitted using 30 spline points, and this preliminary model does not seem to fit very well. The balanced and fitted model is given in Table 7 and the diet in Table 8 and the fits of the model to catch and biomass in Figures 7 and 8, respectively. The estimated forcing function is shown in Figure 9 and compared to the Pacific decadal oscillation (PDO) and Arctic oscillation index (AOI).

Table 6. Vulnerabilities (Vuln) and biomass accumulation (BA) rates estimated to fit the model.

#	Group	Vuln.	BA (year^{-1})
1	Transient orca	>100	
2	Toothed whales	1	
3	Baleen whales	1	
7	Steller sea lion adults	1	
8	Small mammals	1	
10	Otters	>100	0.08
11	Mammal sharks	>100	
12	Sharks and skates	>100	
13	Salmon	1	
20	Adult pollock	>100	0.07*
21	Pacific Ocean perch	7.59	
23	Sablefish	1	
24	Pacific cod	1	
25	Halibut	1	
26	Arrowtooth		0.08

* Relative biomass accumulation rate (BA/B)

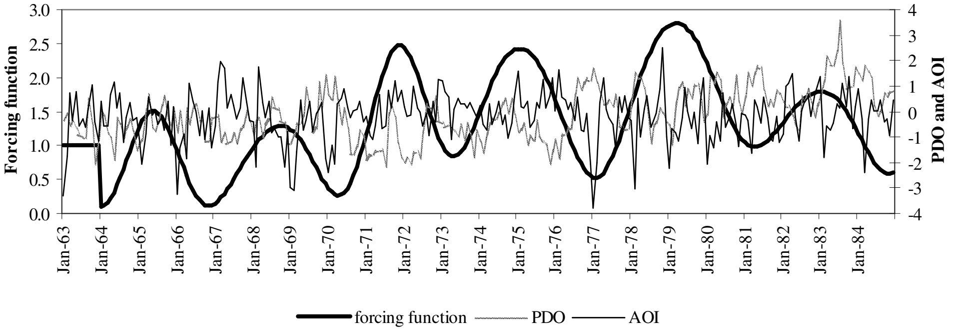


Figure 9. The forcing function estimated by the model to fit the data compared to the Pacific Decadal Oscillation (PDO) and Arctic Oscillation Index (AOI).

CONCLUSION

This is a preliminary model of the Gulf of Alaska, it should be updated and the data should be verified with Sarah Gaichas from NMFS to construct an improved model. Since the model was not fitted with much detail, the results are not conclusive.

ACKNOWLEDGEMENTS

This report was prepared under Award Number NA16FX0124/NA16FX2629 from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, through the North Pacific Universities Marine Mammal Research Consortium and the North Pacific Marine Science Foundation. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration or the Department of Commerce. I want to acknowledge and thank Sylvie Guénette and Villy Christensen for their help with the data and model, specifically Sylvie's help with the herring and Steller sea lion data. In addition. I would like to thank Ivonne Ortiz and Sarah Gaichas from NMFS for their data to construct this preliminary model. In addition, data were obtained from the National Marine Fisheries Service (NOAA) in Seattle, the Alaska Department of Fish and Game, the North Pacific Marine Mammal Consortium and the USGS.

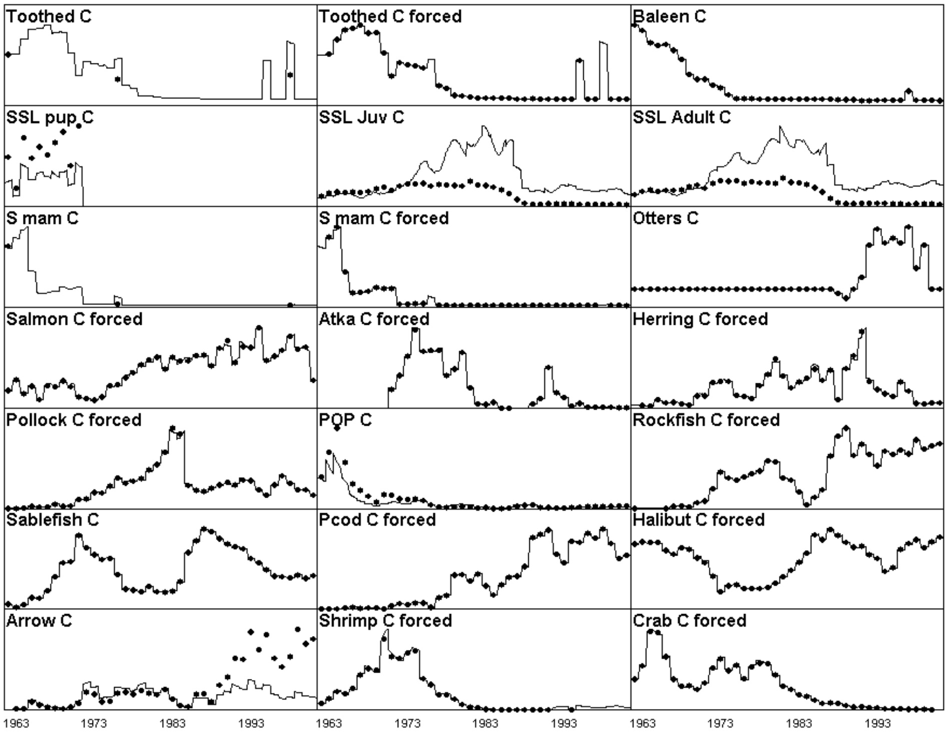


Figure 7. Fits of catches to the preliminary 1963 model. Dots indicate time series values, and lines results from Ecosim simulations.

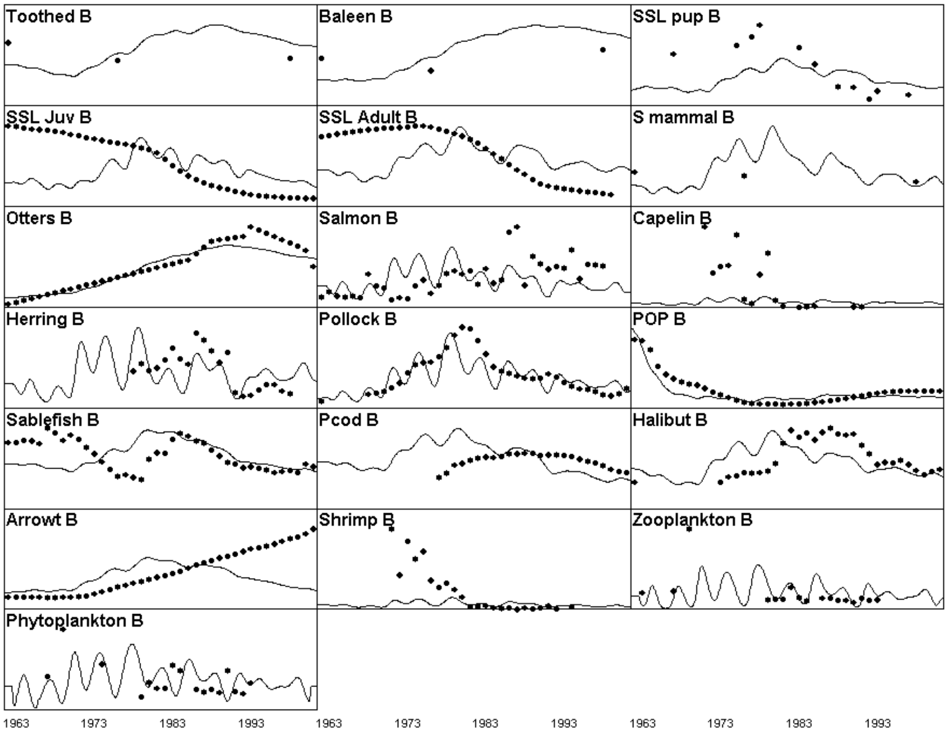


Figure 8. Fits of biomass to the preliminary 1963 model. Dots indicate time series values, and lines results from Ecosim simulations.

Table 8. Diet matrix (%) of the balanced and fitted Gulf of Alaska model.

	Prey \ Predator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Trans killer	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	Toothed whales	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-
3	Baleen whales	10	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-
4	Sea lion embryo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	Sea lion pup	-	-	-	-	-	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-
6	Sea lion juveniles	43.4	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-
7	Sea lion adult	45.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	Small mammals	1	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-
9	Sea otters	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	Birds	0.1	-	-	-	-	-	-	-	-	0.01	-	1	-	-	-	-	-	-	-
11	Mammal sharks	-	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	Sharks & Skates	-	0.40	-	-	-	0.4	0.3	-	-	-	-	0.9	-	-	-	-	-	-	-
13	Salmon	-	0.10	1.4	-	-	0.4	0.3	1.0	-	2.7	4.5	10.3	-	1.7	-	-	-	-	-
14	Large pelagics	-	-	-	-	-	-	-	-	-	-	-	0.8	-	0.3	-	-	-	-	-
15	Small pelagics	-	1.30	16.1	-	-	64.2	25.3	21.1	9.9	45.1	-	4	-	7.6	-	-	-	-	-
16	Atka mackerel	-	-	-	-	-	0.4	0.3	0.1	-	3	-	0.3	-	-	-	-	-	-	-
17	Sand lance	-	0.30	4.0	-	-	16.5	23.3	13.4	2.4	12.2	-	4.1	-	4.5	-	0.02	-	-	-
18	Herring	-	0.04	-	-	-	0.4	0.3	1.9	0.3	7	-	4.9	-	9.3	-	-	-	-	-
19	Juvenile pollock	-	0.10	1.1	-	-	0.4	-	0.4	0.7	1	-	0.6	-	1	-	-	-	-	1.6
20	Adult pollock	-	0.80	-	-	-	0.4	0.3	5.8	5.8	-	5.2	4.6	-	1	-	-	-	-	-
21	POP	-	1.90	-	-	-	2.6	-	0.4	-	0.04	0.9	0.5	-	-	-	-	-	-	-
22	Rockfish	-	2.70	-	-	-	2.6	-	0.5	0.1	0.06	1.2	0.6	-	-	-	-	-	-	-
23	Sablefish	-	2.10	-	-	-	-	0.3	0.09	-	-	-	9.1	-	-	-	-	-	-	-
24	Pacific cod	-	3.30	-	-	-	0.4	0.3	0.2	-	3	-	1.4	-	-	-	-	-	-	-
25	Halibut	-	0.20	-	-	-	0.3	8.4	0.2	-	-	0.4	1.7	-	-	-	-	-	-	-
26	Arrowtooth	-	0.80	-	-	-	0.3	4.0	0.6	-	-	67.4	6.4	-	-	-	-	-	-	-
27	Flatfish	-	0.30	-	-	-	0.3	13.0	0.2	-	-	1.5	5.4	-	0.8	-	-	-	-	-
28	Small demersals	-	2.00	-	-	-	6.6	11.4	5.9	-	-	-	3.8	-	-	-	0.01	-	-	-
29	Large deep fish	-	2.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	Large demersals	-	-	0.9	-	-	3.1	11.4	2.8	-	-	0.5	1.3	-	-	-	-	-	-	-
31	Small deep fish	-	0.10	-	-	-	0.4	0.3	1.0	-	1	-	0.2	-	1.9	-	-	-	-	-
32	Shrimp	-	-	0.5	-	-	-	-	0.01	-	0.04	0.01	15	-	3.1	-	-	-	-	7.4
33	Benthic carnivores	-	-	12.8	-	-	0.4	0.3	-	39	3.5	-	8.2	-	-	-	0.1	-	0.05	5.9
34	Benthic inverts	-	-	0.1	-	-	-	-	-	36.8	-	0.7	2.4	-	13.4	-	0.7	-	-	8.9
35	Cephalopods	-	81.40	0.3	-	-	0.4	0.3	44.3	5	9.5	5.4	3.9	19.5	9.9	-	-	-	-	-
36	Large zooplankton	-	-	51.1	-	-	-	-	-	-	6	-	5.8	59.8	33	90	87.8	90	95.7	49.8
37	Small zooplankton	-	-	11.7	-	-	-	-	-	-	5.9	-	2.7	20.7	12.6	10	11.4	10	4.3	26.4
38	Phytoplankton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39	Algae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	Detritus	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-
41	Import	-	-	-	100	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 8 continued

	Prey \ Predator	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
1	Trans killer	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	Toothed whales	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	Baleen whales	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	Sea lion embryo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	Sea lion pup	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	Sea lion juveniles	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	Sea lion adult	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	Small mammals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	Sea otters	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	Birds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	Mammal sharks	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	Sharks & Skates	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	Salmon	-	-	-	-	-	0.3	2.5	-	-	-	-	-	-	-	-	-	-	-	-
14	Large pelagics	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	Small pelagics	5.3	0.60	-	0.4	4.7	2	29.6	0.02	0.70	-	0.7	-	-	-	-	16.4	-	-	-
16	Atka mackerel	-	-	-	-	0.06	1.6	0.7	-	-	-	-	-	-	-	-	-	-	-	-
17	Sand lance	1.2	-	0.20	0.03	1.3	2.1	4.1	0.20	-	-	0.09	-	-	-	-	4.1	-	-	-
18	Herring	0.02	-	-	-	-	0.7	0.8	-	0.04	-	0.02	-	-	-	-	-	-	-	-
19	Juvenile pollock	0.9	-	1.70	2.1	0.9	0.1	2.0	0.20	0.03	-	0.9	-	-	-	-	-	-	-	-
20	Adult pollock	0.8	-	-	19.7	18.8	5	5.0	-	0.20	-	0.3	-	-	-	-	-	-	-	-
21	POP	-	-	-	-	0.1	10.2	5.0	-	-	-	-	-	-	-	-	-	-	-	-
22	Rockfish	-	-	-	0.4	0.1	-	0.01	-	-	-	-	-	-	-	-	-	-	-	-
23	Sablefish	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-
24	Pacific cod	-	-	-	-	0.01	1.4	0.01	-	-	-	0.01	-	-	-	-	-	-	-	-
25	Halibut	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26	Arrowtooth	0.01	-	-	-	1.3	3.5	0.4	-	-	-	-	-	-	-	-	-	-	-	-
27	Flatfish	0.09	-	-	-	0.5	0.7	0.09	-	0.02	-	0.5	-	-	-	-	-	-	-	-
28	Small demersals	0.09	-	0.02	0.8	4.3	1.3	2.9	0.40	1.90	-	0.5	-	-	-	-	-	-	-	-
29	Large deep fish	-	0.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	Large demersals	0.1	0.02	-	0.6	0.4	0.4	0.7	0.07	2.50	-	0.2	-	-	-	-	-	-	-	-
31	Small deep fish	0.03	1.20	0.05	1.6	0.04	-	13.7	-	-	2.3	-	-	-	-	-	4.1	-	-	-
32	Shrimp	18.4	1.30	23.70	5.5	19.9	1	12.9	18.00	26.10	77.8	7.4	-	-	-	0.02	-	-	-	-
33	Benthic carnivores	6.7	4.40	7.20	3.6	9.9	0.5	0.4	69.20	58.80	-	2.2	-	40.	4.9	69.9	7.1	-	-	-
34	Benthic inverts	1.4	0.04	6.90	2.9	24.6	29.3	0.01	5.40	8.20	-	1.0	-	-	-	0.4	10.7	-	-	-
35	Cephalopods	0.7	0.50	0.30	26.6	2.8	36.6	0.3	0.01	-	19.9	0.1	-	-	-	-	-	-	-	-
36	Large zooplankton	58.7	80.40	43.80	30.3	4.4	0.5	18.9	6.30	0.60	-	85.0	90.00	20.	-	-	49.3	0.6	-	-
37	Small zooplankton	5.4	10.90	16.10	-	0.01	-	0.01	0.20	0.90	-	0.3	10.00	-	-	-	8.2	40.0	14.7	-
38	Phytoplankton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	59.4	65.3	-
39	Algae	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2	5.5	-	-	-	-
40	Detritus	0.08	0.50	-	5.4	5.70	2.5	0.2	-	0.06	-	0.8	-	40.	94.9	24.2	-	-	20	-
41	Import	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

REFERENCES

ADFG, 2002. Annual management report for the shellfish fisheries of the westward region, 2001. Alaska Department of Fish and Game, Kodiak, AK, Regional Information Report No. 4K02-54, 41 pp.

Alton, M. S., 1981. Gulf of Alaska bottomfish and shellfish resources. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS F/NWC-10. 51 pp.

Alverson, D. L. 1992. A review of commercial fisheries and the Steller sea lion (*Eumetopias jubatus*): The conflict arena. Reviews in Aquatic Sciences, 6(3-4):203-256.

Anderson, P. J., Balckburn, J. E., and Johnson, B. A., 1997. Declines of forage species in the Gulf of Alaska, 1972-1995, as an indicator of regime shift. *In*: International Symposium on the Role of Forage Fishes in Marine Ecosystems, Anchorage, Alaska, USA, 13-16 Nov. 1996, University of Alaska Sea Grant College Program. Vol. AK-SG-97-01, 643 pp. pp. 531-543.

Angliss, R. P., and Lodge, K. L., 2002. Alaska marine mammal stock assessments. NMFS Department of Commerce, NOAA Technical Memorandum, NMFS-AFSC-133. 119 pp.

Bodkin, J. L., Ballachey, B. E., Cronin, M. A., and Scribner, K. T. 1999. Population demographics and genetic diversity in remnant and translocated populations of sea otters. Conservation Biology, 13(6):1378-1385.

Brueggeman, J. J., Green, G. A., Grotefendt, R. A., and Chapman, D. G., 1987. Aerial surveys of endangered cetaceans and other marine mammals in the Northwestern Gulf of Alaska and Southeasterns Bering Sea. OCSEAP Research Unit 673, Contract No. 85-ABC-00093.

Byerly, M., Brooks, B., Simonson, B., Savikko, H. M., and Geiger, H. J., 1999. Alaska commercial salmon catches, 1878 - 1997. Alaska Department of Fish & Game, Division of Commercial Fisheries, Juneau, Regional Information Report, 5J99-05.

Calkins, D. G., 1987. Marine mammals. *In*: The Gulf of Alaska: Physical Environment and Biological Resources. *Edited by* D. W. Hood and S. T. Zimmerman, US Government Printing Office, Washington DC. pp. 527-558.

Clark, W. G., and Parma, A. M., 1999. Assessment of the Pacific halibut stock in 1999. Pacific Halibut Commission.

Clark, W. G., and Hare, S. R., 2003. Assessment of the Pacific halibut stock at the end of 2003. Pacific Halibut Commission.

Clausen, D. M., Fujioka, J. T., and Heifetz, J., 2003a. Shortraker/rougheye and other slope rockfish. NPFMC Gulf of Alaska SAFE, 531-572 pp.

Clausen, D. M., Lunsford, C. R., Hanselman, D., and Fujioka, J. T., 2003b. Pelagic shelf rockfish. NPFMC Gulf of Alaska SAFE, 573-598 pp.

Courtney, D., Clausen, D. M., Heifetz, J., Hanselman, D., Fujioka, J. T., and Ianelli, J., 2003. Gulf of Alaska northern rockfish. NPFMC Gulf of Alaska SAFE, 481-530 pp.

Dorn, M., Barbeaux, S., Guttormsen, M., Megrey, B., Hollowed, A., Wilkins, M., and Spalinger, K., 2003. Assessment of walleye pollock in the Gulf of Alaska. NPFMC Gulf of Alaska SAFE, 33-148 pp.

Doroff, A. M., Estes, J. A., Tinker, M. T., Burn, D. M., and Evans, T. J. 2003. Sea otter population declines in the Aleutian archipelago. Journal of Mammalogy, 84(1):55-64.

Duesterloh, S., and Burkey, C. J., 2003. Alaska peninsula - Aleutian islands management area herring sac roe and food and bait fisheries annual management report, 2003. Alaska Department of Fish and Game, Kodiak, Alaska, Regional Information Report, 4K03-63. 58 pp.

Fiscus, C. H., and Baines, G. A. 1966. Food and feeding behavior of Steller and California sea lions. Journal of Mammalogy, 47(2):195-200.

Forrester, C. R., Beardsley, A. J., and Takahaski, Y., 1978. Groundfish, shrimp, and herring fisheries in the Bering Sea and Northeast Pacific - Historical catch statistics through 1970. International North Pacific Fisheries Commission, Vancouver, Canada, INPRC Bulletin, 37. 100 pp.

Forrester, C. R., Bakkala, R. G., Okada, K., and Smith, J. E., 1983. Groundfish, shrimp, and herring fisheries in the Bering Sea and Northeast Pacific - Historical catch statistics, 1971-1976. International North Pacific Fisheries Commission, Vancouver, Canada, INPRC Bulletin, 41. 100 pp.

Fox, J., and Shields, F., 2003. Upper Cook Inlet commercial fisheries annual management report, 2002. Alaska Department of Fish and Game, Anchorage, Alaska, Regional Information Report, 2A03-14. 80 pp.

Gaichas, S., and Ianelli, J., 2003. Assessment of thornyheads (*Sebastolobus* spp.) in the Gulf of Alaska. NPFMC Gulf of Alaska SAFE, 659-698 pp.

Gosho, M. E., and Rice, D. W. 1984. The sperm whale, *Physeter macrocephalus*. Marine Fisheries Review, 46(4):54-64.

Gray, D., Ashe, D., Johnson, J., Merizon, R., and Moffitt, S., 2002. Prince William Sound Management area 2001 annual finfish management report. Alaska Department of Fish and Game, Anchorage, Alaska, Regional Information Report, 2A02-20. 189 pp.

Gretsch, D., 2004. Kodiak management area herring sac roe fishery harvest strategy, for the 2004 season. Alaska Department of Fish and Game, Regional Information Report, 4K04-11. 25 pp.

Hammarstrom, L. F., and Dickson, M. S., 2004. 2003 Lower Cook Inlet annual finfish management report. Alaska Department of Fish and Game, Anchorage, Alaska, Regional Information Report, 2A04-01. 177 pp.

Hanselman, D., Heifetz, J., Fujioka, J. T., and Ianelli, J., 2003. Gulf of Alaska Pacific Ocean perch. NPFMC Gulf of Alaska SAFE, 429-480 pp.

Imler, R. H., and Sarber, H. R., 1947. Harbor seals and sea lions in Alaska. U.S. Department of the Interior, Special Scientific Report, 28. 23 pp.

Johnson, J., Sharp, D., Joyce, T., and Moffitt, S., 2002. Prince William Sound Management area 2000 annual finfish management report. Alaska Department of Fish and Game, Anchorage, Alaska, Regional Information Report, 2A02-02. 187 pp.

Lowe, S., and Lauth, R., 2003. Assessment of Gulf of Alaska Atka mackerel. NPFMC Gulf of Alaska SAFE, 699-718 pp.

Lunsford, C. R., Hanselman, D., Heise, K., Fujioka, J. T., Courtney, D., and Clausen, D. M., 2003. Dusky rockfish age-structured model. NPFMC Gulf of Alaska SAFE, 599-616 pp.

National Research Council, 2003. Decline of the Steller sea lion in Alaskan waters: untangling food webs and fishing nets. The National Academies Press, Washington, DC. 204 pp.

NOAA, 2003. Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. Introduction:. NPFMC Gulf of Alaska SAFE, 32 pp.

O'Connell, V. M., Brylinsky, C., and Carlile, D., 2003. Demersal shelf rockfish assessment for 2004. NPFMC Gulf of Alaska SAFE, 617-658 pp.

Perez, M. A., 2003. Compilation of marine mammal incidental take data from the domestic and joint venture groundfish fisheries in the U.S. EEZ of the North Pacific, 1989-2001. U.S. Department of Commerce, NOAA Technical Memorandum, NMFS-AFSC-138. 145 pp.

Perez, M. A., and Loughlin, T. R., 1991. Incidental catch of marine mammals by foreign and joint venture trawl vessels in the U.S. EEZ of the North Pacific, 1973-88. U.S. Department of Commerce, NOAA Technical Report, NMFS-104. 57 pp.

Perry, S. L., DeMaster, D. P., and Silber, G. K. 1999. The great whales: History and status of six species listed as endangered under the U.S. Endangered Species Act of 1973. Marine Fisheries Review, 61(1):1-74.

Pitcher, K. W., 1977. Population productivity and food habits of harbor seals in the Prince William Sound - Copper River Delta area, Alaska. U.S. Marine Mammal Commission, Anchorage, Alaska, MMC-75/03. 36 pp.

Pitcher, K. W. 1990. Major decline in number of harbor seals, *Phoca vitulina richardsi*, on Tugidak Island, Gulf of Alaska. Marine Mammal Science, 6(2):121-134.

Shaul, A., Murphy, B., Dinnocenzo, J., and Connolly, D., 2001. Preliminary summary of 2001 salmon season Alaska Peninsula, Aleutian Islands, and Atka-Amlia Islands. Alaska Department of Fish and Game, 12 pp.

Shaul, A., Murphy, B., Witteveen, M., Dinnocenzo, J., and Connolly, D., 2000. Preliminary summary of 2000 salmon season Alaska Peninsula Area Aleutian Islands area. Alaska Department of Fish and Game, 12 pp.

Shaul, A., Murphy, B., Dinnocenzo, J., Burkey, C., and Ford, M., 2002. Alaska Peninsula, Aleutian Islands, and Atka-Amlia Islands management areas salmon season summary, 2002. Alaska Department of Fish and Game, 10 pp.

Sigler, M. F., Lunsford, C. R., Fujioka, J. T., and Lowe, S., 2003. Alaska sablefish assessment for 2004. NPFMC Gulf of Alaska SAFE, 243-312 pp.

Small, R. J., Pendleton, G., and Pitcher, K. W. 2003. Trends in abundance of Alaska harbor seals, 1983-2001. Marine Mammal Science, 19(2):344-362.

Sugimoto, T., and Tadokoro, K. 1997. Interannual-interdecadal variations in zooplankton biomass, chlorophyll concentration and physical environment in the subarctic Pacific and Bering Sea. Fisheries Oceanography, 6(2):74-93.

Thompson, G., Zenger, H., and Dorn, M., 2003. Assessment of the Pacific cod stock in the Gulf of Alaska. NPFMC Gulf of Alaska SAFE, 149-242 pp.

Trites, A., and Larkin, P. A., 1992. The status of Steller sea lion populations and the development of fisheries in the Gulf of Alaska and Aleutian Islands. Pacific States Marine Fisheries Commission, Vancouver, BC, NOAA Report, Award No. NA17FD0177. 134 pp.

Trites, A., and Pauly, D. 1998. Estimating mean body masses of marine mammals from maximum body lengths. Canadian Journal of Zoology, 76:886-896.

Trites, A. W., and Larkin, P. A. 1996. Changes in the abundance of Steller sea lions (*Eumetopias jubatus*) in Alaska from 1956 to 1992: how many were there? Aquatic Mammals, 22:153-166.

Trites, A. W., Miller, A. J., Maschner, H. D. G., Alexander, M. A., Bograd, S. J., Calder, J. A., Capotondi, A., Coyle, K. O., Di Lorenzo, E., Finney, B. P., Fritz, L., Gregr, E. J., Grosch, C. E., Hare, S. R., Hunt, G. L., Jahncke, J., Kachel, N. B., Kim, H.-J., Ladd, C., Mantua, N. J., Marzban, C., Maslowski, W., Mendelssohn, R., Neilson, D. J., Okkonen, S., Overland, J. E., Reedy-Maschner, K. L., Royer, T. C., Schwing, F. B., Wang, J. X. L., and Winship, A. J. 2004 in press. Bottom-up forcing and the decline of Steller sea lions in Alaska: Assessing the ocean climate hypothesis. Fisheries Oceanography:1-62.

Trowbridge, C., and Bechtol, W. R., 2003. Review of commercial fisheries for Dungeness crab, shrimp, and miscellaneous shellfish in Lower Cook Inlet. Report to the Alaska Board of Fisheries. Alaska Department of Fish and Game, Kodiak, AK, Regional Information Report No. 2A03-09, 41 pp.

Turnock, B. J., Wildebuer, T., and Brown, E. S., 2003. Arrowtooth flounder. NPFMC Gulf of Alaska SAFE, 369-406 pp.

U.S.F.W.S., 1994. Conservation plan for the sea otter in Alaska. U.S. Fish and Wildlife Service, 51 pp.

Wade, P. R. 2002. A Bayesian stock assessment of the eastern North Pacific gray whale using abundance and harvest data from 1967 to 1996. Journal of Cetacean research and management, 4:85-98.

Whitehead, H. 2002. Estimates of the current global population size and historical trajectory for sperm whales. Marine Ecology Progress Series, 242:295-304.

Wolfe, R. J., Fall, J. A., and Stanek, R. T., 2002. The subsistence harvest of harbor seal and sea lion by Alaska natives in 2001. Alaska Department of Fish & Game, Division of Subsistence, Juneau, Technical Paper, No. 273. 124 pp.

Zerbini, A. N., Wade, P. R., and Waite, J. M., 2003. Abundance and distribution of fin, humpback and minke whales from the Kenai Fjords to the Central Aleutian Islands, Alaska: Summer 2001-2002. International Whaling Commission, Scientific Committee Report, SC/55/O9. 14 pp.

Models of Southeast Alaska

Sylvie Guénette[1]

Fisheries Centre University of British Columbia, Vancouver BC; *s.guenette@fisheries.ubc.ca*

ABSTRACT

The paper documents Ecopath models of the Southeast Alaska shelf, area east of 140°W. Three models, 1999, 1977 and 1963, were built in this particular order which reflects the availability of data. The more recent models served as stepping stones for building the 1963 model. They are composed of 39 functional groups including 9 mammals and 21 fish groups. The structure reflects the goal of the project, that is to examine the influence of environmental variations, predation, and fishing on the decline of Steller sea lions in Alaska. The paper recounts the steps to fit the model to time series data of biomass and catch. The model was also fit to the Pacific decadal oscillation. The calculation of fish consumption was discussed.

AREA

The study area is the shelf east of 140°W to 1000m depth here called Southeast Alaska (SEAK) (Figure 1). It includes the eastern part of the Yakutat (YKT) region (140-137°W) and southeast Alaska which is east of 137°W. The study area comprised the administrative regions 650, the exterior shelf, and 659 the interior waters (Table 1). The area of each depth strata was calculated from rasterized depth data at the 2 degree scale, except for the outside shelf, which was taken from the survey data (Britt and Martin 2001). The study area is about 91 thousand km^2 of which 89% are shallower than 300 m (Table 1). The mean annual water temperature is 10°C. The outside shelf of the study area has been under a trawling prohibition since 1998, which has considerably decreased the Pacific ocean perch and slope rockfish fishery in the area.

Table 1. Area by depth strata in Southeast Alaska

	East of 137°W		**East YKT**	**Total**
Depth (m)	**outside**	**inside**	**(137-140°W)**	**SEAK**
0-100	6,547	31,863	4,837	43,247
100-200	11,085	4,692	11,720	27,497
200-300	5,053	2,770	2,395	10,218
300-500	3,117	2,340	550	6,007
500-700	1,034	1,297	368	2,699
700-1000	1,206	195	282	1,683
Total	28,042	43,157	20,152	91,351

POPULATION RECONSTRUCTION

For most species I used the population assessment available from the Alaska Department of Fish and Game (ADFG) or the National Marine Fisheries and Service (NMFS). However, it was sometimes necessary to attempt population reconstruction to estimate biomass, especially for the 1963 model. I used a simple Schaefer model:

$$N_{t+1} = N_t + N_t \cdot r \cdot (1 - N_t/k) - C_t$$

where r is the intrinsic rate of growth, N_t is the abundance at time t, k is the carrying capacity, and C_t the catch (Hilborn and Walters 1992, p. 306). The best solution for k given a value of r and the initial abundance in the model time series (N_i) was found using the Solver routine in Excel.

---

[1] Cite as: Guénette, Sylvie., 2005. Models of Southeast Alaska. In: Guénette, S., and V. Christensen (editors). 2005. Food web models and data for studying fisheries and environmental impacts on Eastern Pacific ecosystems Fisheries Centre Research Reports 13(1):106-178.

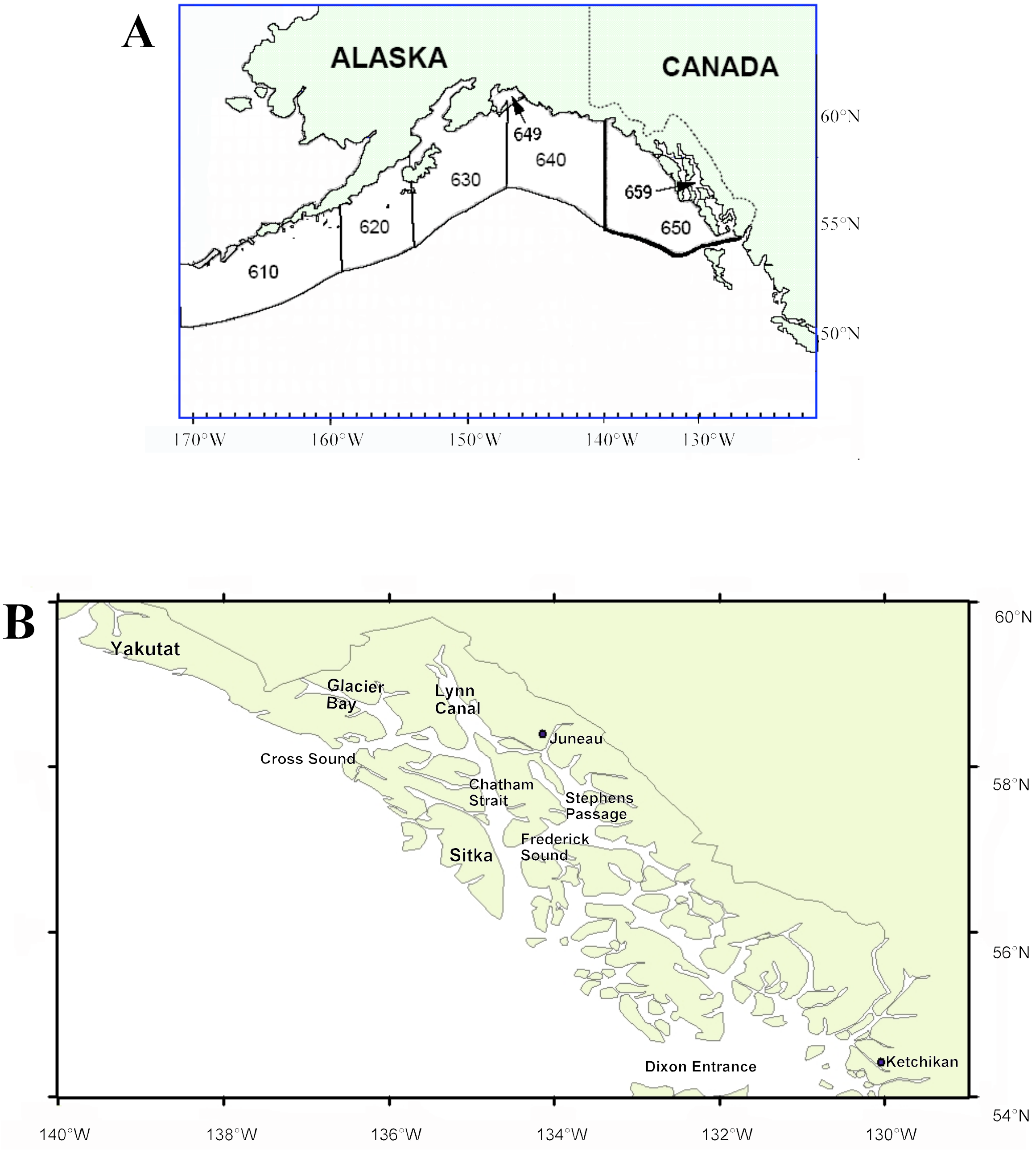


Figure 1. A. Map of the Gulf of Alaska showing the fishing reporting areas. Southeast Alaska; B. the study area, which is defined by statistical areas 650 and 659. (Modified from http://www.fakr.noaa.gov/ npfmc/current_issues/groundfish/C-1©)%20 attachments.pdf). The detailed map shows the principal cities and waterways referred to in the report.

MAMMALS

Marine mammals were divided into nine groups: transient killer whale; toothed whales (sperm, resident killer whales); baleen whales (fin, sei, humpback, minke, gray); sea lions (4 stanzas); small mammals (harbour seal, northern fur seal, Pacific white-sided dolphin, Dall's and harbour porpoises); and sea otters. Species that were deemed to feed in other areas or were present in very low numbers were not included in the model.

Parameters calculation

Consumption per unit of biomass (Q/B) was first calculated using an empirical equation for daily ration $R=0.1 \cdot W^{0.8}$, as modified from Innes et al. (1987) in Trites and Heise (1996), where W is body weight in kg and R the daily ration in $kg \cdot day^{-1}$ (method 1). Method 2 was based on energy requirements found in Perez and McAlister (1993) using the empirical equation used in Hunt et al. (2000): $E = a M^{0.75}$ where E is the energy requirement per day ($kcal \cdot day^{-1}$), M the mean body weight (kg), and a is a coefficient varying with the group of mammals (a=320 for otariids, 200 for phocids, 192 for mysticetes, 317 for odontocetes, and 320 for sea otters). In addition, the resulting values were compared to ration estimates found in the literature for individual species. I preferred direct measurements for sea lions, otters, and toothed whales. In all other cases, I kept the results from method 2 which were larger than method 1 (Table 2). The average consumption per unit of biomass has been weighted by the species biomass within the group.

Otters Q/B value calculated using method 1 (Table 2) is underestimated because of the nature of the diet composition (large proportion of the weight is non-edible material). Estes and Palmisano (1974) mentioned that sea otters in captivity eat 20 to 23% of their body weight per day which, assuming an average body weight of 23kg, yielded a Q/B value of 84 $year^{-1}$. Perez and McAlister (1993) used an energy requirement of 4,900 $kcal \cdot day^{-1}$. Assuming an average caloric value for the prey of 0.9 $kcal \cdot g^{-1}$, the annual consumption would be 86 $year^{-1}$. I used a Q/B value of 85 per $year^{-1}$.

The Q/B value for transient orca calculated in Barrett-Lennard et al. (1994) was derived based on the caloric daily consumption of captive whales fed on fish (176,000 kcal/day) increased by 25% to account for additional activity of a wild animal, divided by the average kcal contained in northern fur seals and ringed seals (3,000 kcal per kg of mammalian prey). In the case of resident orcas, their total caloric consumption was divided by the fish average kcal content (2,088 kcal per kg of fish), which amounted to 10.8 $year^{-1}$. Both these estimates compared those calculated according to method 1. However, these consumption values are based on average body weight of 3.55 tonnes and are likely to be underestimates. Assuming a mean body weight of 2,435 kg (see section on transient orca) and using method 2, I estimated Q/B at 11 and 16 $year^{-1}$ for transient and resident orcas respectively (see Table 2). In addition, transient orcas, feeding on mammals, do not utilise their prey entirely as large pieces of carcasses of baleen whales are left untouched after the choice parts have been taken (N. Friday, NMFS, Seattle, *pers. comm.*). To account for this, various scenarios of consumption and assimilation should be explored.

The production per unit biomass (P/B) was obtained by halving the value of r_{max} as published in Angliss and Lodge (2002) for large whales (Table 2). For other groups, I used estimates from direct survival measurements (e.g. sea lions) and using a life table model (Barlow and Boveng 1991) (see Table 2). Diet compositions are briefly described in each section and the resulting diet for each functional group are found in Appendix 2 for initial and balanced models.

Transient killer whale, group 1

Of the 219 transient whales (*Orcinus orca*) catalogued so far, 6% have only been seen in SEAK, 50% have been seen in SEAK and BC, and 44% in BC and WA (Ford and Ellis 1999). Between 1984 to 2002, there has been 703 sightings of 137 different whales in SEAK (Straley et al. 2003). Since 1997, 10 transients that were previously identified in Prince William Sound (PWS) have also been sighted in SEAK which may be an indication of killer whales moving into areas that have larger population of marine mammals (Straley et al. 2003). Thus, 133 transients ((50%+6%) ·219+10 from PWS) were assumed to be present in 1999. Transients are constantly travelling and may cover large distances within a month (Ford and Ellis 1999). Although they may visit the study area all year round, they stay only for brief periods at a time and nothing is known of their winter habits. I assumed that they stay in the area for 2 to 3 months, which amounted to about 26 whales year round or 0.0007 $t \cdot km^{-2}$ (Table 3). In 1977, the abundance of transient orcas may have been a bit lower given the killings by fishermen that allegedly happened in the 1960-1970s. I used a conservative value of 123 whales for 1977.

Table 2. Comparison of estimates of Q/B and annual natural mortality (M) using empirical equations and other sources. Retained values are in bold.

	Mean W (kg)	Q/B(year^{-1})				M(year^{-1})		
		Method 1 [a]	Method 2 [b]	Other sources		r/2	other	source
Transient orca			**11**			**0.02**		
	2435 [g]	7.7	11	7.5	Barrett-Lennard et al. (1994)	0.02		
Toothed whales				**11.5**		**0.02**		
Sperm whale	18518 [c]	5.1	7	**11.0**	Calkins (1986)	0.02	0.05	life table [i, m]
Resident orca	2435 [g]	7.7	**16**	10.8	Barrett-Lennard et al. (1994)	0.02		
Baleen whales		4.7	3	**10.9**		0.02	**0.034**	
Fin whale	37000 [p]	4.1	2.4	9.4	Lockyer 1981 in Trites et al. (1999) [h]	0.02	0.02	
Sei whales	16810 [c]	5.2	5.9				0.03	life table [i]
Humpback	30408 [c]	4.6	3	11.0	Matkin and Hobbs (1999)	0.02	0.02	Straley et al. (2002)
Minke whale	6566 [c]	6.3	4.6	14.6	Laws (1977)	0.02	0.04	life table [i]
Gray whale	15372 [c]	5.3	6			0.03	0.05	life table [i]
Sea lions								
0-1 year old							**0.59**	from mark-resight data (Pendleton et al. 2004) [q]
1-3 yrs old	133	13.9		**51.1**	Winship and Trites (2003)		**0.19**	
adult	279 [d]	11.1	27.4	**25.6**	Winship and Trites (2003)	0.06	**0.11**	
Small mammals		19.3	**29**				**0.21**	
Harbour seal	64 [c]	15.9	19.7	20.1	Bigg (1981)	0.06	0.23	Olesiuk (1993)
Northern fur seal	28 [c]	18.8	40.5			0.04	0.16	Wickens and York (1997)
Pacific white-sided dolphin	78 [c]	15.3	31.9			0.05	0.14	Aydin et al. (2003)
Dall's porpoise	61 [c]	16	27.3			0.02	0.1	Aydin et al. (2003)
Harbour porpoise	31 [c]	18.4	26.5	25.6	Spalding 1964 in Alaska Groundfish Fisheries (2001)	0.02	0.22	life table [i] see text
Sea otter	22 [f]	19.8		**85.0**	captive study [k]	0.1		

a. as modified from Innes *et al.* (1987) in Trites and Heise (1996); b. Perez and McAlister (1993); c. Trites and Pauly (1998); d. from life table excluding the juveniles (<4 years); e. Robson (2002); f. Kenyon (1981); g. this study, see orca section; h. 14.6 for summer and 4.1 for winter ; i. life history model after Barlow and Boveng (1991); j. based on numbers at age see the section on sea lions; k. see mammals parameters section; m. estimate not used because the reproductive cycle is of 3-6 years (Calkins 1986) which would lower r_{max}; p. Trites and Pauly (1998) estimated the mean weight of fin whales at 55,590 kg, but it was found to be closer to 37 t based on catch records (N. Friday, NMFS, Settle pers. comm.); q. see sea lions section.

Table 3. Biomass and residency time for marine mammals in the study area for 1999 and 1977. Details and sources are found in the text.

			1999				**1977**	**1963**
gr	**Species**	**resi-dency (days)**	**area**	**N**	**Narea ($year^{-1}$)**	**Biomass ($t\cdot km^{-2}$)**	**Biomass ($t\cdot km^{-2}$)**	**Biomass ($t\cdot km^{-2}$)**
1	Transient orca	73	BC- SEAK	133	26	0.0007	0.001	0.00065[g]
2	**Toothed whales**					**0.0114**	**0.0106**	**0.0175**
2	Sperm whale	120	NEP	372	36	0.0105	0.0097	0.0166
2	Resident orca	120	BC- SEAK	99	32	0.0009	0.0009[c]	0.0009[c]
3	**Baleen whales**					**0.1443**	**0.056**	**0.08**
3	Fin whale	120	NP	23,897	18	0.0072	0.0039	0.0084
3	Sei whale	120	NP	15,633	12	0.0021	0.001	0.0064
3	Humpback	135	SEAK[a]	961	355	0.118	0.038	0.052
3	Minke	210	NEP	4,816	34	0.0024	0.0024[c]	0.0024[c]
3	Gray	90	NEP	26,635	324	0.0134	0.0076	0.0066
5	SSL pup[b]	365	SEAK	4,260	4,260	0.001	0.001	0.0013
6	SSL juv[b]	365	SEAK	6,110	6,110	0.0088	0.0046	0.0018
7	SSL adult[b]	365	SEAK	10,816	10,816	0.034	0.0175	0.013
8	**Small mammals**					**0.043**	**0.028**	**0.041**
8	White-sided Dolphin	120	GOA EEZ[d]	26,880	6,672	0.0019	0.0019[c]	0.0019[c]
8	Dall's porpoise	365	GOA EEZ[d]	21,200	21,200	0.0035	0.0035[c]	0.0035[c]
8	Harbour porpoise	365	SEAK	12,610	12,610	0.004	0.004[c]	0.004[c]
8	Harbour seal	365	SEAK	44,940	44,940	0.031	0.016[c]	0.027[h]
8	Fur seal	210	NEP	924,503	8,755	0.002	0.003	0.003
9	Sea otter[f]	365	SEAK	8,074	8,074	0.002	0	0 [m]

a. northern part of the study area only (Straley et al. 2002); b. see section on Steller sea lion; c. assuming same density as 1999; d. excluding the Aleutians, 368,011 km^2; e. assuming that half of the biomass of 1999 biomass; f. see section on otters; g. assumed to be the same as 1977; h. from reconstruction model, see harbour seal section; m. the 1963 model was attributed a small biomass to start the time series

The average weight of killer whale populations has been calculated using the female and male life tables (Olesiuk et al. 1990), the length at age extracted from the graph in Christensen (1984), and length weight relationship given in Bigg and Wolman (1975).The average weight of a killer whale population at a stable state is 2,435 kg (Appendix 1). Attacks and killings by orcas were observed on harbour seals (53%), Steller sea lions, Dall's porpoise, and harbour porpoise (Ford et al. 1998). None of the observations of attacks on minke and gray whales have been followed by killings although these species have been found in stomachs of stranded whales (Ford et al. 1998; Ford and Ellis 1999). Harassment and killing of birds were rarely followed by consumption and are thought to be hunting skills practice (Matkin and Dalheim 1995; Ford et al. 1998), and given their body weight, their contribution were set at 1% (see Appendix 2, Table 2.1). I assumed that a large proportion of the sea lions attacked were pups and juveniles as killer whales spend more time around haul-outs and near-shore areas during pupping season (Heise et al. 2003). Mentions of deer and river otters (Matkin and Dalheim 1995) were classified as imports and were given a weight of 2%. Sea otters were never seen attacked in SEAK and BC, presumably because of their odour, low fat, and dense fur (Matkin and Dalheim 1995). In addition there is sufficient numbers of their preferred preys, harbour seals and seal lions in the system. The original percentage attributed to small mammals, 78%, was decreased to 50% to balance the 1999 model. Also the amount of predation on pup sea lions was too large and decreased by half (Table 2.2).

Toothed whales, group 2

Whales catches were compiled for the North Pacific for all species because at this time, it is not possible to separate the International Whaling Commission pelagic catches into northeastern and northwestern Pacific (Guénette and Salter, this volume). Gray whales constitute an exception because their catches have been compiled in detail for the Northeastern Pacific stock (Guénette and Salter, this volume) and corresponds to population estimate for the same region. Exploitation rates (u) were calculated from the ratio catch/population estimate for the North Pacific assuming that the catch would affect the whole population notwithstanding the location of the catch. Then, the relative catch corresponding to our study area was obtained by multiplying u by the relative biomass (Table 4).

Table 4. Whales catches in numbers for the 3 model years in the North Pacific, given separately for the Northeast (NEP) and northwest (NWP) Pacific, and the pelagic catches (throughout the North Pacific).

Species	NEP	Pelagic	NWP coastal	Total	u[a] (year^{-1})	Relative catch[b] (t·km^{-2})
1963						
Sperm	224	7825	7499	15548	0.03	0.0005
Fin	241	2105	213	2559	0.09	0.00077
Sei	251	1459	871	2581	0.06	0.00035
Gray	180			180	0.01	0.00009
Humpback	79	2252	8	2339	0.45[c]	0.026
1977						
Sperm	0	1061	5833	6894	0.19	0.002
Fin	0	0	26	26	0.002	0
Gray	187			187	0.01	0.00009
1999						
Gray	124			124	0.005	0.00006

a. The exploitation rate (u) for the North Pacific (except for gray whales); b. relative catch weight calculated assuming that exploitation rate are similar in Southeast Alaska than in the North Pacific; c. assuming same exploitation rate as in 1965.

Sperm whales, *Physeter macrocephalus*, migrate north for the summer but females and their young stay south of 40°N (Cawardine 1995; Angliss and Lodge 2002) while the males feed in the Gulf of Alaska and northern Bering Sea for the summer. The southward migration starts in November-December, and the northbound migration in mid-February to May, so they would spend as much as 6 months in the area north of the 50°N. They are present on slopes and in deep waters for extended periods as not all of them merely migrate through the area.

Females and their young stay further offshore than males (Gregr and Trites 2001) and whaling data suggests that females were calving in BC in July and August (Gregr et al. 2000). Data from whaling stations show that only one out of the 456 sperm whales taken from 1924 to 1939 at Akutan (western Aleutians) and Port Hobron (Kodiak Island) was a female (Reeves et al. 1985). In the latter whaling station individuals were younger than in the former. The authors mentioned that schools of females and calves were occasionally observed on the whaling grounds off the Queen Charlotte Islands. These observations suggest that few females and calves are present in Alaska in the summer.

The proportion of males present in the study area (29%) was estimated by using the percentage of males in the population older than 12 years (40%, Gosho et al. 1984) and supposing that animals less than 13 years old composed 28% of the population (based on the time table model). The abundance of the Northeastern Pacific population sperm whales was estimated at 39,200 (Barlow and Taylor 1998 in Angliss and Lodge 2002). Assuming that they would be uniformly distributed over an area grossly the size of area 67, the number of males amounts to 36 per year (Calkins 1986) or a biomass of 0.0105 t·km^{-2} (Table 3). In 1977, the biomass was estimated at 0.0097 t·km^{-2} assuming the North Pacific population followed the global trend between the year 1970 and 1999 (Whitehead 2002), assuming a linear rate of increase and applying it to the 1995 abundance estimate. Using the same method, the abundance for 1960 would be 1.7 times larger in 1960 than in 1977 or 0.0166 t·km^{-2} (Table 3). Catches for 1977 and 1963 are given in Table 4.

The diet was adapted from the frequency of occurrence of stomachs samples for males caught between 1963-67 in British Columbia (BC) (Flinn et al. 2002). They feed mainly on cephalopods (55%), deepwater fish and rockfish.

Resident killer whales, *Orcinus orca*, are more commonly seen in the summer when they are hunting for salmon, in ideal conditions for observations. Information on winter behaviour and distribution are scarce. I assumed that resident whales would follow salmon aggregations and disperse in the whole British Columbia-SEAK-Prince William Sound (PWS) area. Therefore, their presence in the system was limited to 4 months (120 days). In 1992, 124 animals were observed in SEAK from June to September but the amount of time spent in the SEAK is unknown (Dalheim and Waite 1993). The 1999 stock assessment estimated 99 residents in SEAK (Angliss and Lodge 2002). The number of whales per year in Eastern GOA is thus estimated at 32 or 0.0009 t·km^{-2} (see Table 3). In absence of information, I kept the same value for 1977 and 1963.

Resident orcas are known to feed on sharks and rays, capelin, smelts, herring, sablefish, Pacific cod, halibut and squids (Tomilin 1957; Dahlheim 1988; Ford et al. 1998). Of all feeding observations, those made on salmon encompass more than 95%, and stomach samples also show their importance (Ford et al. 1998). However, the predominance of attacks on chinook is suspicious given their relatively low numbers in the ecosystem. I assumed that salmon was predominant in the diet of resident orcas (45%) and allocated the remaining percentage on demersal fish and a small part on small pelagics. Since herring aggregations do not seem to attract orcas (Ford et al. 1998), their contribution to the diet has been kept small. P/B and Q/B values are given in Table 2.

Baleen whales, group 3

Baleen whales are said to get most of their food from their summer feeding grounds. Although humpbacks could be seen as feeding mostly in the area during the summer, Southeast Alaska is often not whales' final destination to feed, so I did not automatically assumed that 100% of their food was taken in the study area. P/B and Q/B values are given in Table 2.

Most sightings of **fin whales**, *Balaenoptera physalus*, occur along or inshore of the continental shelf, reaching the Gulf of Alaska (GOA) in April-May, mainly in Prince Williams sound and Kodiak (April-June) (Calkins 1986), on their way to the Bering Sea. Fin whales have been seen aggregating around Cross Sound and Yakutat Bay in Southeast Alaska (Calkins 1986). In the Gulf of Alaska, they are abundant in summer and common in the spring. The majority of summer abundances occur in the Bering Sea, whereas winter abundances range from the Gulf of Alaska and the Aleutian Islands to Southern California (Angliss and Lodge 2002). They come near shore to feed on *Thysanoessa spinifera*, a dominant calanoid copepod, is restricted to waters less than 100 m in the Gulf. Thus, I assumed that they were present for a maximum of 4 months in Southeast Alaska.

The abundance estimates were generated from historical reconstruction modelling (Guénette and Salter, this volume). Assuming homogeneous distribution in the North Pacific, defined by FAO areas 61, 67 and a fourth of area 77 ($4{\cdot}10^7$ km^2), there would be 23,897 whales in the North Pacific in 1999, that is 18 per year in the study area or 0.0072 t·km^{-2}. The 1977 and 1963 biomass were estimated at 0.0039 and 0.0084 t·km^{-2} respectively (Table 3). Catches for 1977 and 1963 are given in Table 4.

Sei whales, *Balaenoptera borealis*, are primarily an offshore species but are seasonally present in the Gulf of Alaska. In the North Pacific, their exploitation became important only after more desirable species became depleted (Calkins 1986). Prior to 1963, the number of sei whales was in the order of 42,000 animals in the North Pacific (0.0064 t·km^{-2}). By 1974, the population had decreased to 7,260-12,620 whales (Tillman 1977 in Perry et al. 1999). The latest estimate, in 1977 amounted to 9,110 whales in the North Pacific, based on catch history and trends in CPUE (Tillman 1977 in Perry et al. 1999). The abundance estimates were generated from historical reconstruction modelling (Guénette and Salter, this volume). Assuming homogeneous distribution in the North Pacific, defined by FAO areas 61, 67 and a fourth of area 77 ($4 \cdot 10^7$ km^2), there would be 15,633 whales in the North Pacific in 1999, that is 12 per year in the study area or 0.002 t·km^{-2}. The 1977 and 1963 biomass were estimated at 0.001 and 0.006 t·km^{-2} respectively (Table 3). Catches for 1977 and 1963 are given in Table 4.

Their diet is composed of 83% copepods, 13% euphausiids, 3% fish (osmerids, sandlance, rockfish, hexagrammids, pollock, capelin, sardines) and 1% squid (Kawamura 1980 in Calkins 1986). On the coast of BC, stomach contents analysis showed that on average, the proportion of copepods was lower (54%) (Flinn et al. 2002).

Humpback whales, *Megaptera novaeangliae*, are found in three areas of the Gulf of Alaska: Kodiak Island, Prince William Sound and southeastern Alaska (Calkins 1986) where they have been sighted in Frederick Sound and coastal areas of the outer coast. They arrive in SEAK in April and May, remain in the Gulf through the summer and fall until November. Their fidelity to a particular location within SEAK or between SEAK and other regions of the Gulf varies greatly between animals (Straley 1990). Females at various reproductive stages (lactating, pregnant and resting) were present in the area. Some humpbacks stay in Southeastern Alaska for the winter but most migrate south. However, the central North Pacific stock that breeds in Hawaii uses principally the region between Prince William Sound and northern British Columbia (Perry et al. 1999).

Straley et al. (2002) estimated the population of humpback whales at 961, which is probably a conservative estimate because the surveys only covered the northern part of Southeast Alaska (north of Frederick Sound) ignoring the Lynn Canal, some areas in Frederick Sound, and the offshore section of the coast. Most whales do make the 230 days oceanic migration to Hawaii in the winter while less than 10 animals stay in SEAK for the winter (Janice Straley, University of Alaska Southeast Sitka Campus, pers. comm.). The migration is staggered with some whales leaving early and then likely arriving back early and some leaving later and arriving (probably) later. In addition, some do have fairly short stays in Hawaii. I therefore assumed that the average individual stayed 135 days in the region (365 minus 230 days migration) so this amounts to 355 individuals staying year round or 0.118 t·km^{-2} (Table 3). In the 1970s, there were about 310 whales in southeastern Alaska (0.04 t·km^{-2}) (Baker et al. 1985). Based on point estimates and catches for the whole North Pacific (Guénette and Salter, this volume), the population reconstruction model resulted in 1963 abundance being 37% larger than that of 1977, or 0.052 t·km^{-2} in SEAK. Catches for 1963 are given in Table 4.

Humpbacks feed primarily on euphausiids and fish: herring, capelin, saury, pollock, mackerel (Nemoto 1959 in Calkins 1986). In Glacier Bay, they were feeding mainly on euphausiids in mid-1970s and mainly on fish in early 1980s. However, in Stephens Passage, Frederick Sound and Chatham Sound, they fed on euphausiids in 1984 (Kreiger and Wing 1985 in Calkins 1986). Judging by echosounder recordings, visual identification and qualitative sampling, humpback whales eat mostly euphausiids and Pacific herring during their stay in SEAK (Straley 1990). Therefore, I used the diet described in Gregr (2004) for the Hecate Strait, which fit the qualitative descriptions cited above. Euphausiids constitute the main part of the diet (80%).

Minke whales, *Balaenoptera acurostrata*, are distributed from the equator to the Chukchi Sea. They move into the Gulf in April and stay until October. They are commonly seen on the continental shelf within the 200 m depth contour (Calkins 1986). They seem to be less abundant in BC and SEAK than in the Gulf of Alaska and the eastern Aleutians. The population abundance in FAO area 67 was estimated at 4,816 individuals (Trites et al. 1997). Winter sightings have been recorded around Icy Bay, and Sitka (Calkins and Pitcher 1978). I assumed that they were present for 6 months of the year in a density equal to the rest of FAO area 67, that is 57 individuals, or 0.002 t·km^{-2}. Since this species was not much exploited in the Northeast Pacific and in absence of further information on abundance, the same density were kept for 1977 and 1963 (Table 3). The diet is dominated by euphausiids and forage fish, and include small amounts of salmon, and demersal fish (Gregr 2004).

Gray whales, *Eschrichtius robustus*, migrate through the Gulf of Alaska both to and from the Bering Sea, and they are generally found within 4 km of the shore, seldom found in waters deeper than 180m (Calkins 1986). They are present in the area during their migration to and from California. The southbound migration peak in late November to early December, most have left by January, and the northbound migration finishes by end of June or early July. I assumed that the time passed in SEAK is limited to 90 days a year which accounts for those who feed while migrating to the north and those aggregating in some areas to feed for a more extended period. The total population for the Northeast Pacific in 1997-1998 was estimated at 26,635 whales (Angliss and Lodge 2002). Assuming that most individuals would migrate in FAO area 67, about 324 whales per year (0.013 t·km^{-2} Table 3) would visit SEAK. The biomass for 1977 and 1963, 0.0076 and 0.0066 t·km^{-2} respectively, were based on estimates from Wade (2002), using the 1967 count *in lieu* of 1963 (Guénette and Salter, this volume). Catches for each model are given in Table 4.

The diet was assumed to be dominated by mysids and benthic invertebrates (78%) and included small demersal fish, crab larvae and shrimps based on various sources describing the diet composition qualitatively (Murison et al. 1984; Oliver et al. 1984; Klinowska 1991; Darling et al. 1998; Dunham and Duffus 2001; 2002).

Steller sea lions, groups 4-7

This group (*Eumetopias jubatus*) has been separated in embryo (6 months), pups (1 year), juveniles (1-3 yrs) and adults (4+). The embryo stanza exists only to bring the baby from weight 0 to 21kg, their weight at birth. This was necessary to compensate for the fact that the growth calculation in Ecosim ignores the von Bertalanffy growth curve parameter t_0. When it comes to fish, t_0 is negligible given their weight at birth, whereas the bias becomes very important with mammals. Given a mean k of 0.282 year^{-1} and a maximum weight of 569 kg (Table 5), it takes 6 months to reach a weight of 21 kg (Table 6). This stanza has no impact in the ecosystem model because they were given a small mortality (Table 6) and they are made to feed on imports. Pups are differentiated from juveniles because they are not eating, depending only from their mother's milk, thus they were also made to eat on imports. Although pups probably constitute easy prey for a large part of the year, their mortality is not dependent on the search for food, so the feeding time adjustment of pups and embryo was set to zero in Ecosim. The ratio W_{mat}/W_∞ used in Ecopath to increase fecundity as body weight increase is unnecessary for mammals and was set at a very small value instead of 0 (Carl Walters, UBC, pers.comm.).

The rule generally admitted for marine mammals is that P/B is equal to half the intrinsic growth rate), that is 0.06 year^{-1} in the case of Steller sea lions. However, annual mortality rate calculated from the slope of natural log of numbers at age, based on published life tables (Trites and Larkin 1992), reached an average of 0.19 for adults, 0.24 for juveniles and 0.52 for pups. Estimates using a life history table similar to that of fur seal (Barlow and Boveng 1991) led to an estimate of 0.27 for juveniles and 2 different estimates for adults depending on the age span considered: 0.07 for ages 4-24 and 0.2 for ages 4-30. Recent estimates from mark-resighting data in Southeast Alaska yielded higher survival at all ages; total annual mortality averaged over sexes reached 0.59 for pups, 0.19 for juveniles and 0.11 for adults (Pendleton et al. 2004). I assumed that the survival estimated for ages 4-6 were also true for older individuals (Table 6). These estimates were compatible with the 1999 model but were too low to balance the 1963 model given the low biomass estimate used in the original model. The next paragraph provides a discussion on the subject.

Table 6. Biomass, P/B, Q/B of Steller sea lions by stanza for the 1999 model. Values in bold were calculated in the Ecopath model and thus differ slightly from biomass estimates given in Table 3.

Stanza	**Time (months)**	**P/B**	**Q/B**	**Biomass (t·km^{-2})**
embryo	0-6	0.0202	**221.7**	**$6.5*10^{-6}$**
pup	7-19	0.59	**84.1**	**0.00025**
juvenile	20-56	0.19	**39.45**	**0.0039**
adult	57+	0.11	25.55	0.034

Biomass times series of pups, juveniles and adults Steller sea lions was first obtained from a simple age-structured population model using pups and non-pups counts on rookeries since 1950 compiled by Andrew Trites (Fisheries Centre, UBC) (see Appendix 3, and Table 3). The age-structured population model described in Appendix 3 was similar in trend and initial abundance (in 1955) to the local regression model proposed by Trites and Larkin (1996). However, the two models differ by the decrease in abundance in the 1960s which is driven by a single low count, and may be underestimating the abundance. I chose to use the initial sea lion abundance from the local regression model and defined the proportion of adults by using the proportion of adults calculated in the age-structured model. The new time series was used instead of that coming from the age-structured model which allowed the survival rates obtained by Pendleton et al. (2004) to be used for all models. Q/B values are given in Table 2.

The diet is based on frequency of occurrence of scats analysis (Trites and Calkins 2003; Trites et al. 2003). This way of compiling prey creates a bias by not accounting for the biomass of each prey, but I considered this prey composition as a good starting point. I assumed that the diet of adult populations is the average of scat contents obtained in both rookeries and haulouts; and that juveniles have a diving behaviour and thus a diet similar to that of females, more numerous on rookeries. Thus adults eat mainly salmon (13%), herring (14%), sandlance (8%) and pollock (30%). Juveniles eat more salmon (22%), sandlance (15%), similar amounts of herring (13%) and less pollock (13%). The remainder of the diet includes various demersal fish, sharks, and birds (Table 2.1). Adults diet composition estimated with this method is similar to that obtained from the average of males and females averaged over 4 seasons (Trites et al. 2003) except that it has a higher proportion of salmon (13 vs 8%) and small pelagics (24 vs 17%), and less pollock (33 vs 48%) and flatfish (2 vs 7%). The proportion of juvenile and adult pollock in the diet composition of Steller sea lion were derived from studies around Kodiak (Merrick and Calkins 1996). I used the number of prey for each length class extracted from a study located in the central GOA (Merrick and Calkins 1996, figure 3) and the length-weight relationship (Britt and Martin 2001) to estimate the proportion of pollock biomass consumed by sea lions, assuming that juvenile pollock were less than 29 cm long based on the von Bertalanffy equation (M. Dorn, NMFS, Seattle, *pers. comm.*). Thus, the juvenile pollock consumed by juvenile sea lions constitute 65% of the pollock consumed while the proportion of juvenile pollock in the adult sea lion diet only reaches 21% of the total pollock consumed. For comparison, the proportion of juvenile pollock to total pollock reaches 10% and 37% in scats taken from haulouts (adult males) and rookeries (breeding females) respectively for an average of 23% (data extracted from figure 6, Trites and Calkins 2003). The diet had to be modified in order to balance the model. The proportion of birds, sharks and skates, pollock and several commercial species had to be decreased in the diet (see Table 2.2 and the section on balancing the model).

Small mammals, group 8

P/B and Q/B values for each member of this group are given in Table 2.

Pacific white-sided dolphin, *Lagenorhyncus ololiquidens*, frequent the continental shelf slope and the coastal headlands of deep-sea canyons (Calkins 1986). They become seasonally abundant in the eastern Gulf. In the fall, they seem to be moving to the northeast and northwest Gulf, so I assumed that they are present 120 days in SEAK. The stock size for the Gulf of Alaska is estimated at a minimum of 26,880 individuals based on the sightings in 4 cells of 5 by 5degree of a line survey carried out in 1987-90 (Angliss and Lodge 2002). Assuming an homogenous distribution, the resulting abundance for the Southeast Alaska would be of 6,672 dolphins or 0.002 t·km^{-2} (see Table 3). The 1977 and 1963 abundances were assumed similar to that of 1997. The diet composition is dominated by salmon (10%), sandlance (20%), herring (40%) and various demersal fish (19%) (based on Trites and Heise 1996; Heise 1997; Gregr 2004). Other studies mentioned the use of 29 species of fish (mainly from the family Myctophidae and including bathylagidae and sandlance) and squids (Jones et al. 1980 and Scheffer 1953 in Calkins 1986).

Dall's porpoises, *Phocoenoides dalliare*, year-round residents of the Gulf of Alaska on the continental shelf and slope avoiding turbid waters such as Icy Bay and prefer large bodies of water rather than narrow bays (Calkins 1986). The abundance in the Gulf of Alaska EEZ was estimated at 106,000 in 1987-1991, multiplied by 0.2 to correct for the strong attraction of Dall's porpoise to boats (Angliss and Lodge 2002). Assuming a homogenous distribution and an area of 368,011 km^2 (area 6 and 7 p. 15 in Hood 1986), the abundance for SEAK is 5,262 animals present year round or 0.0035 t·km^{-2} (see Table 3). The 1977 and 1963 abundances were assumed similar to that of 1997. The diet is dominated by cephalopods (10%), pollock (28%) and small forage fish (50%) (Gregr 2004).

Harbour porpoises prefer coastal habitats and frequent the study area all year round. The actual population number is based on the 1997 surveys of Southeast Alaska, Yakutat Bay and Icy Bay and have been extrapolated by dividing the southeast Alaska in strata of low, average and high abundances, ignoring small bays that constitute only a small proportion of the total area (Angliss and Lodge 2002). The 1997 abundance for SEAK amounts to 10,508 (3,550 · 2.96, the correction factor) to which I added 20% to account for the missing segments of the population. The resulting estimate amounted to 12,610 or 0.004 t·km^{-2} (see Table 3). The 1977 and 1963 abundances were assumed similar to that of 1997. The high P/B for this species derived from life table models (Barlow and Boveng 1991) (Table 2) is justified by the fact that few individuals pass their teens, the first pregnancy occurs at 3 and then each year. In addition the calf leaves the mother after less than a year and grows rapidly (Read et al. 1997). The diet is dominated by sandlance (10%), herring (30%), pollock (10%), and cephalopods (30%) (adapted from Gregr 2004).

Harbour seals, *Phocoena phocoena*, are found in coastal areas of the Gulf of Alaska (Calkins 1986). The population estimate came from the 1993 comprehensive aerial survey based on 11 sites in southeast Alaska. It has been noted that the surveys missed at least half of the 6,000 individuals found in Glacier Bay (Mathews and Kelly 1996 in Angliss and Lodge 2002). I added 20% of the global estimate to account for the missing segments of the population which resulted in an estimated of 44,940 or 0.031 t·km^{-2}. Glacier bay surveys show that the population has decreased at an annual rate of 2.6% for the period 1983-1996 (Small et al. 2001) and have continued to decrease since (Mathews and Pendleton 2003). The next transect to the south, Sitka, shows a stable population since 1994, while the Ketchikan transect, more to the south, shows an increase in abundance for the same period (Small et al. 2001). Recent genetics data suggest relatively fine population structure within Southeast Alaska, which indicates that the trend info may not be very representative far outside the survey area (Bob Small, ADFG, *pers.comm.*). Thus, the trend sites cannot provide a trend for the whole southeast Alaska.

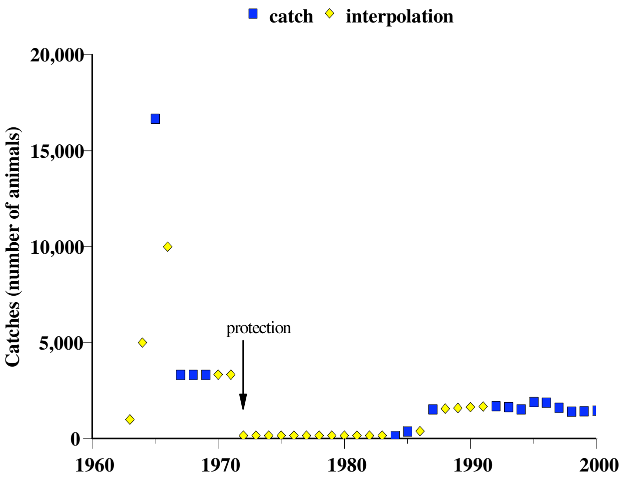


Figure 2. Observed catches for harbour seals, and estimates based on narrative, or interpolation (see text). Harbour seals were granted protection in 1972.

In the 1940s, harbour seals were used as food for fur farms whereas natives only used the meat occasionally (Imler and Sarber 1947). The authors also mentioned that the hides were not kept as there was no regular market for them, thus excluding a large fur operation at the time. The fur industry developed in the 1960s and reached high prices and peak harvests of over 50,000 animals in 1965, and dropped to 10,000 annually as prices fell (Pitcher 1977). A bounty was paid on harbour seal in southern Alaska from 1927 to 1967 but there is no indication of the intensity of the killings (Pitcher 1977). In 1972, when the Marine Mammals Protection Act came into effect, all killings stopped with the exception of native subsistence hunting. Based on the information on the bounty and on the fur industry listed above, I assumed that a third of the 25,000 seals taken in 1965 and of the 10,000 later in the 1960s were hunted in southeast Alaska. The missing years were interpolated starting at 1,000 animals in 1963 assuming that the hunting would be equivalent to that of the 1990s (Figure 2). The subsistence hunt data was taken from Wolfe et al. (2003). As there were no household survey made in 1999 I assumed that hunting activities were of the same intensity as contiguous years resulting in a catch of 1,444 animals. Given an average weight of 31 kg per animal, the yield amounts to 46 t or 0.0005 t·km^{-2} (Table 7). For years 1977-1982, period of missing data, I assumed that hunting activities were stable and similar to the year 1983, at 162 animals which may be an underestimate.

Pitcher (1977) mentioned that the bounty and the hunt has not decreased the population of seals in Prince Williams Sound as much as in Southeast Alaska, suggesting that the population was not that much lower in the late 1970s than in the 1990s. Thus, I assumed that the 1977 population was half as large as that of 1999 in Southeast Alaska (Ken Pitcher personal communication). Using the reconstruction model, with values of r of 0.2 and 0.23, and solving for the initial biomass and the carrying capacity (k), the 1963 biomass amounted to 38,000 to 42,000 animals. Although these results based on such few data are not to be trusted, I used 40,000 as a starting abundance for 1963 (see Table 3). The diet was adapted from Gregr (2004) and Jemison (2001). Harbour seals feed opportunistically on a large number of fish species (Bigg 1981) including herring (17.5%), sandlance (25%), salmon (7.5%), pollock (16.8%), and cephalopods (5%). Frequency of occurrence and % of volume of stomach contents yield similar diet composition (Imler and Sarber 1947; Pitcher 1977).

Northern fur seals, *Callorhinus ursinus*, reproduce mainly in the Bering Sea and disperse widely afterwards in the North Pacific and the Gulf of Alaska for 7-8 months (Calkins 1986). The population abundance was estimated based on pup counts (data base obtained from Rod Towell, National Marine Mammal Laboratory, Seattle) and using the method detailed in Robson (2002). The resulting abundances amounted to 1,476,549; 1,253,732; and 919,298 for 1963, 1977 and 1999 respectively (see Table 3). These estimates are slightly lower than those obtained by multiplying the pup count by 4.5 (Angliss and Lodge 2002). The fur seal density is equal to the abundance divided by the surface of the northeast Pacific approximated by the FAO area 67. In the North Pacific, fur seals concentrate in areas of upwellings over seamounts and along the continental slopes (Gentry 1981). Thus, they are only present in the outer shelf of SEAK for about one month (Andrew Trites, UBC, pers comm.).

Sea otters, group 9

Sea otters, *Enhydra lutris*, were reintroduced into Southeast Alaska in 1965 and by 1969, 412 otters had been transferred in the area (Riedman and Estes 1990). The 2003 estimate indicated that the average rate of population increase since the 1988 count has been 1.04, less than the anticipated growth of about 1.20. Causes for the reduced growth rate, not significantly different from zero, are not completely understood (James Bodkin, USGS, Anchorage, Alaska, *pers. comm.*). Only the lower Glacier Bay has seen a dramatic increase in population, mainly due to immigration. Sea otters began recolonizing Glacier Bay in 1993 and have increased from 5 in 1995 to 1,266 in 2002 (Bodkin et al. 2003). This tremendous increase in Glacier Bay is probably due to reproduction as well as migration in the Bay (Bodkin et al. 2003).

Table 7. Abundance of otters from various sources. Numbers in italics are cumulative numbers of otters introduced in SEAK, constituting the early population.

Author	**1965**	**1966**	**1968**	**1969**	**1975**	**1982**	**1983**	**1987**	**1988**	**1994**	**2003**
Estes (1990)[a]					500		1100		4000		
J. Bodkin, *pers.comm.*								5047[c]			9031[d]
Jameson et al. (1982)	*23*	*53*	*355*	*413*	476						
Angliss and Lodge (2002)[b]						2000				8180	
Riedman and Estes (1990)				412					4520		
value used	23	**53**	**355**	**412**	**476**	**2000**	**1100**	**5047**	**4520**	**8180**	**9031**

a. from graph; b. value corrected by a factor of 1.43 for unseen otters; c. data gathered by K. Pitcher (ADFG, Juneau), values not corrected; d. corrected for otters in the water at counting time. The area surveyed includes the known current distribution of sea otters from Cape Spencer in the north to Cape Chacon in the south.

Hunting or at least data about otter hunting started in 1989 in SEAK with 157 animals harvested while 347 animals were harvested in 2000 (Angliss and Lodge 2002). I have compiled population abundance estimates from various sources for the period 1965-2003 (Table 7) and reconstructed the population starting in 1969 using the surplus production model described earlier. Using the sum of squares to fit the model to the data led to r and k values of 0.17 and 12,000 t·km^{-2} respectively (Figure 3). The number of otters was estimated at 7,868 in 1999 (0.0185 t·km^{-2}) and 1,352 in 1977 (0.00032 t·km^{-2}). Note that the rate of increase predicted by the model for the late 1990s is still high compared to that suggested by the data. There was no otters in 1963 but the biomass was assumed to be one tenth of the 1977 (0.00003 t·km^{-2}) to initialise the model. The F values are the ratio of catch to the model derived biomass. P/B and Q/B values are given in Table 2.

Otters feeding success rate is estimated at 86% of the dives which is in the same range (70-90%) as that reported for the coast from California to Alaska (Bodkin et al. 2003). Sea otters feed on a variety of invertebrates including crabs, mussels, clams and urchin;, species also sought by the dive fishery. In SEAK, they prey heavily on butter clams, barnacles, Dungeness, king and tanner crabs, geoduck, sea urchins and sea cucumbers. In Sitka Sound, the commercial harvest of sea urchins has been eliminated by otters predation (Hebert and Pritchett 2002).

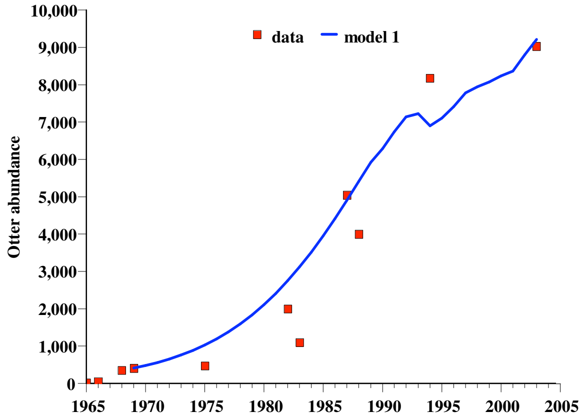


Figure 3. Observed abundance and model predictions for otters in Southeast Alaska

BIRDS , GROUP 10

The daily ration of birds in grams per day was derived using an empirical equation: $\log R = -0.293 + 0.85 * \log W$ (Nilsson and Nilsson 1976 in Wada 1996) where W is the body weight in grams and R the ration in grams per day. The Q/B value is the average of individual values weighted by the biomass, resulting in a value of 70.4 year^{-1}. Diets from Hunt et al. (2000) were reallocated in the functional group according to rules in Table 8.

The biomass of birds by species was taken from Hunt et al. (2000) to which were added additional information for nesting birds (Table 9). The total biomass calculated on a yearly basis for the Alaskan continental shelf amounts to 0.006 t·km^{-2}. The P/B was taken from mortality rate found in various publications (see Table 9). It is the average of 19 species weighted by their biomass, for a total of 0.38 year^{-1}.

Table 8. Conversion of food items in the original diet of birds (Hunt et al. 2000) to our functional groups.

Groups in original diet	No.	Functional group
Gelatinous zooplankton	36	L zoo
Crustacean zooplankton	36-37	L or S zooplankton[a]
Small cephalopods	35	cephalopods
Low energy fish	18	pollock juv
	19	pollock adult
	21	slope rockfish
	22	shelf rockfish
	24	Pacific cod
	28	flatfish
	29	dem S
Medium energy fish	15	pel S
	16	sandlance
High energy fish	17	herring
	32	deep S [b]
	15	pel S
Birds and mammals	10	birds

[a] based on DeGange and Sanger (1986); [b] includes myctophids

Table 9. Abundance, residency, body weight, relative biomass and Q/B of birds present in coastal Alaska.

Species		**Abundance** [c]	**Residency (days)** [c]	**Body mass (kg)**	**Biomass ($kg \cdot km^{-2}$)**	**Q/B ($year^{-1}$)**	**P/B ($year^{-1}$)**	
Piscivores								
Laysan albatross	*Phoebastria immutabilis*	400	92	3.042	0.001	55.8	0.4	d
Sooty shearwater	*Puffinus griseus*	2,900,000	92	0.787	1.34	68.4	0.4	e
Brandt's cormorant	*Phalacrocorax penicilatus*	25	92	2.103	0	59	0.1	d
Red-faced cormorant	*Phalacrocorax urile*	7,000	92	2.157	0.009	58.8	0.1	d
Pelagic cormorant	*Phalacrocorax pelagicus*	6,000	92	1.868	0.026	60.1	0.1	d
Double-crested cormorant	*Phalacrocorax auritus*	1,000	92	1.674	0.001	61	0.1	d
Jaegers	*Stercorarius spp*	140,000	92	0.7275	0.06	69.1	0.4	f
Herring gull	*Larus argentatus*	1,000	92	1.135	0.001	64.7	0.07	d
Glaucous-winged gull	*Larus glaucescens*	210,000	92	1.01	0.125	65.9	0.15	d
Mew gull	*Larus canus*	15,000	92	0.4035	0.014	75.6		
Black-legged kittiwake	*Rissa tridactyla*	870,000	92	0.407	0.208	75.5	0.4	g
Common murre	*Uria aalge*	720,000	92	0.9925	0.42	66	0.4	e
Pigeon guillemot	*Cepphus columba*	28,000	92	0.487	0.008	73.5	0.4	d
Murrelets	*Brachyramphus spp*	687,061 [a]	92	0.223	0.09	82.6		
Marbled murrelet	*Brachyramphus marmoratus*			0.222				
Kittlitz's murrelet	*Brachyramphus brevirostris*			0.224				
Long-billed murrelet	*Brachyramphus perdix*							
Rhinoceros auklet	*Cerorhinca monocerata*	161,278 [b]	92	0.52	0.23	72.8		
Horned puffin	*Fraterculata corniculataa*	172,000	92	0.619	0.063	70.9		
Tufted puffin	*Fratercula cirrhata*	1,900,000	92	0.779	0.87	68.4		
Invertebrate eaters								
Black-footed albatross	*Phoebastria nigripes*	9,000	92	3.148	0.017	55.5	0.07	h
Northern fulmar	*Fulmarus glacialis*	360,000	92	0.544	0.12	72.3	0.38	e
Fork-tailed storm-petrel	*Oceanodrama furcata*	1,200,000	92	0.0553	0.039	101.8	0.4	I
Red phalarope	*Phalaropus fulicaria*	49,200	92	0.0557	0.002	101.7		
Red-necked phalarope	*Phalaropus lobatus*	361,000	92	0.0338	0.007	109.6		
Arctic tern	*Sterna paradisaea*	87,000	92	0.11	0.006	91.8	0.12	j
Aleutian tern	*Sterna aleutica*	92,000	92	0.12	0.006	90.6	0.12	j
Thick-billed murre	*Uria lomvia*	73,000	92	0.964	0.04	66.3		
Short-tailed shearwater	*Puffinus tenuirostris*	6,100,000	92	0.543	1.94	72.3	0.4	e
Ancient murrelet	*Synthliboramphus antiquus*	190,000	92	0.206	0.02	83.6		
Cassin's auklet	*Ptychotamphus aleuticus*	370,000	92	0.188	0.04	84.8		
Parakeet auklet	*Aethia psittaculata*	59,000	92	0.258	0.009	80.8		
Crested auklet	*Aethia cristatella*	6,000	92	0.264	0.001	80.5		
Whiskered auklet	*Aethia pygmaea*	200	92	0.121	0	90.5		
Least auklet	*Aethia pusilla*	3,000	92	0.084	0			
Leach's Storm-Petrel	*Oceanodrama leucorhoa* [b]	793,052	92	0.0398	0.09	107	0.4	e
All birds					**6**	**68**	**0.38**	

a. summer 1994 (Agler et al. 1998); b. abundance of nesting birds taken from The Beringian Seabird Colony Catalog is maintained by the U.S. Fish and Wildlife Service, Division of Migratory Bird Management, Marine and Coastal Bird Project, 1011 E. Tudor Rd., Anchorage, Alaska 99503; c. data from Hunt et al. (2000) for the coastal Alaska shelf (ASK) unless other noted; d. Nelson (1979); e. Russell (1999); Z values for parasitic and long-tailed jaegers Russell (1999); g. Hatch et al. 1993 in Trites et al. (1999); h. range of 0.03-0.11 for 7 species of albatross in Nelson (1979); i. using the values of three other species of storm-petrel (Russell 1999); j. value for the Caspian tern (Nelson 1979)

FISH PARAMETERS

Fish species were grouped according to their diet, size, production, commercial use and assessment availability. The name of generic groups reflects this classification. The first term characterises the habitat (pelagic, demersal) and the second term determines the size (small, medium, large). Catch and biomass time series were compiled in Appendix 4. In order to give an idea of the reliability of the diet data, each diet composition used is described by the area of the study, the quality (quantitative, qualitative, occurrence), and the proportion of unidentified fish in the diet in Appendix 5. Diets of large predators, taken from the central GOA or the Bering Sea studies, were characterised by a large proportion of pollock which is unlikely in SEAK. Thus, the diet compilation from Hecate strait (Fargo and Pearsall 2004) was used to modify the fish allocation in the diets and often completed with studies from the Gulf of Alaska (Yang and Nelson 2000) for invertebrates.

Fish biomass were generally obtained from the trawl survey on the exterior shelf in years 1984, 1987, 1991, 1993, 1996, and 1999 (Wilkins, AFSC, Seattle, *pers. comm.*). Unfortunately, the depth strata covered in each survey was quite variable (Table 10) which caused underestimation of biomass in several species and decreased reliability of some time series. The biomass for the entire area, including interior waters, was estimated by assuming similar densities in inside and outside waters by depth strata according to the area per depth listed in Table 1, unless otherwise noted.

Table 10. Depth covered by each trawl survey.

Year	**Depth strata (m)**
1984	100-500
1987	0-700
1990	100-500
1993	100-500
1996	0-500

The natural mortality (M) of fish was preferably taken from the literature, (e.g., stock assessment reports) for commercial species. For other species natural mortality was derived from the empirical model of Pauly (1980):

$$M= K^{0.65} \cdot L_{\infty}^{-0.279} \cdot T^{0.463}$$

where K and L_{∞} (cm) refer to the curvature and asymptotic length parameters of the von Bertalanffy growth function, and T is the mean annual water temperature in Celsius. Alternative estimates were taken from Hoenig's empirical equation (Hoenig 1983) for species that are not as well known:

$$\ln(M)=1.44-0.982*\ln(\text{max age}).$$

Fish consumption per unit of biomass (Q/B) per year was calculated according to the empirical regression of Christensen and Pauly (1992) (called method 1):

$$Q/B=10^{6.37} \cdot 0.0313^{Tk} \cdot W_{\infty}^{-0.168} \cdot 1.38^{Pf} \cdot 1.89^{Hd}$$

where W_{∞} is the asymptotic body weight in grams, Tk is the mean annual temperature expressed as 1000/(T°C + 273.1), Pf equals one for predators and zooplankton feeders and zero for all others, and Hd equals one for herbivores and zero for carnivores. W_{∞} is generally calculated from L_{∞} using published length-weight relationships. I also used a more recent empirical equation that included mortality (Palomares and Pauly 1998), called method 2:

$$\log_{10}(Q/B)=5.847+0.28 \cdot \log_{10}(Z)-0.152 \cdot \log_{10}(W_{\infty})-1.36 \cdot Tk+0.062*A+0.51 \cdot h+0.39 \cdot d$$

where A is the aspect ratio of the caudal fin (square of max height/surface); h=1 for herbivorous fish and d=1 for detritivores (carnivorous fish have 0 for both h and d).

Q/B estimates obtained using method 2 were lower than those obtained from method 1 and thus yielded a higher production to consumption ratio (P/Q), although still well below 0.1 for most species (Table 11). Q/B was also recalculated using a lower mean annual water temperature to account for life in deep waters, which led to only small changes (Table 11) Finally, Q/B was estimated assuming a fixed P/Q of 0.2 (hereby called fixed-Q/B). I constructed an index of the gap between the estimates by taking the ratio of the Q/Bs resulting from each empirical equation, over the fixed-Q/B. This index showed that the gap between the methods was larger for long-lived species such as POP and rockfish (fixed-Q/B was about 30 times lower than method 1 and 15 times lower than method 2) whereas the gap was smaller for herring and capelin (index of about 2; Figure 4A). This seems to be caused by their relatively large rate of growth in the first few years and then the number of years spent approaching L_{∞} (Figure 4B). Thus, I assumed that most fish had a P/Q ratio of 0.2, except for small fish, deemed more efficient, and given a P/Q ratio of 0.25. Sharks and rays were allowed to have a lower efficiency because of their physiology (see the following sections).

Table 11. Comparison of Q/B (year^{-1}) and P/Q calculated according to two different methods based on the von Bertalanffy parameters (L_∞ and k) and total mortality (Z year^{-1}). Q/B was calculated using an annual water temperature of 10°C except for one trial using method 2 and temperature of 5°C (Q/B 5°).

				von Bertalanffy parameters				**Method 1**		**Method 2**					
Group	**Name**	**English**	**Max age (year)**	**L_∞ (cm)**	**k (year^{-1})**	**W_∞ (g)**	**Z 1999**	**Q/B**	**P/Q**	**Q/B**	**P/Q**	**Aspect ratio [a]**	**Q/B 5°**	**Depth (m)**	**Fixed-Q/B[e]**
14	*Trachurus symmetricus*	Pacific jack mackerel	30	72.3	0.093	4,144	0.19	3.87	0.05	3.22	0.06	3.6	2.4	<400[a]	0.95
15	*Mallotus villosus*	Capelin	5	19	0.48	31	0.79	8.82	0.09	8.05	0.10	1.9	6.01	<300[a]	3.95
15	*Scomber japonicus*	Chub mackerel	18	60	0.306	1,485	0.43	4.60	0.09	4.26	0.10	2.81	3.18	<300[a]	2.15
18	*Clupea pallasii*	Pacific herring	12	35.6	0.558	442	0.78	5.64	0.14	5.68	0.14	2.32		0-150[a]	3.9
21	*Sebastes alutus*	Pacific ocean perch	84	40	0.142	619	0.04	5.33	0.01	2.16	0.02	1.91	1.77	100-450[c]	0.2
22	*Sebastes aleutianus*	Rougheye rockfish	95	52.2	0.108	1,915	0.07	4.41	0.02	2.11	0.03	1.89	1.73	100-500[c]	0.35
23	*Sebastes mystinus*	Blue rockfish	44	38.7	0.168	1,001	0.03	4.92	0.01	1.99	0.02	2.28	1.63	0-550[c]	0.15
23	*Sebastes melanops*	Black rockfish	60	60	0.143	4,560	0.03	3.81	0.01	1.37	0.02	1.28	1.12	0-366[c]	0.15
23	*Sebastes caurinus*	Copper rockfish	55	50	0.12	2,183	0.03	4.31	0.01	1.54	0.02	1.34	-	10-183[a]	0.15
24	*Anoplopoma fimbria*	Sablefish [d]	94	83.2	0.134	43,514	0.18	2.61	0.07	1.82	0.10	2.21	1.49	200-1000[b]	0.9
25	*Gadus macrocephalus*	Pacific cod	18	94	0.27	8,041	0.39	3.46	0.11	2.56	0.18	1.25	2.09	<300[c]	1.95
28	*Ophiodon elongatus*	Lingcod	21	113	0.18	19,190	0.25	2.99	0.09	1.98	0.04	1.22	1.48	<300[c]	1.25
30	*Pleurogrammus monopterygius*	Atka mackerel	13	54.6	0.22	2,315	0.30	4.27	0.07	3.09	0.12	1.75	2.53	<300[c]	1.5

a. taken from FishBase (Froese and Pauly 2000); b. most common depth habitat Mike Sigler NMFS, Juneau, *pers comm*; c. Mecklenburg et al. (2002); d. female only here; e. calculated using a fixed ratio P/Q=0.2

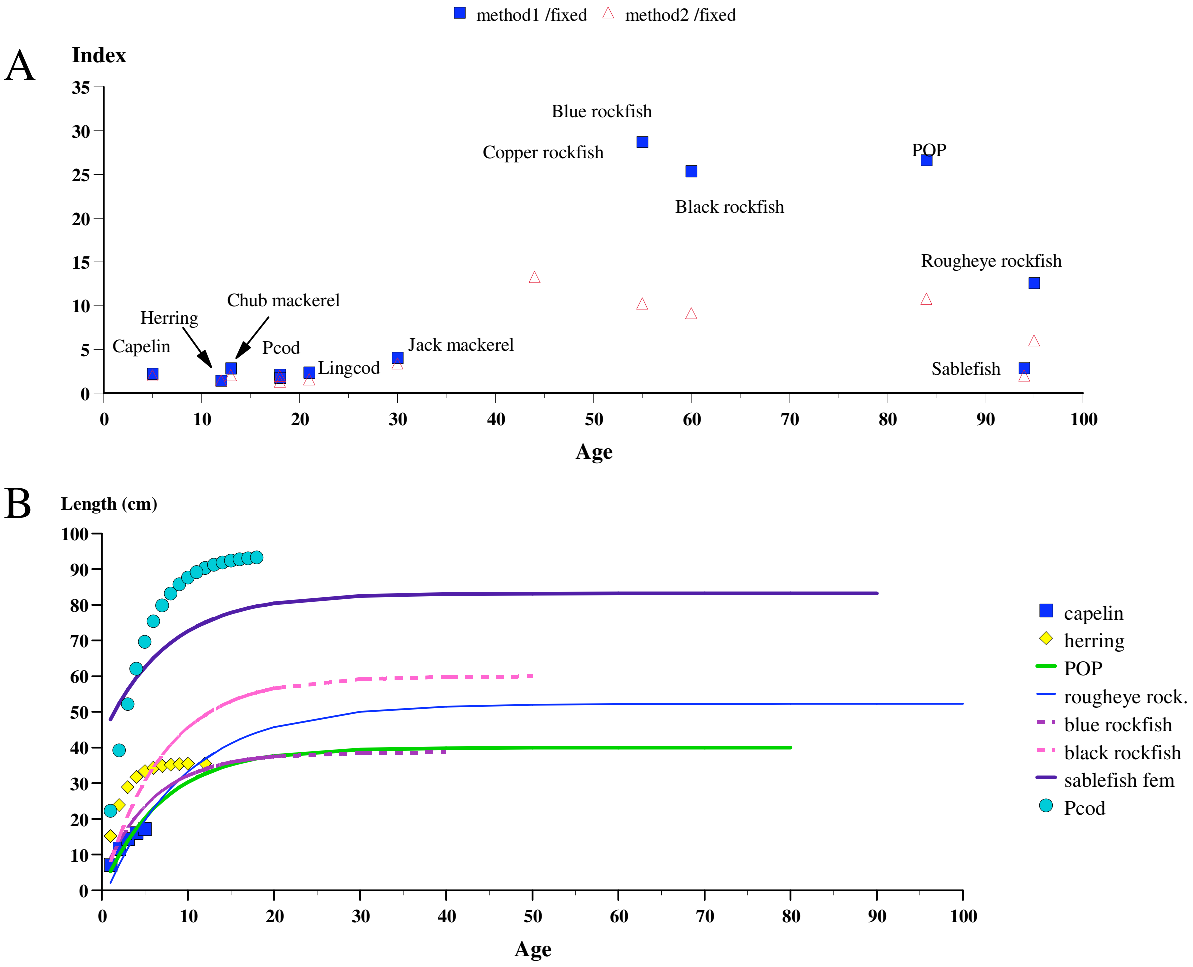


Figure 4. Comparison Q/B and growth curves of 8 species. A. Gap Index (see text) plotted against the maximum age by species. B. Age-length relationship as calculated using the von Bertalanffy equation.

Shark mammal eater, group 11

Sleeper sharks (*Somniosus pacificus*) are the most important species of this group which also contains the great white shark (*Carcharodon carcharias*) and the bluntnose sixgill shark (*Hexanchus griseus*). Biomass estimates for 1999 survey are 0.019 and 0.005 $t \cdot km^{-2}$ for sleeper and sixgill sharks respectively. The estimates for sleeper sharks for SEAK are much smaller than those mentioned for Prince Williams Sound (0.11 $t \cdot km^{-2}$) for the period 1994-1996 (Hulbert 1999). This is consistent with the relative population numbers calculated by Courtney and Sigler (2003) showing that the population numbers of sleeper sharks in eastern Alaska constitutes 2.9% of that of the central Gulf of Alaska.

Incidental catches of skates by the hook and line fishery were estimated based on observer data in groundfish fisheries (S. Gaichas, NMFS, Seattle, *pers. comm.*) and halibut survey rates (Gaichas et al. 2003). The estimated catches amounted to an average of 435 $tonnes \cdot year^{-1}$ for the period 1997-2003 (Table 12). For earlier years, I used the estimates from the observer data for SEAK during the period 1990-1996 (Gaichas et al. 1999) augmented to account for bycatch in the halibut fishery assuming that its contribution was still 40% (average of the bycatch of other groundfish fisheries). The resulting bycatch reached an average of 334 $t \cdot year^{-1}$ for the period 1990-1996.

The shark bycatch was derived from observer data of groundfish and salmon fisheries statistics (O'Connell et al. 2002c; Boldt et al. 2003). The break down by species show that in southeastern Alaska, spiny dogfish and sleeper sharks were the more abundant while salmon sharks only appeared in 1999 (Boldt et al. 2003) (Table 12). The low catch of salmon sharks in the region is due to the fact they are generally caught by pelagic trawl (Boldt et al. 2003) which are not used in the region.

Table 12. Compilation of bycatch (t) of sharks and rays and their attribution to functional groups.

	Skates				**Sharks**							
Area	**2C**[a]	**650**[b]	**659**[c]	**Total**	**650**[c]	**659**[c]	**650**[d]			**659**[e]	**Total sharks**	
	all species				**all species**		**dogfish**	**salmon**	**sleeper**	**dogfish**	**gr 11**	**gr 12**
1990		98		246	18		21					18
1991		149		372	18		21					18
1992		111		277	24		32					24
1993		127	103	420	138	41.16	6					180
1994		268		670	34		42					34
1995		60		150	31		17		6.3		6.3	25
1996		81		201	55		38		12.5		12.5	43
1997	300	173		473	37		42		6.3		6.3	31
1998	269	68	35	372	48	21.9	33		12.5		12.5	57
1999	292	95	0.36	387			50	19.2	10.0	0.13	10.0	59
2000	352	230	2.88	585			158		12.5	16.28	12.5	162
2001	358	86	0.06	444			75		12.5	41.55	12.5	104
2002	248	103	0.33	351			8			0.57		9

a. (Gaichas et al. 2003) halibut fishery; b. groundfish fisheries observer data (S. Gaichas *pers. comm.*) ; c. observer data (Gaichas et al. 1999); d. Boldt et al. (2003) and Gaichas et al. (1999); e. salmon troll plus groundfish and halibut fishery (O'Connell et al. 2002c)

There were no available biomass estimate for 1977 and 1963 so the biomass was estimated using an EE of 0.5 in Ecopath. In 1977 for example, the resulting estimate was equal to 0.7% of the 1999 biomass which may be too low. The calculation of bycatch is detailed in the next functional group section. Using sleeper shark as the representative species, P/B was estimated at 0.13 year^{-1} based on Hoenig's equation (Smith et al. 1998), and Q/B at 3.65 year^{-1} (Hulbert 1999). Diets of the great white shark and bluntnose sharks are taken from general descriptions in the literature. The diet of sleeper shark featured 67% arrowtooth in the Kodiak area (Yang and Page 1999) but did not include any predation on marine mammals. In a recent study Hulbert et al. (2003) reported a frequency of occurrence of 15% of marine mammals, mainly cetaceans. So I took the 15% of the arrowtooth predation and redistributed it to large and small cetaceans. In order to balance the model, predation on whales, skates and sharks (group 12), and arrowtooth were decreased (Appendix 2, Table 2.2).

Sharks and skates, group 12

This group is composed of 6 species of skates and 3 species of sharks: piked dogfish, salmon shark and blue shark. Sandpaper skates are found in waters shallower than 500 m (Mecklenburg et al. 2002). Aleutian skates are found in waters of 15-1,600 m but more commonly on the outer shelf (100-800 m) and Alaska skates at depth of 90-250 m (Mecklenburg et al. 2002). Salmon sharks are warm bodied, ovoviviparous, might have up to 5 pups, they have high metabolic rate, and attain a maximum age of more than 25 years (Goldman 2002). In Northeast GOA, >93% are females of 2-2.5m (http://fakr.noaa.gov/oil/sharks/ sleepersharks.htm). Salmon shark is a seasonal migrant and large sharks predominate in higher latitudes (mainly male) (Nagasawa 1998). They are also said to be quite important around salmon fishing operations. Their population seems to have increased since the stop of the harvest by Japanese operations (V. Gallucci, University of Washington, *comm. pers.*).

The total biomass of skates, calculated from the assessment survey, amounted to 0.08 t·km^{-2} (0.23 t·km^{-2} if extrapolated to inside waters); spiny dogfish were estimated at 0.09 t·km^{-2} and salmon sharks were assumed to be present in the same density as spiny dogfish, as was the case in PWS (Hulbert 1999). So the total biomass amounts to 0.25 t·km^{-2} (or 0.36 if skates densities for the shelf are extrapolated to inside waters). However for preceding years, I have no time series. The bycatch for these species were described in the preceding group (Table 12).

The average P/B for blue shark, salmon shark, piked dogfish, and longnose skate was estimated at 0.16 year^{-1}. Q/B was estimated at 18.25 year^{-1} for salmon shark, 3.65 year^{-1} for piked dogfish (Hulbert 1999), and 2.56 year^{-1} for roughtail skate (Trites et al. 1999). Given the biomass repartition of the species skates were given a weight of 6 and sharks a weight of 2 when calculating the group average Q/B (3.17 year^{-1}). The diet composition was taken from studies carried out in Russian waters (Aleutian Alaska and sandpaper skates), BC (spiny dogfish), and the Bering Sea (salmon shark). The diet of salmon shark has been modified to include detritus (carrions) (Hulbert 1999), and compensated by decreasing the percentage of large zooplankton. The group diet is taken from the unweighted average of frequency of occurrence. I supposed that spiny dogfish were present in the area all year round as it seems to occur year round in the Strait of Georgia and Puget sound (Hart 1973). Assuming that blue sharks were present for half of the year similar to salmon sharks

(Hulbert 1999), and that skates are full time residents in eastern GOA, I assumed that 20% of the diet consisted of items taken out of the study area (imports).

Salmon, group 13

Salmon spend only a small period of their life in coastal marine waters of the study area but they sustain a large fishery. I considered including the juveniles in the model but their small sizes during the short period of time they spend in the ecosystem made it insignificant in the model. Therefore, only adults migrating back in the coastal waters were considered. Salmon are caught with troll (chinook and coho), gillnet and seine. The troll fishery is known to catch small amounts of pelagic and demersal shelf rockfish as well as lingcod. It is interesting to note the relatively large bycatch of 16 and 41 tonnes of spiny dogfish in 2000-2001, respectively (O'Connell et al. 2002c). The catches in number were transformed by using the average body weight of the catch by species for years 1969-2002 (data provided by Martina Kallenberger, ADFG, Juneau Alaska) (Figure 5).

The total mortality (=P/B) value for salmons is the weighted average by species biomass. The natural mortality was taken from various sources (Table 13). The annual exploitation rate (u=C/B) was transformed into instantaneous fishing mortality (F=-ln(1-u)) because at high exploitation rates, the difference can be important. The average fishing mortality reached 0.69 year^{-1} in 1999 (Table 13). Q/B (10.75 year^{-1}) was obtained using a P/Q of 0.2, which is a lower value than that used by Aydin et al. (2003), i.e., 15 year^{-1} . The biomass for 1963 (101,057 t =C/u=0.54/0.49=1.11 t·km^{-2}) was calculated using the same exploitation rate as 1977 given a catch of 49,501 tonnes (Table 13). The biomass between 1963-1977 was assumed to change linearly. Although the biomass time series data are not very good since I had to interpolate for several years for pink, chum, and sockeye, they conformed with the general increase in abundance observed for several species (see Appendix 4).

Cohos (*Oncorhynchus kisutch*) occur in 2,000 streams, mostly small in Southeast Alaska, and lake systems (Lynch et al. 2003). The majority of coho salmon are 3-4 years old and are of Alaskan origin (Lynch et al. 2003). Catches were in the order of 2 millions in the 1940s and decreased to 1 million in the 1970s. By then, capitalization, effort and efficiency had increased, and the harvest in outside waters increased. The management plan adopted in 1980 provided for better escapements, while environmental conditions allowed higher marine survival. The recent increase in catches was attributed to more intensive fishing in highly mixed-stocks areas, increases in targeting coho during chinook fishing and increases in contribution of hatchery-produced coho (Lynch et al. 2003). The biomass and exploitation rate were obtained from Leon Shaul (ADFG, *pers comm.*). The troll fishery, responsible for 50-75% of the catch, caused an exploitation rate of 0.42 year^{-1} but the total rate from all fisheries would be of 0.61 year^{-1} (Lynch et al. 2003) (Table 13). The latter estimates for years 1982 to 2000 was used to upscale the biomass proportionally.

Native **chinook** salmon (*Oncorhynchus tshawytscha*) stocks occur throughout Southeast Alaska and Yakutat, in the large mainland rivers and their tributaries (Lynch et al. 2003). All these stocks are spring types. The young remain one year in freshwater and 2-4 years at sea. Chinook salmon caught in Southeast Alaska are produced from rivers in the Pacific Northwest including Canada (Lynch et al. 2003). Total catches for this species have peaked in the 1920s and 1940s (800-900,000 individuals) and reached 185,000 fish in 1999. The 15-year rebuilding program for chinook was started in 1981, capping the total catch. As a result, the abundance has doubled since 1979-1982 (Lynch et al. 2003). The proportion of chinook in the catch that come from hatcheries has increased since 1986 (Lynch et al. 2003). Chinook biomass and F were obtained from John Carlile (ADFG, Juneau, *pers comm,*). Historically, the troll fishery harvested about 85-90% of the total catches for the species but this proportion has declined since 1980.

Chum salmon (*Onchorhynchus keta*) harvests reached high levels in the 1910s, exhibited a long-term decline through the 1970s, and then increased to record levels in the 1990s (Heinl et al. 2003) (Figure 5). Currently, most chum harvested in SEAK are hatchery-produced, and catches are twice the level of the early 20th century. Long-term time series are only available for 6% of the 1500 streams used by this species, which make the estimation of escapements and harvest rates rather imprecise. I used the average exploitation rate of the summer run at Fish Creek, fished in Dixon entrance for 1991-95 (avg=56.7%; 38.1-67.8%) to calculate the biomass for 1999 (Table 13). I assumed a fishing mortality of 0.5 year^{-1} in 1977, and a linear increase of biomass between 1977 and 1999, which was used to calculate the F time series.

Table 14. Fishing and natural mortality, catches and biomass of salmon by species.

Species	Max age (year)	M (year^{-1})	F (year^{-1})		Z (year^{-1})		Biomass (t)		Catches (t)		
			1977	1999	1977	1999	1977	1999	1963	1977	1999
Coho [d]	38049	2.04[k]	0.84	0.55	2.9	2.98	8,534	22,267	4,185	3,692	9,747
Chinook [g]	38050	0.73[i]	0.11[f]	0.1	0.5	0.49	6,303	14,664	1,746	1,891	1,277
Chum [h]	7	1.0[l]	0.69	0.84 [c]	1.7	1.84	6,804	112,412	6,533	3,402	63,737
Pink [j]	2	1.75 [a]	1.05	0.69 [b]	2.8	2.44	47,449	206,883	35,084	30,842	103,441
Sockeye	38082	0.32 [a]	0.47	0.64 [e]	0.8	0.96	75,555	6,573	1,952	3,426	3,104
Total							91,816	362,798	49,501	43,242	181,307
Weighted average		1.44	0.67	0.71	2.1	2.18					

a. Huato (1996); b. from year 1991; c. average(38.1-67.8%) summer run at Fish Creek, fished in Dixon entrance in 1991 (Heinl et al. 2003); d. biomass and exploitation rate for the troll fishery only (Leon Shaul, ADFG, *pers. comm.*) upscaled to total mortality (Lynch et al. 2003); e. calculated from u given for various sockeye rivers listed in Geiger et al. (2003), biomass obtained from C/F; f. based on the F of 1979-83; g. Biomass and F from John Carlile (ADFG, pers comm); h. Biomass= catch/u; i. Newlands (1998) for BC; j. Biomass = catch/u; k. from 1999 estimate for 1999 (Shaul, ADFG, Juneau, *pers. comm.*); l. Orsi et al.(2003)

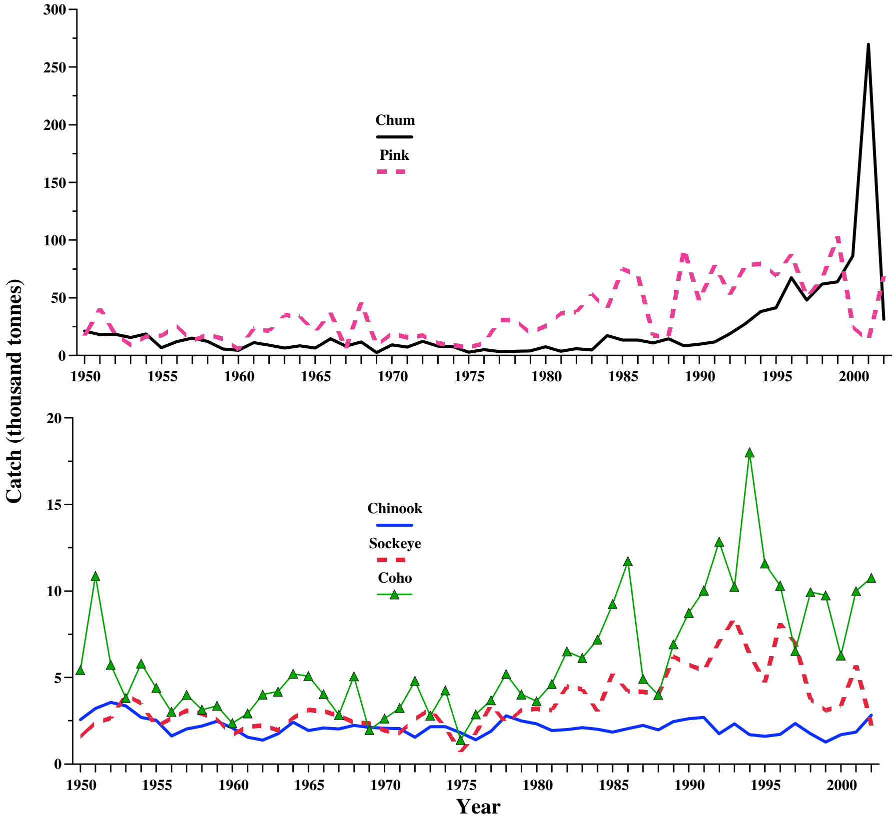


Figure 5. Catches of Pacific salmon in Southeast Alaska for 1950-1999.

Pink salmon (*Oncorhynchus gorbuscha*) spawn in about 2,500 coastal streams throughout the Southeast Alaska and Yakutat area (Zadina et al. 2003). Although the index streams are not considered representative, most show an increase in escapement since the 1970s. The population in SEAK is at an all time high and they are the most abundant in the North Pacific constituting 60% in numbers and 40% in weight. Historically, pink salmon has been harvested on average 60-75% of the total run (The Technical Team for Essential Fish Habitat 1998). The current harvest rate is probably lower now than in the 1970s (H. Geiger, ADFG, Juneau, *pers. comm.*). I assumed an exploitation rate of 50% and 65% in 1999 and 1977 respectively, and a linear increase of biomass between 1977 and 1999 which I used to calculate time series. Subadults and adults are eaten by 15 species such as halibut, sharks, humpback, birds (Alaska Department of Fish and Game 1998). Pink salmons are likely to be the most abundant prey to marine mammals (Heard 1991).

Sockeye salmon (*Oncorhynchus nerka*) spawn in over 200 coastal lakes and in several large rivers. There is good assessment information for 15 systems (Geiger et al. 2003), but the exploitation rate is variable among these systems. So I used the times series of catch, population numbers and exploitation rate each of these stocks, and calculated the weighted mean of the exploitation rate which was then applied to the total catch to obtain the biomass.

The diets for adults came for studies made in Hecate Strait and Juan de Fuca, British Columbia (Appendix 5) (Beacham 1986; Beattie 2001). Assuming that coho and chinook eat proportionally more in the system, their weight has been increased in the calculation of the mean weighted by their respective biomass (Table 14). However, the resulting diets did not differ appreciably between 1977 and 1963 so I used the one calculated for 1999 for all models. I assumed that salmon spent a small amount of their time in SEAK and fed outside the system 75% of the time, so75% of the diet has been classified as imports. The proportion of imports in the diet was increased to 87% to relieve pressure on herring while balancing the 1999 model.

Table 14. Weight of each species in the group diet composition for each model based on the number of months they eat in the study area, in addition of their respective biomass.

Species	Months eating	Weight in diet	
		1977	1999
Coho	6	0.17	0.18
Chinook	6	0.37	0.17
Chum	1	0	0.22
Pink	1	0.16	0.41
Sockeye	1	0.29	0
Total		1	1

Pel L, group 14

The large pelagics group include species not well known such as ocean sunfish (*Mola mola*), King-of-the-salmon (*Trachipterus altivelis*), Pacific barracuda (*Sphyraena argentea*), Pacific bonito (*Sarda chiliensis lineolata*), Pacific pomfret (*Brama japonica*), North Pacific hake (*Merluccius productus*), and Pacific jack mackerel (*Trachurus symmetricus*). Their length vary from 61-183 cm, except for sunfish which can attain more than 3 m.

The distribution of hake has been increasingly moving north since the 1980s, with the species reaching Southeast Alaska in 1998 and 1999 (Hay and McCarter 2000). Their presence is noticeable in the 1999 survey trawling samples when they reached 4,013 tonnes or 0.044 $t{\cdot}km^{-2}$. M was estimated at 0.22 $year^{-1}$ using Pauly's equation for barracuda, hake and jack mackerel. Q/B (1.1 $year^{-1}$) was obtained using a P/Q of 0.2. There is no recorded catch for this group although catches of 284 tonnes of hake were declared in SEAK in 1968, and 3 t in 1969 (Forrester et al. 1978). The biomass was left to be estimated by Ecopath for the 1977 and 1963 models, and I expected a lower biomass than in the 1999 because of the absence of hake in the study area at the time.

Pel S, group 15

Small pelagics represent smelts and various osmerids such as surf smelt (*Hypomesus pretiosus*), capelin (*Mallotus villosus*), Arctic rainbow smelt (*Osmerus mordax dentex*), night smelt (*Spirinchus starksi*), longfin smelt (*Spirinchus thaleichthys*), chub mackerel (*Scomber japonicus*) and eulachons (*Thaleichthys pacificus*). Eulachons were first considered as a separate group but were integrated with the small pelagics due to the paucity of data and the very low catches (see Appendix 6 for details on eulachons). Based on Pauly's equation, the natural mortality of capelin and chub mackerel was estimated at 0.79 and 0.43 $year^{-1}$ respectively, while eulachons mortality, 1.43 $year^{-1}$, calculated using Hoenig's equation and a maximum age of 3. The resulting average reached 0.89 $year^{-1}$. I assumed a P/B of 1.15 $year^{-1}$ as in Newfoundland (Bundy et al. 2000) to account for small species. Most of these fish are invertebrates feeders although rainbow smelt and chub mackerel feed partly on fish. Q/B (5.75 $year^{-1}$) was obtained using a P/Q of 0.2. The diets were taken from the North Pacific and Bering Sea and often from qualitative descriptions (Appendix 5).

Sandlance, group 16

Sandlance (*Ammodytes hexapterus*) has been singled out because of its importance in diet of several species. Sandlance biomass was estimated by using the average catch in numbers by beach seine between 1998 and 2003 throughout Southeast Alaska (Scott Johnson, Auke Bay, Juneau, *pers. comm.*). The catch was extrapolated by using the area of sandy beaches (428 km^2) present in Southeast Alaska after data provided by Mitch Lorentz (NMFS, Juneau, *pers. comm.*). The average body weight has been calculated by assuming it was 75% of the average W_∞ for males (58g) and females (23g) (Froese and Pauly 2000), that is 30.4g. The average weight multiplied by the catch in numbers yielded a crude estimate of biomass of 0.75 t·km^{-2}. This estimate does not account for the sandlance found more offshore, so the biomass is likely to be higher. In order to balance the model, the biomass was allowed to increase to 1.3 t·km^{-2}. Natural mortality was taken from similar species in Newfoundland estimated at 1.15 year^{-1} (Bundy et al. 2000). Q/B (5.75 year^{-1}) was obtained using a P/Q of 0.2. The same biomass was kept for 1977 and 1963 models. Based on qualitative information (see Appendix 5), sandlance feed mainly on small (73%) and large (21%) zooplankton (FishBase, Okey and Pauly 1999; Chikilev and Datskii 2000). Black rockfish have been seen feeding on sandlance at the surface (Mecklenburg et al. 2002).

Herring, group 17

Herring, *Clupea pallasii*, have been exploited since the 1880s in southeast Alaska for reduction and fish meal, but this practice was phased out in the 1960s (Hebert and Pritchett 2003). Southeast Alaska has been supplying most of the bait for Alaska's longline and pot fisheries. This fishery occurred during the fall and winter. Most of the current annual harvest is taken in the spring roe fishery which developed in the 1970s. The spawn on kelp fishery had stopped in the 1960s and resumed in 1990. Catches are compiled from the fall of one year to the next. Since most of the catch is taken by the spring roe fishery, the fall and winter bait harvest was assigned to the following year, that is the catch for 2000-2001 was assigned to the year 2001. Catches for 1976-2001 were taken from the ADFG database (D. Carlile, *pers. comm.*) and data before 1976 from Hebert and Pritchett (2003).

There are 5 major groups of herring that sustain the commercial fishery: Sitka Sound, Seymour Canal, Tenakee Inlet, Craig, Kah Shakes/Cat Islands, all of which are considered as discrete stocks for management purposes. The biomass estimate for these areas were subjected to an egg deposit survey, which encompasses about 75% of the egg deposition that have been identified by airplane in 2002. The additional spawning deposition is rather marginal, often shallow and less dense than the main aggregation, and may account for about 10% of the total egg deposition in SEAK; this is ignored for management purposes (Mark Pritchett, ADFG, *pers. comm.*). The spawning biomass (3+) of the five main areas was obtained from age-structured models (Carlile et al. 1996), to which I added the biomass of 1 and 2 years old, back calculating the numbers assuming a mortality of 0.5 year^{-1} and using body weight of 25 g at age 1 and 46 g at age 2. The missing biomass estimate for years 1976-1981for Tenakee Inlet was calculated by using the spawners biomass calculated from the egg deposition survey, and assuming a ratio of 39% between the spawners biomass estimates obtained from egg deposition and that from the age-structured stock assessment (the average for years 1982-2000). For the minor sites for which I only had spawners estimates, the spawn biomass was assumed to constitute 75% of the total biomass, a conservative ratio, given that the biomass estimated from the egg deposition constituted 61% of the age-structured stock assessment value on average. The main difference between the adjusted biomass as described above and the spawners estimates is largely due to the results of the age structured assessment as illustrated by the Sitka and Craig inlet (Figure 6A). The total population has increased dramatically from 35,630 t in 1976 to 257,056 t in 1999 (Figure 6B).

I used the 1976-2002 biomass and the 1963-2002 catch time series to estimate the 1963 biomass. The Schaefer model, described earlier, was solved for k (assumed to be equal to biomass in year 1900) using a series of initial value of r because the data is not informative enough to estimate both parameters at once. The penalised likelihood was calculated using F prior calculated as $(F_{avg} - 0.07)^2$ where F_{avg} is the average fishing mortality (=ratio of observed catches to the predicted biomass) for years 1990-2001 (Steve Martell, Fisheries Centre, UBC, pers. comm.). For a set of r values ranging from 0.3-0.7, the reconstruction model yielded a 1963 population biomass of 48,787 to 24,007 t as the likelihood increased (Table 15). Based on a maximum value of exploitation rate set arbitrarily at 0.9, and the comparison of predicted and observed (from age-structured stock assessment), the initial intrinsic growth rate of 0.5 year^{-1} yielded a reasonable scenario (Figure 6 C, D). The rounded value for 1963 biomass, 32,000 t (0.89 t·km^{-2}), is similar to the average result from

Table 15. Results of the herring stock reconstruction using a range of intrinsic growth rate.

r (year^{-1})	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**
Biomass 1963	48,787	37,681	**31,516**	27,225	24,007
Biomass 1977	113,597	85,136	**65,289**	52,715	32,429
k^{a}	484,662	408,579	354,137	312,655	279,829
F max	0.57	0.75	0.89	1.008	1.12
Likelihood	-23	-20	-17	-15	-16

a. carrying capacity

simulations done with r= 0.4 to 0.6. Note that according to the model predictions, the 1977 biomass would be twice as high as those derived from the stock assessment data, which were incomplete. Thus, in order to balance the 1977 model, the original biomass was left to increase to 0.45 t·km^{-2}, while the proportion of herring in the diet of small mammals, sea lions, Pacific cod, arrowtooth and salmon was reduced.

For the period 1980-2000, fishing mortality, catch/biomass, was the weighted average by stock. The biomass and fishing mortality time series for the period 1963-1979 were taken from the results of the production model. Q/B (3.9 year^{-1}) has been calculated by Ecopath using a PQ of 0.2. P/B was calculated at 0.78 year^{-1} (M=0.73 and F=0.05). Herring's diet is dominated by large zooplankton (82%), small zooplankton (17%) and benthic invertebrates (1%) (Bering Sea, Niggol 1982; Brodeur 1988).

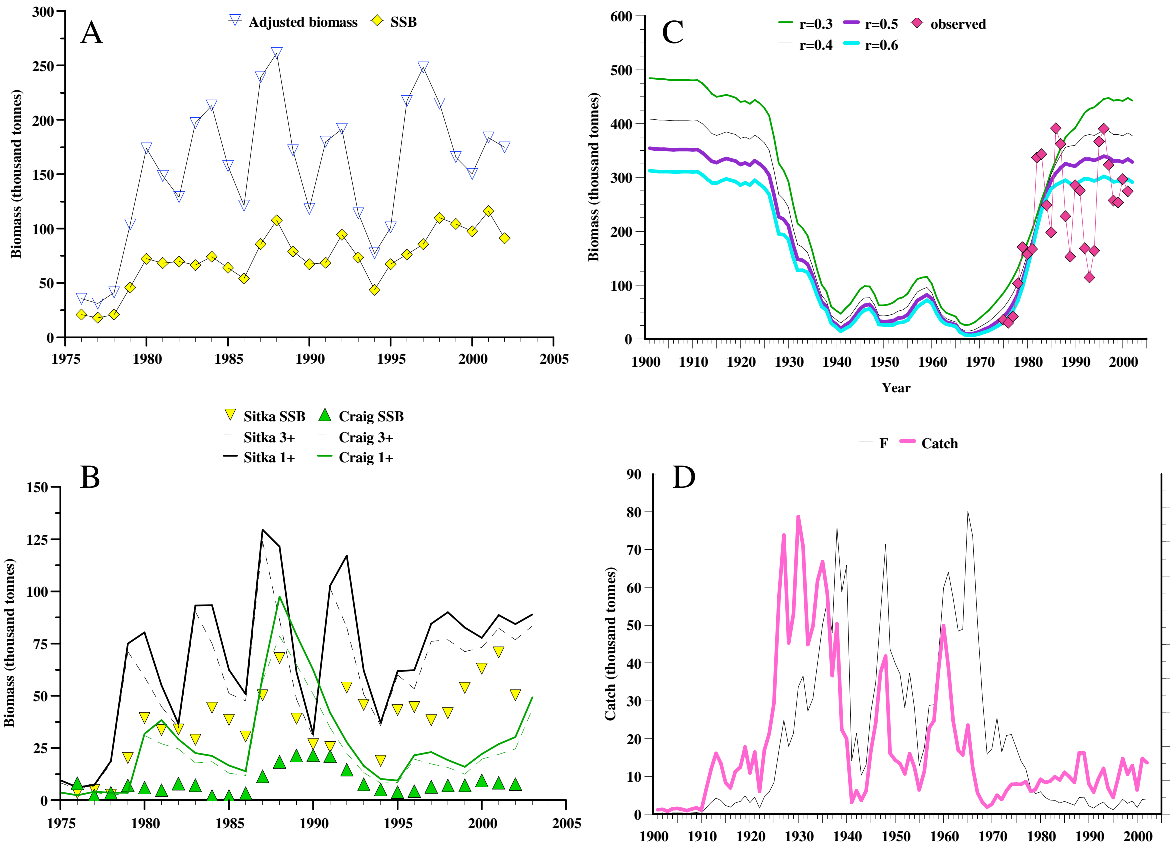


Figure 6. A. Herring biomass obtained from stock assessment (adjusted biomass) and estimates of spawner biomass from surveys (SSB) in SEAK.; B. Comparison of spawners biomass from surveys, and age structured stock assessment for 3+ and 1+ herring; C. Biomass estimate obtained from the surplus production model under 4 scenarios compared to the adjusted biomass (observed); D. Observed catch and exploitation rate (u) series obtained assuming that r=0.5.

Pollock, group 18-19

Pollock, *Theragra chalcogramma*, in Southeast Alaska has been considered separately from the rest of the Gulf of Alaska (Dorn et al. 2002). They are organised in a metapopulation structure characterized by numerous fjord populations. A large spawning aggregations has been found in the Dixon Entrance and larger catches in survey trawls are taken from the shelf north of Dixon Entrance. Pollock density on the outer coast is evaluated at 1.03 t·km^{-2} in 1999 for the outer coast, when adding estimate for the Yakutat section (0.17 t·km^{-2}) and extrapolation by depth strata for inside waters, the resulting density is 1.79 t·km^{-2}. In comparison, estimates of pollock reached 1.9 t·km^{-2} in 2000 for Frederick Sound and Lynn Canal (M. Sigler, Auke Bay Lab., *pers. comm.* in Trites et al. 2003). Combining these three areas, the 1999 biomass for the study area was estimated at 109,772 t or 1.2 t·km^{-2}. The biomass in the 1970s were thought to be much smaller (0.3 t·km^{-2}) (M. Sigler, opt cit.). The 1984 estimate of 0.03 t·km^{-2} from the trawl survey is probably an underestimate because the survey did not cover shallow waters (Table 10). In addition, survey catch rate of pollock increased from 14 kg/h in 1961 to 61kg/h in 1974-75 (Alton 1981), suggesting a substantial increase in the pollock population in SEAK during this period. Survey coverage varies a lot from year to year (Table 10) thus the biomass calculated is highly variable (Figure 7). Only two data points, 0.3 t·km^{-2} in 1977 and 1.2 t·km^{-2} in 1999, were kept for reference in the Ecosim simulation. The 1963 biomass (0.06 t·km^{-2}) was assumed to be 23% of the 1977 biomass based on the trawl survey assessment reported mentioned earlier (Alton 1981). Fishing mortality time series were obtained from the ratio catch/biomass assuming linear increase in biomass between data points.

Pollock have been divided into two stanzas defined as juveniles, 0-2 years old, and adults, more than 2 years old (Table 16). I used a von Bertalanffy relationship from the Gulf of Alaska (K=0.34 year^{-1}, L_∞=37cm, M. Dorn, NOAA, Seattle, *pers. comm.*) and the length-weight relationship from Britt and Martin (2001) yielding a weight at infinity of 1.25 kg. This length at infinity seems low but recent studies suggest large variations in growth and overestimates in aging in earlier studies (M. Dorn, NOAA, Seattle, *pers. comm.*). As length at maturity varies a lot among years (Dorn et al. 2002); (30 cm in the 1970s, and 43cm in 1999), I chose to use the mean length at age 3, 37 cm, to obtain a weight at maturity of 374g, which yielded a ratio of $W_{maturity}/W_\infty$ of 0.3.

Table 16. Parameters for pollock stanzas in 1999. The value in bold were calculated by Ecopath

	Biomass (t·km^{-2})	**P/B (year^{-1})**	**QB (year^{-1})**
juveniles	**0.0327**	1.2^{a}	**9.8**
adults	1.209	0.3	2.5

The present trawl ban in SEAK prevents further developments in pollock fishery and the catch is very limited. Catches were more important in the 1970s reaching 3,669 t in 1981 (Appendix 4). P/B (=M) was estimated at 0.3 year^{-1} (Dorn et al. 2002). The fishing mortality time series was calculated assuming linear change in biomass between years of available estimates (Forrester et al. 1983). The Q/B for adult pollock was obtained by assuming a production/consumption ratio of 0.2, while the Q/B for juveniles was calculated in Ecopath. The adult Q/B had to be increased in 1977 and 1963 (Table 22 and 23) to decrease the ratio P/Q to more reasonable levels. The diet has been adapted from a study made in SEAK (Clausen 1983) using information from Yang and Nelson (2000) to allocate unidentified fish to functional groups. Adult pollock cannibalism reached 1.1% of each juveniles and adults (Table 2.1). Adults eat more shrimp and fish (unidentified) and less Lzoo (see Table 2.1).

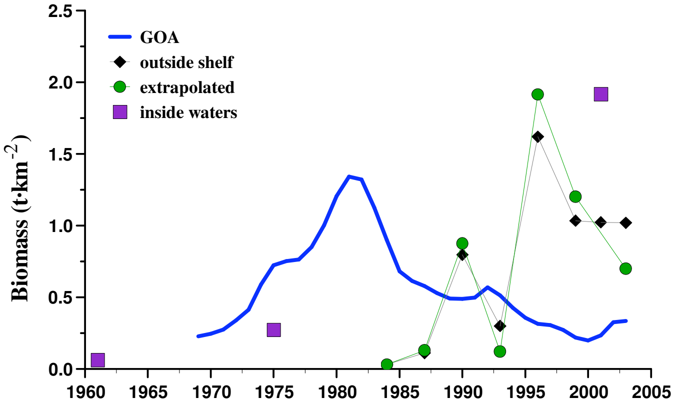


Figure 7. Pollock biomass densities on the outside shelf of SEAK (outside shelf), for the whole study area including inside waters (extrapolated) and inside waters obtained from M. Sigler (inside waters). The biomass from the stock assessment for the Gulf of Alaska is shown for comparison (GOA).

Pacific ocean perch, group 20

Pacific ocean perch (POP, *Sebastes alutus*) has been separated from the slope rockfish group because of its historical importance. In fact, it was having the highest biomass of rockfish in the Gulf of Alaska before the 1970s. This species is long-lived, viviparous and require internal fertilisation. The biomass estimates from surveys are highly variable so I chose instead to use the estimate obtained from stock assessment for the whole Gulf and apportion the biomass (biomass of 2+) present in the SEAK using the average percentage given in Hanselman et al. (2003) for years 1993, 1996, 1999, 2000, i.e. 18.6%. The latter values gave a more stable estimate from year to year consistent with its life history. POP biomass has decreased drastically after 1964 and increased slowly after 1985 (Figure 8). The biomass for 1999 was estimated at 0.6 t·km^{-2} for the outside waters and east Yakutat and at 0.19 t·km^{-2} in 1977. I assumed that the density of POP in the inside waters was negligible (D. Clausen, NMFS, Juneau, *pers. comm.*). The 1963 biomass amounted to 2.38 t·km^{-2}. The survey catch rate of POP decreased from 72 kg/h in 1961 to 5 kg/h in 1974-75 (Alton 1981), which resembled the change observed Gulf wide.

As a consequence of the prohibition of trawling east of 140°W the effort and catch of rockfish has declined substantially since 1998 as these species do not respond to bait (D. Clausen, NMFS, Juneau, *pers. comm.*). Since POP is mainly caught by trawl, most of the reported catches since 1998 are bycatch from the halibut and sablefish longline fisheries. Starting in 1991, catches for POP were reported separately and I directly used the catch statistics from NMFS and ADFG for this period. The catch for 1999 is quite small, amounting to 0.23 tonnes. For years before 1991, the proportion of POP in the rockfish catches was largely unknown and probably variable. Catches from Eastern GOA (Heifetz et al. 2002) were apportioned by assuming that 86% of the catch of rockfish were POP, as was the case in 1991. In addition, I assumed that the catches of Yakutat were equally distributed in the whole area (East and West Yakutat) when I had that level of detail, or alternatively, equally distributed in the whole Eastern GOA (area 640-650).

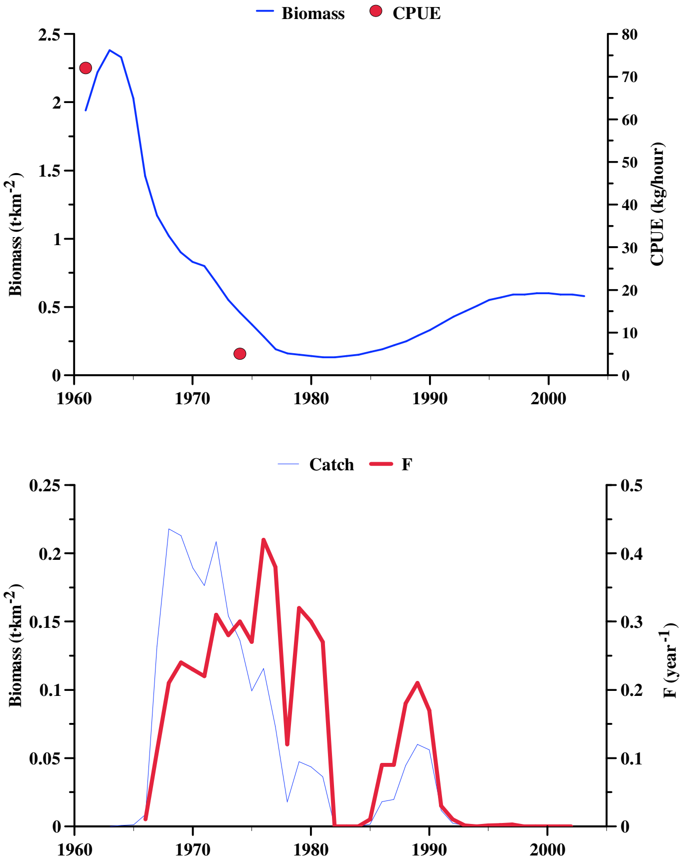


Figure 8. A. Biomass of POP derived from stock assessment and from CPUE (Alton 1981); B. catch in SEAK and fishing mortality (F).

Natural mortality was estimated at 0.04 year^{-1} (0.02-0.06 in Kronlund et al. 1999). The 1999 fishing mortality was very small, given the low level of catches due to the ban on trawling starting in 1998, while it reached 0.38 year^{-1} in 1977. Q/B was estimated at 5.3 year^{-1} by using a P/Q value of 0.2 to account for the species longevity. POP feed mainly on L zoo (71%) and benthic invertebrates (11%) (Yang and Nelson 2000).

Slope rockfish, group 21

This group includes 21 species, several of which are caught commercially. In order to offer protection from possible overfishing, slope rockfish have been divided in 4 subgroups: Pacific Ocean Perch (POP; preceding section), shortraker/rougheye, northern and other rockfish. Each subgroup was assigned a separate TAC (Heifetz et al. 2002). Northern rockfish is ignored here given its very low biomass in the study area. Most of the biomass of other rockfish species is concentrated in the eastern Gulf (Heifetz et al. 2002). The functional group slope rockfish contains all 22 species of deep water rockfish except POP. These species inhabits the outer continental shelf and slope in depths greater than 150-200 m in a very patchy distribution.

The relative biomass of rougheye (*Sebastes aleutianus*) and shortraker (*S. borealis)* rockfish obtained from the trawl survey is very variable from year to year, slightly more than the longline index of abundance (Figure 9). The total 1999 biomass was derived from the trawl survey for the outer shelf and assuming similar density per depth strata for the interior waters (Table 13).

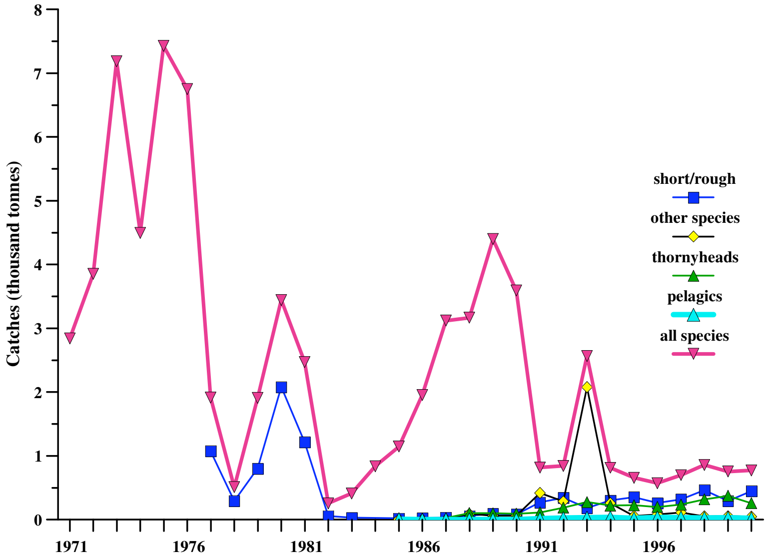


Figure 10. Catches of slope rockfish by subgroup for the period 1971-2000.

survey to survey and probably not that reliable. The surveys started in 1984 with a total biomass of 0.47 t·km^{-2} which is probably an underestimate for that year, given that the survey covered only depth of 100-500m, and there was no indication of what the biomass would have been in 1977 or in 1963. Thus, the biomass was left to be estimated by Ecopath for the 1977 and 1963 models.

Fishing mortality, based on the ratio of catch over biomass, is not very reliable before 1990, but it is estimated at 0.005 year^{-1} in 1999 and 0.04 year^{-1} in 1977, assuming that a biomass similar to that of 1984. Natural mortality, based on thornyheads (Gaichas and Ianelli 2001) and on dusky rockfish (Clausen et al. 2002), was estimated at 0.06 year^{-1}. Q/B (0.35 year^{-1}) has been calculated by Ecopath using a P/Q of 0.2. The diet of slope rockfish is dominated by shrimps (22%) and L zoo (36%), S zoo (21%) and a large selection of fish (Appendix 2).

Shelf rockfish, group 22

This group of 11 species is dominated by the yelloweye rockfish (*Sebastes ruberrimus*) in abundance, at least for commercial purposes. The yelloweye rockfish lives longer than 100 years and exhibit slow growth. They are mainly distributed in waters shallower than 220m (David Carlile, ADFG, Juneau, pers. comm.) although they can be found as deep as 500 m. There are 11 species in this group, but only the yelloweye abundance has been estimated.

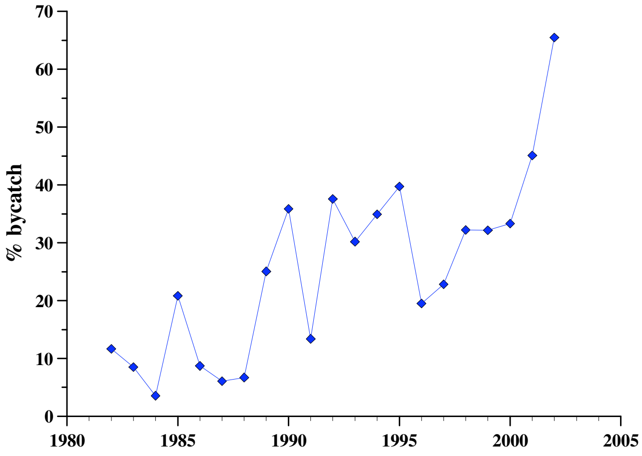


Figure 11. Amount of bycatch as a percentage of total landings of demersal shelf rockfish as calculated from O'Connell et al. (2002).

The two internal state water subdistricts are managed entirely by ADFG and not included in the NMFS stock assessment. The directed fishery started in 1979 as a small shore-based hook and line fishery, fishing inside the 110m contour (O'Connell et al. 2002b). The current fishery operates between the 90 to 200m contour using mainly longline gear. The current fishery targets yelloweye rockfish, accounting for over 90% of the catch in the last five years, while quillback accounts for 8%. Outside waters catches have declined since the late 1980s. Landed bycatch of this fishery included lingcod, Pacific cod and other rockfishes (O'Connell et al. 2003). In turn, the bycatch of shelf rockfish in the halibut fishery constituted a significant portion (40% in 2002) of the TAC (O'Connell et al. 2002a) (Figure 11). Bycatch is probably underestimated because discarded fish die of embolism. The proportion of bycatch from the halibut fishery is also difficult to assess as there is no linear relationship with the amount of halibut caught because of their patchy distribution. The bycatch of yelloweye varies from 3 to 18% depending on regions (O'Connell et al. 2003). There is now a maximum percentage of bycatch of demersal shelf rockfish that can be retained and sold by halibut longliners.

The shelf rockfish are surveyed by direct observations from a manned submersible covering the habitat down to 220m conducted by the ADFG. The survey concerns mainly yelloweye rockfish as the other species are not as detectable because of their skittish behaviour or their very low numbers. Their habitat is defined as the rocky habitat where they are known to occur or mentioned in commercial logbooks (confidential data), mostly in the northern area because that is where the fishery is operating (Dave Carlile, ADFG, Juneau, *pers. comm.*). The area of identified suitable habitat for rockfish represents only 18% of the depth strata of less than 200m in outside waters including eastern YKT and Fairweather grounds. The biomass was calculated as the abundance by management area multiplied by the average body weight (O'Connell et al. 2003). Assuming the same proportion of habitat for the inside waters, the total yellowtail biomass is estimated at 0.334 t·km^{-2} for the whole area in 1999. Assuming a catch rate similar to yellowtail (F=0.014 year^{-1}) applied to their catch, other species biomass amount to 0.051 t·km^{-2} (16% of the yelloweye biomass). In contrast, the biomass estimate from the NMFS survey would amount to only 0.09 t·km^{-2}: 0.014 for yelloweye rockfish and 0.074 for the other species. I used the ADFG survey for yelloweye rockfish and the NMFS surveys for the other species. The minimum total biomass for this group is 0.41 t·km^{-2} and the catch 0.005 t·km^{-2} in 1999. The catch time series were obtained from O'Connell et al. (2002a) and ADFG database. It is useful to keep in mind that the NMFS survey accounts for 8 of 11 species and do not sample shallow waters so the biomass is the minimum estimate. Based on the 1984 trawl survey, the minimum estimate of shelf rockfish biomass for 1977 reached 0.67 t·km^{-2}. Both the 1977 and 1963 biomass were increased to1.64 and 1.68 t·km^{-2} respectively in order to balance the model.

The natural (annual M = 0.02, O'Connell et al. 2002a) and fishing (F = catch/biomass = 0.01 year^{-1}) mortalities are those of the yelloweye. Q/B (0.2 year^{-1}) has been calculated by Ecopath using a PQ of 0.2. The diet is the average of 9 species taken from studies in the Gulf of Alaska and North Pacific (Appendix 5). Shelf rockfish feed mainly on forage fish (sandlance, pel. S, herring; 21%), small demersals (5%), benthic invertebrates (shrimps, benthic inverts, epibenthic carnivorous; 32%) and L. zoo (20%) (see Table 2.1).

Sablefish, group 23

Sablefish, *Anoplopoma fimbria*, show substantial movement between the Bering Sea, Aleutian Island and the Gulf of Alaska and therefore it is considered a single stock for the whole area (Sigler et al. 2002). Most juveniles are found in the central and eastern Gulf of Alaska (Sigler et al. 2001). By the end of the first summer, juveniles have drifted inshore where they spend the next year. They typically move offshore during the next few years so that they are found on the upper continental slope, the adult habitat, when they reach 4-5 years old. Adults are generally found at depths of 366-915 m (Sigler et al. 2002). They are long-lived (the oldest individual was 88 years old in inside waters of SEAK). They mature at 5 years for males and 6.5 years for females.

In the inside waters, the major fishing grounds were in Clarence Strait, Frederick Sound, and Chatham Strait (Alverson et al. 1964). The fishery started very early as there were reports of 27 tonnes in 1906 (Richardson and O'Connell 2002). The harvest level varied over time as a function of prices and the availability of other opportunities. Management measures became more stringent with time as the fishing capacity increased. Most catches (85%) came from the Chatham Strait (Richardson and O'Connell 2002). Sablefish are caught with longlines in directed fisheries and various other trawl and line fisheries as bycatch (Carlile et al. 2002). The exploitation rate estimated with a tagging study amounted to 0.166 year^{-1} (0.133-0.186) (table 1 in Alverson et al. 1964; Carlile et al. 2002). In federal waters, the fishery started in the early 1900s but the stock was not heavily exploited until the 1960s when Japan extended its distant water longline fleet (McDevitt 1986). By 1984, the US fleet harvested 86% of the sablefish caught in US waters (McDevitt 1986). Most of the foreign and US catches were made using longlines so I attributed all the catches to longliners.

Catches were taken from Alverson et al. (1964) for 1950-1955; McDevitt (1986) for 1956-1984, allocating the catch taken in Yakutat to East Yakutat in proportion of its area; adapted from Sigler et al. (2002) for 1985-1990, and from the NOAA data base for 1991-1999 (Appendix 4). Data for inside waters start in 1969 and come from various sources: NOAA data base, Carlile et al. (2002) and Clausen and Fujioka (1988). Data from Carlile et al. (2002) were for northern part of the inside waters only. Catches were at their highest between 1967-1975 (10-15,000 t) and declined between 1976-1985 (3-

5,000 t). In 2000, catches reached 5,726 t (Figure 12). Discards were estimated at 2.8% in the longline fishery in GOA between 1995-2000 (Sigler et al. 2002) and for the whole time series.

Abundance and CPUE are higher in SEAK because it appears to be a preferred habitat for sablefish. In fact, quotas by discrete management area were recommended so that fishing mortality (the proportion of fish caught) is equal among areas (Sigler et al. 2002). The biomass of 4+ sablefish was estimated from the Gulf of Alaska stock assessment and an estimate of the proportion of the stock present in outside waters of SEAK and east Yakutat (13-20% for the period 1979-2000; M. Sigler *pers. comm.*). For the period 1963-1978, the outside waters biomass was assumed to be 13% of the GOA assessment as it was for 1979-1981. The biomass in inside waters was estimated assuming that the density in Frederick Sound were similar to the outside waters. Similar assumptions for the Chatham Strait led to a large estimate, which was three times as large as the estimate obtained from 2003 mark-recapture studies (Dave Carlile, ADFG, Juneau, *pers. comm.*), so the time series for Chatham Strait has been decreased to one third as a conservative estimate. As a result, the biomass in inside waters represented 18% of the total biomass (Table 14). Then, the biomass was augmented by 20%, the average weight of pre-recruits for the years 1979-2000, to account for individuals younger than age 4 not included in the biomass estimate. The total biomass was estimated at 0.8 $t\cdot km^{-2}$ in 1999 (Table 14).

The biomass for 1960 to 1978 were obtained following the same calculations using the 1979 proportion of sablefish in inside waters. The resulting biomass trajectory, resembled the original stock assessment, and showed a pronounced decrease in 1963 (Figure 12). A second time series was obtained using the Schaefer model, population estimates from Dr Sigler's stock assessment for years 1979-2000, and the catch times series. The resulting biomass trajectory resemble the original stock assessment but stayed high between 1960-1968. I first used the 1963 estimates obtained from the first method (0.46 $t\cdot km^{-2}$, Table 14) but it was impossible to fit the catch and biomass time series using this value and I utilised the 1963 biomass estimate obtained with the second method instead (see the fitting section). Natural mortality was estimated at 0.1 $year^{-1}$ (Sigler et al. 2002) and F=C/B for adult at 0.07 $year^{-1}$ in 1999 (see Table 14). Q/B (0.9 $year^{-1}$) has been calculated by Ecopath using a PQ of 0.2.

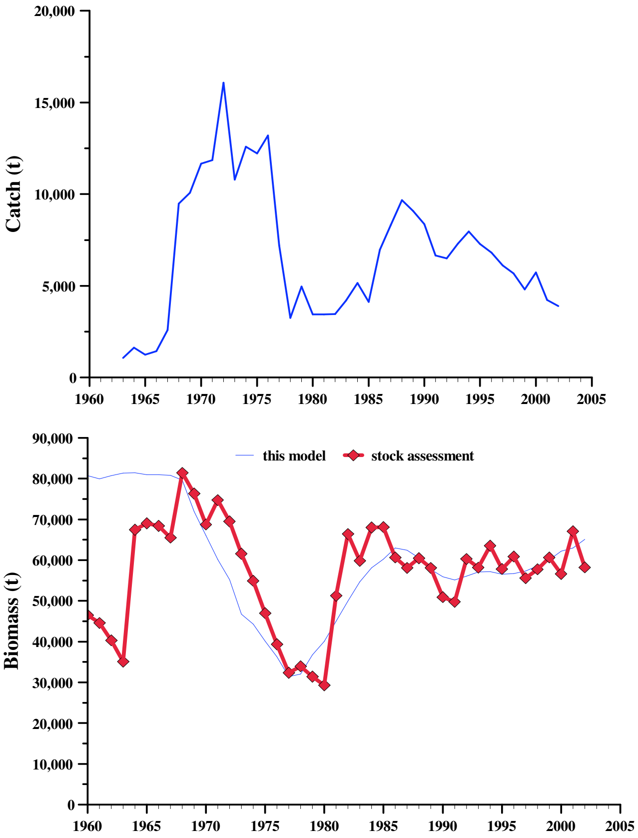


Figure 12. Sablefish catch and biomass for the period 1960-2003. The biomass graph shows the stock assessment data extrapolated for inside waters and the results from the production model as used to obtain the 1963 biomass value.

Table 14. Estimation of biomass of sablefish in outside and inside waters of the study area.

	Outside waters [a] (t)	**Chatham Strait [b] (t)**	**Frederick Sound [c] (t)**	**Total area (t)**	**Biomass adult ($t\cdot km^{-2}$)**	**plus juveniles ($t\cdot km^{-2}$)**	**F ($year^{-1}$)**
1999	49,952	6,115	4,594	60,660	0.66	0.8	0.07
1979[d]	25,877	3,168	2,380	31,424	0.34	0.41	
1977	26,661			32,377	0.35	0.43	0.19
1963	28,883			35,075	0.38	0.46	0.03

a. Stock assessment (M. Sigler, Auke Bay, Juneau, *pers. comm.*) in the study area f; b. Assuming same density as in outside waters; c. using a third of the density of outside waters based on biomass estimate using mark-recapture; (D. Carlile, ADFG, Juneau, *pers. comm.*); d. last year of stock assessment for which the proportion of the biomass in each area of the GOA was known; e. calculated using the 1979 proportion of sablefish in inside waters.

The only species preying on adult sablefish is halibut (<1% of the diet (Sigler et al. 2002). However, diets for a few rockfish (Rosenthal et al. 1988) and sharks (LeBrasseur 1964; Jones and Geen 1977; Harvey 1989; Hulbert 1999; Hulbert and Rice 2002) include sablefish in their diet. Sablefish feed mainly on Large zooplankton (21%) and benthic inverts (14%) and a large variety of fish of which dem S was the most abundant.

Pacific cod (Pcod), group 24

Pacific cod (*Gadus macrocephalus*) is present both in inside and outside waters of the SEAK, occurring from the shoreline to depth of 500 m. There is a significant migration between the GOA and the eastern Bering Sea and the Aleutians, so it is managed as one stock. The species lives up to 21 years old (Coonradt 2002). Larvae and juveniles are transported to nurseries (shallow and intertidal areas) by currents.

In outside waters (>3 nm of the coast), the fishery was small before 1976, and mainly taken by foreign fleets as incidental catches compared to the rest of GOA in which the catch reached 36,000 t in 1981 (Zenger and Blackburn 1987). Although Pcod is presently exploited by trawl, longline, pot, and jig gear. Most of the catch is taken by longliners in SEAK. The state-managed fishery (<3nm + inside waters) is small and probably underestimated because SEAK Pcod tend to be have parasites; it is used as bait for halibut fishery and shellfish fishery, uses that are under-reported. Decreases in catches in the last few years was caused by low prices and the cost of fuel. The catches in state-managed waters were included in the global catches used for the assessment model. To accommodate the state fishery, the federal TAC has been set below its 'optimal' level. In the state waters, most of the bycatch comes from miscellaneous longline fisheries (mainly halibut) in the northern inside region and longline and sablefish fishery in the southern inside region (Coonradt 2002). Catch statistics were obtained from Grant Thompson (NMFS, Seattle) for the period 1991-2002 in outside waters and from Coonradt (2002) for inside waters after 1985 (Appendix 4). Catches for 1977-1983 came from observer records (NMFS data, J. Berger, Seattle) and catch statistics reports (Zenger 1981; Forrester et al. 1983).

The biomass from NMFS survey was 0.336 t·km^{-2} (0.181 t·km^{-2} in outside waters). Using the stock assessment for the whole GOA and assuming that southeast Alaska account for only 5% of the population (Britt and Martin 2001), the biomass of 3+ cod would amount to 0.32 t·km^{-2}. Therefore, the biomass trend of the stock assessment going back to 1978 was used to obtain the 1977 biomass estimate (0.286 t·km^{-2}). In absence of data for previous years and given the low catches in the region in the 1960s, the 1963 biomass was assumed to be similar to that of 1977.

The natural mortality was estimated at 0.37 year^{-1} as derived from stock assessment (Thompson et al. 2002), which is similar to the value obtained from Pauly's equation (0.35 year^{-1}). Fishing mortality was very low 0.02, 0.01 and 0 year^{-1} in 1999, 1977 and 1963 respectively. Q/B (1.95 year^{-1}) has been calculated by Ecopath using a P/Q of 0.2. Predators include halibut, salmon shark, northern fur seal, sea lions, harbour porpoise, whales, tufted puffin (Thompson et al. 2002). The diet information from Hecate strait (Fargo and Pearsall 2004) was used for fish preys allocation (less pollock than in GOA central) and completed with Yang and Nelson (2000) for invertebrates (Table 2.1). To balance the 1999 model, the proportion of flatfish in the diet was decreased from 18 to 10% while the proportion of Dem S increased (Appendix 2, Table 2.2).

Halibut, group 25

Halibut (*Hippoglossus stenolepis*) biomass, effort and fishing mortality (1974-2001) were all taken from assessment reports (Clark and Hare 2002) for IPHC area 2C, which covers the area delimited by 137°W on the western side. Catch statistics for 1929-2002 were available from the International Pacific Halibut Commission (IPC) (http://www.iphc.washington.edu/halcom/). The biomass of legal size (larger than 80 cm, which corresponds to age 4-5 in the 1990s) was 0.64 t·km^{-2} and the biomass of small individuals considered negligible. In 1977, the biomass amounted to 18,794 tonnes or 0.26 t·km^{-2}. Natural mortality was estimated at 0.1year^{-1} (Pauly's empirical equation) and fishing mortality at 0.16 and 0.1year^{-1} in 1999 and 1977, respectively. Catches amounted to 7,528 t or 0.0824 t·km^{-2} for 1999, and 2,219 t or 0.0243 t·km^{-2} in 1977. In 1963, the catches amounted to 6,192 t and the biomass was assumed to be similar to that of 1974.

A value of Q/B (1.3 year^{-1}) was calculated by Ecopath using a P/Q of 0.2. The diet was adapted from that described for Hecate Strait (Fargo and Pearsall 2004) for fish (less pollock than in GOA central) and completed with GOA studies (Yang and Nelson 2000) for invertebrates. Sablefish was added to the diet as it was mentioned as a potential prey for halibut (Sigler et al. 2002). Their diet has been modified somehow to balance the 1999 model, decreasing the amount of shelf rockfish, and POP.

Arrowtooth flounder, group 26

Arrowtooth (*Reinhardtius stomias*) is an abundant species throughout the Gulf of Alaska and its abundance has increased in the Gulf of Alaska since the 1970s. This species occurs from 20-800m but peaks at 100-300 m with indications of ontogenic migration towards deeper waters (Turnock et al. 2002b). Because of its low economic value, arrowtooth flounder is mainly taken as bycatch and largely discarded.

The 1999 biomass, calculated using the NMFS survey, reached 2.22 t·km^{-2} for the outside shelf, and 3.06 t·km^{-2} for the whole study area, assuming that arrowtooth occurred in only half the density in inside waters. An alternative calculation uses the stock assessment for the whole Gulf assuming that SEAK contained 13% of the GOA biomass (J. Turnock, NMFS, Seattle, *pers. comm.*) and that the same percentage was valid for the whole time series. The resulting biomass of 3+ arrowtooth amounted to 2.55 t·km^{-2} for the outside waters which was assumed to be a fair assessment (Figure 13). The biomass was estimated at 0.9 and 0.48 t·km^{-2} in 1977 and 1963, respectively.

Catches for the period 1991-2002, were taken from the NOAA data base. Before that, arrowtooth were mostly discarded and declared as part of the flatfish group. In the NMFS data base, in 1956-1970 and 1977-1990, all flatfish were reported together so I assumed that 2/3 of the flatfish were arrowtooth (J. Berger, NMFS, Seattle, *pers. comm.*). Arrowtooth was not a target species except for the Canadian fleet that were selling it for animal food on fur farms (Forrester et al. 1978). For the period 1971-1976, Japanese flatfish catches were said to be composed mainly of arrowtooth (Forrester et al. 1978). Catches were generally under 1,000 tonnes except in the 1970s where it reached close to 5,000 tonnes (Figure 13). Fishing mortality was low in 1999 (F=C/B=0.001 year^{-1}) compared to 1977 (F=0.05 year^{-1}) and 1963 (F=0.0006 year^{-1}). Using the Hoenig's equation and a maximum age of 14 and 20 years for male and female respectively, natural mortality amounts to 0.3 and 0.2 year^{-1}; I kept the value of 0.2 year^{-1} as did Turnock et al. (2002b). Q/B, 1.05 year^{-1}, has been calculated using a P/Q of 0.2.

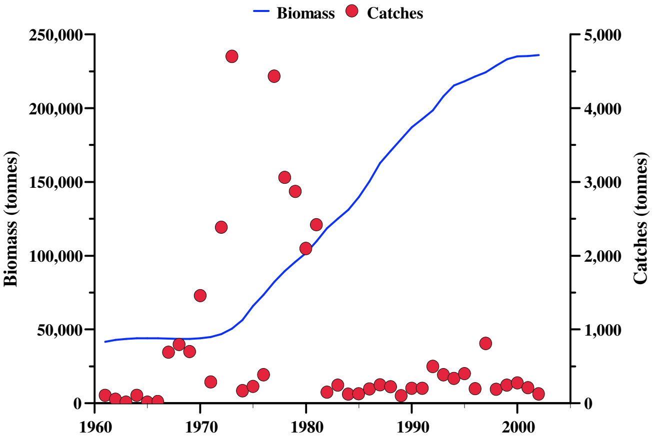


Figure 13. Catches and biomass of arrowtooth in Southeast Alaska.

The diet composition derived from samples from central GOA (Appendix 5) is dominated by pollock. I preferred using the diet information from Hecate Strait (Fargo and Pearsall 2004) for fish prey (less pollock than in GOA central) and completed with Yang and Nelson (2000) for invertebrates (Table 2.1). I assumed that in SEAK, arrowtooth eat less pollock, as in the Hecate Strait. Its main predators are halibut and Pacific cod. Arrowtooth biomass is so important that their diet is most influential in the ecosystem model. Their consumption of several commercially exploited fish including POP, rockfishes, and flatfish had to be reduced in the 1999 model (Appendix 2).

Dem L, group 27

This group contains 18 species such as wolf-eel (*Anarrhichthys ocellatus*), spotted ratfish (*Hydrolagus colliei*), cabezon (*Scorpaenichthys marmoratus*), prowfish (*Zaprora silenus*), Pacific lamprey (*Lampetra tridentata*), American river lamprey (*Lampetra ayresii*), skilfish (*Erilepis zonifer*), and lingcod (*Ophiodon elongatus*). It also contains saffron cod (*Eleginus gracilis*), great sculpin (*Myoxocephalus polyacanthocephalus*), Pacific sandfish (*Trichodon trichodon*), and shortfin eelpout (*Lycodes brevipes*). Species of this group reach a maximum length of about 84 cm (20-240 cm) and the average trophic level is estimated at 4 (from Fishbase Froese and Pauly 2000). The smallest species, the snailfin sculpin (*Nautichthys oculofasciatus*), has been classified in this group because of its trophic level of 4.05.

Although the biomass from surveys is rather sketchy, I used the same technique for estimation of biomass in inside waters as the other species except for the ratfish for which I assumed that the density was only 20% that of outside waters. The minimum estimate of 1999 total biomass was 0.51 t·km^{-2} for the first 15 species of the group which includes that of lingcod (0.137 t·km^{-2}). The 1984 trawl survey yielded a biomass of 0.11 t·km^{-2} which is probably an underestimate given that lingcod was estimated at only 0.05 t·km^{-2}. Thus, the biomass was left to be estimated by Ecopath.

Lingcod catches were obtained from Gordon (1994), and Victoria O'Connell (*pers. comm.*). CPUE have declined since 1988 in all regions of SEAK (O'Connell and Brookover 2000) and quotas have been decreased notably. All other species are mainly bycatch by longline fisheries and salmon troll. Natural mortality (M= 0.24 year^{-1}) values have been calculated from Pauly's equation for cabezon, lingcod and spotted ratfish and taken from Gaichas et al. (1999) for sculpins. Fishing mortality was considered negligible. Q/B (1.2 year^{-1}) has been calculated by Ecopath using a P/Q of 0.2.

The diet of lingcod was adapted from the fish description in Hecate strait (Fargo and Pearsall 2004) (less pollock than in the central GOA) and completed with diet description of the Gulf of Alaska (Yang and Nelson 2000) for invertebrates. Most diets came from the Bering Sea, and other parts of GOA (Appendix 5), and two species (bigmouth sculpin, Pacific sandfish) show enormous amounts of predation on pollock, which is doubtful for SEAK. However the overall quantity of juvenile and adult pollock eaten by the group amounts to 2 and 6% respectively, which was considered acceptable (Table 2.1). The amount of juvenile pollock was decreased to 0.2% to balance the 1999 model (Table 2.2).

Flatfish, group 28

This group is composed of 18 species among which were the starry flounder (*Platichthys stellatus*), rock sole (*Lepidopsetta bilineata*), Dover sole (*Microstomus pacificus*), rex sole (*Glyptocephalus zachirus*), English sole (*Parophrys vetulus*) and flathead sole (*Hippoglossoides elassodon*) and several non-commercial species.

There is relatively limited estuarine, soft bottom habitat in Southeast Alaska where trawl fisheries can target flatfishes and it is limited to 4 areas (O'Connell et al. 2002c). The beam trawl fishery targets spawning aggregations and produce high level of bycatch of crab, shrimp, and halibut (Bracken et al. 1990 in O'Connell et al. 2002c). I used the NMFS trawl survey and extrapolated for inside waters assuming half the density in inside waters. The total biomass amounted to 1.12 t·km^{-2}. However, this may be an underestimate because of the non-commercial and very shallow water species. Natural mortality estimates (M=0.19 year^{-1}) came from Turnock et al. (2002a). With catches being really low in 1999 (505 t or 0.0055 t·km^{-2}) and the biomass high at 1.12 t·km^{-2}, F reached 0.006 year^{-1}. The biomass was increased to 2.7 t·km^{-2} to balance the model in 1999, to 1.29 t·km^{-2} in 1977, and estimated by Ecopath in the 1963 model because inshore species were overlooked so the biomass was underestimated. Q/B (0.19 year^{-1}) has been calculated by Ecopath using a P/Q of 0.2.

Recent catch data (1991-2000) for state and federal waters were taken from Coonradt (ADFG, *pers. comm.*), the ADFG web site (http://www.cf.adfg.state.ak.us/region1/), and Turnock et al. (2002a). Catch data for 1956-1990 were taken from summary reports on foreign and domestic fisheries (Forrester et al. 1978, INPFC yearly statistics 1977-1990; Forrester et al. 1983). As all flatfish were reported together until 1986, I assumed that arrowtooth flounder constituted two thirds of the catch as suggested by the observer data (J. Berger, NMFS, Seattle *pers. comm.*). Diet descriptions were taken from the Hecate strait study (Fargo and Pearsall 2004) for fish prey description (less pollock than in GOA central) and completed with Yang and Nelson (2000) for invertebrates (Table 2.1).

Dem S, group 29

The Dem S regroups 118 species of greenlings (Hexagrammids), snailfish (Liparidae), eelpouts (Zoarcidae), sculpins (Cottidae), poachers (Agonidae), and sticklebacks (Gasterosteidae). Their average length is 22 cm (6-61cm) and the average trophic level is 3.3 (from Fishbase, Froese and Pauly 2000). Atka mackerel is classified in this group because of its trophic level but it is practically not important in SEAK. Most species do not go deeper than 500 m. The northern and staghorn sculpins are the most abundant sculpins in SEAK (Scott Johnson, NMFS, Juneau, *pers. comm.*). There is no information on biomass and there are no reported catch. The natural mortality was estimated at 1.07 year^{-1} on the basis of 4 species for which it was possible to calculate M with Pauly's equation. Q/B (4.28 year^{-1}) has been calculated by Ecopath using a P/Q of 0.25. The diet composition is dominated by benthic invertebrates (53%), shrimps (11%), epibenthic carnivorous (8%), and zooplankton (24%).

Deep L, group 30

The deepwater fish, pelagic and demersal, were grouped by size regardless of their diet because there is little information and their direct importance is probably less than coastal and slope species. The group includes 30 species such as grenadiers, lancetfish, rattail, eel, of average length of 80 cm (25-215 cm) generally occurring below 500 m. Natural mortality was estimated at 0.45 year^{-1}. Q/B (2.25 year^{-1}) has been calculated by Ecopath using a P/Q of 0.2. Diet composition, often taken from FishBase (Froese and Pauly 2000, and see Appendix 5), is dominated by zooplankton (22%), cephalopods (7%), 3 groups of benthic invertebrates (51%), deep S (12%) and various other fish (9%). The minimum biomass (0.105 t·km^{-2}) was based on 9 species dominated by giant grenadiers obtained from the trawl survey.

Deep S, group 31

The small deepwater fish regroup 21 fish including myctophids (Myctophidae and Bathylagidae), snailfish, and eelpouts. Pacific saury were classified in this group because they are generally found offshore (Mecklenburg et al. 2002). The northern lampfish (*Stenobrachius leucopsarus*) and northern smoothtongue (*Leuroglossus schmidti)* are the most abundant species of mesopelagics in Alaska (Purcell 1996 in Abookire et al. 2002). Natural mortality, based on Pauly's equation using 4 species, amounted to 0.56 year^{-1} which is probably an underestimate for such small and short-lived species and thus has been increased to 1 year^{-1} to balance the model. Gjøsaeter (1980) estimated the biomass of myctophids in the Eastern Pacific at 4.5 t·km^{-2}. However, using a value of EE= 0.5, the 1999 biomass was estimated at 2.26 t·km^{-2} by the Ecopath model. Q/B (4 year^{-1}) has been calculated by Ecopath using a P/Q of 0.25. Diet compositions, taken from the Bering Sea, the North Pacific and the Kamchatka area (Appendix 5) show a predominance of zooplankton (85%).

SHRIMPS, GROUP 32

This group includes commercial and non-commercial species. I considered separating the two types but in absence of biomass estimate and the lack of precision of a lot of diets on the type of shrimps eaten, I had to regroup them.

The pot fishery started in 1962, harvesting primarily spot shrimp (Love and Clark 2003) at a harvest rate of about 34% in southern interior waters (with large confidence intervals). The pot fishery in Yakutat started in 1969 and caught an average of 4 tonnes a year. The beam trawl fishery targeting primarily northern shrimp and secondarily sidestripe shrimp, occurs in a small part of the northern area due to the resource abundance, the proximity of processors, and limited vessels capability (Love and Bishop 2002). Following the start of the fishery in 1915, the fleet size, production capacity and expansion of fishing grounds increased well into the 1950s. Since 1997, there has been a directed fishery for sidestripe shrimp by beam trawl only. The decrease in landings in the last 5 years may be due to a decrease in effort because of low prices. Theses species are also fished with otter trawl with a lower annual tonnage in SEAK. In Yakutat, catches were at their largest in 1980 (865 tonnes) and was rather low in other years. The shrimps catch stayed below 2,000 tonnes for most of the time series (Figure 14). There is no estimate of biomass for this group. P/B was estimated at 0.7 year^{-1} for *Pandalus jordani* (Jarre-Teichmann and Guénette 1996) and increased to 2 year^{-1} to account for smaller species. Q/B was estimated at 13 year^{-1} based on a gross efficiency of 0.15 (Jarre-Teichmann and Guénette 1996). Shrimps diet was assumed to be dominated by detritus (50%), benthic invertebrates (32%) and zooplankton (16%).

BENTHIC INVERTS, GROUP 33

The group includes meio- and macrobenthos. The meiobenthos was defined as the fauna that passes through a sieve of 500 µm and retained by sieve of 37-44 µm such as nematodes, copepods, ostracods and foraminifera (Tietjen 1992). Using an empirical method, the biomass of the study area was estimated at 321 t·km^{-2}. Macrobenthos, defined as mobile epifauna dominated by amphipods (Lysianassidae), shrimps, other decapods, coelenterates, echinoderms (Vasconcellos 2002). According to the authors and their empirical method, the biomass of macrobenthos is evaluated at 206 t·km^{-2}. From this large amount, cursory estimates of biomass of commercial benthos would account for only 4,752 tonnes or 0.13 t·km^{-2} in 1999 (Figure 14). Species exploited commercially are the scallops which supported a very small fishery, and a dive fishery that started in the 1980s for urchins, abalone, geoduck, and sea cucumbers (see Appendix 7). P/B (2 year^{-1}) has been adapted from Jarre-Teichmann and Guénette (1996), and Q/B=17 based on a gross efficiency of 0.15 (Jarre-Teichmann and Guénette 1996). Their diet was assumed to be dominated by detritus (50%), zooplankton (20%) and phytoplankton (20%).

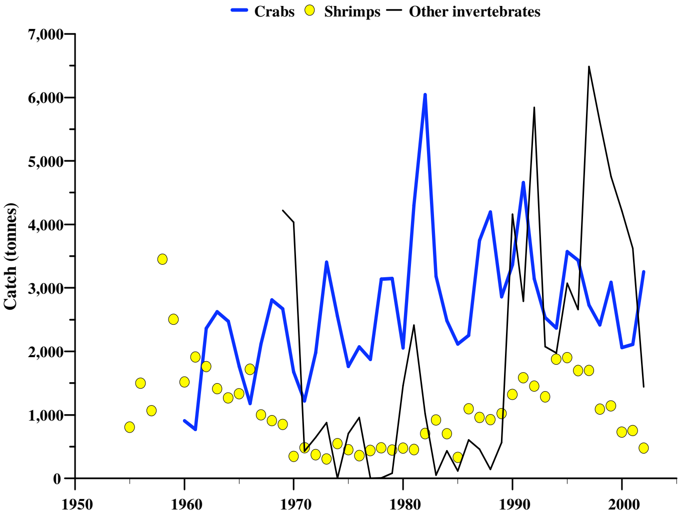


Figure 14. Catches of crabs, shrimps and other invertebrates (urchins, scallops, sea cucumbers, geoducks).

EPIBENTHIC CARNIVOROUS, GROUP 34

This group contains crabs, including the commercial species, sea stars, and carnivorous snails. Commercial crabs are the tanner, king (golden and red), Dungeness. I estimated the biomass of commercial species using a very crude method at 0.07 t·km^{-2} (see Appendix 8).This biomass estimate is quite small compared to the other species included in this group. The total biomass estimated by Ecopath reached 6.3 t·km^{-2} in 1999. Fishing mortality was evaluated at 0.92 year^{-1} and M at 0.38 year^{-1} for a total of 1.3 year^{-1} (Table 16). Natural mortality could be higher for smaller species of crabs. The gross efficiency (P/Q) for crabs were estimated at 0.25 and that of sea stars at 0.09 (Jarre-Teichmann and Guénette 1996), so I used a value of 0.15, yielding a Q/B value of 8.6 year^{-1}. Based on qualitative and frequency of occurrence data for king crab (Jewett et al. 1990), Dungeness (Alaska Department of Fish and Game 1985) and tanner (AJ Mine Project 1996), crabs were assumed to eat shrimps (10%), benthic invertebrates (40%), Szoo (3%), 20% plants and 20% detritus and 7% other epibenthic carnivorous (7%).

Table 16. Maximum age, natural and fishing mortality of commercial crab

Crab species		**Max age**	**M (year^{-1})**	**F 1999**	**F 1977**
Golden king	*Lithodes aequispina*		0.38[a,d]		
Dungeness	*Cancer magister*	8 [b]	0.42[i]	1.74[f]	0.91[h]
Red king	*Paralithodes camtschatica*	>20 [b]	0.32[c]	0.28[g]	0.51[g]
Tanner	*Chionoecetes bairdi*	12-15 [b]	0.32[c]	0.92[e]	
Average			**0.36**	**0.92**	

a. assumed to be 0.38 for the golden king crab, the lower limit of the range was given for the Aleutians (0.38-0.54) Siddeek et al. (2002); b. Orensaz et al. (1998); c. M=0.32 for red king crab and considered good also for tanner (John Clark, ADFG, Juneau, pers. comm);
d. Gretchen Bishop, ADFG, pers comm.; e. Bishop et al. (2002) was used as reasonable value for the whole group; f. annual exploitation rate 80-85% (J. Rumble, ADFG, Juneau, pers. comm.); g. F for 1999 and 1979 from Clark et al. (2003); h. assuming an exploitation rate of 60% in the 1970s; [i] 0.29-0.55 (Gretchen Bishop, ADFG, Juneau, *pers. comm.*)

CEPHALOPODS, GROUP 35

This group represents a large number of species rather scarcely known. It includes the North Pacific giant octopus (*Octopus dofleini*), smoothskin octopus (*Octopus leioderma*), flapjack devilfish (*Opisthoteuthis californiana*), *Berryteuthis magister* and other squids. Their P/B was estimated at 3.5 year^{-1} based on general values for octopi and squids (Gaichas et al. 1999), in comparison P/B of Bering sea squids was estimated at 2.5 year^{-1} and Q/B of 7.13 year^{-1} (Aydin et al. 2003). Qualitative diets from the North Pacific were obtained from CephBase (www.cephbase.org) for *Enteroctopus dofleini* (Vincent et al. 1998), *Berryteuthis magister* (Nesis 1998), *Loligo opalescens* (Boletzky and Hanlon 1983), *Ommastrephes bartramii* (Araya 1983), *Rossia pacifica pacifica* (Boletzky and Hanlon 1983). Cephalopods feed mainly on invertebrates (72%), Deep S (13%), dem S (3.6%), pollock juv. (2.9%) and herring (2.4%) (Table 2.1). To balance the 1999 model, the proportion of deep S in the diet was increased while the importance of other fish were decreased (Table 2.2)

LARGE ZOOPLANKTON, GROUP 36

Large zooplankton include mysids, salps, chaetognaths, euphausiids and jellies. P/B and Q/B amounted to 4.3 year^{-1} and 16.9 year^{-1} respectively (Table 16).The biomass was derived from sampling made on the Southeast Alaskan shelf averaged over years 1998-2001 (S. Romaine, IOS, Fisheries and Oceans Canada, Sidney, *pers. comm.*). The biomass was converted from dry weight to wet weight (dW:WW) using Brey's (2002) conversion factors for a total of 84 t·km^{-2} (Table 17). While balancing the model, it appeared that the amount of large zooplankton was overestimated and the biomass was reduced to 40 t·km^{-2}. Their diet was adapted from qualitative descriptions (Table 18).

SMALL ZOOPLANKTON, GROUP 37

The biomass of small zooplankton, estimated at 12.7 t·km^{-2}, was obtained from data provided by S. Romaine (IOS, see Table 17). In balancing the model, this value was too small for the consumption of large zooplankton. Thus I have let Ecopath estimate the biomass using a value of EE=0.9. P/B and Q/B were estimated at 24 year^{-1} and 112 year^{-1} respectively for copepods (Aydin et al. 2003). The diet was assumed to 100% phytoplankton.

PHYTOPLANKTON, GROUP 38

The 1999 primary productivity (PRISME, gC.m^{-2}·yr^{-1}) was calculated after Nicolas Hoepffner (nicolas.hoepffner@jrc.it) modelling results as compiled in the Sea Around Us database (www.seaaroundus.org). The integrated annual production by 0.5 degree cells were summed for the study area for a total of 355 g C·m^{-2}·year^{-1}. Assuming a conversion factor of 1gC=9gWW (Pauly and Christensen 1995) and a P/B of 100 year^{-1}, the resulting biomass reached 31.8 tWW ·km^{-2}.

Table 16. Annual P/B and Q/B values for large zooplankton.

	P/B	Q/B
Chaetognaths	2.5 *b*	12.5 *b*
Salps	9 *b*	30 *d*
Euphausiids	3 *c*	15 *c*
Jellies	3 *c*	10 *a,e*
Average	**4.3**	**16.9**

a Arai (1996); b. Aydin (2002); c. Alaska Gyre (Jarre-Teichmann 1996); d. Purcell (1996); e. based on GE=0.3; f. Samaeto (1976 in Bundy et al. 2000)

Table 17. Biomass of zooplankton in southeast Alaska (S. Romaine, IOS, Fisheries and Oceans Canada, Sidney, pers. comm.) and conversion factors used to convert from dry to wet weight (Brey 2002).

	S zoopl	L zoopl	Jellies	#of samples
1998	4.71	9.52	36.89	54
1999	10.31	13.95	67.41	37
2000	20.51	6.13	135.02	10
2001	15.45	8.22	62.34	37
average	**12.74**	**9.46**	**75.41**	
dW:WW	0.186:1	0.225:1	0.041:1	

Table 18. Large zooplankton diet in percentages.

Prey	Group	Chaetognatha [a]	Mysids [a]	Salpa [a]	Euphausiids [b]	Pelagic shrimps [c]	Average
phytoplankton	phyto		33	90	33	50	41.2
copepods	s zoo	90	34		34		31.6
chaetognaths	L zoo	5				10	3
euphausiids	L zoo					10	2
salps	L zoo	5					1
detritus			33	10	33	30	21.2

a. Raymont (1983); b. Lalli and Parsons (1993); c. Omori (1974)

MARINE PLANTS, GROUP 39

Macrocystis kelp on the west coast of Prince of Whales Island have been surveyed over 59 km^2 showing a relative biomass of 5,787 g·m^{-2} in kelp beds (van Tamelen and Woodby 2001). The surface of various species of kelp, which contained only small portion of macrocystis, was estimated at 183 km^2 in SEAK at the beginning of the 20th century (Cameron 1915 in van Tamelen and Woodby 2001). Assuming that the total surface of macrophytes is twice the surface mentioned for kelp beds (2·183 = 366 km^2), the relative biomass reported for the entire study area is estimated at 23.2 t·km^{-2}, which is probably an underestimate (see the section on balancing the 1999 model). The P/B was taken from Mackinson (1996) calculated for British Columbia.

BALANCING THE 1999 MODEL

Balancing the model required few modifications of the original parameters. The biomass of slope rockfish were allowed to increase from 1.5 to 1.9 t·km^{-2} and that of shelf rockfish from 0.41 to 1.5 t·km^{-2} to account for the predation, the contagious distribution, and the difficulty in sampling them (Table 19). The biomass of flatfish (1.12 to 2.65 t·km^{-2}) was increased to account for predation and the fact that several species have very coastal shallow waters distributions that escape trawl survey. Finally, the minimal biomass entered for fish of deep L group were replaced by the Ecopath estimate after having decreased the predation by arrowtooth flounders. The biomass of macrophytes was probably grossly underestimated since the model yielded a value of EE of 0.91 where a value of less than 0.1 would be expected.

Table 19. Ecopath parameters of the balanced **1999** model. The values in bold have been estimated by the model.

Group name	Trophic level	Biomass ($t \cdot km^{-2}$)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	P/Q	Catch ($t \cdot km^{-2} \cdot year^{-1}$)	Discards ($t \cdot km^{-2} \cdot year^{-1}$)
1 Transient orca	5.37	0.00071	0.02	11	**0**	**0.0018**		
2 Toothed whales	4.72	0.0114	0.02	11.5	**0.41**	**0.0017**		
3 Baleen whales	3.45	0.1353	0.034	10.92	**0.55**	**0.0031**	0.00151	
4 Sea lions embryo	1	6.53E-06	0.02	221.7	**0**	**0.0001**		
5 Sea lions pup	1	0.000248	0.59	84.1	**0.96**	**0.007**		
6 Sea lions juv	4.51	0.00394	0.19	39.4	**0.77**	**0.0048**		
7 Sea lions adults	4.46	0.034	0.11	25.55	**0.73**	**0.0043**		
8 Small mammals	4.44	0.043	0.21	28.85	**0.78**	**0.0073**	0.0005	
9 Sea otters	3.3	0.002	0.14	85	**0.26**	**0.0016**	0	
10 Birds	4.02	0.006	0.38	68	**0.81**	**0.0056**		
11 Shark mammal eater	4.76	0.024	0.13	**1.3**	**0.06**	0.1	0.0001	
12 Shark and skate	4.06	0.251	0.12	**1.2**	**0.92**	0.1	0.005	
13 Salmon	3.56	3.9	2.15	**10.75**	**0.28**	0.2	1.985	
14 Pel L	3.74	0.044	0.22	**1.1**	**0.88**	0.2		
15 Pel S	3.38	**1.304**	1.15	**5.75**	0.95	0.2	0.000051	
16 Sandlance	3.1	1.3	1.15	**5.75**	**0.92**	0.2		
17 Herring	3.33	2.914	0.78	**3.9**	**0.87**	0.2	0.141	
18 Pollock juv	3.46	0.0327	1.2	5.89	**0.72**	**0.2**		
19 Pollock adult	3.57	1.209	0.3	1.5	**0.78**	**0.2**		
20 POP	3.44	0.6	0.04	**0.2**	**0.85**	0.2	0	
21 Rockfish slope	3.63	1.9	0.07	**0.35**	**0.88**	0.2	0.008	0
22 Rockfish shelf	3.68	1.5	0.04	**0.2**	**0.95**	0.2	0.005	
23 Sablefish	3.26	0.798	0.17	**0.85**	**0.67**	0.2	0.053	0.00081
24 Pacific cod	4.26	0.336	0.39	**1.95**	**0.68**	0.2	0.006	
25 Halibut	4.17	0.64	0.26	**1.3**	**0.53**	0.2	0.0824	
26 Arrowtooth	4.24	2.55	0.21	**1.05**	**0.46**	0.2	0.003	0.00267
27 Dem L	3.92	0.51	0.24	**1.2**	**0.7**	0.2	0.003	
28 Flatfish	3.5	2.7	0.19	**0.95**	**0.98**	0.2	0.004	0.00011
29 Dem S	3.32	**1.9297**	1.07	**4.28**	0.95	0.25		
30 Deep L	3.74	**0.1465**	0.45	**2.25**	0.95	0.2		
31 Deep S	3.27	**2.2357**	1	**4**	0.5	0.25		
32 Shrimps	2.65	**4.486**	2	13	0.95	**0.1538**	0.016	
33 Benthic inverts	2.24	50	2	17	**0.46**	**0.1176**	0.032	0.024
34 Epibenthic carnivorous	2.82	**6.3027**	0.98	6.53	0.95	0.15	0.043	
35 Cephalopods	3.71	**0.3484**	2.55	10	0.95	**0.255**		
36 L zoo	2.4	40	4.3	16.9	**0.94**	**0.25**		
37 S zoo	2	**17.4205**	20	112	0.9	**0.18**		
38 Phyto	1	31.8045	100	-	**0.75**	-		
39 Marine plants	1	23.228	4.4	-	**0.91**	-		
Detritus	1	13.95	-	-	**0.37**	-		

The model was balanced mainly by modifying the diet composition which were highly uncertain in some cases. For example the transient orca diet overestimated the proportion of small mammals they consumed, which had to be decreased from 78 to 50% (see Table 2.2). The proportion of small mammals, juvenile sea lions and birds, as well as cannibalism was decreased in the diet of shark mammals eaters. Predation was too high on Pel L, sandlance, pollock, POP and rockfishes, and had to be decreased in the diet of several functional groups. The diet of Steller sea lions were modified substantially as for the predation on pollock which had to reduced considerably (Table 20 and 2.2). This is more consistent with recent work on the size of pollock in the diet of sea lions of Southeast Alaska (Tollit et al. 2004) that shows that in southeast Alaska, juvenile pollock constitute only 0.5-5 % of the pollock eaten by sea lion, depending on the location (inside or outside waters).

Table 20. Change in the percentage of adult and juvenile pollock consumed by adult and juvenile Steller sea lion to balance the 1999 and 1977 models.

	Sea lion diet							
	Original		**Balanced 1999**		**Balanced 1977**		**Balanced 1963**	
Prey	**juvenile**	**adult**	**juvenile**	**adult**	**juvenile**	**adult**	**juvenile**	**adult**
Pollock juv.	13.9	6.4	0.5	0.5	0.5	0.4	0.1	0.5
Pollock adult	7.5	23.9	3	5.7	3	4	3	4

BALANCING THE 1977 MODEL

I used the 1999 balance diet matrix as a starting point for the 1977 model. Most P/B values have changes compared to the 1999 model due to different fishing mortalities. As a consequence, most Q/B values estimated by Ecopath have increased according to the given P/Q ratio imposed. Only the Q/B for pollock had to be increased manually to keep the P/Q ratio plausible (below 0.3) (see Table 21). In absence of valid biomass estimates for shark mammal eater I used the 1999 biomass knowing that it was an overestimate for 1977. Thus, to balance the model, their biomass has been arbitrarily decreased by half.

In 1977, several important species such as herring, arrowtooth, POP, Pacific cod, pollock and harbour seals had lower abundances, so it was necessary to modify the diet matrix (Table 2.3). The proportion of small mammals and pup and juvenile sea lions in the transient killer whale diet were decreased while the proportion of adult sea lions was increased. The small biomass of herring forced the reduction of its presence in the diets of salmon, small mammals, sea lions, arrowtooth and Pacific cod. In addition, herring biomass was increased from 0.29 to 0.45t·km^{-2} because the initial value may have been underestimated (see the herring section). For the same reasons, adult pollock contribution to diets of adult sea lion was reduced (Table 20), small mammals and Pcod has been decreased; POP contribution to baleen whales, Pcod, small mammals, sea lions, halibut and arrowtooth were also diminished. The biomass of rockfish and flatfish were left to estimate by the model because the estimate taken for the 1984 survey was probably too low. The resulting biomass estimates may be biassed because they are linked to the assumptions about diet in the 1999 model. The biomass of dem L obtained from the trawl survey was probably too low, so it was left to be estimated by Ecopath.

BALANCING THE 1963 MODEL

I used the 1999 balance diet matrix as a starting point for the 1977 model. Most P/B values have changed compared to the 1999 model due to a different fishing mortality (but see next section for further modifications). In absence of valid biomass estimate for shark mammal eater, the 1977 biomass was used.

In 1963, the abundance of sea lions, pollock and arrowtooth was lower than in 1999 while POP abundance was higher. As a consequence, the diet of transient orcas was rearranged to decrease pup and juvenile sea lions in its diet. Also, the proportion of POP in mammals and fish was returned to the original percentages while pollock had to be reduced in the diet of sea lions, small mammals, sablefish, rockfish shelf, halibut and flatfish. Predation on herring had to be decreased to accommodate the low biomass in 1963. The biomass of pollock was increased to 0.2 t·km^{-2}. Further modification were necessary to fit time series in Ecosim and are discussed in the next section.

The present model structure was useful to think about the species and assess their relative importance. For instance the lack of information for nearshore species of flatfish and rockfish became evident when balancing the model and forced me to reconsider their biomass estimate. However, several of these groups did not bring much value to the simulations and could be regrouped.

Table 21. Ecopath parameters of the balanced **1977** model. The values in bold have been estimated by the model.

	Group name	**Trophic level**	**Biomass (t·km^{-2})**	**P/B (year^{-1})**	**Q/B (year^{-1})**	**EE**	**P/Q**	**Landings (t·km^{-2}· year^{-1})**	**Discards (t·km^{-2}· year^{-1})**
1	Transient orca	5.37	0.0007	0.02	11	**0**	**0.002**		
2	Toothed whales	4.71	0.0106	0.21	11.5	**0.85**	**0.0183**	0.00185	
3	Baleen whales	3.45	0.0276	0.037	10.9	**0.84**	**0.003**	0	
4	Sea lions embryo	1	>0.00001	0.02	228	**0**	**0.0001**		
5	Sea lions pup	1	0.000122	0.59	86.6	**0.84**	**0.007**		
6	Sea lions juv	4.51	0.00194	0.19	40.6	**0.97**	**0.005**		
7	Sea lions adults	4.49	0.0175	0.11	25.6	**0.97**	**0.004**		
8	Small mammals	4.44	0.028	0.21	28.8	**0.90**	**0.007**	0	
9	Sea otters	3.3	0.000142	0.1	85	**0**	**0.001**		
10	Birds	4.02	0.00595	0.38	68	**0.38**	**0.006**		
11	Shark mammal eater	4.73	0.01	0.13	**1.3**	**0.13**	0.1	0.000078	
12	Shark and skate	4.06	0.251	0.12	**1.2**	**0.54**	0.1	0.00037	
13	Salmon	3.54	1.859	2.1	**10.5**	**0.18**	0.2	0.4734	
14	Pel L	3.74	**0.0339**	0.22	**1.1**	0.95	0.2		
15	Pel S	3.38	**1.0102**	0.89	**4.4**	0.95	0.2		
16	Sandlance	3.1	1.3	1.15	**5.8**	**0.67**	0.2		
17	Herring	3.33	0.45	1.022	**5.1**	**0.98**	0.2	0.0946	
18	Pollock juv	3.46	0.0288	1.2	7.5	**0.77**	**0.16**		
19	Pollock adult	3.57	0.27	0.574	2.5	**0.92**	**0.23**	0.0312	
20	POP	3.44	0.19	0.42	**2.1**	**0.99**	0.2	0.0729	
21	Rockfish slope	3.63	**0.82**	0.107	**0.5**	0.95	0.2	0.021	
22	Rockfish shelf	3.68	**1.48**	0.022	**0.1**	0.95	0.2	0.00131	
23	Sablefish	3.26	0.43	0.29	**1.4**	**0.87**	0.2	0.079	0.00221
24	Pacific cod	4.25	0.29	0.38	**1.9**	**0.77**	0.2	0.00186	
25	Halibut	4.17	0.26	0.215	**1.1**	**0.67**	0.2	0.0312	
26	Arrowtooth	4.21	0.9	0.254	**1.3**	**0.82**	0.2	0.05	
27	Dem L	3.91	**0.23**	0.267	**1.3**	0.95	0.2	0.0004	0.0068
28	Flatfish	3.5	**1.32**	0.263	**1.3**	0.95	0.2	0.0334	
29	Dem S	3.32	**1.11**	1.07	**4.3**	0.95	0.25		9.72E-06
30	Deep L	3.74	**0.14**	0.45	**2.2**	0.95	0.2		0.0068
31	Deep S	3.27	**1.47**	1	**4**	0.5	0.25		
32	Shrimps	2.65	**2.6**	2	13	0.95	**0.15**	0.00615	
33	Benthic inverts	2.24	50	2	17	**0.27**	**0.12**		0.1009
34	Epibenthic carnivorous	2.82	2.8	**1.3**	**8.7**	0.95	0.15	0.0191	0.0238
35	Cephalopods	3.71	0.2	**2.55**	10	0.95	**0.25**	0.00137	
36	L zoo	2.4	40	4.3	16.9	**0.83**	**0.25**		
37	S zoo	2	**17.17**	20	112	0.9	**0.18**		
38	Phyto	1	31.80	100	-	**0.74**	-		
39	Marine plants	1	23.228	4.4	-	**0.88**	-		
	Detritus	1	13.95	-	-	**0.35**	-		

FITTING TO TIMES SERIES

Searching for the forcing function

Starting from the 1963 model, I fitted the model to the 1963-2002 time series (see Appendix 4). The Ecosim fitting procedure was used to estimate vulnerabilities and production anomalies (forcing function) that will allow the best fit to the data. The model was fitted by searching for vulnerabilities for the most important species (for which we had good data) and for production anomalies at the same time. The vulnerability parameters applies to the predator relationship and convey the idea that only a portion of a prey population is available to the predator. A vulnerability of 1 means that the predator does not have access to a large portion of the prey and therefore cannot increase predation mortality on this prey. It also means that the predator biomass in the baseline model is near its carrying capacity. Conversely a high vulnerability indicate that the predator baseline biomass is much below its carrying capacity and, given the possibility its biomass and it level of predation on the prey could increase. This corresponds also to a top-down control situation.

A weight of zero for vulnerability fitting was put on sea lions juveniles as they were highly correlated with the adults. Flatfish were also excluded from the sum of squares calculation because the time series, showing a steep increase in biomass, was not deemed reliable. The feeding adjustment time was set to 0.5 for marine mammals (except for pup and embryo sea lions) and at 0 for other species, assuming that large predators are more likely to vary their feeding search time as food availability changes. Orcas, because they have no predators, were allowed to increase their maximum feeding time to 10 instead of 2 times the initial default value, and the fraction of the other mortality sensitive to predation mortality was set at 0.2. In cases where we had catches but no biomass or F series, the biomass was estimated by Ecopath with Ecosim forcing the catches using a stock reduction model. Hence forced biomass was used for toothed whales, sea lions, small mammals, otters, sharks, slope rockfish, pollock, and flatfish. For halibut, Pcod, and shelf rockfish the original catch and F series for the latest period were used in conjunction with forced catches for the beginning of the time series (see Appendix 4). The biomass of salmon was forced on the model because the portion of its mortality that is explained by the model is small (EE=0.32) and its history is not driven only by fishing as hatcheries played a significant role in Alaska in recent years.

Table 22. Summary of changes in vulnerability, initial biomass, and biomass accumulation rate necessary to fit the time series

	Vulner-ability	**Biomass accumulation rate (year^{-1})**	**New biomass (t·km^{-2})**
Transient orca	>100		
Toothed whales	1	-0.03	
Baleen whales	1	-0.05	
Sea lions juveniles	1		
Sea lions adults	**1**		
Small mammals	1		
Sea otters	68.7	0.2	
Salmon	1		
Herring	19.3	-0.2	
Pollock adult	1		
POP	1.39		
Sablefish	1.33	0.03	0.89
Pacific cod	1		
Halibut	1	-0.03	
Arrowtooth	>100		

[a] in addition the P/B has been increased to 0.21

Predicted catches of sablefish was lower that those observed. The original sablefish biomass in the 1963 model was too low, so the biomass was increased to 0.89 t·km^{-2} as calculated with the Schaefer model (see sablefish section), and a biomass accumulation (0.03) was necessary to fit the time series (Tables 23 and 24). The trajectories for sablefish, arrowtooth and Pacific cod were well replicated by the model. Rockfish and flatfish time series were not very informative and thus were not expected to be fitted by the model. Baleen and toothed whales are reasonably well fitted in the model except for the large catch of baleen whales in 1963 (Figure 15). The model was also capable of reproducing the increasing trend of sea lions, and herring. In fact, the latter was largely responsible for the variations in the estimated forcing function.

I used the count of pups as an index for the sea lion pups group to compare with Ecosim predictions. Predicted adult biomass were compared with the times series of biomass obtained from the local prediction model (see sea lion section). Juveniles trends are showed for visual verification but are not included in the calculation of the sum of squares. Moreover, the counts being rather sparse in the 1960s, the exact shape of the biomass trend should not be seen as compelling. Otters biomass trends are not well explained by the model and catches could not be recreated without modifying several parameters. P/B was increased to 0.21 year^{-1}, a value equal to that of small mammals (Table 3), and a biomass accumulation of 0.2 year^{-1} was included. Yet this combination of factors did not recreate the levelling off of the biomass in the 1990s. Recent data showed that otters abundance has stabilised recently although there is no shortage of food or no known predators in Southeast Alaska. The resulting forcing function varies steeply among years and follows the variation in herring biomass.

There is little correspondence between the estimated forcing function and the Pacific Decadal Oscillation (PDO), especially for 1963-1975 for which the forcing function is rather flat compared with the following years (Figure 16). This could be explained by the fact that most of the variation in the forcing function is driven by the herring biomass derived from an age-structured stock assessment for 1975-2000, but from Schaefer model in preceding years. The latter yields smoother estimates in absence of information on recruitment pulse. Forcing the biomass of salmon made the model artificially stable with regards to Steller sea lions. For example, increasing the fishery on herring did not have much effect on sea lion, who started feeding more exclusively on salmon.

Table 23. Ecopath parameters of the balanced **1963** model after fitting the time series data, searching for forcing function and vulnerability parameters. The values in bold have been estimated by the model.

Group name	Trophic level	Biomass ($t \cdot km^{-2}$)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	P/Q	Catch ($t \cdot km^{-2} \cdot year^{-1}$)	Discards ($t \cdot km^{-2} \cdot year^{-1}$)
1 Transient orca	5.35	0.0007	0.02	11	**0**	**0.0018**		
2 Toothed whales	4.71	0.0175	0.034	11.5	**0.049**	**0.003**	0.0005	
3 Baleen whales	3.44	0.0361	0.096	10.9	**0.12**	**0.0088**	0.00147	
4 Sea lions embryo	1	2.39E-06	0.02	227.6	**0**	**0.0001**		
5 Sea lions pup	1	0.00009	0.59	86.5	**0.82**	**0.0068**		
6 Sea lions juv	4.5	0.00144	0.19	40.5	**0.75**	**0.0047**		
7 Sea lions adults	4.5	0.013	0.11	25.5	**0.70**	**0.0043**		
8 Small mammals	4.4	0.041	0.21	28.85	**0.80**	**0.0073**		
9 Sea otters	3.3	0.00003	0.21	85	**0.95**	**0.0025**		
10 Birds	4.02	0.00595	0.38	68	**0.39**	**0.0056**		
11 Shark mammal eater	4.76	0.01	0.13	**1.3**	**0.07**	0.1		1.18E-06
12 Shark and skate	4.05	0.251	0.12	**1.2**	**0.71**	0.1		5.61E-06
13 Salmon	3.52	1.11	2.1	**10.5**	**0.34**	0.2	0.5419	
14 Pel L	3.73	**0.034**	0.22	**1.1**	0.95	0.2		
15 Pel S	3.38	**0.91**	0.89	**4.45**	0.95	0.2		3.05E-10
16 Sandlance	3.1	1.3	1.15	**5.75**	**0.58**	0.2		
17 Herring	3.33	0.345	1.27	**6.35**	**0.82**	0.2	0.1856	
18 Pollock juv	3.46	0.0054	1.2	5.89	**0.88**	**0.204**		
19 Pollock adult	3.57	0.2	0.3	1.5	**0.87**	**0.2**		
20 POP	3.44	2.38	0.07	**0.35**	**0.77**	0.2		
21 Rockfish slope	3.63	**0.671**	0.107	**0.535**	0.95	0.2		
22 Rockfish shelf	3.68	**2.6**	0.022	**0.11**	0.95	0.2		
23 Sablefish	3.26	0.89	0.13	**0.65**	**0.60**	0.2	0.0117	0.00033
24 Pacific cod	4.25	0.28	0.37	**1.85**	**0.91**	0.2	0.000153	
25 Halibut	4.12	0.26	0.36	**1.8**	**0.98**	0.2	0.087	
26 Arrowtooth	4.25	0.5	0.2	**1**	**0.97**	0.2	0.000262	
27 Dem L	3.91	**0.196**	0.267	**1.335**	0.95	0.2		
28 Flatfish	3.5	**1.74**	0.263	**1.315**	0.95	0.2	0.0003	0.000103
29 Dem S	3.32	**0.99**	1.07	**4.28**	0.95	0.25		
30 Deep L	3.74	**0.14**	0.45	**2.25**	0.95	0.2		1.47E-07
31 Deep S	3.27	**1.33**	1	**4**	0.5	0.25		0.000103
32 Shrimps	2.65	**2.51**	2	13	0.95	**0.154**	0.0154	
33 Benthic inverts	2.24	50	2	17	**0.27**	**0.12**		
34 Epibenthic carniv.	2.82	**2.85**	1.3	**8.67**	0.95	0.15	0.03	0.00116
35 Cephalopods	3.71	**0.22**	2.55	10	0.95	**0.26**		2.6E-07
36 L zoo	2.4	40	4.3	16.9	**0.82**	**0.25**		
37 S zoo	2	**17.15**	20	112	0.9	**0.179**		
38 Phyto	1	31.8045	100	-	**0.74**	-		
39 Marine plants	1	23.228	4.4	-	**0.88**	-		
40 Detritus	1	13.95	-	-	**0.35**	-		

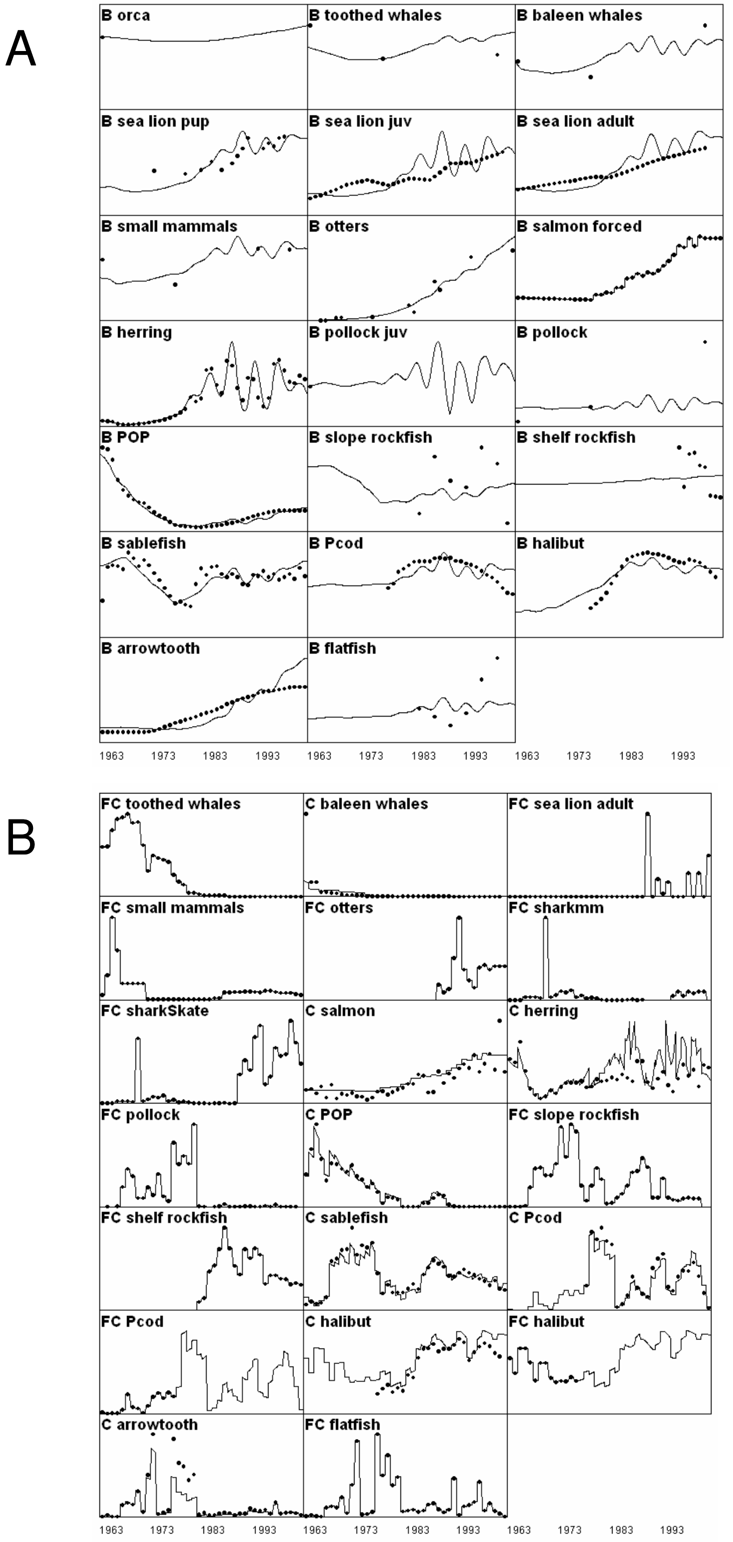


Figure 15. The fit of observed (dots) and predicted (line) biomass (A) and catches (B). Note that the salmon biomass has been forced and that juvenile sea lions biomass has not been included in the calculation of the sum of squares. The panel headings starting with FC indicate forced catches.

Using the Pacific Decadal Oscillation

Given that the Pacific Decadal Oscillation (PDO) has been linked to sea surface temperature and the amount of precipitation in Southeast Alaska (Mantua et al. 1997), I used it to force climate variations, adjusting the model by estimating vulnerabilities parameters for the same commercial species as in the fitting described earlier. In addition, salmon biomass and catches were not forced. The original PDO series was rescaled to an average of 1 and a maximum range of 1 (10% of the original PDO series) called PDO2 (Figure 16). The necessary changes made to fit the time series are listed in Table 24. PDO2 is flatter and did not produced the large variations in production that would be necessary to emulate the herring biomass as well as in the preceding simulation. No amount of parameters changes allowed to make salmon biomass to increase in the 1990s. As a consequence, sea lion biomass declined in the 1990s. The fit to catches and biomass are rather good for most species except for otters, flatfish, pollock and rockfishes (Figure 17). The present model is ready for further simulations to explore the dynamics of Steller sea lions in Southeast Alaska, using the Pacific Decadal Oscillation.

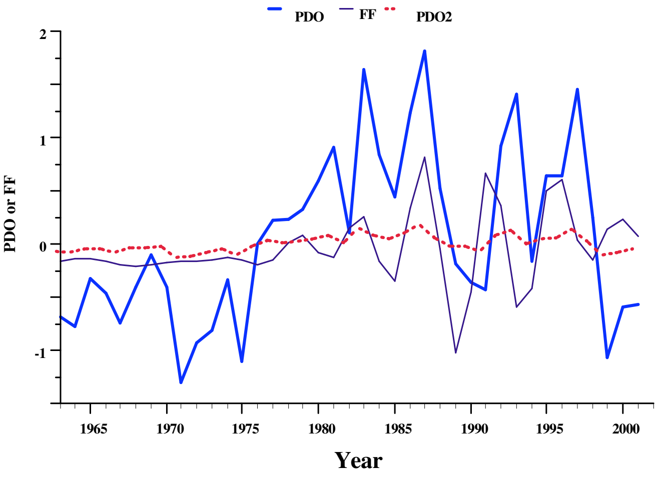


Figure 16. Forcing function (FF) estimated with Ecosim compared with the yearly estimate of the Pacific Decadal Oscillation (PDO), and the one rescaled for Ecosim by reducing the amplitude to 1 (PDO2).

Table 24. Summary of changes in vulnerability, initial biomass, and biomass accumulation rate necessary to fit the time series and forcing with the PDO2, Values in bold were changed manually.

	PDO2		
	Vulner-ability	**Biomass accumulation rate ($year^{-1}$)**	**New biomass ($t{\cdot}km^{-2}$)**
Transient orca	>100		
Toothed whales	1.03	-0.03	
Baleen whales	**1.8**	-0.05	
Sea lions juveniles	1		
Sea lions adults	1		
Small mammals	1		
Sea otters	**65**	0.2	
Salmon	1.11		
Herring	**25**	-0.2	
Pollock adult [a]	>100	*0.02*	
POP	1.31		
Sablefish	1.24	0.03	
Pacific cod	**2**		0.3
Halibut	1	0.01	
Arrowtooth	>100	0.03	0.6

[a] biomass accumulation in $t{\cdot}km^{-2}{\cdot}year^{-1}$

ACKNOWLEDGEMENTS

This report was prepared under Award Number NA16FX0124/NA16FX2629 from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, through the North Pacific Universities Marine Mammal Research Consortium and the North Pacific Marine Science Foundation. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration or the Department of Commerce. This work would not have been possible without the contribution of numerous researchers from NOAA, ADFG and Glacier Bay National Park, Marine Mammal Research Unit (University of British Columbia), and Department of Fisheries and Oceans of Canada who shared their data and ideas. I would like to thank more particularly Michael Sigler, Dave Carlile and Martina Kallenberger for recompiling their data to estimate biomass for the study area; Patricia Livingston, Kerim Aydin, Sarah Gaichas, Ivonne Ortiz, and Dave Preikshot for helpful discussions and exchange of data and models. Thank you also to Adrian Ketchingman for the patient help with my apprenticeship with GIS and to Steve Martell and Carl Walters for advice on modelling. Finally, I would like to thank Sheila Heymans, Villy Christensen and Andrew Trites for their valuable input and discussion in the project.

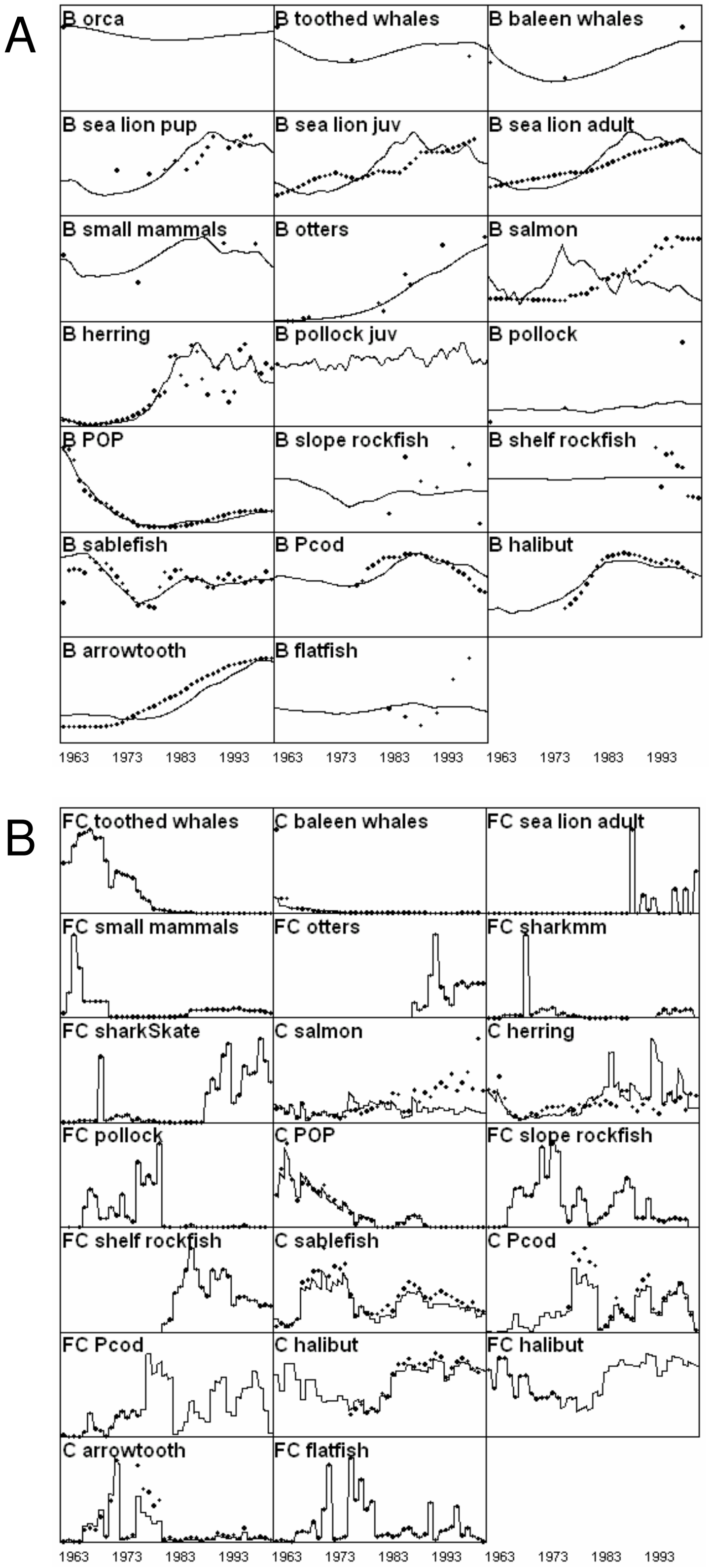


Figure 17. The fit of observed (dots) and predicted (line) biomass (A) and catches (B) using PDO2. Note that juvenile sea lions biomass has not been included in the calculation of the sum of squares. The panel headings starting with FC indicate forced catches.

References

Abookire, A. A., Piatt, J. F., and Speckman, S. G. 2002. A nearsurface, daytime occurrence of two mesopelagic fish species (*Stenobrachius leucopsarus* and *Leuroglossus schmidti*) in a glacial fjord. Fish. Bull., 100:376-380.

Agler, B. A., Kendall, S. J., and Irons, D. B. 1998. Abundance and distribution of marbled and kittlitz's murrelets in southcentral and southeast Alaska. The Condor, 100(254-265)

AJ Mine Project, 1996. Demersal fish and shellfish communities, food web relationships. Task 3.2. Prepared for U.S. Environmental Protection Agency Region 10, Juneau, AK, Draft Technical Memorandum.

Alaska Department of Fish and Game, 1985. Dungeness crab - *Cancer magister*. *In*: Alaska habitat management guide, Southcentral region, volume 1: Life histories and habitat requirements of fish and wildlife. pp. 379-385, Division of Habitat, Juneau, AK.

Alaska Department of Fish and Game, 1998. Essential fish habitat assessment report for the groundfish resources of the Gulf of Alaska region. North Pacific Fishery Management Council, Anchorage, AK, 119 pp.

Alaska Groundfish Fisheries, 2001. Final programmatic supplemental environmental impact statement. US. Dep. of Commerce, NOAA, National Marine Fisheries Service, Alaska Region.

Alton, M. S., 1981. Gulf of Alaska bottomfish and shellfish resources. NOAA Technical Memorandum, NMFS F/NMC-10. 51 pp.

Alverson, D. L., Pruter, A. T., and Ronholt, L. L., 1964. A study of demersal fishes and fisheries of the Northeastern Pacific Ocean. Institute of Fisheries, University of British Columbia, Vancouver, BC. 190 pp.

Angliss, R. P., and Lodge, K. L., 2002. Alaska marine mammal stock assessments, 2002. U.S. Department of Commerce, NOAA, Technical Memorandum, NMFS-AFSC-133. 224 pp.

Arai, M., 1996. Carnivorous zooplankton, jellies and *Velella* in the Alaska Gyre. *In*: Mass-balance models of North-eastern Pacific ecosystems. pp. 18-19, *Edited by* D. Pauly and V. Christensen, Fisheries Centre, University of British Columbia, Vancouver, BC. Vol. 4 (1) 129 pp.

Araya, H., 1983. Fishery, biology and stock assessment of *Ommastrephes bartrami* in the North Pacific Ocean. *In*: Memoirs of the National Museum of Victoria: Proceedings of the Workshop on the Biology and Resource Potential of Cephalopods, pp. 269-283, *Edited by* C. F. E. Roper, F. E. Clyde, C. C. Lu, and F. G. Hochberg, Melbourne, Australia, 9-13 March 1981. Vol. 44. *as cited in CephBase*.

Armstrong, J. L., Armstrong, D. A., and Mathews, S. B. 1995. Food habits of estuarine staghorn sculpin, *Leptocottus armatus*, with focus on consumption of juvenile Dungeness crab, *Cancer magister*. Fish. Bull., 93:456-470. *as cited in FishBase*.

Aydin, K., 2002. The Eastern Bering Sea. *In*: The use of ecosystem models to investigate multispecies management strategies for capture fisheries. pp. 33-38, *Edited by* T. Pitcher and K. Cochrane, Fisheries Centre Research Reports, FAO/Fisheries Centre Workshop, Vancouver Canada. Vol. 10.

Aydin, K. Y., MacFarlane, G. A., King, J. R., and Megery, B. A., 2003. PICES-GLOBEC international program on climate change and carrying capacity; The BASS/MODEL report on trophic models of the subarctic Pacific Basin Ecosystems. North Pacific Marine Scienve Organization (PICES), Sidney, BC, PICES Scientific Report, 25. 93 pp.

Baker, C. S., Herman, L. M., Perry, A., Lawton, W. S., Straley, J. M., and Straley, J. H. 1985. Population characteristics and migration of summer and late-season humpback whales (*Megaptera novaeangliae*) in southeastern Alaska. Mar. Mamm. Sci., 1:304-323.

Balanov, A. A. 1994. Diet of common mesopelagic fishes of the Bering Sea. J. Ichthyol., 34(6):73-82. *as cited in FishBase*.

Balanov, A. A., and Radchenko, V. I. 1998. New data on the feeding and consumption behaviors of *Anotopterus pharao*. J. Ichthyol., 38(6):447-453. *as cited in FishBase*.

Balanov, A. A., Gorbatenko, K. M., and Gorelova, T. A. 1994. Daily feeding dynamics of mesopelagic fishes in the Bering sea during summer. J. Ichthyol., 34(9):85-99. *as cited in FishBase*.

Barlow, J., and Boveng, P. 1991. Modelling age mortality for marine mammal populations. Mar. Mamm. Sci., 7:50-65.

Barrett-Lennard, L. G., Heise, K., Saulitis, E., Ellis, G., and Matkin, C., 1994. The impact of killer whale predation on Steller sea lion populations in British Columbia and Alaska. North Pacific Universities Marine Mammal Research Consortium, Fisheries Centre, Vancouver, BC, 66 pp.

Beacham, T. D. 1986. Type, quantity, and size of food of Pacific salmon (*Oncorhynchus*) in the Strait of Juan de Fuca, British Columbia. Fish. Bull., 84(1):77-90.

Beattie, A., 2001. A new model for evaluating the optimal size, placement and configuration of marine protected areas. Masters thesis, University of British Columbia, Vancouver, BC, 166 pp.

Bigg, M. A., 1981. Harbour seal *Phoca vitulina* Linnaeus, 1758 and *Phoca largha* Pallas, 1811. *In*: Handbook of marine mammals, Volume ! The walrus, sea lions, fur seals and sea otter. pp. 1-27, *Edited by* S. H. Ridgway and R. Harrisson, Academic Press Ltd, London, 359 pp.

Bigg, M. A., and Wolman, A. A. 1975. Live-capture killer whale (*Orcinus orca*) fishery, British Columbia and Washington, 1962-73. *In*: Special Issue: Review of Biology and Fisheries for Smaller Cetaceans, J. Fish. Res. Bd. Canada, 32:1213-1221.

Bishop, G., 2002. Yakutat scallop fishery. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau, Alaska, Report to the Board of Fisheries, 2002. Regional Information Report, 1J02-46. 9.1-9.16 pp.

Bishop, G., Rumble, J., and Merkouris, S. E., 2002. Southeast Alaska tanner crab fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau, Alaska, Report to the Board of Fisheries, 2002. Regional Information Report, 1J02-14. 4.1-4.32 pp.

Bodkin, J. L., Kloecker, K. A., Esslinger, G. G., Monson, D. H., DeGroot, J. D., and Doherty, J., 2003. Sea otter studies in Glacier Bay National Park and Preserve. Annual Report 2002. U.S. Geological Survey, Biological Resources Division, Anchorage, AK, 82 pp.

Boldt, J., Goldman, K. J., Bechtol, B., Dykstra, C., Gaichas, S., and Kong, T., 2003. Shark bycatch in Alaska State and Federal waters. *In*: NPFMC Gulf of Alaska SAFE, Ecosystem considerations for 2004. Appendix C. pp. 138-154, *Edited by* J. Boldt, North Pacific Fishery Management Council, Anchorage, AK.

Boletzky, S. V., and Hanlon, R. T., 1983. A review of the laboratory maintenance, rearing and culture of cephalopod molluscs. *In*: Memoirs of the National Museum of Victoria: Proceedings of the Workshop on the Biology and Resource Potential of Cephalopods, pp. 147-187, *Edited by* C. F. E. Roper, F. E. Clyde, C. C. Lu, and F. G. Hochberg, Melbourne, Australia, 9-13 March 1981. Vol. 44. *as cited in CephBase*.

Brey, T. 2002. Population dynamics in benthic invertebrate, a virtual handbook. http://www.awi-bremerhaven.de/Benthic/Ecosystem/FoodWeb/Handbook/navlog/index.html

Britt, L. L., and Martin, M. H., 2001. Data report: 1999 Gulf of Alaska bottom trawl survey. US Dep. Commerc. NOAA Technical Memorandum, NMFS-AFSC-121. 249 pp.

Brodeur, R. D., and Pearcy, W. G. 1984. Food habits and dietary overlap of some shelf rockfishes (Genus *Sebastes*) from the northeastern Pacific ocean. Fish. Bull., 82(2):269-293.

Brodeur, R. D., and Livingston, P. A., 1988. Food habits and diet overlap of various eastern Bering Sea fishes. U.S. Department of Commerce, NOAA, NOAA Technical Memorandum, NMFS F/NWC-127. 76 pp. *as cited in FishBase*.

Brown, E. D., 1999. Sandlance. *In*: Trophic mass balance model of Alaska's Prince William Sound ecosystem, for the post spill period 1994-1996, 2nd edition. pp. 28-30, *Edited by* T. A. Okey and D. Pauly, Fisheries Centre, University of British Columbia, Vancouver, BC, Canada, 137 pp.

Brown, E. D., and Okey, T. A., 1999. Eulachon. *In*: Trophic mass balance model of Alaska's Prince William Sound ecosystem, for the post spill period 1994-1996, 2nd edition. pp. 30-31, *Edited by* T. A. Okey and D. Pauly, Fisheries Centre, University of British Columbia, Vancouver, BC, Canada, 137 pp.

Bundy, A., Lilly, G. R., and Shelton, P. A., 2000. A mass balance model of the Newfoundland-Labrador shelf. Canadian Technical Report of Fisheries and Aquatic Sciences, 2310. xiv + 157 pp.

Calkins, D., and Pitcher, K., 1978. Population assessment, ecology and trophic relationships of Steller sea lions in the Gulf of Alaska. *In*: Environmental assessment of the Alaskan continental shelf. Annual reports of principal investigators for the year ending March 1978. Volume 1 - mammals-birds. pp. 373-413, *Edited by* V. E. Sokolov, NOAA/ERL/OCSEAP, Princ. Invest. Rep. Environ. Assess. Alaskan Cont. Shelf, Boulder, CO (USA).

Calkins, D. G., 1986. Marine mammals. *In*: The Gulf of Alaska: physical environment and biological resources. pp. 527-558, *Edited by* D. W. Hood and S. T. Zimmerman, US Department of Commerce, NOAA, and US Department of Interior, OCS Studies, 655 pp, Anchorage, AK.

Carlile, D. W., Larson, R. C., and Minicucci, T. A., 1996. Stock assessments of Southeast Alaska herring in 1994 and forecasts for 1995 abundance. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau, Alaska, Report to the Board of Fisheries. Regional Information Report, 1J96-05. 78 pp.

Carlile, D. W., Richardson, B., Cartwright, M., and O'Connell, V. M., 2002. Southeast Alaska sablefish stock assessment activities 1988-2001. Alaska Department of Fish and Game, Division of Commerical Fisheries, Juneau, Alaska, Report to the Board of Fisheries. Regional Information Report, 1J02-02. 86 pp.

Carlisle, J. G. 1971. Food of the jack mackerel, *Trachurus symmetricus*. Calif. Fish Game, 57(3):205-208.

Cawardine, M., 1995. Whales, dolphins and porpoises. The visual guide to all the cetaceans. Stoddart Publishing, Toronto, Canada. 256 pp.

Chikilev, V. G., and Datskii, A. V. 2000. Pacific stout sand lance *Ammocytes hexapterus* in the Gulf of Anadyr and adjacent waters. J. Ichthyol., 40(6):772-779.

Christensen, I. 1984. Growth and reproduction of killer whales, *Orcinus orca*, in Norwegian coastal waters. *In*: Reproduction in whales, dolphins and porpoises, *Edited by* W. F. Perrin, J. Brownell, Robert L. , and D. P. DeMaster, Report of the International Whaling Commision, Special Issue 6

Christensen, V., and Pauly, D., 1992. A guide to the Ecopath II software system (version 2.1). ICLARM Software 6. International Centre for Living Aquatic Resources Management, Manila, Philippines. 72 pp.

Clark, J. E., Imamura, K. K., and Koeneman, T. M., 2001. The 1997-1998 southeast Alaska tanner crab stock assessment surveys. Alaska Department of Fish and Game, Juneau, Ak, Regional Information Report, 1J2001-06. 42 pp.

Clark, J. E., Koeneman, T. M., Botelho, C. A., Merkouris, S., and Woodby, D., 2003. Estimation of red king crab (*Paralithodes camtschaticus*) abundance and available harvest in southeast Alaska for the 2001/2002 season using a pot survey. Alaska Department of Fish and Game, Juneau, Ak, Regional Information Report, 1J03-25. 75 pp.

Clark, W. G., and Hare, S. R., 2002. Assessment of the Pacific halibut stock at the end of 2001. International Pacific halibut Commission, 26 pp.

Clausen, D. M. 1983. Food of walleye pollock, *Theragra chalcogramma*, in an embayment of southeastern Alaska. Fish. Bull., 81:637-642.

Clausen, D. M., and Fujioka, J. T., 1988. Relative abundance of sablefish in southeastern Alaska, based on trap indexing surveys, 1978-1985. U.S. Department of Commerce, NOAA, NOAA Technical Memorandum, NMFS F/NWC-134. 57 pp.

Clausen, D. M., Lunsford, C. R., and Fujioka, J. T., 2002. Pelagic shelf rockfish. *In*: NPFMC Gulf of Alaska SAFE. pp. 383-418, North Pacific Fishery Management Council, Anchorage, AK.

Coonradt, E. E., 2002. The southeast Alaska Pacific cod fishery. Alaska Department of Fish and Game, Juneau, Alaska, Report to the Board of Fisheries. Regional Information Report, 1J02-10. 31 pp.

Cortés, E. 1999. Standardized diet compositions and trophic levels of sharks. ICES J. Mar. Sci., 56:707-717. *as cited in FishBase*.

Courtney, D. L., and Sigler, M. F., 2003. Analysis of Pacific sleeper shark (*Somniosus pacificus*) abundance trends from sablefish longline surveys 1979-2003. *In*: NPFMC Gulf of Alaska SAFE, Ecosystem considerations for 2004. Appendix C. pp. 155-169, *Edited by* J. Boldt, North Pacific Fishery Management Council, Anchorage, AK.

Craig, P. C., and Haldorson, L. 1981. Fish. Environmetal Assessment of the Alaskan Continental Shelf, Final Reports, Biological Studies, 7:384-678. *as cited in FishBase*.

Dahlheim, M. E., 1988. Killer whale (*Orcinus orca*) depredation on longline catches of sablefish (*Anoplopoma fimbria*) in Alaskan waters. Northwest and Alaskan Fisheries Center - NMFS, Seattle, WA, 88. 14 pp.

Dalheim, M., and Waite, J. M., 1993. Abundance and distribution of killer whales (*Orcinus orca*) in Alaska in 1992. NOAA, Alaska Fisheries Center, National Marine Mammal Laboratory, Seattle, WA, 28 pp.

Darling, J. D., Keogh, K. E., and Steeves, T. E. 1998. Gray whale (*Eschrichtius robustus*) habitat utilization and prey species off Vancouver Island, BC. Mar. Mamm. Sci., 14:692-720.

DeGange, A. R., and Sanger, G. A., 1986. Marine birds. *In*: The Gulf of Alaska: physical environment and biological resources. pp. 479-524, *Edited by* D. W. Hood and S. T. Zimmerman, US Department of Commerce, NOAA, and US Department of Interior, OCS Studies, 655 pp, Anchorage, AK.

Dorn, M., Barbeaux, S., Guttormsen, M., Megrey, B., Hollowed, A., Brown, E., and Spalinger, K., 2002. Assessment of walleye pollock in the Gulf of Alaska. *In*: NPFMC Gulf of Alaska SAFE. pp. 33-88 + 35, North Pacific Fishery Management Council, Anchorage, AK.

Drazen, J. C., Buckley, T. W., and Hoff, G. R. 2001. The feeding habits of slope dwelling macrourid fish in the eastern North Pacific. Deep-Sea Research, Part 1(48):909-935.

Dunham, J. S., and Duffus, D. A. 2001. Foraging patterns of gray whales in central Clayoquot Sound, British Columbia, Canada. Mar. Ecol. Prog. Ser., 223:299-310.

Dunham, J. S., and Duffus, D. A. 2002. Diet of gray whales (*Eschrichtius robustus*) in Clayoquot Sound, B C, Canada. Mar. Mamm. Sci., 18:419-437.

Ebeling, A. W., and Laur, D. R. 1986. Foraging in surfperches: resource partitioning or individualistic responses? Environ. Biol. Fish., 16(1-3):123-133. *as cited in FishBase*.

Ebert, D. A., 1986. Aspects on the biology of hexanchid sharks along the California coast. *In*: Indo-pacific fish biology: Proceedings of the Second INterantional Conference on Indo-pacific fishes. pp. 437-449, *Edited by* T. Uyeno, R. Arai, t. Taniuchi, and K. Matsuura, Ichthyological Society of Japan, Tokyo.

Estes, J. A. 1990. Growth and equilibrium in sea otter populations. J. Anim. Ecol., 59(2):385-401.

Estes, J. A., and Palmisano, J. F. 1974. Sea otters: Their role in structuring shore communities. Science, 185(4159):1058-1060.

Fargo, J., and Pearsall, I. 2004. Diet analysis of Hecate Strait groundfish: predation, competition and habitat fidelity.Manuscript.

Fisher, J. P., and Pearcy, W. G. 1983. Reproduction, growth and feeding of the mesopelagic fish *Tactostoma macropus*. Mar. Biol., 74:257-267.

Flinn, R. D., Trites, A., Gregr, E. J., and Perry, I. 2002. Diets of fin, sei and sperm whales in British Columbia: an analysis of commercial whaling records, 1963-1967. Mar. Mamm. Sci., 18:663-679.

Ford, J. K. B., and Ellis, G. M., 1999. Transients: mammal-hunting killer whales of British Columbia, Washington, and Southeastern Alaska. UBC Press, Vancouver, and University of Washington Press, Seattle, 96 pp.

Ford, J. K. B., Ellis, G., Barrett-Lennard, L., Morton, A., Palm, R. S., and Balcomb, K. C. 1998. Dietary specialization in two sympatric populations of killer whales (*Orcinus orca*) in coastal British Columbia and adjacent waters. Can. J. Zool., 76:1456-1471.

Forrester, C. R., Beardsley, A. J., and Takahashi, Y. 1978. Groundfish, shrimp, and herring fisheries in the Bering Sea and Northeast Pacific- historical catch statistics through 1970. International North Pacific Fisheries Commission Bulletin, 37:1-147.

Forrester, C. R., Bakkala, R. G., Okada, K., and Smith, J. E. 1983. Groundfish, shrimp, and herring fisheries in the Bering Sea and Northeast Pacific-historical catch statistics. International North Pacific Fisheries Commission Bulletin, 41:1-100.

Froese, R., and Pauly, D., (*Editors*). 2000. FishBase 2000: concepts, design and data sources. ICLARM, Los Baños, Laguna, Philippines, Vol. 76, 344 pp. http://www.fishbase.org,

Gaichas, S., and Ianelli, J. N., 2001. Assessment of thornyheads (*Sebastolobus* sp.) in the Gulf of Alaska. *In*: NPFMC Gulf of Alaska SAFE. pp. 9.1-9.42, North Pacific Fishery Management Council, Anchorage, AK.

Gaichas, S., and Ianelli, J. N., 2002. Assessment of thornyheads (*Sebastolobus* sp.) in the Gulf of Alaska. *In*: NPFMC Gulf of Alaska SAFE. pp. 459-500, North Pacific Fishery Management Council, Anchorage, AK.

Gaichas, S., Fritz, L., and Ianelli, J. N., 1999. Appendix D. Other species considerations for the Gulf of Alaska. *In*: 1999 Groundfish Stock Assessment and Fishery Evaluation Report, Gulf of Alaska SAFE. pp. 1-42, North Pacific Fishery Management Council,

Gaichas, S., Ruccio, M., Stevenson, D., and Swanson, R., 2003. Stock assessment and fishery evaluation of skate species (Rajidae) in the Gulf of Alaska. *In*: NPFMC Gulf of Alaska SAFE. pp. 719-749, North Pacific Fishery Management Council, Anchorage, AK.

Geiger, H. J., Cartwright, M. A., Clark, J. H., Conitz, J., Heinl, S. C., Jensen, K., Lewis, B., McGregor, A. J., Riffe, R., Woods, G., and Zadina, T. P., 2003. Sockeye salmon stock status and escapement goals in Southeast Alaska. Alaska Department of Fish Game, Juneau, Alaska, Report to the Board of Fisheries. Regional Information Report, 1J03-04. 131 pp.

Gentry, R. L., 1981. Northern fur seal *Callorhinus ursinus* (Linnaeus, 1758). *In*: Handbook of marine mamals, Volume ! The walrus, sea lions, fur seals and sea otter. pp. 143-160, *Edited by* S. H. Ridgway and R. Harrisson, Academic Press Ltd, London, 235 pp.

Gjøsaeter, J., and Kawaguchi, K., 1980. A review of the world resources of mesopelagic fish. Rome, FAO Fisheries Technical Paper, 193. 151 pp.

Goldman, K. J., 2002. Other Species: Sharks and shark bycatch in Alaska and Federal waters. *In*: NPFMC Gulf of Alaska SAFE, Ecosystem considerations for 2003. Appendix C. pp. 60-79, *Edited by* P. Livingston, North Pacific Fishery Management Council, Anchorage, AK.

Gordon, D. A. 1994. Lingcod fishery and fishery monitoring in Southeast Alaska. Alaska Fish. Res. Bull., 1:140-152.

Gorelova, T. A., and Kobylyanskiy, S. G. 1985. Feeding of deepsea fishes of the family Bathylagidae. J. Ichthyol., 25(5):89-100.

Gosho, M. E., Rice, D. W., and Breiwick, J. M. 1984. The sperm whale, *Physeter macrocephalus*. Mar. Fish. Rev., 46(4):54-64.

Gregr, E. J., 2004. Marine mammals in the Hecate Strait ecosystem. Canadian Technical Report of Fisheries and Aquatic Sciences, 2503. 56 pp.

Gregr, E. J., and Trites, A. W. 2001. Predictions of critical habitat for five whale species in the waters of coastal British Columbia. Can. J. Fish. Aquat. Sci., 58(7):1265-1285.

Gregr, E. J., Nichol, L., Ford, J. K. B., Ellis, G., and Trites, A. W. 2000. Migration and population structure of northeastern Pacific whales off coastal British Columbia: An analysis of commercial whaling records from 1908-1967. Mar. Mamm. Sci., 16(4):699-727.

Hanselman, D., Heifetz, J., Courtney, D. L., Clausen, D. M., Fujioka, J. T., and Ianelli, J. N., 2003. Pacific Ocean Perch. *In*: NPFMC Gulf of Alaska SAFE. pp. 429-479, North Pacific Fishery Management Council,

Hart, J. L., 1973. Pacific fishes of Canada. Bulletins of the Fisheries Research Board of Canada, Vol. 180, 741 pp.

Harvey, J. T. 1989. Food habits, seasonal abundance, size, and sex of the blue shark, Prionace glauca , in Monterey Bay, California. California Fish and Game, 75(1):33-44.

Hay, D., and McCarter, P. B., 2000. Status of eulachon *Thaleichthys pacificus* in Canada. Canadian Stock Assessment Secretariat, DFO, Research Document 2000/145, 92 pp.

Heard, W. R., 1991. Life history of pink salmon (*Oncorhynchus gorbuscha*). *In*: Pacific salmon life histories. pp. 121-230, *Edited by* C. Groot and L. Margolis, UBC Press, Vancouver, Canada, 564pp.

Hebert, K., and Pritchett, M., 2002. Miscellaneous dive fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau, Alaska, Report to the Board of Fisheries. Regional Information Report, 1J02-45. 29 pp.

Hebert, K., and Pritchett, M., 2003. Southeast Alaska-Yakutat herring fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau, Alaska, Report to the Board of Fisheries. Regional Information Report, 1J02-43. 29 pp.

Heifetz, J., Courtney, D. L., Clausen, D. M., Hanselman, D., Fujioka, J. T., and Ianelli, J. N., 2002. Slope rockfish. *In*: NPFMC Gulf of Alaska SAFE. pp. 295-382, North Pacific Fishery Management Council, Anchorage, AK.

Heinl, S. C., Zadina, T. P., McGregor, A. J., and Geiger, H. J., 2003. Chum salmon stock status and escapement goals in Southeast Alaska. Alaska Department of Fish Game, Juneau, Alaska, Report to the Board of Fisheries. Regional Information Report, 1J03-08. 40 pp.

Heise, K. 1997. Diet and feeding behaviour of Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) as revealed through the collection of prey fragments and stomach content analysis. Report of the International Whaling Commission, 47:807-815.

Heise, K., Barrett-Lennard, L. G., Saulitis, E., Matkin, C., and Bain, D. 2003. Examining the evidence for killer whale predation on Steller sea lions in British Columbia and Alaska. Aquat. Mamm., 29:325-334.

Higgs, D. A., Macdonald, J. S., Levings, C. D., and Dosanjh, B. S., 1991. Nutrition an feeding habits in relation to life history stage. *In*: Physiological ecology of Pacific salmon. pp. 159-315, *Edited by* C. Groot, L. Margolis, and W. C. Clarke, UBC Press, Vancouver, Canada, 510 pp.

Hilborn, R., and Walters, C. J., 1992. Quantitative fisheries stock assessment; Choice, dynamics and uncertainty. Chapman and Hall, New York. 570 pp.

Hobson, E. S., and Chess, J. R. 1988. Trophic relations of the blue rockfish, *Sebastes mystinus* in a coastal upwelling system off northern California. Fish. Bull., 86(4):715-743. *as cited in FishBase*.

Hoenig. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull., 82:898-903.

Hood, D. W., 1986. Physical setting and scientific history. *In*: The Gulf of Alaska: physical environment and biological resources. pp. 5-27, *Edited by* D. W. Hood and S. T. Zimmerman, US Department of Commerce, NOAA, and US Department of Interior, OCS Studies, 655 pp, Anchorage, AK.

Huato, L., 1996. Salmon in the ocean. *In*: Mass-Balance Models of North-eastern Pacific ecosystems, pp. 21-23, *Edited by* D. Pauly, V. Christensen, and N. Haggan, University of British Columbia, Fisheries Centre. Vol. 4 (1) 129 pp.

Hulberg, L. W., and Graber, P. 1980. Diet and behavioural aspects of the wolf-eel *Anarrhichthys ocellatus*, on sandy bottom in Monterey Bay, California. California Fish and Game, 66(3):172-177.

Hulbert, L., 1999. Sharks. *In*: Trophic mass balance model of Alaska's Prince William Sound ecosystem, for the post spill period 1994-1996, 2nd edition. pp. 43-47, *Edited by* T. A. Okey and D. Pauly, Fisheries Centre Research Report, Fisheries Centre, University of British Columbia, Vancouver, BC, Canada, 137 pp. Vol. 7 (4).

Hulbert, L., Sigler, M., and Lunsford, C., 2003. Sleeper shark - Sea lion predation study. *In*: Marine Science Symposium, January 2003, Steller Sea Lion (SSL) Presentations, http://www.afsc.noaa.gov/stellers/symposium2003.htm.

Hulbert, L. B., and Rice, S. D., 2002. Salmon shark, *Lamna ditropis*, movements, diet,, and abundance in the eastern North Pacific Ocean and Prince William Sound, Alaska. NOAA Fisheries, Auke Bay Laboratory, Juneau, Alaska, Exxon Valdez Oil Spill Restoration project final report, Restoration Project 02396. 40 pp.

Hunt, G. L. J., Kato, H., and McKinnel, S. M., 2000. Predation by marine birds and mammals in the subarctic Pacific Ocean. North Pacific Marine Science Organisation, Sidney, BC, Canada, PICES Scientific Report, 14. 165 pp.

Imler, R. H., and Sarber, H. R., 1947. Harbor seals and sea lions in Alaska. US Fish and Wildlife Service, Washington DC, Special Scientific Report, 28. 23 pp.

Innes, S., Lavigne, D. M., Earle, W. M., and Kovacs, K. M. 1987. Feeding rates of seals and whales. J. Anim. Ecol., 56:115-130.

Jameson, R. J., Kenyon, K. W., Johnson, A. M., and Wight, H. M. 1982. History and status of translocated sea otter populations in North America. Wildlife Society Bulletin, 10:100-107.

Jarre-Teichmann, A., 1996. Initial estimates on krill in the Alaska Gyre. *In*: Mass-balance models of North-eastern Pacific ecosystems. 129 pp. p. 20, *Edited by* D. Pauly and V. Christensen, Fisheries Centre, University of British Columbia, Vancouver, BC. Vol. 4 (1):20.

Jarre-Teichmann, A., and Guénette, S., 1996. Invertebrate benthos. *In*: Mass-balance models of North-eastern Pacific ecosystems. pp. 38-39, *Edited by* D. Pauly and V. Christensen, Fisheries Centre, University of British Columbia, Vancouver, BC. Vol. 4 (1) 129 pp.

Jemison, L. A., 2001. Summary of harbor seal diet data collected in Alaska from 1990-1999. *In*: Harbor seal investigations in Alaska, Annual report. pp. 314-322, NOAA Grant NA87FX0300, Alaska Dep. of Fish and Game, Division Wildlife Conservation, Anchorage, AK.

Jewett, S. C., and Feder, H. M. 1980. Autumn food of adult starry flounders, *Platichthys stellatus*, from the northeastern Bering Sea and the southeastern Chukchi Sea. J. Cons. Int. Explor. Mer 39(1):7-14. *as cited in FishBase*.

Jewett, S. C., Gardner, L. A., and Rusanowski, P. M., 1990. Food and feeding habits of red king crab from Northwestern Norton Sound, Alaska. *In*: Proceedings of the International Symposium on king and tanner crabs, pp. 219-232, Anchorage, Alaska, Alaska Sea Grant College Program. Vol. 90-04.

Jewett, S. C., R. H. Day , and Feder, H. M. 1989. Feeding biology of the blackfin sculpin (*Malacocottus kincaidi* Gilbert and Thompson, 1905) and the spinyhead sculpin (*Dasycottus setiger* Bean 1890) in the northeastern Gulf of Alaska. Pac. Sci., 43(2):144-151.

Jones, B. C., and Geen, G. H. 1977. Food and feeding of spiny dogfish *Squalus acanthias* in British-Columbia Canada waters. J. Fish. Res. Bd. Canada, 34(11):2067-2078.

Kenyon, K. W., 1981. Sea otter *Enhydra lutris* (Linnaeus, 1758). *In*: Handbook of marine mammals. pp. 209-223, *Edited by* S. H. Ridgway and R. Harrisson, Academic Press Ltd, London, 235 pp. Vol. 1. The walrus, sea lions, fur seals and sea otter.

Klinowska, M., 1991. Dolphins, porpoises, and whales of the world: the IUCN red data book. IUCN - The World Conservation Union, IUCN - The World Conservation Union, Gland, Switzerland. 429 pp.

Konchina, Y. V. 1982. Feeding of the Pacific mackerel, *Scomber japonicus*, near the Peruvian coast. J. Ichthyol., 22(6):102-111.

Konchina, Y. V., Nesin, A. V., Onishchik, N. A., and Pavlov, Y. P. 1996. On the migration and feeding of the jack mackerel *Trachurus symmetricus murphyi* in the Eastern Pacific. J. Ichthyol., 36(6):793-803.

Kravitz, M. J., Pearcy, W. G., and Guin, M. P. 1976. Food of five species of co-occurring flatfishes on Oregon's continental shelf. Fish. Bull., 74(4):984-990.

Kronlund, A. R., Yamanaka, K. L., and Workman, G. D., 1999. Inshore rockfish stock assesment for the west coast of Canada in 1998 and recommendations for 1999/2000. Fisheries and Oceans, Canadian Stock Assessment Secretariat Research Document, 99/58. 54 pp.

Lalli, C. M., and Parsons, T. R., 1993. Biological oceanography. Pergamon Press, New York. 301 pp.

Laws, R. M. 1977. Seals and whales in the southern Ocean. Phil. Trans. R. Soc. Lond. B, 279:81-96.

LeBrasseur, R. J. 1964. Stomach contents of blue shark (*Prionace glauca* L.) taken in the Gulf of Alaska. J. Fish. Res. Bd. Canada, 21:861-862.

Love, D., and Bishop, G., 2002. Southeast Alaska shrimp beam trawl fishery. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau, Alaska, Report to the Board of Fisheries. Regional Information Report, 1J02-45. 3.1-3.24 pp.

Love, D., and Clark, J., 2003. SE pot shrimp nearshore II final report. 1-18 pp.

Lynch, B., Skanes, P., and Shull, J., 2003. Report to the Board of Fisheries, Summary of the Southeast Alaska/Yakutat salmon troll fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Douglas, AK, Report to the Board of Fisheries. Regional Information Report, 1J03-03. 79 pp.

Mackinson, S., 1996. System definition and primary production. *In*: Mass-balance models of North-eastern Pacific ecosystems. pp. 63-64, *Edited by* D. Pauly and V. Christensen, Fisheries Centre, University of British Columbia, Vancouver, BC. Vol. 4 (1) 129 pp.

Mantua, N. J., Hare, S. R., Zhang, Y., Wallace, J. M., and Francis, R. C. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bull. Amer. Meteor. Soc., 78:1069-1079.

Mathews, E. A., and Pendleton, G. W. 2003. Decline in harbor seal (*Phoca vitulina* richardsi) numbers in Glacier Bay National Park, Alaska, 1992-2002.

Matkin, C., and Hobbs, R., 1999. Baleen whales. *In*: Trophic mass balance model of Alaska's Prince William Sound ecosystem, for the post spill period 1994-1996, 2nd edition. p. 56, *Edited by* T. A. Okey and D. Pauly, Fisheries Centre, University of British Columbia, Vancouver, BC, Canada, 137 pp.

Matkin, D. R., and Dalheim, M. E., 1995. Feeding behaviors of killer whales in northern Southeastern Alaska. *In*: Proceedings of the Third Glacier Bay Science Symposium, 1993, pp. 246-253, *Edited by* D. R. Engstrom, National Park Service, Anchorage, Alaska.

McDevitt, S. A., 1986. A summary of sablefish catches in the northeast Pacific Ocean, 1956-84. U.S. Department of Commerce, NOAA, NOAA Technical Memorandum, NMFS F/NWC-101. 34 pp.

Mecklenburg, C. W., Mecklenburg, T. A., and Thorsteinson, L. K., 2002. Fishes of Alaska. American Fisheries Society, Bethesda, Maryland. 1037 pp.

Merrick, R. L., and Calkins, D. G., 1996. Importance of juvenile walleye pollock, *Theragra chalcogramma*, in the diet of Gulf of Alaska Steller sea lions, *Eumetopias jubatus*. *In*: Ecology of Juvenile Walleye Pollock, *Theragra chalcogramma*. Papers from the workshop "The importance of prerecruit walleye pollock to the Bering Sea and North Pacific Ecosystems", pp. 153-166, *Edited by* R. D. Brodeur, P. A. Livingston, T. R. Loughlin, and A. B. Hollowed, Seattle WA, USA, US Dept. of Commerce, NOAA Technical Report NMFS. Vol. 126.

Murison, L. D., Murie, D. J., Morin, K. R., and da Silva Curiel, J., 1984. Foraging of the gray whale along the west coast of Vancouver Island, British Columbia. *In*: The gray Whale *Eschrichtius robustus*. pp. 451-463, *Edited by* M. L. Jones and S. L. Swartz, Academic Press, New York.

Nagasawa, K., 1998. Predation by salmon sharks (*Lamna ditropis*) on Pacific salmon. *In*: Proceeding of Assessment and Status of Pacific Rim Salmonid Stocks. pp. 419-433, North Pacific Anadromous Fish Commission, Vol. 1.

Nelson, B., 1979. Seabirds, their biology and ecology. A&S Publishers Inc, New York, US. 219 pp.

Nelson, M., 2003. Forage fish species in the Gulf of Alaska. *In*: NPFMC Gulf of Alaska SAFE. pp. 757-770, North Pacific Fishery Management Council, Anchorage, AK.

Nesis, K. N., 1998. The gonatid squid *Berryteuthis magister* (Berry, 1913): distribution, biology, ecological connections and fisheries. *In*: Contributed Papers to International Symposium on Large Pelagic Squids, pp. 233-249, *Edited by* T. Okutani, July 18-19, 1996, Japan Marine Fishery Resources research Center, Tokyo. *as cited in CephBase*.

Newlands, N., 1998. Salmon population parameters. *In*: Back to the future: reconstructing the Strait of Georgia ecosystem, pp. 77-78, *Edited by* D. Pauly, T. J. Pitcher, and D. Preikshot, Vancouver Canada, The Fisheries Centre, University of British Columbia. Vol. 6 (5).

Niggol, K., 1982. Data on fish species from Bering Sea and Gulf of Alaska. NOAA Technical Memorandum, NMFS F/NWC-29, 125 pp.

O'Connell, V., and Brookover, T., 2000. Alaska Board of Fisheries Charge to the Lingcod Fishery Task Force. Department of Fish and Game, AK, Sitka, AK, 17 pp.

O'Connell, V., Brylinsky, C., and Carlile, D., 2002a. Demersal shelf rockfish assessment for 2003. *In*: NPFMC Gulf of Alaska SAFE. pp. 419-458, North Pacific Fishery Management Council, Anchorage, AK.

O'Connell, V., Brylinsky, C., and Carlile, D., 2002b. Demersal shelf rockfish assessment for 2003. Alaska Department of Fish and Game, Anchorage, AK, Report to the Board of Fisheries. Regional Information Report, 1J02-44. 48 pp.

O'Connell, V., Brylinsky, C., and Carlile, D., 2003. Demersal shelf rockfish assessment for 2004. *In*: NPFMC Gulf of Alaska SAFE. pp. 617-657, North Pacific Fishery Management Council, Anchorage, AK.

O'Connell, V. M., Coonradt, E. E., Richardson, B., Vaughn, M., Holum, D., Brylinsky, C., and Carroll, K., 2002c. 1999-2001 Report to the Board of Fisheries, Region 1 groundfish fisheries, Southeast Alaska-Yakutat. Alaska Department of Fish and Game, Juneau, Ak, Regional Information Report, 1J02-46. 49 pp.

Okey, T. A., and Pauly, D., (*Editors*). 1999. Trophic mass balance model of Alaska's Prince William Sound ecosystem, for the post spill period 1994-1996, 2nd edition. Fisheries Centre, University of British Columbia, Vancouver, BC, Canada, 137 pp.

Olesiuk, P. F. 1993. Annual prey consumption by harbor seals (*Phoca vitulina*) in the Strait of Georgia, British Columbia. Fish. Bull., 91:491-515.

Olesiuk, P. F., Bigg, M. A., and Ellis, G. M. 1990. Life history and population dynamics of resident killer whales (*Orcinus orca*) in the coastal waters of British Columbia and Washington state. *In*: Individual recognition of cetaceans: use of photo-identification and other techniques to estimate population parameters, *Edited by* P. S. Hammond, S. A. Mizroch, and G. P. Donovan, Report of the International Whaling Commission, Special Issue 12:209-243.

Oliver, J. S., Slattery, P. N., Silberstein, M. A., and O'Connor, E. F. 1984. Gray whale feeding on dense ampeliscid amphipod communities near Bamfield, BC. Can. J. Zool., 62:41-49.

Omori, M. 1974. The biology of pelagic shrimps in the ocean. Adv. Mar. Biol., 12:233-324.

Orensaz, J. M. L., Armstrong, J., Armstrong, D., and Hilborn, R. 1998. Crustacean resources are vulnerable to serial depletion - the multifaceted decline of crab and shrimp fisheries in the Greater Gulf of Alaska. Rev. Fish Biol. Fish., 8:117-176.

Orlov, A. M. 1998. On feeding of mass species of deep-sea skates (*Bathyraja* spp.) from the Pacific waters on the Northern Kurils and Southeastern Kamchatka. J. Ichthyol., 38(5):659-668.

Orlov, A. M., 1999. Some aspects of trophic relations among Pacific predatory fishes off the northern Kuril Islands and southeastern Kamchatka.

Orsi, J. A., Weirtheimer, A. C., Sturdevant, M. V., Fergusson, E. A., Mortensen, D. G., and Wing, B. L. 2003. Hatchery and wild stock interactions of juvenile chum salmon in marine waters of southeastern Alaska: a bioenergetic approach.manuscript.

Palomares, M. L. D., and Pauly, D. 1998. Predicting food consumption of fish populations as functions of mortality, food type, morphometrics, temperature and salinity. Mar. Freshwater Res., 49:447-453.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer 39:175-192.

Pauly, D., and Christensen, V. 1995. Primary production required to sustain global fisheries. Nature, 374:255-257.

Pearcy, W. G., and Hancock, D. 1978. Feeding habits of dover sole, *Microstomus pacificus*; rex sole, *Glyptocephalus zachirus*; slender sole, *Lyopsetta exilis*; and pacific sanddab, *Citharichthys sordidus*, in a region of diverse sediments and bathymetry off Oregon. Fish. Bull., 76(3):641-651. *as cited in FishBase*.

Pendleton, G. W., Pitcher, K. W., Fritz, L. W., and Gelatt, T. S., 2004. Survival rates of Steller sea lions in southcentral and southwestern Alaska. *In*: Sea Lions of the World, Conservation and Research in the 21st CenturyAnchorage Alaska, Sept. 30-Oct. 3, 2004, poster.

Perez, M. A., and McAlister, W. B., 1993. Estimates of food consumption by marine mammals in the Eastern Bering Sea. U.S. Department of Commerce, NOAA, Alaska Fisheries Centre, Seattle WA, NOAA Technical Memorandum, NMFS-AFSC-14. 36 pp.

Perry, S. L., DeMaster, D. P., and Silbec, G. K. 1999. The great whales: history and status of six species listed as endangered under the US Endangered Species Act of 1973. Mar. Fish. Rev., 61(1):1-74.

Pitcher, K. W., 1977. Population productivity and food habits of harbor seals in Prince Williams Sound-Copper River delta area, Alaska. U.S. Marine Mammal Commission, Washington DC, MMC-75/03. 36 pp.

Pitcher, K. W., and Calkins, D. G. 1981. Reproductive biology of Steller sea lions in the Gulf Alaska. Journal of Mammalogy, 62:599-605.

Purcell, J., (*Editor*). 1996. Lower trophic levels in the Alaska Gyre. Fisheries Centre, University of British Columbia 129 pp., Vancouver, BC, Mass-balance models of North-eastern Pacific ecosystems, Vol. 4 (1), 16-18 pp.

Raymont, J. E. G., 1983. Plankton and productivity in the oceans. Pergamon Press, Toronto. Vol. 2 - Zooplankton, 824 pp.

Read, A. J., Wiepkema, P. R., and Nachtigall, P. E., 1997. The harbor porpoise (*Phocoena phocoena*). *In*: The biology of the harbor porpoise. pp. 3-6, *Edited by* A. J. Read, P. R. Wiepkema, and P. E. Nachtigall, De Spil Publishers, Woerden, The Netherlands.

Reeves, R. R., Leatherwood, S., Karl, S. A., and Yohe, E. R. 1985. Whaling results at Akutan (1912-39) and Port Hobron (1926-37), Alaska. Report of the International Whaling Commision, 35:441-457.

Reilly, C. A., Echeverria, R. W., and Ralston, S. 1992. Interannual variation and overlap in the diets of pelagic juvenile rockfish (Genus: *Sebastes*) off central California. Fish. Bull., 90(3):505-515.

Richardson, B., and O'Connell, V., 2002. The southeast Alaska northern southeast inside sablefish fishery information report with outlook to the 2002 fishery. Alaska, Department of Fish and Game, Division of Commercial Fisheries, Juneau, Alaska, Regional Information Report Series, 1J02-34. 41 pp. + Appendix, 15 pp.

Riedman, M. L., and Estes, J. A., 1990. The sea otter (*Enhydra lutris*): behavior, ecology and natural history. U.S. Fish and Wildlife Service, Biological Report, Vol. 90 (14), 126 pp.

Robson, B. W., (*Editor*). 2002. Fur seal investigations, 2000-2001. U.S. Department of Commerce, NOAA, 80 pp. http://www.afsc.noaa.gov/Publications/AFSC-TM/NOAA-TM-AFSC-134.pdf,

Rogers, D. E., Rabin, D. J., Rogers, B. J., Garrison.K., and Wangerin, M., 1979. Seasonal composition and food web relationships of marine organisms in the nearshore zone of Kodiak Island including ichthyoplankton, meroplankton (shellfish), zooplankton, and fish. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Environ. Res. Lab., Boulder, Colo, 529-662 pp. *as cited in FishBase*.

Rosenthal, R. J., 1979. Preliminary observations on the distribution abundance and food habits of some nearshore fishes in the northeastern Gulf of Alaska. *In*: Environmental assessment of the Alaskan continental shelf. Final reports of the principal investigators. pp. 730-804, NOAA/ERL, Boulder, CO (USA). Vol. Volume 4, Biological Studies.

Rosenthal, R. J., O'Connell, V. M., and Murphy, M. C. 1988. Feeding ecology of ten species of rockfishes (Scorpaenidae) from the Gulf of Alaska. California Fish and Game, 74(1):16-37. *as cited in FishBase*.

Rumble, J., and Bishop, G., 2002. Southeast Alaska dungeness crab fishery. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau, Alaska, Report to the Board of Fisheries. Regional Information Report, 1J02-45. 2.1-2.16 pp.

Russell, R. W., 1999. Comparative demography and life history tactics of seabirds: Implications for conservation and marine monitoring. *In*: Proceedings of the Symposium Life in the slow lane: ecology and conservation of long-lived marine animals, pp. 51-76, *Edited by* J. A. Musick, Monterey, California, American Fisheries Society Symposium. Vol. 23.

Salo, E. O., 1991. Life history of chum salmon (*Oncorhynchus keta*). *In*: Pacific salmon life histories. pp. 233-309, *Edited by* C. Groot and L. Margolis, UBC Press, Vancouver, Canada, 564pp.

Sandercock, F. K., 1991. Life history of coho salmon (*Oncorhynchus kisutch*). *In*: Pacific salmon life histories. pp. 397-445, *Edited by* C. Groot and L. Margolis, UBC Press, Vancouver, Canada, 564pp.

Savinykh, V. F. 1994. Diet of the Pacific pomfret, *Brama japonica*. J. Ichthyol., 34(1):107-116.

Shenker, J. M. 1983. Distribution, size relationships, and food habits of juvenile king-of-the-salmon, *Trachipterus altivelis*, caught off the Oregon Coast. Fish. Bull., 81(1):161-164.

Siddeek, M. S. M., Watson, L. J., Blau, S. F., and Moore, H., 2002. Estimating natural mortality of king crabs from tag recapture data. *In*: Crabs in cold water regions: biology, management, and economics, pp. 51-75, *Edited by* A. J. Paul, E. G. Dawe, R. Elner, G. S. Jamieson, G. H. Kruse, R. S. Otto, B. Sainte-Marie, T. C. Shirley, and D. Woodby, Anchorage, AK, 17-20 January 2001, Lowell Wakefield Fisheries Symposium, Alaska Sea Grant Program, 866 pp. Vol. AK-SG-02-01.

Sigler, M. F., Lunsford, C. R., Fujioka, J. T., and Lowe, S. A., 2002. Alaska sablefish assessment for 2003. *In*: NPFMC Gulf of Alaska SAFE. pp. 229-294, North Pacific Fishery Management Council, Anchorage, AK.

Sigler, M. F., Rutecki, T. L., Courtney, D. L., Karinen, J. F., and Yang, M.-S. 2001. Young-of the year sablefish abundance, growth and diet. Alaska Fish. Res. Bull., 8:57-70.

Small, R. J., Pendelton, G., and Wynne, K. M., 2001. Harbor seal population trends in the Ketchikan, Sitka, and Kodiak Island areas of Alaska, 1983-1999. *In*: Harbor seal investigations in Alaska, Annual report. pp. 8-30, NOAA Grant NA87FX0300, Alaska Dep. of Fish and Game, Division Wildlife Conservation, Anchorage, AK.

Smith, R. L., Paulson, A. C., and Rose, J. R., 1978. Food and feeding relationships in the benthic and demersal fishes of the Gulf of Alaska and Bering Sea. *In*: Environmental assessment of the Alaskan continental shelf. Final reports of the principal investigators. pp. 33-107, NOAA/ERL, Boulder, CO (USA). Vol. Volume 1, Biological Studies.

Smith, S. E., Au, D. W., and show, C. 1998. Intrinsic rebound potentials of 26 species of Pacific sharks. Mar. Freshwater Res., 49:663-678.

Sobolevskii, E. I., and Senchenko, I. A. 1996. The spatial structure and trophic connections of abundant pelagic fish of Eastern Kamchatka in the Autumn and Winter. J. Ichthyol., 36(1):30-39. *as cited in FishBase*.

Spangler, R., and Koski, K., 2003. Ecology of eulachon (*Thaleichthys pacificus*) in the Antler River, Berners Bay, Southeast Alaska. *In*: Marine Sciences in the Northeast Pacific Symposium: Science for Resource Dependent CommunitiesAnchorage, AK, 13-17 January 2004, Alaska Fisheries Science Center, http://www.afsc.noaa.gov/stellers/symposium2003.htm#ssl_biology.

Straley, J., Matkin, D., Gabriele, C., Ellis, G., and Barrett-Lennard, L., 2003. Transient killer whales in Southeastern Alaska: Who are they? What are they eating? *In*: Marine Science Symposium, January 2003, http://www.afsc.noaa.gov/stellers/symposium2003.htm.

Straley, J. M. 1990. Fall and winter occurrence of humpback whales (*Megaptera novaeangliae*) in southeastern Alaska. Report of the International Whaling Commision, Special issue 12:319-323.

Straley, J. M., Quinn II, T. J., and Gabriele, C. M., 2002. Estimate of abundance of humpback whales in southeastern Alaska 1994 to 2000. Final report submitted to NMFS, National Marine Mammal Laboratory, Seattle, Wa, 23 pp.

Tanasichuk, R. W., Ware, D. M., Shaw, W., and McFarlane, G. A. 1991. Variations in diet, daily ration, and feeding periodicity of Pacific hake (*Merluccius productus*) and spiny dogfish (*Squalus acanthias*) off the lower west coast of Vancouver Island. Can. J. Fish. Aquat. Sci., 48(11):2118-2128.

The Technical Team for Essential Fish Habitat, 1998. Essential fish habitat assessment report for the salmon fisheries in the EEZ coast of Alaska. North Pacific Fishery Management Council, Anchorage, AK, 66 pp.

Thompson, G. G., Zenger, H. H., and Dorn, M. W., 2002. Assessment of the pacific cod stock in the Gulf of Alaska. *In*: NPFMC Gulf of Alaska SAFE. pp. 89-168, North Pacific Fishery Management Council, Anchorage, AK.

Tietjen, J. H., 1992. Abundance and biomass of metazoan meiobenthos in the deep sea. *In*: Deep-sea food chanins and the global carbon cycle. pp. 45-62, *Edited by* G. T. Rowe and V. Pariente, Kluwer Academic Publishers, Boston.

Tokranov, A. M. 1990. Feeding of the yellowfin sole, *Limanda aspera*, in the southern part of the Bering Sea. Jounral of Ichthyology, 30(1):59-67. *as cited in FishBase*.

Tokranov, A. M. 1992a. Features of feeding of benthic predatory fishes of the West Kamchatka Shelf. J. Ichthyol., 32(7):45-55. *as cited in FishBase*.

Tokranov, A. M. 1992b. Dietary characteristics of sea poachers (Agonidae) in the coastal waters of Kamchatka. J. Ichthyol., 32(9):85-94. *as cited in FishBase*.

Tokranov, A. M. 1998. Some traits of biology of *Bathymaster signatus* (Bathymasteridae) in the Pacific waters of southeastern Kamchatka and the Northern Kurils. J. Ichthyol., 38(6):488-490. *as cited in FishBase*.

Tokranov, A. M., and Maksimenkov, V. V. 1995. Feeding habits of predatory fishes in the Bol'shaya River estuary (West Kamchatka). J. Ichthyol., 35(9):102-112. *as cited in FishBase*.

Tollit, D. J., Heaslip, S. G., and Trites, A. W. 2004. Sizes of walleye pollock (*Theragra chalcogramma*) consumed by the eastern stock of Steller sea lions (*Eumetopias jubatus*) in Southeast Alaska from 1994 to 1999. Fish. Bull., 102:522-532.

Tomilin, A. G., 1957. Mammals of the USSR and adjacent countries. Mammals of eastern Europe and adjacent countries (translated in 1967). Zveri SSSR i Prilezhasfchikh Stran. Zveri Vostochnoi Evropy i Severnoi Azii. Izdatel' stvo Akademi Nauk SSSR, Moscow [original title]. Cetacea, Israel Program for Scientific Translations, Jerusalem. Vol. 9, 756 pp.

Trites, A., and Heise, K., 1996. Marine mammals (in the Southern BC shelf model). *In*: Mass-Balance Models of North-eastern Pacific ecosystems, pp. 51-55, *Edited by* D. Pauly, V. Christensen, and N. Haggan, University of British Columbia, Fisheries Centre. Vol. 4 (1) 129 pp.

Trites, A., and Pauly, D. 1998. Estimating mean body masses of marine mammals from maximum body lengths. Can. J. Zool., 76:886-896.

Trites, A. W., and Larkin, P. A., 1992. The status of Steller sea lion populations and the development of fisheries in the Gulf of Alaska and Aleutian Islands. Pacific States Marine Fisheries Commission, NOAA, NA17FD0177. 134 pp.

Trites, A. W., and Larkin, P. A. 1996. Changes in the abundance of Steller sea lions (*Eumetopias jubatus*) in Alaska from 1956 to 1992: how many were there? Aquat. Mamm., 22:153-166.

Trites, A. W., and Calkins, D. G. 2003. Do breeding age male and female Steller sea lions eat the same things? manuscript,

Trites, A. W., Christensen, V., and Pauly, D. 1997. Competition between fisheries and marine mammals for prey and primary production in the Pacific Ocean. J. Northw. Atl. Fish. Sci., 22:173-187.

Trites, A. W., Calkins, D. G., and Winship, A. J. 2003. Diets of Steller sea lions (*Eumetopia jubatus*) in Southeast Alaska from 1993-1999. manuscript,

Trites, A. W., Livingston, P. A., Mackinson, S., Vasconcellos, M. C., Springer, A. M., and Pauly, D., 1999. Ecosystem change and the decline of marine mammals in the eastern Bering Sea; testing the ecosystem shift and commercial whaling hypotheses. Fisheries Centre research reports, Vancouver, BC, 7(1). 106 pp.

Turnock, B. J., Wilderbuer, T. K., and Brown, E. S., 2002a. Gulf of Alaska flatfish. *In*: NPFMC Gulf of Alaska SAFE. pp. 169-198, North Pacific Fishery Management Council, Anchorage, AK.

Turnock, B. J., Wilderbuer, T. K., and Brown, E. S., 2002b. Arrowtooth flounder. *In*: NPFMC Gulf of Alaska SAFE. pp. 199-228, North Pacific Fishery Management Council, Anchorage, AK.

Tyler, H. R., and Pearcy, W. G. 1975. The feeding habits of three species of lanternfish (Family Myctophidae) off Oregon, USA. Mar. Biol., 32:7-11.

van Tamelen, P. G., and Woodby, D. 2001. Macrocystis biomass, quality, and harvesting effects in relation to the herring spawn-on-kelp fishery in Alaska. Alaska Fish. Res. Bull., 8:118-131.

Vasconcellos, M., 2002. Mass-balance models of oceanic ecosytems of the Atlantic. Fisheries Centre, University of British Columbia, Vancouver BC, Fisheries Centre Research Report, 76 pp.

Vincent, T. L. S., Scheel, D., and Hough, K. R. 1998. Some aspects of diet and foraging behaviour of *Octopus dofleini* (Wülker, 1910) in its northernmost range. P. S. Z. N. I.: Mar. Ecol., 19(1):13-23. *as cited in CephBase*.

Wada, Y., 1996. Marine mammals and birds. *In*: Mass-Balance Models of North-eastern Pacific Ecosystems. p. 71, *Edited by* D. Pauly, V. Christensen, and N. Haggan, Fisheries Centre of the University of British Columbia, Vancouver, BC, 129 pp. Vol. 4(1).

Wade, P. R. 2002. A Bayesian stock assessment of the eastern North Pacific gray whale using abundance and harvest data from 1967 to 1996. J. Cetacean Res. Manage., 4:85-98.

Walker, S., 2003. 2003 eulachon summary in Southeast Alaska. State of Alaska Department of Gish and Game, Commercial Fisheries Division, Ketchikan, AK, Memorandum, 15 September 2003, 3 pp.

Whitehead, H. 2002. Estimates of the current global populations size and historical trajectory for sperm whales. Mar. Ecol. Prog. Ser., 242:295-304.

Wickens, P., and York, A. E. 1997. Comparative population dynamics of fur seals. Mar. Mamm. Sci., 13(2):241-292.

Winship, A. J., and Trites, A. W. 2003. Prey consumption of Steller sea lions (*Eumetopias jubatus*) off Alaska: How much prey do they require. Fish. Bull., 101:147-167.

Wolfe, R. J., Fall, J. A., and Stanek, R. T., 2003. The susbsistence harvest of harbor seals and sea lions by Alaska Natives in 2002. Alaska Department of Fish and Game, Division of Subsistence, Juneau. Alaska, 90 +Appendixes 50 pp.

Yang, M. S., and Page, B. N. 1999. Diet of Pacific sleeper shark, *Somniosus pacificus*, in the Gulf of Alaska, U.S. Fish. Bull., 97:406-409.

Yang, M.-S., 1996. Diets of the important groundfishes in the Aleutian Islands in summer 1991. NOAA Technical Memo, NMFS-AFSC-60. 105 pp.

Yang, M.-S., and Nelson, M. W., 2000. Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990, 1993, and 1996. NOAA Technical Memo, NMFS-AFSC-112. 174 pp.

York, A. E. 1994. The population dynamics of northern sea lions, 1975-1985. Mar. Mamm. Sci., 10(1):38-51.

Yoshiyama, R. M., and Darling, J. D. S. 1982. Grazing by the intertidal fish *Anoplarchus purpurescens* upon a distasteful polychaete worm. Env. Biol. Fish., 7(1):39-45. *as cited in FishBase*.

Zadina, T. P., Heinl, S. C., McGregor, A. J., and Geiger, H. J., 2003. Pink salmon stocks status and escapement goals in Southeast Alaska and Yakutat. Alaska Department of Fish Game, Juneau, Alaska, Report to the Board of Fisheries. Regional Information Report, 1J03-06. 50 pp.

Zenger, H. H., Jr, and Blackburn, J. E., 1987. Pacific cod. *In*: Condition of groundfish resources of the Gulf of Alaska Region as assessed in 1986. pp. 85-117, *Edited by* R. L. Major, U.S. Department of Commerce, NOAA Technical Memorandum, Vol. NMFS F/NWC-119.

Zenger Jr, H. H., 1981. Relative abundance and size composition of sablefish in coastal waters of Southeast Alaska, 1978-81. NOAA Technical Memorandum, NMFS F/NWC-20. 47 pp.

Zhang, C. I. 1988. Food habits and ecological interactions of Alaska plaice, *Pleuronectes quadrimaculatus*, with other flatfish species in the Eastern Bering Sea. Bull. Kor. Fish. Soc., 21(2):150-160. *as cited in FishBase*.

APPENDIX 1. KILLER WHALES LIFE TABLE

Table 1.1. Condensed life table, length at age and weight at age for killer whales used in this model.

	N at age [a]		**Length at age (m)**[b]		**Weight at age (kg)** [c]	
Age	**female**	**male**	**female**	**male**	**female**	**male**
	1754	1754	2.3	2.3	253.7	253.7
1	980	980	3.2	3.3	609.7	645.4
2	947	947	3.7	3.7	843.1	864.6
3	923	923	4.1	4	1073.9	1073.9
4	902	902	4.2	4.2	1229.2	1229.2
5	882	882	4.4	4.4	1368.5	1368.5
6	863	863	4.6	4.6	1486.5	1517.0
7	846	846	4.7	4.7	1642.6	1642.6
8	833	833	4.9	4.9	1740.9	1774.4
9	820	820	5	5.1	1842.7	1948.1
10	807	807	5.1	5.1	1948.1	2020.3
11	799	799	5.1	5.2	2020.3	2131.7
12	794	794	5.3	5.3	2131.7	2208.0
13	790	790	5.3	5.5	2169.6	2365.5
14	786	786	5.4	5.6	2246.7	2488.1
15	781	781	5.5	5.8	2365.5	2789.0
16	779	776	5.5	6.0	2446.8	2970.4
17	779	769	5.5	6.1	2446.8	3111.1
18	779	763	5.6	6.2	2488.1	3207.1
19	779	757	5.6	6.2	2529.8	3255.8
20	779	751	5.6	6.2	2529.8	3304.9
25	779	684	5.6	6.3	2529.8	3354.5
30	772	550	5.6	6.3	2529.8	3455.0
35	758	402	5.6	6.3	2529.8	3455.0
40	731	279	5.6	6.4	2529.8	3557.4
45	692	194	5.6	6.4	2555.0	3557.4
50	632	134	5.6	6.4	2571.9	3609.2
55	557	93	5.6	6.5	2571.9	3630.1
60	481	65	5.6	6.5	2571.9	3661.6
65	407	0	5.6	6.5	2571.9	3661.6
70	313	0	5.6	6.5	2571.9	3661.6
75	219	0	5.6	6.5	2571.9	3661.6
80	153	0	5.6	6.5	2571.9	3661.6
85	107	0	5.6	6.5	2571.9	3661.6
90	75	0	5.6	6.5	2571.9	3661.6

a. from Olesiuk et al (1990)

b. extracted from figure 4 in Christensen (1984)

c. $P = 0.000208 * L^{2.577}$; L(cm) , P (kg) (Bigg and Wolman 1975)

Appendix 2. diet tables

Table 2.1 Original diet (%) used in the 1999 model. Predators are listed in columns and prey in rows.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	14	15	16	**17**	**18**
1 Transient orca	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-
2 Toothed whales	-	-	-	-	-	-	-	-	-	-	0.7	-	-	-	-	-	-	-
3 Baleen whales	3	-	-	-	-	-	-	-	-	-	2.24	-	-	-	-	-	-	-
4 Sea lions embryo	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-
5 Sea lions pup	1	-	-	-	-	-	-	-	-	-	0.2	-	-	-	-	-	-	-
6 Sea lions juveniles	9	-	-	-	-	-	-	-	-	-	3.52	-	-	-	-	-	-	-
7 Sea lions adults	6	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-
8 Small mammals	78	-	-	-	-	-	-	-	-	-	8.35	-	-	-	-	-	-	-
9 Sea otters	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-
10 Birds	1	-	-	-	-	0.3	0.15	-	-	0.04	0.36	-	-	-	-	-	-	-
11 Shark mammal eater	-	-	-	-	-	-	-	-	-	-	-	0.03	-	-	-	-	-	-
12 Shark and skate	-	6.42	-	-	-	2.93	6.82	-	-	-	15.51	2.72	-	-	-	-	-	-
13 Salmon	-	3.91	0.08	-	-	21.94	12.99	6.25	-	-	2.19	5.81	0.04	1.67	-	-	-	-
14 Pel L	-	0.44	-	-	-	1.47	0.83	0.73	-	-	2.61	2.1	-	0.3	-	-	-	-
15 Pel S	-	1.2	0.18	-	-	0.2	1.89	3.88	-	27.23	0.69	4.06	-	7.56	0.91	-	-	2.22
16 Sandlance	-	-	0.35	-	-	14.76	8.02	21.55	-	27.14	-	1.01	3.04	4.52	1.42	-	-	0.49
17 Herring	-	0.3	8.66	-	-	12.94	14.02	20.80	-	0.04	0.69	4.57	3.63	9.33	-	-	-	
18 Pollock juv	-	-	0.02	-	-	13.94	6.4	4.36	-	0.3	0.43	0.37	-	0.97	-	-	-	0.07
19 Pollock adult	-	-	0.07	-	-	7.49	23.93	11.27	-	0.3	2.06	1.02	-	0.97	-	-	-	-
20 POP	-	3.28	0.02	-	-	1.13	0.66	0.34	-	0.03	0.22	0.03	-	-	-	-	-	-
21 Rockfish slope	-	6.55	0.04	-	-	4.53	2.63	0.57	-	0.09	0.92	0.69	-	-	-	-	-	-
22 Rockfish shelf	-	6.55	0.04	-	-	5.66	3.29	0.77	-	0.3	0.92	0.51	-	-	-	-	-	-
23 Sablefish	-	0.6	-	-	-	0.15	0.2	0.84	-	-	0.69	4.11	-	-	-	-	-	-
24 Pacific cod	-	0.6	0.08	-	-	0.46	0.85	1.87	-	0.3	0.75	0.75	-	-	-	-	-	-
25 Halibut	-	0.6	-	-	-	0.25	0.13	0.00	-	-	1.53	1.04	-	-	-	-	-	-
26 Arrowtooth	-	-	-	-	-	6.37	6.66	3.64	-	-	15.78	0.39	-	-	-	-	-	-
27 Dem L	-	1.72	-	-	-	2.04	1.59	0.26	-	-	4.87	0.18		-	-	-	-	-
28 Flatfish	-	-	-	-	-	0.66	1.21	9.04	-	0.09	2.14	1.58	0.13	0.76	-	-	-	1.73
29 Dem S	-	0.3	0.02	-	-	0.81	1.32	5.15	-	0.09	1.1	4.22	0.51	-	0.19	-	-	2.71
30 Deep L	-	17.18	0.03	-	-	0.05	0.038	0.26	-	-	2.61	2.41	-	-	0	-	-	0.49
31 Deep S	-	-	-	-	-	0.2	0.84	0.26	-	0.08	1.5	2.38	-	1.94	0	-	-	1.73
32 Shrimps	-	-	0.08	-	-	-	-	0.09	-	-	0.2	7.1	-	3.07	9.3	-	-	10.27
33 Benthic inverts	-	-	5.66	-	-	0.25	0.63	-	90	-	0.59	16.34	-	13.42	26.32	6.3	1	13.25
34 Epibenthic carniv.	-	-	0.08	-	-	-	-	-	10	-	0.4	3.73	0.18	-	1.99	-	-	-
35 Cephalopods	-	50.38	-	-	-	1.47	4.9	8.08	-	11.7	22.13	8.06	1.5	9.9	1.64	-	-	-
36 L zoo	-	-	66.43	-	-	-	-	-	-	28.3	-	3.98	15.13	34.92	45.18	21	81.7	56.99
37 S zoo	-	-	9.82	-	-	-	-	-	-	3.88	-	-	0.84	10.68	12.34	72.7	17.3	10.05
38 Phyto	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39 Marine plants	-	-	-	-	-	-	-	-	-	-	-	0.35	-	-	-	-	-	-
detritus	-	-	-	-	-	-	-	-	-	0.07	4.1	0.47	-	-	-	-	-	-
imports	2	-	-	100	100	-	-	-	-	-	-	20	75	0	0.71	-	-	-
sum	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table 2.1 (continued). **Original** diet (%) used in the 1999 model. Predators are listed in columns and prey in rows.

	19	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
1 Transient orca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2 Toothed whales	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3 Baleen whales	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4 Sea lions embryo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5 Sea lions pup	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6 Sea lions juv.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7 Sea lions adults	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8 Small mammals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9 Sea otters	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10 Birds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11 Shark mammal eater	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12 Shark and skate	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13 Salmon	-	-	-	2	-	-	1.79	-	6.85	-	-	1.74	-	-	-	-	-	-	-
14 Pel L	-	-	-	-	-	-	-	-	1.44	-	-	2.22	-	-	-	-	-	-	-
15 Pel S	7.12	-	1.9	2.91	3.76	17.22	5.01	12.62	3.89	1.62	0.09	0.04	0.06	-	-	-	1.6	-	-
16 Sandlance	0.21	-	9.66	10.38	1.22	17.22	5.01	12.62	2.46	0.41	0.46	-	-	-	-	-	0.8	-	-
17 Herring	0.06	-	1.37	7.78	2.46	9.34	7.28	14.99	6.69	1.3	0.32	-	-	-	-	-	2.4	-	-
18 Pollock juv	1.14	-	0.3	2	2.46	-	-	0.02	1.9	1		-	-	-	-	-	2.86	-	-
19 Pollock adult	1.14	-	0.27	-	0	6.13	1.1	0.06	5.71	3.01	-	-	-	-	-	-	-	-	-
20 POP	-	-	-	-	-	0.7	1.01	4.62	0.11	-	-	0.29	-	-	-	-	-	-	-
21 Rockfish slope	0.06	-	-	-	-	1.66	2.01	4.62	-	-	0.04	0.58	-	-	-	-	-	-	-
22 Rockfish shelf	-	-	-	2.57	-	0.08	2.01	6.41	2.19	-	0.217	0.52	-	-	-	-	-	-	-
23 Sablefish	-	-	1.01	-	-	-	0.3	-	0.52	-	-	0.29	-	-	-	-	-	-	-
24 Pacific cod	0.05	-	-	-	-	0.4	1	-	1.2	0.09	-	-	-	-	-	-	-	-	-
25 Halibut	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26 Arrowtooth	0.06	2	-	-	1.88	0.9	9.77	-	0.58	0.42	-	0.07	-	-	-	-	-	-	-
27 Dem L	-	-	0.24	0.73	-	3.31	1.02	0.58	0.23	0.04	-	0.8	-	-	-	-	-	-	-
28 Flatfish	0.68	-	0.02	2.56	3.76	18.11	7.58	7.24	6.65	1.64	0.39	1.8	-	-	-	-	-	-	-
29 Dem S	1.58	-	2.51	5.38	8.1	9.79	7.09	8.67	7.02	4.34	0.64	2.63	-	-	-	-	3.66	-	-
30 Deep L	0.05	-	0.24	-	-	-	-	3.46	0.24	0.18	-	0.93	-	-	-	-	-	-	-
31 Deep S	0.18	1	1.43	0.01	1.88	-	-	10.39	0.53	0.93	0.12	10.91	0.06	-	-	-	12.97	-	-
32 Shrimps	33.09	7	21.89	7.17	5.08	3.9	1.22	6.09	4.02	9.76	12.17	8.65	-	2	-	10	4.74	-	-
33 Benthic inverts	12.68	11	3.58	11.93	14.43	3.3	5	-	12.91	63.73	51.6	28.23	7.05	32	-	40	17.78	-	-
34 Epibenthic carniv.	-	-	2.3	12.78	0.6	7.93	36.82	-	15.12	6.35	8.32	11.59	8.01	-	-	7	18.07	-	-
35 Cephalopods	-	2	4.8	0.54	2.31	-	2.91	3.04	0.67	1.35	0	7.39	0.09	-	-	-	10.74	-	-
36 L zoo	36.53	70	36.75	19.96	22.17	-	0.22	4.57	14.07	2.22	9.41	19.78	44.95	16	10	-	20.38	6	-
37 S zoo	4.78	7	11.15	3.82	0.03	-	-	-	1.29	0.75	14.43	1.51	39.76	-	10	3	4	31.6	-
38 Phyto	-	-	-	-	-	-	-	-	2.65	-	0.86	-	-	-	20	-	-	41.2	100
39 Marine plants	-	-	-	4.74	-	-	-	-	1.02	-	0.79	-	-	-	10	20	-	-	-
detritus	-	-	0.58	2.74	29.86	-	1.84	-	-	0.87	0.09	-	-	50	50	20	-	21.2	-
imports	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
sum	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Table 2.2. Diet matrix (%) of the **balanced 1999** model. Predators are listed in columns and prey in rows. This matrix has been used as the starting matrix for models 1977 and 1963.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
1 Transient orca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2 Toothed whales	-	-	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-
3 Baleen whales	4	-	-	-	-	-	-	-	-	-	2.27	-	-	-	-	-	-	-	-
4 Sea lions embryo	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-
5 Sea lions pup	1	-	-	-	-	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-
6 Sea lions juv	7	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-
7 Sea lions adults	35	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-
8 Small mammals	50	-	-	-	-	-	-	-	-	-	8.46	-	-	-	-	-	-	-	-
9 Sea otters	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-
10 Birds	1	-	-	-	-	0.1	0.15	-	-	0.05	0.36	-	-	-	-	-	-	-	-
11 Shark mammal eater	-	-	-	-	-	-	-	-	-	-		0.03	-	-	-	-	-	-	-
12 Shark and skate	-	6.42	-	-	-	0.3	0.5	-	-	-	15.71	1.5	-	-	-	-	-	-	-
13 Salmon	-	3.91	0.09	-	-	22.44	14.21	8	-	-	3.04	5.81	-	1.67	-	-	-	-	-
14 Pel L	-	0.44	-	-	-	0.1	0.1	0.1	-	-	2.64	0.8	-	0.3	-	-	-	-	-
15 Pel S	-	-	0.19	-	-	0.52	5	12	-	27.23	2.03	6.3	0.00213	7.56	0.91	-	-	2.22	7.97
16 Sandlance	-	-	0.39	-	-	14.76	10.38	18.2	-	27.14	-	1.01	0.00145	4.52	1.42	-	-	0.49	1
17 Herring	-	0.3	9.45	-	-	20.28	26	20.82	-	0.04	0.7	4.57	0.0045	9.33	-	-	-		0.06
18 Pollock juv	-	-	0.03	-	-	0.5	0.5	0.3	-	0.31	0.44	0.37	-	0.97	-	-	-	0.07	0.1
19 Pollock adult	-	-	0.08	-	-	3	5.7	7	-	0.31	2.09	1.02	-	0.97	-	-	-	-	1.14
20 POP	-	2	0.03	-	-	0.7	0.3	0.2	-	0.03	0.22	0.03	-	-	-	-	-	-	-
21 Rockfish slope	-	6.55	0.05	-	-	3	2.63	0.57	-	0.09	0.93	0.69	-	-	-	-	-	-	0.06
22 Rockfish shelf	-	6	0.05	-	-	0.6	1	0.4	-	0.31	0.93	0.51	-	-	-	-	-	-	-
23 Sablefish	-	0.6	-	-	-	0.15	0.2	0.73	-	-	0.7	4.11	-	-	-	-	-	-	-
24 Pacific cod	-	0.65	0.09	-	-	5	0.9	2.3	-	0.31	0.76	0.75	-	-	-	-	-	-	0.05
25 Halibut	-	0.6	-	-	-	0.4	0.13	-	-	-	1.55	1.04	-	-	-	-	-	-	-
26 Arrowtooth	-	-	-	-	-	8	6.67	3.92	-	-	15.99	0.39	-	-	-	-	-	-	0.06
27 Dem L	-	1.72	-	-	-	2.03	1.59	0.27	-	-	4.93	0.46	-	-	-	-	-	-	-
28 Flatfish	-	-	-	-	-	0.6	1.21	8.5	-	0.09	2.17	1.58	0.000194	0.76	-	-	-	1.73	0.68
29 Dem S	-	0.8	0.02	-	-	11.17	16.42	7.99	-	0.09	1.52	4.22	0.00213	-	0.19	-	-	2.71	1.59
30 Deep L	-	17.18	0.04	-	-	1.1	0.04	0.27	-	-	2.64	2.41	-	-	-	-	-	0.49	0.05
31 Deep S	-	-	-	-	-	3.53	0.84	0.27	-	0.08	1.52	2.38	-	1.94	-	-	-	1.73	0.18
32 Shrimps	-	-	0.09	-	-	-	-	0.09	-	-	0.2	7.1	-	3.07	9.28	-	-	10.27	33.09
33 Benthic inverts	-	-	6.17	-	-	0.25	0.63	-	90	-	0.6	16.34	-	13.42	26.29	6.3	1.01	13.25	12.68
34 Epibenthic carniv.	-	-	0.09	-	-	-	-	-	10	-	0.41	3.73	0.000291	-	1.99	-	-	-	-
35 Cephalopods	-	50.35	0.01	-	-	1.47	4.9	8.07	-	11.68	22.42	8.06	0.00233	9.9	1.63	-	-	-	-
36 L zoo	-	-	72.42	-	-	-	-	-	-	28.3	-	3.98	0.0608	34.92	45.23	21	81.72	56.99	36.53
37 S zoo	-	-	10.71	-	-	-	-	-	-	3.88	-	-	0.00339	10.68	12.35	72.7	17.27	10.05	4.78
38 Phyto	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39 Marine plants	-	-	-	-	-	-	-	-	-	-	-	0.35	-	-	-	-	-	-	-
Detritus	-	-	-	-	-	-	-	-	-	0.07	4.15	0.47	-	-	-	-	-	-	-
Import	2	-	-	100	100	-	-	-	-	-	-	20	0.9227	-	-	-	-	-	-

Table 2.2 continued. Diet matrix (%) of the **balanced 1999** model. Predators are listed in columns and prey in rows.

	20	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
1 Transient orca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2 Toothed whales	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3 Baleen whales	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4 Sea lions embryo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5 Sea lions pup	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6 Sea lions juv	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7 Sea lions adults	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8 Small mammals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9 Sea otters	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10 Birds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11 Shark mammal eater	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12 Shark and skate	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13 Salmon	-	-	2	-	-	1.79	-	6.85	-	-	1.74	-	-	-	-	-	-	-
14 Pel L	-	-	-	-	-	-	-	0.1	-	-	0.5	-	-	-	-	-	-	-
15 Pel S	-	1.9	2.91	3.76	17.22	5.01	12.63	4.39	1.62	0.17	0.04	0.07	-	-	-	3	-	-
16 Sandlance	-	9.66	10.38	1.22	17.22	5.01	12.63	2.46	0.41	0.47	-	-	-	-	-	0.8	-	-
17 Herring	-	1.37	7.78	2.46	9.34	7.28	15	6.69	1.5	0.32	-	-	-	-	-	2.4	-	-
18 Pollock juv	-	0.3	2	0.5	-	-	0.02	0.2	-	0.004	-	-	-	-	-	0.01	-	-
19 Pollock adult	-	0.27	-	-	6.13	1.1	0.06	5.71	1	-	-	-	-	-	-	-	-	-
20 POP	-	-	-	-	0.5	0.4	0.1	0.12	-	-	0.29	-	-	-	-	-	-	-
21 Rockfish slope	-	-	-	-	1.66	2	1.1	-	-	0.04	0.59	-	-	-	-	-	-	-
22 Rockfish shelf	-	-	2.57	-	0.08	0.8	0.2	0.5	-	0.01	0.52	-	-	-	-	-	-	-
23 Sablefish	-	1.01	-	-	-	0.3	-	0.52	-	-	0.29	-	-	-	-	-	-	-
24 Pacific cod	-	-	-	-	0.4	1.4	-	2	0.2	-	-	-	-	-	-	-	-	-
25 Halibut	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26 Arrowtooth	2	-	-	1.88	0.9	9.5	-	0.6	0.42	-	0.07	-	-	-	-	-	-	-
27 Dem L	-	0.24	0.73	-	3.31	1.2	0.63	0.23	0.04	-	0.8	-	-	-	-	-	-	-
28 Flatfish	-	0.03	2.56	3.76	10	7.4	2.5	6.65	1.64	0.39	1.8	-	-	-	-	-	-	-
29 Dem S	-	2.51	5.38	8.1	18.11	8.79	26.14	10.43	5.04	0.77	2.63	-	-	-	-	7.09	-	-
30 Deep L	-	0.24	-	-	-	-	0.5	0.24	0.18	-	0.93	-	-	-	-	-	-	-
31 Deep S	1	1.43	0.01	3.84	-	-	14.8	0.53	2.93	0.12	12.64	0.07	-	-	-	14.83	-	-
32 Shrimps	7	21.89	7.17	5.08	3.9	1.22	6.09	4.02	9.76	12.17	8.65	-	2	-	10	4.74	-	-
33 Benthic inverts	11	3.57	11.93	14.43	3.3	5	-	12.91	63.72	51.62	28.23	7.05	32	-	40	23.67	-	-
34 Epibenthic carniv.	-	2.3	12.78	0.6	7.93	36.83	-	15.13	6.35	8.33	11.59	8.01	-	-	7	18.07	-	-
35 Cephalopods	2	4.8	0.54	2.31	-	2.91	3.04	0.67	1.35	0.002	7.39	0.09	-	-	-	1	-	-
36 L zoo	70	36.75	19.96	22.17	-	0.22	4.57	14.07	2.22	9.41	19.78	44.95	16	10	-	24.38	6	-
37 S zoo	7	11.15	3.82	0.03	-	-	-	1.29	0.75	14.44	1.51	39.77	-	10	3	-	31.6	
38 Phyto	-	-	-	-	-	-	-	2.65	-	0.86	-	-	-	20	-	-	41.2	100
39 Marine plants	-	-	4.74	-	-	-	-	1.03	-	0.79	-	-	-	10	20	-	-	-
Detritus	-	0.58	2.74	29.86	-	1.84	-	-	0.87	0.09	-	-	50	50	20	-	21.2	-
Import	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2.3 Diet matrix (%) of the **balanced 1977** model. Predators are listed in columns and prey in rows.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
1 Transient orca	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-
2 Toothed whales	-	-	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-
3 Baleen whales	6	-	-	-	-	-	-	-	-	-	2.27	-	-	-	-	-	-	-	-
4 Sea lions embryo	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-
5 Sea lions pup	0.7	-	-	-	-	-	-	-	-	-	0.05	-	-	-	-	-	-	-	-
6 Sea lions juv	4.5	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-
7 Sea lions adults	24.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8 Small mammals	61.6	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-
9 Sea otters	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10 Birds	1	-	-	-	-	0.1	0.1	-	-	0.05	0.36	-	-	-	-	-	-	-	-
11 Shark mam. eater	-		-	-	-			-	-	-	-	0.03	-	-	-	-	-	-	-
12 Shark and skate	-	6.42	-	-	-	0.3	0.3	-	-	-	15.71	1.5	-	-	-	-	-	-	-
13 Salmon	-	3.91	0.09	-	-	22.44	22.44	8	-	-	3.04	5.81	0.01	1.67	-	-	-	-	-
14 Pel L	-	0.44	-	-	-	0.1	0.2	0.1	-	-	2.64	0.8		0.3	-	-	-	-	-
15 Pel S	-	3.48	0.19	-	-	0.52	1.52	20	-	27.23	2.03	6.3	0.22	7.56	0.91	-	-	2.22	7.97
16 Sandlance	-	-	0.39	-	-	18	21.4	20.2	-	27.14	-	1.01	0.15	4.52	1.42	-	-	0.49	1
17 Herring	-	0.3	9.45	-	-	10	3.2	3	-	0.04	0.7	4.57	0.59	9.33	-	-	-	-	0.06
18 Pollock juv	-	-	0.03	-	-	0.5	0.5	1.4	-	0.31	0.44	0.37	-	0.97	-	-	-	0.07	0.1
19 Pollock adult	-	-	0.08	-	-	3	4	3	-	0.31	2.09	1.02	-	0.97	-	-	-	-	1.14
20 POP	-	0.5	0.03	-	-	0.7	0.1	0.1	-	0.03	0.22	0.03	-	-	-	-	-	-	-
21 Rockfish slope	-	6.55	0.05	-	-	3	3	0.57	-	0.09	0.93	0.69	-	-	-	-	-	-	0.06
22 Rockfish shelf	-	6	0.05	-	-	0.6	0.6	0.4	-	0.31	0.93	0.51	-	-	-	-	-	-	-
23 Sablefish	-	0.6		-	-	0.15	0.15	0.73	-		0.7	4.11	-	-	-	-	-	-	-
24 Pacific cod	-	0.65	0.09	-	-	7	5	4.3	-	0.31	0.76	0.75	-	-	-	-	-	-	0.05
25 Halibut	-	0.6	-	-	-	0.4	0.4	0	-	-	1.55	1.04	-	-	-	-	-	-	-
26 Arrowtooth	-		-	-	-	8	8	3.92	-	-	15.99	0.39	-	-	-	-	-	-	0.06
27 Dem L	-	1.72	-	-	-	2.03	2.03	0.27	-	-	4.93	0.46	-	-	-	-	-	-	-
28 Flatfish	-		-	-	-	0.6	0.6	8.7	-	0.09	2.17	1.58	0.02	0.76	-	-	-	1.73	0.68
29 Dem S	-	1.3	0.02	-	-	16.21	14.24	11.79	-	0.09	1.52	4.22	0.22	-	0.19	-	-	2.71	1.59
30 Deep L	-	17.18	0.04	-	-	1.1	1.5	0.27	-		7.1	2.41	-	-	-	-	-	0.49	0.05
31 Deep S	-	-	0	-	-	3.53	9	5.09	-	0.08	1.69	2.38	-	1.94	-	-	-	1.73	0.18
32 Shrimps	-	-	0.09	-	-	-	-	0.09	-	-	0.2	7.1	-	3.07	9.28	-	-	10.27	33.08
33 Benthic inverts	-	-	6.17	-	-	0.25	0.25	-	90	-	0.6	16.34	-	13.42	26.29	6.3	1.01	13.25	12.68
34 Epibenthic carniv.	-	-	0.09	-	-	-	-	-	10	-	0.41	3.73	0.03	-	1.99	-	-	-	-
35 Cephalopods	-	50.35	0	-	-	1.47	1.47	8.07	-	11.68	22.42	8.06	0.24	9.9	1.63	-	-	-	-
36 L zoo	-	-	72.42	-	-	-	-	-	-	28.3	-	3.98	6.27	34.92	45.23	21	81.72	56.99	36.52
37 S zoo	-	-	10.71	-	-	-	-	-	-	3.88	-	-	0.35	10.68	12.35	72.7	17.27	10.05	4.78
38 Phyto	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39 Marine plants	-	-	-	-	-	-	-	-	-	-	-	0.35	-	-	-	-	-	-	-
40 Detritus	-	-	-	-	-	-	-	-	-	0.07	4.15	0.47	-	-	-	-	-	-	-
41 Import	2	-	-	100	100	-	-	-	-	-	-	20	91.91	-	0.71	-	-	-	-

Table 2.3 continued. Diet matrix (%) of the **balanced 1977** model. Predators are listed in columns and prey in rows.

	20	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
1 Transient orca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2 Toothed whales	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3 Baleen whales	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4 Sea lions embryo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5 Sea lions pup	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6 Sea lions juv	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7 Sea lions adults	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8 Small mammals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9 Sea otters	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10 Birds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11 Shark mammal eater	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12 Shark and skate	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13 Salmon	-	-	2	-	-	1.79	-	6.85	-	-	1.74	-	-	-	-	-	-	-
14 Pel L	-	-	-	-	-	-	-	0.1	-	-	0.5	-	-	-	-	-	-	-
15 Pel S	-	1.9	2.91	3.76	17.56	5.01	12.63	4.39	1.62	0.17	0.04	0.07	-	-	-	3	-	-
16 Sandlance	-	9.66	10.38	1.22	21.42	5.11	22.63	2.46	0.41	0.47	-	-	-	-	-	0.8	-	-
17 Herring	-	1.37	7.78	2.46	5	7.28	1	6	1.5	0.32	-	-	-	-	-	1	-	-
18 Pollock juv	-	0.3	2	0.5	-	-	0.02	0.2	-	0.0045	-	-	-	-	-	0.01	-	-
19 Pollock adult	-	0.27	-	-	3.13	1.1	0.06	4.71	1	-	-	-	-	-	-	-	-	-
20 POP	-	-	-	-	0.1	0.3	0.05	0.12	-	-	0.29	-	-	-	-	-	-	-
21 Rockfish slope	-	-	-	-	1.66	2	1.1		-	0.04	0.59	-	-	-	-	-	-	-
22 Rockfish shelf	-	-	2.57	-	0.08	0.8	0.2	0.5	-	0.01	0.52	-	-	-	-	-	-	-
23 Sablefish	-	1.01	-	-	-	0.3	-	0.52	-	-	0.29	-	-	-	-	-	-	-
24 Pacific cod	-	-	-	-	0.4	1.4	-	2	0.2	-	-	-	-	-	-	-	-	-
25 Halibut	-	-	-	-	-	-	-			-	-	-	-	-	-	-	-	-
26 Arrowtooth	2	-	-	1.88	0.9	9.5	-	0.6	0.42	-	0.07	-	-	-	-	-	-	-
27 Dem L	-	0.24	0.73		3.31	1.2	0.63	0.23	0.04	-	0.8	-	-	-	-	-	-	-
28 Flatfish	-	0.03	2.56	3.76	10	7.4	2.5	6.65	1.64	0.39	1.8	-	-	-	-	-	-	-
29 Dem S	-	2.51	5.38	8.1	21.31	8.79	29.94	11.65	5.04	0.77	2.63	-	-	-	-	7.29	-	-
30 Deep L	-	0.24	-	-	-	-	0.5	0.24	0.18	-	0.93	-	-	-	-		-	-
31 Deep S	1	1.43	0.01	3.84	-	-	15.05	1	2.93	0.12	12.64	0.07	-	-	-	16.03	-	-
32 Shrimps	7	21.89	7.17	5.08	3.9	1.22	6.09	4.02	9.76	12.17	8.65	-	2	-	10	4.74	-	-
33 Benthic inverts	11	3.57	11.93	14.43	3.3	5	-	12.91	63.72	51.62	28.23	7.05	32	-	40	23.67	-	-
34 Epibenthic carniv.	-	2.3	12.78	0.6	7.93	36.83	-	15.13	6.35	8.33	11.59	8.01	-	-	7	18.07	-	-
35 Cephalopods	2	4.8	0.54	2.31	-	2.91	3.04	0.67	1.35	0.0019	7.39	0.09	-	-	-	1	-	-
36 L zoo	70	36.75	19.96	22.17	-	0.22	4.57	14.07	2.22	9.41	19.78	44.95	16	10	-	24.38	6	-
37 S zoo	7	11.15	3.82	0.03	-	-	-	1.29	0.75	14.44	1.51	39.77	-	10	3	-	31.6	-
38 Phyto	-	-	-	-	-	-	-	2.65	-	0.86	-	-	-	20	-	-	41.2	100
39 Marine plants	-	-	4.74	-	-	-	-	1.03	-	0.79	-	-	-	10	20	-	-	-
40 Detritus	-	0.58	2.74	29.86	-	1.84	-	-	0.87	0.09	-	-	50	50	20	-	21.2	-
41 Import	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-

Table 2.4 Diet matrix (%) of the balanced **1963** model fitted with Ecosim. Predators are listed in columns and prey in rows.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
1 Transient orca	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-
2 Toothed whales	-	-	-	-	-	-	-	-	-	-	0.71	-	-	-	-	-	-	-	-
3 Baleen whales	6	-	-	-	-	-	-	-	-	-	2.27	-	-	-	-	-	-	-	-
4 Sea lions embryo	-							-	-	-	-	-	-	-	-	-	-	-	-
5 Sea lions pup	0.4	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-
6 Sea lions juv	2.5	-	-	-	-	-	-	-	-	-	0.1	-	-	-	-	-	-	-	-
7 Sea lions adults	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8 Small mammals	75.1	-	-	-	-	-	-	-	-	-	8.45	-	-	-	-	-	-	-	-
9 Sea otters	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10 Birds	1	-	-	-	-	0.1	0.15	-	-	0.05	0.36	-	-	-	-	-	-	-	-
11 Shark mammal eater	-	-	-	-	-	-	-	-	-	-	-	0.03	-	-	-	-	-	-	-
12 Shark and skate	-	6.42	-	-	-	0.3	0.5	-	-	-	15.51	1.5	-	-	-	-	-	-	-
13 Salmon	-	3.91	0.09	-	-	22.44	20.21	10	-	-	3.04	5.81	0.0053	1.67	-	-	-	-	-
14 Pel L	-	0.44	-	-	-	0.1	0.1	0.1	-	-	2.64	0.8	-	0.3	-	-	-	-	-
15 Pel S	-	1.75	2.19	-	-	0.52	5	15	-	27.23	2.03	6.3	0.18	8	0.91	-	-	2.22	7.97
16 Sandlance	-	-	2.39	-	-	15.16	15	22	-	27.24	-	1.01	0.13	4.75	1.42	-	-	0.49	1
17 Herring	-	0.3	4	-	-	16	15	2.5	-	0.04	0.85	4.83	0.3	9.33	-	-	-		0.06
18 Pollock juv	-	-	0.03	-	-	0.1	0.5	0.1	-	0.05	0.1	0.02	-	0.3	-	-	-	0.07	0.1
19 Pollock adult	-	-	0.08	-	-	3	4	1.5	-	0.31	2.09	1	-	0.97	-	-	-	-	1.14
20 POP	-	3.28	0.03	-	-	2	2	2	-	0.03	0.22	0.03	-	-	-	-	-	-	-
21 Rockfish slope	-	6.55	0.05	-	-	3	5	0.57	-	0.09	0.93	0.69	-	-	-	-	-	-	0.06
22 Rockfish shelf	-	6	0.05	-	-	0.6	3	1	-	0.31	0.93	0.51	-	-	-	-	-	-	-
23 Sablefish		0.6	-	-	-	0.15	0.2	0.73	-	-	0.7	4.11	-	-	-	-	-	-	-
24 Pacific cod	-	0.6	0.09	-	-	5	4.13	5	-	0.31	0.76	0.75	-	-	-	-	-	-	0.05
25 Halibut	-	0.6	-	-	-	0.4	0.13	0	-	-	1.55	1.04	-	-	-	-	-	-	-
26 Arrowtooth	-	-	-	-	-	8	6.37	1	-	-	15.99	0.39	-	-	-	-	-	-	0.06
27 Dem L	-	1.72	-	-	-	2.03	1.59	0.4	-	-	4.93	0.46	-	-	-	-	-	-	-
28 Flatfish	-	-	-	-	-	1.5	2.21	13.5	-	0.09	2.17	1.58	0.02	0.76	-	-	-	1.73	0.68
29 Dem S	-	0.3	1.47	-	-	13.25	8.5	11.51	-	0.24	1.52	4.24	0.18	-	0.19	-	-	2.71	1.59
30 Deep L	-	17.18	0.04	-	-	1.1	0.04	0.27	-	-	2.64	2.41	-	-	-	-	-	0.49	0.05
31 Deep S	-	-	0.0013	-	-	3.53	0.84	4.66	-	0.08	1.62	2.46	-	1.94	-	-	-	1.73	0.18
32 Shrimps		-	0.09	-	-	-	-	0.09	-	-	0.2	7.1	-	3.07	9.28	-	-	10.27	33.08
33 Benthic inverts	-	-	6.17	-	-	0.25	0.63	-	90	-	0.6	16.34	-	13.42	26.29	6.3	1.01	13.25	12.68
34 Epibenthic carniv.	-	-	0.09	-	-	-	-	-	10	-	0.41	3.73	0.03	-	1.99	-	-	-	-
35 Cephalopods	-	50.35	0.0062	-	-	1.47	4.9	8.07	-	11.68	22.42	8.06	0.2	9.9	1.63	-	-	-	-
36 L zoo	-	-	72.42	-	-	-	-	-	-	28.3	-	3.98	5.37	34.92	45.23	21	81.72	56.99	36.52
37 S zoo	-	-	10.71	-	-	-	-	-	-	3.88	-	-	0.3	10.68	12.35	72.7	17.27	10.05	4.78
38 Phyto	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39 Marine plants	-	-	-	-	-	-	-	-	-	-	-	0.35	-	-	-	-	-	-	-
40 Detritus	-	-	-	-	-	-	-	-	-	0.07	4.15	0.47	-	-	-	-	-	-	-
41 Import	2	-	-	100	100	-	-	-	-	-	-	20	93.28	-	0.71	-	-	-	-
Sum	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

*** <0.001**

Table 2.4 (continued) Diet matrix (%) of the balanced **1963** model fitted with Ecosim. Predators are listed in columns and prey in rows.

	20	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
1 Transient orca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2 Toothed whales	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3 Baleen whales	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4 Sea lions embryo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5 Sea lions pup	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6 Sea lions juv	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7 Sea lions adults	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8 Small mammals	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9 Sea otters	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10 Birds	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11 Shark mammal eater	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12 Shark and skate	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13 Salmon	-	-	2	-	-	1.79	-	6.85	-	-	1.74	-	-	-	-	-	-	-
14 Pel L	-	-	-	-	-		-	0.1	-	-	0.5	-	-	-	-	-	-	-
15 Pel S	-	1.9	3.91	3.76	17.22	5.01	12.63	5.39	1.62	0.17	0.04	0.07	-	-	-	3	-	-
16 Sandlance	-	9.66	10.78	1.22	23	7.51	13	4.46	0.41	0.47	-	-	-	-	-	0.8	-	-
17 Herring	-	1.37	3	1	2	2	3	3	0.5	0.32	-	-	-	-	-	0.5	-	-
18 Pollock juv	-	0.05	0.1	0.1	-	-	0.02	-	-	0.0045	-	-	-	-	-	0.03	-	-
19 Pollock adult	-	0.32	-	-	-	0.3	0.1	2	0.1	-	-	-	-	-	-	-	-	-
20 POP	-	-	-	-	3	4	10	2	-	-	0.29	-	-	-	-	-	-	-
21 Rockfish slope	-	-	-	-	1.66	2	1.1	-	-	0.04	0.59	-	-	-	-	-	-	-
22 Rockfish shelf	-	-	2.57	-	0.08	0.8	0.2	1	-	0.01	0.52	-	-	-	-	-	-	-
23 Sablefish	-	1.01	-	-	-	0.3	-	0.52	-	-	0.29	-	-	-	-	-	-	-
24 Pacific cod	-	-	-	-	0.4	2.4	-	2.5	0.2	-	-	-	-	-	-	-	-	-
25 Halibut	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
26 Arrowtooth	2	-	-	1.88	0.9	2.5	-	0.6	0.42	-	0.07	-	-	-	-	-	-	-
27 Dem L	-	0.24	0.73		3.31	1.2	0.63	0.23	0.04	-	0.8	-	-	-	-	-	-	-
28 Flatfish	-	0.03	2.56	3.76	17	9.8	2.5	7.65	1.64	0.39	1.8	-	-	-	-	-	-	-
29 Dem S	-	2.71	10.6	8.1	16.3	12.37	27.2	10.15	6.94	0.77	2.63	-	-	-	-	8.49	-	-
30 Deep L	-	0.24	-	-	-	-	1	0.24	0.18	-	0.93	-	-	-	-	-	-	-
31 Deep S	1	1.43	0.07	5.7	-	-	14.92	1.53	2.93	0.12	12.64	0.07	-	-	-	15.33	-	-
32 Shrimps	7	21.89	7.17	5.08	3.9	1.22	6.09	4.02	9.76	12.17	8.65	-	2	-	10	4.74	-	-
33 Benthic inverts	11	3.57	11.93	14.43	3.3	5	-	12.91	63.72	51.62	28.23	7.05	32	-	40	23.65	-	-
34 Epibenthic carniv.	-	2.3	12.78	0.6	7.93	36.83	-	15.13	6.35	8.33	11.59	8.01	-	-	7	18.07	-	-
35 Cephalopods	2	4.8	0.54	2.31	-	2.91	3.04	0.67	1.35	0.0019	7.39	0.09	-	-	-	1	-	-
36 L zoo	70	36.75	19.96	22.17	-	0.22	4.57	14.07	2.22	9.41	19.78	44.95	16	10	-	24.38	6	-
37 S zoo	7	11.15	3.82	0.03	-	-	-	1.29	0.75	14.44	1.51	39.77	-	10	3	-	31.6	-
38 Phyto	-	-	-	-	-	-	-	2.65	-	0.86	-	-	-	20	-	-	41.2	100
39 Marine plants	-	-	4.74	-	-	-	-	1.03	-	0.79	-	-	-	10	20	-		-
40 Detritus	-	0.58	2.74	29.86	-	1.84	-	-	0.87	0.09	-	-	50	50	20	-	21.2	-
41 Import	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sum	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

APPENDIX 3. POPULATION ASSESSMENT MODEL FOR STELLER SEA LIONS

I built an age-structured model to reconstruct the structure and abundance of the total population. The primary goal was to estimate the number and biomass by stage (pup, juvenile, adult) and derive a time series estimate. The model starts in 1955, 2 years before the first counts. Based on rookery counts and modelling, Trites and Larkin (1996) estimated the population at 5,800 sea lions in 1955. The initial population structure was assumed to be that of a stable population and includes 21.54% juveniles with equal ratio of males and females, 53.42% of females and 25.04% of males on the rookeries (Trites and Larkin 1996). These animals were allocated to each age group following the time table survival given in Trites and Larkin (1996), adjusted so that the population would maintain itself over 30 years. The time table was based on animals collected in the Gulf of Alaska during 1975-1978 and frequently used in sea lions modelling (York 1994; Trites and Larkin 1996) and modified to obtain a stable population (Table 3.1).

Table 3.1 Survival for male and female, and net birthrate at age for sea lions.

Age	S male	S fem	Birth rate
0	0.53	0.67	0
1	0.66	0.82	0
2	0.79	0.91	0
3	0.87	0.94	0.202
4	0.88	0.92	0.359
5	0.86	0.91	0.523
6	0.84	0.89	0.63
7	0.82	0.88	0.63
8	0.81	0.88	0.63
9	0.79	0.87	0.63
10	0.78	0.86	0.63
11	0.76	0.86	0.63
12	0.75	0.85	0.63
13	0.74	0.85	0.63
14	0.72	0.84	0.63
15	0.71	0.84	0.63
16	0.70	0.83	0.63
17	0.69	0.83	0.63
18	0.67	0.82	0.63
19	0.66	0.82	0.63
20	0.65	0.82	0.63
21	0.64	0.81	0.63
22	0.63	0.81	0.63
23	0.62	0.81	0.63
24	0.61	0.80	0.63
25	0.60	0.80	0.63
26	0.59	0.80	0.63
27	0.58	0.79	0.63
28	0.57	0.79	0.63
29	0.56	0.79	0.63
30	0.55	0.79	0.63

The number of age 0 sea lions at time t ($N_{0,t}$) was calculated as:

$$N_{0,t}=\sum_{a=1}^{A} N_{a-1,t-1,f}\cdot S_{a-1,f}\cdot m_t\cdot B_a$$

where $S_{a-1,f}$ is the female survival and B_a the birth rate fecundity at age a, and m_t is the survival modifier for year t. The number of females pregnant each year was established at about 87% of females over age of 8 based on a 1978 sampling in GOA however, taking into account the spontaneous abortions, the net birth rate was established at 67% of females (Pitcher and Calkins 1981). This information was adapted by York (1994) to provide net birth rate (see Table 3.1). We assumed an equal proportion of males and females at birth.

The number of individuals of ages 1-30 are:

$$N_{a,t}=N_{a-1,t-1}\cdot S_{a-1,g}\cdot m$$

where $S_{a-1,g}$ is the survival at age, for each sex (f or m) calculated separately. The non-pup counts on rookeries only account for the part of the population that reproduce or only accompany adults in any given years. In the model, the number of non-pups on rookeries is obtained by:

$$N_{rook}=p\cdot\sum_{a=1}^{A} N_{a-1,t-1,f}\cdot B_a+\sum_{a=1}^{A} N_{a-1,t-1,m}\cdot pres$$

where *p* accounts for the proportion of non-breeding females that are present on the rookeries; and *pres* is the schedule of presence of males on the rookeries. The parameter p has been set at 1.05, meaning that non-breeding females represent about 5% of the breeding female population. The presence schedule (pres) has been obtained from observations in the Gulf of Alaska, where males reach sexually maturity between 5-7 years of ages (Pitcher and Calkins 1981). However, territorial bulls are mostly from 9-13 years old (Thorsteinson and Lensink 1962 in Pitcher and Calkins 1981). Trites and Larkin (1996) assumed that males are reproducing starting at about 8 yrs old.

We used a logistic curve of the form: age^b (age_h^b+age^b) where age at 50% maturity (age_h) had been set at 11, and b at 7 (Figure 3.1). The number of mature males is not a critical factor in the model, but assumptions about the proportion of males present around rookeries and susceptible to be counted is more important since it is compared to the non-pup counts. The presence schedule would allow for more of the younger males to be present around the rookeries although they are not yet successful at holding a territory (Figure 3.1). The shape of the curve and the proportion of non-breeding males assumed to be present around the rookeries influences the initial abundance of the total population estimate and its trajectory for 1955-1960, while the estimates for subsequent years changed only slightly (Figure 3.1).

Comparison of several combinations of age_h and b show that as the proportion of juvenile male present on the rookeries decreases, the initial population estimate increases. Attempts to let the Solver routine of Excel estimate the parameters of the curve led to an underestimate of the predicted number of non-pups on rookeries (scenario 3). The retained combination (scenario 2) was the middle trajectory which also yielded the average likelihood and best visual fit to the non-pup count (Figure 3.2). The retained parameters, age_h= 10, b=5, produce a trajectory similar to scenario 3 except that the fit to the 1990 data point is better. These simulations were carried out using 4 year-blocks for survival (see next paragraph).

The model was fitted by minimizing the difference between the model $(\hat{N})$ and the counts (N) for both non-pups on rookeries and pup numbers. Likelihood (LL) is calculated using twice the weight on pup counts because of the larger certainty associated with the pup counts. The Solver routine was used to estimate both the initial population size and the survival multiplier array.

$$\overline{N}_{pup} = \sum \ln(N_{pup} / \hat{N}_{pup})$$

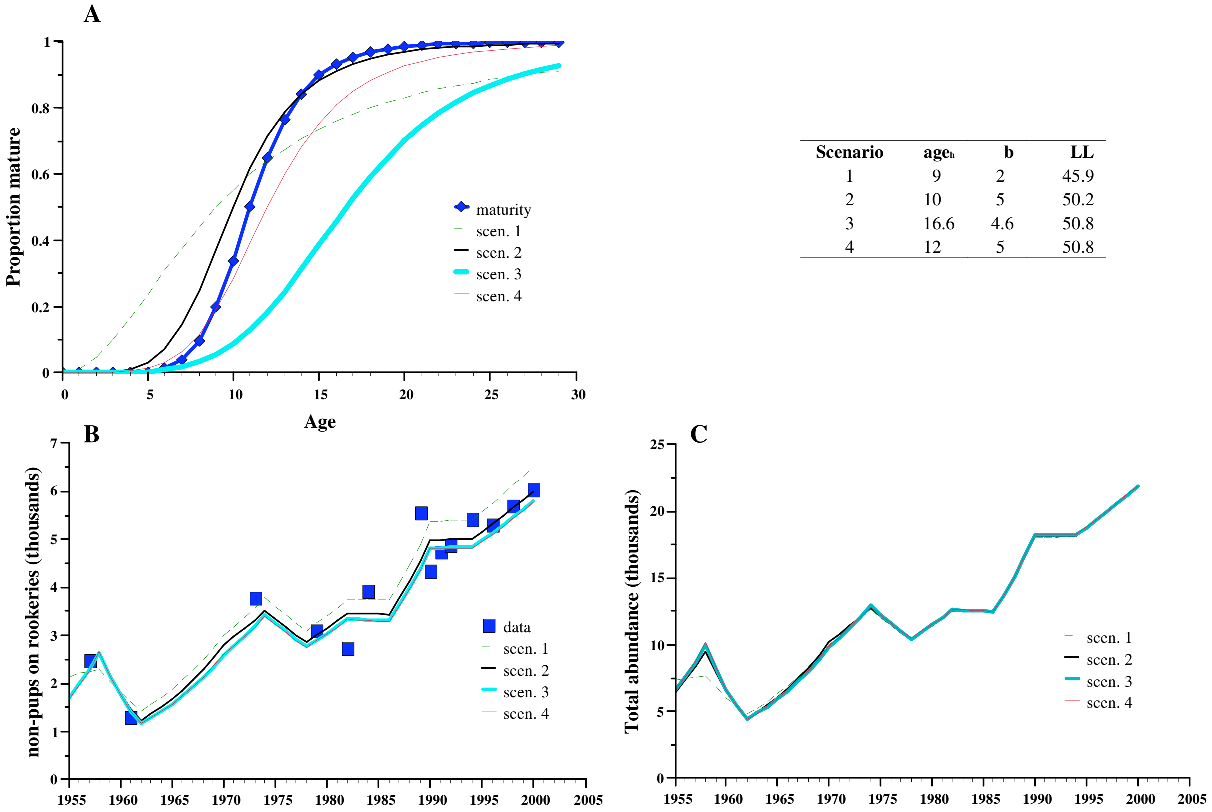
$$\overline{N}_{rook} = \sum \ln(N_{rook} / \hat{N}_{nonpup})$$

$$LL = 2 \cdot (n-1) \cdot 0.5 \cdot \ln\left(\sum (\ln(N_{pup} / \hat{N}_{pup}) - \overline{N}_{pup})^2\right) + (n-1) \cdot 0.5 \cdot \ln\left(\sum (\ln(N_{rook} / \hat{N}_{rook}) - \overline{N}_{rook})^2\right)$$

A first version of the model let the multipliers to be estimated by Solver each year, which left too many parameters to be estimated and prevented Solver from reaching a single solution. To avoid the estimation of an excessive number of parameters, the survival multiplier was estimated by block of years. At first, the block size was increased incrementally from 3 to 8 years. The likelihood value was the highest for a 3 year block (Table 3.2) because short blocks allow the model to chase all points regardless of their credibility. In contrast, the 7-year block scenario (not shown) behaves strangely due to the location of the boundaries and the lack of data points in the 1962-1972 period. In order to determine the location of the most probable boundary for changes in m values, the blocks were made smaller around these boundaries. Modifications were retained when they improved the likelihood value. Changes to the 3 year and 4 year blocks scenarios did not increase the likelihood value but tended to smooth the trajectory and dampen the importance of peaks of abundance that could be considered as spurious (e.g. the 1991 sudden peak of non-pup counts). In order to adopt the most conservative series I preferred the solution using 4-year blocks of m. It is interesting to note that our population estimates are similar to those of the model proposed by Trites and Larkin (1996) in the 1990s and even in the 1970s, but are quite different in the 1960s. Our estimate for 1963 amounts to 4,960 sea lions that is 61% of the abundance (8,030 sea lions) obtained by Trites and Larkin (1996).

Table 3.2. Likelihood calculated for each block size

Block length (years)	3	4	5	6
LL	64.9	54.2	47.1	44.6



Scenario	age$_h$	b	LL
1	9	2	45.9
2	10	5	50.2
3	16.6	4.6	50.8
4	12	5	50.8

Figure 3.1. Comparison of scenarios concerning the presence of male on the rookeries; A. presence schedule according to various scenarios; B. trajectories of non-pups abundance predicted to be present on rookeries compared to the count data; C. trajectories of total abundance corresponding to scenarios. The inset table shows the parameters and likelihood value corresponding to each scenario.

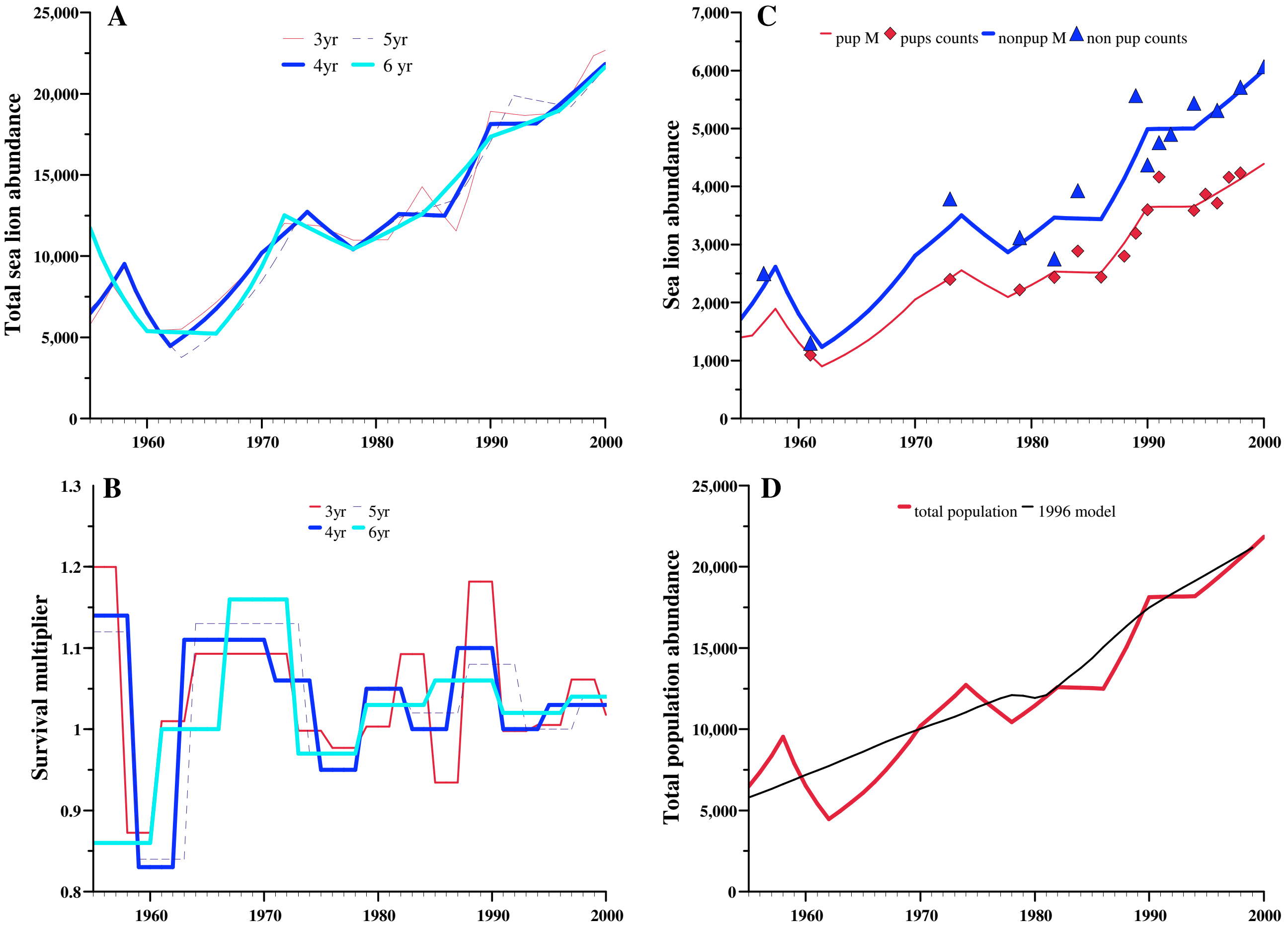


Figure 3.2. Comparison of simulations using 3 to 6 year block for the multiplier for survival A. Total population; B. Trajectory of survival multiplier for each block size; C. Predicted numbers of pups (pup M), non-pup (non-pup M) present on rookeries compared to counts; D. Total abundance of sea lions predicted by the present model compared to the model developed by Trites and Larkin [1996 #21].

APPENDIX 4 CATCHES AND BIOMASS TIME SERIES

Table 4.1 Catches (t) by fish functional groups for 1961-2002 and sources.

	15	17	19	20	21 slope rockfish					22	24		26	28
	eulachon [p]	herring [t]	pollock	POP	shortraker /rougheye	others [i]	thornyhead [i]	pelagics [g]	all spp [k]	shelf [g]	Pcod		arrow-tooth	flatfish
											650	659 [b]		
1961		38,906											108[r]	54[t]
1962		24,709		6[k]									53[r]	26[t]
1963		16,959		0[k]					5		14[k]		12[r]	24[t]
1964		15,703	1[k]	64[k]					14		2[k]		107[r]	72[t]
1965		23,553	0[k]	100[k]					18		5[k]		15[r]	25[t]
1966		12,390	23[k]	793[k]					110		3[k]		22[r]	11[t]
1967		5,670	879[k]	12,056[k]					1,768		40[k]		690[r]	345[t]
1968		3,214	1,677[k]	19,894[k]					3,430		191[k]		795[r]	398[t]
1969	7	1,852	1,366[k]	19,462[k]					3,535		65[c]		700[r]	350[t]
1970	0	2,644	396[k]	17,286[k]					2,815		50[c]		1,457[r]	728[t]
1971	0	5,015	384[k]	16,110[k]					2,844		8[c]		286[r]	143[t]
1972	2	3,867	872[k]	19,034[k]					3,852		75[c]		2,383[r]	1,192[t]
1973	9	6,307	526[k]	14,073[k]					7,189		164[c]		4,700[r]	2,804[t]
1974	5	7,837	1,447[k]	12,456[k]					4,497		205[c]		169[r]	85[t]
1975	13	7,985	468[k]	9,052[k]					7,427		155[d]		228[r]	114[t]
1976	16	7,942	254[k]	10,556[k]					6,753		210[e]		386[r]	193[t]
1977	2	8,640	2,851[d]	6,656[k]	533[h]				1,915		169[n]		4,431[r]	3,052[t]
1978	2	6,071	1,884[d]	1,630[d]	293[d]				508		257[n]		3,059[r]	1,530[t]
1979	2	6,532	2,258[d]	4,328[q]	802[d]				1,906		822[n]		2,871[r]	2,272[t]
1980	2	9,217	1,912[d]	3,976[q]	2,080[d]				3,442		748[n]		2,095[r]	1,175[t]
1981	2	8,393	3,669[d]	3,311[q]	1,214[d]				2,471		870[n]		2,417[r]	1,478[t]
1982	2	8,723	35[k]	15[i]	56[d]				254	120	729[n]		148[r]	195[t]
1983	8	9,903	14[k]	16[i]	28[d]				411	176	691[n]		245[r]	234[t]
1984	17	9,081	0[k]	3[i]					836	563	33[e]		121[r]	268[t]
1985	2	11,104	0[k]	156[i]	20[i]	6	12	9	1,145	652	0[a]	64	126[r]	188[t]
1986	2	9,792	27[k]	1,645[i]	25[i]	4	16	2	1,954	888	0[a]	153	193[s]	230[t]
1987	0	8,369	114[k]	1,801[i]	34[i]	4	24	4	3,119	1,198	0[a]	354	247[s]	454[t]
1988	0	16,152	2[k]	4,069[i]	59[i]	88	102	2	3,166	900	0[a]	237	223[s]	501[t]
1989	2	16,156	12[k]	5,474[i]	94[i]	60	100	3	4,399	644	0[a]	172	100[s]	285[t]
1990	16	8,056	9[k]	5,121[i]	81[i]	61	94	5	3,590	516	0[a]	141	201[s]	167[t]
1991	10	5,882	24[m]	1,060[i]	270[i]	419	112	15	81,693	889	175[a]	267	202[m]	274[t]
1992	2	9,415	20[m]	219[i]	343[i]	285	189	24	84,102	755	141[a]	402	495[m]	1,420[t]
1993	15	12,096	7[m]	67[i]	182[i]	2,078	276	30	256,699	901	155[a]	436	383[m]	70[u]
1994	15	6,948	3[m]	11[i]	302[i]	257	221	35	81,402	803	60[a]	182	336[m]	387[u]
1995	9	4,478	47[m]	76[i]	355[i]				65,595	382	50[a]	154	401[m]	442[u]
1996	5	9,425	0[m]	107[i]	260[i]				57,123	503	63[a]	290	196[m]	545[u]
1997	7	14,742	96[m]	141[i]	317[i]				69,696	508	65[a]	353	809[m]	1,293[u]
1998	0	10,590	8[m]	0[i]	461[i]				85,619	457	116[a]	294	188[m]	229[u]
1999	5	12,903	11[m]	0[i]	295[i]				75,313	451	137[a]	367	245[m]	505[u]
2000	1	6,451	6[m]	2[i]	448[i]				77,107	376	87[a]	269	275[m]	214[u]
2001		14,706	0[m]	1[i]	630[i]					392	25[a]	158	208[m]	120[u]
2002		13,658	2[m]	1[i]	259[i]					372	23[a]	35	123[m]	10[u]

a. Grant Thompson, NMFS *pers. comm.*; b. Coonradt (2002); c max value of Forrester et al. or NMFS catch dabase; d. NMFS observer data base (from Berger, NOAA, Seattle); e. Zenger and Blackburn (1987); f. Hebert and Pritchett ; g. max of O'Connell et al. (2002a) or state data base provided by Dave Carlile (ADFG, Juneau); h. Heifetz et al. (2002)*(1-0.86) assuming that catches that were not POP (86%) were shortraker and rougheye; i. max of NMFS and state data base; k. Forrester et al. (1983); L. state data base (Dave Carlile, ADFG, Juneau, *pers. comm.*); m. NMFS data catches 1991-2002.xls; n. max value of Forrester et al. (1983) or observer dabase; p. Walker (2003), confidential data extrapolated see appendix 6; q. observer data (from Berger, NOAA, Seattle) assuming 86% of the catch being POP; r. Forrester (1983) assuming arrowtooth constitutes 2/3 of the flatfish catch; s. note r plus catches from US boats; t. max of federal waters estimates (Forrester et al. 1983; Turnock et al. 2002a), plus state fishery (state database: http://www.cf.adfg.state.ak.us/region1/FINFISH/GRNDFISH/flatfish/flatinfo.htm, and Coonradt (ADFG., pers comm) u, federal waters estimates (Turnock et al. 2002a) plus state fishery (state database)

Figure 4.1 continued

	11	12	13 Salmon[b]						25	
	Shark mm[a]	**Skate shark**[a]	**Chinook**	**Sockeye**	**Coho**	**Chum**	**Pink**	**Total**	**Halibut**	**Lingcod**
1963	1	0.5	1746	1953	4185	6533	35084	49501	6192[c]	2[e]
1964	0.1	0.5	2412	2661	5215	8554	34051	52893	4495[c]	3[e]
1965	0.1	0.5	1940	3126	5085	6512	19938	36600	7298[c]	2[e]
1966	4.6	21.7	2081	3036	4030	14461	37453	61062	7280[c]	1[e]
1967	4.4	21.1	2033	2798	2845	7998	5701	21376	5689[c]	2[e]
1968	4.4	20.7	2240	2393	5068	11682	45969	67352	3695[c]	3[e]
1969	3.0	14.2	2112	2338	1955	2477	8929	17810	5639[c]	21[f]
1970	1237	586.5	2065	1927	2630	9295	18689	34605	5664[c]	31[f]
1971	4.3	20.4	2052	1797	3238	7298	15616	30001	3996[c]	34[f]
1972	7.6	35.8	1538	2584	4811	12175	17370	38479	3495[c]	47[f]
1973	13.1	62.3	2155	3175	2790	8038	10606	26763	3614[c]	46[f]
1974	11.2	53.1	2154	2108	4263	7718	8737	24981	3610[d]	34[f]
1975	14.8	70.4	1804	687	1398	2920	7038	13846	4045[d]	34[f]
1976	4.2	19.8	1406	1781	2879	4993	10573	21632	3646[d]	40[f]
1977	7.1	33.8	1891	3426	3682	3402	30842	43242	2219[d]	32[f]
1978	2.2	10.3	2786	2364	5207	3674	30738	44769	2794[d]	30[f]
1979	3.8	18.1	2490	3102	4015	3832	19616	33054	3229[d]	47[f]
1980	2.5	11.9	2335	3197	3635	7450	25519	42137	2413[d]	25[f]
1981	0.3	1.3	1927	3108	4629	3722	36442	49827	2860[d]	25[f]
1982	0.1	0.5	1995	4479	6508	5907	37675	56565	2534[d]	34[f]
1983	0.1	0.6	2099	4324	6130	4818	53135	70506	4324[d]	46[f]
1984	0.0	0.0	2014	3050	7200	17388	40402	70053	4039[d]	106[f]
1985	0.1	0.5	1847	5219	9242	13400	74941	104648	6234[d]	91[f]
1986	0.2	1.1	2039	4196	11720	13438	69532	100924	7238[d]	170[f]
1987	0.9	4.4	2242	4174	4914	10926	17207	39463	7274[d]	253[f]
1988	0.0	0.2	1973	4014	3997	14450	16572	41006	7770[d]	314[f]
1989	0.2	0.9	2447	6207	6908	8565	92509	116636	6942[d]	305[f]
1990	0	264	2627	5727	8734	9919	47300	74308	7244[d]	355[f]
1991	0	390	2687	5389	10031	11864	78267	108238	7226[d]	480[f]
1992	0	301	1762	7085	12853	18977	52646	93323	7667[d]	469[f]
1993	0	600	2325	8423	10237	27394	78300	126679	8308[d]	464[f]
1994	0	703	1696	6359	18014	38163	79407	143640	7927[d]	403[f]
1995	6	174	1594	4713	11589	41303	69278	128477	5926[d]	418[f]
1996	13	244	1707	8125	10309	67290	87951	175382	6821[d]	379[f]
1997	6	504	2342	6997	6537	48099	50564	114538	7480[d]	290[f]
1998	13	430	1751	3746	9934	61961	66544	143935	7849[d]	285[f]
1999	10	446	1277	3104	9747	63737	103441	181307	7528[d]	305[f]
2000	13	747	1693	3348	6276	86186	24589	122092	6754[d]	234[f]
2001	13	548	1847	5711	9990	269853	12951	300351	6385[d]	208[f]
2002	0	360	2826	2244	10767	31375	68299	115510		

a based on observer data and Gaichas see Table 13 in text; values for 1963-1964 were assumed to be equal to 1965;

b. from Martina Kallenberger, ADFG, Juneau;

c. http://www.iphc.washington.edu/halcom/research/sa/legacy.data/landings.data/hist.comcat.txt

d. total removal (Clark and Hare 2002); e. (Forrester et al. 1983); f. maximum of data provided in (Gordon 1994) and by V. O'Connell ADFG, *pers. comm.*; g. F for 1964-1976 based on C/B and assuming a linear decrease in biomass from 1963to 1977

Table 4.2 Time series for fish used in Ecosim. Biomass and annual catches are in t·km^{-2} and fishing mortality (F year^{-1}.)r

	13 Salmon			**17 Herring**			**19 Pollock**			**20 POP**			**21 Slope rockfish**		
	Forced biom.	**Catch** [a]	**F** [a]	**Biom.**	**Catch forced**	**F**	**Biom.**	**Catch forced**	**F** [a]	**Biom.**	**Catch**	**F**	**Biom.**	**Catch forced**	**F** [a]
1963	1.250	0.542	0.673	0.345	0.186	0.538	0.063	0.000	0.000	2.380	0.161	0.068		0.000	
1964	1.230	0.579	0.748	0.316	0.172	0.543		0.000	0.000	2.330	0.288	0.124		0.000	
1965	1.209	0.401	0.457	0.290	0.258	0.890		0.000	0.000	2.030	0.413	0.204		0.000	
1966	1.189	0.668	0.958	0.166	0.136	0.817		0.000	0.002	1.460	0.238	0.163		0.001	
1967	1.169	0.234	0.245	0.110	0.062	0.565		0.010	0.063	1.170	0.132	0.113		0.019	
1968	1.148	0.737	1.168	0.101	0.035	0.348		0.018	0.109	1.020	0.218	0.213		0.038	
1969	1.128	0.195	0.203	0.116	0.020	0.176		0.015	0.081	0.900	0.213	0.236		0.039	
1970	1.107	0.379	0.444	0.151	0.029	0.192		0.004	0.022	0.830	0.189	0.229		0.031	
1971	1.087	0.328	0.376	0.195	0.055	0.283		0.004	0.020	0.800	0.176	0.222		0.031	
1972	1.067	0.421	0.518	0.233	0.042	0.183		0.010	0.042	0.680	0.208	0.306		0.042	
1973	1.046	0.293	0.333	0.300	0.069	0.232		0.006	0.024	0.550	0.154	0.278		0.079	
1974	1.026	0.273	0.310	0.369	0.086	0.234		0.016	0.061	0.460	0.136	0.296		0.049	
1975	1.006	0.152	0.161	0.450	0.087	0.196		0.005	0.019	0.370	0.099	0.267		0.081	
1976	0.985	0.237	0.266	0.562	0.087	0.156		0.003	0.008	0.280	0.116	0.416		0.074	
1977	0.965	0.473	0.673	0.715	0.095	0.128	0.274	0.031	0.078	0.190	0.073	0.380		0.021	0.044
1978	1.178	0.490	0.563	0.912	0.066	0.148		0.021	0.044	0.160	0.018	0.115		0.006	0.044
1979	1.183	0.362	0.398	1.139	0.072	0.062		0.025	0.047	0.150	0.047	0.317		0.021	0.044
1980	1.301	0.461	0.452	1.907	0.101	0.047		0.021	0.035	0.140	0.044	0.302		0.038	0.044
1981	1.278	0.545	0.574	1.630	0.092	0.069		0.040	0.061	0.130	0.036	0.270		0.027	0.044
1982	1.491	0.619	0.563	1.836	0.095	0.081		0.000	0.001	0.130	0.000	0.001		0.003	0.019
1983	1.536	0.772	0.724	3.695	0.108	0.067		0.000	0.000	0.140	0.000	0.001		0.004	0.019
1984	1.937	0.767	0.517	3.767	0.099	0.060		0.000	0.000	0.150	0.000	0.000	0.471	0.009	0.019
1985	1.979	1.146	0.863	2.727	0.122	0.075		0.000	0.000	0.170	0.002	0.010		0.013	0.019
1986	2.160	1.105	0.738	2.178	0.107	0.146		0.000	0.000	0.190	0.018	0.094		0.021	0.019
1987	2.105	0.432	0.243	4.294	0.092	0.074		0.001	0.001	0.220	0.020	0.092	1.947	0.034	0.018
1988	2.260	0.449	0.231	3.980	0.177	0.047		0.000	0.000	0.250	0.045	0.181		0.035	0.018
1989	2.235	1.277	0.829	2.518	0.177	0.043		0.000	0.000	0.290	0.060	0.206		0.048	0.018
1990	2.337	0.813	0.443	1.694	0.088	0.080		0.000	0.000	0.330	0.056	0.168	1.325	0.039	0.030
1991	2.506	1.185	0.639	3.162	0.064	0.073		0.000	0.000	0.380	0.012	0.031		0.009	0.005
1992	2.770	1.022	0.455	3.079	0.103	0.057		0.000	0.000	0.430	0.002	0.006		0.009	0.005
1993	3.109	1.387	0.586	1.873	0.132	0.053		0.000	0.000	0.470	0.001	0.002	1.150	0.028	0.024
1994	3.413	1.572	0.657	1.294	0.076	0.169		0.000	0.000	0.510	0.000	0.000		0.009	0.005
1995	3.343	1.406	0.571	1.839	0.049	0.157		0.001	0.000	0.550	0.001	0.002		0.007	0.005
1996	3.879	1.920	0.685	4.081	0.103	0.051		0.000	0.000	0.570	0.001	0.002	2.194	0.006	0.003
1997	3.538	1.254	0.430	4.348	0.161	0.073		0.001	0.001	0.590	0.002	0.003		0.008	0.005
1998	3.948	1.576	0.517	3.676	0.116	0.050		0.000	0.000	0.590	0.000	0.000		0.009	0.005
1999	3.896	1.985	0.712	2.915	0.141	0.123	1.202	0.000	0.000	0.600	0.000	0.000	1.759	0.008	0.005
2000	3.896	1.337	0.730	2.815	0.071	0.091		0.000	0.000	0.600	0.000	0.000		0.008	0.005
2001	3.896	3.288		3.323	0.161	0.048		0.000	0.000	0.590	0.000	0.000	0.217		
2002	3.896	1.264		3.078	0.150	0.049		0.000	0.000	0.590	0.000	0.000			

a. not used, the catch was forced instead (see text)

Table 4.2 continued

	22 Shelf rockfish		**23 Sablefish**			**24 Pcod**				**25 Halibut**				**26 B arrowt**			**28 Flatfish**	
	Biom.	**Catch forced**	**Biom.**	**Catch**	**F**	**Biom.**	**Catch forced**	**Catch**	**F**	**Biom.**	**Catch forced**	**Catch**	**F**	**Biom.**	**Catch**	**F**	**Biom.**	**Catch forced**
1963			0.460	1071	0.030		0.000				0.087			0.477	0.000	0.000		0.000
1964			0.890	1629	0.020		0.000				0.063			0.481	0.001	0.002		0.001
1965			0.910	1242	0.010		0.000				0.103			0.482	0.000	0.002		0.000
1966			0.900	1432	0.020		0.000				0.102			0.483	0.000	0.007		0.000
1967			0.860	2597	0.030		0.000				0.080			0.479	0.008	0.007		0.004
1968			1.070	9479	0.100		0.002				0.052			0.476	0.009	0.005		0.004
1969			1.000	10076	0.110		0.001				0.079			0.477	0.008	0.004		0.004
1970			0.900	11666	0.140		0.001				0.080			0.482	0.016	0.006		0.008
1971			0.980	11853	0.130		0.000				0.056			0.490	0.003	0.003		0.002
1972			0.910	16080	0.190		0.001				0.049			0.513	0.026	0.012		0.013
1973			0.810	10793	0.150		0.002				0.051			0.552	0.051	0.026		0.031
1974			0.720	12599	0.190		0.002				0.051			0.616	0.002	0.011		0.001
1975			0.620	12225	0.220		0.002				0.057			0.720	0.003	0.005		0.001
1976			0.520	13199	0.280		0.002				0.051			0.805	0.004	0.005		0.002
1977			0.430	7214	0.190		0.002			0.264		0.031	0.100	0.902	0.049	0.015		0.033
1978			0.450	3254	0.080	0.286		0.003	0.010	0.302		0.039	0.120	0.980	0.033	0.012		0.017
1979			0.410	4968	0.130	0.310		0.009	0.029	0.347		0.045	0.110	1.047	0.031	0.001		0.025
1980			0.390	3441	0.100	0.379		0.008	0.022	0.403		0.034	0.070	1.115	0.023	0.010		0.013
1981			0.670	3438	0.060	0.396		0.010	0.024	0.485		0.040	0.070	1.203	0.026	0.009		0.016
1982		0.001	0.870	3465	0.040	0.418		0.008	0.019	0.558		0.036	0.060	1.298	0.002	0.005		0.002
1983		0.002	0.790	4199	0.060	0.437		0.008	0.017	0.640		0.061	0.090	1.368	0.003	0.007		0.003
1984		0.006	0.890	5161	0.060	0.440		0.000	0.001	0.705		0.057	0.080	1.436	0.001	0.003	0.448	0.003
1985		0.007	0.900	4126	0.050	0.441		0.001	0.002	0.731		0.088	0.120	1.531	0.001	0.001		0.002
1986		0.010	0.800	6975	0.100	0.440		0.002	0.004	0.747		0.102	0.130	1.647	0.002	0.001		0.003
1987		0.013	0.760	8316	0.120	0.458		0.004	0.008	0.759		0.102	0.130	1.782	0.003	0.004	0.321	0.005
1988		0.010	0.800	9682	0.130	0.459		0.003	0.006	0.767		0.109	0.140	1.871	0.002	0.004		0.005
1989		0.007	0.760	9083	0.130	0.455		0.002	0.004	0.755		0.098	0.130	1.958	0.001	0.002		0.003
1990		0.006	0.670	8371	0.140	0.461		0.002	0.003	0.751		0.102	0.130	2.048	0.002	0.005	0.220	0.002
1991		0.010	0.660	6656	0.110	0.443		0.005	0.011	0.739		0.101	0.130	2.108	0.002	0.007		0.003
1992		0.008	0.790	6500	0.090	0.441		0.006	0.013	0.719		0.108	0.140	2.173	0.005	0.010		0.016
1993		0.010	0.770	7308	0.100	0.428		0.006	0.015	0.697		0.117	0.160	2.277	0.004	0.010	0.370	0.001
1994	0.504	0.009	0.840	7973	0.100	0.420		0.003	0.006	0.682		0.111	0.160	2.356	0.004	0.014		0.004
1995	0.268	0.004	0.760	7276	0.100	0.408		0.002	0.005	0.672		0.083	0.120	2.388	0.004	0.011		0.005
1996	0.464	0.006	0.800	6807	0.090	0.383		0.004	0.010	0.705		0.096	0.130	2.425	0.002	0.013	0.720	0.006
1997	0.471	0.006	0.730	6113	0.090	0.361		0.005	0.013	0.694		0.105	0.150	2.455	0.009	0.009		0.014
1998	0.396	0.005	0.760	5679	0.080	0.346		0.004	0.013	0.677		0.110	0.160	2.505	0.002	0.007		0.003
1999	0.385	0.005	0.800	4810	0.070	0.321		0.006	0.017	0.636		0.106	0.160	2.553	0.003	0.009	0.978	0.006
2000	0.214	0.004	0.740	5726	0.080	0.284		0.004	0.014	0.595		0.095	0.150	2.574	0.003	0.013		0.002
2001	0.210	0.004	0.880	4229	0.050	0.258		0.002	0.008	0.547		0.090	0.160	2.576	0.002	0.011		0.001
2002	0.204	0.004	0.770	3903	0.060	0.248		0.000	0.001					2.584	0.001	0.010		0.000

Table 4.3 Mammals time series used for Ecosim simulations. Biomass and annual catches are in t·km^{-2} and fishing mortality (F year^{-1}).

	2		**3**			**5**	**7**			**8**		**9**		
	Toothed whales		**Baleen whales**			**SSL pup**	**Sea lions (SSL) adults**			**Small mammals**		**Sea otters**		
	Biom.	**Catch forced**	**Biom.**	**Catch**	**F**	**Biom.**	**Biom.**	**Catch**	**F**	**Biom.**	**Catch forced**	**Biom.**	**Catch**	**F**
1963	0.02	4.6e-04	0.04	0.03039	0.0628	0.0002	0.0080			0.325	3e-04			
1964		4.7e-04		0.0053	0.0982	0.0003	0.0088				2e-03			
1965		6.2e-04		0.0054	0.0875	0.0003	0.0098				6e-03	5e-06		
1966		7.2e-04		0.0017	0.1091	0.0003	0.0108				3e-03	1e-05		
1967		7.4e-04		0.0017	0.1327	0.0003	0.0120				1e-03	0		
1968		7.7e-04		0.0015	0.1377	0.0004	0.0133				1e-03	8e-05		
1969		6.9e-04		0.0012	0.1313	0.0004	0.0147				1e-03	1e-04		
1970		6.9e-04		0.001	0.1028	0.0005	0.0163				1e-03	1e-04		
1971		4.8e-04		0.001	0.0896	0.0005	0.0172				1e-03	1e-04		
1972		2.4e-04		0.001	0.0751	0.0005	0.0182				6e-05	2e-04		
1973		3.8e-04		4.90e-04	0.0641	0.0006	0.0192				6e-05	2e-04		
1974		3.6e-04		4.10e-04	0.0541	0.0006	0.0203				6e-05	2e-04		
1975		3.4e-04		2.10e-04	0.0235	0.0006	0.0193				6e-05	2e-04		
1976		3.2e-04		1.00e-04	0.006	0.0005	0.0184				6e-05	3e-04		
1977	0.01	2.0e-04	0.03	1.00e-04	0.005	0.0005	0.0175			0.246	6e-05	3e-04		
1978		1.4e-04		1.00e-04	0.006	0.0005	0.0167				6e-05	4e-04		
1979		1.1e-04		1.00e-04	0.005	0.0005	0.0175				6e-05	4e-04		
1980		3.8e-05		9.00e-05	0.005	0.0005	0.0183				6e-05	5e-04		
1981		3.5e-05		7.00e-05	0.003	0.0006	0.0192				6e-05	5e-04		
1982		2.6e-05		8.00e-05	0.004	0.0006	0.0201				6e-05	6e-04		
1983		1.3e-05		9.00e-05	0.004	0.0006	0.0201				6e-05	7e-04		
1984		1.2e-05		8.00e-05	0.004	0.0006	0.0200				6e-05	8e-04		
1985		1.2e-05		9.00e-05	0.004	0.0006	0.0200				1e-04	9e-04		
1986		1.2e-05		9.00e-05	0.004	0.0006	0.0200				1e-04	1e-03		
1987		1.1e-05		8.00e-05	0.003	0.0006	0.0219				5e-04	1e-03		
1988		0e+00		8.00e-05	0.003	0.0007	0.0240				5e-04	1e-03		
1989		0e+00		9.00e-05	0.004	0.0008	0.0264				5e-04	1e-03	4e-05	0.02
1990		0e+00		8.00e-05	0.003	0.0008	0.0290	6.4e-05	2.2e-03		6e-04	1e-03	2e-05	0
1991		0e+00		8.00e-05	0.003	0.0008	0.0290	0	0		6e-04	2e-03	3e-05	0.01
1992		0e+00			0	0.0008	0.0290	1.4e-05	5.0e-04		6e-04	2e-03	1e-04	0.05
1993		0e+00			0	0.0008	0.0290	2.3e-06	7.9e-05	0.492	6e-04	2e-03	2e-04	0.09
1994		0e+00		2.00e-05	0	0.0008	0.0290	1.1e-05	4.0e-04		5e-04	2e-03	7e-05	0.04
1995		0e+00		5.00e-05	0.002	0.0009	0.0299	0	0		7e-04	2e-03	5e-05	0.02
1996		0e+00		2.00e-05	7.00e-04	0.0009	0.0309	0	0		6e-04	2e-03	3e-05	0.01
1997		0e+00		4.00e-05	0.001	0.0009	0.0318	0	0		6e-04	2e-03	8e-05	0.04
1998		0e+00		6.00e-05	0.002	0.0010	0.0328	1.8e-05	6.0e-04		5e-04	2e-03	8e-05	0.04
1999	0.01	0e+00	0.143	6.00e-05	0.002	0.0010	0.0338	0	0	0.488	5e-04	2e-03	7e-05	0.03
2000		1.5e-07		6.00e-05	0.002	0.0010	0.0349	1.8e-05	5.0e-04		5e-04	2e-03	8e-05	0.04
2001		2.4e-07		6.00e-05	0.002			0			4e-04	2e-03	8e-05	0.04
2002		0e+00						0			3e-04	2e-03	8e-05	0.04
2003		0e+00									3e-04	2e-03	8e-05	0.04

APPENDIX 5. SOURCE OF FISH DIETS

Gr	Name		Region	Type [a]	%	Source
11	*Somniosus pacificus*	Pacific sleeper shark	Kodiak, AK	%W	0.3	Yang and Page (1999) Hulbert et al. (2003) [b]
11	*Carcharodon carcharias*	Great white shark		%FO	35.5	Cortés (1999)
11	*Hexanchus griseus*	Bluntnose sixgill shark		%FO	22.9	Cortés (1999), Ebert (1986)
12	*Bathyraja aleutica*	Aleutian skate	N Kuril Islands and SE Kamchatka	% FO	10.7	Orlov (1998)
12	*Bathyraja interrupta*	sandpaper skate	SEAK	%W	26.3	AJ Mine Project (1996)
12	*Raja binoculata*	big skate	Hecate strait	%W	9	Fargo and Pearsall(2004)
12	*Lamna ditropis*	Salmon shark	N Pacific, Bering S.	qualitative	0	Nagasawa (1998)
12	*Lamna ditropis*		PWS	%W	0	Hulbert (1999)
12	*Prionace glauca*	Blue shark	Monterey Bay, California	%W	8.1	Harvey (1989), LeBrasseur (1964)
12	*Squalus acanthias*	Spiny dogfish	BC	%Vol	16.5	Jones and Geen (1977)
12	*Bathyraja parmifera*	Alaska skate	SE Kamchatka	% FO	44	Orlov (1999)
13	*Oncorhynchus kisutch*	Coho	Hecate strait	qualitative		Healy 1986 in Beattie (2001), Harvey (1989), Beacham (1986), Sandercock (1991)
13	*Oncorhynchus tshawytscha*	Chinook	Hecate strait	qualitative		Healy 1986 in \Beattie (2001), Beacham (1986)
13	*Oncorhynchus nerka*	Sockeye	BC, Strait of Juan de Fuca	%Vol		Beacham (1986)
13	*Oncorhynchus gorbuscha*	Pink	BC, Strait of Juan de Fuca	%Vol		Beacham (1986)
13	*Oncorhynchus keta*	Chum		qualitative		Higgs (1991), Salo (1991)
14	*Brama japonica*	Pacific pomfret	E and W Pacific	semi quant [c]	38.4	Savinykh (1994) [c]
14	*Trachurus symmetricus*	Jack mackerel	California	%N	0	Carlisle (1971); Konchina et al. (1996)
14	*Trachurus symmetricus*	Jack mackerel	off Peru and Chile	qualitative	0	Konchina et al. (1996)
14	*Merluccius productus*	Pacific hake	W of Vancouver Island	% Vol	0	Tanasichuk et al. (1991)
14	*Trachipterus altivelis*	King-of-the -salmon	Oregon	% FO [d]	0	Shenker (1983) [d]
15	*Mallotus villosus*	Capelin	SE Bering S.	%W	0	Smith (1978)
15	*Osmerus mordax dentex*	Arctic rainbow smelt	Kamchatka		99.7	Tokranov and Maksimenkov (1995) [c]
15	*Hypomesus pretiosus*	Surf smelt	Pacific Canada	qualitative	0	FishBase
15	*Spirinchus starksi*	Night smelt	N Pacific	qualitative	0	FishBase
15	*Spirinchus thaleichthys*	Longfin smelt	N Pacific	semi quant	0	FishBase
15	*Scomber japonicus*	Pacific mackerel	Peruvian coast	%W	2.8	Konchina (1982)
15	*Thaleichthys pacificus*	Eulachon	PWS and Hecate Strait	semi quant [e]	0	Fargo and Pearsall(2004) Brown and Okey (1999)
16	*Ammodytes hexapterus*	Pacific sandlance	N Bering S	pres abs	0	Chikilev and Datskii (2000), Brown (1999) [c]
17	*Clupea harengus pallasi*	Pacific herring	W Bering Sea	semi quant	0	Brodeur (1988), (Niggol 1982)
18	*Theragra chalcogramma*	Pollock juvenile	SEAK	% Vol	3.7	Clausen (1983)
19	*Theragra chalcogramma*	Pollock adult	SEAK	% Vol	9.7	Clausen (1983)
20	*Sebastes aleutus*	Pacific Ocean perch	central GOA	%W	0	Yang and Nelson (2000)
21	*Sebastes polyspinis*	Northern rockfish	central GOA	%W	0	Yang and Nelson (2000)
21	*Sebastes borealis*	Rougheye rockfish	central GOA	%W	2.8	Yang and Nelson (2000)
21	*Sebastolobus alascanus*	Shortspine thornyhead	central GOA	%W	2.3	Yang and Nelson (2000)
21	*Sebastes borealis*	Shortraker rockfish	central GOA	%W	0	Yang and Nelson (2000)
21	*Sebastes goodei*	Chilipepper	California	% N	0	Reilly et al. (1992)
21	*Sebastes diploproa*	Splitnose rockfish	NE Pacific	%W	0.1	Brodeur and Pearcy (1984),
21	*Sebastes ciliatus*	Dusky rockfish	central GOA	%W	0	Yang and Nelson (2000)
21	*Sebastes flavidus*	Yellowtail rockfish	GOA	%W	11.6	Rosenthal et al. (1988)
21	*Sebastes entomelas*	Widow rockfish	GOA	%W	45.1	Rosenthal et al. (1988)
22	*Sebastes mystinus*	Blue rockfish	N California	%W	1.4	Hobson (1988)
22	*Sebastes melanops*	Black rockfish	GOA	%W	91.4	Rosenthal et al. (1988)
22	*Sebastes ruberrimus*	Yelloweye rockfish	GOA	%W	32.2	Rosenthal et al. (1988)
22	*Sebastes nigrocinctus*	Tiger rockfish	GOA	%W	7.2	Rosenthal et al. (1988)
22	*Sebastes nebulosus*	China rockfish	GOA	%W	2.8	Rosenthal et al. (1988)
22	*Sebastes pinniger*	Canary rockfish	N Pacific	pres/abs	0	FishBase
22	*Sebastes pinniger*	Canary rockfish	NE Pacific	%W	6	Brodeur (1984)
22	*Sebastes maliger*	Quillback rockfish	GOA	%W	10.2	Rosenthal et al. (1988)
22	*Sebastes caurinus*	Copper rockfish	GOA	%W	3.5	Rosenthal et al. (1988)
22	*Sebastes emphaeus*	Puget Sound rockfish	GOA	%W	0.6	Rosenthal et al. (1988)
23	*Anoplopoma fimbria*	Sablefish	GOA	%W	1.3	Yang (2000)
24	*Gadus macrocephalus*	Pacific cod	Hecate Strait	%W	16.5	Fargo and Pearsall(2004),Yang and Nelson (2000)
25	*Hippoglossoides stenolepis*	Halibut	Hecate Strait	%W	10.1	Fargo and Pearsall(2004), Yang (2000)
26	*Reinhardtius stomias*	Arrowtooth flounder	Hecate Strait	%W	52.5	Fargo and Pearsall(2004),Yang (1996)
27	*Anarrhichthys ocellatus*	Wolf-eel	California	%W	5.6	Hulberg and Graber (1980) [c]

Gr	Name		Region	Type [a]	%	Source
27	*Hydrolagus colliei*	Spottet ratfish		qualitative	20	FishBase
27	*Scorpaenichthys marmoratus*	Cabezon		qualitative	11.1	FishBase
27	*Lampetra tridentata*	Pacific lamprey		qualitative	0	FishBase
27	*Lampetra ayresi*	American river lamprey		qualitative	0	FishBase
27	*Zaprora silenus*	Prowfish	SE Kamchatka and N Kuril	% FO	0	Yang and Nelson (2000)
27	*Ophiodon elongatus*	Lingcod	Hecate Strait	%W	64	Beattie (2001), Fargo and Pearsall(2004)
27	*Eleginus gracilis*	Saffron cod	SE Chuchki Sea	%W	69	Craig and Haldorson (1981)
27	*Myoxocephalus jaok*	Plain sculpin	East Bering Sea	%W	18.9	Brodeur (1988)
27	*Myoxocephalus polyacanthocephalus*	Great sculpin	W Kamchatka	%W	5.8	Tokranov (1992a)
27	*Hemitripterus bolini*	Bigmouth sculpin	East Bering Sea	%W	9.5	Brodeur (1988)
27	*Trichodon trichodon*	Pacific sandfish	East Bering Sea	%W	51.5	Brodeur (1988)
27	*Lycodes brevipes*	Shortfin eelpout	GOA	%W	0.5	Smith et al. (1978)
27	*Myoxocephalus polyacanthocephalus*	Great sculpin	NE GOA	% N	0	Rosenthal (1979)
28	*Glyptocephalus zachirus*	Rex sole	GOA	%W	0.9	Smith et al. (Smith et al. 1978)
28	*Platichthys stellatus*	Starry flounder	Bering Sea	%W	0	Jewett and Feder (Jewett and Feder 1980)
28	*Lepidopsetta bilineata*	Rock sole	East Bering Sea	%W	5.21	Brodeur (1988)
28	*Limanda aspera*	Yellowfin sole	Bering Sea	%W	2.1	Tokranov (1990)
28	*Psettichthys melanostictus*	West American sole	Canada, GOA	pres/abs	12.5	FishBase
28	*Isopsetta isolepis*	Butter sole	Can, Kodiak	pres/abs	16.7	FishBase
28	*Pleuronectes quadrituberculatus*	Alaska plaice	Bering Sea	%W	0	Zhang (1988)
28	*Parophrys vetulus*	English sole	NE Pacific	pres/abs	0	FishBase
28	*Pleuronichthys coenosus*	C-O sole	S. California	pres/abs	0	FishBase
28	*Pleuronichthys decurrens*	Curlfin sole	NW Pacific	pres/abs	0	FishBase
28	*Hippoglossoides elassodon*	Flathead sole	central GOA	%W	0.5	Yang and Nelson (2000)
28	*Reinhardtius hippoglossoides*	Greenland halibut	Bering Sea	%W	5.02	Zhang (1988)
28	*Microstomus pacificus*	Dover sole	GOA	%W	0	Smith et al. (1978)
28	*Eopsetta jordani*	Petrale sole	Oregon and Hecate Srait	%FO	0	Kravitz et al. (1976), Fargo and Pearsall , 2004 #610], Smith et al. (1978)
28	*Lyopsetta exilis*	Slender sole	Oregon	%W	0	Pearcy and Hancock (1978)
29	*Microgadus proximus*	Pacific tomcod	NE GOA	% N	0.7	Rosenthal (1979)
29	*Hemilepidotus jordani*	Yellow Irish Lord	Kodiak	%W	27.7	Rogers et al. (1979)
29	*Anoplarchus purpurescens*	High cockscomb	California	%W	0	Yoshiyama and Darling (1982)
29	*Apodichthys flavidus*	Penoint gunnel	N Pacific	pres/abs	0	FishBase
29	*Artedius lateralis*	Smoothhead sculpin	USA	pres/abs	0	FishBase
29	*Artedius harringtoni*	Scalyhead sculpin	USA	pres/abs	0	FishBase
29	*Aulorhynchus flavidus*	Tube-snout poacher	Canada	pres/abs	0	FishBase
29	*Bathymaster signatus*	Searcher	SE Kamchatka	%W	14.7	Tokranov (1998)
29	*Bathymaster caeruleofasciatus*	Alaskan ronquil	NE GOA	% N	0	Rosenthal (1979)
29	*Careproctus rastrinus*	Salmon snailfish	SEAK	%W		AJ Mine Project(1996)
29	*Chirolophis nugator*	Mosshead warbonnet	California	pres/abs	0	FishBase
29	*Citharichthys sordidus*	Pacific sanddab	Oregon	%W	0	Pearcy and Hancock (1978)
29	*Citharichthys stigmaeus*	Speckled sanddab	S California	pres/abs	20	FishBase
29	*Clinocottus globiceps*	Mosshead sculpin	USA	pres/abs	0	FishBase
29	*Cryptacanthodes aleutensis*	Dwarf wrymouth	Canada	pres/abs	0	FishBase
29	*Dasycottus setiger*	Spinyhead sculpin	SE GOA	%W	7.6	Jewett and Feder (1989)
29	*Embiotoca lateralis*	Striped seaperch	S California	%W	0	Ebeling and Laur (1986)
29	*Enophrys diceraus*	Antlered sculpin	NE GOA	% N	0	Rosenthal (1979)
29	*Enophrys bison*	Buffalo sculpin	Canada	pres/abs	20	FishBase
29	*Gasterosteus aculeatus aculeatus*	Three-spined stickleback	Canada	pres/abs	10	FishBase
29	*Gymnocanthus pistilliger*	Threaded sculpin	Kamchatka	pres/abs	0	FishBase
29	*Gobiesox maeandricus*	Northern clingfish	N Pacific	pres/abs	0	FishBase
29	*Hemilepidotus hemilepidotus*	Red Irish Lord	East BS	%W	1.4	Brodeur (1988)
29	*Hemilepidotus spinosus*	Brown Irish Lord	Canada	abs/pres	0	FishBase
29	*Hexagrammos decagrammos*	Kelp greenling	NE GOA	% N	0.7	Rosenthal (1979)
29	*Hexagrammos lagocephalus*	Rock greenling	NE GOA	% N	0	Rosenthal (1979)
29	*Hexagrammos stelleri*	Whitespotted greenling	NE GOA	% N	0	Rosenthal (1979)

Gr	Name		Region	Type [a]	%	Source
29	*Icelinus borealis*	Northern sculpin	Canada	pres/abs	0	FishBase
29	*Icelinus filamentosus*	Threadfin sculpin	Canada	pres/abs	0	FishBase
29	*Icelus spiniger*	Thorny sculpin	Bering Sea	pres/abs	0	FishBase
29	*Jordania zonope*	Longfin sculpin	USA	pres/abs	0	FishBase
29	*Leptagonus frenatus*	Sawback poacher	W Kamchatka	%W	0	Tokranov (1992b),
29	*Leptocottus armatus*	Pacific staghorn sculpin	Grays harour, WA	%W	6	Armstrong et al. (1995)
29	*Liparis fucensis*	Slipskin snailfish	Pacific, Canada	pres/abs	0	FishBase
29	*Liparis pulchellus*	Showy snailfish	N Pacific	pres/abs	25	FishBase
29	*Liparis rutteri*	Ringtail snailfish	Pacific, Canada	pres/abs	0	FishBase
29	*Lumpenella longirostris*	Longsnout prickleback	SEAK	%W		AJ Mine Project (1996)
29	*Lumpenus sagitta*	Snake prickleback	Canada	pres/abs	0	FishBase
29	*Lycodes palearis*	Wattled eelpout	E Bering Sea	%W	0	Brodeur (1988)
29	*Oligocottus snyderi*	Fluffy sculpin	Canada	pres/abs	0	FishBase
29	*Pallasina barbata*	Tubenose poacher	W Kamchatka	%W	0	Tokranov (1992b)
29	*Pholis laeta*	Crescent gunnel	AK	pres/abs	0	FishBase
29	*Phytichthys chirus*	Ribbon prickleback	Pacific, Canada	pres/abs	0	FishBase
29	*Podothecus acipenserinus*	Sturgeon poacher	E Bering Sea	%W	0	Brodeur (1988)
29	*Psychrolutes paradoxus*	Tadpole sculpin	Pacific, Canada	pres/abs	0	FishBase
29	*Psychrolutes sigalutes*	Soft sculpin	Pacific, Canada	pres/abs	0	FishBase
29	*Pungitius pungitius pungitius*	Ninespine stickleback	Kamchatka	pres/abs	0	FishBase
29	*Rhamphocottus richardsoni*	Grunt sculpin	Pacific, Canada	pres/abs	0	FishBase
29	*Rhacochilus vacca*	Pile perch	S California	%W	0	Ebeling and Laur (1986)
29	*Ronquilus jordani*	Northern ronquil	Canada	pres/abs	0	FishBase
29	*Syngnathus leptorhynchus*	Bay pipefish	Pacific, Canada	pres/abs	0	FishBase
29	*Stichaeus punctatus punctatus*	Arctic shanny	Canada	pres/abs	0	FishBase
29	*Xiphister atropurpureus*	Black prickleback	N Pacific	pres/abs	0	FishBase
30	*Coryphaenoides acrolepis*	Pacific grenadier	NE Pacific	%W	12.6	Drazen (2001)
30	*Anotopterus pharao*	Daggertooth	NW Pacific	%W	0	Balanov and Radchenko (1998)
30	*Icosteus aenigmaticus*	Ragfish	N Pacific	pres/abs	33.3	FishBase
30	*Lampris guttatus*	Opah	Pacific, Canada	pres/abs	0	FishBase
30	*Icichthys lockingtoni*	Medusafish	California	pres/abs	0	FishBase
30	*Antimora microlepis*	Finescale mora		pres/abs	0	FishBase
30	*Avocettina infans*	Avocet snipe eel		pres/abs	0	FishBase
30	*Nemichthys scolopaceus*	Slencer snipe eel		pres/abs	0	FishBase
30	*Polyacanthonotus challengeri*	Longnose tapirfish		pres/abs	0	FishBase
30	*Spectrunculus grandis*	Pudgy cuskeel		pres/abs	8.3	FishBase
30	*Psychrolutes phrictus*	Blob sculpin	N Pacific	pres/abs	0	FishBase
30	*Tetragonurus cuvieri*	Smalleye squaretail	N Pacific	pres/abs	0	FishBase
30	*Bothrocara brunneum*	Twoline eelpout	E Bering Sea	%W	0	Brodeur (1988)
30	*Lycodes pacificus*	Blackbelly eelpout	Pacific, Canada	pres/abs	0	FishBase
30	*Eptatretus deani*	Black hagfish		pres/abs	14.3	FishBase
30	*Chauliodus macouni*	Pacific viperfish	SW Bering Sea	%W	0	Balanov (1994),
30	*Tactostoma macropus*	Longfin dragon fish	Oregon	%FO	0	Fisher and Pearcy (1983)
31	*Careproctus melanurus*	Blacktail snailfish	N Pacific	pres/abs	0	FishBase
30	*Cololabis saira*	Pacific saury	Pacific, Canada	pres/abs	0	FishBase
31	*Oneirodes bulbosus*	Bulb fish	SW Bering Sea	%W	0	Balanov (1994)
31	*Oneirodes thompsoni*		SW Bering Sea	%W	0	Balanov (1994)
31	*Bathylagus ochotensis*	Eared blacksmelt	Bering Sea	%W	0	Balanov et al. (1994)
31	*Bathylagus pacificus*		N Pacific	%FO	0	Gorelova and Kobylyanskiy (1985)
31	*Leuroglossus schmidti*	Northern smoothtongue	Bering Sea	%W	0	Balanov et al. (1994)
31	*Pseudobathylagus milleri*	Stout blacksmelt	E Kamchatka	%W	0	Sobolevskii and Senchenko (1996)
31	*Poromitra crassiceps*	Crested bigscale	Pacific, Canada	pres/abs	0	FishBase
31	*Diaphus theta*	California headlightfish	E Kamchatka	%W	1.6	Sobolevskii and Senchenko (1996)
31	*Diaphus theta*	California headlight fish	Oregon	%FO	0	Tyler and Pearcy (1975)
31	*Tarletonbeania crenularis*	Blue lanternfish	Oregon	%FO	0	Tyler and Pearcy (1975)
31	*Nannobrachium regale*	Pinpoint lampfish	California	pres/abs	0	FishBase
31	*Stenobrachius leucopsarus*	Northern lampfish	Bering Sea	%W	0	Balanov et al. (1994)
31	*Stenobrachius leucopsarus*	Northern lampfish	Oregon	%FO	0.2	Tyler and Pearcy (1975)
31	*Stenobrachius nannochir*	Garnet lanternfish	Bering Sea	%W	0	Balanov et al. (1994)
31	*Tarletonbaenia crenularis*	Blue lanternfish		pres/abs	0	FishBase
31	*Bathophilus flemingi*	Highfin dragonfish	California	pres/abs	0	FishBase

[a] W: weight, vol: volume, N: numbers, FO: frequency of occurence [b] assuming 15% of marine mammals in the diet based on Hulbert et al. (2003); [c] completed with information from FishBase; [d] transformed into weight assuming that all preys were of similar size; [e] the diet from Hecate Strait was quantitative

APPENDIX 6. EULACHONS

Eulachons reach sexual maturity at about 2 or 3 years old, and are probably semelparous (Hay and McCarter 2000). In the southeast, there are 27 river systems in which eulachons occur, of which 3 rivers house a commercial fishery. Following Hoenig's equation, the natural mortality was estimated at 1.43 year^{-1} based on a maximum age of 3 years. Historical catches were provided by Scott Walker (ADFG. Ketchikan, *in litt.*), and attained a maximum of 16 tonnes per year. For privavy reasons, catches were not available when less than 3 permits were delivered for a river. For these areas, the data was extrapolated by calculating the catch per river based on neighbouring years, assuming two permits (Table 6.1). The catch of 4.6 tonnes in 1999 all came from the Unuk river. Given the very small catch, F is practically negligible. The biomass was obtained from a special assessment of forage fish (Nelson 2003) and estimated at 0.03 t·km^{-2} for the whole SEAK and Yakutat area. This estimate has two sources of errors: 1. it is assumed that the biomass would be homogeneously distributed in the whole area, which may be incorrect; 2. the trawl net is not adapted to catch small species causing an underestimate of the real biomass (Nelson 2003). The estimate for 2003 is twice as high as the early 1990s and 6 times higher than 1999 (Figure 6.1).

Eulachons are prey for a lot of fish (dogfish, Pacific cod, hake), birds and mammals (Hay and McCarter 2000). Steller sea lions are known to frequent estuaries at times when eulachons migrate into the rivers to spawn (Spangler and Koski 2003). The diet is dominated by euphausids (57%), and macrobenthos (43%) (adapted diet from the Hecate Strait, Fargo and Pearsall 2004).

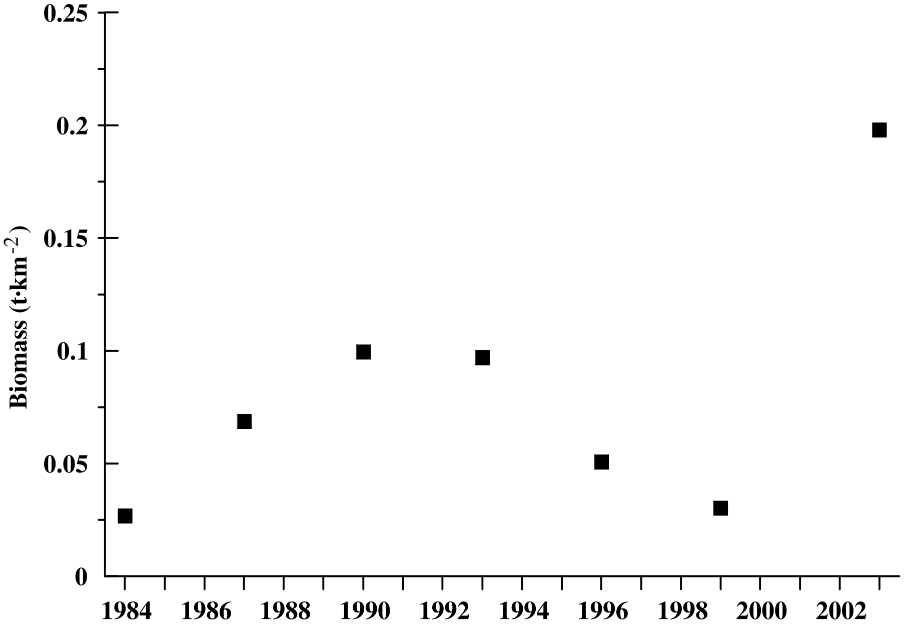


Figure 6.1 Biomass of eulachons in Southeast Alaska according to Nelson (2003).

Table 6.1 Catches of eulachons in 3 rivers of Southeast Alaska and extrapolation of missing data. The letter c stands for confidential when less then 3 permits where active. (lbs= pounds)

	Unuk			**Stikine**			**Bradfield**			**Total (t)**
	Catch (lbs)	**Inferred (lbs)**	**Permits**	**Catch (lbs)**	**Inferred (lbs)**	**Permits**	**Catch (lbs)**	**Inferred (lbs)**	**Permits**	
1969	15800		c							7.2
1970	0		0							0.0
1971	0		0							0.0
1972	0		0	c	5002	c				2.3
1973	14207		3	c	5002	c				8.7
1974	c	5002	c	c	5002	c				4.5
1975	c	5002	c	23851	23851	3				13.1
1976	c	5002	c	29492	29492	3				15.6
1977	0		0	c	5002	c				2.3
1978	0		0	c	5002	c				2.3
1979	0		0	c	5002	c				2.3
1980	c	5002	c		0					2.3
1981	c	5002	c		0					2.3
1982	c	5002	c		0					2.3
1983		16746	3		0					7.6
1984		34900	3		0			2204	1	16.8
1985		5002	c		0					2.3
1986		0	0	c	5002	c				2.3
1987		0	0		0					0.0
1988		0	0		0					0.0
1989		0	0	c	5002	c				2.3
1990		31000	3	c	5002	c				16.3
1991		20800	3	1200	1200	3				10.0
1992		0	0	c	5200	c				2.4
1993		27000	3	c	5200	c				14.6
1994		28000	3	c	5200	c				15.1
1995		19700	4		0					8.9
1996		5002	c	c	5200	c				4.6
1997		15000	4		0					6.8
1998		0	0		0		833	833	6	0.4
1999		10200	5		0		0	0	0	4.6
2000		0	0		0		1667	1667	3	0.8
2001		0	0		0					0.0
2002		0	0		0					0.0
2003		0	0		0					0

Appendix 7. The scallop and dive fisheries in Southeast Alaska

The **scallop** fishery is limited to the Yakutat region (excluding YKT bay) and a small area in SEAK. The known offshore beds are small compared with those historically fished elsewhere in Alaska. The catch is rather small (Bishop 2002). The fishery started in in the Yakutat area in 1968, and was largely unregulated until 1993. As a consequence, exploitation rate was sometimes too large and catches quite variable. The high catches of 1968-69 were followed by 2 decades of reduced effort and harvests. Harvests given in net weight of meat were transformed in total weight by assuming that the meat represent 9% (6-11%) of the total weight (Bishop 2002).

The dive fishery was open access until 1996 and targets abalone, sea cucumber, geoduck, sea urchins. Low levels of the **abalone** population in SEAK are due in part to continued predation by sea otters and overexploitation (Hebert and Pritchett 2002). Fishery has started in the early 1970s and is characterized by a boom in 1979-82 followed by dramatically reduced seasons and decline of catch per unit effort by 64%.

The fishery for **sea cucumber** started in 1981, based around Ketchikan and over the years, the management strategy evolved towards one of three seasonal rotations (Hebert and Pritchett 2002). The number of exploited fishing grounds increased in 2000-2002. Effort increased in the fishery to a maximum of 424 divers during the 1995-96 season due to high prices.

Known **geoduck** clam beds have a patchy distribution in the central and southern portions of SEAK, in protected waters near the outside coast (Hebert and Pritchett 2002). The management goal is to maintain a very low exploitation rate given the longevity of the species. Since the beginning of the fishery in 1986, an average of 89 tonnes per year were harvested.

Harvests for **red sea urchins** started in 1981 and continued until 1989 when the major processor ceased operations. The areas fished changed over time and were conditional to the completion of surveys and the development of a management plan. The Sitka fishery has been closed indefinitely due to extreme predation by sea otters (Hebert and Pritchett 2002). There is no fishery in Glacier Bay where there are only green urchins)

Data sources and derivation of parameters for generalised Northeast Pacific Ocean Ecopath with Ecosim models[1]

Dave Preikshot

Fisheries Centre, University of British Columbia, Vancouver BC; d.preikshot@fisheries.ubc.ca

ABSTRACT

Ecosystem models of two different size, and nested Northeast Pacific ecosystems were constructed to organise available knowledge of trophic interactions, fisheries effects and climate change. Species groups were the same for both ecosystem models, with a focus upon commercially important fish species. The models were dynamic and spanned the period from 1950 to the present. Time series data for biological indicators were compared to predicted model time series, given different scenarios of ecosystem control: top-down, bottom-up, or combinations thereof. Results of these scenarios suggest that fisheries, and predation / competition effects explain most population changes for commercially important fish species. Significant dynamic changes to all species modelled, however, appear to result from bottom-up effects driven by climate change, and regime shifts. The ecosystem models predicted primary production anomalies similar to decadal cycling seen in climate indices the Pacific Decadal Oscillation and Pacific Upwelling Index at 54ºN off the west Coast of North America. The results of this work suggest that regime shifts and climate change are useful indicators for the ecosystem foundation upon which fisheries and predation effects are manifested.

DETERMINING THE ECOSYSTEMS TO BE MODELLED

General description

Two models were constructed of Northeast Pacific ecosystems, see Figure 1. The first was for the coastal shelf ecosystem of British Columbia, Canada (BC shelf, see Figure 2). The second model was comprised of the Eastern Bering Sea, Gulf of Alaska (GoA), and BC shelf (NEPac). The models were made up of 53 and 56 groups, respectively. The models were intended to be used as a means of examining how bottom-up and top-down ecosystem control dynamics change over different area scales. To examine ecosystem data model outputs of biomass (B), total mortality (Z), and catch (Y) were compared to reference time series from stock assessments and surveys.

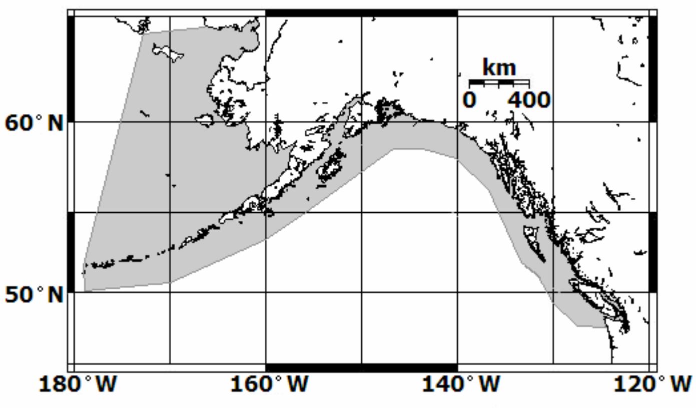


Figure 1. Areas included in the two ecosystem models shown in grey. The smaller scale ecosystem was the British Columbia continental shelf and slope (150,000 km2). The larger scale model added the BC continental shelves of the Gulf of Alaska and Eastern Bering Sea. (1,500,000 km2). Map ©Martin Weinelt, Online Map Creation: www.aquarius.geomar.de/omc/make_map.html.

The geographic areas chosen for the model were based on the need to examine how populations in ecosystems with similar species behave over time at very different area scales. In these two models the area of the BC shelf model was defined as the marine waters of the province of British Columbia, Canada to the 500 m isobath. The BC shelf model also included estuarine waters such as river mouths and fjords. The NEPac model includes the BC shelf model but extends further north including the Gulf of Alaska to the 500 m isobath, including the western extension of 500 m and shallower water in the Aleutians, and north to encompass the eastern continental shelf of the Bering Sea. The northern extent of the NEPac model is bounded by the geographic constriction of the Bering Strait. The delineation of these two oceanographically defined ecosystems was based upon; physical and chemical oceanographic

---

[1] Preikshot, Dave., 2005. Data sources and derivation of parameters for generalised Northeast Pacific Ocean Ecopath with Ecosim models. In: Guénette, S., and V. Christensen (editors). 2005. Food web models and data for studying fisheries and environmental impacts on Eastern Pacific ecosystems. Fisheries Centre Research Reports 13(1):179-206.

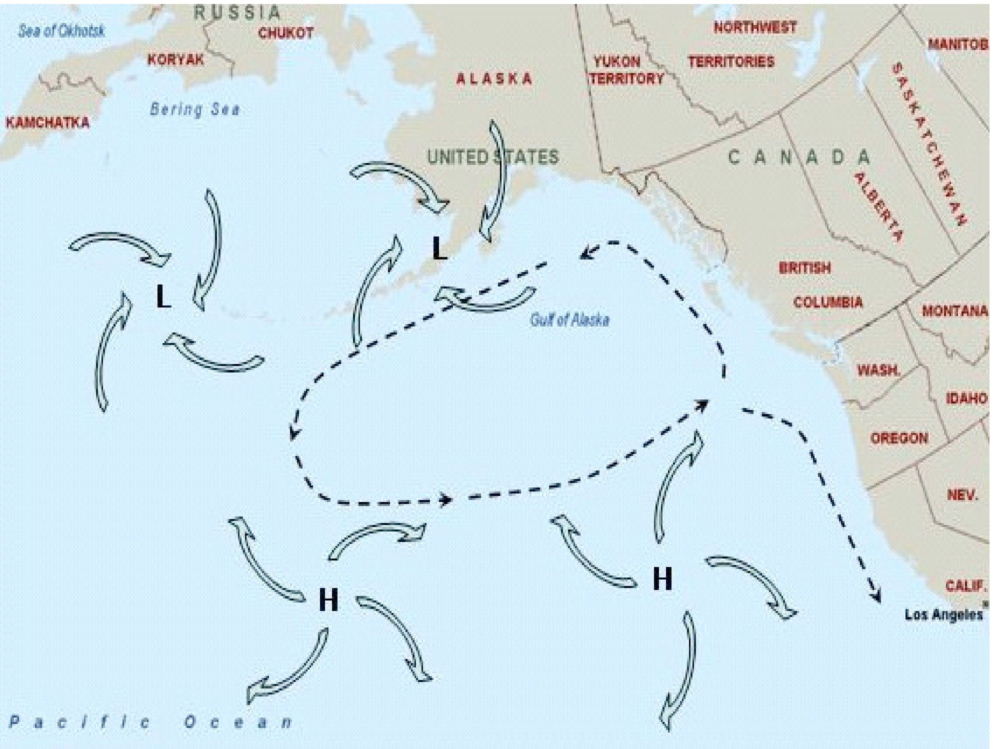


Figure 2. Generalised atmospheric and oceanic circulation of the Northeast Pacific. The hollow arrows represent winds generated by air flowing from and towards areas of high (H) and low (L) atmospheric pressure. These winds are deflected to the right by the Coriolis force. The wind acts upon the surface layer of the ocean to generate the current patterns shown as the dashed black lines. The counterclockwise flow of surface water is referred to as the Alaska Gyre.

characteristics, distribution and migration of the biota being modelled, and the availability of high quality stock assessment and survey data.

Chemical and physical characteristics

One way to define ecosystems is by the dominant climate systems within which they exist. By using such a definition, however an important consequence results: selecting an appropriate size scale to represent such a system. The term climate refers to average conditions prevailing over a region based upon many years of observation. This implies that climate must be understood in two senses of scale; the area over which it occurs and the time through which it is manifested. Bear in mind that these two manifestations of scale are also linked. Natural ecosystems tend to show a correlation within increasing spatial and temporal scales and speeds of ecosystem change (Pahl-Wostl 1998). Thus, when a mix of physical and chemical characteristics, which are influenced by climate are used to define an ecosystem, the temporal and spatial meaning of those characteristics must be relative to the temporal and spatial scale of the ecosystem being modelled.

The water circulation of the Northeast Pacific is dominated by the Alaska Gyre, the counter clockwise flow of surface water in the Northeast Pacific Ocean (see Figure 2). This counter clockwise flow is in turn driven by the winds of the Northeast Pacific basin. These winds are generated by the low pressure system, the Aleutian low, that tends to exist in the Gulf of Alaska region. Low pressure implies an atmospheric zone in which the air is rising. Rising air at the centre of the low pressure cell draws in replacement air, as surface winds towards the low pressure centre. Due to the Coriolis force the moving air is deflected to the right (in the northern hemisphere). The general result is cyclonic, *i.e.*, counter clockwise air circulation. These cyclones typically manifest themselves over spatial scales of 1 to 10 million square kilometres. This can be seen in the Aleutian Low Pressure Index (ALPI) a measurement of the area in the Northeast Pacific covered by a pressure of less than 100.5 kPa (Beamish et al. 1997). The centre of the Aleutian low pressure system varies in magnitude and position as the seasons change (Parrish et al. 2000) and also appears to go through changes in magnitude and position on a decadal scale.

It has been suggested that as the magnitude of the Aleutian Low increases various physical mechanisms are changed to increase or decrease primary productivity. Examples of such changes in the physical nature of the Northeast Pacific are numerous. Polovina et al. (1995) devised a model expressing phytoplankton production as a function of nutrient availability and light extinction. As the Aleutian low intensifies, the model suggested that the mixed layer depth (MLD) decreases in the Gulf of Alaska region, which may increase phytoplankton production if light extinction is the primary factor limiting production. It has been further suggested that such physical changes, expressed through a number of climate indices, act through primary production to cascade up the food web leading to larger biomasses of several species of commercially exploited fish. Studies that have examined this effect include ones specifically on salmonids (Beamish et al. 1997, Mantua et al. 1997), groundfish and halibut species in particular (Hollowed and Wooster 1992, Clark and Hare 2001b), and also bottom-up cascades on Northeast Pacific ecosystems in general (Beamish 1995, Hare and Mantua 2000, McFarlane et al. 2000, Hollowed et al. 2001, Benson and Trites 2002)

The physical oceanographic context of the Aleutian Low provides the boundaries to which marine organisms respond and thus is useful in defining ecosystems. The currents in the Northeast Pacific are generated by winds which blow according to patterns of air pressure shown in Figure 2. In terms of the two ecosystem models considered here, the temperature and nutrient fields created by the currents suggest that the NEPac and BC shelf models represent real and distinct zones of the oceans. The BC shelf model provides an example of how ocean ecosystems can have geographically flexible boundaries. Figure 2 shows that the BC shelf is dominated by both the eastern portion of the Alaska gyre that flows north along the coast and the spur which flows to the south. These two currents are called the Alaska and California currents (which just goes to show you that Canadians don't get to name Oceanographic features). Important qualities that these currents bring to the BC shelf include a relatively nutrient poor downwelling zone in the north, and in the south a zone relatively rich in nutrients due to upwelling generated by the California current.

Upwelling and downwelling associated with these currents results from a phenomenon called Ekman transportation. Just as atmospheric wind is deflected by the Coriolis force, so, too are the waters of the sea. The deflection to the right, however is manifested at the point of contact between air and water. As depth increases at the point of contact between wind and sea, so does the angle at which the water is deflected to the right. Because the velocity of deflected water decreases as depth increases, the net effect is that the layer of water moved by the wind (the 'Ekman layer') is deflected about 45 degrees to the right of the wind direction (Bearman 1989). Thus, even though the surface of the ocean appears to be moving in the same direction as the wind, the whole body of water moving, due to the wind, moves to the right. This deflection of the water body is called 'Ekman transport'. This implies that the California current is actually transporting ocean water away from the continent and the Alaska current is transporting ocean water towards the continent. In the case of the California current this net deficit is replenished by nutrient rich water from deeper in the ocean. The waters from the Alaska current, however are forced to the depths as they reach the shore, as there is no where else for it to go. A similar upwelling process occurs at the middle of the Alaska Gyre because the counterclockwise current also has Ekman transport, to the right, which moves upper ocean water away from the middle of the gyre. The deficit of water in the middle of the gyre is made up for by local upwelling. Incidentally, this mechanism causes the changes in the MLD noted by Polovina et al. (1995) as a result of wind derived currents increasing or decreasing in magnitude on seasonal, annual, and decadal scales.

The place at which these two currents divide, however is not geographically fixed. Indeed, it moves seasonally and interannually in response to seasonal and long term patterns of atmospheric pressure and therefore wind. On average the whole of the BC coast tends to be in the downwelling zone during the winter, while in the summer the upwelling may extend as far north as North Vancouver Island (Thomson 1981). This movement of water not only has an effect on available nutrients, but also can change the relative temperature of upper ocean waters.

Figure 3 shows seasonal and annual upwelling and downwelling at three stations off the coast of BC. Five aspects of this graph are important to our present discussion. The first is that all three stations show strong downwelling conditions prevalent in the winter (negative numbers). Second, in the summer the Olympic Peninsula and Queen Charlotte Sound tend to have upwelling, whereas Graham Island is, on average, slightly downwelling. Third, the magnitude of winter downwelling is greater than that of summer upwelling. This is due to the relatively stronger winds of winter months, which generate the water movement. Fourth, the relative upwelling or downwelling appears to wax and wane on cycles varying from 15 to 25 years. Fifth, the winter values appear to be highly correlated, whereas those for summer are less so. Through most years the latitudinal position of the divergence point for the California and Alaska currents moves north in the summer, to about 54ºN, and south in the winter, usually to about 48ºN. What is also apparent, however, is that the absolute north position of the seasonal divergence point may change from year to year in addition to changes in the seasonal

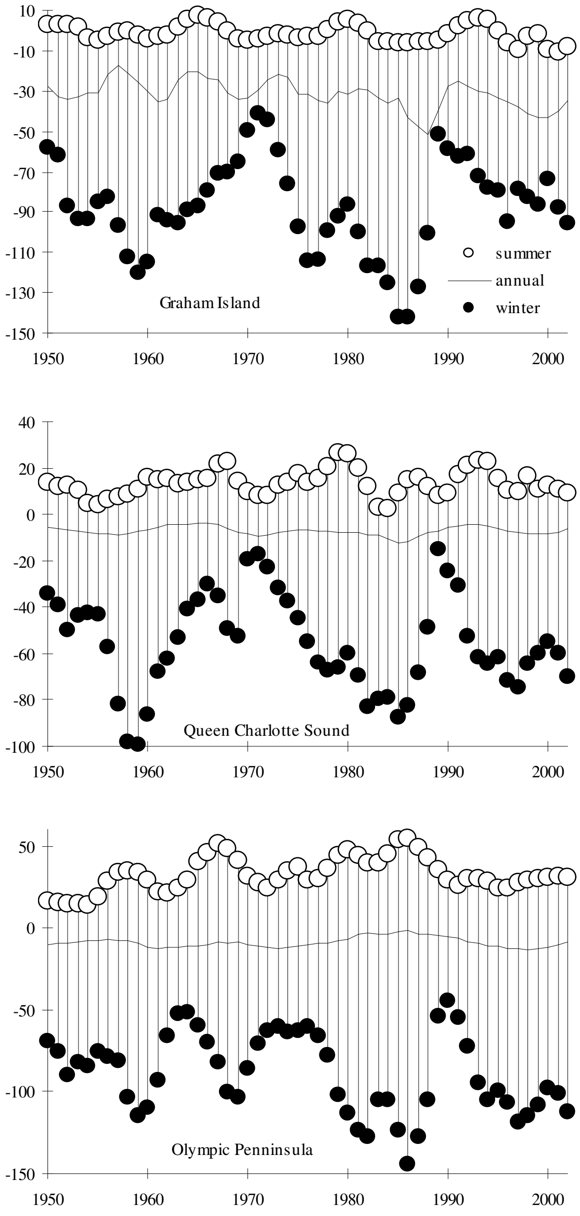


Figure 3. Interannual trends in upwelling and downwelling ($m^3 \cdot s^{-1} \cdot 100m^{-1}$) at three BC coast stations. The raw data was filtered through a LOWESS filter using an 8 year window and a 2nd degree polynomial. Summer was assumed to be June to September, while winter was December to March.

magnitude of upwelling or downwelling. It is widely recognised that one important environmental gradient to which marine organisms respond is temperature. Thus the position of the divergence point should be important in defining the ecosystem, because of the very different temperatures that are associated with seasonal and interannual upwelling and downwelling conditions. The example of hake is important here, as they are known to be more abundant in British Columbia waters when warmer summer ocean surface waters are observed (Ware and McFarlane 1995). This is not the response of a hake stock that is exclusive to British Columbia. Rather, the stock is widely regarded as inhabiting the coasts of California, Oregon and Washington, and the northern boundary of the stock appears to extend further into Canada when conditions, like temperature, are more favourable.

The 'ecosystems' under consideration here are therefore not fixed in their position on the earth. The areas encompassed by the described physical setting must therefore not only move north and south both seasonally and interannually, but also increase and decrease in total area on different time scales. These changes likely affect the total amount of primary production and therefore the amount of food available to secondary producers and on up through the food web. The climate of the Gulf of Alaska, the Bering Sea and the BC coast are dominated by changes in the Aleutian low pressure index (ALPI), therefore so too are the physical and chemical oceanic conditions there. Because the BC coast experiences changes from upwelling to downwelling, it may be more accurate to describe the BC coast as containing the boundary of two ecosystems. The first extending from the south as the California current. The second being the southeastern portion of the Alaska current. As we shall see from the sections on biology and data, however, there are reasons that compel us to view the area of the BC shelf and coast as an ecosystem viable for modelling.

Biological characteristics

The Ecosystems under consideration here correspond to those defined by Longhurst (1995) as the Gulf of Alaska (ALSK) BGCP and the eastern half of the 'enclosed high latitude seas (BERS)' BGCP. The BC shelf includes the northern portion of the California current BGCP (CCAL). The two model areas roughly correspond to these defined 'ecosystem' areas. The Bering shelf, the eastern half of the BERS BGCP, is effectively isolated from the western half (the Sea of Okhotsk) by the Kamchatka peninsula, and is connected to the ALSK BGCP via the Aleutians, so considering the exchange between the two as part of a continuous ecosystem seems reasonable. Now, depending on the divergence of the Alaska and California currents, the BC Shelf, is either entirely within the ALSK BGCP, or also includes the Northern Portion of the CCAL BGCP.

This moving boundary problem was dealt with by Pauly et al. (2000), who merged the BGCP theory with the Large Marine Ecosystem (LME) concept, described as coastal regions larger than 200 000 km^2 that are "characterised by unique bathymetry, hydrography, and productivity within which marine populations have adapted reproductive, growth, and feeding strategies" (Sherman et al. 1990). The value of wedding the LME concept to the BGCP concept is that it is possible to use the strengths of each theory to boost their applications in total, *i.e.*, the whole is greater than the sum of its parts. Pauly et al. (2000) state that "For BGCPs, we identify sub-provinces that are pragmatically defined to serve as framework for fisheries, coastal area and other applied research. As for the LMEs, they obtain, via their incorporation into the scheme of biomes and BCGPs … explicit physical definitions, including borders… that allow GIS-based computation of system properties, such as mean depth, temperature, primary production, etc."

According to this new combined LME mapping work, the NEPac ecosystem consists of two LMEs: the East Bering Sea (made up of the Bering shelf and the Aleutian Islands) and the Gulf of Alaska (extending from the western end of the Alaska Peninsula to British Columbia and Washington). See www.seaaroundus.org/lme/lme.aspx for a complete set of all the maps and derived biological data for these and other LMEs.

Data characteristics

Given the logic of thus defining marine ecosystems, a problem arises with the relatively small scale BC shelf ecosystem. Although the southern boundary of the BC shelf ecosystem is well delimited by the Juan de Fuca Strait in the south, land to the east and a continental slope to the west, the northern boundary is merely the arbitrary and politically imposed Alaska-British Columbia border. There is movement of fishes, mammals and birds across this border, and yet the availability of data sets collected by the Canadian Department of Fisheries and Oceans compels the examination of the BC shelf as a separate unit. One persuasive argument to do so is the identification of distinct local stocks of important and abundant species like salmon and herring which are part of metapopulations extending along the west coast of North America. Many of the stocks that spend most of their time in Canadian waters are well studied, with detailed stock assessments for the herring stocks of British Columbia extending back to 1950, see, e.g., (Schweigert 2000). Many demersal species like rockfish, sablefish, Pacific cod and lingcod are thought to have a high fidelity to a rather small range (Stocker et al. 2001), implying that such local populations of a larger population complex, if affected by fisheries will respond chiefly to the regulatory regime imposed by the Canadian government. For these reasons it appears that temporal changes in the population dynamics of many of the commercially important fish stocks in the BC shelf ecosystem may be largely explained by local environmental and fisheries changes.

Before describing the derivation of parameters for the basic Ecopath input values and reference time series data used in Ecosim time dynamics models, a couple of matters relating to general practices should be mentioned. For both models the Ecopath basic input values were determined by finding the best possible estimations for the present day. The models were then back calculated to set up Ecosim with a 1950 start time by changing biomass (B) and mortality, fishing or total (F, Z), values for groups known to have changed over time. All other parameters were assumed to be unchanged in the absence of evidence to the contrary. For most of the fish groups consumption (Q/B), values were determined by the empirical equation available in FishBase (Froese and Pauly 2004), which requires that estimates be provided for W_∞, average environmental temperature, fin aspect ratio (ratio of the ratio of the square of the height of the caudal fin and its surface area), and food type (detritivore, herbivore, omnivore, carnivore) (Palomares and Pauly 1999).

PARAMETERISATION OF THE MODELS

Grouping species in the models

In order to allow for ready comparison between the two models the species included in both are almost identical, Table 1. The BC shelf model (53 species) differs from the NEPac model (56 species) only by omitting 3 species: Atka mackerel, northern rockfish, and Alaska plaice. Species may be included in an Ecopath with Ecosim (EwE) model as a unique group or aggregated with other species that function similarly in the ecosystem. These species groups may be called 'functional groups'. Because the focus of this modelling exercise was the behaviour of the populations of fish species in response to environmental forcing, the greatest detail lies in the functional groups of those species. Indeed, each of the focal species was modelled using what is referred to as multi-stanzas, *i.e.*, more than one life history stage of that species was modelled. Other significant species that interact with these important fishes were modelled as single species functional groups, with no attempt to monitor life history changes. Most invertebrates, zooplankton and primary producers were put into highly aggregated functional groups, some of which contain hundreds of species.

Multi-stanza groups

There are 12 functional groups within the 'multi-stanza' category representing six species; arrowtooth flounder, Pacific cod, Pacific halibut, sablefish, pollock, and herring. These species were examined in detail for several reasons. All six have been intensively studied by the research community in the Northeast Pacific. This means that not only were the

Table 1. Groups used in the construction of the Northeast Pacific EwE models. Note that the BC shelf model did not include three of these groups; Atka mackerel, northern rockfish, and Alaska plaice.

Birds / mammals	**Pelagic fishes**	**Demersal fishes**	**Invertebrates**	**Multi-stanza**
birds pelag. pisciv.	salmon shark	dogfish	krill	arrowtooth juv.
birds demer. pisciv.	pelagic sharks	rajidae / ratfish	carn. zooplankton	arrowtooth ad.
birds zooplanktiv	pink salmon	Pac. Ocean perch	herb. zooplankton	Pacific cod juv.
odontocetae	chum salmon	Northern rockfish	jellies	Pacific cod ad.
mysticetae	sockeye salmon	rockfish other	large squids	Pac. halibut juv.
sea lions	coho salmon	Pacific hake	small squids	Pac. halibut ad.
seals	chinook salmon	Atka mackerel	shrimps	sablefish juv.
	myctophids	lingcod	crabs	sablefish ad.
	mis. prd. pelag.	yellowfin sole	bivalves	pollock juv.
	mis. sm. pelag.	rock sole	echinoderms	pollock ad.
		plaice	other benthos	herring juv.
		flatfish other	phytoplankton	herring ad.
		misc. sm. demer.	macrophytes	
			detritus	

population dynamics well documented over spans of 20 or more years, but also that energetic, dietary, and ontogenetic research had been done on the species. All of these groups are culturally significant to the civic, provincial, state, federal and first nations communities of the Pacific Northwest. All of these groups spent the majority of their life, did the majority of feeding and experience the majority of their mortality within the confines of the ecosystems described above.

Lastly, these groups together occupy most of the three dimensional physical space available in the two ecosystems. Herring moves between shallow coastal areas to deep water pelagic habitats, whereas halibut moves from offshore demersal to coastal demersal habitats seasonally, pollock moves daily between deep and shallow water (diel vertical migration), sablefish, and Pacific cod are in shallow coastal waters as juveniles, but move to the deeper waters of the continental shelf and slope as they mature, and arrowtooth flounder are found in many depths on soft bottoms (Froese and Pauly 2004).

Time series of biomasses were therefore relatively easy to obtain for all multi-stanza species. Time series of F, Z, or both were also found for some of them. These time series were used as reference data for Ecosim time dynamic models, to compare to output biomass. The three largest biomass of commercially exploited fish in the two models are those of arrowtooth flounder, Pacific cod and walleye pollock. As seen in Figures 4 and 5, however the biomass may be much larger in one part of an ecosystem than in others. For example, the walleye pollock stocks of the Bering Sea / Aleutian Islands (BSAI) have usually been far larger than that of the GoA. It is interesting to note, though, that from the early 1970s to the early 1980s the two areas had more similar biomass of walleye pollock. Another interesting feature is an apparent cyclicity of some stocks, e.g., suggested by the assessments for BC shelf and GoA Pacific cod, contrasted by the monotonic behaviour of the increase seen in GoA arrowtooth flounder since the early 1970s. However, in terms of assessments at different area and time scales, not all species were represented at all levels.

The values of the Ecopath basic input parameters for multi-stanza species can be seen in Table 2. For these multi-stanza groups the basic input parameters are slightly different from standard Ecopath groups. This is because multi-stanza species are assumed to undergo some trophic ontogeny and that each stage in this process contains individuals with similar mortality rates and diet compositions. Biomass and Q/B values for one leading stanza (often one for which assessment data is available) are entered and the biomass and Q/B are calculated for the other stanzas by Ecopath which assumes that body growth follows a von

Table 2. Ecopath basic input parameters used for multi-stanza groups in the final, mass balanced, BC shelf and NEPac models.

	Biom. (t·km^{-2})	**P/B** (year^{-1})	**Q/B** (year^{-1})
BC Shelf			
arrowtooth juv.	0.008	0.500	4.414
arrowtooth ad.	0.070	0.300	2.000
P. cod juv.	0.176	0.800	3.421
P. cod ad.	0.300	0.660	1.800
P. halibut juv.	0.023	0.500	2.550
P. halibut ad.	0.175	0.300	1.000
sablefish juv.	0.067	0.300	4.400
sablefish ad.	0.400	0.200	2.200
pollock juv.	0.024	0.800	6.715
pollock ad.	0.700	0.400	2.000
herring juv.	1.233	0.800	7.272
herring ad.	2.000	0.650	4.400
NEPac			
arrowtooth juv.	0.024	0.500	4.560
arrowtooth ad.	0.280	0.250	2.000
P. cod juv.	0.282	0.800	3.421
P. cod ad.	0.480	0.660	1.800
P. halibut juv.	0.022	0.500	2.550
P. halibut ad.	0.170	0.300	1.000
sablefish juv.	0.034	0.300	4.400
sablefish ad.	0.203	0.200	2.200
pollock juv.	0.113	0.800	6.715
pollock ad.	3.268	0.400	2.000
herring juv.	0.277	0.800	7.272

Bertalanffy growth curve and that the species has stable mortality and relative recruitment to have achieved stable age-size distribution (Christensen et al. 2004). Thus, in order to allow Ecopath to calculate unknown biomass and Q/B values the user enters values for the von Bertalanffy k value (k), a recruitment power value (between 0 and 1), a biomass accumulation rate (BA), a value for weight at maturity divided by maximum possible weight (W_{mat}/W_∞), and a start age for each stanza of that species. In all cases the recruitment power value was set to 1 and the BA value to 0. In most cases k was estimated using the empirical equation available in FishBase (Froese and Pauly 2004), and estimates of L_∞ for the relevant species.

The range of arrowtooth flounder (*Atheresthes stomias*) extends from California to the eastern Bering Sea (EBS) although it is more abundant in the northern portion of its range (Hart 1973). Information was found on biomass, and mortality for the Gulf of Alaska (GoA) (Turnock et al. 2003b), EBS (Wilderbauer and Sample 2003), and BC shelf (Fargo and Starr 2001). Time series of biomass can be seen in Figure 4. Note that in Canada arrowtooth flounder is sometimes referred to as 'turbot'. P/B was derived for all populations by using mortality information in Turnock et al. (2003b), which has M = 0.2 year^{-1} for 3+ females and 0.35 year^{-1} for 3+ males. Therefore we can assume a weighted M ≈ 0.25 year^{-1} if there will be more females in the resulting cohorts as they age. Fishing mortality was estimated as being from 0.01 year^{-1} to 0.03 year^{-1} for the stock over the last few decades, thus Z ≈ 0.25 year^{-1}. Mortality for juveniles was assumed to be somewhat higher ≈ 0.5 year^{-1}. W_{mat}/W_∞ was calculated from length at maturity information (Turnock et al. 2003b). Length at 50% mature was estimated as 47 cm, and $L_\infty \approx 100$ cm therefore $L_{mat}/L_\infty = 0.5$, *i.e.*, $W_{mat}/W_\infty \approx 0.13$. For arrowtooth flounder only time series for the BSAI and GoA were available. Because there was no BC shelf specific biomass time series available, it was assumed that the BC population would reflect relative changes in the GoA stocks of these species. This approach is supported by GoA assessments for both species which were done under the assumption that there were no sub-populations within the area (Dorn et al. 2003, Turnock et al. 2003b).

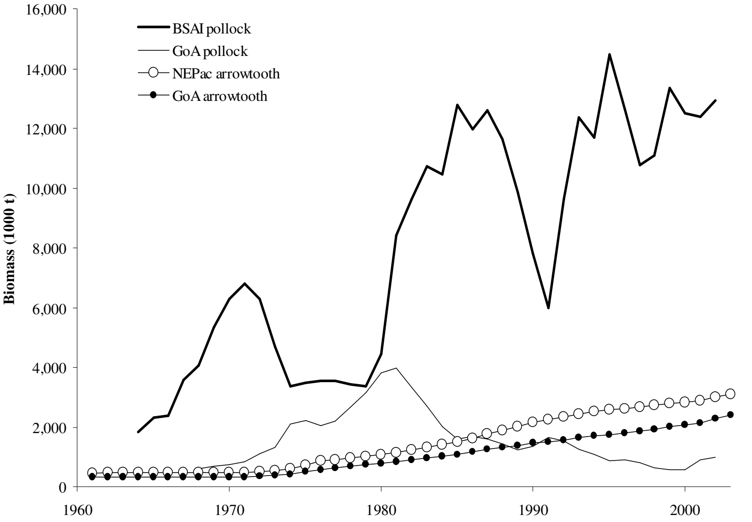


Figure 4. Time series of biomass for arrowtooth flounder and walleye pollock. Note that biomass reported for walleye pollock in both the BSAI (Ianelli et al. 2003) and GoA (Dorn et al. 2003) sub-regions was for age 3+ adults. For arrowtooth flounder the BSAI assessment (Wilderbuer and Sample 2003) provided biomass for age 1+ individuals, whereas the GoA assessment (Turnock et al. 2003b) was for age 3+ adults. Therefore, the NEPac arrowtooth flounder B is a mix of 3+ GoA and 1+ BSAI.

Walleye pollock (*Theragra chalcogramma*) occurs from central California north to the Bering sea and west to the Sea of Okhotsk and Japan (Hart 1973). The Alaskan fishery on this species is one of the largest in the world. There appear to be three distinct stocks in the United States portion of the Bering Sea (Ianelli et al. 2003), whereas there has been little evidence to suggest there is more than one stock in the GoA area (Dorn et al. 2003). Stock assessment information was available for BSAI and GoA populations (Figure 4). Dorn et al. (2003) estimated M as 0.1 year^{-1} and F as 0.07 year^{-1} and 0.13 year^{-1} for 2003 and 2004, so P/B ≈ 0.2 year^{-1}. However, Ianelli et al. (2003) say that by age 4 and older M is 0.3 year^{-1}, while for age 1, 2, 3 it is 0.9 year^{-1}, 0.45 year^{-1}, and 0.3 year^{-1}. FishBase (Froese and Pauly 2004) listed default L_{mat} and L_∞ values of 39 cm and 73 cm thus $W_{mat}/W_\infty \approx 0.15$. For pollock only time series of biomass for the BSAI and GoA were available. It was assumed that the BC population would reflect relative changes in the GoA stocks of these species, as with arrowtooth flounder.

Pacific cod (*Gadus macrocephalus*) occurs throughout the North Pacific from southern California to Korea, while preferring to stay in water from 6 ºC to 9 ºC (Hart 1973). Stock assessment information was available for three regions: EBS (Thompson and Dorn 2003), GoA (Thompson et al. 2003), and BC shelf (Sinclair et al. 2001) (Figure 5). Thompson et al (2003) list an M = 0.37 year^{-1} for the GoA and have recommended F of 0.29 year^{-1} thus P/B (Z) ≈ 0.66 year^{-1}. Information on L_{mat}/L_∞ was found in Thompson and Dorn (2003) which suggested a ratio of about 0.5, thus a $W_{mat}/W_\infty \approx$

0.13. Assessments of Pacific cod for the BC shelf extends back to the 1950s (Sinclair et al. 2001), but assessments for the BSAI and GoA regions have only been done back to the late 1970s (Thompson and Dorn 2003, Thompson et al. 2003). The biomass appears to have undergone significant changes at both area scales, though the changes appear to be longer frequency at the larger NEPac scale than at that of the BC shelf (Figure 5).

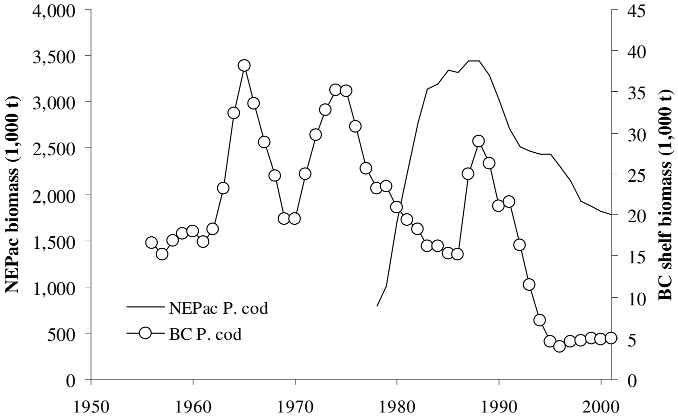


Figure 5. Time series of biomass for Pacific cod in the BC shelf and whole NEPac ecosystem (Sinclair et al. 2001, Thompson and Dorn 2003, Thompson et al. 2003). Note that B values for the whole NEPac ecosystem are 2 orders of magnitude larger than for the BC shelf.

Pacific halibut (*Hippoglossus stenolepis*) are found across the north Pacific from Baja California north to the Bering Sea and west to the Hokkaido and the Sea of Okhotsk (Froese and Pauly 2004). It is most commonly found between 55 and 422 m, but may be found in shallower water as juveniles (Hart 1973). The International Pacific Halibut Commission (IPHC) assesses 'stocks' for several geographic regions along the west coast of North America; area 2A (Oregon, Washington), area 2B (British Columbia), area 2C (southeast Alaska), area 3A (central Alaska), area 3B (Alaskan peninsula), Area 4A and B (Aleutian Islands), and Areas 4C,D, and E (Bering Sea). These 'stocks' are modelled as separate populations because there is believed to be little movement between areas, *i.e.*, high habitat fidelity by adults (Sullivan et al. 1997) (Figure 6). The P/B of 0.3 year^{-1} represents the lower range of Zs estimated for several halibut stocks from 1975 to 2000 in Anonymous (2000). Age of 50% maturity is about 11 according to Anonymous (2000) at which point they are ≈ 120 cm long (according to Table A3.5 in Sullivan et al. 1997). FishBase lists L_∞ as ≈ 270 cm. Thus $L_{mat}/L_\infty \approx 0.44$ and $W_{mat}/W_\infty \approx 0.09$. Halibut population trends have been closely examined at different time and area scales by the IPHC. Biomass time series were available for the BC shelf from 1974 to the present and for the whole NEPac ecosystem from 1950 to the present (Sullivan et al. 1997, Clark and Hare 2001a). The biomass trajectories for the two different areas are similar, though there appears to be a five year lag in the BC shelf population behind the whole NEPac population (Figure 6).

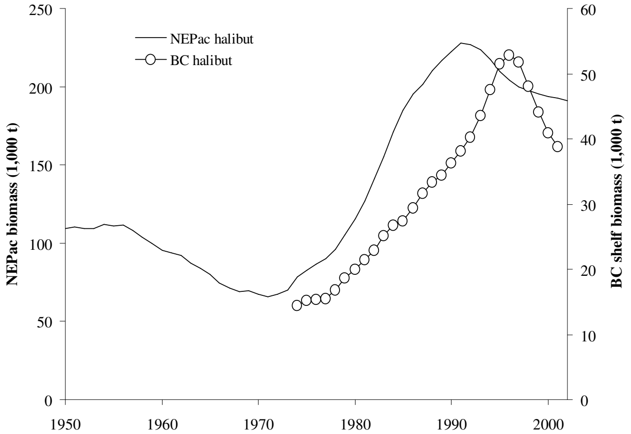


Figure 6. Biomass time series for halibut in the BC shelf (Clark and Hare 2001a) and NEPac (Sullivan et al. 1997) ecosystems.

Pacific herring (*Clupea pallasii*) stocks occur from Baja California to the Beaufort Sea, but the area of greatest density occurs from northern California to Central Alaska (Hart 1973). Although significant stocks exist in Alaska most of the detailed information on herring biology was obtained from studies on Canadian stocks (Figure 7). P/B was estimated from adding estimated natural and fishing mortalities reported in Schweigert and Fort (1999). W_{mat}/W_∞ was estimated as 0.22 based on a FishBase (Froese and Pauly 2004) estimate of $L_{mat}/L_\infty = 0.6$. Herring catches have been important to the NEPac area as a whole, but only the populations of the BC shelf have good assessment data readily available (Anonymous 2002a; b; c; d; e). Five stocks form the vast majority of herring biomass in the BC shelf and they are commonly referred to by the geographic area in which they spawn; Queen Charlotte Islands, Prince Rupert, central coast, west coast Vancouver Island, and Strait of Georgia. The five stocks often increase or decrease at different times, but all underwent dramatic declines during the 1960s as a result of overexploitation by a reduction fishery (Stocker et al. 2001) (Figure 7). Biomass is therefore well known at the smaller scale of the BC shelf back to 1950, but absolute historic herring biomass at the larger scale of the NEPac ecosystem are not.

Sablefish (*Anoplopoma fimbria*) appear to have two populations in the northeast Pacific, based on growth, mortality and tagging information. A northern population inhabits waters around Alaska and northern British Columbia and a southern one from southern British Columbia to California (Sigler et al. 2003). Therefore the BC shelf 'stock' includes portions of two separate populations. Sablefish biomass estimates for GoA (Sigler et al. 2003) and BC shelf populations (Haist et al. 2001) can be seen in Figure 8. Sigler et al. (2003) estimated M as 0.1 and suggest an F of between 0.07 year^{-1} and 0.13 year^{-1} in 2003 and 2004, so Z is ≈ 0.2 year^{-1}. Sigler et al. (2003) suggest that sablefish males and females achieve 70% and 40% maturity, respectively, at age 6 when their lengths are 59 and 64 cm. Given that FishBase lists sablefish $L_{max} \approx$ 120cm, we can approximate that $L_{mat}/L_\infty \approx 0.5$ and, therefore, $W_{mat}/W_\infty \approx 0.13$. Biomass time series for sablefish are similar to halibut in that longer term data was available at the larger scale. Because the biomass of the BC shelf assessment was seen to be almost an order of magnitude smaller, than that for the northern stock alone, the BSAI/GoA assessment was used as the NEPac biomass time series (Figure 8).

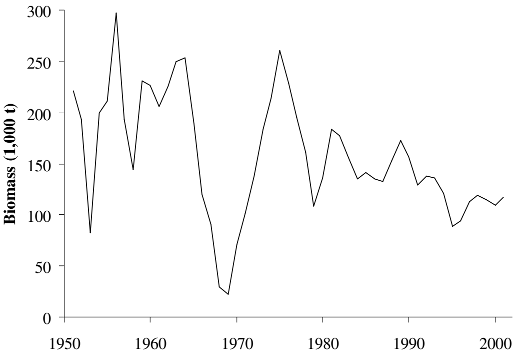


Figure 7. Biomass time series of herring in the BC shelf ecosystem. This represents a composite of 5 stocks that form the majority of herring in the area (Anonymous 2002a,b,c,d,e).

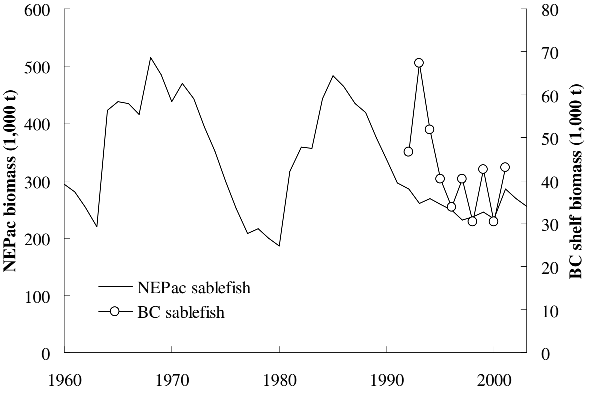


Figure 8. Time series of sablefish in the NEPac and BC shelf ecosystems (Haist et al. 2001, Sigler et al. 2003).

Birds / marine mammals

Marine bird species were divided into 3 functional groups based on an analysis of their diet compositions; zooplanktivorous birds (parakeet auklet, least auklet, whiskered auklet, crested auklet, and Cassin's auklet), pelagic feeding birds (fork-tailed storm-petrel, Leach's storm-petrel, glaucous-winged gull, black-legged kittiwake, and red-legged kittiwake), and demersal feeding birds (rhinoceros auklet, common murre, thick-billed murre, tufted puffin, marbled murrelet, pigeon guillemot, horned puffin, double-crested cormorant, pelagic cormorant, and ancient murrelet). Population estimates were found for all species in the three functional groups for British Columbia and Alaska (Vermeer and Sealy 1984, Piatt and Naslund 1995, Hunt et al. 2000, Fitzgerald et al. 2003, Anonymous 2004b). Other species found in the area, such as raptors and shorebirds were omitted from consideration as functional groups in either ecosystem, as they were found to be either migratory or reliant on the marine environment for only a portion of their food. Population estimates for species in each of the three functional groups were multiplied by values for average adult mass found in Dunning (1993). When both male and female masses were available, the average of the two was used as the multiplier.

In the calculation of P/B for bird functional groups, bird populations often tend to have well reported survival rates. As instantaneous mortality (Z, *i.e.*, P/B) is equal to the negative logarithm of the survival rate, this conversion was applied to available survival data. Most survival rates were found in Saether and Bakke (2000), marbled murrelet was from Burger (2001), least auklet from Jones and Hunter (2002). Leach's storm petrel and Cassin's auklet from Vermeer and Sealy (1984). Auklets, murrelets and guillemots for which no data could be found were based on average values for conspecifics. The P/B estimates for each species was multiplied by the fraction of that species' biomass over the whole functional group's biomass to provide biomass weighted P/Bs for all functional groups (Table 3).

The Q/B for each bird species group was calculated through a two step process. The first step was obtaining the average daily energy requirement of an adult of each of the species in kJ·day^{-1} provided by Hunt et al. (2000; Table 6.3, except for gulls and jaegers which were derived from gulls and jaegers in Table 6.5, and red legged kittiwake also from Table 6.5). Then given the diet compositions and energy density of prey items shown in Hunt et al. (2000), average prey energy densities were calculated as kj·g^{-1}. Average values for energy in prey items and diet composition of those prey items were taken from Table 7.3, with the following exceptions; albatross from Table 7.10 entry for laysan albatross, leach's storm petrel from Table 7.4, Brandt's cormorant from Table 7.9, red legged kittiwake from Table 7.1, and least auklet from Table

7.1 in Hunt et al. (2000). The daily energy consumption was then divided by the average energy density of that species' prey to yield a daily food consumption in grams. These daily food consumptions were divided by the average adult weights from Dunning (1993) then multiplied by 365 to yield Q/B. These Q/B values were then biomass weighted by species for functional groups in the same manner as P/B values (Table 3).

Table 3: Ecopath basic input parameters for bird and mammal groups in the mass balanced BC Shelf and NEPac models.

	Biom (t·km^{-2})	**P/B (year^{-1})**	**Q/B (year^{-1})**
BC Shelf			
birds pelag pisciv	0.001	0.159	278.205
birds demer pisciv	0.003	0.176	164.945
birds zooplanktiv	0.003	0.186	247.942
odontocetae	0.036	0.030	13.100
mysticetae	0.155	0.020	13.370
sea lions	0.019	0.060	12.700
seals	0.040	0.160	15.950
NEPac			
birds pelag pisciv	0.002	0.129	202.630
birds demer pisciv	0.016	0.061	148.904
birds zooplanktiv	0.001	0.175	253.793
odontocetae	0.036	0.030	13.100
mysticetae	0.155	0.020	13.370
sea lions	0.174	0.060	12.700
seals	0.001	0.160	15.950

Biomasses of cetaceans are difficult for management agencies to quantify due to their highly migratory nature, see, *e.g.*, Hill and DeMaster (1998). Although it is often easier to count pinnipeds, due to their tendency to 'haul out' at consistent and predictable landfalls for migration, mating, and relaxing, such counts may be confounded by different portions of a population hauling out at different times or more than once during a census. Biomasses of mysticetae and odontocetae groups in these two models, therefore are very speculative and in need of more precision in future iterations. The present biomass estimate for mysticetae for both models assumes that the parameter will be similar in both areas. For the estimated biomass then, the work of Trites and Heise (1996) for the west coast of Vancouver Island (WCVI) was used. Trites and Heise (1996) estimated that for grey whales (*Eschristus robustus*) there is a summer population ≈ 1167 (range 1000-1500) and a winter population of 585 (range 200-1000) off the WCVI. Thus a yearly average of about 900. They assumed 100 humpbacks (*Megaptera novaeangliae*) year round, while minkes (*Balaenoptera acutorostrata*) were set at 100. Though the population estimates in Trites and Heise (1996) were specifically for the WCVI area, the same individuals would likely range over the whole BC shelf ecosystem. The mass of the mammal populations was then calculated using the above population estimates and the average weights of male and female marine mammals from Trites and Pauly (1998). The total mass estimate was then divided by the area of the BC shelf (a little more than 100,000 km^2), yielding a mysticetae biomass of 0.15 t·km^{-2}. Odontocetae numbers were also based on Trites and Heise (1996) for WCVI and converted to masses using values in Trites and Pauly (1998). Estimated numbers were: 1,000 Dall's porpoise (*Phocoenoides dalli*), 1,000 harbour porpoise (*Phocoena phocoena*), 2,000 Pacific white sided dolphin (*Lagenorhynchus obliquidens*), 100 northern right whale dolphin (*Lissodelphis borealis*), and 200 killer whales (*Orcinus orca*). The resulting biomass for BC Shelf odontocetae was 0.036 t·km^{-2} (Table 3). This biomass value was used for both the NEPac and BC shelf model as there was no compelling evidence to suggest that either the density or functional group composition was different in the larger modelled areas from the estimates suggested for the WCVI.

Northern fur seals (*Callorhinus ursinus*) and Steller sea lion (*Eumetopias jubatus*) were modelled as one functional group. Estimated present day populations for both species in the NEPac region were found in Angliss and Lodge (2002). These population estimates were then multiplied by weights (Trites and Pauly 1998) to estimate system wide biomasses. A time series for the abundance of Steller sea lions was found in Trites and Larkin (1996). Time series of male northern fur seals for two major breeding areas (St. Paul and St. George Islands) were found on the NOAA fur seal web page (Anonymous 2004a), which was used as an index to generate a biomass time series assuming a relative portions of males to the total population was constant over the perios from 1950 to the present. Population and biomass estimates for the sea lion group in the BC shelf model also included the California sea (*Zalophius californianus*) lion as in Trites and Heise (1996). There were 9,400 sea lions in BC waters in 1996, with an additional 3,500 male California sea lions during summer. Using masses from Trites and Pauly (1998) total biomass in BC was estimated to be ≈ 0.019 t·km^{-2}.

The P/B for sea lions for both models was based on net production rates for California sea lions off the US West Coast from 1980-1999 (excluding el Niño years) reported in Forney et al. (2000). The Q/B for sea lions in both models was taken from Trites et al. (1999). Their calculation was done with the same formula used for odontocetae. Diet composition for sea lions was based on an amalgamation of sea lion diet data in Trites and Heise (1996).

Harbour seal (*Phoca vitulina*) counts for Alaska (Angliss and Lodge 2002) were multiplied by weights from Trites and Pauly (1998) for the NEPac biomass estimate. The BC shelf estimated biomass was derived from a population assessment by Olesiuk (1999), which was also the source of the biomass time series of this species for the BC shelf. No time series of harbour seals was found for Alaskan waters, thus there was none for the NEPac model. P/B for harbour seal in both models was from Olesiuk (1999), which states that in the Strait of Georgia (SoG) the maximum net productivity was ≈ 11.4% (3,200 seals) when the population was 75% (28,500 seals) of carrying capacity (38,000 seals). So at maximum carrying capacity the population should be able to withstand a total mortality of ≈ 11.4% *i.e.*, a P/B ≈ 0.12 year^{-1}. Q/B for seals in both models was taken from Trites et al. (1999) and calculated based on estimations of mean weight and daily ration. Mean weight data came from Trites and Pauly (1998), which estimated daily ration per individual as a percentage of body weight using the equation $R=0.1W^{0.8}$ in which W is the mean weight in kg. The dimension less parameters 0.8 and 0.1 were borrowed from Innes et al. (1987), although 0.1 was adjusted downwards from the original value of 0.123.

Pelagic fishes

Biomass values for the five salmon species considered in the NEPac model; chinook salmon (*Oncorhynchus tshawytscha*), chum salmon (*O. keta*), coho salmon (*O. kisutch*), pink salmon (*O. gorbuscha*), and sockeye salmon (*O. nerka*), were similar to those reported as eastern subarctic salmon biomasses in Aydin et al. (2003). For NEPac salmon species biomass trends are often assumed to be a function of catch trends (*e.g.*, Hare and Francis 1994, Beamish et al. 1997, Mantua et al. 1997). The catch time series for 5 salmon species was summed over two of the regions (Canada for the BC shelf model and North America for the NEPac model) reported in Eggers et al. (2003). The resulting historic catch trends were used to represent relative changes in biomass from 1950 to the present, see Figures 9 and 10. P/ and Q/B values for chinook salmon were based on results reported from the Great Lakes of North America reported in Rand and Stewart (1997). The P/Q ratio implied by that data for chinook (0.148) was then applied to the P/B for coho from the Great Lakes to estimate a Q/B for coho salmon in the North Pacific. Sockeye salmon P/B from (Aydin et al. 2003) was also divided by the chinook P/Q to estimate a North Pacific sockeye Q/B (Table 4). Pink and chum salmon P/B and Q/B values were estimated as relative to the other salmon species; pink being assigned high P/B and Q/B values, as it is the smallest of the 5 species, and chum being assigned smaller P/B and Q/B values as it is intermediate in size.

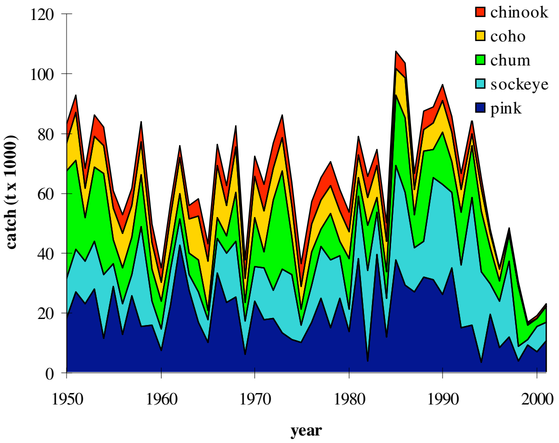


Figure 9. Time series of catches for chinook, coho, chum, sockeye, and pink salmon from Eggers et al. (2003) used as proxies for biomass in the BC shelf model.

For the BC salmon catch trend two major shifts appear to have occurred from 1985 to the present; a broad decline across all salmon species, and an even more acute decline in the catch of sockeye, coho and chinook (Figure 9). At the scale of the Northeast Pacific, however, these declines are dampened (coho, chinook and sockeye) or reversed (pink and chum). Indeed, at the scale of the Northeast Pacific (Figure 10) there has been a steadily increasing catch trend for pink, chum and sockeye. Thus BC salmon catches at present are much lower than averages since 1950, whereas for the whole Northeast Pacific salmon catches are similar or even higher than averages dating to 1950.

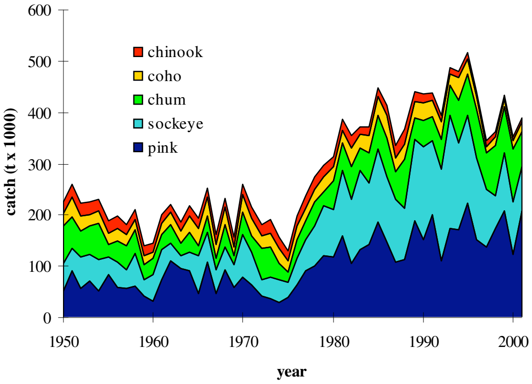


Figure 10. Time series of catches for chinook, coho, chum, sockeye, and pink salmon from Eggers et al. (2003), used as proxies for biomass in the NEPac model.

Salmon shark (*Lamna ditropis*) was represented as a unique functional group. All other pelagic sharks, chiefly made up of blue shark (*Prionace glauca*) and thresher shark (*Alopias vulpinus*), were aggregated as one group. The North Pacific population of salmon shark was estimated at 2,000,000 (Nagasawa 1998). Assuming an average mass of 100 kg, based on the average size of individuals sampled by Nagasawa (1998) between 50ºN and 56ºN, and a total North Pacific area of 10,000,000 km^2, the estimated biomass amounts to 0.02 t·km^{-2}. The North Pacific estimated biomass was applied to both models (Table 4). The biomass for pelagic sharks was the difference between the biomass value for salmon sharks and that reported for all sharks in the eastern subarctic model (Aydin et al. 2003). Assuming that fishing activity is minimal on these species, and assuming an average temperature of 12ºC FishBase (Froese and Pauly 2004), we estimated an M of 0.1 year^{-1}

to 0.2 year^{-1}. We used the upper value, 0.2 year^{-1} as a value of Z (Table 4). P/B for salmon shark was assumed to be equal to M, because of the small fishing mortality on the species. Assuming salmon sharks live in waters with average temperature of 12ºC, FishBase (Froese and Pauly 2004) estimated an M of 0.1 year^{-1} to 0.2 year^{-1}, the upper value was used as Z. The P/B for pelagic sharks was calculated in a similar fashion, with the average of values estimated for blue shark (M=0.17 year^{-1}) and thresher sharks (M=0.1 year^{-1}). Pelagic shark Q/B was also calculated as the average FishBase value for blue shark (0.8 year^{-1}) and thresher shark (0.12 year^{-1}).

The biomass for myctophids was taken from an estimate for the North Pacific (Gjosaeter and Kawaguchi 1980). P/B was based on M from FishBase (Froese and Pauly 2004) record for northern lampfish (*Stenobrachius leucopsarus*), assuming that the average annual temperature is 10ºC. Northern lampfish was found to be the most common myctophid in the North Pacific (Gjosaeter and Kawaguchi 1980). Q/B for myctophids was also derived from FishBase from values for northern lampfish (Table 4).

Table 4: Ecopath basic input parameters for pelagic fishes groups in the mass balanced BC Shelf and NEPac models

	Biom ($t \cdot km^{-2}$)	**P/B ($year^{-1}$)**	**Q/B ($year^{-1}$)**	**EE**	**P/Q**
BC Shelf					
Salmon shark	0.02	0.20	1.20		
Pelagic sharks	0.03	0.14	1.00		
Pink	0.20	1.40	8.90		
Chum	0.40	1.00	7.00		
Sockeye	0.20	1.27	8.40		
Coho	0.25	1.10	7.70		
Chinook	0.39	0.74	5.00		
Myctophids	4.50	0.50	6.80		
Misc. pred. pelagics	0.21	0.45	6.60		
Misc. small pelagics		2.30		0.95	0.30
NEPac					
Salmon shark	0.02	0.20	1.20		
Pelagic sharks	0.03	0.14	1.00		
Pink	0.20	1.40	8.90		
Chum	0.40	1.00	7.00		
Sockeye	0.20	1.27	8.40		
Coho	0.25	1.10	7.70		
Chinook	0.39	0.74	5.00		
Myctophids	4.50	0.50	6.80		
Misc. pred. pelagics	0.21	0.45	6.60		
Misc. small pelagics		2.30		0.95	0.30

A miscellaneous predatory pelagics group was created to include species like Pacific pomfret (*Brama japonica*), which are common offshore. Biomass for the group, therefore, was based on the value for pomfret in the eastern subarctic model of Aydin et al. (2003). P/B was based on M for Pacific pomfret and Pacific bonito (*Cololabis saira*) at 10 ºC in FishBase (0.66 and 0.26 year^{-1} respectively), thus, 0.45 year^{-1} was used as an intermediate value (Table 4). In that absence of any fishery on such species F ≈ 0 year^{-1} so Z ≈ 0.45 year^{-1}. Q/B was also based on a FishBase average for saury and bonito.

The miscellaneous small pelagics group was assumed to be made up of species like smelt and eulachon. P/B was set at 2.3 year^{-1} to represent a total mortality of 90% per year (Table 4). No reliable study of biomass for this group was available so the Ecotrophic Efficiency (EE) was set to 0.95, *i.e.*, 95% of mortality is due to explained ecosystem mortality like predation and fisheries. The P/Q was set at 0.3, which means that consumption should be about 3 times higher than production for this group: a reasonable guess, given that the species in this group are small and fast growing (Christensen et al. 2004).

Demersal fishes

Dogfish (*Squalus acanthias*) are perhaps the most abundant shark in the North Pacific. Their biomass was estimated as 150,000 to 200,000 t for the outer BC coast and 60,000 for the Strait of Georgia stock in 1994 (Thomson 1994). The outer coast middle value and Strait of Georgia value (175,000 t + 60,000 t) divided by the ecosystem area (176,000) gives a biomass ≈ 1.3 $t \cdot km^{-2}$ which was used on a coast-wide basis with total Canadian biomass (above) and the sum of catches over all areas from (which was taken from the DFO Fishery Observer Database). Thus, Beattie (2001) calculated F as 0.005 year^{-1} and the Z (P/B) = 0.099 year^{-1} (Table 5). The Q/B for dogfish has been estimated as 2.6 year^{-1} by Tanasichuk et al. (1991). Jones and Geen (1977) completed a detailed consumption study for dogfish, separating various life stages and the sexes of adults; the weighted mean of those consumption rates was 2.719 year^{-1}.

The biomass for ratfish (*Hydrolagus colliei*) and skates/rays (Rajiformes) was estimated respectively as 0.517 and 0.335 $t \cdot km^{-2}$ (Beattie 2001), i.e., ≈ 0.8 $t \cdot km^{-2}$ Thus, the two are added for these models. P/B and Q/B values for skates and rays were also from Beattie (2001).

Pacific Ocean perch biomass and time series of biomass estimates were available from stock assessments for the BC shelf (Schnute et al. 2001), BSAI (Spencer and Ianelli 2003b), and GoA (Hanselman et al. 2003), Figure 11. (Hanselman et al.

2003) have an M of 0.05 year^{-1} and an F ranging from 0.01 year^{-1} to 0.32 year^{-1}, (long term average 0.08 year^{-1}), so Z was estimated as 0.1 year^{-1}.

Table 5. EwE basic input parameters for demersal fishes groups in the mass balanced BC Shelf and NEPac models.

Group	Biom. (t·km^{-2})	P/B (year^{-1})	Q/B (year^{-1})	PQ
BC Shelf				
Dogfish	1.300	0.100	2.700	
Rajidae / ratfish	0.835	0.300	1.320	
Pac. Ocean perch	0.500	0.100	2.400	
Rockfish other	1.000	0.180	2.600	
Pac. hake	0.930	0.500	2.400	
Lingcod	0.363		2.400	0.10
Yellowfin sole	0.001	0.190	2.400	
Rock sole	0.144	0.220	2.300	
Flatfish other	1.300		3.000	0.20
Misc. small demersals	7.000		5.256	0.30
NEPac				
Dogfish	1.300	0.100	2.700	
Rajidae / ratfish	0.835	0.300	1.320	
Pac. Ocean perch	1.300	0.100	2.400	
Northern rockfish	0.158	0.900	2.600	
Rockfish other	1.000	0.180	2.600	
Pac. hake	0.093	0.500	2.400	
Atka mackerel	0.269	0.600	3.000	
Lingcod	0.363		2.400	0.10
Yellowfin sole	0.505	0.190	2.400	
Rock sole	0.572	0.220	2.300	
Plaice	0.461	0.250	2.000	
Flatfish other	1.300		3.000	0.20
Misc. small demersals	7.000		5.256	0.30

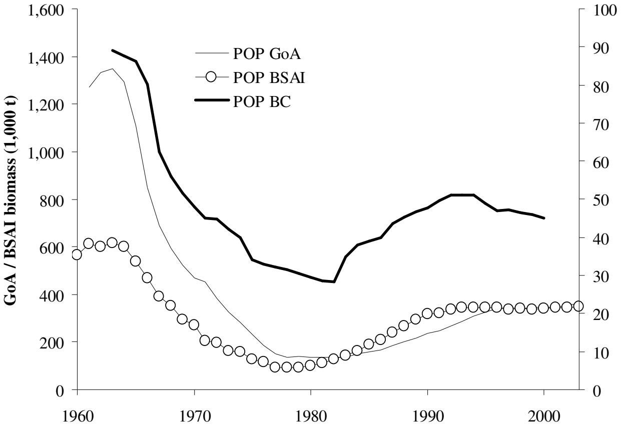


Figure 11. Time series of Pacific Ocean perch biomass from stock assessments for the Gulf of Alaska (Hanselman et al. 2003), Bering Sea / Aleutian Islands (Spencer and Ianelli 2003b), and BC coast (Schnute et al. 2001).

The other rockfish group can be thought of as containing species commonly referred to as shelf and inshore rockfish. As such, an estimation of biomass for the group is difficult because of the diversity of species it contains. For these models the biomass estimate is an extrapolation from Murie et al. (1994). Submersible estimates of inshore rockfish density in Saanich Inlet suggested that the average density was 5 per 100 m^2. Assuming an average weight of 2 kg for an inshore rockfish, the biomass density for the study area is 0.1 $t{\cdot}km^{-2}$. Shelf rockfish data was taken from Bonfil (1997) for silvergrey rockfish (*Sebastes brevispinis*), yellowtail rockfish (*S. flavidus*), and canary rockfish (*S. pinniger*). Table 2 in Bonfil (1997) lists total B.C. biomass estimates in tonnes as 6,316 t silvergray, 4,994 t yellowtail, 2,215 t canary. For widow rockfish (*S. entolomelas*) biomass was estimated from dividing catch reported in Anonymous (1999b) by the average proportion of fish caught over biomass reported for the other 3 species in Bonfil (1997) to give a biomass estimate for widow rockfish of 4,860 t. Thus, for the whole BC coast, the shelf rockfish biomass $\approx$ 0.163 $t{\cdot}km^{-2}$. Therefore, the other rockfish biomass is at least 0.263 $t{\cdot}km^{-2}$, but given that there are many unfished species in this group, the true value may be much higher.

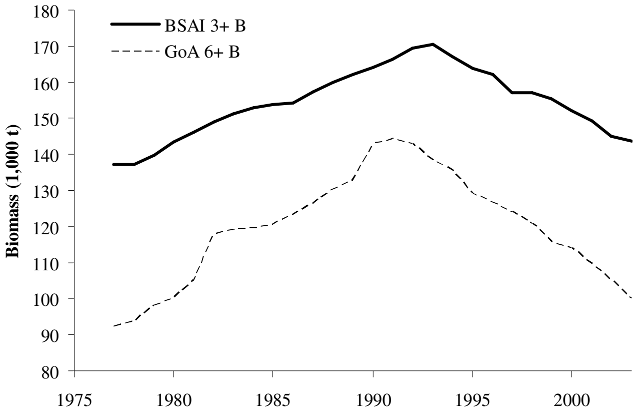


Figure 12. Biomass time series of age 3+ northern rockfish in the Bering Sea / Aleutian Islands area (Spencer and Ianelli 2003a) and 6+ northern rockfish in the Gulf of Alaska area (Courtney et al. 2003).

Northern rockfish (*Sebastes polyspinis*) stock assessments were available for the BSAI (Spencer and Ianelli 2003a) and GoA (Courtney et al. 2003) stocks. This assessment was used to estimate biomass and time series of biomass for that species in the NEPac model, Figure 12. Spencer and Ianelli (2003a) have an F $\approx$ 0.05 $year^{-1}$ and an M $\approx$ 0.07 $year^{-1}$. Thus, for the EwE model Z $\approx$ 0.12 $year^{-1}$ (Table 5).

Pacific hake (*Merluccius productus*) is represented in the ecosystems modelled by a Strait of Georgia (SoG) population and one off the West Coast of Canada which is actually the northern arm of one centered further south off the coasts of California, Oregon and Washington. The SoG population (Saunders and McFarlane 1998) is so much smaller than that off the West Coast of Vancouver Island that the latter's stock assessment (Jagielo and Sinclair 2002) was used for the effective BC shelf biomass and biomass time series data (Figure 13). Because the population that exists off BC represents only a small portion of the west coast of North America (WCNAm) hake stock, the biomass for that stock was divided by 10 to represent the BC portion of that stock in determining the BC shelf biomass value. Because the hake do not range north of Canadian waters, the biomass for the NEPac model was presumed to be approximately one tenth (the proportion of area within the NEPac model occupied by the BC shelf model) that of the BC shelf. Dorn et al. (1998) estimate that the M for hake is about 0.25 $year^{-1}$ and an F_{MSY} of about 0.25 $year^{-1}$, therefore P/ was determined to be 0.5 $year^{-1}$.

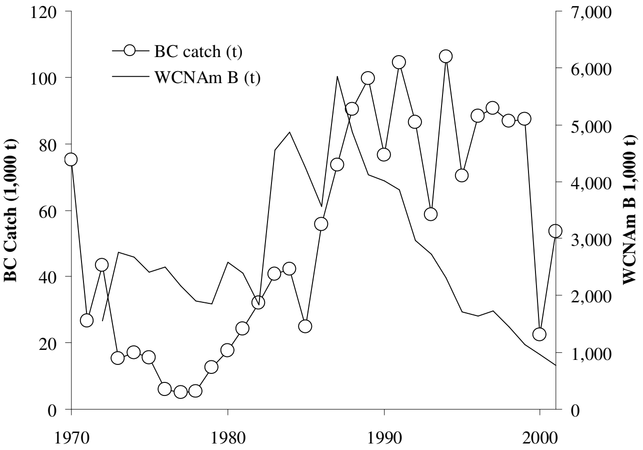


Figure 13. Time series of biomass for the west coast of North America (WCNAm) hake stock and catch of hake in Canadian waters (Jagielo and Sinclair 2002).

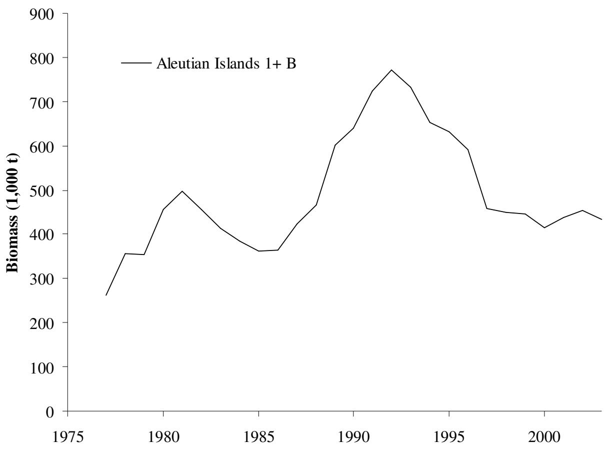


Figure 14. Time series of biomass for age 1+ Atka mackerel in the Aleutian Islands area from (Lowe et al. 2003).

Atka mackerel (*Pleurogrammus monopterygius*) exist almost entirely within the Aleutian Islands area. Relatively small numbers are known to be in the GoA (Lowe and Lauth 2003), so the biomass and temporal dynamics of the Aleutian Islands stock (Lowe et al. 2003) were used as representative of dynamics for the NEPac ecosystem (Figure 14). Lowe et al. (2003) have an M of 0.3 year^{-1} and F ranging from 0.06 year^{-1} to 0.7 year^{-1}, with an average of 0.3 year^{-1}, so Z is about 0.6 year^{-1}.

For lingcod (*Ophiodon elongatus*) biomass was taken from the Hecate Strait analysis (Martell 1999) as representative of trends in both ecosystems. P/B was left as an unknown, so the P/Q was set at 0.1, *i.e.*, production being about one tenth of consumption, based on arguments on acceptable P/Q values (Christensen et al. 2004).

The vast majority of yellowfin sole (*Limanda aspera*) biomass in the NEPac ecosystem is within the BSAI area. The biomass and biomass time series (Figure 15) were taken from Wilderbauer and Nichol (2003) as were estimates of M (0.12 year^{-1}) and F (0.07 year^{-1}) for a total P/B of 0.19 year^{-1} (Table 5). The biomass for yellowfin sole was set to a very low 0.001 t/km^{-2} to represent its presence. Alaska plaice (*Pleuronectes quadrituberculatus*) is found chiefly within the BSAI region of the NEPac ecosystem. A stock assessment and time series of biomass for the BSAI population was found in Spencer et al. (2003) which also estimated M (0.25 year^{-1}) and F (0.05 year^{-1}), suggesting a P/B ≈ 0.3 year^{-1}. Rock sole (*Lepidopsetta polyxystra*) is found throughout the NEPAc area and is common in the BC shelf ecosystem. Stock assessments with time series of biomass were available for the BSAI in Wilderbauer and Walters (2003) and BC shelf in Anonymous (1999a) (Figure 15). Estimates of M (0.18 year^{-1}) and F (0.04 year^{-1}) were from Wilderbauer and Walters (2003) to give a P/B of 0.22 year^{-1} (Table 5).

The other flatfish group includes species like butter sole (*Pleuronectes isolepis*), starry flounder (*Platichthys stellatus*), Dover sole (*Microstomus pacificus*), rex sole (*Glyptocephalus zachirus*), sand sole (*Psettichthys melanostictus*), flathead sole (*Hippoglossoides elassodon*), and Greenland turbot (*Reinhardtius hippoglossoides*). Based on biomass estimates for these species in the GoA (Turnock et al. 2003a), this group of species is approximately as abundant as Alaska plaice, rock sole and yellowfin sole combined, *i.e.*, a biomass of about 1.0 to 1.5 t·km^{-2}. Q/B was estimated as an upper value for all of the species in this group based on values from FishBase (Froese and Pauly 2004). P/Q was estimated as 0.2 as this group represents creature that are in neither particularly short lived, and fast growing, nor long lived and slow growing (Christensen et al. 2004).

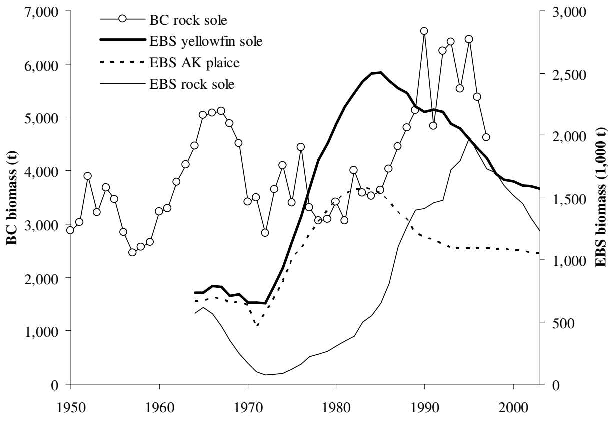


Figure 15. Time series of biomass for the northern British Columbia stock of rock sole (Anonymous 1999a) and Eastern Bering Sea stocks of yellowfin sole (Wilderbauer and Nichol 2003), rock sole (Wilderbauer and Walters 2003), and Alaska plaice (Spencer et al. 2003). Note that the BC rock sole biomass is three orders of magnitude smaller than the values for the other time series.

An estimate of biomass for miscellaneous small demersals was derived from Acuna et al. (2003, Table 7) for cottidae, zoarcidae, agonidae, cyclopteridae, and 'other fish'. The biomass derived for the EBS from that source is slightly more than 0.5 t·km^{-2}. Based on the ubiquity of these fishes in the shallower waters that estimate appears low. Bear in mind that most trawl surveys would be in waters unlikely to contain much of the small demersal biomass. For example Acuna et al. (2003, Appendix A Tables 1 and 2) list 355 tows, the average depth of which was about 77 m. Less than 14% of those tows were shallower than 40 m and none were shallower than 17 m. Thus, it seems likely that the real small demersal biomass is much higher than estimated above. The Q/B estimate

(5.256 year^{-1}) was the unweighted mean for three species (poacher, eelpout and a sculpin) given in Wakabayashi (1986). P/Q was estimated as 0.3 following the logic of previous P/Q estimates.

Invertebrates / primary producers

Krill biomass was based on Mackas (1991) for the WCVI from 1979-1989 using values from his Figure 11: 'Average seasonal cycles of euphausiid biomass off the outer coast of Vancouver Island'. The average value for the period of record was 4.46 t·km^{-2}. But Beamish et al. (2001) used 80 t·km^{-2} as a conservative estimate of euphausiid biomass for the SoG. Thus, an area-weighted method was employed to get total BC Shelf biomass with SoG = 18,000km^{2}/ 113,000km^{2} of the total ecosystem area. About 16% of the total area is SoG and the rest was accounted for based on Mackas (1991), i.e., (80 t·km^{-2} · 0.16) + (4.5 t/km^{2}· 0.84) = 16.58 t·km^{-2}. Note also that Aydin *et al.* (2003) have 25 t·km^{-2} as an estimate of eastern subarctic Pacific Ocean krill biomass. Fulton et al. (1982) estimated a krill P/B = 5.5 year^{-1} from a survey of the Pacific Coast of Canada. Robinson and Ware (1994) estimated that a P/B = 8 year^{-1} would be required for euphausiids in the southwest Vancouver Island upwelling system to support estimated predation. Iguchi and Ikeda (1999) estimated a yearly P/B = 6 year^{-1} for *Euphasia pacifica* in Toyama Bay, Japan (Table 6). The Q/B was calculated from the average daily consumption of *E. pacifica* required to maintain the population growth, metabolism and reproduction (Iguchi and Ikeda 1999). The average daily consumption was 6.8% of biomass, giving a Q/B = 24.82 year^{-1}.

Table 6: EwE basic input parameters for invertebrate groups in the mass balanced BC Shelf and NEPac models

Groups	Biom. (t·km^{-2})	P/B (year^{-1})	Q/B (year^{-1})	EE	PQ
BC Shelf					
Krill	18.00	6.00	24.80		
Carn. zooplankton	25.00	7.00	20.00		
Herb. Zooplankton	25.00	27.00	80.00		
Jellies	12.50	9.60	13.00		
Large squids	0.50	2.60	6.40		
Small squids		3.00	15.00	0.9	
Shrimps	5.65	1.20	9.67		
Crabs	3.80	1.50	3.50		
Bivalves	7.70	0.90			0.20
Echinoderms	14.80	0.30			0.25
Other benthos	43.00	4.50			0.30
Phytoplankton	22.00	130.00			
Macrophytes	9.00	9.00			
Detritus	10.00				
NEPac					
Krill	18.00	6.00	24.80		
Carn. zooplankton	25.00	7.00	20.00		
Herb. Zooplankton	25.00	27.00	80.00		
Jellies	12.50	9.60	13.00		
Large squids	0.50	2.60	6.40		
Small squids		3.00	15.00	0.9	
Shrimps	5.65	1.20	9.67		
Crabs	3.80	1.50	3.50		
Bivalves	7.70	0.90			0.20
Echinoderms	14.80	0.30			0.25
Other benthos	43.00	4.50			0.30
Phytoplankton	22.00	130.00			
Macrophytes	9.00	9.00			
Detritus	10.00				

Carnivorous zooplankton biomass was based on values for miscellaneous predatory zooplankton, amphipods, and pteropods (Aydin et al. 2003). Herbivorous zooplankton biomass was estimated from copepods and microzooplankton (Aydin et al. 2003). Carnivorous zooplankton P/B and Q/B as well as herbivorous zooplankton Q/B was taken from the estimate used by Beamish et al. (2001). Herbivorous zooplankton P/B was estimated by the model of Robinson and Ware (1994).

The biomass of jellies, 12 t·km^{-2}, was taken from Mackas (1991, Figure 7) for the south Vancouver Island shelf system. Note that this weight is calculated assuming dry weight is 4.2 % of wet weight (Larson 1986). To estimate P/B, Hansson (1997) claimed a growth rate for *Aurelia aurita* of 0.053·day^{-1} at 5°C to 0.15·day^{-1} at 16.5°C. The average conservative estimate was the basis for the value used in these models assuming they only persist for about half the year (Arai 1996), *i.e.*, 0.053 · 365/2 ≈ 9.6 year^{-1}. To estimate Q/B, Matishov and Denisov (1999) have a diurnal consumption rate of 7% of biomass for medusae in the Black Sea. This would translate to an annual consumption per unit biomass of 365·0.07= 25.55 year^{-1}, which, divided by two to represent disappearance in the winter, is ≈ 13 year^{-1} (Table 6).

Large squid biomass was the combined biomass of the three large squid groups; neon flying squid, clubhook squid, and large gonatid squid (Aydin et al. 2003), 0.45, 0.012, and 0.03 respectively for a total biomass of 0.5 t·km^{-2}. Small squid biomass was left to be estimated by Ecopath by setting ecotrophic efficiency for the group to 0.9, *i.e.*, 90% of mortality due to explainable sources within the ecosystems (Table 6). Q/B and P/B for these two groups were also synthesised from the comparable groups (Aydin et al. 2003).

Shrimp biomass was based on the shrimp group of Aydin et al. (2003) and included sergestid shrimps. Thus, the biomass was higher than it would have been for benthic shrimps and prawns by themselves. Martell et al. (2000) have an F of 0.18

year^{-1} and an M of 0.96 year^{-1} for *Pandalus jordani* of the WCVI. Thus Z ≈ 1.14 year^{-1}. Heymans (2001) has a P/B of 1.45 year^{-1} for *Pandalus borealis* off the east coast of Canada (Bundy et al. 2000). So for these models Z was 1.2 year^{-1}, the estimation biased to the locally derived number. Shrimp Q/B was based upon the value used by Bundy et al. (2000).

To obtain an estimate of biomass for crabs, an area-weighted system using data in Burd and Brinkhurst (1987) and Nyblade (1979) was used. The former for deeper marine waters, the latter for waters less than 20 m depth. The area assigned to the two for weighting was 5% shallow water, based on areas reported for SoG depth strata in Guénette (1996). Total instantaneous mortality for male dungeness crabs (*Cancer magister*) was estimated to be 2.5 year^{-1} (2.3 year^{-1} - 2.8 year^{-1}) from a study in Clayoquot Sound, B.C. (Smith and Jamieson 1989, Smith and Jamieson 1991). Female Z was estimated at 1.3 year^{-1} (Smith and Jamieson 1989, Smith and Jamieson 1991). Boutillier et al. (1998) modelled mortality rates of 0.6 year^{-1} - 1.4 year^{-1}, and found resultant exploitation rates of 33-68% for McIntyre Bay and 41 - 54 % for Hecate Strait. Thus, total Z in the area could be expected to be a maximum of 2.01 year^{-1}, and a minimum of 0.97 year^{-1}, with an average value of Z ≈ 1.5 year^{-1}. As there are smaller crabs in this group, the Q/ B may be higher, although 1.5 year^{-1} implies the population turns over twice every three years, which is pretty high production. Wakabayashi (1986) reported the Q/B for the red king and tanner crab in Alaskan waters, and for the present I took the mean value of those estimates: Q/B = 3.541 year^{-1} (Table 6).

To estimate biomass for bivalves, echinoderms, and 'other benthos' an area-weighted system using data from Burd and Brinkhurst (1987) and Nyblade (1979) was used. In order to calculate the biomass for the BC Shelf the same area weighting method was used as for crabs. For bivalve P/B, Jørgensen et al. (2000) have a P/B for *Macoma baltica* of 1.5 year^{-1}, whereas *Mytilus sp.* is assigned a value of 0.3 year^{-1}. For the two models, the average of the two P/Bs was used (0.9 year^{-1}). P/B for echinoderms was from Jørgensen et al. (2000) for 'echinodermate'. P/B for 'other benthos' was derived from Jørgensen et al. (2000) as a weighted average of: *Spirorbis sp.*, a polychaete, P/B=4 year^{-1} (45% of other benthos biomass); amphipoda P/B= 0.024 per day, i.e., 8.76 year^{-1} (10% of other benthos biomass); and *Litorina saxatilis*, a gastropod: P/B = 4.1 year^{-1} (45% of other benthos biomass). Thus, the weighted average P/B ≈ 4.5 year^{-1}. Q/B was left unknown and P/Q was estimated for all three groups. P/Q values were assigned to bivalves, echinoderms and other benthos on the basis of general knowledge of their biology. Because other benthos includes many fast growing herbivores, their P/Q was high, whereas the lower value of 0.20 for bivalves reflects their longer lived, slower growing nature. Echinoderms were assigned a middle value, they grow slow, but many are heavily predated upon, *e.g.*, holothuroideans and echinoideans.

For phytoplankton biomass estimates, Beamish et al. (2001) have values of 36 t·km^{-2} and 72 t·km^{-2} for two different years modelled in the SoG. For the BC Shelf model the average of 50 t·km^{-2} was used for calculatinging an area-weighted value. Robinson and Ware (1994) stated that the average biomass off the WCVI was 2.7 gC·m^{-2}. A conversion factor of 6 was applied to the carbon weight to get wet weight. The conversion ratio was averaged from references for different diatoms in Jørgensen et al. (2000). Thus, resulting in an estimate of 16.236 t·km^{-2} for the WCVI area. Therefore, to calculate a biomass for all of the BC Shelf, the SoG biomass was weighted as 10% of the total area, and the WCVI estimate used for the other 90% of the total ecosystem area. Yielding an area weighted biomass for the BC Shelf ≈ 20 t·km^{-2}. Phytoplankton P/B was also taken from Beamish et al. (2001).

To estimate macrophyte biomass an EE of 0.9 was assumed for the group. However, data from exposed rocky shores (Nyblade 1979) suggested a macrophyte biomass of 2,300 g·m^{-2}. Multiplying this favourable habitat biomass by 0.05, i.e., the available macrophyte habitat accounted for 5% of the total ecosystem area, provides a potential BC Shelf total of 115 t·km^{-2} . However, this estimate appeared too high and it is also probable that not all the habitat would be so favourable, leading to likely overestimation of biomass for this group. Without more precise studies of macrophyte distribution and biomass throughout these areas, estimation of the biomass via an an assumed EE will be necessary. In these models an EE of 0.9 was used, despite the fact that some argue for a much lower value.

DIET COMPOSITIONS

Multi-stanza groups

Arrowtooth flounder adult, Pacific cod adult, Pacific halibut adult, walleye pollock adult, and sablefish adult diet compositions were taken from Yang and Nelson (1999). Note that as a general rule when a multi- stanza group species was in the diet composition of a predator 1/3 was apportioned to the juvenile stanza, and 2/3 to the adult stanza, to divide up their contribution as prey items (see Table 7). Arrowtooth flounder juvenile diet composition was based on information on diet of juvenile arrowtooth flounder on FishBase. Herring juvenile, Pacific cod juvenile, and walleye pollock juvenile diet compositions were from Sturdevant (1999). The herring juvenile diet composition was modified to show some trophic ontogeny. Pacific halibut juvenile diet composition was from St-Pierre and Trumble (2000). Sablefish juvenile diet composition was inferred from information in FishBase (Froese and Pauly 2004) to represent feeding chiefly on zooplankton as age 0-1 with small fish and benthos included as the juveniles neared adulthood.

Table 7: Diet compositions for adult (normal type) and juvenile (bold type) multi-stanza groups in the NEPac and BC Shelf models.

Prey	**Arrowtooth**	**P. cod**	**P. halibut**	**Sablefish**	**Pollock**	**Herring**
Arrowtooth juv.	0.004		0.002	0.004		
Arrowtooth ad.			0.02	0.006		
P. cod juv.	0.016	0.01	0.01	0.01/ **0.01**	0.01	
P. cod ad.			0.006			
P. halibut juv.	0.01					
Sablefish juv.	0.001					
Pollock juv.	0.002	0.001	0.002	0.002/ **0.002**	0.002	
Pollock ad.	0.03	0.03	0.1	0.03		
Herring juv.	0.01		0.005/ **0.001**	0.003		
Herring ad.	0.02	0.01	0.005 /**0.005**	0.007		
Rajidae / ratfish	0.02		0.02			
Pink	0.01		**0.001**			
Chum	0.01		**0.001**			
Sockeye	0.01					
Pac. Ocean perch						
Rockfish other	0.01		**0.01**			
Atka mackerel		0.01	0.01			
Rock sole			0.02			
Flatfish other	0.02		0.06/ **0.03**			
Myctophids	0.01		**0.01**	0.01	0.001	
Misc. small demersals	0.1/ **0.15**	0.15 **0.03**	0.15/ **0.1**	0.138/ **0.15**	0.07/ **0.079**	
Misc. small pelagics	0.13/ **0.23**	0.05 **0.03**	0.042	0.02/ **0.2**	0.02/ **0.079**	
Krill	0.15/ **0.22**	0.05 **0.115**		0.08/ **0.2**	0.442/ **0.183**	0.37/ **0.132**
Carn. zooplankton		0.419		0.02/ **0.19**	0.1/ **0.307**	0.23/ **0.304**
Herb. zooplankton		0.109			0.02/ **0.286**	0.4/ **0.434**
Jellies				0.13	**0.007**	
Large squids			0.01	0.05		
Small squids	0.028	0.01	**0.01**	**0.01**	**0.01**	
Shrimps	0.11/ **0.15**	0.05/ **0.056**	0.3	0.08	0.15/ **0.017**	**0.01**
Crabs		0.22/ **0.056**	0.33 0.19	0.04	0.02/ **0.017**	
Bivalves		0.01				
Echinoderms		0.02			0.02	
Other benthos	0.299/ **0.25**	0.389/ **0.175**	0.198	0.15/ **0.25**	0.145/ **0.015**	**0.12**
Detritus				0.22		

Birds / marine mammals

Bird diets were synthesised from Dragoo et al. (2001), Bertram et al. (2001), Sydeman et al. (2001), Burkett (1995), Wehle (1983), and Ainley et al. (1981). These diet compositions provided the logical basis for splitting birds into 3 functional groups: pelagic piscivorous; demersal piscivorous; zooplanktivorous (Table 8).

Table 8. Diet compositions for the three groups of bird in the NEPac and BC Shelf models.

Prey	**Pelag pisciv**	**Demer pisciv**	**Zoo planktiv**
Pollock juv.	0.020	0.002	
Herring juv.	0.050	0.005	
Herring ad.	0.020	0.010	
Myctophids	0.602	0.020	
Misc. sm. Dem.	0.060	0.667	
Misc. sm. pel.	0.160	0.100	
Krill	0.010	0.036	0.570
Carn. zoop.		0.010	0.430
Large squids	0.010	0.010	
Small squids	0.040	0.047	
Shrimps		0.015	
Other benthos	0.028	0.078	

Mysticetae diet was weighted, by biomass data of the three species that make up this group; grey (79%), humpback (17%), minke (4 %). The diets of the three species in this group were derived from Pauly et al. (1998) (see Table 9). Odontocetae diet composition was also based on a biomass-weighted mean of the species; Dall's porpoise 8.6%, Pacific white-sided dolphin 21.9%, harbour porpoise 4.3%, northern right whale dolphin 1.5%, and orcas 63.7%, reported by Pauly et al. (1998). The group eats primarily fish, followed by zooplankton, squid, benthic animals and higher vertebrates, such as seals. The fish component of the diet in Pauly et al. (1998) was not reported by species or family. For the purpose of this study the diet composition contributed by fish and squid was also informed by the diet composition attributed to fish for toothed whale groups in Aydin et al. (2003). The diet component arising from 'higher vertebrates' was assumed to be seals and sea lions as a result of transient orca predation. The rockfish component of the diet distributed to reflect abundances of the three groups. Also, pollock was included in the diet composition. Sea lion diet composition was based on an amalgamation of Steller sea lion diet data in Trites and Heise (1996) and pollock was added based on the fact that the UBC Marine Mammal Research Unit web page suggests pollock is anywhere from 25 to 50 % of Steller sea lion diet. Seal diet composition was derived from harbour seal diets in Everett Washington used in Preikshot and Beattie (2001).

Table 9. Diet compositions for marine mammal groups in the NEPac and BC Shelf models.

Prey	**Odontocetae**	**Mysticetae**	**S.lion**	**Seal**
P. cod juv.			0.001	0.001
P. cod ad.			0.039	
S	0.001		0.001	
Sablefish ad.	0.005		0.003	
Pollock juv.	0.02		0.005	0.009
Pollock ad.	0.08		0.2	0.1
Herring juv.	0.01	0.005	0.005	0.01
Herring ad.	0.02	0.003	0.005	0.01
Mysticetae	0.0001			
Sea lions	0.02			
Seals	0.0001			
Dogfish	0.05			
Rajidae / ratfish			0.02	
Pink	0.01		0.05	0.1
Chum	0.02		0.05	0.15
Sockeye	0.04		0.032	0.1
Coho	0.005		0.05	0.1
Chinook	0.005		0.05	0.1
Pac. Ocean perch	0.01		0.001	0.001
Northern rockfish	0.005		0.001	0.001
Rockfish other	0.01		0.001	0.001
Pac. hake			0.001	0.01
Atka mackerel	0.02		0.02	
Yellowfin sole	0.01			
Rock sole	0.01		0.025	
Plaice	0.02		0.03	
Flatfish other			0.04	
Myctophids	0.1			
Misc. small Demersals	0.05		0.05	0.02
Misc. pred. pelagics	0.04		0.01	0.01
Misc. small Pelagics	0.119	0.14	0.232	0.23
Krill		0.16		
Carn. zooplankton		0.013		
Large squids	0.2098		0.02	0.01
Small squids	0.11	0.03	0.02	0.01
Shrimps		0.001		
Crabs		0.012		
Bivalves		0.09		
Echinoderms		0.05		
Other benthos		0.496	0.038	0.027

Pelagic fishes

Chinook salmon diet was based on a synthesis of Aydin et al. (2003) and feeding of chinook off Northern California as reported in Hunt et al. (1999). Aydin et al. (2003) have their eastern subarctic chinook diet almost evenly divided between pelagic forage fish, small squid, and mesopelagic fish. Coho salmon diet composition was adapted from LeBrasseur (1966), which reports 'fish' as one of the groups in coho diet. In order to assign the most likely prey groups, some representative part of this predation, misc. pelagics were given half (*i.e.*, 11% of total diet composition), herring 10%, eulachon 1%, and misc. small demersals a trace. Part of the krill fraction of coho diet was instead allocated to myctophids as coho tend to be more piscivorous than planktivorous, for example, Aydin et al. (2003) have coho diet almost evenly divided between pelagic forage fish, small squid, and mesopelagic fish. Chum salmon diet composition was adapted from eastern subarctic chum in Aydin et al. (2003). Pink salmon diet composition was adapted from eastern subarctic pink in Aydin et al. (2003). Sockeye diet composition was adapted from Kaeriyama (2000) and eastern subarctic sockeye in Aydin et al. (2003), although Aydin et al. (2003) have sockeye eating less squid than the former document suggests. Therefore, some of the diet composition apportioned to squid was shifted to carnivorous zooplankton (Table 10).

The miscellaneous predatory pelagic diet composition was based on eastern subarctic pomfret in Aydin et al. (2003) and the entry for bonito in Fishbase (Froese and Pauly 2004) which has them eating squid fish and shrimp (see Table 10). Miscellaneous small pelagic diet data was inferred from Sturdevant (1999), and represents a mixture of diets given for eulachon and capelin. Myctophids diet composition was derived from Moku et al. (2000). Pelagic sharks diet composition was taken from Cortes (1999) for blue shark and thresher shark and qualitatively informed by information in Aydin et al. (2003). Salmon shark diet composition information was obtained from Nagasawa (1998), in which Figure 6 shows that of stomachs containing food 2/3 of prey was salmonids and 1/3 was ‘other species’. The salmonid portion was divided up among the 5 salmon species roughly according to their biomass proportion for all salmon. The other species portion was divided up among pollock, dogfish, myctophids, miscellaneous predatory pelagics, miscellaneous small pelagics, large squids and small squids.

Table 10. Diet compositions for pelagic fish groups in the NEPac and BC Shelf models. Note; s shark is salmon shark, p shark is pelagic sharks, myct is myctophids, pred pel is predatory pelagics, and sm pel is miscellaneous small pelagics.

Prey	S shark	P shark	Pink	Chum	Sock.	Coho	Chin	Myct	Pred. pel.	Sm pel
Pollock ad.	0.033									
Herring juv.				0.005		0.010	0.010			
Herring ad.						0.005	0.005			
Dogfish	0.033									
Pink	0.100	0.020								
Chum	0.167	0.030								
Sockeye	0.300	0.050								
Coho	0.087	0.005								
Chinook	0.013	0.005								
Pac. Ocean perch							0.005			
Rockfish other							0.005			
Myctophids	0.033	0.030	0.030	0.005	0.030	0.255	0.200		0.100	
Misc. small emersals		0.100	0.064	0.075	0.026	0.005	0.001			0.050
Misc. pred. pelagics	0.020	0.020								
Misc. small pelagics	0.047	0.030	0.103	0.125	0.030	0.236	0.335		0.250	0.050
Krill		0.050	0.090	0.055	0.044	0.124	0.170	0.230	0.020	0.200
Carn. zooplankton			0.391	0.299	0.368	0.020		0.220	0.010	0.320
Herb. zooplankton			0.100	0.140	0.083			0.220		0.180
Jellies			0.006	0.109	0.003					
Large squids	0.100	0.550								
Small squids	0.067	0.050	0.102	0.020	0.400	0.345	0.225		0.600	
Shrimps		0.030	0.014	0.012	0.001			0.010	0.020	0.030
Crabs		0.030	0.014	0.012			0.044			0.010
Bivalves			0.001	0.005						
Other benthos			0.088	0.138	0.015			0.320		0.160

Demersal fishes

Dogfish diet was adapted from Jones and Geen (1977). Other flatfish diets were based on flathead sole diet in Yang and Nelson (1999). Lingcod diet was taken from Beattie (2001), which was, in turn, derived from Cass et al. (1986). Miscellaneous small demersals diet composition was adapted from sculpin diets in Wakabayashi (1986, Appendix Table 3). Pacific hake diet composition was adapted from Rexstad and Pikitch (1986, Table 2). Pacific Ocean perch diet was from Brodeur and Livingstone (1988) and Yang (1993). Rajidae/ratfish diets were based on qualitative and quantitative information in Casillas et al. (1998). Note that ratfish have a remarkably varied diet that includes mollusks, squid, nudibranchs, opisthobranchs, annelids, small crustaceans, and even seaweed (Table 11). Rock sole diet composition was taken from Wakabayashi (1986). Other rockfish diet composition was made up of an aggregation of rougheye rockfish, dusky rockfish, and shortspine thornyhead as found in Yang (1993). Yellowfin sole diet was taken from Wakabayashi (1986).

Invertebrates

Other benthos diet composition was based on diet composition of macrobenthos in Okey and Pauly (1999) (see Table 12). Bivalves, carnivorous zooplankton, crabs, shrimps, echinoderms diet compositions were adapted from previous EwE models for the northeast Pacific, (Okey and Pauly 1999, Beattie 2001, Preikshot and Beattie 2001, Aydin et al. 2003), and feeding tendencies were qualitatively examined based on general knowledge of these animals. Because many of the invertebrate groups are highly aggregated such inferences are likely to reflect general flows of energy derived from primary production. Herbivorous zooplankton diet composition was from Robinson and Ware (1994). Jellies diet composition was based on a mixture of the eastern subarctic diet compositions for the large jelly and ctenophore group in Aydin et al. (2003). Krill diet composition was from Robinson and Ware (1994). Large squids diet composition was based on a mixture of eastern subarctic diet compositions for clubhook squid, neon flying squid and large gonatid squid in Aydin et al. (2003). Small squids diet composition was based on eastern subarctic micronectonic squid diet composition in Aydin et al. (2003).

Table 11. Diet compositions for demersal fish groups in the NEPac and BC Shelf models. Note; dogf is dogfish, raj ra is rajidae / ratfish, POP is Pacific Ocean perch, NRF is northern rockfish, ORF is rockfish other, AM is Atka mackerel, ling is lingcod, YFS is yellowfin sole, r sole is rock sole, OFF is flatfish other, and sdem is miscellaneous small demersals.

Prey	Dogf	Rajra	POP	NRF	ORF	Hake	AM	Ling	YFS	R sole	Plaice	OFF	Sdem
Arrowtooth juv.								0.003					
Arrowtooth ad.								0.005					
P. cod juv.	0.002							0.015					
P. cod ad.								0.005					
Pollock juv.	0.004		0.002			0.005	0.002	0.003				0.001	
Pollock ad.	0.069					0.010		0.012					
Herring juv.	0.020					0.050		0.010					
Herring ad.	0.005					0.003		0.010					
Rajidae / ratfish	0.017												
Coho	0.001												
Chinook	0.001												
POP								0.005					
Rockfish other	0.001							0.010					
Pac. hake	0.002					0.002		0.002					
Yellowfin sole								0.030					
Rock sole	0.003							0.020					
Plaice								0.010					
Flatfish other	0.016		0.040			0.006		0.005					0.010
Myctophids													
Sdem	0.098	0.010	0.020		0.100	0.017	0.040	0.205	0.037	0.164		0.040	0.020
Misc. pred. pel.													
Misc. small pel.	0.206					0.007		0.550	0.003	0.004			0.250
Krill	0.139		0.670	0.930	0.200	0.701	0.150		0.007				0.010
Carn. zoopl	0.099			0.050		0.101	0.220		0.093	0.060	0.100		0.010
Herb. zoopl						0.050	0.220						
Jellies	0.037						0.190						
Small squids					0.100				0.005				0.010
Shrimps	0.008	0.010	0.190		0.130	0.001			0.022	0.001		0.100	0.030
Crabs	0.073	0.130			0.050				0.052	0.015		0.050	0.040
Bivalves	0.004	0.170					0.020		0.157	0.020	0.350		0.010
Echinoderms		0.180							0.081	0.003		0.200	0.040
Other benthos	0.195	0.500	0.078	0.020	0.420	0.047	0.158	0.100	0.543	0.733	0.550	0.609	0.570

Table 12: Diet compositions used for the invertebrate groups for the NEPac and BC shelf models. Note; C zoop is carnivorous zooplankto, H zoop is herbivorous zooplankton, l squid is large squids, s squid is small squids, bivalv is bivalves, echino is echinoderms, and betho is other benthos.

Prey	Krill	C zoop	H zoop	Jelly	L squid	S squid	Shrimp	Crabs	Bivalv	Echino	Benthos
Myctophids					0.050						
Misc. sm pel					0.100						
Krill		0.050		0.120	0.100	0.250	0.250				
Carn zoop	0.025	0.050		0.330	0.150	0.450	0.250		0.100		0.005
Herb. zoop	0.075	0.850		0.300	0.100	0.250	0.250		0.050		0.010
Jellies				0.050							
Small squids					0.500	0.050					
Crabs								0.050			
Bivalves								0.100			
Echinoderms								0.010			
Other benthos								0.550		0.700	0.050
Phytoplankton	0.900	0.050	1.000	0.200					0.550		0.400
Macrophytes								0.100		0.250	0.100
Detritus							0.250	0.190	0.300	0.050	0.435

FISHERIES AND CATCH DATA

For almost all functional groups catches and times series of catches for the two models were obtained from the same assessment documents used for generating biomass and time series of biomass. The exception to this was a time series of fishing mortality assigned to seals in the BC shelf model. In this case, an F of 0.1 for each year from 1950 to 1971 was included for seals to represent the hunt which existed at that time. This is the same mortality that was used by Martell et al. (2002) for a model of the Strait of Georgia. Bycatch and discards in both models were derived from discard rates reported for target and non target species in Gulf of Alaska fisheries (Gaichas and Boldt 2003, Hiatt and Terry 2003). For non target speces this worked out to 30,000 t (0.07 $t \cdot km^{-2}$) made up of a mixture of species including dogfish, skates, miscellaneous small demersals, crabs, echinoderms, and other benthic invertebrates. For the target species discard rates in the GoA were ≈ 20% of catch so groups subject to trawl fisheries were apportioned 10% of fishery to the juvenile group and 10% to the adult if it was a multi stanza group or 20% to that group fishery catch itself if it was not a multi stanza group. Note that Alverson et al. (1994) estimate 1,000,000 t of bycatch in the NEPa area. The area covered by that study is about 5,000,000 km^2, i.e., discards ≈ 0.2 $t \cdot km^{-2}$. Alverson et al. (1994) also point out that various trawl fisheries in the NEPac area have discard rates from 2-3 times that retained. Thus, for the trawl fisheries the functional groups miscellaneous small demersals, other rockfish, dogfish and rajidae/ ratfish were added to the bycatch such that bycatch was twice catch. The sum of discards thus calculated was 0.17 $t \cdot km^{-2}$ a favourable comparison to the general value suggested by Alverson et al. (1994).

PRELIMINARY RESULTS

The BC shelf and NEPac ecosystem models were run in Ecosim from 1950 to the present, to simulate the effects of different ecosystem control scenarios on output time series of biomass. Table 13 shows time series that were used as reference data for both models in their Ecosim simulations. The model output time series of biomass were compared to reference time series of biomass listed in Table 13 for all model simulations. The goodness of fit in these runs is measured by Ecosim as a weighted sum of squared differences (SS) between log reference and log predicted biomass (Christensen et al. 2004).

Table 13. Time series available as reference data for the NEPac and BC shelf models. Note that mortality refers to time series of fishing (F), and total (Z)

species group	**Biomass**	**Mortality rate**	**Catch**
Sea lions	NEPac		
Harbour seal	BC		
Atka mackerel	NEPac	NEPac	NEPac
Arrowtooth flounder	BC, NEPac		BC, NEPac
Pacific cod	BC, NEPac	BC, NEPac	BC, NEPac
Pacific halibut	BC, NEPac	BC, NEPac	BC, NEPac
Sablefish	BC, NEPac		BC, NEPac
Walleye pollock	BC, NEPac	BC, NEPac	BC, NEPac
Pacific hake	BC, NEPac		BC, NEPac
Pacific Ocean perch	BC, NEPac	BC, NEPac	BC, NEPac
Northern rockfish	NEPac	NEPac	NEPac
Yellowfin sole	NEPac	NEPac	NEPac
Rock sole	BC, NEPac	NEPac	BC, NEPac
Alaska plaice	NEPac	NEPac	NEPac
Pacific herring	BC	BC	BC, NEPac
Chinook salmon			BC, NEPac
Chum salmon			BC, NEPac
Coho salmon			BC, NEPac
Pink salmon			BC, NEPac
Sockeye salmon			BC, NEPac

Ecosim allows the modeller to change the so-called ‘vulnerability’ of prey to predators in any ecosystem modelled. The rate at which prey species move in and out of states vulnerable to predation can be increased or decreased with this parameter. This allows the emulation of top-down dynamics, *i.e.*, the prey species have little ability to evade predators and bottom-up dynamics, implying that the prey species can find refuge from predators (Christensen et al. 2004). These mechanics were built around the arena foraging theory described in Walters and Juanes (1993). The introduction of these dynamics into the Ecosim component of EwE is described in Walters et al. (2000) and Christensen and Walters (2004). In Ecosim, the vulnerability setting can be universally adjusted for all trophic (predator prey) linkages or for ones selected by the modeller. Deciding which vulnerabilities to examine for studying the potential ecosystem dynamics is discussed in Christensen et al. (2004) and ways to test their effects on ecosystem dynamics is discussed in Walters et al. (2000) and Christensen and Walters (2004). The NEPac and BC shelf models were run in Ecosim using three vulnerability settings to all trophic linkages; bottom-up (v=1), top-down (v=4), and mixed bottom-up / top-down control (v=2) to see how SS values were affected by fishing effects, primary production anomalies, and combined fishing effects and primary production anomalies. Ecosim can also generate a time series of primary production that minimizes SS by allowing increased or decreased production to cascade up through the food web.

Table 14: Summed squared differences between log of reference and log of predicted biomass for different scenarios tested to simulate ecosystem dynamics in NEPac and BC shelf models.

	Top down	Mixed	Bottom up
Fishing effects only			
BC	900.1	864.6	871.8
NEPac	1965	1367.5	722.8
Fishing effects with primary production anomaly			
BC	872.3	805.2	823.9
NEPac	1722.3	1326.7	674.8
Best fit			
BC		743.9	
NEPac		569.3	

Each of the vulnerability setting runs of the Ecosim model was done while comparing the reference time series of biomass (1950 - present) for both NEPac and BC shelf models in two situations; explaining biomass change as a result of only fishing mortality and explaining biomass change as a result of changes in both fishing mortality and primary production changes. The performance of each model run was judged by the SS value of predicted to reference biomass time series, lower SS implying a greater probability of explaining actual ecosystem dynamics.

The SS associated with different model runs can be seen in Table 14. Two further scenarios were tested with the NEPac and BC shelf model runs having the lowest SS scores. The vulnerabilities in these two scenarios were changed at each trophic linkage specifically to minimise the SS score. In both NEPac and BC shelf models the SS was lowest for the simulation combining fishing effects with a primary production anomaly to explain biomass change from 1950 to present. These last scenarios are called ‘best fit’ in Table 14 as they have the lowest SS score of all simulation. Figure 16 shows a comparison of predicted versus reference biomass data for both of the best fit scenarios.

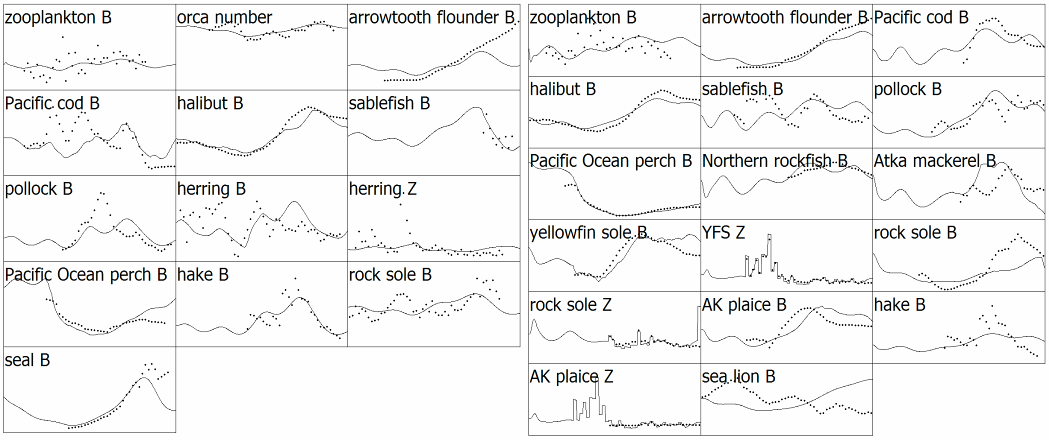
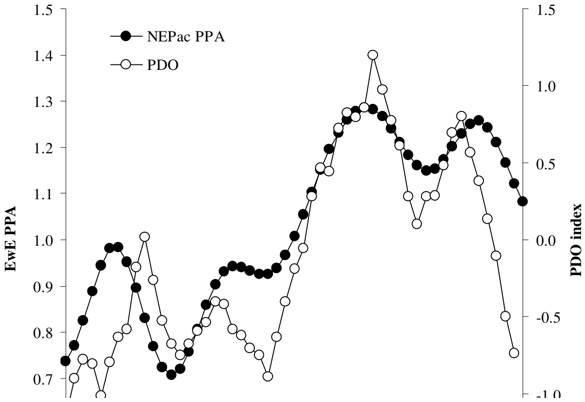


Figure 16. Graphs comparing BC (left 13 graphs) and NEPac (right 17 graphs) ‘best fit’ model output (line) to reference data (dots) for biomass (B), number, and total mortality (Z) by species. The y-axis indicates relative variable change, the x-axis shows time (1950-present).



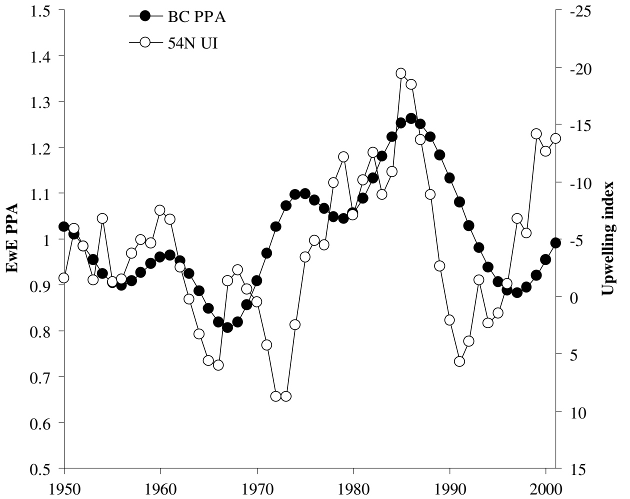


Figure 18. Primary production anomaly predicted by BC shelf model to minimise SS score of predicted to reference data compared to the five year running average of the upwelling index at 54° North

The primary production anomaly (PPA) time series generated by Ecosim appear to match climate time series available at geographic scales similar to those for the particular model, see Figures 17 and 18. For the NEPac model the PPA anomaly appears to be correlated with the Pacific decadal oscillation (PDO), whereas the BC shelf model appears to be more closely related to the upwelling index as measured at 54ºN. The PDO has already been linked to the production of salmonids (Mantua et al. 1997). While many of the species in the NAPac model therefore appear to be responding to climatic changes. It also appears that the model predicts the rate and intensity of that response variation. For example, the BC shelf biomass trajectories of herring and Pacific cod inflect at the same times but have very different absolute changes. The biomass trajectories of halibut and orcas appear to have longer periods of inflection than other species in both models. Further, when the response to environmental change is tempered by known changes in fishing mortality our knowledge of trophic linkages appears to provide a realistic history of changes in the biomass of many of the fish species in the NEPac model. For instance, the biomass trajectories of NEPac Pacific Ocean perch and yellowfin sole, are opposite because of the difference in the way the model predicts biomass of each responding to bottom-up production or top-down mortality (fishing).

The matching of climate change indices to PPAs generated by similarly scaled models also makes sense in that it reflects the internal logic governing the way these ecosystem were defined to begin with. Because the NEPac ecosystem covers the GoA and BSAI region it is not surprising that the PDO, which is a measure of North Pacific sea surface temperatures north of 20ºN in the Pacific Ocean, relates well to it. Remember that the way in which the NEPac ecosystem was defined was by the ocean atmospheric dynamics of the North Pacific area manifested itself as currents and upwelling/ downwelling in the Northeast Pacific. Such upwelling and downwelling will have a significant effect on north Pacific Sea surface temperature and is therefore linked to physical and chemical ecosystem changes described in the introduction.

The BC shelf, however, was more similar to a smaller scale climate change indicator; the upwelling index at 54ºN. This should not surprise us as the most of the BC coast can experience either upwelling or downwelling and the intensity or direction can vary seasonally and annually. This model suggests that, at the scale of the BC shelf, populations, even though part of larger scale metapopulation NEPac changes, nonetheless display internal dynamics responding to environmental cues. The ability to accommodate these different biomass responses at different scales may allow the delineation of appropriate policies to effect desired ecosystem changes. This synthesis also represents an exciting prospect to resolve disagreements between the so-called 'bottom-up' and 'top-down' schools of thought in describing populations changes in aquatic ecosystems.

FUTURE WORK

Future research in this work will involve the creation of both larger (North Pacific) and smaller (Strait of Georgia) area scale models. Salmon biomass time series will be improved by looking at estimations of returning spawners plus harvest in Rogers (1999) and calculating biomass by using an average weight per fish derived from total biomass catch divided by total numbers caught in Eggers et al. (2003). Bycatch and discards also need to be more accurately accounted for in future iterations of these models. Future research with the models will examine similarities between predicted primary production anomalies at the different scales to different environmental indicators in the North Pacific, *e.g.*, the Northern Oscillation Index (Schwing et al. 2002), The Pacific Decadal Oscillation (Mantua et al. 1997), The Aleutian Low Pressure Index (Beamish et al. 1997), and Upwelling Indices measured at various stations in the North Pacific. The work presented here shows that when models incorporate primary production anomalies SS scores are lower. Preliminary analysis of the Ecosim derived primary production anomalies suggests that different scale models generate anomalies that correlate with similarly scaled climate indices.

ACKNOWLEDGEMENTS

The author would like to recognise the help of the following individuals in the achievement of this model; Dr. Daniel Pauly, for his continued support as thesis advisor, Dr. Richard Beamish for the insight given on ecosystem processes in the north Pacific. Dr. Villy Christensen for continued help in the implementation of climate data to EwE models, and Drs. Sylvie Guénette and Sheila Heymans for our many data exchanges and valuable talks on ecosystem modelling.

REFERENCES

Acuna, E., P. Goddard and S. Kotwicki. 2003. 2002 Bottom Trawl Survey of the Eastern Bering Sea Continental Shelf. AFSC Proc. Rept. 2003-0:172 p.

Ainley, D.G., D.W. Anderson and P.R. Kelly. 1981. Feeding ecology of marine cormorants in Southwestern North America. Condor 83: 120-131.

Alverson, D.L., M.H. Freeberg, J.G. Pope and S.A. Murawski. 1994. A global assessment of fisheries bycatch and discards. FAO Fish. Tech. Pap. 339: 223 p.

Angliss, R.P. and K.L. Lodge. 2002. Alaska marine mammal stock assessments, 2002. NOAA Tech. Mem. NMFS-AFSC-133: 224 pp.

Anonymous. 1999a. Rock sole Queen Charlotte Sound (areas 5A/B) and Hecate Strait (areas 5C/D). DFO Science Stock Status Report A6-03(1999): 3 pp.

Anonymous. 1999b. Widow rockfish. DFO science stock status report A6-10: 3 pp.

Anonymous (ed.). 2000. Appendix A: Pacific halibut stock assessment and fishery evaluation. International Pacific Halibut Commission, Seattle. 37 pp.

Anonymous. 2002a. Central coast herring: DFO Science Stock Status Report B6-02. Department of Fisheries and Oceans. 3 pp.

Anonymous. 2002b. Prince Rupert Herring: DFO Science Stock Status Report B6-01. Department of Fisheries and Oceans. 3 pp.

Anonymous. 2002c. Queen Charlotte Islands herring: DFO Science Stock Status Report B6-03. Department of Fisheries and Oceans. 4 pp.

Anonymous. 2002d. Strait of Georgia herring: DFO Science Stock Status Report B6-05. Department of Fisheries and Oceans. 3 pp.

Anonymous. 2002e. West Coast Vancouver Island herring: DFO Science Stock Status Report B6-04. Department of Fisheries and Oceans. 4 pp.

Anonymous. 2004a. Male Northern Fur Seal Counts, 1911 - 2002. NOAA National Marine Mammal Laboratory http://nmml.afsc.noaa.gov/Alaska Ecosystems/nfshome/pribbullnew.htm.

Anonymous. 2004b. Seabirds an indicator of marine ecosystem status for coastal British Columbia, Environment Canada http://www.ecoinfo.ec.gc.ca/env_ind/region/seabird/seabird_e.cfm.

Arai, M. 1996. Carnivorous jellies. pp. 39-40. *In:* D. Pauly, V. Christensen and N. Haggan (ed.) Mass-Balance Models of North-eastern Pacific Ecosystems, Fisheries Centre, University of British Columbia, Vancouver, Fish. Ctr. Res. Rept. 4(1).

Aydin, K., G.A. McFarlane, J. King and B.A. Megrey. 2003. The BASS/MODEL report on trophic models of the subarctic Pacific basin ecosystems. PICES Sci. Rept. 25: 93 p.

Beamish, R.J. 1995. Climate change and northern fish populations. National Research Council, Ottawa. 739 pp.

Beamish, R.J., G.A. McFarlane, C.M. Neville and I. Pearsall. 2001. Changes in the Strait of Georgia ECOPATH model needed to balance the abrupt increases in productivity that occurred in 2000. PICES Sci. Rept. 17: 5-9.

Beamish, R.J., C.M. Neville and A.J. Cass. 1997. Production of Fraser River sockeye salmon (*Oncorhynchus nerka*) in relation to decadal-scale changes in the climate and the ocean. Can. J. Fish. Aquat. Sci. 54: 543-554.

Bearman, G. (ed.). 1989. Ocean circulation. The Open University and Pergamon Press, Milton and Oxford. 238 pp.

Beattie, A. 2001. A new model for evaluating the optimal size, placement, and configuration of marine protected areas. M.Sc., University of British Columbia, Vancouver. 159 pp.

Benson, A. and A.W. Trites. 2002. Ecological effects of regime shifts in the Bering Sea and eastern North Pacific. Fish and Fisheries 3: 95-113.

Bertram, D.F., D.L. Mackas and S.M. McKinnell. 2001. The seasonal cycle revisited: interannual variation and ecosystem consequences. Prog. Oceanogr. 49: 283-307.

Bonfil, R. 1997. B.C. Groundfish Research Project, 4th and 5th quarterly reports (Jun.-Dec., 1997) October, 1997. University of British Columbia Fisheries Centre, Vancouver. 23 pp.

Boutillier, J.A., T.H. Butler, H. Bond, I. Winther and A. Phillips. 1998. Assessment of the area A crab (*Cancer magister*) fishery in British Columbia. CSAS Res. Doc. 98/86: 39 p.

Brodeur, R.D. and P. Livingston. 1988. Food habits and diet overlap of various eastern Bering Sea fishes. NOAA Tech. Mem. NWC 127: 78 p.

Bundy, A., G.R. Lilly and P.A. Shelton. 2000. A mass balance model of the Newfoundland-Labrador shelf. Can. Tech. Rep. Fish. Aquat. Sci. 2310: 157 p.

Burd, B.J. and R.O. Brinkhurst. 1987. Macrobenthic Infauna from Hecate Strait, British Columbia. Can. Tech. Rep. Hydrogr. Ocean Sci. 88: 125 p.

Burger, A.E. 2001. Marbled Murrelets in the new millennium: a review of the biology, habitat associations, and management of this threatened species in British Columbia. Alan Burger Consulting, Victoria. 192 pp.

Burkett, E.E. 1995. Marbled murrelet food habits and prey ecology. pp. 223-246. *In:* C.J. Ralph, G.L.J. Hunt, M.G. Raphael and J.F. Piatt (ed.) Ecology and conservation of the marbled murrelet, USDA Forest Service Gen. Tech. Rep. PSW-152.

Casillas, E., L. Crockett, Y. deReynier, J. Glock, M. Helvey, B. Meyer, C. Schmitt, M. Yoklavich, A. Bailey, B. Chao, B. Johnson and Y. Pepperell. 1998. Essential fish habitat west coast groundfish appendix, National Marine Fisheries Service.

Cass, A.J., J.R. Selsby and L.J. Richards. 1986. Lingcod maturity cruise off southwest Vancouver Island and Queen Charlotte Sound, R/V G.B. Reed, August 20 - September 5, 1985. Can. Data Rept. Fish. Aquat. Sci. 594: 58 p.

Christensen, V. and C.J. Walters. 2004. Ecopath with Ecosim: methods, capabilities and limitations. Ecol. Model 172: 109-139.

Christensen, V., C.J. Walters and D. Pauly. 2004. Ecopath with ecosim: a user's guide. University of British Columbia, Fisheries Centre, Vancouver. 154 pp.

Clark, W.G. and S.R. Hare. 2001a. Assessment of the Pacific halibut stock at the end of 2001. pp. 121-196 International Pacific Halibut Commission Report of Assessment and Research Activities, 2001.

Clark, W.G. and S.R. Hare. 2001b. Effects of climate and stock size on recruitment and Growth of Pacific halibut. N. Amer. J. Fish. Manage. 22: 852-862.

Cortes, E. 1999. Standardized diet compositions and trophic levels of sharks. ICES J. Mar. Sci 56: 707-717.

Courtney, D., D.M. Clausen, J. Heifetz, D. Hanselman and J.T. Fujioka. 2003. Gulf of Alaska northern rockfish. pp. 481-530. *In:* Anonymous (ed.) Appendix B: stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, North Pacific Fishery Management Council, Anchorage.

Dorn, M., S. Barbeaux, M. Guttormsen, B. Megrey, A. Hollowed, M. Wilkins and K. Spalinger. 2003. Assessment of walleye pollock in the Gulf of Alaska. pp. 33-148. *In:* Anonymous (ed.) Appendix B: stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, North Pacific Fisheries Management Council, Anchorage.

Dorn, M., M.W. Saunders, C.D. Wilson, M. Guttormsen, K. Cooke, R. Kieser and M. Wilkins. 1998. Status of the coastal Pacific hake / whiting stock in U.S. and Canada in 1998. CSAS Res. Doc. 99/90: 101 p.

Dragoo, D.E., G.V. Byrd and D.B. Irons (ed.). 2001. Breeding status, population trends and diets of seabirds in Alaska, 2000. U.S. Fish and Wildl. Serv. Report AMNWR 01/07. 77 pp.

Dunning, J.B. 1993. CRC handbook of avian body masses. CRC Press Inc., Boca Raton. 371 pp.

Eggers, D.M., J. Irvine, M. Fukuwaka and V. Karpenko. 2003. Catch trends and status of North Pacific salmon. NPAFC Doc. 723: 34 p.

Fargo, J. and P.J. Starr. 2001. Turbot stock assessment for 2001 and recommendations for management in 2002. CSAS Res. Doc. 2001/150: 70 p.

Fitzgerald, S., K.J. Kuletz, M. Perez, K. Rivera, D.E. Dragoo and R. Suryan. 2003. Seabirds. pp. 206-239. *In:* J. Boldt (ed.) Ecosystem Considerations for 2004, North Pacific Fishery Management Council, Anchorage.

Forney, K., J. Barlow, M.M. Muto, M. Lowry, J. Baker, G. Cameron, J. Mobley, C. Stinchcomb and J.V. Carretta. 2000. U.S. Pacific Marine Mammal Stock Assessments: 2000. NOAA Tech. Mem. 300: 281 p.

Froese, R. and D. Pauly. 2004. FishBase. World Wide Web electronic publication, www.fishbase.org, version (05/2004).

Fulton, J.M., N. Arai and J.C. Mason. 1982. Euphausiids, coelenterates, ctenophores and other zooplankton from the Canadian Pacific coast ichthyoplankton survey, 1980. Can. Tech. Rep. Fish. Aquat. Sci. 1125: 75 p.

Gaichas, S. and J. Boldt. 2003. Time Trends in Bycatch of Prohibited Species. pp. 251. *In:* J. Boldt (ed.) Ecosystem Considerations for 2004, North Pacific Fisheries Management Council, Anchorage.

Gjøsaeter, J. and K. Kawaguchi. 1980. A review of the World resources of mesopelagic fish. FAO Fish. Tech. Pap. 151 pp.

Guénette, S. 1996. Macrobenthos. pp. 65-67. *In:* D. Pauly, V. Christensen and N. Haggan (ed.) Mass balance models of northeast Pacific ecosystems, Fisheries Centre, University of British Columbia, Vancouver, Fish. Ctr. Res. Rept. 4(1).

Haist, V., R. Hilborn and M. Wyeth. 2001. Sablefish stock assessment for 2001 and advice to managers for 2002. CSAS Res. Doc. 2001/135: 39 p.

Hanselman, D., J. Heifetz, J.T. Fujioka and J.N. Ianelli. 2003. Gulf of Alaska Pacific ocean perch. pp. 429-480. *In:* Anonymous (ed.) Appendix B: stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, North Pacific Fisheries Management Council, Anchorage.

Hansson, L.J. 1997. Effect of temperature on growth rate of *Aurelia aurita* (Cnidaria, Scyphozoa) from Gullmarsfjorden, Sweden. Mar. Ecol. Prog. Ser. 161: 145-153.

Hare, S.R. and R.C. Francis. 1994. Climate change and salmon production in the Northeast Pacific Ocean. pp. 357-372. *In:* R.J. Beamish (ed.) Climate Change and Northern Fish Populations, Can. Spec. Publ. Fish. Aquat. Sci. 121.

Hare, S.R. and N.J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Prog. Oceanogr. 47: 103-145.

Hart, J.l. 1973. Pacific fishes of Canada. Bull. Fis. Res. Board Can. 180: 740.

Heymans, J.J. 2001. The Gulf of Maine, 1977-1986. pp. 128-150. *In:* S. Guénette, V. Christensen and D. Pauly (ed.) Fisheries impacts on North Atlantic ecosystems: mode3ls and analysis, Fish. Ctr. Res. Rept. 9(4).

Hiatt, T. and J. Terry. 2003. Time trends in groundfish discards. pp. 250. *In:* J. Boldt (ed.) Ecosystem Considerations for 2004, North Pacific Fisheries Management Council, Anchorage.

Hill, P.S. and D.P. DeMaster. 1998. Alaska marine mammal stock assessments 1998. National Marine Mammal Laboratory Alaska Fisheries Science Center, Seattle. 165 pp.

Hollowed, A.B., S.R. Hare and W.S. Wooster. 2001. Pacific basin climate variability and patterns of Northeast pacific marine fish production. Prog. Oceanogr. 49: 257-282.

Hollowed, A.B. and W.S. Wooster. 1992. Variability of winter ocean conditions and strong year classes of Northeast Pacific groundfish. ICES Mar. Sci. Symp. 195: 433-444.

Hunt, G.L.J., H. Kato and S.M. McKinnell. 2000. Predation by marine birds and mammals in the subarctic north Pacific Ocean. PICES Sci. Rept. 14: 165.

Hunt, S.L., T.J. Mulligan and K. Komori. 1999. Oceanic feeding habits of chinook salmon, *Oncorhynchus tshawytscha*, off northern California. Fish. Bull. 97: 717-721.

Ianelli, J.N., S. Barbeaux, G. Walters and N. Williamson. 2003. Eastern Bering Sea walleye pollock stock assessment. pp. 39-126. *In:* Anonymous (ed.) Appendix A: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea / Aleutian Islands regions, North Pacific Fisheries Management Council, Anchorage.

Iguchi, N. and T. Ikeda. 1999. Production, metabolism and P:B ratio of *Euphausia pacifica* (Crustacea: Euphausiacea) in Toyama Bay, southern Japan Sea. Plankton Biol. Ecol. 46: 68-74.

Innes, S., D.M. Lavigne, W.M. Earle and K.M. Kovacs. 1987. Feeding rates of seals and whales. J. Animal Ecol. 56: 115-130.

Jagielo, T. and A. Sinclair. 2002. Proceedings of the joint Canada - USA review group on the stock assessment of coastal Pacific hake / whiting stock off the west coast of North America February 20 - 22, 2002. CSAS Proc. Ser. 2002/002: 16 p.

Jones, B.C. and G.H. Geen. 1977. Food and Feeding of Spiny Dogfish (*Squalus acanthias*) in British Columbia waters. J. Fish. Res. Board Can. 34: 2067-2078.

Jones, I.L. and F.M. Hunter. 2002. Annual adult survival of least auklets (Aves, Alcidae) varies with large-scale climatic conditions of the north Pacific Ocean. Oecologia 133: 38-44.

Jørgensen, L.A., S.E. Jørgensen and S.N. Nielsen. 2000. Ecotox, CD-ROM. Elsevier Science B.V., Amsterdam.

Kaeriyama, M., M. Nakamura, M. Yamaguchi, H. Ueda, G. Anma, S. Tagaki, K. Aydin, R.V. Walker and K.W. Myers. 2000. Feeding ecology of sockeye and pink salmon in the Gulf of Alaska. N. Pac. Anadr. Fish. Comm. Bull. 2: 55-63.

Larson, R.L. 1986. Seasonal changes in the standing stocks, growth rates and production rates of gelatinous predators in Saanich Inlet, British Columbia. Mar. Ecol. Prog. Ser. 33: 89-98.

LeBrasseur, R.J. 1966. Stomach contents of salmon and steelhead trout in the Northeast Pacific Ocean. J. Fish. Res. Board Can. 22: 85-100.

Longhurst, A. 1995. Seasonal cycles of pelagic production and consumption. Prog. Oceanogr. 36: 77-167.

Lowe, S.A., J.N. Ianelli, H.H. Zenger and R. Lauth. 2003. Stock assessment of Aleutian Islands Atka mackerel. pp. 711-776. *In:* Anonymous (ed.) Appendix A: stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea / Aleutian Islands regions, North Pacific Fishery Management Council, Anchorage.

Lowe, S.A. and R. Lauth. 2003. Assessment of Gulf of Alaska Atka mackerel. pp. 699-718. *In:* Anonymous (ed.) Appendix B: stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, North Pacific Fishery Management Council, Anchorage.

Mackas, D.L. 1991. Seasonal cycle of zooplankton off Southwestern British Columbia, 1979-1980. Can. J. Fish. Aquat. Sci. 49: 903-921.

Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace and R.C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bull. Am. Meteorol. Soc. 78: 1069-1079.

Martell, S. 1999. Estimating lingcod biomass in Hecate Strait using stock reduction analysis. pp. 49-55. *In:* N. Haggan, A. Beattie and D. Pauly (ed.) Back to the future: reconstructing the Hecate Strait ecosystem, Fisheries Centre, University of British Columbia, Vancouver.

Martell, S., J. Boutillier, H. Nguyen and C. Walters. 2000. Reconstructing the offshore *Pandalus jordani* trawl fishery off the west coast of Vancouver Island and simulating alternative management policies. CSAS Res. Doc. 2000(149): 38 pp.

Martell, S.J.D., A.I. Beattie, C.J. Walters, T. Nayar and R. Briese. 2002. Simulating fisheries management strategies in the Strait of Georgia ecosystem using ecopath with ecosim. pp. 16-23. *In:* T. Pitcher and K. Cochrane (ed.) The use of ecosystem models to investigate multispecies management strategies for capture fisheries, Fish. Ctr. Res. Rept. 10(2).

Matishov, G.G. and V.V. Denisov. 1999. Ecosystems and biological resources of Russian European seas at the turn of the 21st century. Murmansk Marine Biological Institute, Murmansk. 118 pp.

McFarlane, G.A., J.P. King and R.J. Beamish. 2000. Have there been recent changes in climate? Ask the fish. Prog. Oceanogr. 47: 147-169.

Moku, M., K. Kawaguchi, H. Watanabe and A. Ohno. 2000. Feeding habits of three dominant myctophid fishes, *Diaphus theta*, *Stenobrachius leucopsarus* and *S. nannochir*, in the subarctic and transitional waters of the western North Pacific. Mar. Ecol. Prog. Ser. 207: 129-140.

Murie, D.J., D.C. Parkin, B.G. Clapp and G.G. Krause. 1994. Observations on the distribution and activities of rockfish, Sebastes spp., in Saanich Inlet, British Columbia from the Pisces IV submersible. Fish. Bull. 92: 313-323.

Nagasawa, K. 1998. Predation by salmon sharks (*Lamna ditropis*) on Pacific salmon (*Oncorhynchus spp.*) in the north Pacific Ocean. N. Pac. Anadr. Fish. Comm. Bull. 1: 419-433.

Nyblade, C.F. 1979. The Strait of Juan de Fuca intertidal and subtidal benthos, 2nd annual report: Spring 1977 - Winter 1978. U.S. Environmental Protection Agency, Washington. 129 pp.

Okey, T. and D. Pauly. 1999. A trophic mass-balance model of Alaska's Prince William Sound ecosystem for the post-spill period 1994-1996, 2nd ed. Fish. Ctr. Res. Rept. 7(4): 137 pp.

Olesiuk, P.F. 1999. An assessment of the status of harbour seals (*Phoca vitulina*) in British Columbia. CSAS Res. Doc. 99/33: 71 p.

Pahl-Wostl, C. 1998. Ecosystem organization across a continuum of scales: a comparative analysis of lakes and rivers. pp. 141-170. *In:* D.L. Peterson and V.T. Parker (ed.) Ecological scale: theory and applications, Columbia University Press, New York.

Palomares, M.L.D. and D. Pauly. 1999. Predicting the food consumption of fish populations as functions of mortality, food type, morphometrics, temperature and salinity. Mar. Freshwat. Res. 49: 447-453.

Parrish, R.H., F.B. Schwing and R. Mendelssohn. 2000. Mid-latitude wind stress: the energy source for climatic shifts in the North Pacific Ocean. Fish. Oceanogr. 9: 224-238.

Pauly, D., V. Christensen, R. Froese, A. Longhurst, T. Platt, S. Sathyendranath and K. Sherman. 2000. Mapping fisheries onto marine ecosystems: a consensus approach for regional, oceanic and global integrations. Theme Session on Classification and Mapping of Marine Habitats CM 2000/T ICES 2000 Annual Science Conference 16 pp.

Pauly, D., A. Trites, E. Capuli and V. Christensen. 1998. Diet composition and trophic levels of marine mammals. ICES J. Mar. Sci. 55: 467-481.

Piatt, J.F. and J.L. Naslund. 1995. Abundance, distribution, and population status of marbled murrelets in Alaska. pp. 285-294. *In:* C.J. Ralph, G.L.J. Hunt, M.G. Raphael and J.F. Piatt (ed.) Ecology and conservation of the marbled murrelet, USDA Forest Service Gen. Tech. Rep. PSW-152.

Polovina, J.J., G.T. Mitchum and G.T. Evans. 1995. Decadal and basin-scale variation in mixed layer depth and the impact on biological production in the Central and North Pacific, 1960-88. Deep-Sea Res. 42: 1701-1716.

Preikshot, D. and A. Beattie. 2001. Fishing for answers: analysis of ecosystem dynamics, trophic shifts and salmonid population changes in Puget Sound, WA, 1970-1999, Fish. Ctr. Res. Rept. 9(6): 33 pp.

Rand, P.S. and D.J. Stewart. 1997. Prey fish exploitation, salmonine production, and pelagic food web efficiency in Lake Ontario. Can. J. Fish. Aquat. Sci. 57: 318-327.

Rexstad, E.A. and E.K. Pikitch. 1986. Stomach contents and food consumption estimates of Pacific hake, *Merluccius productus*. Fish. Bull. 84: 947 - 956.

Robinson, C.L.K. and D.M. Ware. 1994. Modelling pelagic fish and plankton trophodynamics off southwestern Vancouver Island, British Columbia. Can. J. Fish. Aquat. Sci. 51: 1737-1751.

Rogers, D.E. 1999. Estimates of annual salmon runs from the North Pacific, 1951-1998. Fisheries Research Institute, University of Washington, Seattle: 10 pp.

Saether, B.-E. and O. Bakke. 2000. Life history variation and contribution of different demographic traits to the population growth rate in birds: a comparative approach. Ecology 81: 642-653.

Saunders, M.W. and G.A. McFarlane. 1998. Pacific hake - Strait of Georgia stock assessment for 1997 and recommended yield options for 1998. PSARC Working Paper G97.

Schnute, J.T., R. Haigh, B.A. Krishka and P. Starr. 2001. Pacific Ocean perch assessment for the west coast of Canada in 2001. CSAS Res. Doc. 2001/138: 90 pp.

Schweigert, J. 2000. Stock assessment of British Columbia herring in 2000 and forecast of potential harvest in 2001. CSAS Res. Doc. 2000/165: 74 p.

Schweigert, J. and C. Fort. 1999. Stock assessment of British Columbia herring in 1999 and forecast of potential harvest in 2000. CSAS Res. Doc. 99/178: 99 p.

Schwing, F.B., T. Murphee and P.M. Green. 2002. The northern oscillation index (NOI): a new climate index for the northeast Pacific. Prog. Oceanogr. 53: 115-139.

Sherman, K., L.M. Alexander and B.D. Gold (ed.). 1990. Large marine ecosystems: patterns, processes and yields. American Association for the Advancement of Science, Washington. 242 pp.

Sigler, M.F., C.R. Lunsford, J.T. Fujioka and S.A. Lowe. 2003. Alaska sablefish assessment for 2004. pp. 223-292. *In:* Anonymous (ed.) Appendix A: stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea / Aleutian Islands regions, North pacific fisheries Management Council, Anchorage.

Sinclair, A., S. Martell and J. Boutillier. 2001. Assessment of Pacific cod off the west coast of Vancouver Island and in Hecate Strait, November 2001. CSAS Res. Doc. 2001/159: 60 p.

Smith, B.D. and G.S. Jamieson. 1989. Exploitation and mortality of male Dungeness crabs (*Cancer magister*) near Tofino, British Columbia. Can. J. Fish. Aquat. Sci. 46: 1609-1614.

Smith, B.D. and G.S. Jamieson. 1991. Movement, spatial distribution, and mortality of male and female Dungeness crab *Cancer magister* near Tofino, British Columbia. Fish. Bull. 89: 137-148.

Spencer, P.D. and J.N. Ianelli. 2003a. Northern rockfish. pp. 611-652. *In:* Anonymous (ed.) Appendix A: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea / Aleutian Islands regions, North Pacific Fishery Management Council, Anchorage.

Spencer, P.D. and J.N. Ianelli. 2003b. Pacific Ocean perch. pp. 563-610. *In:* Anonymous (ed.) Appendix A: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea / Aleutian Islands regions, North Pacific Fisheries Management Council, Anchorage.

Spencer, P.D., G. Walters and T.K. Wilderbauer. 2003. Alaska plaice. pp. 511-552. *In:* Anonymous (ed.) Appendix A: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea / Aleutian Islands regions, North Pacific Fisheries Management Council, Anchorage.

St.-Pierre, G. and R.J. Trumble. 2000. Diet of juvenile Pacific halibut, 1957-1961. International Pacific Halibut Commission Tech. Rep. 43: 16 p.

Stocker, M., A. Mentzelopoulos, G. Bartosh, J. Hrynyshyn, J. Burns and N. Fowler (ed.). 2001. Fish Stocks of the Pacific Coast. Fisheries and Oceans Canada, Vancouver. 152 pp.

Sturdevant, M.V. 1999. Forage fish diet overlap, 1994-1996, Restoration project 98163C final report. National Marine Fisheries Service Alaska Fisheries Science Center Auke Bay Laboratory, Juneau, AK. 107 pp.

Sullivan, P.J., A.M. Parma and W.G. Clark. 1997. The Pacific halibut stock assessment of 1997. International Pacific Halibut Commission Sci. Rept. 79: 84 pp.

Sydeman, W.J., M.M. Hester, J.A. Thayer, F. Gress, P. Martin and J. Buffa. 2001. Climate change, reproductive performance and diet
composition of marine birds in the southern California
Current system, 1969–1997. Prog. Oceanogr. 49: 309-329.

Tanasichuk, R.W., D.M. Ware, W.A. Shaw and G.A. McFarlane. 1991. Variations in the diet, daily ration and feeding periodicity of Pacific hake (*Merluccius productus*) and spiny dogfish (*Squalus acanthias*) off the lower west coast of Vancouver Island. Can. J. Fish. Aquat. Sci. 48: 2112-2128.

Thompson, G.G. and M.W. Dorn. 2003. Assessment of the Pacific Cod stock in the Eastern Bering Sea and Aleutian Islands area. pp. 127-222. *In:* Anonymous (ed.) Appendix A: stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea / Aleutian Islands regions, North pacific fisheries Management Council, Anchorage.

Thompson, G.G., H.H. Zenger and M.W. Dorn. 2003. Assessment of the Pacific cod stock in the Gulf of Alaska. pp. 149-242. *In:* Anonymous (ed.) Appendix B: stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska, North Pacific Fisheries Management Council, Anchorage.

Thomson, B.L. 1994. Spiny dogfish. pp. 204-217. *In:* M. Stocker (ed.) Groundfish stock assessment for the west coast of Canada in 1993 and Recommended yield options for 1994, Can. Tech. Rep. Fish. Aquat. Sci. 1975.

Thomson, R.E. 1981. Oceanography of the British Columbia Coast. Can. Spec. Publ. Fish. Aquat. Sci. 56: 291 p.

Trites, A. and K. Heise. 1996. Marine mammals. pp. 51-55. *In:* D. Pauly and V. Christensen (ed.) Mass-balance models of Northeastern Pacific ecosystems, Fish. Ctr. Res. Rpt. 4 (1).

Trites, A. and P.A. Larkin. 1996. Changes in the abundance of Steller sea lions (*Eumetopias jubatus*) in Alaska from 1956 to 1992: how many were there? Aquat. Mamm. 22: 153-166.

Trites, A., P.A. Livingstone, S. Mackinson, M. Vasconcellos, A.M. Springer and D. Pauly. 1999. Ecosystem change and the decline of marine mammals in the Bering sea: testing the ecosystem shift and commercial whaling hypothesis, Fish. Ctr. Res. Rept. 7(1). 106 pp.

Trites, A. and D. Pauly. 1998. Estimating mean body masses of marine mammals from maximum body lengths. Can. J. Zool. 76: 886-896.

Turnock, B.J., T.K. Wilderbauer and E.S. Brown. 2003a. Gulf of Alaska flatfish. pp. 313-340. *In:* Anonymous (ed.) Appendix B: stock assessment and fishery evaluation report for the grounfish resources of the Gulf of Alaska, North Pacific Fisheries Management Council, Anchorage.

Turnock, B.J., T.K. Wilderbuer and E.S. Brown. 2003b. Arrowtooth flounder. pp. 369-406. *In:* Anonymous (ed.) Appendix B: stock assessment and fishery evaluation report for the grounfish resources of the Gulf of Alaska, North Pacific Fishery Management Council, Anchorage.

Vermeer, K. and S.G. Sealy. 1984. Status of the nesting seabirds of British Columbia. pp. 29-40. *In:* J.P. Croxall, P.G.H. Evans and R.W. Schrieber (ed.) Status and conservation of the World's seabirds, International Council for Bird Preservation Tech. Publ. 2.

Wakabayashi, K. 1986. Interspecific feeding relationships on the continental shelf of the eastern Bering Sea, with special reference to Yellowfin sole. Int. N. Pac. Fish. Comm. Bull. 47: 3-30.

Walters, C. and F. Juanes. 1993. Recruitment limitations as a consequence of natural selection for use of restricted feeding habitats and predation risk taking by juvenile fishes. Can. J. Fish. Aquat. Sci. 50: 2058-2070.

Walters, C., D. Pauly, V. Christensen and J.F. Kitchell. 2000. Representing density dependent consequences of life history strategies in aquatic ecosystems: EcoSim II. Ecosystems 3: 70-83.

Ware, D.M. and G.A. McFarlane. 1995. Climate-induced changes in Pacific hake (*Merluccius productus*) abundance and pelagic community interactions in the Vancouver Island upwelling system. pp. 509-521. *In:* R.J. Beamish (ed.) Climate Change and Northern Fish Populations, Can. Spec. Publ. Fish. Aquat. Sci. 121.

Wehle, D.H.S. 1983. The food, feeding and development of young tufted and horned puffins in Alaska. Condor 85: 427-442.

Wilderbauer, T.K. and D. Nichol. 2003. Yellowfin sole. pp. 293-338. *In:* Anonymous (ed.) Appendix A: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea / Aleutian Islands regions, North Pacific Fisheries Management Council, Anchorage.

Wilderbauer, T.K. and T.M. Sample. 2003. Arrowtooth flounder. pp. 367-408. *In:* Anonymous (ed.) Appendix A: stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea / Aleutian Islands regions, North Pacific Fishery Management Council, Anchorage.

Wilderbauer, T.K. and G. Walters. 2003. Rock sole. pp. 409-462. *In:* Anonymous (ed.) Appendix A: stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea / Aleutian Islands regions, North Pacific Fisheries Management Council, Anchorage.

Yang, M.-S. 1993. Food habits of the important groundfishes in the Aleutian Islands in the Gulf of Alaska. NOAA Tech. Memo., NMFS-AFSC 22: 150 p.

Yang, M.S. and M.W. Nelson. 1999. Food habits of the commercially important groundfishes in the Gulf of Alaska in 1990, 1993, and 1996. NOAA Tech. Memo. AFSC 112: 187 p.

Mass balance models of the Northern California Current[1]

John Field[1] and Robert Francis[2]

[1] Southwest Fisheries Science Center, NMFS, Santa Cruz, CA 95062. Email: John.Field@noaa.gov

[2] School of Aquatic and Fisheries Sciences, University of Washington, Seattle, WA 98195.

ABSTRACT

This paper briefly describes ecosystem models of the Northern California Current for the 1960s and the 1990s. The study area does not include the full extent of the California current, but instead includes shelf and slope habitat between Cape Mendocino, CA and the border between the United States and Canada, for practical reasons. The model includes 63 functional groups, of which 29 are significantly exploited fish or shellfish, and 8 are marine mammals.

INTRODUCTION

This short review briefly summarizes the development of a two mass-balance ecosystem models of the U.S. portion of the Northern California Current (NCC), off of the west coast of North America. Generally, the shelf, slope and offshore regions of the California Current System (CCS) have their greatest changes in physical and biological characteristics at major promontories along the west coast, including Point Conception, Cape Mendocino, Cape Blanco and the northern tip of Vancouver Island (U.S. GLOBEC 1994). The northern half of the CCS, the region of coastal ocean between Cape Mendocino and Vancouver Island, is often described as a zoogeographic transition between Californian and Aleutian biological provinces (Bottom et al. 1993). Although this entire area should rightly be referred to as the Northern California Current Ecosystem, the political boundary between the U.S. and Canada (which runs southwest off of Cape Flattery, WA) has been used here as a northern boundary for the purposes of these modelling efforts (Figure 1). This is due both to data limitations and the significance of model results and implications to regional management entities.

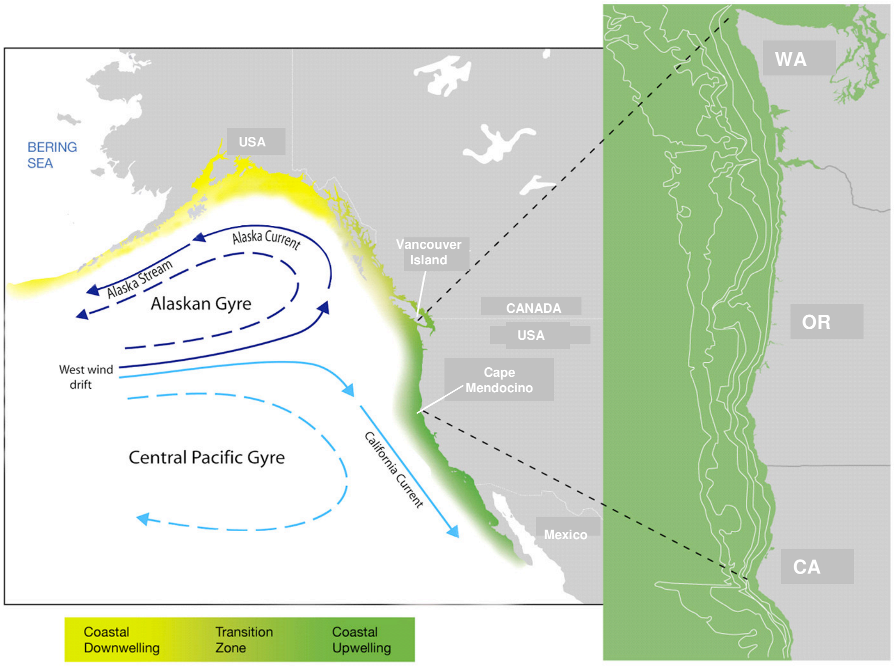


Figure 1. Map of the study area and the major North Pacific currents.

---

[1] Field, John and Robert Francis. 2005. Mass balance models of the Northern California Current. In: Guénette, S., and V. Christensen (editors). 2005. Food web models and data for studying fisheries and environmental impacts on Eastern Pacific ecosystems. Fisheries Centre Research Reports 13(1):207-216

Throughout this region, there are extreme gradients in physical conditions and biological communities between the highly energetic waters of the nearshore and continental shelf, and the cold, low oxygen waters of the continental slope. The region modelled includes the entire area between the nearshore and the continental slope to a depth of approximately 1280 metres (typically 20 to 80 kilometres offshore), as this represents the limits of available data from continental slope surveys and the approximate limits of most historical and contemporary fishing effort for trawl and fixed gear. Although the true extent of the California Current itself is far seaward of these boundaries, and many important highly migratory species occur largely outside this area, this region does represent a substantial portion of the habitat for most resident groundfish species (sablefish, flatfish and rockfish), and much of the range of hake, salmon, sardine, mackerel and other migrants. This coastal margin also includes the regions of greatest biological production from lower trophic levels and the greatest densities of migratory seabirds and marine mammals.

Preliminary results from two mass balance models of the NCC, representing the 1960s and the 1990s, were included in Field et al. (2001) and extensive documentation and results (including the results of dynamic simulations) were developed in Field (2004). Detailed discussions of the derivation of model parameters and reviews of food habits studies are not included here for the sake of brevity. In general, stock assessments provide some information on the abundance and productivity of roughly 20 commercially important stocks as far back as the 1960s. Where stock assessments exist, but did not model population abundance as far back as the early 1960s, estimates of catches and the results of assessments were used to fit known biomass surplus production models (MacCall 2002) to arrive at reasonable estimates for the 1960s model. For several other components, including rex sole and functional groups such as shelf and slope rockfish, survey results were used with estimates of catchability (q) borrowed from the same or similar species in other ecosystems and then fit to surplus production models to estimate plausible 1960s abundance. Obviously such results are given a lower rating with regard to parameter confidence. Catch and landings data were taken first from stock assessments (where available), from Lynde (1986) and other sources up to 1980, and from the Pacfin database since 1981. Estimates of bycatch rates were obtained from stock assessments where available, or inferred from the data collected during the bycatch studies in the mid-1980s (Pikitch et al. 1988).

Estimates for non-commercially important species were based on a compilation of survey estimates, literature values, or model estimates. Abundance data for top-level predators, particularly seabirds and marine mammals, were obtained primarily from NMFS Marine Mammal Stock Assessments (Carretta et al. 2002), a comprehensive seabird and mammal assessment off Oregon and Washington done in the early 1990s (Green et al. 1992), and literature sources on colony and rookery densities. Estimates of abundance and productivity for lower trophic levels were typically based on top-down balances, supplemented where possible with literature values of standing stocks and population rates were available. Food habits data from the NCC was available for most groundfish and top-predator populations between 1960 and 1990 (most marine mammal food habits studies were conducted in the 1950s and 1960s, when lethal sampling methods were more commonly used); including over 30,000 stomach samples of groundfish alone, although most studies were highly limited in space and time.

The final model includes 63 components; 21 of which were commercially significant species or stocks of fish or shellfish, 8 of which were aggregations (at the genus or family level) of commercially significant groups (e.g., salmon, skates), 4 of which were aggregated juvenile groups (of commercially significant fishes), 11 of which were top predators (seabirds and marine mammals), 4 of which were either producers (phytoplankton) or detritus (benthic, pelagic, fisheries offal), with the remaining 15 representing broad aggregates of zooplankton, benthic fauna, and non-commercial fishes (Table 1). Along with these groups, seven fisheries were included, ranging from species-specific fisheries (such as salmon and Dungeness crab), to fisheries that target a wide range of habitats, species and assemblages (such as shrimp and groundfish trawl). As such, the model overemphasizes detail for mid-trophic level predators, in particular commercially important groundfish, for which considerably more data (and interest) tend to be focussed. Other specific weaknesses in the model include the amalgamated functional groups of forage fish, mesopelagic fish, benthic fish, and cephalopods, for which species richness and diversity is very high and basic population rate or food habits data are rare.

Table 2 presents the model parameters for the 1960s model, Table 3 presents model parameters for the 1990s model, and Table 4 presents the diet matrix for the 1960s model. Figure 2 presents the 1960s model in a more graphical form, consistent with that developed by Aydin et al. (2002). In this figure, the estimated trophic level is along the y axis, the size of the boxes is scaled to the log of the standing biomass, the width of the bars represents biomass flux of prey to predators, and the colours represent the alternative energy pathways such that pelagic (primary production) energy is shown in blue and the benthic (detrital loop) energy is shaded in red. Dynamic simulations of these models, run with both fishing effort and climate indices as both top-down and bottom-up forcing mechanisms, are presented for the period

Table 1. Summary of the more significant species or taxon in functional groups.

Functional group	**Description**
Phytoplankton	All photosynthetic primary producers, diatoms generally dominate
Infauna	Polychaetes, bivalves, small crustaceans, and some echinoderms
Amphipods	All gammarid, caprellid and hyperiid amphipods
Epibenthic	Includes many echinoderms (holothuroids, asteroids, ophiuroids), brachyurans, mysids, isopods, cumaceans, gastropods, and other organisms
Micro-zoopl.	Small heterotrophic zooplankton, primarily protozoans such as gymnodiniods, dinoflagellates, ciliates, and nanoflagellates
Copepods	All developmental stages of species in the subclass Copepoda
Euphausiids	All developmental stages of species in the order Euphausiacea
Carniv-zoopl.	Includes pasiphaid, seregestid and other pelagic shrimps, chaetognaths, pelagic polychaetes, and the pelagic stages of many invertebrates, such as crab megalopae
Small jellies	Filter-feeding urochordate herbivores; salps, doliolids and and larvaceans, as well as thecosome pteropods (such as *Limacina helecina*)
Large jellies	Essentially all gelatinous carnivores, principally cnidarians (hydrozoans and scyphozoans), ctenophores and heteropods
Pandalid shrimps	Primarily the ocean shrimp, *Pandalus jordanii*, but including *P. platyceros*, *P. borealis* and several other less commonly encountered species
Benthic shrimp	Benthic decapod shrimps (excluding *Pandalus jordani*) such as Crangon, Eualus, Daridea, and Calocaris species
Dungeness	*Cancer magister*
Tanner crab	*Chionoecetes tanneri*
Cephalopods	Cephalopods, such as *Loligo*, *Gonatus*, and *Octopus* species
Forage fish	Principally clupeids and osmerids, including northern anchovy, Pacific herring, sandlance, eulachon, surf smelt, and whitebait smelt
Mesopelagics	Many meso and bathypelagic species, including northern lampfish, California headlightfish, blue lanternfish and longfin dragonfish
Benthic fish	Common families include eelpouts (Zoarcidae), snailfish (Cyclopteridae), poachers (Agonidae), and sculpins (Cottidae)
Macrourids	Includes all grenadiers (family Macrouridae)
Sardine	
Mackerel	Includes jack mackerel (*Trachurus symetricus*) and Pacific mackerel (Scomber japonicus)
Salmon	Chinook and coho salmon (*Oncorhynchus* spp.)
Hake	*Merluccius productus*
Skates	Primarily *Raja* and *Bathyraja* species, such as big skate, longnose skate, and black skate
Dogfish	Primarily dogfish (*Squalus acanthias*), but includes cat sharks (*Apristurus* spp.)
Sablefish	*Anoplopoma fimbria*
Juv rockfish	All juvenile stages of *Sebastes* rockfish
POP	*Sebastes alutus*
Canary rockfish	*Sebastes pinniger*
Widow rockfish	*Sebastes entomelas*
Yellowtail rockf.	*Sebastes flavidus*
Black rockfish	Primarily black rockfish (*Sebastes melanops*) but includes other common nearshore *Sebastes* (such as blue, china, tiger, quillback and others)
Shelf rockfish [a]	Includes *Sebastes* species such as bocaccio, yelloweye, chilipepper, redstripe, greenstripe, and silvergrey rockfish.
Slope rockfish [a]	Includes *Sebastes* species such as aurora, blackgill, darkblotched, rougheye, sharpchin, shortraker, splitnose, and yellowmouth rockfish
Shortspine thornyheads	*Sebastolobus alascanus*
Longspine thornyheads	*Sebastolobus altivelis*
Juv thornyheads	All juvenile stages of *Sebastolobus* species
Juv roundfish	All juvenile stages of sablefish, lingcod, and other commercially significant roundfish
Lingcod	*Ophiodon elongates*
Juv flatfish	All juvenile stages of Pleuronectiform fishes
English sole	*Parophys vetulus*
Petrale sole	*Eopsetta jordani*
Small flatfish	Functional group that includes all remaining flatfish, including sanddab (*Citharichthys* spp.), slender sole, butter sole, and starry flounder
Rex sole	*Glyptocephalus zachirus*
Dover sole	*Microstomus pacificus*
Arrowtooth	*Atheresthes stomias*
Halibut	*Hippoglossus stenolepis*
Albacore	*Thunnus alalunga*
Coastal sharks	Functional group includes soupfin (*Galeorhinus galeus*) and thresher sharks (*Alopias* spp)
Shearwaters	Functional group primarily of *Puffinus griseus*, but including petrels and phalaropes
Murres	Primarily common murre (*Uria aalge*), but including other alcids such as Cassin's auklets, rhinoceros auklets, and tufted puffins

Table 1. continued

Functional group	**Description**
Gulls	Primarily Larus species, but including kittiwakes, fulmars and albatross
Orcas	includes both resident and transient killer whales (*Orcinus orca*)
Toothed whales	Primarily Dall's porpoise, harbor porpoise and Pacific white-sided dolphin
Sperm whales	*Physeter macrocephalus*
Harbor seals	*Phoca vitulina richardsi*
Sea lions	Primarily Steller sea lions, but including seasonally migrating California sea lions and northern elephant seals
Baleen whales	Primarily humpback whales, but including minke, fin, blue, and sei whales
Gray whales	*Eschrichtius robustus*
Baleen whales	Humpback (*Megaptera novaeangliae*), minke (*Balaenoptera acutorostrata*), and fin (*B. pysalus*) whales are the most frequently occurring baleen whales (other than gray whales) that occur in the NCC, although blue (*B. musculus*) and sei (*B. borealis*) are occasionally noted.

a. Based on PFMC designations

between 1960 and 2003 in Field (2004) and Field et al. (in prep). These simulations suggested that while substantial challenges exist in modelling the dynamics of migrant species (hake, salmon, and sardine in particular), model behavior is substantially improved by the inclusion of climate as a driving factor for many species.

In general, both static and dynamic model results suggest that strong interspecific interactions have not played an enormous role in determining the dynamics of many components in the NCC food web. This makes sense in a community dominated in part by long-lived groundfish, where low mortality rates are generally indicative of low predation rates and weaker trophic interactions. Significant exceptions include apparently strong interactions between sablefish and thornyheads, and in groups such as shrimp, salmon, hake and small flatfish, where high turnover rates and predation mortality is coupled with substantial changes in many of their key predators (hake, sablefish, marine mammals) over the last forty years. Future modelling efforts would clearly benefit by the inclusion of split-pool or stage-based modelling of many commercially and ecologically important species, particularly with regard to evaluating the potential role of cannibalism and juvenile predation by hake, sablefish, lingcod and larger rockfish. Future efforts should also both expand and reduce the spatial scales being considered; clearly a model of the entire California Current system would be desirable at many levels, and one might also gain considerable insight modelling unique habitats (such as shelf rocky reef and continental slope communities) independently.

CITATIONS

Aydin, K.Y., V.V. Lapko, V.I. Radchenko and P.A. Livingston. 2002. A comparison of the Eastern Bering and Western Bering Sea shelf and slope ecosystems through the use of mass-balance food web models. NOAA Technical Memorandum NMFS-AFSC-130.

Bottom, D.L., Jones K.K., Rodgers, J.D., and Brown, R.F. 1993. Research and management in the Northern California Current Ecosystem. In K. Sherman, L.M. Alexander, and B.D. Gold (editors) Large Marine Ecosystems: Stress, Mitigation and Sustainability. AAAS Press, pp. 259-271.

Carretta, J.V., J. Barlow, K.A. Forney, M.M. Muto and J. Baker. 2002. U.S. Pacific Marine Mammal Stock Assessments: 2002. NOAA Technical Memorandum SWFSC 346.

Field, J.C. 2004. Application of ecosystem-based fishery management approaches in the northern California Current. Ph.D. Dissertation, School of Aquatic and Fishery Sciences, University of Washington.

Field, J.C., R.C. Francis, and A. Strom. 2001. Toward a fisheries ecosystem plan for the Northern California Current. California Cooperative Oceanic and Fisheries Investigations Reports 42: 74-87.

Field, J.C., R.C. Francis, and K. Aydin. in prep. Top down modeling and bottom up dynamics: linking a fisheries-based ecosystem model with climate hypotheses in the northern California Current.

Green, G.A., J.J. Brueggerman, R.A. Grotefendt, C.E. Bowlby, M.L. Bonnell, K.C. Balcomb, III. 1992. Cetacean distribution and abundance off Oregon and Wshington, 1989-1990. Ch. 1 in J.J. Brueggeman (ed) Oregon and Washington Marine Mammal and Seabird Surveys. Minerals Management Service Contract Report 14-12-0001-30426.

Lynde, M.V.H. 1986. The Historical Annotated Landings (HAL) database: Documentation of annual harvest of groundfish from the Northeast Pacific and Eastern Bering Sea from 1956 to 1980. NOAA Technical Memorandum NMFS F/NWC-103.

MacCall, A.D. 2002. Use of known-biomass production models to determine productivity of West Coast groundfish stocks. North American Journal of Fisheries Mangement 22: 272-279.

Pikitch, E.K., D.L. Erickson and J.R. Wallace. 1988. An evaluation of the effectiveness of trip limits as a management tool. NWAFC Processed Report 88-27: NMFS

U.S. GLOBEC. 1994. Eastern Boundary Current Program: a science plan for the California Current. U.S. global ocean ecosystems dynamics, report number 11. U.S. GLOBEC Scientific Steering Coordination Office, Berkeley, CA.

Table 2. Parameter estimates of the 1960s Northern California Current model.

Group name	**Trophic level**	**Biomass (t·km^{-2})**	**Production/ biomass (year^{-1})**	**Consumption/ biomass (year^{-1})**	**Ecotrophic efficiency**	**Production/ consumption**	**Catch (t·km^{-2}·year^{-1})**	**Biomass accumulation (t·km^{-2}·year^{-1})**
Phytoplankton	1.0	55.150	120.00	-	0.43	-	0.000	0.000
Infauna	2.0	35.700	2.50	12.00	0.89	0.21	0.000	0.000
Amphipods	2.0	4.380	3.50	22.00	0.80	0.16	0.000	0.000
Epibenthic	2.5	12.564	2.00	10.00	0.80	0.20	0.012	0.000
Micro-zoop	2.0	3.947	100.00	300.00	0.80	0.33	0.000	0.000
Copepods	2.2	16.609	14.00	70.00	0.80	0.20	0.034	0.000
Euphausiids	2.1	27.037	8.00	40.00	0.80	0.20	0.000	0.000
Carniv-zoops	3.1	7.731	2.00	10.00	0.80	0.20	0.158	0.000
Small jellies	2.3	1.342	9.00	30.00	0.80	0.30	0.000	0.000
Large jellies	3.2	1.168	3.00	12.00	0.80	0.25	0.000	0.000
Pandalid shrimps	2.8	1.518	2.00	10.00	0.80	0.20	0.000	0.000
Benthic shrimp	3.0	1.608	2.50	12.00	0.80	0.21	0.000	0.000
Dungeness	3.5	0.843	0.75	3.80	0.71	0.20	0.000	0.000
Tanner crab	3.0	0.975	0.30	1.50	0.80	0.20	0.000	0.000
Cephalopods	3.6	2.059	2.00	6.00	0.80	0.33	0.000	0.000
Forage fish	3.2	27.101	1.50	6.00	0.80	0.25	0.004	0.000
Mesopelagics	3.2	7.575	0.60	3.00	0.80	0.20	0.000	0.000
Benthic fish	3.3	4.110	0.50	2.50	0.80	0.20	0.100	0.000
Macrourids	3.7	0.468	0.20	1.00	0.38	0.20	0.000	0.000
Sardine	2.8	0.663	0.50	5.00	0.80	0.10	0.000	0.000
Mackerel	3.5	0.286	0.35	6.00	0.71	0.06	0.001	0.000
Salmon	4.1	0.367	0.93	5.82	0.83	0.16	0.014	0.000
Hake	3.6	25.990	0.23	2.50	0.58	0.09	0.141	0.000
Skates	4.0	0.421	0.20	2.00	0.51	0.10	0.046	0.000
Dogfish	4.1	1.000	0.20	2.50	0.17	0.08	0.028	0.000
Sablefish	4.1	2.756	0.06	1.95	0.44	0.03	0.011	-0.008
Juv rockfish	3.3	0.704	1.50	6.00	0.80	0.25	0.029	0.000
POP	3.3	1.217	0.07	2.00	0.77	0.04	0.000	-0.010
Canary rockfish	3.2	0.757	0.10	1.60	0.43	0.06	0.045	-0.006
Widow rockfish	3.5	2.828	0.14	2.10	0.46	0.07	0.008	0.023
Yellowtail rockfish	3.6	1.966	0.11	1.60	0.65	0.07	0.027	0.000
Black rockfish	4.0	0.407	0.09	1.95	0.77	0.05	0.020	0.000
Shelf rockfish	3.7	1.179	0.10	1.90	0.64	0.05	0.006	0.000
Slope rockfish	3.3	0.864	0.06	1.45	0.86	0.04	0.025	0.000
Shortspine thornyheads	4.0	0.751	0.07	0.45	0.74	0.14	0.017	0.000
Longspine thornyheads	3.7	1.800	0.05	0.35	0.89	0.14	0.003	0.000
Juv thornyheads	3.4	0.714	0.50	2.50	0.80	0.20	0.009	0.000
Juv roundfish	3.2	0.247	1.50	5.13	0.80	0.29	0.000	0.000
Lingcod	4.3	0.522	0.24	2.20	0.13	0.11	0.012	-0.007
Juv flatfish	3.1	0.959	1.00	4.00	0.80	0.25	0.000	0.000
English sole	3.2	0.600	0.35	2.12	0.89	0.17	0.057	-0.019
Petrale sole	4.1	0.326	0.28	2.00	0.52	0.14	0.032	-0.015
Small flatfish	3.4	3.684	0.50	2.50	0.80	0.20	0.026	0.000
Rex sole	3.1	0.400	0.50	2.12	0.84	0.24	0.020	-0.005
Dover sole	3.1	3.861	0.08	1.10	0.42	0.07	0.093	-0.040
Arrowtooth	4.3	0.321	0.34	2.12	0.47	0.16	0.027	0.000
Halibut	4.3	0.089	0.34	2.12	0.51	0.16	0.003	-0.002
Albacore	4.3	0.014	0.36	7.30	0.64	0.05	0.000	0.000
Coastal sharks	4.4	0.050	0.18	2.80	0.47	0.06	0.000	0.000
Shearwaters	4.2	0.003	0.100	138.00	0.00	0.00	0.000	0.000
Murres	4.2	0.009	0.100	129.00	0.27	0.00	0.000	0.000
Gulls	4.1	0.002	0.120	122.00	0.00	0.00	0.000	0.000
Orcas	5.0	0.001	0.020	11.15	0.00	0.00	0.000	0.000
Toothed whales	4.4	0.052	0.070	28.85	0.09	0.00	0.000	0.000
Sperm whales	4.7	0.037	0.020	6.61	0.55	0.00	0.000	0.000
Harbor seals	4.4	0.004	0.084	17.44	0.70	0.01	0.000	0.001
Sea lions	4.5	0.012	0.074	16.38	0.67	0.01	0.000	0.001
Baleen whales	4.5	0.006	0.091	39.03	0.80	0.00	0.000	0.000
Gray whales	3.0	0.008	0.037	8.87	0.54	0.00	0.000	0.000
Baleen whales	3.6	0.075	0.037	7.58	0.95	0.01	0.000	0.003
Fishery offal	1.0	1.0	10.000	-	-	0.02	-	0.000
Pelagic detritus	1.0	1.0	10.000	-	-	0.09	-	0.000
Benthic detritus	1.0	1.0	10.000	-	-	1.09	-	1.000

Table 3. Parameter estimates of the 1990s Northern California Current model.

Group name	**Trophic level**	**Biomass (t·km^{-2})**	**Production/ biomass (year^{-1})**	**Consumption/ biomass (year^{-1})**	**Ecotrophic efficiency**	**Production/ consumption**	**Catch (t·km^{-2}·year^{-1})**	**Biomass accumulation (t·km^{-2}·year^{-1})**
Phytoplankton	1.0	55.150	120.00	-	0.40	-	0.000	0.000
Infauna	2.0	35.700	2.50	12.0	0.84	0.21	0.000	0.000
Amphipods	2.0	4.276	3.50	22.0	0.80	0.16	0.000	0.000
Epibenthic	2.5	12.091	2.00	10.0	0.80	0.20	0.014	0.000
Micro-zoop	2.0	3.693	100.00	300.0	0.80	0.33	0.000	0.000
Copepods	2.2	15.614	14.00	70.0	0.80	0.20	0.000	0.000
Euphausiids	2.1	25.238	8.00	40.0	0.80	0.20	0.000	0.000
Carniv-zoops	3.1	7.136	2.00	10.0	0.80	0.20	0.000	0.000
Small jellies	2.3	1.114	9.00	30.0	0.80	0.30	0.000	0.000
Large jellies	3.2	1.035	3.00	12.0	0.80	0.25	0.004	0.000
Pandalid shrimps	2.8	1.500	2.00	10.0	0.80	0.20	0.417	0.000
Benthic shrimp	3.0	1.548	2.50	12.0	0.80	0.21	0.000	0.000
Dungeness	3.5	1.028	0.75	3.8	0.64	0.20	0.180	0.000
Tanner crab	3.0	0.761	0.30	1.5	0.80	0.20	0.000	0.000
Cephalopods	3.6	1.954	2.00	6.0	0.80	0.33	0.001	0.000
Forage fish	3.2	25.710	1.50	6.0	0.80	0.25	0.035	0.000
Mesopelagics	3.2	6.550	0.60	3.0	0.80	0.20	0.000	0.000
Benthic fish	3.3	3.706	0.50	2.5	0.80	0.20	0.000	0.000
Macrourids	3.7	0.468	0.20	1.0	0.31	0.20	0.003	0.000
Sardine	2.8	1.000	0.50	5.0	0.93	0.10	0.000	0.200
Mackerel	3.5	1.780	0.35	6.0	0.15	0.06	0.000	0.000
Salmon	4.1	0.418	0.93	5.8	0.73	0.16	0.104	0.000
Hake	3.6	28.925	0.18	2.0	0.69	0.09	2.924	-2.900
Skates	4.0	0.421	0.20	2.0	0.78	0.10	0.034	0.000
Dogfish	4.1	1.000	0.20	2.5	0.39	0.08	0.028	0.000
Sablefish	4.1	1.472	0.09	2.1	0.90	0.04	0.122	-0.040
Juv rockfish	3.3	0.616	1.50	6.0	0.80	0.25	0.000	0.000
POP	3.3	0.298	0.08	2.1	0.72	0.04	0.021	-0.014
Canary rockfish	3.2	0.214	0.11	1.7	0.78	0.07	0.038	-0.026
Widow rockfish	3.5	1.486	0.16	2.2	0.43	0.07	0.122	-0.117
Yellowtail rockfish	3.6	1.433	0.15	1.7	0.81	0.09	0.076	0.005
Black rockfish	4.0	0.240	0.13	2.0	0.55	0.06	0.021	-0.018
Shelf rockfish	3.7	0.828	0.13	2.2	0.66	0.06	0.059	-0.041
Slope rockfish	3.3	0.585	0.06	1.9	0.86	0.03	0.037	-0.032
Shortspine thornyheads	4.0	0.337	0.08	0.5	0.84	0.17	0.044	-0.023
Longspine thornyheads	3.7	1.720	0.06	0.4	0.89	0.16	0.052	0.000
Juv thornyheads	3.4	0.414	0.50	2.5	0.80	0.20	0.000	0.000
Juv roundfish	3.2	0.234	1.50	5.1	0.80	0.29	0.000	0.000
Lingcod	4.3	0.171	0.30	2.4	0.17	0.13	0.032	-0.020
Juv flatfish	3.1	1.154	1.00	4.0	0.80	0.25	0.000	0.000
English sole	3.2	0.600	0.35	2.1	0.90	0.17	0.029	0.011
Petrale sole	4.1	0.136	0.36	1.7	0.52	0.21	0.022	0.000
Small flatfish	3.4	3.886	0.50	2.5	0.80	0.20	0.040	0.000
Rex sole	3.1	0.400	0.50	2.1	0.82	0.24	0.009	0.006
Dover sole	3.1	1.394	0.12	1.1	0.59	0.11	0.223	-0.072
Arrowtooth	4.3	0.325	0.34	2.1	0.82	0.16	0.061	0.000
Halibut	4.3	0.156	0.34	2.1	0.48	0.16	0.003	0.006
Albacore	4.3	0.014	0.36	7.3	0.64	0.05	0.000	0.000
Coastal sharks	4.4	0.050	0.18	2.8	0.49	0.06	0.000	0.000
Shearwaters	4.2	0.003	0.100	138.0	0.00	0.00	0.000	0.000
Murres	4.2	0.009	0.100	129.0	0.28	0.00	0.000	0.000
Gulls	4.1	0.002	0.120	122.0	0.00	0.00	0.000	0.000
Orcas	5.0	0.000	0.020	11.2	0.00	0.00	0.000	0.000
Toothed whales	4.4	0.052	0.070	28.9	0.09	0.00	0.000	0.000
Sperm whales	4.7	0.037	0.020	6.6	0.19	0.00	0.000	0.000
Harbor seals	4.4	0.014	0.084	17.4	0.19	0.01	0.000	0.000
Sea lions	4.5	0.038	0.074	16.4	0.22	0.01	0.000	0.001
Baleen whales	4.5	0.005	0.091	39.0	0.31	0.00	0.000	0.000
Gray whales	3.0	0.033	0.037	8.9	0.14	0.00	0.000	0.000
Baleen whales	3.6	0.160	0.037	7.6	0.22	0.01	0.000	0.001
Fishery offal	1.0	10.000	-	-	0.02	-	0.000	
Pelagic detritus	1.0	10.000	-	-	0.02	-	0.000	
Benthic detritus	1.0	10.000	-	-	0.09	-	0.000	

Table 4A. Diet for the first 20 functional groups of the Northern California Current model. The predators are in columns.

	infauna	amphipods	epibenthic	microzoo	copepods	euphausiids	carniv-zoopl	small jellies	large jellies	pandalid shp	benthic shp	dungeness	tanner crb	cephalopods	foragefish	mesopelagics	benthic fish	macrourids	sardine	mackerel
Phytoplankton	8	0.2		0.75	0.8	0.9	0.03	0.5											0.28	
Infauna			0.43							0.25	0.4	0.4	0.792				0.3	0.15		
Amphipods			0.02				0.02			0.02	0.04	0.025			0.01	0.03	0.18	0.05		0.01
Epibenthic										0.05	0.4	0.2	0.118	0.009			0.4	0.15		
Micro-zoop					0.2	0.05	0.03	0.25	0.03						0.1				0.02	
Copepods						0.05	0.5		0.3	0.1				0.15	0.45	0.32			0.4	0.05
Euphausiids							0.35		0.6	0.2				0.38	0.4	0.52			0.3	0.6
Carniv-zoopl									0.02	0.03				0.15	0.025	0.04				0.07
Small jellies							0.05		0.05						0.01	0.045				
Large jellies							0.02									0.02				0.01
Pandalid shrimps														0.005			0.01	0.01		
Benthic shrimps												0.2		0.005			0.04	0.04		
Dungeness												0.005					0.005			
Tanner crab																	0.002			
Cephalopods												0.001		0.001	0.005	0.02	0.001	0.3		0.005
Forage fish												0.1		0.2			0.01			0.2
Mesopelagics														0.1		0.005		0.05		0.01
Benthic fish												0.01						0.05		0.004
Macrourids																				
Sardine																				
Mackerel																				
Salmon																				0.001
Hake																		0.05		
Skates																				
Dogfish																				
Sablefish																				
Juv rockfish												0.001					0.003			0.005
POP																				
Canary rockfish																				
Widow rockfish																				
Yellowtail Rockfish																				
Black rockfish																				
Shelf rockfish																				
sSope rockfish																				
Shortspine Thorny.																				
Longspine Thorny.																				
Juv thornyheads																				
Juv roundfish												0.002					0.002			0.005
Lingcod																				
Juv flatfish											0.01	0.01					0.02			0.02
English sole																				
Petrale sole																				
Small flatfish												0.02					0.01			0.01
Rex sole												0.001								
Dover sole																				
Arrowtooth																				
Halibut																				
Albacore																				
Coastal sharks																				
Shearwaters																				
Murres																				
Gulls																				
Orcas																				
Toothed whales																				
Sperm whales																				
Harbor seals																				
Sea lions																				
Baleen whales																				
Gray whales																				
Baleen whales																				
Fishery offal												0.02								
Pelagic detritus		0.1		0.25				0.25												
Benthic detritus	1	0.7	0.55							0.35	0.15	0.005	0.09				0.017	0.15		

Table 4B. Diet for the second 20 functional groups of the Northern California Current model.

	salmon	hake	skates	dogfish	sablefish	juv rock	POP	canary	widow	yellowtail	black	shelf rock	slope rock	ssthorny	lsthorny	juv thorny	juv round	lingcod	juv flat	english
Phytoplankton																		0.28		
Infauna		0.02		0.02	0.009								0.05	0.16			0.15			
Amphipods0.001		0.02		0.001	0.006	0.005	0.001	0.035	0.002	0.002	0.005	0.01	0.05	0.03		0.011	0.05		0.001	
Epibenthic		0.002	0.2	0.05	0.05	0.022	0.005			0.002	0.05	0.04	0.02	0.03	0.2			0.15		
Micro-zoop																			0.02	
Copepods	0.001					0.39			0.002							0.2	0.818		0.4	0.001
Euphausiids	0.1	0.575		0.2	0.06	0.44	0.78	0.92	0.3	0.55	0.1	0.35	0.8			0.5	0.123		0.3	0.1
Carniv-zoopl	0.2	0.029			0.01	0.004	0.07	0.008	0.2	0.025	0.1	0.01	0.05	0.01		0.25	0.029			0.2
Small jellies	0.002				0.04	0.001		0.001	0.32	0.05	0.08			0.005	0.01	0.05				0.002
Large jellies	0.002			0.05	0.05				0.04	0.01	0.02		0.005							0.002
Pandalid shrimps		0.02	0.02	0.001	0.015	0.03	0.03	0.03	0.001	0.02	0.001	0.12	0.03	0.05	0.01			0.01		
Benthic shrimps		0.007	0.2		0.002	0.075					0.042	0.01	0.01	0.15	0.25			0.04		
Dungeness			0.05	0.02	0.001						0.001									
Tanner crab			0.025		0.002	0.012								0.2	0.1					
Cephalopods	0.01	0.005	0.01	0.005	0.05		0.03		0.005	0.025	0.01	0.005	0.015	0.025	0.05			0.3		0.01
Forage fish	0.612	0.324	0.05	0.2	0.25	0.004	0.01	0.02	0.015	0.2	0.5	0.25	0.04	0.02			0.019			0.612
Mesopelagics	0.002	0.016			0.03	0.004	0.06	0.02	0.035	0.05		0.1	0.02	0.02	0.1			0.05		0.002
Benthic fish	0.002	0.002	0.05	0.07	0.08	0.003	0.01			0.01	0.03	0.05		0.05	0.05			0.05		0.002
Macrourids					0.005									0.005						
Sardine	0.01																			0.01
Mackerel																				
Salmon					0.006						0.02									
Hake	0.002	0.014	0.05	0.2	0.128				0.02	0.01				0.12				0.05		0.002
Skates					0.002															
Dogfish																				
Sablefish																				
Juv rockfish	0.025	0.002		0.01	0.02				0.02	0.03	0.02	0.015		0.05	0.015					0.025
POP				0.001	0.003									0.001						
Canary rockfish				0.001	0.002							0.001								
Widow rockfish				0.001	0.01							0.005								
Yellowtail Rockfish				0.001	0.01							0.003								
Black rockfish												0.001								
Shelf rockfish				0.001	0.003							0.001		0.002						
sSope rockfish				0.001	0.001									0.002						
Shortspine Thorny.					0.005															
Longspine Thorny.					0.01									0.05						
Juv thornyheads					0.05									0.05						
Juv roundfish	0.01		0.02	0.01	0.025				0.002	0.002	0.004	0.004								0.01
Lingcod				0.001	0.001															
Juv flatfish	0.01		0.05	0.02	0.003				0.002	0.002		0.005								0.01
English sole			0.02	0.01	0.001						0.001	0.005								
Petrale sole			0.005	0.005																
Small flatfish	0.01	0.004	0.15	0.12	0.02				0.002	0.012	0.018	0.02		0.007	0.005					0.01
Rex sole	0.001	0.001	0.03	0.01	0.002				0.001		0.001			0.001						0.001
Dover sole			0.02	0.01	0.001									0.001						
Arrowtooth			0.01	0.002										0.001						
Halibut																				
Albacore																				
Coastal sharks																				
Shearwaters																				
Murres																				
Gulls																				
Orcas																				
Toothed whales																				
Sperm whales																				
Harbor seals																				
Sea lions																				
Baleen whales																				
Gray whales																				
Baleen whales																				
Fishery offal					0.03									0.05						
Pelagic detritus																				
Benthic detritus					0.001										0.02			0.15		

Table 4C. Diet for the third 20 functional groups of the Northern California Current model. The predators are in columns.

	petrale	small flat	rex	dover	arrowtooth	halibut	albacore	coastal sharks	shearwaters	murres	gulls	orcas	toothed whales	sperm whales	harbor seals	sea lions	fur seals	grey whales	baleen whales
Phytoplankton																			
Infauna	0.15	0.55	0.85	0.001	0.006												0.025		
Amphipods0.005	0.1	0.3	0.03	0.001													0.95		
Epibenthic	0.15	0.38	0.12	0.1		0.05					0.01				0.02	0.01		0.025	
Micro-zoop																			
Copepods		0.08								0.01									0.01
Euphausiids	0.005	0.1			0.04				0.03	0.01	0.01								0.5
Carniv-zoopl		0.02			0.001		0.1		0.015		0.01								0.005
Small jellies			0.005																
Large jellies		0.01							0.005										
Pandalid shrimps	0.02	0.01		0.01	0.04	0.025													
Benthic shrimps	0.25	0.06	0.02	0.01	0.002	0.025													
Dungeness	0.005	0.005			0.002	0.025		0.005							0.025				
Tanner crab						0.001													
Cephalopods	0.005	0.005					0.25	0.01	0.1	0.03	0.17	0.1	0.2	0.65	0.05	0.2	0.3		0.035
Forage fish	0.1	0.05			0.3	0.15	0.3	0.35	0.75	0.817	0.579	0.11	0.35		0.35	0.259	0.26		0.35
Mesopelagics					0.004		0.2	0.025		0.01	0.02		0.07	0.05		0.02	0.024		
Benthic fish	0.19	0.01				0.05		0.025		0.002			0.01		0.05	0.02	0.011		
Macrourids														0.025					
Sardine							0.05	0.05		0.001	0.001	0.005	0.05			0.01	0.01		0.09
Mackerel							0.08	0.025				0.005	0.03			0.021	0.021		0.01
Salmon						0.05		0.05		0.01	0.01	0.1	0.02		0.1	0.05	0.07		
Hake					0.5	0.45		0.25					0.15	0.05	0.1	0.22	0.148		
Skates								0.01				0.04	0.005	0.025		0.02			
Dogfish								0.01				0.04	0.005	0.025		0.02			
Sablefish						0.01						0.1	0.02	0.05		0.01	0.02		
Juv rockfish					0.002		0.01		0.085	0.094	0.082					0.015			
POP					0.001	0.01		0.005				0.002		0.02		0.005	0.01		
Canary rockfish					0.001	0.004		0.01				0.005	0.002	0.005	0.005	0.001	0.01		
Widow rockfish					0.001	0.004	0.005	0.01				0.01	0.023	0.015	0.005	0.02	0.036		
Yellowtail Rockfish					0.002	0.01	0.005	0.01				0.01	0.015	0.02	0.015	0.02	0.03		
Black rockfish								0.005				0.005	0.001		0.01	0.01			
Shelf rockfish					0.002	0.008		0.015			0.001	0.005	0.003	0.01	0.01	0.015	0.02		
sSope rockfish					0.001	0.002		0.005			0.001			0.02		0.005	0.02		
Shortspine Thorny.														0.01					
Longspine Thorny.																			
Juv thornyheads																			
Juv roundfish					0.002	0.01		0.005	0.015				0.01		0.005	0.005	0.01		
Lingcod								0.01							0.02	0.01			
Juv flatfish	0.01	0.01			0.01	0.01				0.008	0.005								
English sole	0.02				0.005	0.003		0.01					0.005		0.075	0.01			
Petrale sole					0.002	0.002		0.002							0.01	0.002			
Small flatfish	0.21		0.005		0.06	0.035		0.06		0.008	0.015		0.025		0.14	0.02			
Rex sole	0.025				0.01	0.01		0.01											
Dover sole	0.005				0.01	0.02		0.01					0.001			0.002			
Arrowtooth						0.01		0.008				0.05	0.001		0.01				
Halibut								0.01				0.05	0.001	0.025					
Albacore								0.005				0.005	0.001						
Coastal sharks												0.01	0.002						
Shearwaters																			
Murres											0.001								
Gulls																			
Orcas																			
Toothed whales												0.14							
Sperm whales												0.018							
Harbor seals												0.003							
Sea lions												0.037							
Baleen whales												0.06							
Gray whales												0.03							
Baleen whales												0.06							
Fishery offal											0.085								
Pelagic detritus																			
Benthic detritus		0.01				0.02													

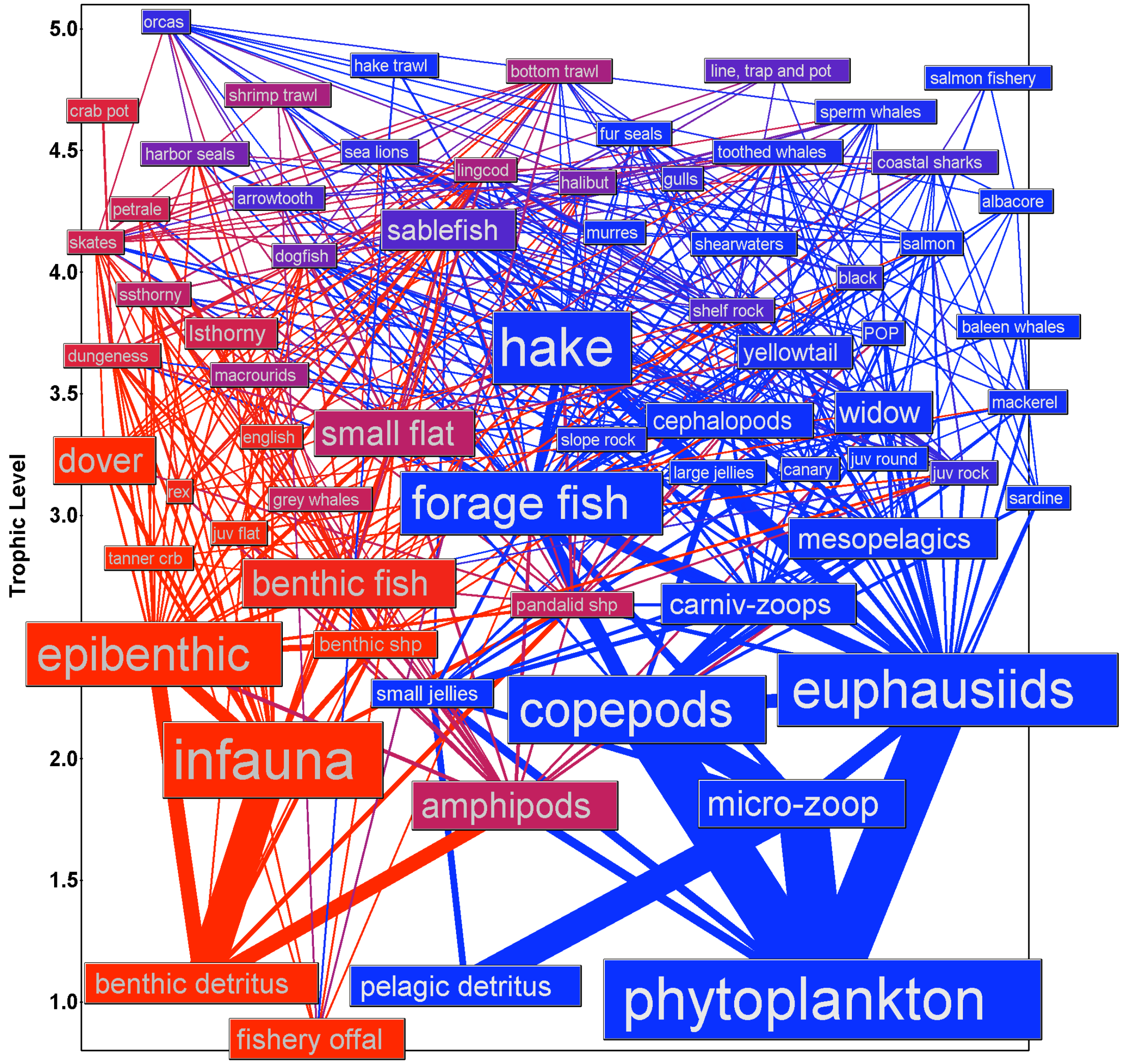


Figure 2. The significant food web of the Northern California Current for the 1960s, with blue (or dark gray) representing pelagic energy pathways, and red (or light gray) representing benthic energy pathways.

Historical reconstruction of whale abundance in the North Pacific

Sylvie Guénette and Zarin Salter[1]

Fisheries Centre University of British Columbia, Vancouver BC; *s.guenette@fisheries.ubc.ca*

ABSTRACT

We compiled the abundance information for whales of the North Pacific for the 20th century, and compared it with their catch history and distributions. This information was necessary to complete the Gulf of Alaska models (this volume). We concentrated on the commercially important whales: fin, sei, gray, sperm and humpback. Examination of the catch data show that pelagic whaling occurred throughout the Pacific and increased in importance in the mid 1900s. In order to refine the compilation, in the future, it will be necessary to examine the exact locations of the catch to determine the catch taken from a particular stock.

INTRODUCTION

This work was undertaken to provide catch time series and preliminary populations estimates for North Pacific whales during the 20th century for the models of the Gulf of Alaska (this volume). It also constituted the first step to examine the role of whale depletion in the Northeast Pacific ecosystem (Figure 1). The purpose of this report is to compile abundance data for commercially important whales of the North Pacific and if possible of the study area, the Northeast Pacific (NEP) for the 20th century, taking into account their known distributions in the North Pacific and their catch history. Catch statistics were obtained from the International Whaling Commission (IWC) and supplemented with other sources when available.

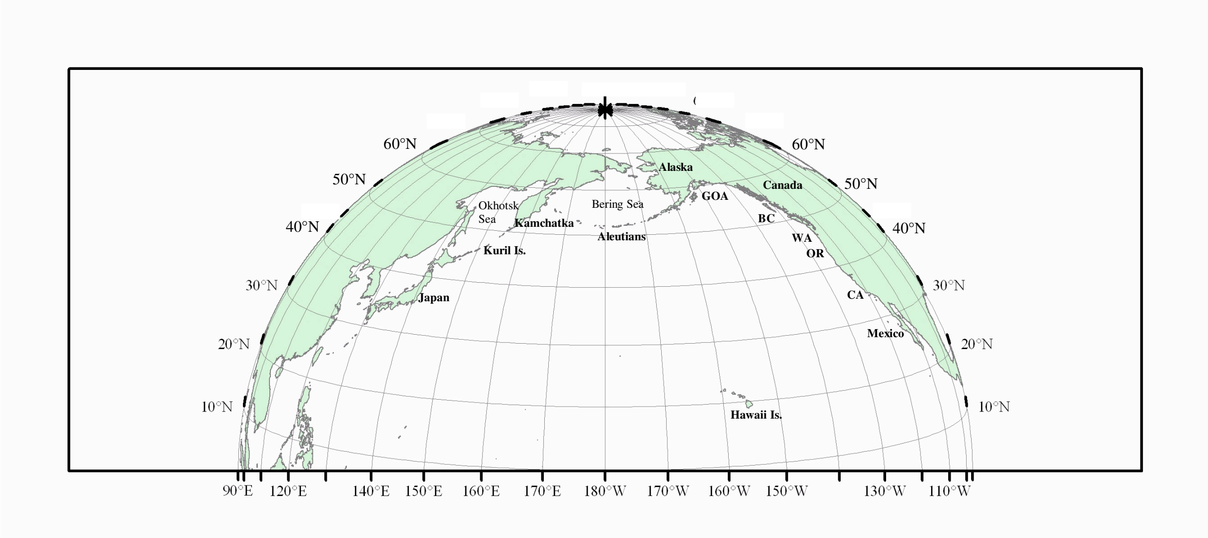


Figure 1. Map of the North Pacific. GOA: Gulf of Alaska; BC: British Columbia (Canada), WA, OR, CA: Washington, Oregon and California states (USA).

FIN WHALE

In the Eastern Pacific, fin whales (*Balaenoptera physalus*) are distributed year round from as far south as Baja California to the Bering Sea (Calkins 1986; Angliss and Lodge 2002). The majority of summer abundances occur in the Bering Sea, whereas winter abundances range from the Gulf of Alaska and the Aleutian Islands to Southern California (Calkins 1986; Angliss and Lodge 2002).

The stock structure of fin whales in the North Pacific is currently equivocal due to limited information, and consequently the International Whaling Commission considers all North Pacific fin whales to belong to the same stock. Based on the

---

[1] Guénette, Sylvie and Zarin Salter. 2005. Historical reconstruction of whales abundance in the North Pacific. In: Guénette, S., and V. Christensen (editors). 2005. Food web models and data for studying fisheries and environmental impacts on Eastern Pacific ecosystems.. Fisheries Centre Research Reports 13(1):217-224.

work of Dizon et al. (1992), the National Marine Fisheries Service (NMFS) has recently recognized three stocks within the eastern population of fin whales: 1) Alaska 2) California/Oregon /Washington, and 3) Hawaii (Angliss and Lodge 2002). Calkins (1986) cites two tagging studies, which indicated little east/west movement across the North Pacific and thus supports the division of the North Pacific fin whale population into at least two stocks. Both stocks migrate north and south, with the eastern stock staying closer to the coastline (Calkins 1986). However, a suggestion that they may intermingle around the Aleutian Islands creates further ambiguity in stock distinction.

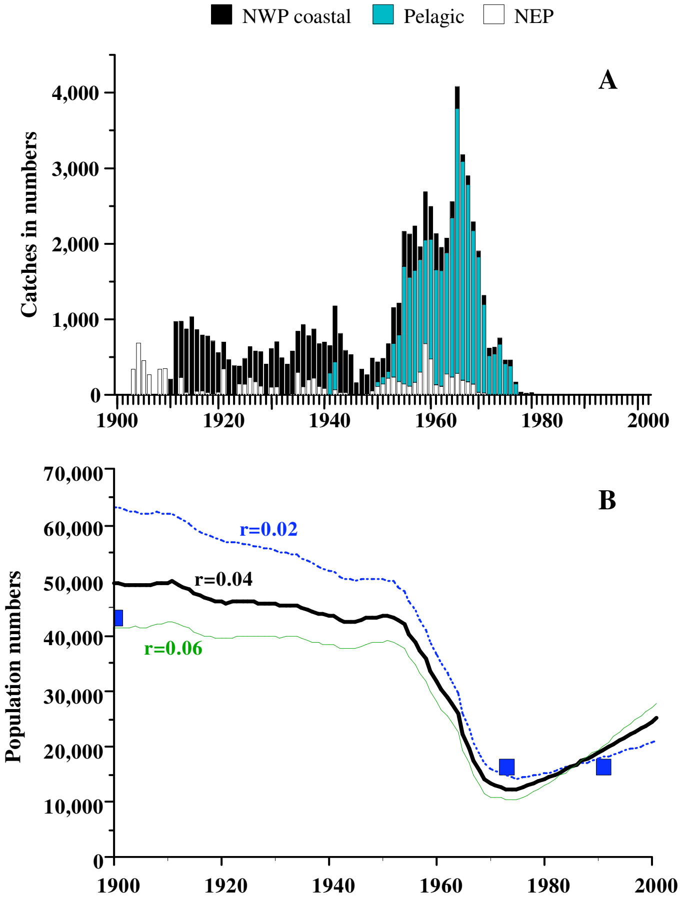


Figure 2. A. Fin whale catches in the North Pacific off the west coast of North America (NEP), coastal northwestern Pacific (NWP), and from pelagic whaling (pelagic). B. abundance estimates taken from the literature (squares) and results of the production model using global catches and combinations of starting abundance (N_i) and intrinsic growth rate (r). A) N_i=60,000, r=0.04; B) N_i=43,500, r=0.04; C) N_i=35,000, r=0.04. The inset table show the carrying capacity (k) estimated using the each of the 3 scenarios.

As early as the mid 17th century, the Japanese were capturing fin, blue and other large whales with an open netting technique, harvesting 480 fin whales a year until 1913. From 1914 to 1975, 26,040 whales were caught throughout the North Pacific. Fin whales were scarce after WWII, and their capture was banned by IWC in 1976 (Perry et al. 1999). Given that this species was exploited as one stock for the North Pacific, we used the entire catch data (global) including Norway (whaling in the Northeast Pacific) and North American captures (NEP), Russian and Japanese coastal catches (NWP), and pelagic catches (Russian and Japanese pelagic whaling throughout the North Pacific) (Figure 2). Catches in the northwestern Pacific were larger than in the Northeast Pacific early in the times series. Pelagic whaling was the most important source of catches between 1950 and 1974 reaching 3,507 whales in 1964 (Figure 2).

The number of fin whales in the northeast Pacific in the 1970s was estimated at 8,520-10,970 (Braham 1991 in Perry et al. 1999), that is 59% of the estimate of 4,620-18,630 (Ohsumi and Wada 1974 in Perry et al. 1999) given for the North Pacific (Table 1). The estimate for 1991 amounts to 14,620-18,630 animals in the North Pacific. To verify that the catches compiled were in fact sufficient to provoke the decline in abundance shown by historical estimates (Table 1), and to generate a population abundance trajectory we used a simple stock reduction model:

$$N_{t+1}= N_t + N_t \cdot r \cdot (1-N_t/k) -C_t$$

where r is the intrinsic rate of growth, N_t is the abundance at time t, k is the carrying capacity, and C_t the catch. The initial abundance in the model (N_i) was set at 80% of the carrying capacity and r set at various values from 0.02 to 0.06 to explore its implications, and the carrying capacity was estimated using Solver in Excel. Catches from IWC were complemented by adding missing catches of 480 animals per year from 1895 to 1908.

Given the small number of population estimates through time, it is impossible to find an optimal solution using numerical procedures, but trials show that the decline is plausible given the catches for all values of intrinsic growth rate. As r is set higher, the original biomass (and k) is estimated at lower values (Figure 2). Using a value of r equal to 0.02 resulted in a larger abundance at the beginning of the century (64,000) than that reported in the literature, and also resulted in a slow recovery rate after the decline of the 1960-70s. Using an r value of 0.04, a value commonly accepted as realistic for baleen whales, the original abundance was estimated at 50,000 whales and show a greater depletion in 1979 than the previous scenario. The case with r=0.06 is unlikely because of the rate of reconstruction of the population after 1979.

Table 1. Historical abundance of fin whales in the North Pacific.

Year	Area	Range	Estimate	Source
1895	NP	42,000-45,000	43500	Ohsumi and Wada (1974 in Perry et al. 1999)
1970	NEP	8,520-10,970	9750	Braham (1991 in Perry et al. 1999)
1973[b]	NP	13,620-18,630	16625	Ohsumi and Wada (1974 in Perry et al. 1999)
1982	GOA +BS [a]	10000		Consiglieri and Braham (1982 in Calkins 1986)
1991	NP	14,620-18,630	16625	Braham (1991 in Perry et al. 1999)

a. estimate in the Central and Northern Gulf of Alaska and Bering Sea, time period not specified ; b. early 1970s

SEI WHALE

Derived from blood typing examinations, differences in parasite species, morphological features and reproductive activity, the sei whale (*Balaenoptera borealis*) population of the North Pacific appears to be segregated into 3 stocks separated at about 174ºW and 155ºW (Horwood 1987; Perry et al. 1999). The history of catch timing and location, sightings, and marking studies indicate that all North Pacific sei whales migrate north to the Aleutian Islands and the Gulf of Alaska to feed during the summer months. Masaki (1976 in Calkins 1986) found that the areas of greatest sei whale abundance between May and August are in the northwestern and northeastern parts of the Gulf of Alaska. Few sei whales remain in the Gulf during the winter, and most leave the Gulf for southern waters by September (Calkins 1986).

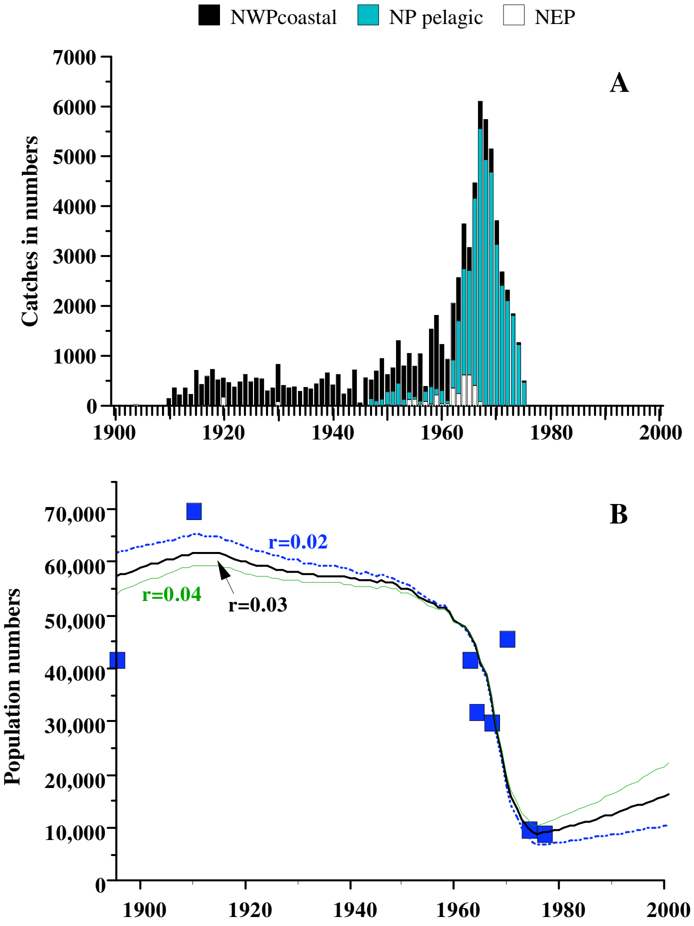


Figure 3. A. Sei whale catches off the west coast of North America (NEP), coastal northwestern Pacific (NWP), and from pelagic whaling (pelagic). B. Sei whale abundance estimates taken from the literature (squares) and results of the production model using combinations of starting abundance (N_i) and intrinsic growth rate (r). A. N_i=70,000, r=0.02; B. N_i=70,000, r=0.04; C. N_i=42,000, r=0.04; D. N_i=42,000, r=0.02. The inset table show the carrying capacity (k) estimated using each of the 4 scenarios.

Exploitation of sei whales started as early as the mid 17th century on the coast of Japan using a unique netting method (Mizroch et al. 1984). Modern whaling was introduced to the Western Pacific by the Soviet from 1864-1885 (Horwood 1987) and to the Northeast Pacific (NEP) in 1905. Although the commercial hunting of sei whales began in the early 1900s, major exploitation occurred between 1954 and 1974, when the abundances of the more desirable fin whale species had decreased significantly (Horwood 1987). Sei whales were slightly more important in Canadian catches then in other locations in NEP and only few sei whales were taken in Alaskan whaling stations. Except for the high catches of the 1950-1960s, catches off North America were pretty insignificant compared to those of other species (Mizroch et al. 1984) and compared to the combined catches in the northwestern Pacific and from pelagic whaling (Figure 3).

Tillman (1977 in Perry et al. 1999) estimated the abundance of sei whales in the North Pacific prior to modern exploitation (late 1800s to early 1900s) at 42,000 while

Table 2. Population estimates for sei whales in the North Pacific

Year	area	Range	Estimate	Reference
1900	NP		42,000	Tillman (1977 in Perry et al. 1999)
1910	NP	58-82,000	70,000	Ohsumi, Shimadzu and Doi (1971 in Horwood 1987)
1963	NP		42,000	Tillman (1977 in Horwood 1987)
1964	NP		32,000	Scientific Committee for the IWC (1967 in Horwood 1987)
1967	NP		30,000	Doi and Ohsumi (1968 in Horwood 1987)
1970	NP	34-58,000	46,000	Ohsumi, Shimadzu and Doi (1971 in Horwood 1987)
1974	GOA		8,600	Tillman (1977 in Horwood 1987)
1974	NP	7,260-12,620	9,940	Tillman (1977 in Perry et al. 1999)
1977	NP		9,110	Tillman (1977 in Perry et al. 1999)

Ohsumi, Shimadzu and Doi (1971 in Horwood 1987) estimated it at 70,000 (Table 2). The population decreased markedly between 1963 and 1974 when the catch increased to unprecedented levels (Figure 3). CPUE and sighting indices declined abruptly as the catch increased (Horwood 1987). The latest estimate amounts to 9,110 whales in 1977, based on catch history and trends in CPUE (Tillman 1977 in Perry et al. 1999). We used the stock reduction model assuming that the population was at 80% of the carrying capacity at the beginning of the century (Figure 3). Given the lack of data on the actual size of the Japanese catch at the beginning of the century, the population estimate of that time is probably less accurate than the rest of the series. The resulting initial abundance was quite variable (62,000-54,000) for r values varying from 0.02 to 0.04. The differences in predicted abundance were relatively small in the 1960s and 1970s but quite large in the 1990s (9,400-18.340 sei whales). The scenario with r=0.03 was chosen as an intermediate value. However it is useful to remember that these projections are not substantiated by any data.

HUMPBACK WHALE

Photo ID, vessel and aerial surveys as well as genetic studies indicate that there are at least three distinct stocks of humpback whales (*Megaptera novaengliae*) in the North Pacific (Angliss and Lodge 2002): 1) A population referred to as the California/ Oregon/ Washington stock (CA/OR/WA), which migrates from the breeding and calving areas of coastal Central America and Mexico to feeding grounds between California and southern British Columbia; 2) A population referred to as the Western North Pacific (western) stock which, based on Discovery Tag information, migrates from breeding grounds off Japan to summer feeding grounds in the Bering Sea and Aleutian Islands; and 3) A population known as the Central North Pacific stock (central), which migrates from breeding and calving waters near Hawaii to summer feeding grounds in the Gulf of Alaska and Southeast Alaska (Angliss and Lodge 2002). Perry et al. (1999) added a fourth stock located offshore of Mexico for which the feeding grounds are unknown and that will be ignored here. Thus, in order to estimate the abundance of humpback whales that inhabit the North Pacific and more particularly the GOA-Aleutians region, all three stocks will be included.

Prior to 1900 there has been an unknown number of humpbacks taken by aboriginal hunting. Modern operations began in 1889 in the Northwest Pacific and in 1905 in the northeast. According to the data obtained from IWC 10,727 humpbacks were caught between 1905-1960, and 5,023 between 1960-1965 (Figure 4). Johnson and Wolman (1984) reported similar numbers

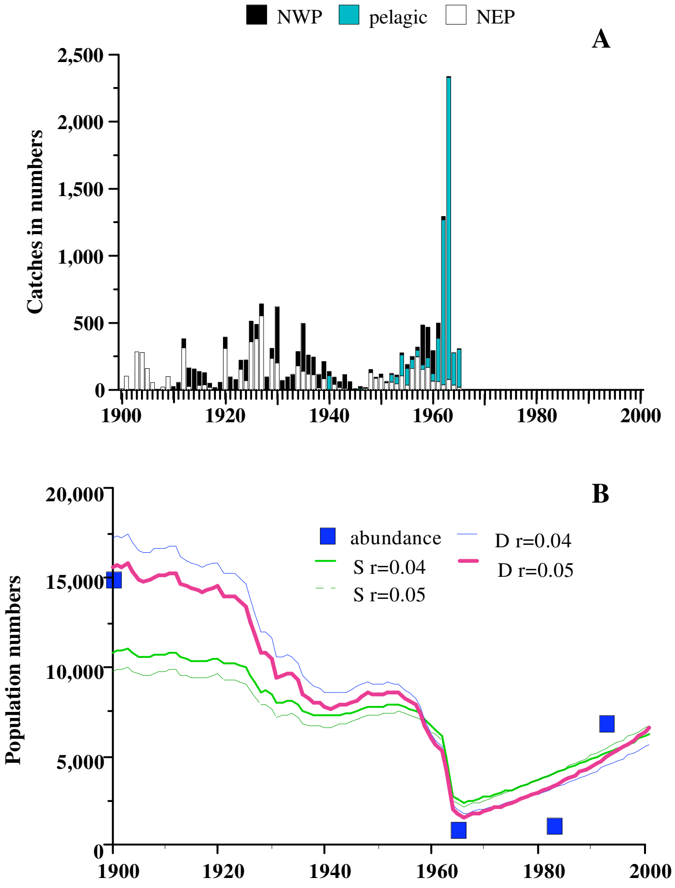


Figure 4. A. Humpback whale catches per area, northeast (NEP) northwest (NWP) and pelagic whaling (labelled North Pacific or NP); B. Abundance of humpback whales based on the reconstruction models using the catch as found in the IWC statistics (S) and double D the catches for 1905-1965 and intrinsic rate of growth (r) of 0.04 or 0.05.

for the last period but twice as much (23,000) for the 1905-1960. Catches reached a peak of 2,339 animals in 1963, and were dominated by pelagic whaling in the 1950-1960s (Figure 4) and exploitation was stopped in 1965 (Perry et al. 1999). Further analysis of the catch should explore the spatial distribution of the whales caught to delineate the catch per stock.

Prior to modern exploitation the abundance of humpback whale was estimated at 15,000 (Table 3). The abundance declined rapidly to 1,000 in 1965 and started increasing after exploitation stopped. In 1993, the NP abundance reached 6-8 thousands of which 90% were from the NEP (central and CA /OR /WA). We used the surplus production model assuming that the population was at 80% of the carrying capacity at the beginning of the century (Figure 4). Using the original catch from IWC, the initial abundance was estimated around 10,00 animals for r values of 0.04 and 0.05 (figure 4). Doubling the catch to levels reported by Johnson and Wolman (1984) resulted in initial abundance of around 16,000 animals, estimate similar that reported by Rice (1978 in Perry et al. 1999). The scenario with r=0.04 using the initial catch was chosen as a conservative value. However, the trajectories for the period 1963 to 2000 are similar for the four scenarios.

Table 3. Historical abundance of humpback whales compiled from the literature.

Year	Range	Estimate	Region	Source
1900		15,000	NP	Rice (1978 in Perry et al. 1999)
1965		1,000	NP	Rice (1978 in Perry et al. 1999)
1982	635-1,536	1086	central	Baker and Herman (1987)
1983		1200	NP	Johnson and Wolman (1984)
1983	550-790	670	central	Rice and Wolman (1984 in Johnson and Wolman 1984)
1983	<100	100	western	Johnson and Wolman (1984)
1993[a]	6,000-8,000	6880	NP	Calambodikis et al. (1997)
	1,611-2,250	1931	CA /OR /WA	Calambodikis et al. (1997)
	4,005-5,000	4503	central	Calambodikis et al. (1997)
	394-500	447	western	Calambodikis et al. (1997)

a. 1991-1993

GRAY WHALE

Distributional data and population response data suggest that the gray whales (*Eschrichtius robustus*) of the North Pacific belong to two distinct stocks; the Northwest Pacific stock and the Northeast Pacific stock (Angliss and Lodge 2002). The distribution of the western North Pacific stock appears to be from their wintering grounds in the South China Sea to their summer feeding grounds in the west central Okhotsk Sea off the northeastern coast of Sakhalin Island (Weller et al. 2002). Most of the eastern North Pacific gray whale stock migrates yearly from their wintering areas in Baja California, Mexico to their summer feeding grounds in the northern Bering and Chukchi Seas (Angliss and Lodge 2002). The northeastern Pacific stock is the only of the two stocks that inhabits the study area, and as such abundance estimates for these alone are investigated here.

The northeastern Pacific gray whales begin their primarily coastal (Gregr 2004) northbound migration in mid-February and March (Angliss and Lodge 2002), and enter the Bering Sea by late June and early July (Calkins 1986). Their southbound migration through the Gulf of Alaska appears to be further from the shore (Gregr 2004) and peaks from late November to early December, spending 45 days in the Gulf of Alaska (Calkins 1986). However, there are suspected to be some pockets of gray whale populations that remain in the Gulf year round (N. Friday, *pers. comm.* 2004 and Calkins 1986).

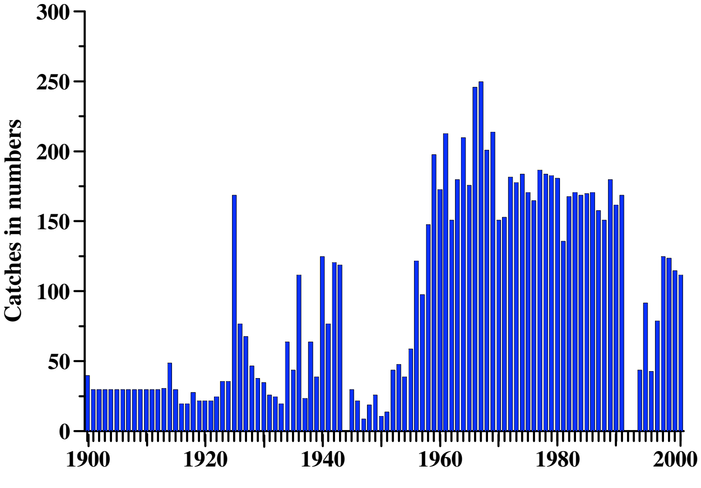


Figure 5. Gray whale catches in the Northeast Pacific.

Catches were taken from the IWC statistics completed with aboriginal and early industrial catch for the NEP before 1947 (Punt and Butterworth 2002) (see Figure 5). The Northeastern Pacific gray whales were significantly depleted between 1846 and 1874 when nineteenth-century commercial whaling exploited the cows and calves resident in their southern wintering and calving lagoons (Rice et al. 1984). Modern whaling began in 1905 using factory vessels whaling in pelagic environment off Baja California, the west coast of Canada and US and the Bering sea (Rice et al. 1984). The stock was protected in 1966 and exploitation stopped except for Russians whaling taking an average of 170 whales per year. In 1979, gray whales were redesignated a 'sustained management stock', and as such, the indigenous peoples of Russia and the United States are allowed a subsistence take (Calkins 1986). This species is considered recovered after the cessation of whaling and may be nearing their carrying capacity (Witting 2003).

We used the abundance time series as calculated by Wade (2002) for the Eastern stock from 1967-1995 (Table 4). The reconstruction of the stock for the beginning of the 20th century and precedent centuries were attempted using various methods but it is difficult to decide between various initial assumptions (Butterworth et al. 2002). However Witting (2003) proposed a population model that was able to reconstruct the various stage of exploitation and population depletion. Depending on the simulations, the estimates could vary between 1,000 and 5,000 animals for 1900.

Table 4. Estimates for the eastern Pacific gray whales population.

Year	Population estimate	Source
1845	15,000- 24,000	Reilly (1981 in Calkins 1986)
1874	4,000	Henderson (1984 in Calkins 1986)
1885	1,571	from graph 2a in Witting (2003)
1967	13,012	Wade (2002)
1968	12,244	Wade (2002)
1969	12,777	Wade (2002)
1970	11,170	Wade (2002)
1971	9,841	Wade (2002)
1972	16,962	Wade (2002)
1973	14,817	Wade (2002)
1974	13,134	Wade (2002)
1975	14,811	Wade (2002)
1976	15,950	Wade (2002)
1977	17,127	Wade (2002)
1978	13,300	Wade (2002)
1979	16,581	Wade (2002)
1984	21,942	Wade (2002)
1985	20,450	Wade (2002)
1987	21,113	Wade (2002)
1992	17,674	Wade (2002)
1993	23,109	Wade (2002)
1995	22,571	Wade (2002)
1997	26,635	Hobbs and Rugh (1999 in Angliss and Lodge 2002)

SPERM WHALE

Using distributional data, the stock structure of the North Pacific sperm whale (*Physeter macrocephalus*) population has been classified into two stocks, eastern and western (Calkins 1986). Although two stocks might exist, a substantial amount of intermingling has been observed among only the male sperm whales and thus North Pacific sperm whales should be assessed as a whole (Ohsumi 1980a). Recent information suggest that there may be three stocks in the eastern Pacific: Alaska, Ca/OR/WA and Hawaii (Perry et al. 1999; Angliss and Lodge 2002). During the winter months, sperm whales are found primarily in the tropical and temperate waters of the North Pacific, from the equator to 40ºN. In the summer months males migrate far north to feed in the waters of the Bering Sea, Aleutian Islands and the Gulf of Alaska, while females and young sperm whales of both sexes remain below 50ºN (Angliss and Lodge 2002), well south of the study area. In the Atlantic, sperm whaling started in 1712, and by the end of the 18th century vessels searching for whales began venturing around Cape Horn and began exploiting sperm whales around south America, Hawaii and the Indian Ocean (Gosho et al. 1984). Organized traditional whaling started in the 16th century in Japan. In 1820, the coast of Japan was opened to sperm whaling, and American and European boats operated in the area; The open boat whaling is estimated to have harvested 60,842 whales between 1800-1909 in the North Pacific (Ohsumi 1980b). Modern whaling using explosives was introduced in the North Pacific in 1890 (Ohsumi 1980b). Catches remained relatively small until 1947 and peaked in 1968 (Figure 6). During the 1960's modern sperm whaling was particularly intense due to the decline in other commercially valuable whale species after which it slowly decreased until its virtual cessation in 1988 (Whitehead 2002).

Catches were taken from IWC statistics and completed with data provided by Ohsumi (1980b).

Whitehead (2002), using catch data, recent census extrapolated to missing areas, and a population model, recently suggested that the initial world population of sperm whales would have been around 1,110,000 in 1700 and 355,200 in 1999 (32% of the original abundance). The abundance of sperm whales in the eastern North Pacific has been estimated at 24,000 based on ship survey and 39,200 based on acoustic detections (Barlow and Taylor 1998 in Caretta et al. 2002). Comparing Whitehead's world population trajectory and estimates from Ohsumi (1980a), the latter seems rather overestimated (Figure 6, Table 5).

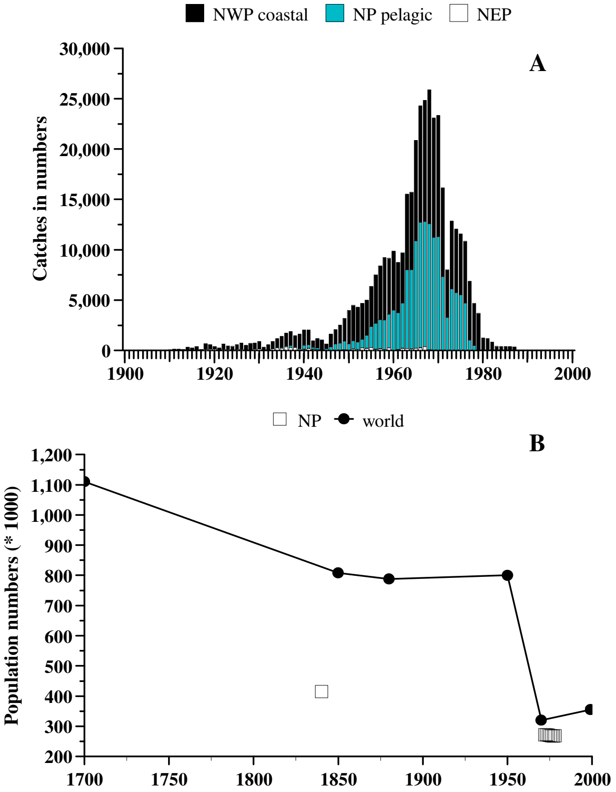


Figure 6. A. Sperm whale catches in northeastern Pacific (NEP), northern Pacific pelagic whaling (NP pelagic) and coastal northwestern Pacific (NWP coastal) from IWC statistics; B. Comparison of world and North Pacific abundance estimates.

Table 5. Abundance estimates for sperm whale.

Year	World	North Pacific	Northeast Pacific	Source
1700	1110000			Whitehead (2002)
1840		416,200		Ohsumi (1980a)
1850	808,000			Whitehead (2002)
1880	788,100			Whitehead (2002)
1950	800,000			Whitehead (2002)
1970	320,000			Whitehead (2002)
1972		273,079		Ohsumi (1980a)
1973		273,512		Ohsumi (1980a)
1974		271,706		Ohsumi (1980a)
1975		270,379		Ohsumi (1980a)
1976		269,343		Ohsumi (1980a)
1977		268,945		Ohsumi (1980a)
1978		269,569		Ohsumi (1980a)
1995			39,200	Barlow and Taylor (1998 in Angliss and Lodge 2002)
1999	355,200			Whitehead (2002)

MINKE WHALE

Based on the limited information derived from distributional data, the IWC recognizes three stocks of minke whales (*Balaenoptera acurostrata*) in the North Pacific: 1) Sea of Japan/ East China Sea, 2) the rest of the western Pacific west of 180°, and 3) the 'remainder of the Pacific' (Donovan 1991 in Angliss and Lodge 2002). The remainder stock is considered relatively common in the Bering and Chukchi Seas and in the inshore waters of the Gulf of Alaska, and is considered migratory in these areas. Further south, they appear to establish home ranges off the Washington and California coasts. Thus the “remainder” stock is divided in two, 1) Alaska and 2) California/ Washington /Oregon (Angliss and Lodge 2002). Abundance estimates are very rare for the Eastern Pacific stock because these have not been nearly as heavily hunted as those that live further west (Angliss and Lodge 2002). According to IWC statistics, catches in the western Pacific reached more than a 1,000 minke whales per year during the 1970s and declined to around 100 per year in the 1990s. In contrast, catches in the northeast Pacific never reached 20 per year. Sheffer (1976 in Calkins 1986) provides a worldwide estimate of 325,000 while Trites et al. (1997) suggested 860,000 individuals for the late 1980s and early 1990s.

CONCLUSION

This report presents a compilation of abundance and catches for the 20th century as compiled from the literature. The pelagic whaling that occurred throughout the North Pacific and the Bering Sea became important around the middle of the century. Unfortunately, these catches are labelled only ‘North Pacific’ in the data base we have summarized. It was not possible, given the time allocated, to look in detail at the spatial distribution of the catches. It would be useful to delineate the catch location to provide data for ecosystem models of the northeastern Pacific.

ACKNOWLEDGMENTS

We thank the Sea Around Us project for providing access to the IWC data and Adrian Kitchingman for guidance in producing the map.

REFERENCES

Angliss, R. P., and Lodge, K. L., 2002. Alaska marine mammal stock assessments, 2002. U.S. Department of Commerce, NOAA, Technical Memorandum, NMFS-AFSC-133. 224 pp.

Baker, C. S., and Herman, L. M. 1987. Alternative population estimates of humpback whales (*Megaptera novaeangliae*) in Hawaiian waters. Can. J. Zool., 65:2818-2821.

Butterworth, D. S., Korrubel, J. L., and Punt, A. E. 2002. What is needed to make a simple density-dependent response population model consistent with data for eastern North Pacific gray whales? J. Cetacean Res. Manage., 4(1):63-76.

Calambokidis, J., Steiger, G. H., Straley, J. M., Quinn II, T. J., Herman, L. M., Cerchio, S., Salden, D. R., Yamaguchi, M., Sato, F., Urbán R., J., Jacobsen, J., von Ziegesar, O., Balcomb, K. C., Gabriele, C. M., E.Dahlheim, M., Higashi, N., Uchida, S., Ford, J. K. B., Miyamura, Y., Ladrón, P., de Guevara, P., Mizroch, S. A., Schlender, L., and Rasmussen., K., 1997. Abundance and population structure of humpback whales in the North Pacific basin. Southwest Fisheries Science Center, La Jolla, Ca, 72 pp.

Calkins, D. G., 1986. Marine mammals. *In*: The Gulf of Alaska: physical environment and biological resources. pp. 527-558, *Edited by* D. W. Hood and S. T. Zimmerman, US Department of Commerce, NOAA, and US Department of Interior, OCS Studies, 655 pp, Anchorage, AK.

Caretta, J. V., Muto, M. M., Barlow, J., Baker, J., Forney, K. A., and Lowry, M., 2002. U.S. Pacific marine mammal stock assessments: 2002. NOAA Technical Memorandum, Southwest Fisheries Science Center, Honolulu, HI, NOAA-TM-NMFS-SWFSC-346. 290 pp.

Dizon, A. E., Lockyer, C., Perrin, W. F., DeMaster, D. P., and Sisson., J. 1992. Rethinking the stock concept: a phylogeographic approach. Conserv. Biol., 6:24-36.

Gosho, M. E., Rice, D. W., and Breiwick, J. M. 1984. The sperm whale, *Physeter macrocephalus*. Mar. Fish. Rev., 46(4):54-64.

Gregr, E. J., 2004. Marine mammals in the Hecate Strait ecosystem. Canadian Technical Report of Fisheries and Aquatic Sciences, 2503. 56 pp.

Horwood, J., 1987. The sei whale: population biology, ecology and management. Crom Helm Ltd., London - New York - Sydney. 375 pp.

Johnson, J. H., and Wolman, A. A. 1984. The humpback whale, *Megaptera novaeangliae*. Mar. Fish. Rev., 46(4):30-37.

Mizroch, S. A., Rice, D. N., and Breiwick, J. M. 1984. The sei whale, *Balaenoptera borealis*. Mar. Fish. Rev., 46(4):25-29.

Ohsumi, S., 1980a. Population assessment of the sperm whale in the North Pacific. *In*: Sperm Whales. pp. 31-42, Report of the International Whaling Commission, Vol. Special Issue 2.

Ohsumi, S., 1980b. Catches of the sperm whales by modern whaling in the North Pacific. *In*: Sperm Whales. pp. 11-18, Report of the International Whaling Commission,

Perry, S. L., DeMaster, D. P., and Silbec, G. K. 1999. The great whales: history and status of six species listed as endangered under the US Endangered Species Act of 1973. Mar. Fish. Rev., 61(1):1-74.

Punt, A. E., and Butterworth, D. S. 2002. An examination of certain of the assumptions made in the Bayesian approach used to assess the eastern North Pacific stock of gray whales (*Eschrichtius robustus*). J. Cetacean Res. Manage., 4(1):99-110.

Rice, D. N., Wolman, A. A., and Braham, H. W. 1984. The gray whale, *Eschrichtius robustus*. Mar. Fish. Rev., 46(4):7-14.

Trites, A. W., Christensen, V., and Pauly, D. 1997. Competition between fisheries and marine mammals for prey and primary production in the Pacific Ocean. J. Northw. Atl. Fish. Sci., 22:173-187.

Wade, P. R. 2002. A Bayesian stock assessment of the eastern North Pacific gray whale using abundance and harvest data from 1967 to 1996. J. Cetacean Res. Manage., 4:85-98.

Weller, D. W., Burdin, A. M., Wursig, B., Taylor, B. L., and Brownell, R. L., Jr. 2002. The western gray whale: A review of past exploitation, current status and potential threats. J. Cetacean Res. Manage., 4(1):7-12.

Whitehead, H. 2002. Estimates of the current global populations size and historical trajectory for sperm whales. Mar. Ecol. Prog. Ser., 242:295-304.

Witting, L. 2003. Reconstructing the population dynamics of eastern Pacific gray whales over the past 150 to 400 years. J. Cetacean Res. Manage., 5(1):45-54.

Energy contents and conversion factors for sea lion's prey[1]

Geneviève Cauffopé and Sheila J.J. Heymans
Fisheries Centre, UBC, Vancouver, BC

ABSTRACT

In order to understand the effect the diet of Steller sea lions may have had on their decline in the North West Pacific and the Gulf of Alaska, a database of the energetic contents of Steller sea lion's prey was compiled and added to the database of general conversions used by the students and researchers at the Fisheries Centre. Multiple conversions were compiled according to the group of prey, and (or) the availability of the data.

METHODOLOGY

General conversion factors in the carbon transfer food chain are given in Table 1. The general transfer of DOC produced by phytoplankton and the derivations of detritus biomass shown in Table 2 were obtained from Pauly et al. (1993). The conversion factors for elemental carbon are shown in Table 3. The conversion factors for crabs, birds and mammals were compiled in Joules per mg of dry weight ($J\cdot mg^{-1}$ DW), as shown in Tables 4, 5 and 6. Phytoplankton conversion factors taken from Cushing et al. (1958), were compiled in Table 7 and from other references in Table 8. Conversion factors for bacteria were compiled in kilocalories per gram of carbon ($kcal\cdot gC^{-1}$), as shown in Table 9. Macroalgae conversion factors were expressed in $J\cdot mg^{-1}$ DW, as well as per mg of wet weight (mg WW)and the percentage ash content (see Table 10).

Conversion factors for zooplankton varied according to functional groups and classes. General conversions from carbon to wet and dry weight as well as displacement volume are shown in Table 11. Copepod and ctenophore conversions were compiled in carbon as a percentage of dry weight or grams of carbon as kilocalories (Table 12). Conversion factors for different zooplankton families were compiled in all categories, such as dry weight to wet weight, dry weight to carbon, dry weight to proteins, dry weight to ash free dry weight, non specific energy density ($kJ\cdot g^{-1}$), protein to organic carbon and in joules per milligram of ash free dry weight ($J\cdot mg^{-1}$ AFDW, see Tables 13 and 14). Energy densities in five species of copepods (Table 15), protozoans, euphausiids, hyperiids, ctenophores and mysids were compiled in joules per mg of dry weight and in joules per mg of ash free dry weight (Table 16).

Energy densities for small and large cephalopods were expressed in kilojoules per gram (Table 17) and conversions for various species of squid are shown in joules per mg dry weight and in joules per mg ash free dry weight in Table 18. Pelecypods energy conversion factors were obtained in joules per milligram of dry weight, wet weight, ash free dry weight and the percent of water they contain (Table 19).

The energy density for invertebrates and benthos were converted from wet weight (WW) to dry weight, dry weight to ash free dry weight, wet weight to ash free dry weight, in joules per mg dry weight and in joules per mg wet weight (Tables 20, 21, 22). The conversion factors for sea cucumbers were compiled in joule per mg of dry weight and wet weight (Table 23). Similar measurements for sea urchins as well as the conversion to joules per mg of ash free dry weight are shown in Table 24. The conversion factors of the remaining groups of benthic species were classified in joules per mg of dry weight, wet weight, and of ash free dry weight (Table 25), while the conversion factors of nudibranchs were given in joules per milligram of dry weight and in mg of ash free dry weight (Table 26).

The energy content of various shrimp species in wet weight, dry weight, ash free dry weight, % water and % ash are given in Table 27, while the same conversions for various fish species are given in Table 28. Energy conversions were given separately for flatfish (Table 29), gadids (Table 30), salmon (Table 31), hexagrammids (Table 32), herring (Table 33) and forage fish (Table 34). We did not include recent analysis of energy densities for sea lion prey species in the Gulf of Alaska, including Southeast Alaska presented in a poster in October 2004 (Schaufler et al. 2004) as the complete results should be published soon (L. Schaufler, Auke Bay Lab. NOAA Juneau).

---

[1] Cauffopé, Geneviève and Sheila J.J. Heymans. 2005. Energy contents and conversion factors for sea lion's prey. In: Guénette, S., and V. Christensen (editors). 2005. Food web models and data for studying fisheries and environmental impacts on Eastern Pacific ecosystems. Fisheries Centre Research Reports 13(1):225-237

Table 1. General conversion factors in the carbon transfer food chain (McLusky 1981; Antonelis 1994)

Conversion
1gC ~ 10-12 kcal
1gC ~ 2 g ash-free dry weight
1 g ash-free dry weight ~ 23.7 kJ
1g organic C ~ 46 kJ
1 l O2 ~ 4.825 kcal

Table 2. Conversion factors and empirical relationship for detritus.

Conversion	**Reference**
DOC = 16% of total phytoplankton production	O'Reilly and Busch (1987)
The detritus biomass is estimated using an empirical relationship that relates detritus biomass to primary productivity and euphotic depth: $\log_{10} D = -2.41 + 0.954 \log_{10} PP + 0.863 \log_{10} E$ D = detritus standing stock ($gC \cdot m^{-2} \cdot year^{-1}$), PP = primary productivity ($gC \cdot m^{-2} \cdot year^{-1}$), E = euphotic depth (m). The euphotic depth is calculated from the Beer-Bouger Law where:, ln I(1) - ln I(2) = k (D(2)-D(1)) with: I (1) = 100% irradiance (at the surface), I(2) = 1% irradiance (at the euphotic depth), D (1) = depth at surface (0m), D(2) = euphotic depth, k = light attenuation coefficient.	Pauly et al. (1993)

Table 3. Energy content of organic carbon, carbohydrate, protein and lipid.

Substance	**Energy content ($J \cdot mg^{-1}$)**	**References**
mg organic carbon	45.7	Salonen et al. (1976)
mg carbohydrate	17.16	Brody (1945)
mg protein	23.65	Brody (1945)
mg lipid	39550	Brody (1945)

Table 4. Energy density from dry weight ($J \cdot mg^{-1}$ DW) for 2 species of crabs.

Species	**N samples**	**Energy content**	**References**
Uca pugilator	2	8.69	Cummins (1971)
Uca pugnax	2	10.53	Cummins (1971)

Table 5. Energy density from wet weight ($J \cdot mg^{-1}$WW) for birds. Transfer efficiency (or gross efficiency) is the ratio of production:consumption.

Conversion	**Energy density**	**Reference**
Birds	7.0	Hunt et al. (2000)
Seabirds	7.0	Hunt et al. (2000)
Transfer efficiency = 10%		Cohen and Grosslein (1987)

Table 6. Energy density in wet weight and conversion factors for marine mammals. Transfer efficiency (or gross efficiency) is the ratio of production:consumption.

Type	**Value**	**Reference**
Energy density ($J \cdot mg^{-1}$ WW)	7.0	Hunt et al. (2000)
Transfer efficiency	16 %	Cohen and Grosslein (1987)
Wet weight:kcal	1:1.25	Cohen and Grosslein (1987)

Table 7. Conversion factors for phytoplankton from wet weight to dry weight, carbon and oxygen equivalents Cushing et al. (1958).

Conversion factors	**Carbon**	**Dry organic matter**	**Oxygen equivalent**	**Wet weight**	**Dry weight**
	1 mg:	1 mg:	1 ml:	1 mg:	1 mg:
Carbon (mg)	1	0.43	0.53	0.024	0.3
Dry organic matter (mg)	2.3	1	1.2	0.055	0.69
Oxygen equivalents (ml)	1.9	0.83	1	0.046	0.57
Plankton biomass (mg)	42	18	22	1	13
Dry plankton (mg)	3.3	1.4	1.8	0.08	1

Table 8. Conversion factors for phytoplankton.

Conversion	**Reference**
1 gC = 11.4 kcal	Platt and Irwin (1973)
1 gC = 45% dry weight	Jorgensen et al. (1991)
DOC = 16% of total primary production	O'Reilly et al. (1987)
1 gC=9 g wet weight	Pauly and Christensen (1995)

Table 9. Conversion factor of bacteria from carbon to kilocalories.

Conversion	**Reference**
1 gC = 10 kcal	Cohen and Grosslein (1987)

Table 10. General data and conversion factors for carbon in 3 species of macroalgae.

Species	**Parameter**	**Value**	**Reference**
Laminaria spp.	Dry weight:wet weight	21%	Mackinson (1996)
Laminaria spp.	Annual P/B ratio	4.43	Brady-Campbell et al. (1984) in Mackinson (1996)
Ditylus brihtwelli	Energy (J·mg^{-1} DW)	7.84	Durbin and Durbin (1981)
Ditylus brihtwelli	Energy (J·mg^{-1} AF DW)	17.5	Durbin and Durbin (1981)
Ditylus brihtwelli	% ash	55%	Durbin and Durbin (1981)
Phaedactylus tricormutus	Carbon: dry weight	18.52%	Durbin and Durbin (1981)

Table 11. Conversion factors for zooplankton (Cushing 1958).

Conversion factors	**Carbon**	**WW**	**DW**	**Displacement**
	1 mg	1 mg	1 mg	**volume** (1ml)
Carbon (mg)	1	0.12	0.6	96
Plankton wet weight (mg)	8.3	1	5	800
Dry plankton (mg)	1.7	0.2	1	160
Displacement volume (ml)	0.01	0.0012	0.006	1

Table 12. Conversion factors for copepods and ctenophores.

Conversion factors	**Reference**
1 g dry weight = 5.25 kcal	Laurence (1976)
1 gC = 10 kcal	Steele (1974)
Copepods C = 37% of dry weight	Table 1-793 in Jørgensen et al. (2000)
Ctenophora C = 6.4% dry weight	Table 1-793 in Jørgensen et al. (2000)

Table 13. Compilation of conversion factors for various types of zooplankton.

Taxon	**WW: DW**	**DW: protein**	**DW: AFDW**	**DW: organic carbon**	**Protein : organic carbon**	**Energy content**		**References**
						kJ·g^{-1} WW	J·mg^{-1} AFDW	
Gelatinous						3		Hunt et al. (2000)
Miscellaneous invertebrates						4		Hunt et al. (2000)
Miscellaneous invertebrates						3		Hunt et al. (1981)
Gelatinous	0.041	0.094	0.362	0.092	0.981			Hunt et al. (1981)
Ctenophora	0.042	0.109	0.304	0.05	0.460			Hunt et al. (1981)
Hydromedusae	0.041	0.144	0.373	0.100	0.881			Hunt et al. (1981)
Siphonophora	0.039	0.071	0.374	0.087	1.224			Hunt et al. (1981)
Thaliacea	0.04	0.058	0.361	0.088	1.523		24.12	Hunt et al. (1981)
Pteropoda	0.118			0.297				Hunt et al. (1981)
Polychaeta	0.138	0.347	0.862	0.38	1.097			Hunt et al. (1981)
Chaetognatha	0.115	0.295	0.658	0.35	1.186			

Table 14. Compilation of conversion factors for various groups of zooplankton (Hunt et al. 1981).

Taxon	**WW: DW**	**DW: protein**	**DW: AFDW**	**DW: organic carbon**	**Protein: organic carbon**	**Energy density (kJ·g^{-1} WW)**
Crustacea *	0.209	0.414	0.851	0.43	1.04	4
Rotifera			0.803	0.38	1.097	
Cladocera			0.795	0.426		
Copepoda	0.186	0.404	0.904	0.461	1.141	
Ostracoda			0.903			
Amphipoda	0.238		0.794	0.393		
Decapoda			0.791			
Euphausiacea	0.225	0.473	0.862	0.436	0.922	
Zooplankton				0.303		

* data also from Hunt et al. (2000);

Table 15. Energy densities for five species of copepods.

Copepods	**Energy content (J·mg^{-1})**		**Other information**	**References**
	DW	**AFDW**		
Acartia tonsa	17.91	22.39	DW = 10.86% WW	Durbin and Durbin (1981)
Calanus helgolandicus		22.61		Slobodkin and Richman (1961)
Cyclops vernalis *	23.82	24.36		Cummins and Wuycheck (1971)
Mesocyclops edax		22.94		Cummins and Wuycheck (1971)
Trigriopus californicus		23.09		Slobodkin and Richman (1961)

* total samples = 3

Table 16. Energy content for euphausiids, protozoans, hyperiids, ctenophores and mysids.

Species	**Energy content (J·mg^{-1})**			**Other information**	**References**
	DW	**AFDW**	**WW**		
Euphausia superba	19.76		3.73	81.0% water; lipid =7.4% DW	Tarverdiyeva (1972)
Tetrahymena pyriformis (Protozoan)		24.86			Slobodkin and Richman (1961)
Hyperiids		2.51			Tarverdiyeva (1972)
Ctenophores			0.17		Tarverdiyeva (1972)
Mysids			3.77		Tarverdiyeva (1972)

Table 17. Energy content (kJ g^{-1}WW) in small and large cephalopods.

Size	**Energy content (kJ·g^{-1} WW)**	**References**
Small	3.5	Hunt et al. (1981); Hunt et al. (2000)
Small	4.0 *	Hunt et al. (2000); Ashmole (1971)
Large	4.0	Hunt et al. (2000)
Large	4.0-6.0	Anthony and Roby (1997); Harris et al. (1986); Miller (1978);(Paul and Paul 1998) ; Paul et al. (1993); Paul et al. (1998a); Paul et al. (1998b); Perez (1994); Smith et al. (1988); Smith et al. (1990); Van Pelt et al. (1997)

* Including metabolic digestion

Table 18. Energy conversion factors for squids.

Species	**Energy content (J·mg^{-1})**			**% water**	**Other information**	**Reference**
	DW	**AFDW**	**WW**			
Squids			3.81			Van Pelt et al. (1997)
Squids (5 spp)			3.85-6.53			Perez (1994)
Dosidicus gigas	23.73	24.88	4.22	82.2	beaks removed: lipid= 19.1% DW or 4.4% WW	Peterson (1979)
Loligo opalescens				76.8		Rachor et al. (1982)
Symplectoteuthis ovalaniensis	21.86	23.64	5.59	74.5	beaks removed	Peterson (1979)

Table 19. Energy conversion factors in various species of pelecypods (Cummins and Wuycheck 1971).

Species	**N samples**	**Energy content (J·mg^{-1})**			**% water**
		DW	**AFDW**	**WW**	
Ensis minor			14.65		
Clinocardium ciliatum	3	18.64		1.57	92.0
Modiolus sp.	3	19.26			
Scobicularis plana	60		21.34		
Yoldia sapotilla	3	20.01		2.88	
Yoldia thraciaeformis	3	20.03		2.13	89.0

Table 20. Conversion factors and energy content of various benthic invertebrates (Jangaard 1974; Bigg 1981; Brey 2001).

Family	**WW: DW**	**DW: AFDW**	**WW: AFDW**	**Energy content (J·mg^{-1})**	
				DW	**AFDW**
Mollusca	0.128	0.801	0.143	18.55	23.01
Bivalvia	0.087	0.831	0.057	18.85	22.79
Gastropoda	0.088	0.802	0.107	18.24	23.81
Nudibranchia	0.250	0.693	0.173	16.13	23.27
Cephalopoda	0.203	0.900	0.213	20.4	22.69
Annelida	0.187	0.623	0.157	14.53	23.33
Oligochaeta	0.174	0.323	-	7.54	23.33

Table 21. Conversion factors and energy content from dry weight, ash free dry weight and wet weight for various species of polychaetes obtained from Cummins and Wuycheck (1971).

Species	WW: DW	DW: ash free DW	WW: ash free DW	Energy content ($J\cdot mg^{-1}$)			% water
				DW	AFDW	WW	
Aphrodita hastata				14.39		2.03	
Axiothella sp.				14.86		2.32	84.0
Luabrinereis fragilis				28.34		4.43	78.0
Nethys ciliata				17.00		3.13	81.0
Niochamache sp.				14.91		2.59	83.0
Pectiinaria hypoborea				13.57		2.61	81.0
Pherusa plumosa				11.14		1.94	82.0
Phascolionn stroabi				14.19		2.49	82.0
Stemaspis fossor				8.91		2.25	75.0
Various species				16.91			
Polychaeta errantia	0.199	0.813	0.169	17.50	23.33		
Polychaeta sedentaria	0.188	0.732	0.145	14.19	23.33		

Table 22. Conversion factors and energy contents for various groups of benthic organisms obtained from Brey (2001).

Benthic organisms	WW: DW	DM: AFDW	WW: AFDW	Energy content ($J\cdot mg^{-1}$)	
				DW	AFDW
Crustacea (excluding Cirripedia)	0.226	0.742	0.169	16.75	22.57
Amphipoda	0.2	0.72	0.160	16.37	22.74
Cirripedia	0.066	0.79	0.039	17.96	22.74
Cumacea	0.173	0.63	0.075	14.33	22.74
Decapoda	0.258	0.680	0.18	15.14	22.26
Euphausiacea	0.254	0.883	0.224	20.08	22.74
Isopoda	0.200	0.640	0.142	14.55	22.74
Insecta Larvae	0.210	0.942		22.44	23.81
Chironomidae		0.931		21.83	23.44
Ephemeroptera		0.847		22.07	26.07
Odonata	0.226	0.888		20.99	23.65
Trichoptera		0.942		21.52	24.12
Echinodermata	0.324	0.306	0.091	6.70	21.5
Asteroidea	0.283	0.438	0.124	9.11	20.81
Crinoidea	0.432	0.238	0.080	5.1	21.44
Echinoidea	0.333	0.165	0.049	3.40	20.53
Holothuroidea	0.110	0.476	0.112	11.27	22.95
Ophiuroidea	0.460	0.211	0.09	4.6	21.75
Porifera	0.186	0.372	0.075	7.75	24.99
Actinaria	0.161	0.855	0.138	18.42	21.54
Bryozoa	0.199	0.402	0.080	9.28	23.09
Nemertea	0.208	0.816	0.211	19.04	23.33
Priapulida	0.095	0.861	0.065	20.09	23.33
Sipunculida	0.177	0.654	0.111	15.26	23.33
Ascidiae	0.063	0.358	0.023	6.81	19.01

Table 23. Energy contents ($J\cdot mg^{-1}$) from wet and dry weight, and percentage of water in 3 species of sea cucumbers obtained from Cummins and Wuycheck (1971).

Species	DW	WW	% water
Chirodota laevis	10.76	1.11	90
Cucumaria frondosa	12.87	0.94	93
Malpadia oolitica	7.05	0.74	90

Table 24. Energy content from wet and dry weight in 2 species of sea urchins.

Sea urchins	**Energy content (J·mg^{-1})**			**% water**	**Other information**	**References**
	DW	**AFDW**	**WW**			
Strongylocentrus drombachiensis	3.70		1.20	68	3 samples	Cummins and Wuycheck (1971)
Various species	9.46	22.74			25+20 species	Brey et al. (1988)

Table 25. Energy conversion factors for wet and dry weight and percentage of water in various groups of benthic zooplankton.

Benthic zooplankton	**Energy content (J·mg^{-1})**			**% water**	**Other information**	**References**
	DW	**AFDW**	**WW**			
Anisogammarus pugettensis	12.54		2.46		DW =19.6% WW	Smith et al. (1986)
Crangonyx richmondensis	16.27	22.12			5 samples	Cummins and Wuycheck (1971)
Gammarus duebeni	18.47	21.50		74.0	6 samples	Cummins and Wuycheck (1971)
Gammarus minus		22.50			2 samples	Cummins and Wuycheck (1971)
Porifera	6.10				8 species	Brey et al. (1988)
Oligochaeta	22.36				5 species	Brey et al. (1988)
Ascidians	7.13	19.66			11 species	Brey et al. (1988)
Salps		0.17				Tarverdiyeva (1972)
Hydrozoans						
Chlorohydra viridissima		23.99				Slobodkin and Richman (1961)
Hydra littoralis		25.26				Slobodkin and Richman (1961)
Anthozoans						
Duva multiflora	12.88		2.07	83.0	2 species	Cummins and Wuycheck (1971)
Star fishes						
Asteria vulgaris	10.68		2.65	75.0	3 species	Cummins and Wuycheck (1971)
Ctenodiscus crispatus	7.65		2.55	67.0		Cummins and Wuycheck (1971)
Cumaceans						
Diastylis rathkei		16.4-18.7				Rachor et al. (1982)
Gastropods						
Natica clausa	18.39		3.31	82.0		Cummins and Wuycheck (1971)
Thais lamellosa		24.47				Cummins and Wuycheck (1971)
Thais lapillus	19.24		1.85	82.0		Cummins and Wuycheck (1971)
Various species	18.24	23.27			shells removed	Brey et al. (1988)
Opistobranchs						
Scaphander punctostriatus	13.97		1.75	90.0		

Table 26. Energy contents (J·mg^{-1}) from dry and ash free dry weight for nudibranchs obtained from Cummins and Wuycheck (1971).

Nudibranchs	**DW**	**AFDW**
Acanthodoris rhodoceras		22.77
Aegires albopunctatus		22.23
Aglaja diomeddea		23.26
Bulla gouldiana		26.6
Dendrodoris albopunctata		21.60
Dirona picta		27.95
Flabellina iodinea		20.70
Haminea virescens		22.34
Hermissenda crassicornis		26.99
Hopkinsia rosacea		25.15
Navanax inermis	3.86	25.09
Polycera atra		23.78
Triopha maculata		23.62

Table 27. Percentage of air and ashes, and energy content of various shrimp species from wet, dry and ash free dry weight, percentage of water and ash.

Species	N samples	Energy content ($J \cdot mg^{-1}$) DW	AFDW	WW	% water	% ash	References
Artemia sp.			28.21				Slobodkin and Richman (1961)
Metapenaeus monoceros	69	22			75.6		Ramadhas and Sumitra (1979)
Palaemon debilis		17.90				24.5	Fonds et al. (1987)
Palaemon elegans	6					22	Fonds et al. (1987)
Palaemon elegans	26	18.60				17	Cummins and Wuycheck (1971)
Pandalus hypsinotus		21.36		4.98			Smith et al. (1986)
Pandalus platyceros		20.59		5.02			Smith et al. (1986)

Table 28. Energy content of various fish from wet and dry weight, percentage of water.

Species	N animals	Energy content ($J \cdot mg^{-1}$) DW	AFDW	WW	% water	Other information	References
Auxis thazard	2	22.48	24.03	4.83	70.6	bones removed	Peterson (1979)
Brevoortia tyrannus		26.12	29.32	8.34			Durbin and Durbin (1981)
Canthidermis maculatus	2	23.68	25.11	3.84	74.8	bones removed	Peterson (1979)
Clupea harengus	1	26.63					Cummins and Wuycheck (1971)
Clupea harengus pallasi		25.90				DW =32.2% WW	Smith et al. (1986)
Coryphaena equisalis	2	22.27	23.81	4.81	72.9	bones removed	Peterson (1979)
Cubiceps panciradiatus	7	19.92	22.67	4.80	75.8		Peterson (1979)
Epinephelus aeneus					77.8		Mikhail et al. (1982)
Euthynnus lineatus	2	21.97	23.30	4.27	72.4	bones removed	Peterson (1979)
Exocoetus volitans	6	19.72	23.33	5.35	73.8		Peterson (1979)
Hypomesus pretiosus	4				76.2	lipid=23.6% DW or 5.5% WW	Olson and Boggs (1986)
Lactoria diaphanus	2	20.74	24.26	5.28	74.6		Peterson (1979)
Lethrinus nebulosus							Aldonov and Druzhinin (1978)
Oxyporhamphus micropterus	6	19.96	23.21	5.34	72.2		Peterson (1979)
Raja oricana			23.45	8.07			Cummins and Wuycheck (1971)
Remora remora	2	19.93	24.18	5.27	73.6		Peterson (1979)
Scomber japonicus	7				73.7	lipid=30.7% DW or 8.1% WW	Olson and Boggs (1986)
Stolephorus purpureus	4				76.2	lipid=18.0% DW or 4.3% WW	Olson and Boggs (1986)
Tautogolabrus adspersus	1	20.43					Cummins and Wuycheck (1971)
Vinciguerria lucetia	3	22.12	24.35	5.15	76.1		Peterson (1979)

Table 29. Energy content for flatfish and forage fish from wet weight. See table 35 for latin names.

Species	Energy content ($J \cdot mg^{-1}$ WW)	References
Flatfish	3.0-5.0	Anthony and Roby (1997); Harris et al. (1986); Miller (1978); (Paul and Paul 1998); Paul et al. (1993); Paul et al. (1998a); Paul et al. (1998b); Perez (1994); Smith et al. (1988); Smith et al. (1990); Van Pelt et al. (1997)
Arrowtooth flounder	5.15	Perez (1994)
English sole	4.9 (March) 5.95 (October)	Dygert (1990)
Yellowfin sole	3.3-3.5 (May) 4.4 (June)	Paul et al. (1993)
Pleuronectidae	2.86-3.95	Anthony et al. (2000)
Forage fish	7.5 (4.0-11.0)	Anthony and Roby (1997); Harris et al. (1986); Miller (1978);(Paul and Paul 1998); Paul et al. (1993); Paul et al. (1998a); Paul et al. (1998b); Perez (1994); Smith et al. (1988); Smith et al. (1990); Van Pelt et al. (1997)

Table 30. Energy content from wet weight for gadids. See table 35 for latin names.

Species	**Energy content ($J \cdot mg^{-1}$ WW)**	**Other information**	**References**
Gadids	4.0 (3.0-5.0)		Anthony and Roby (1997); Harris et al. (1986); Miller (1978); (Paul and Paul 1998); Paul et al. (1993); Paul et al. (1998a); Paul et al. (1998b); Perez (1994); Smith et al. (1988); Smith et al. (1990); Van Pelt et al. (1997)
Pacific cod	3.0		Hunt et al. (2000)
Pacific cod	3.93		Perez (1994)
Pacific cod	2.94		Van Pelt et al. (1997)
Pacific cod	3.65	age 0	Anthony et al. (2000)
Pacific cod	3.54	age >0	Anthony et al. (2000)
Pacific cod	4.00-4.30	March	Smith et al. (1990)
Pacific cod	3.33-3.38	July	Smith et al. (1990)
Pacific cod	4.13-4.49	December	Smith et al. (1990)
Pacific cod	3.0		Hunt et al. (2000)
Pollock	4.54-4.72		Rosen and Trites (2000)
Pollock	7.0		Hunt et al. (2000)
Pollock	4.64		Perez (1994)
Pollock	2.73		Van Pelt et al. (1997)
Pollock	5.89		Miller (1978)
Pollock	3.47	age = 0	Anthony et al. (2000)
Pollock	3.24	age >0	Anthony et al. (2000)
Pollock	3.93		Payne (1999)
Pollock	2.7	June	Paul et al. (1998b)
Pollock	3.4	August	Paul et al. (1998b)
Pollock	3.6	October	Paul et al. (1998b)
Pollock	3.4-4.0	March	Paul et al. (1998b)
Pollock	4.0	May	Paul et al. (1998b)
Pollock	3.68-4.03	Ripe	Smith et al. (1988)
Pollock	3.26-3.41	Spent	Smith et al. (1988)
Pollock	5.45		Harris et al. (1986)

Table 31. Energy content for various species of salmon. See table 35 for latin names.

Species	**Energy content ($J \cdot mg^{-1}$ WW)**	**Other information**	**References**
Salmon	5.0-9.0		Anthony and Roby (1997); Harris et al. (1986); Miller (1978); (Paul and Paul 1998); Paul et al. (1993); Paul et al. (1998a); Paul et al. (1998b); Perez (1994); Smith et al. (1988); Smith et al. (1990); Van Pelt et al. (1997)
Chinook	6.06	300 g	Stewart and Ibbarra (1991)
	8.72	3 kg	Stewart and Ibbarra (1991)
Coho	6.06	300 g	Stewart and Ibbarra (1991)
	8.72	3 kg	Stewart and Ibbarra (1991)
Pink	3.41	Age 0	Anthony et al. (2000)
	3.73	Age >0	Anthony et al. (2000)
	3.2-4.4		Paul and Willette (1997)
Sockeye	4.35		Anthony et al. (2000)
	6.68	300 g	Brett (1983)
	7.77	2.1 kg	Brett (1983)
	6.89-7.69		Hendry and Berg (1999)
			Hendry and Berg (1999)

Table 32. Energy density for various species of Hexagrammids. See Table 35 for latin names.

Species	**Energy content ($J\cdot mg^{-1}WW$)**	**References**
Hexagrammids	3.0-6.0	Anthony and Roby (1997); Harris et al. (1986); Miller (1978); (Paul and Paul 1998); Paul et al. (1993); Paul et al. (1998a); Paul et al. (1998b); Perez (1994); Smith et al. (1988); Smith et al. (1990); Van Pelt et al. (1997)
Atka Mackerel	4.02	Van Pelt et al. (1997)
Greenlings	3.45	Van Pelt et al. (1997)
Lingcod	3.98	Anthony et al. (2000)

Table 33. Energy density for herring.

Species	**Energy content ($J\cdot mg^{-1}WW$)**	**Other information**	**References**
Clupea spp.	7.0	Includes metabolic digestion	Hunt et al. (2000)
Clupea pallasii	6.40-7.58		Rosen and Trites (2000)
Clupea pallasii	7.0		Hunt et al. (2000)
Clupea pallasii	5.44	bomb cal.	Perez (1994)
Clupea pallasii	11.72	gulf	Perez (1994)
Clupea pallasii	3.69	age 0	Anthony et al. (2000)
Clupea pallasii	5.84	age > 0	Anthony et al. (2000)
Clupea pallasii	3.43		Payne et al. (1999)
Clupea pallasii	5.7	age 0, fall	Paul et al. (1998a)
Clupea pallasii	8.0	age 1, fall	Paul et al. (1998a)
Clupea pallasii	9.4-10.2	age 2, fall	Paul et al. (1998a)
Clupea pallasii	4.4	Age 0-1, spring	Paul et al. (1998a)
Clupea pallasii	5.2-6.3	Age ≥2 spring	Paul et al. (1998a)
Clupea pallasii	5.23.4-3.8	December	Calkins (1998)
Clupea pallasii	3.4-3.8	March	Calkins (1998)
Clupea pallasii	7.95		Stansby (1976)
Other	3-6		Anthony and Roby (1997); Harris et al. (1986); Miller (1978); Paul and Paul [, 1998 #40]; Paul et al. (1993); Paul et al. (1998a); Paul et al. (1998b); Perez (1994); Smith et al. (1988); Smith et al. (1990); Van Pelt et al. (1997)

Table 34. Energy density for forage fishes. See Table 35 for latin names.

Species	**Number**	**Energy content (J·mg^{-1} WW)**	**Other information**	**References**
Forage fish		7.5 (4.0-11.0)		Anthony and Roby (1997); Harris et al. (1986); Miller (1978); (Paul and Paul 1998); Paul et al. (1993); Paul et al. (1998a); Paul et al. (1998b); Perez (1994); Smith et al. (1988); Smith et al. (1990); Van Pelt et al. (1997)
Capelin		7.03		Perez (1994)
Capelin		5		Hunt et al. (1981)
Capelin		4.84	Age =1	Van Pelt et al. (1997)
Capelin		3.54-4.67	Age = 2	Van Pelt et al. (1997)
Capelin		5.50		Miller (1978)
Capelin		4.17	Age =1	Anthony et al. (2000)
Capelin		6.7	Age ≥1, June	Anthony et al. (2000)
Capelin		3.7	Age ≥1, September	Anthony et al. (2000)
Capelin		5.26	Gulf	Payne et al. (1999)
Capelin		6.48	Bering Sea	Payne et al. (1999)
Capelin		5.0		Hunt et al. (2000)
Eulachon		11.05	August	Perez (1994)
Eulachon		10.96	March	Perez (1994)
Eulachon		7.49		Anthony et al. (2000)
Eulachon		10.10	February-March	Payne et al. (1999)
Eulachon		10.62-10.86	June-September	Payne et al. (1999)
Pacific sandlance		4.95	Age 1	Van Pelt et al. (1997)
Pacific sandlance		5		Hunt et al. (1981)
Pacific sandlance		3.18	Age 0	Van Pelt et al. (1997)
Pacific sandlance		5.67	Age ≥ 2	Van Pelt et al. (1997)
Pacific sandlance		6.5	Age 0, June	Anthony et al. (2000)
Pacific sandlance		4.8	Age 0, June	Anthony et al. (2000)
Pacific sandlance		5.3	Age 0, August	Anthony et al. (2000)
Pacific sandlance		5.6	Age > 0, June	Anthony et al. (2000)
Pacific sandlance		4.9	Age > 0, sep	Anthony et al. (2000)
Pacific sandlance		5.20	Gulf	Payne (1999)
Pacific sandlance		6.11	bomb cal	Payne et al. (1999)
Pacific sandlance		3.40-3.55	Age 0, 6 cm	Robards et al. (1999)
Pacific sandlance		4.62-4.86	Age 0, 9 cm	Robards et al. (1999)
Pacific sandlance		3.22-3.32	Age ≥ 1, November	Robards et al. (1999)
Pacific sandlance		3.23-3.25	Age ≥ 1, February	Robards et al. (1999)
Pacific sandlance		5.0		Hunt et al. (2000)
Pacific sandlance		5.46-5.75	Age ≥ 1, June-July	Robards et al. (1999)
Pricklebacks		5.40		Payne et al. (1999)
Pricklebacks	6	4.11-4.90		Anthony et al. (2000)
Rockfish		2.97		Van Pelt et al. (1997)
Rockfish		3		Hunt et al. (2000)
Rockfish	3	5.77-6.23		Perez (1994)
Northern rockfish		5.56	Bering Sea, July	Perez (1994)
Northern rockfish		6.85	Gulf, February	Perez (1994)
Sculpins	4	3.51-5.19		Perez (1994)
Sculpins	12	3.05-5.26		Anthony et al. (2000)
Myctophids		7		Hunt et al. (2000)
Saury		7		Hunt et al. (2000)
Epipelagic fishes		7.0		Hunt et al. (2000)
Mesopelagic fishes		7.0		Hunt et al. (2000)

Table 35. Common and latin names for fish species presented in tables 29-34

Common name	Latin name
Arrowtooth flounder	*Reinhardtius stomias*
Atka mackerel	*Pleurogrammus monopterygius*
Capelin	*Mallotus villosus*
Chinook salmon	*Oncorhynchus tshawytscha*
Coho salmon	*Oncorhynchus kisutch*
English sole	*Parophrys vetulus*
Eulachon	*Thaleichythus pacificus*
Flatfish	Pleuronectidae
Greenling	*Hexagrammos spp.*
Lingcod	*Ophiodon elongatus*
Pacific cod	*Gadus macrocephalus*
Pacific herring	*Clupea pallasii*
Pacific sandlance	*Ammodytes hexapterus*
Pink salmon	*Oncorhynchus gorbuscha*
Pollock	*Theragra chalcogramma*
Pricklebacks	Stichaeidae
Rockfish	Sebastidae
Saury	*Cololabis saira*
Sculpins	Cottidae
Sockeye salmon	*Oncorhynchus nerka*
Yellowfin sole	*Limanda aspera*

REFERENCES

Aldonov, V. K., and Druzhinin, A. D. 1978. Some data on scavengers (Family Lethrinidae) from the Gulf of Aden region. J. Ichthyol., 18:527-535.

Anthony, J. A., and Roby, D. D., 1997. Proximate composition of some northeastern Pacific forage species. University of Alaska Fairbanks, Fairbanks, AK, Alaska Sea Grant College Program Report 97-01, 725-729 pp.

Anthony, J. A., Roby, D. D., and Turco, K. R. 2000. Lipid content and energy density of forage fishes from the northern Gulf of Alaska. J Exp. Mar. Biol. Ecol., 248:53-78.

Antonelis, G. A., Melin, S.R., Bukhtiyarov, Y.A. 1994. Early spring feeding habits of bearded seals (Erignathus barbatus) in the central Bering Sea, 1981. Arctic, 47:74-79.

Ashmole, N. P., 1971. Sea birds ecology and the marine environment. *In*: Avian Biology. *Edited by* D. S. Farner and J. R. King, Academic Press, New York. Vol. 1 pp. 223-286.

Bigg, M. A., 1981. Harbour seal - *Phoca vitulina* and *P. largha*. *In*: Handbook of marine mammals. *Edited by* S. H. Ridgway and R. J. Harrison, Academic Press, London. Vol. Vol. 2 pp. 1-27.

Brett, J. R., 1983. Life energetics of sockeye salmon, *Oncorhynchus nerka*. *In*: Behavioral energetics:the cost of survival in vertebrates. *Edited by* W. P. Aspey and S. I. Lusticks, Ohio State Univ. Press, Columbus. pp. 29-63.

Brey, T. 2001. Population dynamics in benthic invertebrates. A virtual handbook. Alfred Wegener Institute for Polar and Marine Research, Germany. http://www.awi-bremerhaven.de/Benthic/Ecosystem/FoodWeb/Handbook/main.html

Brey, T., Rumohr, H., and Ankar, S. 1988. Energy content of macrobethic invertebrates:general conversion factors from weight to energy. J. Exp. Mar. Biol. Ecol., 117:271-278.

Brody, S., 1945. Bioenergetics and growth. Reinhold, New York.

Calkins, D. G. 1998. Prey of Steller sea lions in the Bering Sea. Biosphere Conservation, 1:33-44.

Cohen, E. B., and Grosslein, M. D., 1987. 37. Production on Georges Bank compared with other Shelf ecosystems. *In*: Georges Bank. *Edited by* R. H. Backus and D. W. Bourne, MIT Press, Cambridge, Mass. pp. 383-391.

Cummins, K. W., and Wuycheck, J. C., 1971. Caloric equivalents for investigations in ecological energetics. Mitt. Int. Ver. Limnol., Vol. 18, 160 pp.

Cushing, D. H., Humphrey, G. F., Banse, K., and Laevastu, T., 1958. Report of the Committee on Terms and Equivalents. Rapports et Procès-verbaux des Réunions du Conseil Permanent International pour l'Exploration de la Mer. 14(4):15-16. pp.

Durbin, E. G., and Durbin, A. G. 1981. Assimilation efficiency and nitrogen excretion of a filter-feeding planktivore, the Atlantic menhaden Brevoortia tyrannus (Pisces: Clupeidae). Fish. Bull., 79((4)):601-616.

Dygert, P. H. 1990. Seasonal changes in energy content and proximate composition associated with somatic growth and reproduction in a representative age-class of female English sole. Trans. Am. Fish. Soc., 119:791-801.

Fonds, M., Drinkwaard, B., Resink, J. W., Eysink, G., and Toet, W., 1987. Measurements of metabolism, feeding and growth of *Solea solea* (L.) fed with mussel meat and with dry food (Unpubl.).

Harris, R. K., Nishiyama, T., and Paul, A. J. 1986. Carbon, nitrogen and caloric content of eggs, larvae, and juveniles of the walleye pollock, Theragra chalcogramma. J. Fish Biol., 29:87-98.

Hendry, A. P., and Berg, O. K. 1999. Secondary sexual characters, energy use, senescence, and the cost of reproduction in sockeye salmon. Can. J. Zool., 77:1663-1675.

Hunt, G. L. J., Burgeson, B., and Sanger, G. A., 1981. Feeding ecology of seabirds of the eastern Bering Sea. *In*: The Eastern Bering Sea Shelf: Oceanography and Resources. *Edited by* D. W. C. Hood, J.A., NOAA, Univ. of Washington Press, Seattle, Washington. Vol. 2 pp. 629-647.

Hunt, G. L. J., Kato, H., and McKinnel, S. M., 2000. Predation by marine birds and mammals in the subarctic Pacific Ocean. North Pacific Marine Science Organisation, Sidney, BC, Canada, PICES Scientific Report, 14. 165 pp.

Jangaard, P. M. 1974. The capelin (*Mallotus villosus*): Biology, distribution, exploitation. utilization and composition. Fish. Res. Board Can. Bull., 186.

Jørgensen, L. A., Jørgensen, S. E., and Nielsen, S. N. 2000. ECOTOX: Ecological Modelling and Ecotoxicology. Elsevier Science. 2000. www.elsevier-ecotox.com

Jorgensen, S. E., S.N. Nielsen and L. Jorgensen, Editors, 1991. Handbook of ecological parameters and ecotoxicology. Elsevier Press, Amsterdam. 1,263 pp.

Laurence, G. C. 1976. Caloric values of some North Atlantic calanoid copepods. Fisheries Bulletin, 74:218-220.

Mackinson, S., 1996. System definition and primary production. *In*: Mass-balance models of North-eastern Pacific ecosystems. *Edited by* D. Pauly and V. Christensen, Fisheries Centre, University of British Columbia, Vancouver, BC. Vol. 4 (1) 129 pp. pp. 63-64.

McLusky, D. S., 1981. The estuarine ecosystem. Blackie Press, Glasgow.

Mikhail, M. Y., Ezzat, A. A., Hashem, M. T., and Wadie, W. F. 1982. Fluctuations in fat and water contents of two species of serranid fishes in the Egyptian Mediterranean waters. Bull. Inst. Oceanogr. Fish Cairo, 8(1):123-144.

Miller, L. K., 1978. Energetics of the northern fur seal in relation to climate and food resources of the Bering sea. US Marine Mammal Commission, Washington DC, MMC-75/08.

Olson, R. J., and Boggs, C. H. 1986. Apex predation by yellowfin tuna (*Thunnus albacares*): independent estimates from gastric evacuation and stomach contents, bioenergetics and cesium concentrations. Can. J. Fish. Aquat. Sci., 43(9):1760-1775.

O'Reilly, E.-Z., C. Busch, D.A., 1987. Primary Production. *Edited by* R. H. B. Backus, D.W. Georges, Bank. MIT Press, Cambridge.

Paul, A. J., and Willette, M., 1997. Geographical variation in somatic energy content of migrating pink salmon fry from Prince William Sound: a tool to measure nutritional status. University Alaska Sea Grant College Program Report, Fairbanks, Ak, 707-720 pp.

Paul, A. J., and Paul, J. M. 1998. Comparisons of whole body energy content of captive fasting age zero Alaskan Pacific herring (*Clupea pallasi* Valenciennes) and cohorts over-wintering in nature. J. Exp Mar Biol Ecol, 226:75-86.

Paul, A. J., Paul, J. M., and Smith, R. L. 1993. The seasonal changes in somatic energy content of Gulf of Alaska yellowfin sole, *Pleuronectes asper.* J. Fish Biol., 43:131-138.

Paul, A. J., Paul, J. M., and Brown, E. D. 1998a. Fall and spring somatic energy content for Alaskan Pacific herring (*Clupea pallasi* Valenciennes 1847) relative to age, size and sex. J. Exp. Mar. Biol. Ecol., 223:133-142.

Paul, A. J., Paul, J. M., and Smith, R. L. 1998b. Seasonal changes in whole-body energy content and estimated consumption rates of age 0 Walleye pollock from Prince William Sound, Alaska. Estuarine, Coastal and Shelf Science, 47:251-259.

Pauly, D., and Christensen, V. 1995. Primary production required to sustain global fisheries. Nature, 374:255-257.

Pauly, D., M.L. Soriano-Bartz and M.L.D. Palomares, 1993. Improved construction, parameterisation and interpretation of steady-state ecosystem models. *In*: ICLARM Conf. Proc. Trophic models of aquatic ecosystems., *Edited by* V. a. D. P. e. In: Christensen. Vol. 26. pp. 1-13.

Payne, S. A., Johnson, B. A., and Otto, R. S., 1999. Proximate composition of some north-eastern Pacific forage fish species. 32 pp.

Perez, M. 1994. Calorimetry measurements of energy value of some Alaskan fishes and squids. NOAA Technical Memo NMFS-AFSC-32.

Peterson, C. I., 1979. Annual report of the Inter-American Tropical Tuna Commission, 1978. La Jolla, California, 163 pp.

Platt, T. I., B. 1973. Caloric content of phytoplankton. Limnol. Oceanogr., 18:306-310.

Rachor, E., Arntz, W. E., Rumorh, H., and Mantau, K. H. 1982. seasonal and long-term population fluctuations in *Diastylis rathkel* (Crustacean: Cumacea) of Kiel Bay and German Bight. Neth. J. Sea Res., 16:141-150.

Ramadhas, V., and Sumitra, V. 1979. Efficiency of energy utilization in the shrimp, Metapenaeus monoceros fed mangrove leaves. Indian J. Mar. Sci., 8:114-115.

Robards, M. D., Anthony, J. A., Rose, G. A., and Piatt, J. F. 1999. Changes in proximate composition and somatic energy content forPacific sand lance (*Ammodytes hexapterus*) from Kachemak Bay, Alaska relative to maturity and season. J. Exp. Mar. Biol. Ecol., 242:245-258.

Rosen, D. A. S., and Trites, A. W. 2000. Digestive efficiency and dry-matter digestability of Steller sea lions fed herring, pollock, squid, and salmon. Can. J. Zool., 78:234-239.

Salonen, K., Sarvala, J., Hakala, I., and Viljanen, M.-L. 1976. The relation of energy and carbon in aquatic invertebrates. Limnol. Oceanogr., 21:724-730.

Schaufler, L. E., Loggerwell, E., and Vollenweider, J. J., 2004. Variation in the quality of Steller sea lion prey from the Aleutian Islands and Southeastern Alaska. *In*: Sea Lions of the World, Conservation and Research in the 21st Century, Anchorage Alaska, Sept. 30-Oct. 3, 2004, poster.

Slobodkin, L. B., and Richman, S. 1961. Calories/gm in species of animals. Nature, 191:299.

Smith, R. L., Paul, A. J., and Paul, J. M. 1986. Effect of food intake and temperature on growth and conversion efficiency of juvenile wall eye pollock (*Theragra chalcogramma* Pallas): a laboratory study. J. Cons. CIEM, 42:241-253.

Smith, R. L., Paul, A. J., and Paul, J. M. 1988. Aspects of energetics of adult walleye pollock, *Theragra chalcogramma* (Pallas), from Alaska. J. Fish Biol., 33:445-454.

Smith, R. L., Paul, A. J., and Paul, J. M. 1990. Seasonal changes in energy and the energy cost of spawning in Gulf of Alaska Pacific cod. J. Fish Biol., 36:307-316.

Stansby, M. E. 1976. Chemical characteristics of fish caught in the northeast Pacific Ocean. Mar. Fish. Rev., 38:1-11.

Steele, J. H., 1974. The structures of Marine Ecosystems. Harvard University Press, Cambridge, Mass., 128 pp pp.

Stewart, D. J., and Ibbarra, M. 1991. Predation and production by salmonid fishes in Lake Michigan. Can. J. Fish. Aquat. Sci., 48:909-922.

Tarverdiyeva, M. I. 1972. Daily food consumption and feeding pattern of the georgian cod (Notohteniidae) in the south Georgia area. J. Ichthyol., 12(4):684-692.

Van Pelt, T. I., Piatt, J. F., Lance, B. K., and Roby, D. D. 1997. Proximate composition and energy density of some North Pacific forage fishes. Comp. Biochem. Physiol., A118:1393-1398.