Appendix: Forage Fish Species in the Gulf of Alaska

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Executive Summary

As part of a move toward ecosystem-based management of Alaskan fisheries, the North Pacific Fisheries Management Council and the Alaska Fisheries Science Center have included the forage fish assemblage in the biennial cycle for groundfish stock assessment in the Gulf of Alaska (GOA). Forage fish represent a crucial component of ecosystem dynamics and food webs in the GOA, and assessment of this assemblage is designed to monitor trends that could effect populations of predators including commercial groundfish, seabirds, and marine mammals. This is the second assessment for forage fish in the GOA (Nelson 2003). Data on the abundance, distribution, and life histories of forage fish species are still extremely limited, but a number of studies are underway that may lead to more complete assessment of the dominant species in this assemblage (capelin) in future years. This report reviews available data, summarizes ongoing studies, and identifies future assessment needs. This document does not calculate OFL and ABC limits for forage fish, since directed harvest of all species in the assemblage is prohibited under the exiting fishery management plan for the GOA. A small amount of forage fish are taken as incidental catch by GOA groundfish fisheries, primarily the pollock trawl fishery. Estimated annual catch of forage fish from 2000 – 2005 has ranged between 125 and 1,053 mt. Very rough estimates of exploitation rates, based on bottom trawl survey biomass estimates, are 2% or less. A provisional biomass estimate based on 2003 acoustic survey indicates that actual biomass of forage fish is much higher than indicated by the bottom trawl survey, which would mean that true exploitation rates are even smaller than those estimated. Review of observer data indicates that incidental catch of forage fish is generally well under the 2% of target species catch permitted by current regulations,.

Introduction

Forage fishes are a critical part of all marine ecosystems, providing food not only for larger fishes, but also for seabirds and marine mammals (Wespestad 1987, Yang and Nelson 2000, Palsson 1997, Carscadden and Vilhjalmsson 2002, Baillie and Jones 2003). As the science of fisheries management has developed toward more ecosystem-based approaches, the key role of forage species and the often sizable gaps in data for these species have become increasingly apparent (Bogstad and Gjosaeter 2001, Ushakov and Prozorkevich 2002, Yndestad and Stene 2002, Matthiasson 2003). The Bering Sea and GOA share with other boreal marine ecosystems the characteristic of a small number of dominant species, with strong predator-prey interactions (Livingston and Tjelmeland 2000). In these systems, populations of forage species may undergo large changes due to climate shifts, fishing, and shifts in abundance of other prey and predator species (Anderson et al 1997, Dolgov 2002). These shifts in forage species may, in turn, strongly affect the abundance of predatory groundfish (Rose and O'Driscoll 2002), seabirds (Anker-Nilssen et al 1997, Davoren and Montvecci 2003), and marine mammals (Hansen 1997, Sinclair et al 1994). In the GOA, fluctuations in availability of forage fishes have been suggested as contributing to the decline of seabirds and sea lions (Kultez et al 1997, Rosen and Trites 2000, Trites and Donnelly 2003).

Species, Scientific Names, and Life-History Characteristics

In 1999, amendments 36 (BSAI) and 39 (GOA) to the fishery management plan (FMP) created a new forage fish species category from selected species previously non-specified or contained within the other species category. The goal of these amendments was to protect the forage fish resource by controlling harvest of these species and to emphasize the importance of these species in the process of stock assessment and management. The families and species included within this category are listed in Table 16.1. This list was compiled from Fishes of Alaska (Mecklenburg et al. 2002).

The forage fish category includes a diverse collection of species. They range in depth from intertidal to over 1000 meters, are found in the water column from the epinekton to the benthos, and have vastly divergent life histories (Brodeur et al 1999). Little is known about the life history characteristics or distribution of many forage fish species in Alaska. Life history characteristics of forage fish are described in the Programmatic Supplemental Environmental Impact Statement (PSEIS). General distribution and life history information for each of the major families is described below.

Family Osmeridae

Smelts are slender schooling fishes found throughout the world. Smelts may be marine, anadromous, or freshwater, and are key forage species in many of the world's ecosystems (Brodeur et al 1999, Livingston and Tjelmeland 2000). The two dominant smelt species in the GOA are capelin (*Mallotus villosus*) and eulachon (*Thaleichthys pacificus*). These two species represent the overwhelming majority of the biomass and incidental catch in the forage fish assemblage. Other members of the Osmerid family in the GOA are generally not identified to species and make up only a small fraction of incidental catch.

Capelin

Capelin are distributed along the entire coastline of Alaska and south along British Columbia to the Strait of Juan de Fuca (Brown 2002, Naumenko 1996). In the North Pacific Ocean, capelin can grow to a maximum of 25 cm at age 4. Most capelin spawn at age 3 or 4, when they are only 11 to 17 cm (Pahlke 1985). Spawning in Norton Sound, northern Bristol Bay, and around Kodiak Island occurs in intertidal zones of course sand and fine gravel during spring. Few capelin survive spawning. Capelin age of maturity in the Barents Sea was found to be a function of growth rate, with fast-growing cohorts reaching maturity at an earlier age than slow-growing cohorts (Huse, 1998). Thus, it is possible to have slow- and fast-growing cohorts mature in the same year, resulting in added variability in spawning biomass. In the Bering Sea, adult capelin distribution is associated with the polar ice front (Cianelli and Bailey 2005). However, in the GOA, which remains ice free year round, capelin are thought to overwinter in bays (Brown 2002, Blackburn et al 1981).

Eulachon

Eulachon spawn during the spring in rivers along the GOA, possibly with some contribution from rivers that drain into the southeastern Bering Sea. Eulachon live to age 5 and grow to 25 cm, but most die following their first spawning at age 3. Eulachon are consistently found by groundfish fisheries and surveys between Unimak Island and the Pribilof Islands in the Bering Sea, and in Shelikof Strait in the GOA. Evidence from fishery observer and survey data suggests that eulachon abundance declined in the 1980s. These data should be interpreted with caution because surveys were not designed to sample small pelagic fishes such as eulachon, and fishery data were collected primarily to estimate total catch of target groundfish. Causes of the decline, if real, are unknown. The decline may be simply related to natural variability in year-class strength or perhaps due to environmental factors that affects the availability of eulachon to fishing gear.

Family Myctophidae and Bathylagidae

Lantern fishes (family Myctophidae) and deep-sea smelts (family Bathylagidae) are pelagic fishes, distributed in the deep sea throughout the world's oceans. Species in both families occur at depth during the day and migrate to the surface at night to feed. The northern lampfish (*Stenobrachius leucopsarus*), a common Myctophid found in the Bering Sea and GOA, has a maximum length of 13 cm. Deep-sea smelt of the North Pacific Ocean include blacksmelt (*Bathylagus* spp.) and northern smoothtongue (*Leuroglossus stilbius*), which have maximum lengths of 12–25 cm. Lanternfish and deep-sea smelt are important forage fishes for marine birds and mammals. Because they are rarely caught in survey or fishery trawls, little is known of their distribution or abundance.

Family Pholidae and Stichaeidae

Gunnels (family Pholidae) and pricklebacks (family Stichaeidae, including warbonnets, eelblennys, cockscombs and shannys) are long, compressed, eel-like fishes with long dorsal fins often joined with the caudal fin. Pricklebacks are so named because of the spiny rays in the dorsal fin in most species (some have soft rays at the rear of the dorsal fins). Gunnels have flexible dorsal fin rays; they also differ from pricklebacks in that the anal fin is smaller (the distance from the tip of the snout to the front of the anal fin is shorter than the length of the anal fin). Most species of both families live in shallow nearshore waters among seaweed and under rocks and are less than 45 cm in length. Approximately 24 species of stichaeids and 6 species of pholids occur in Alaska. Nothing is known about their abundance, and little is known about growth rates, maturity, and trophic relationships, although they are believed to grow quickly. Some cockscombs in British Columbia attain sexual maturity at age 2 years.

Family Gonostomatidae

This is a large and diverse family (Gonostomatidae) of bathypelagic fish that are rarely observed except by researchers. They grow to about 8 cm and can be abundant at depths of up to 5,000 m. As many as six species may occur in the North Pacific Ocean and Bering Sea. Little is known about trends in their abundance.

Order Euphausiacea

Along with many copepod species, the euphausiids form a critical zooplanktonic link between the primary producers (phytoplankton) and all upper pelagic trophic levels. These crustaceans, also known as krill, occur in large swarms in both neritic (nearshore) and oceanic (offshore) waters. Members of at least 11 genera of euphausiids are known from the North Pacific Ocean. The most important, in terms of numbers of species, being *Thysanopoda, Euphausia, Thysanoëssa,* and *Stylocheiron*. Euphausiids are generally thought to make diurnal vertical migrations, remaining at depth during the day and ascending at night to 100 m or less to feed. However, this is complicated by the fact that as euphausiids grow they are found at deeper depths, except during spawning, which occurs in surface waters.

Spawning occurs in spring to take advantage of the seasonal phytoplankton bloom. Hatched nauplii larvae live near the surface to about 25 m. By winter, the young crustaceans are found mainly at depths of 100 m or less, and make diurnal vertical migrations to feed. Sexual maturity is reached the following spring at age 1. After spawning, adult euphausiids gradually descend to deeper depths until winter, when they no longer migrate daily to near-surface waters. In their second spring, they again rise to the surface to spawn; euphausiids older than 2 years are very rarely found. This classical view of euphausiid life history and longevity was recently questioned by Nichol (1990), who reported that Antarctic euphausiids may live as long as 6 to 10 years. If north Pacific euphausiids exhibited similar longevity then expected productivity may be much lower.

While euphausiids are found throughout oceanic and neritic waters, their swarms are most commonly encountered in areas where nutrients are available for phytoplankton growth. This occurs primarily in areas where upwelling waters are a consistent oceanographic feature. Areas with such features are at the edges of the various domains on the shelf or at the shelf-break, at the heads of submarine canyons, on the edges of gullies on the continental shelf (e.g., Shumagin, Barnabas, Shelikof gullies in the GOA), in island passes in the Aleutian Islands (e.g., Seguam Pass, Tanaga Pass), and around submerged seamounts (e.g., west of Kiska Island). It is no coincidence that these are also prime fishing locations used by commercial fishing vessels seeking zooplanktivorous groundfish, such as pollock, Atka mackerel, sablefish, and many rockfish and flatfish.

The species comprising the euphausiid group occupy a position of considerable importance within the North Pacific Ocean food web. Euphausiids are eaten by almost all other major taxa inhabiting the pelagic realm. The diet of many fish species other than the groundfish listed previously, including salmon, smelt (capelin, eulachon, and other osmerids), gadids such as Arctic cod and Pacific tomcod, and Pacific herring is composed, to varying degrees, of euphausiids (Yang and Nelson 2000). They are also the principal item in the diet of most baleen whales (Perez 1990). While copepods generally constitute the major portion of the diet of planktivorous seabirds (e.g., auklets), euphausiids are prominent in the diets of some predominately piscivorous seabirds in certain areas (e.g., kittiwakes on Buldir Island in the Aleutian Islands, Middleton Island in the GOA, and Saint Matthew Island in the Bering Sea).

Euphausiids are not currently sought for human use or consumption from the North Pacific Ocean on a scale other than local, but large (about 500,000 mt per year) krill fisheries from Japan and Russia have been operating in Antarctic waters since the early 1980s. A limited (500 t) fishery is allowed off the coast of British Columbia, Canada. The catch is used in fish food for fish aquaculture and aquaria.

Management Units

Amendments 36 (BSAI) and 39 (GOA) to the FMPs prohibit the directed fishery of any species in the forage fish species category. It also limits bycatch and places limits on the sale, barter, trade or processing of any species included in the group. A maximum of 2 percent retainable bycatch of forage fish species was established by the rule. Forage fish taken as incidental catch are recorded by fishery observers and included in the catch accounting system but are generally not identified to species.

Currently, regulation of forage fish harvest is based on two management units, with the Bering Sea and Aleutian Islands in one unit and all of the Gulf of Alaska in the other.

Evidence of Capelin Stock Structure

Capelin are a dominant forage fish in the Barents Sea, around Iceland, and off the coast of Labrador, and genetic studies of stock structure in these stocks have been conducted (Roed et al 2003). There is at present no work on genetic stock structure in capelin of the Bering Sea or GOA. If future management and assessment of capelin in Alaska warrants analysis of stock structure, the AFSC has capability in the techniques used for Atlantic capelin. The data section of this report presents some analyses of growth curves for different subsets of capelin within the GOA and discussion of possible regional units for future assessment modeling.

Fishery Information

Directed Fishery

Directed fisheries for capelin exist in the Barents Sea, near Iceland, and off the Labrador coast of Canada, using trawls and purse seines. These fisheries have historically harvested as much as two million tons per year, but have been subject to wide fluctuations in capelin abundance and repeated stock collapses (Ushakov and Prozorkevic 2002). A small directed fishery for capelin was tried in the Bering Sea in the 1980’s, but it lasted only a few years and had harvest less than 5,000 tons (Wespestad 1987). Current management of BSAI and GOA forage fish assemblages prohibits the development of a directed fishery, limits bycatch, and places limits on the sale, barter, trade, or processing of any species included in the group (FMP Amendment 36 and 39, 3/17/98, 63 FR 13009). Members of the assemblage other than smelts are rarely encountered by the fishery and are generally not vulnerable to capture by commercial gears currently used in the GOA.

Incidental Catch

Small amounts of forage fish are taken as incidental catch by trawl gear in federal groundfish fisheries in the GOA, primarily by the pelagic trawls of the pollock fishery. Forage fish catches are recorded by observers and monitored during the season to ensure compliance with MRA limits. Estimating total incidental catch of forage fish in the GOA is complicated by a number of factors. First, observer coverage is only approximately 30% in the GOA. To generate catch estimates it is assumed that the catch of forage fish species observed on covered vessels is representative of unobserved vessels. However, the observer coverage is also not randomly assigned throughout the fisheries and could therefore violate this assumption. Second, most forage fish species have in the past been identified only to the familial level. Efforts to improve observer identification of the two major forage fish species have been implemented in recent years. In 2004, catch accounting for the smelt family, which comprises the largest percentage of the forage fish catch, was divided into estimates for capelin, eulachon, surf smelt, and other osmerids. This improved identification and accounting represents a significant improvement in data quality, since capelin and eulachon make up the majority of the incidental catch. Other groups within the forage fish assemblage are still identified primarily to family level.

Estimated catch of forage fishes in the GOA is presented in Tables 16.2. Forage fish are only a small part of commercial fisheries catch. From 1997 to 2000, total catch of forage fish, ranged from 27 to 125 tons. Estimated catches for 2001-2004 were somewhat higher, from 158 to 540 tons. In 2005, the estimated catch was 1053 tons (data through Oct 4, 2005). The overwhelming majority of all catches was smelts. In 2005, eulachon made up 85% of the estimated catch and unidentified osmerids 15%, with all of the remaining groups contributing less than 1% (Table 16.2). Most of the 2004 and 2005 catches of smelts in the GOA came from the pollock fishery in the Kodiak and Chirikof regions, primarily from midwater trawls but to some extent from bottom trawls. Anecdotal reports and observer data suggest that historical catches of smelts were also predominantly eulachon and capelin. The reason for the large increase in eulachon catch in 2005 is unknown, but bottom trawl survey data for both species suggest increased abundance of these fishes in 2001- 2005.

The catch of other families within the forage fish assemblage in the GOA from 1997 to 2005 was small. Stichaeidae (pricklebacks) and Pacific sandfish each had catches of two to five tons per year, but no other family in the assemblage had a recorded catch of greater than one ton since 1997. This lack of catch is probably due to small size and habitat preferences that make these species unavailable to commercial gear. Pacific sand lance, for example, is known to be a major prey item for seabirds and sea lions (Aydin et al in review, Sinclair and Zeppelin 2002) but is very difficult to catch with any gear other than beach seines.

Data

Pavlof Bay Survey

NMFS and ADF&G have conducted a small-mesh (32 mm stretched mesh) trawl survey in Pavlof Bay every year since 1972 (Anderson et al. 1997). This survey is directed to sample shrimp populations in the bay. The survey uses a small mesh net, which has proven to be effective at capturing smelt and other forage species when they are present. Biomass estimates were calculated for capelin in Pavlof Bay by an area swept technique involving simple extrapolation of the CPUE data across the entire bay (Table 16.3).

As these numbers attest, estimated capelin biomass has fallen precipitously from a peak estimate of over 1,500 to virtually no biomass in recent years. In five of the most recent ten years of the survey, no capelin were collected. Anderson and Piatt (1999) attribute this decline to a transformation in the ebibenthic community due to an oceanic climate regime shift. The benthic community in the inshore regions of the GOA changed from a historical domination of crustaceans to a groundfish dominated system. It was hypothesized that the reduction in the capelin catch was due to recruitment failure and increased predation caused by the regime change.

Hollowed et al. (In review) described the mesoscale distribution of capelin in two trough systems off Kodiak Island. They found that capelin spatial distribution was strongly correlated with thermal fronts, not depth or specific bottom traits. This association to thermal cues has also been shown in Atlantic populations (Carscadden and Nakashima 1997).

The ocean regime shift witnessed in the late 1970s resulted in warmer costal water temperatures. Hollowed et al. (In review) hypothesized that the rapid decline in the catches in the inshore small-mesh survey may have been a result of capelin being displaced by warm water in the nearshore areas. In other words, a change in water temperature altered the habitat, such that capelin moved out of the nearshore survey area. If this is the case, perceived capelin declines may be linked to changes in distribution. This could explain the continuing high predation rates of capelin by groundfish seen in the more offshore shelf areas of the GOA sampled by the NMFS groundfish survey (Yang and Nelson 2000).

GOA Groundfish Survey Data

NMFS conducts a biennial (formerly triennial) bottom trawl survey of the GOA for multispecies groundfish stock assessment. The survey employs a bottom trawl with roller gear and a 5-inch mesh size, and covers areas of the continental shelf and upper slope from depths of 30m to approximately 500 m. Bottom trawl survey gear is presumably inefficient in catching very small fish and species that burrow into the substrate, such as sandlance and sandfish. In addition, species which form pelagic schools off bottom, such as smelts, may be under-sampled. Species with primarily inshore habitats may also be poorly represented. The bottom trawl survey is not designed to sample forage fish species and the selectivity of survey gear for forage species is unknown. Although some members of the forage fish category are caught in the groundfish survey, other forage fish species are rarely, if ever, encountered. Therefore, reliable estimates of abundance for many of the forage fish species are difficult to develop.

Nevertheless, the bottom trawl survey provides an extended time series over which gear and methodology have remained consistent, and may provide some indication of temporal fluctuations and trends in species at least partially vulnerable to the survey gear. Table 16.4 presents estimates of biomass for selected species and groups within the forage fish assemblage, assuming a survey selectivity value of one. Survey estimates were calculated for the western, central and eastern GOA from 1984 to 2005 (Table 16.4 and Figure 16.1). The survey years were 1984, 1987, 1990, 1993, 1996, 1999, 2001, 2003 and 2005. In 2001 the survey did not extend into the eastern GOA; therefore, there is no regional estimate for that year. The forage species most abundant in bottom trawls is eulachon, with biomass estimates for the entire GOA on the order of 20,000 – 80,000 tons. Bottom trawl estimates for capelin are generally less than 1,000 tons, although the estimates for 2003 and 2005 are substantially higher than those for 1984-2001. Biomass estimates for other forage fish groups are generally less than 500 tons.

Currently, there are no comprehensive surveys designed to sample forage fish populations, and true biomass estimates for these species are unavailable. The bottom trawl survey probably underestimates the abundance of these species. Further complicating the estimate, many forage species, such as smelts, tend to exhibit patchy distributions leading to high variance in the biomass estimates. Taken as indicators of time trends in abundance, the survey estimates suggest a sharp decline in abundance of sandfish and sand lance in the early 1990s and a sharp increase in abundance of capelin and eulachon in 2003 and 2005. For all of the forage fish groups, trawl survey estimates indicate that the greatest biomass is found in the central GOA.

Estimated Exploitation Rates

The vast majority of the incidental catch of forage fishes is smelt catch in the central GOA (Table 16.2). As a first approximation, a rough calculation of exploitation rates for capelin and eulachon in the central GOA was made based on the reported incidental catch and estimated survey biomass from this region (Table 16.5). Biomass estimates are those for the central GOA (stat areas 620 and 630) from the 1999, 2001, 2003, and 2005 bottom trawl surveys. Catch data for smelt in 1999 and 2001 were divided into estimates of capelin and eulachon based on the proportion of these species in each year's survey. Catch data for 2003 and 2005 are as reported for each species. The estimated exploitation rate is simply the catch as a percentage of the estimated biomass in each year. **These rough exploitation rates are uniformly low, 2.2% or less**. Very high biomass estimates for both eulachon and capelin in 2003 resulted in low estimated exploitation rates. There is an increasing trend in both the catch and estimated exploitation rates for eulachon from 1999 to 2005. **Considering that these rates are calculated from what is thought to be a sizeable underestimate of biomass, the actual exploitation rates for these two species are likely lower.**

Estimates of Capelin Consumption by Groundfish

A historical review of capelin occurrence in groundfish stomach content data from the GOA and Bering Sea was recently conducted by AFSC's Resource Ecology and Ecosystem Modeling program (Yang et al 2005). Records from 1970 in the Bering Sea and 1981 in the GOA through 2001 were reviewed, and the percentage occurrence of capelin in the stomachs of fish predators was calculated. Results were presented by geographic and depth regions (Figure 16.2). Major fish predators of capelin in both regions were arrowtooth flounder, Pacific cod, Pacific halibut, and walleye pollock. Capelin occurred frequently in the stomachs of marine fish in the GOA in 1990, 1993, and 1996, and 2001, but were rare in 1999. The size frequency of capelin in fish stomachs varied substantially from year to year, with the 70-100 mm size class (age 1) being most common in 1990, 1993, 1996, and 1999 but the 100-140 cm size class (age 3) dominating in 2001. **Estimates of total capelin consumed by fish predators during the summer feeding season in the GOA ranged from 21,168 mt in 1999 to 221,408 mt in 1990** (Figure 16.3). Year-to-year variation in capelin consumption was attributed primarily to changes in predator biomass, but also to variation in capelin biomass, the availability of capelin during stomach collections, and physical oceanographic factors.

GOA Ecopath Model

An Ecopath model for the GOA has been developed which can give certain insights into the abundance of forage fish species (Aydin et al. 2002). The GOA Ecopath model uses a top down approach at a mass-balance food web model. The estimates for forage fish species biomass are calculated by finding the amount of forage fish that would need to be present in order to support the trophic levels above them. The model currently estimates gulf wide biomass for Bathylagids, Myctophids, Pacific sand lance, capelin and eulachon. In addition, the model has two miscellaneous forage fish species categories, other pelagic smelt and managed forage fish. The majority of the data used to make the calculations were taken from 1990 through 1993. The GOA Ecopath model give us an independent estimate of the abundance of forage species in the GOA ecosystem, including those species which are not represented in either fishery or survey data. **The model suggests that capelin have the highest biomass of any forage species, followed by Pacific sand lance, about 2 million tons and 1 million tons respectively. Eulachon, which is the most abundant species in bottom trawl surveys, is ranked a distant third at approximately 300,000 tons.** All other species and species groups are estimated to be within the 100,000 – 400,000 ton range. These estimates are several orders of magnitude above the levels of biomass estimated by the bottom trawl survey and reported as incidental catch. **These results suggest that biomass based on the bottom trawl survey are substantial underestimates.**

There are also limitations in biomass estimates from the Ecopath model. Upon inspection of the data, it was noticed that model inputs from Northern fur seal diet were driving the high estimates of capelin and sand lance. The Northern fur seal diet inputs were derived from values found in the literature from the 1970's, when capelin were thought to be more abundant. Therefore, there is reason to believe that the model may not fully reflect the current status of forage species in the GOA. The model has not been updated since the previous forage fish assessment (Nelson 2003).

GOA Echo Integration Trawl Survey

The MACE Program conducted an echo integration-trawl (EIT) feasibility survey with an emphasis on walleye pollock (*Theragra chalcogramma*) between 4 June and 16 July 2003 along the GOA shelf from the Shumagin Islands to Prince William Sound aboard the NOAA Ship *Miller Freeman*. The survey design consisted of parallel-spaced transects at 10 or 20 nmi on the GOA shelf and in Shelikof Strait, with shorter spacing used in selected troughs and bays (1-8 nmi). Midwater echosign was sampled with an Aleutian Wing 30/26 midwater trawl. On- or near-bottom echosign was sampled with a poly nor'eastern trawl with roller gear. The codends of both trawls were fitted with a 0.5-inch liner. Abundance estimates were based on data collected with a Simrad EK500 echosounder and 38-kHz split-beam transducer.

Of the species other than pollock encountered during the survey, capelin have the most potential to be assessed using EIT survey methodology. Daytime aggregations of capelin were often aggregated in distinct schools and did not appear to avoid the trawl. Echosign identified as capelin were stored in a relational database. A multi-frequency technique was applied to validated capelin backscatter from trawl catches to confirm that the scrutinized backscatter corresponded to capelin. This technique, which reduced the backscatter attributed to capelin by 17.8%, was based on Logerwell and Wilson (2004), which was designed to separate capelin from pollock. Capelin length data were aggregated into analytical strata based on geographic proximity of hauls and similarity in size composition data. Estimates of capelin backscattering strength for each stratum were calculated using an s_V threshold of –70 decibels. The echo integration values were summed and scaled using a target strength (TS) to standard length (SL) relationship of TS = 20 Log SL – 69.4 (Guttormsen and Wilson in prep.), and length composition data to produce estimates of numbers by length. Mean weight-at-length was estimated from the trawl data and was used to calculate biomass-at-length.

A distributional plot of capelin acoustic backscatter is shown in Figure 16.4. The densest echosign was detected east of Kodiak Island, with lesser amounts south and north of the island. **The provisional abundance estimate of capelin was 30.3 billion fish weighing 116,000 t (Table 16.6).** Over three-quarters of the abundance in numbers were 7 to 9 cm fish. **This biomass estimate is two orders of magnitude larger than the 2003 capelin abundance estimate based on the GOA bottom trawl survey** (Table 16.4), and confirms the assumption that bottom trawl survey data strongly underestimate forage fish biomass. This provisional EIT estimate is still an order of magnitude smaller than the capelin biomass estimated by the Ecopath model.

While EIT surveys for capelin are well established in the Atlantic (O'Driscoll and Rose 2001, Jorgensen and Olsen 2002, Gjosaeter et al 2002, Carscadden and Vilhjalmsson 2002, O'Driscoll et al 2002), methods for acoustic abundance estimation of capelin in the GOA and Bering Sea are still under development. Current research underway at MACE includes determination of a target strength-length rrelationship specific to Alaskan capelin, application of multi-frequency techniques to separate capelin from age-0 and age-1 pollock, and appropriate transect spacing for capelin assessment. **The abundance estimate in Table 16.6 should be considered provisional at this time,** but it should be feasible to calculate capelin abundance estimates from EIT surveys in 2007 and beyond.

Forage fishes are also encountered during seasonal and regional EIT research surveys conducted in the GOA. From 2000-2005, capelin were present in midwater trawl catches from summer EIT surveys in the central GOA (see below). Summer studies east of Kodiak in 2001, 2002, and 2004 provided valuable observations on use of multi-frequency techniques to separate capelin and pollock backscatter (Logerwell and Wilson 2004) and on small-scale spatial distributions of capelin and pollock with regard to oceanographic features (Hollowed et al. In review). Length frequencies and biological samples collected during these cruises are discussed below. Capelin were rarely encountered during winter EIT surveys in Shelikof Strait and in the Shumagin-Chirikof regions in 2000 – 2005, but eulachon were present in 75-90% of the midwater trawls from surveys of the Shumagin region and 50-70% of trawls in Shelikof Strait.

Capelin Length Frequency and Growth Data from Regional Surveys

AFSC's Fishery Interaction Team (FIT) has been conducting a study on the impacts of fishing on prey availability for Steller sea lions in the central GOA (Wilson et al. 2003). This study is based on EIT surveys of two troughs off the east side of Kodiak Island in mid-late August, conducted around the opening of the pollock trawl fishery. These studies have provided an opportunity to examine the small-scale spatial distribution of caplin in relation to walleye pollock and oceanographic features (Hollowed et al. In review, Logerwell and Wilson 2004). Specimens and biological data for capelin have also been collected from midwater trawls during these surveys. Figure 16.5 shows capelin length-frequency data from Kodiak EIT surveys in 2000, 2001, 2002, and 2004. While capelin ranging from 70 to 150 mm have been collected in all of the surveys, the relative frequency of different length classes has been variable. The largest size classes dominated tows in 2000, when a 32 mm liner was used in the cod end of the survey trawl. In subsequent years, however, a 9.5 mm cod end liner was used and there was greater retention of smaller fish. The largest data set is from 2002, when lengths and weights were recorded for more than 1200 capelin.

One of the important considerations in any future assessment of capelin would be whether to treat the entire GOA as one stock, or whether there are important regional differences in growth and survival rates. Two published sets of length-weight regressions for capelin in different regions of the GOA suggest regional differences in growth rate (Table 16.7). Evelyn Brown (2002) extracted capelin information from historical databases of studies in Prince William Sound (east-central GOA). These studies included collections from both offshore and inshore areas of the sound from April through November of 1989 and April-October 1994-97. Wilson et al. (In press) studied feeding ecology and distributions of capelin and pollock in the west-central (Chirkov) region in September 2000 and 2001. For comparison with these studies, we estimated parameters for length-weight relationships from capelin samples from FIT studies on the eastside of Kodiak in 2000-03 and from a survey conducted by the Auke Bay lab in May 2002 (M. Sigler, personal communication). Length-weight relationships of the form Weight = α * Length $^{\beta}$ were fit by linear regression on log-transformed data (Figure 16.6). Table 16.6 compares parameters estimated from these data sets with published values. It is difficult to make strong comparisons between these results due to differences in season, gear, and methodology between the studies, but estimates of beta suggest some regional differences in growth rate, with capelin growing slightly heavier at length in Prince William Sound and southeast Alaska

Modeling

Analytic Approach, Model Structure, and Parameter Estimation

There is at present no adequate data to support quantitative stock assessment modeling for members of the forage fish assemblage. Quantitative assessments of capelin are conducted in the North Atlantic for the Barents Sea (Gjosaeter et al 2002), Iceland (Gudmundsdottir and Vilhjalmsson 2002), and Labrador (Carscadden et al 2001), where capelin constitute an important component of the ecosystem and support some commercial fisheries. Assessment models for capelin in these systems are complex, and have been only marginally successful (Gjosaeter et al 2002, Hjermann et al 2004). Because capelin are very short-lived and have a length-based, rather than age-based, maturity, it is difficult to apply sequential population analysis (VPA) models commonly used in groundfish management (Carscadden and Vilhjalmsson 2002, Gjosaeter et al 2002). The very low survival rate of adults after spawning means that stock assessment models must be divided into spawning and nonspawning components, with separate seasonal estimation of mortality rates. The summer inshore migration of adults for spawning provides opportunity for index surveys (Blackburn et al 1981, Brown et al 2002), but means that the seasonal timing and spatial extent of survey coverage must be carefully considered. The Barents Sea model uses a monthly time step, and incorporates the biomass of cod into the mortality function and the biomass of herring into the recruitment function (Gjosaeter et al 2002). All of the Atlantic stock assessments are based on annual estimates of capelin abundance from comprehensive EIT surveys. Data inputs needed for stock assessment include annual estimates of biomass by length class, parameters for length-based recruitment and mortality functions, and annual harvest and/or consumption mortality estimates by length class.

Future plans for the GOA include summer gulfwide EIT surveys. Once target-strength and multi-frequency methods and algorithms for capelin are developed, these surveys should yield substantially improved estimates of capelin biomass in the GOA. The combination of better reporting of commercial catch data and better biomass estimation may make it possible to build an assessment model for GOA capelin in the future. Based on experiences with Atlantic capelin, however, this assessment model will likely have to be custom-built based on dynamics of predator-prey relationships in the GOA. Assessment of eulachon will be more difficult, since they produce only very low levels of acoustic backscatter, but some work has also been performed on target strength determinations for this species (Gauthier and

Horne 2004). Methods for a consistent index survey of eulachon abundance are currently being researched at AFSC's Auke Bay laboratory.

Results – Management Actions

Because current regulations prohibit directed fishing for members of the forage fish assemblage, there is no need to develop OFL and ABC limits for this group. Even with recent increases in the rate of incidental catch, total catch rates are well below the 2% MRA limit imposed by the FMPs. The highest catch observed for all forage fish in the GOA was 1,053 tons in 2005, well below the 1,704 tons that would represent 2% of the western/central/Yakutat pollock TAC. Examination of observer records for individual observed hauls showed that only 5-7% of hauls had a ratio of smelt to pollock higher than 2%, and the overall average catch of smelts was only 1% of the pollock catch. Estimates of exploitation rates for forage fishes are less than three percent, and true exploitation rates are probably at least an order of magnitude lower. Time trends from bottom trawl and shrimp trawl survey data indicate that forage fish biomass is still dramatically lower than historical (pre regime shift) levels, but that the most recent observations of capelin and eulachon biomass have increased substantially. While there is a continuing need to understand the dynamics of forage fish populations as a component of ecosystem structure, there is nothing in the available data to suggest any need for further protection or regulation of forage fish. The current 2% MRA restriction appears to provide adequate protection for forage fishes in the GOA.

Ecosystem Considerations

Members of the forage fish assemblage are protected from directed fishing in Alaska because of their critical importance in the ecosystem, supporting not only higher trophic levels of fish but populations of seabirds and marine mammals (Yang and Nelson 2000, Kuletz et al 1997, Baillie and Jones 2003). Several members of the forage fish assemblage are major items in the diet of birds and mammals in Alaska (Ostrand et al 1997, Perez 1990, Table 16.7). One hypothesis that has been put forward for the decline of the Steller sea lion is a forced shift in diet from energy-rich forage species to the more nutritionally poor walleye pollock (Rosen and Trites 2000, Trites and Donnelly 2003). A number of investigators have studied the role forage fishes in the food webs and energy dynamics of the GOA ecosystem (Anderson and Piatt 1999, Mueter and Norcross 2002, Litzow et al 2004).

The main tool in use at the AFSC for mapping food-web dynamics is the Ecopath model (Polovina 1985, Christiansen and Walters 1992, Aydin et al In Review). Ecopath is a mass-balance modeling methodology designed to make extensive use of data as it is already collected for single-species fisheries management. Data on base parameters, survey biomass estimates, age, weight, and mortality studies are supplemented with consumption rate data either from laboratory or shipboard experiments, to determine production and consumption rates for each species. The current version of the model is balanced based primarily on data from the early to mid-1990s (1990-1996). Outputs from the model include ranking of principal predators and prey for each species or species group, along with estimates of total consumption by all predators. Table 16.8 shows model predictions of managed forage fishes in the diets of marine mammals and seabirds in the GOA. Capelin and sand lance are key elements in the diets of gulls, puffins, cormorants, shearwaters, and fur seals. They also ply important roles in the diets of kittiwakes, murres, albatross, minke whales, humpback whales, and resident killer whales. The model does not indicate that forage species play a large role in the current diet of Steller sea lions.

Figure 16.7 shows model estimates of the total consumption of the three key forage species; capelin, sand lance, and eulachon in the GOA. All forage fish groups are top-down balanced in the model and share an identical zooplankton diet of 90% euphausids and 10% copeopods. However important predators differ significantly between forage species and between the GOA, Bering Sea, and AI ecosystems. The GOA system is characterized by a strong role of Arrowtooth flounder, which have increased dramatically in abundance throughout the GOA since the mid-1980's. Arrowtooth account for a larger fraction of forage fish mortality than any other fish species, including walleye pollock. Squids are also primary consumers of forage species in the GOA, especially of myctophids, eulachon, and other smelts. While forage species are important to seabirds and mammals, these groups account for relatively small proportions of the overall consumption of forage fishes. Of these, humpback whales, puffins, and fin whales play the largest roles. Approximately 20% of the overall mortality of all forage species is unexplained by the model.

It is important to note that the species included in the federally-managed forage fish assemblage do not make up the entirety of the forage base in the GOA ecosystem. State-managed Pacific herring and the juvenile stages of several commercial species, including walleye pollock and pink salmon, are also important forage components of the GOA ecosystem (Yang and Nelson 2000). Walleye pollock and other commercial species play roles as prey in their juvenile stages and predators as adults. Modeling or assessment of trophic dynamics must take the abundance of these other species into account, as well as the species in the managed forage fish complex. Fishing and other human activities that significantly affect the abundance of predators will have substantial effects on dynamics and abundance of forage species, although the direction and magnitude of such effects may be difficult to predict.

Spatial distributions of capelin and their interaction with walleye pollock are strongly dependent on oceanographic conditions, including water temperature and frontal stuctures (Logerwell and Wilson 2004, Hollowed et al In Review, Abookire and Piatt 2005). Spawning behavior, fecundity, and reproductive success of capelin is strongly associated with water temperatures and conditions in inshore areas (Brown 2002, Naumenko 2002, Tereshchenko 2002, Davoren and Montevecchi 2003, Doyle et al 2002b), leading to large interannual changes in abundance. Climate-based and anthropogenic changes that affect temperatures and current patterns in the GOA can be expected to have significant effects on the distribution, reproduction, and abundance of forage species. Both climate effects (regime shift) and the expansion of predators arrowtooth flounder and walleye pollock may have already produced significant changes in the composition and biomass of forage fishes in the GOA since the mid 1970's (Kuletz et al 1997, Anderson and Piatt 1999, Conners et al 2002).

Current Studies of Forage Fish in the GOA

Although available data on forage fishes are sparse, there are a number of research efforts underway aimed at improving understanding of the status and role of forage fishes in the GOA. Studies focused on multilevel trophic interactions; distribution, life history, and spawning of forage species; and possible assessment techniques for key forage species have all been conducted in recent years. At the September 2005 meeting of the American Fisheries Society in Anchorage, AK, there were 17 presentations and posters involving forage fish in Alaska. While full results of most ongoing studies are not yet available, some of the studies in progress are outlined below.

<u>Age Determinations and Length-Age Relationships</u>

Otoliths have been collected from capelin and eulachon specimens during EIT cruises in the central GOA from 2000 - 2005. Progress has been made in determining suitable aging methods for this species but age data are not yet available. Ageing of capelin scales is planned during winter and spring 2006.

<u>Multi-level Trophic Interaction Studies</u>

The University of Alaska Fairbanks is conducting the Gulf Apex Predator-prey (GAP) study in waters near Kodiak Island. Initiated in 1999, GAP's primary goal is to document trophic relationships between Steller sea lions, their prey, predators, and potential competitors in waters near Kodiak Island, an area of continued sea lion declines and extensive commercial fishing. Through integrated studies that overlap spatially and temporally, GAP will assess the degree of dietary overlap among Kodiak's sympatric apex predators while exploring processes that drive populations of their prey within a dynamic marine environment. This study includes multidisciplinary monitoring of several trophic levels in the study area, including forage fish species. Field efforts include EIT surveys of the spatial distribution of capelin and juvenile pollock in relation to oceanographic features and frontal structures, and estimation of local fish biomass. This study also includes assessments of prey species, including Pacific sand lance, in nearshore areas. Remote sensing systems are being examined as more efficient means of assessing biomass and seasonal distribution of prey species. Aerial surveys are currently overlapping acoustic cruises to groundtruth the feasibility of a faster method of assessment. Aerial surveys include laser, and digital imaging technology.

Scientists from NOAA's Auke Bay Laboratory and academic collaborators are conducting an interdisciplinary research project evaluating sampling strategies, local distributions, and movement patterns of forage fish species in the southeast Bering Sea (Sigler et al 2005). This study examines forage fish distributions, plankton, and physical oceanography in both offshore shelf and inshore regions using a variety of sampling gears and techniques. Sampling methods to be tested include airborne remote sensing using visual observations and LIDAR; hydroacoustics and midwater trawling in the offshore region; and beach seine, jigging, and ROV transects in nearshore habitats. One of the goals of the project is to test sampling tools and survey strategies for various forage fish species. Field work for this project was conducted in June 2005 in the Bering Sea north of Akutan and Akun Islands. Results of the study are expected to be available in 2006.

Studies of Capelin Larval Distribution

There are few estimates of abundances of larval capelin in the Gulf of Alaska (GOA). Historical collections of ichthyoplankton by the National Oceanic and Atmospheric Administration (NOAA) have been in spring (April-May), when few capelin larvae are present in the water column of the continental shelf. Doyle et al. (2002a, 2002b) synthesized available historical data on capelin early life history in the GOA based on collections from seasonal collections from 1977-1979. Results from that study determined that capelin spawn inshore during summer (peak June-July), and that larvae are subsequently advected from bays in the coastal zone to the continental shelf either by entrainment in freshwater runoff and/or by tidal flushing. Larger capelin larvae (>30 m) appear to actively migrate to the surface layer. Lanksbury et al. (2005) recently analyzed assemblage-level ichthyoplankton data from autumn research cruises conducted in 2000 and 2001 in the GOA region between the Semidi and Shumagin Islands and noted that Osmerids (primarily capelin, *Mallotus villosus*) had a high frequency of occurrence. These two studies offer an opportunity to examine larval capelin distribution and abundance on the GOA continental shelf in autumn between the 1970's and the present. It should be noted however, that there are broad-scale geographic differences in sampling locations between the two time periods, and that gears used between the two time periods also differ (Bongo vs. Tucker trawls), so absolute abundances between the two time periods should not be directly compared. Likewise, length/age analyses of larvae have not been conducted which could affect interpretation of abundance estimates. Nevertheless, it does appear that there were moderately high catches of capelin larvae at selected stations during both time periods. Highest abundances were collected at stations near shore, and reduced catches were noted at stations nearest the slope. Ichthyoplankton collections were also made during autumn 2003-2005 in the vicinity of Kodiak Island using a sampling grid similar to the 1978 cruises. These data are currently being analyzed, and will provide a direct comparison to the sampling conducted in the late 1970s.

Eulachon Studies in Southeast Alaska

Scientists at the Auke Bay Laboratory in southeast Alaska have been conducting studies since 2001 on spawning patterns and distribution of eulachon, their importance as prey of Steller sea lions and other predators, and methods for sampling and assessing eulachon.

Data Gaps and Research Priorities

The NPFMC and the AFSC are moving toward increased emphasis on understanding the role of forage fishes in the GOA ecosystem, and increased efforts are underway to gather data on the abundance, distribution, and life history of forage species. Recent improvements in both forage fish identification by observers and catch accounting of smelt species will provide better catch data in the future. Survey techniques for forage species are being studied by a number of groups with the AFSC and academia (see above). Techniques for estimating capelin biomass from EIT surveys are currently being developed, and future gulfwide EIT surveys should provide one means of assessing this species. Sand lance and eulachon may need to be assessed by index surveys of abundance in inshore areas. The large gaps between biomass estimates from existing surveys and food-web models indicate that the greatest research need is for more realistic estimation of forage fish abundance.

In addition to biomass estimates, a full assessment for capelin or other forage species will also require age or length frequency data, life history data, and age or length-based estimates of harvest and consumption. The short life spans and climate-sensitive spawning of smelts and sand lance probably lead to large natural year-to-year variability in abundance, and some means to track these shifts in abundance is needed. Finally, assessment of forage species will need to take into account the abundance of other forage fishes, including herring and juvenile pollock, as well as the abundance of key groundfish predators. Understanding the dynamics between target fisheries on predators and specific forage fish species is a goal that is far in the future, and will require greatly increased understanding of the GOA ecosystem.

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Tables

Table 16.1. List of scientific name and common name of species contained within the forage fish category. Compiled from Fishes of Alaska (Mecklenburg et al. 2002).

Scientific Name	**Common Name**
Family Osmeridae	smelts
Mallotus villosus	capelin
Hypomesus pretiosus	surf smelt
Osmerus mordax	rainbow smelt
Thaleichthys pacificus	eulachon
Spirinchus thaleichthys	longfin smelt
Spirinchus starksi	night smelt
Family Myctophidae	lanternfish
Protomyctophum thompsoni	bigeye lanternfish
Benthosema glaciale	glacier lanternfish
Tarletonbeania taylori	taillight lanternfish
Tarletonbeania crenularis	blue lanternfish
Diaphus theta	California headlightfish
Stenobrachius leucopsarus	northern lampfish
Stenobrachius nannochir	garnet lampfish
Lampanyctus jordani	brokenline lanternfish
Nannobrachium regale	pinpoint lampfish
Nannobrachium ritteri	broadfin lanternfish
Family Bathylagidae	blacksmelts
Leuroglossus schmidti	northern smoothtongue
Lipolagus ochotensis	popeye blacksmelt
Pseudobathylagus milleri	stout blacksmelt
Bathylagus pacificus	slender blacksmelt
Family Ammodytidae	sand lances
Ammodytes hexapterus	Pacific sand lance
Family Trichodontidae	sandfish
Trichodon trichodon	Pacific sandfish
Arctoscopus japonicus	sailfin sandfish
Family Pholidae	gunnels
Apodichthys flavidus	penpoint gunnel
Rhodymenichthys dolichogaster	stippled gunnel
Pholis fasciata	banded gunnel
Pholis clemensi	longfin gunnel
Pholis laeta	crescent gunnel
Pholis schultzi	red gunnel

Table 16.1. List of scientific name and common name of species contained within the forage fish category. Compiled from Fishes of Alaska (Mecklenburg et al. 2002) (continued).

Scientific Name	**Common Name**
Family Stichaeidae	pricklebacks
Eumesogrammus praecisus	fourline snakeblenny
Stichaeus punctatus	arctic shanny
Gymnoclinus cristulatus	trident prickleback
Chirolophis tarsodes	matcheek warbonnet
Chirolophis nugatory	mosshead warbonnet
Chirolophis decoratus	decorated warbonnet
Chirolophis snyderi	bearded warbonnet
Bryozoichthys lysimus	nutcracker prickleback
Bryozoichthys majorius	pearly prickleback
Lumpenella longirostris	longsnout prickleback
Leptoclinus maculates	daubed shanny
Poroclinus rothrocki	whitebarred prickleback
Anisarchus medius	stout eelblenny
Lumpenus fabricii	slender eelblenny
Lumpenus sagitta	snake prickleback
Acantholumpenus mackayi	blackline prickleback
Opisthocentrus ocellatus	ocellated blenny
Alectridium aurantiacum	lesser prickleback
Alectrias alectrolophus	stone cockscomb
Anoplarchus purpurescens	high cockscomb
Anoplarchus insignis	slender cockscomb
Phytichthys chirus	ribbon prickleback
Xiphister mucosus	rock prickleback
Xiphister atropurpureus	black prickleback
Family Gonostomatidae	bristlemouths
Sigmops gracilis	slender fangjaw
Cyclothone alba	white bristlemouth
Cyclothone signata	showy bristlemouth
Cyclothone atraria	black bristlemouth
Cyclothone pseudopallida	phantom bristlemouth
Cyclothone pallida	tan bristlemouth
Order Euphausiacea	Krill

Table 16.2. Estimated forage fish catch (mt) from all Gulf of Alaska fisheries and areas, 1997-2005 (note: Data for 2005 are through Oct 4, 2005, as provided by FAKR).

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Eulachon							6	169.1	885.3
Capelin							18	68.0	2.8
All Smelts	23.1	122.7	26.1	123.8	534.8	156.4	377.4	303.7	1050.5
Sandfish	3.68	2.16	0.53	0.32	1.24	1.70			
Pricklebacks	0.29	0.03	3.53	0.49	4.66	0.13	0.49	0.11	2.20
Sandlance	0.02	0.01	0.06	0.35	0.04	0.04	0.00	0.01	0.00
Gunnel	0.11	0.03	0.03	0.00	0.00	0.00	0.01	0.00	0.00
Lanternfish	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.16
Total FFS	27.2	125.0	30.2	124.9	540.8	158.3	378.0	303.8	1052.8

Table 16.3. CPUE (in kg / km^2) and biomass estimates (mt) for capelin in Pavlof Bay.

Year	CPUE	Biomass
1972	23.264	1,597.7
1973	2.119	145.5
1974	20.867	1,433.1
1975	12.579	863.9
1976	12.167	835.6
1977	17.039	1,170.2
1978	0.701	48.2
1979	7.540	517.8
1980	15.399	1,057.6
1981	2.700	185.4
1982	0.078	5.4
1983	0.050	3.4
1984	0.008	0.5
1985	0.024	1.7
1986	0.169	11.6
1987	0.005	0.3
1988	0.022	1.5
1989	0.044	3.0
1990	0.040	2.7
1991	0.052	3.5
1992	0.003	0.2
1993	0.002	0.1
1994	0.004	0.3
1995	0.004	0.3
1996	0.000	0.0
1997	0.039	2.7
1998	0.019	1.3
1999	0.000	0.0
2000	0.000	0.0
2001	0.030	0.2
2002	0.000	0.0
2003	0.000	0.0
2004	0.069	4.7
2005	0.010	0.7

Table 16.4. Biomass estimates of forage fish species for the western, central and eastern GOA attained from the GOA groundfish survey.

Pacific sand lance

	Biomass (mt)		
Year	Western	Central	Eastern
1984	0	3	0
1987	2	13	0
1990	0	63	1
1993	0	2	0
1996	1	5	0
1999	1	8	2
2001	5	7	
2003	2	8	1
2005	1	32	0

Capelin

	Biomass (mt)		
Year	Western	Central	Eastern
1984	37	387	7
1987	5	38	8
1990	0	136	14
1993	2	46	76
1996	5	718	755
1999	34	102	106
2001	4	275	
2003	18	2,258	298
2005	2	428	586

Pacific sandfish

	Biomass (mt)		
Year	Western	Central	Eastern
1984	12	1,858	354
1987	28	558	529
1990	16	329	377
1993	69	155	296
1996	2	135	16
1999	9	22	542
2001	6	89	
2003	29	81	3,832
2005	0	383	75

Eulachon

	Biomass (mt)		
Year	Western	Central	Eastern
1984	38	4,767	2,300
1987	1,787	8,663	5,864
1990	453	19,043	8,493
1993	2,553	24,172	8,278
1996	1,444	26,470	4,334
1999	438	11,665	2,587
2001	2,867	49,061	
2003	1,610	95,014	16,882
2005	195	40,796	14,080

Pricklebacks

	Biomass (mt)		
Year	Western	Central	Eastern
1984	7	163	0
1987	0	9	5
1990	5	141	3
1993	23	180	1
1996	19	100	24
1999	2	187	28
2001	7	2,001	
2003	10	231	39
2005	8	221	1

Table 16.5. Estimated biomass, catch (mt) and exploitation rate for GOA capelin and eulachon.

Year	Species	Biomass	Catch	Exploitation rate
1999	Eulachon	11,665	25.0	0.2%
	Capelin	102	0.2	0.2%
2001	Eulachon	49,061	511.6	1.0%
	Capelin	275	2.9	1.0%
2003	Eulachon	95,014	18.1	0.0%
	Capelin	2,258	6.2	0.3%
2005	Eulachon	40,796	885.3	2.2%
	Capelin	428	3.0	0.7%

Table 16.6. Capelin abundance-at-length from the 2003 late spring/early summer echo integration-trawl survey of the Gulf of Alaska (provisional).

Length (cm)	Numbers (millions)	Biomass (thousands)
3	23	0.002
4	23	0.006
5	23	0.013
6	2,873	3.164
7	8,135	15.708
8	8,488	24.219
9	6,286	26.088
10	1,662	11.300
11	1,341	12.832
12	682	9.383
13	552	9.511
14	163	3.594
15	5	0.158
Total	30,256	115.979

Table 16.7. Comparison of length-weight regression parameters for capelin in the GOA.

Data Set / Published Study	n	log(alpha)	beta	r2
SE Alaska May 2002	68	-21.04	4.96	0.859
E of Kodiak Aug 2000	866	-13.22	3.31	0.878
E of Kodiak Aug 2001	409	-14.70	3.61	0.906
E of Kodiak Aug 2002	1240	-14.30	3.52	0.865
Wilson et al 2006 Chirikof Sep 00-01	330	-15.36	3.77	0.970
Brown 2002 PWS Apr-Sep 1989-1997		-17.73	4.23	0.985

Table 16.8. Role of federally-manage forage fishes in the diets of seabirds and marine mammals in the GOA. Diet composition based on the Ecopath model (Aydin et al in prep).

	Percentage of Modeled Diet for the GOA				
	Capelin	Sand lance	Eulachon	Other forage	Myctophids
Toothed Whales					
Killer whales (transient)	-	-	-	-	-
Killer whales (resident)	17.4	6.2	2.6	3.4	1.6
Porpoises	9.9	3.5	-	1.0	-
Sperm & beaked whales	-	-	-	-	-
Baleen Whales					
Fin whales	8.8	3.1	1.0	1.7	-
Humpbacks	17.4	6.1	2.6	3.3	-
Minke	25.8	9.1	3.9	6.0	-
Sei whales	4.6	1.6	-	-	-
Gray whales	-	-	-	-	-
Right whales	-	-	-	-	-
Pinnipeds					
Steller sea lions	0.9	-	4.2	2.1	-
Steller (juveniles)	>1.0	-	4.3	1.9	-
N Fur Seal	37.8	33.8	-	-	-
Resident seals	-	-	-	-	-
Sea Otters	6.3		-	-	-
Seabirds					
Kittiwakes	28.7	10.1	4.3	5.5	5.5
Fulmars	4.0	-	-	-	-
Murres	21.0	7.4	3.0	4.1	-
Puffins	40.2	14.2	6.1	10.7	-
Cormorants	19.7	49.9	3.0	4.8	1.8
Gulls	54.2	19.2	8.2	14.5	-
Auklets	3.3	-	-	-	-
Storm Petrels	2.4	-	-	-	-
Shearwaters	41.6	11.7	5.0	6.4	3.5
Albatross Jaeger	23.4	8.3	3.5	4.5	-

Figures

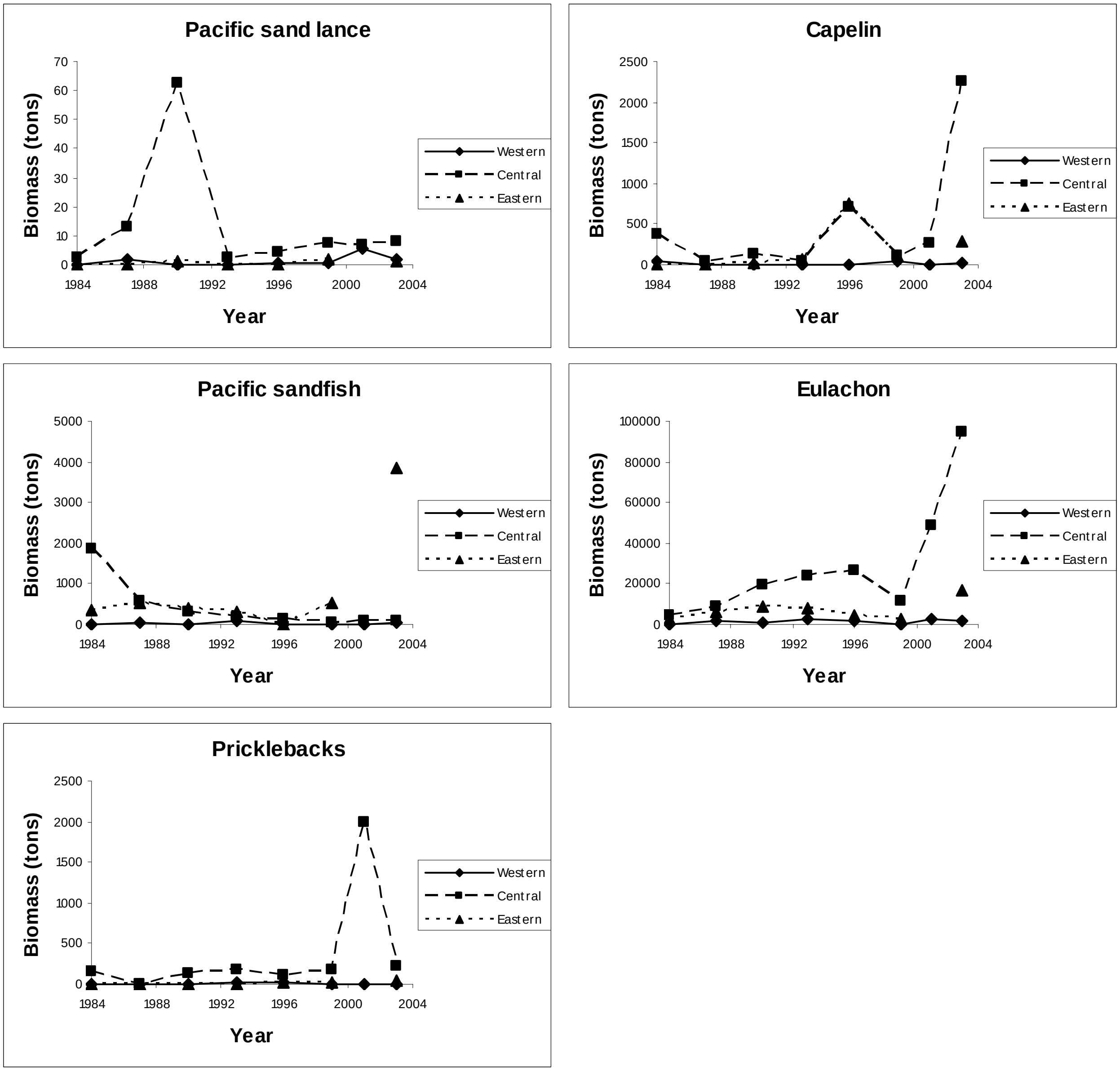

Figure 16.1. Biomass estimates of forage fish species for the western, central and eastern GOA attained from the GOA groundfish survey.

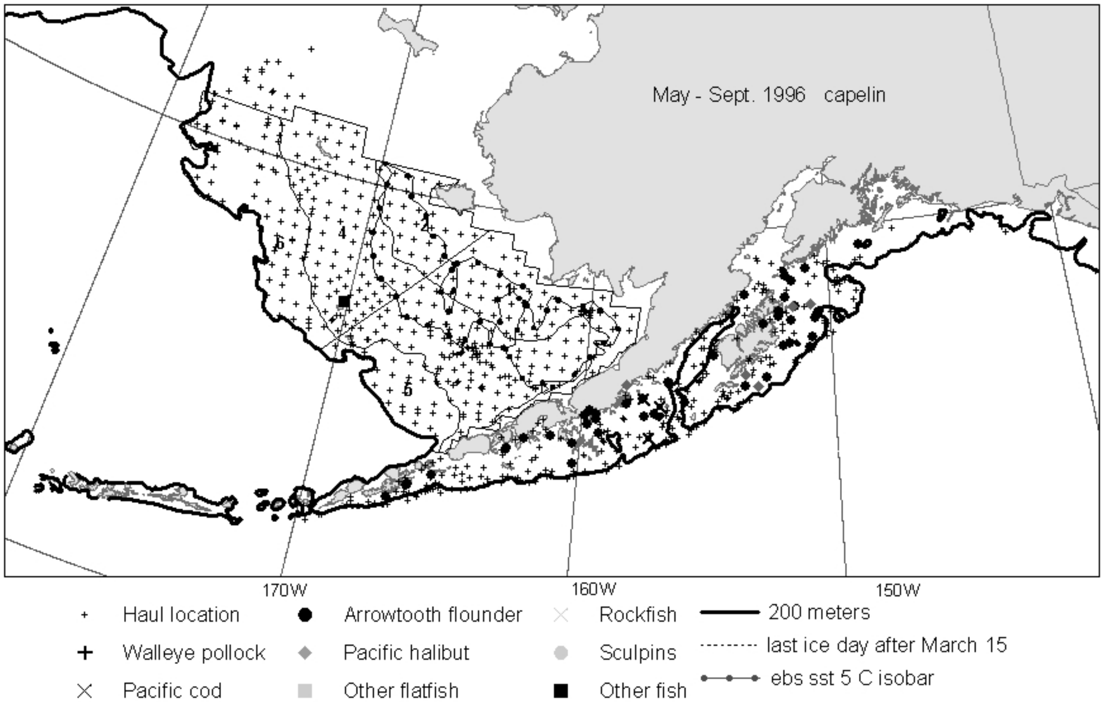

Figure 16.2. Geographic distribution of capelin consumed by groundfishes in 1996 (from Yang et al, 2005).

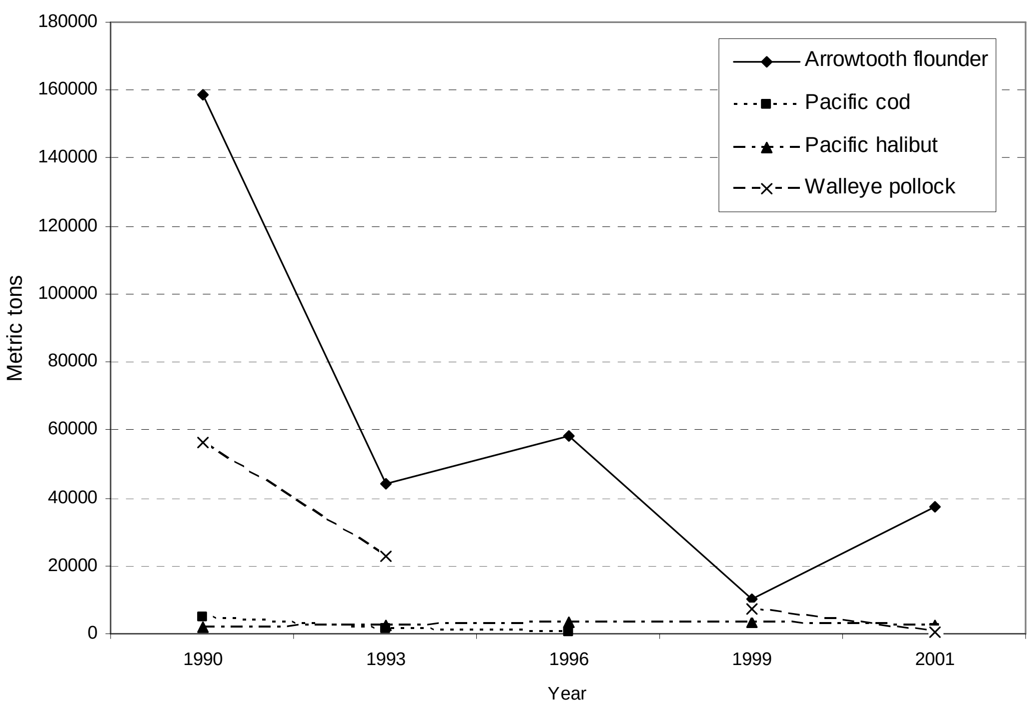

Figure 16.3. Yearly trend of population consumption of capelin by marine fish in the GOA (from Yang et al 2005).

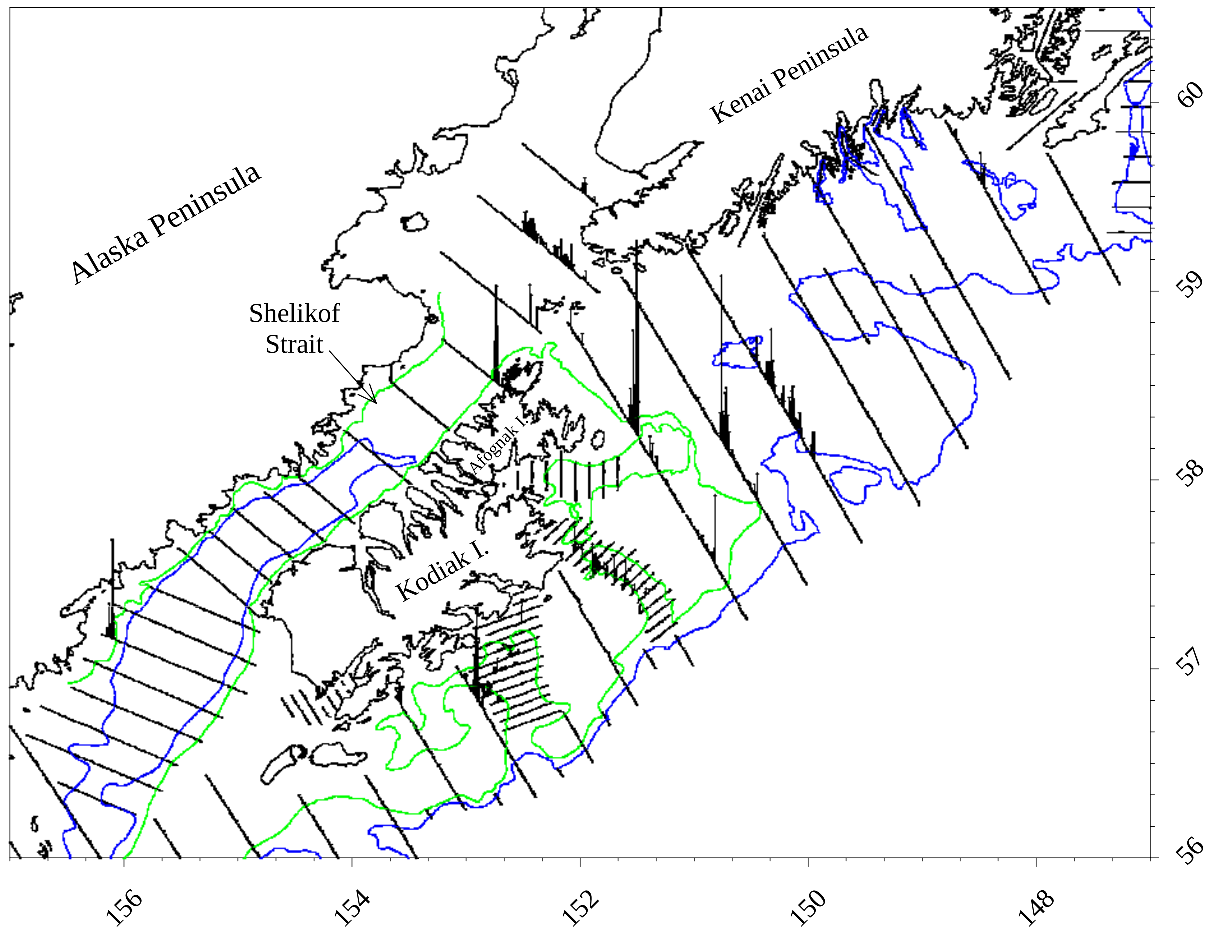

Figure 16.4. Capelin backscatter along transects from the 2003 summer EIT survey of the GOA.

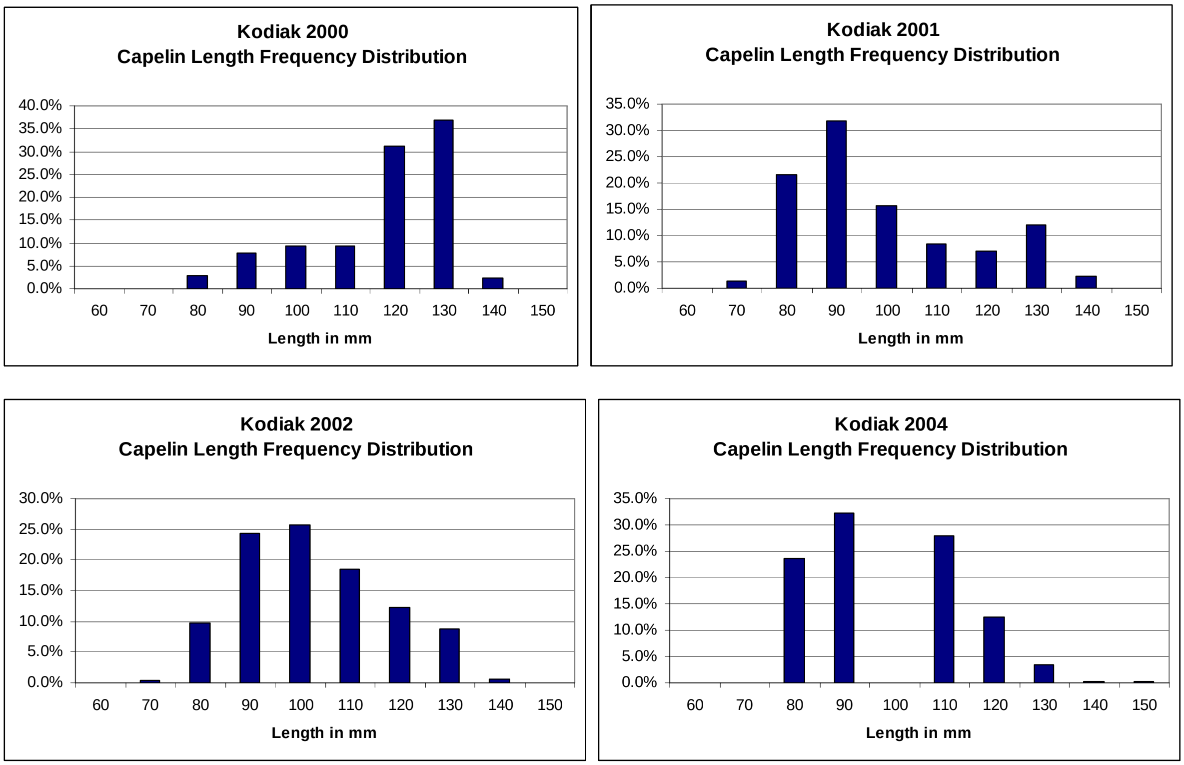

Figure 16.5. Length frequencies of capelin collected during FIT studies east of Kodiak in August 2000-2004.

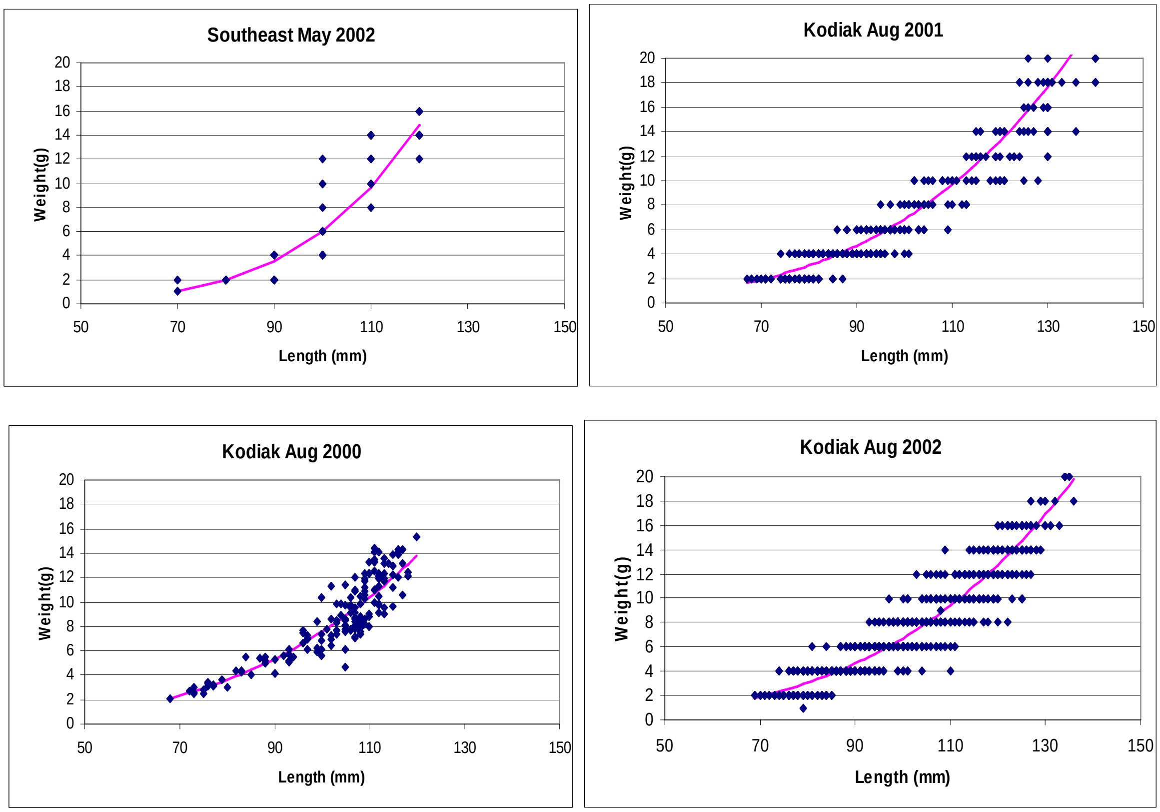

Figure 16.6. Length-weight regressions for capelin data.

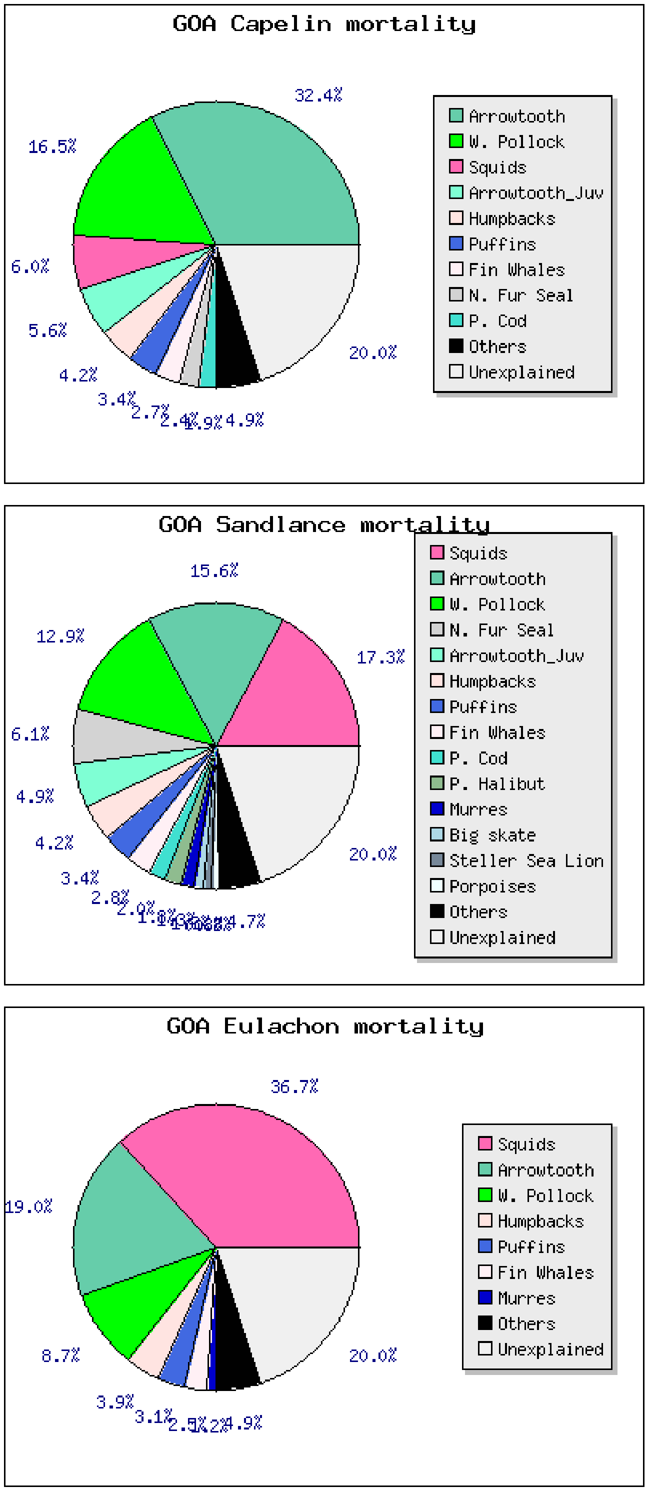

Figure 16.7. Estimates of total consumption of key forage fishes in the GOA, based on the Ecopath mass-balance model (Aydin et al, in prep).