17. Bering Sea and Aleutian Islands Squids

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Executive Summary

Summary of Major Changes

Because reliable biomass estimates do not exist for squids in the Bering Sea and Aleutian Islands (BSAI), harvest recommendations are made using Tier 6 criteria. Under Tier 6 Acceptable Biological Catch (ABC) and Overfishing Level (OFL) are calculated using catch data from 1978-1995, and as a result the harvest recommendations do not change from year to year. However, additional data and analyses are included to improve the understanding of squid biology and their interaction with fisheries. The following changes have been made for the 2009 assessment:

1) Updated catch data, including partial 2009 catch data. In addition, 2003-2008 data have been updated due to changes in the Catch Accounting System.
2) Added estimates of retention rates, 1997-2009
3) Added 2009 EBS shelf survey biomass estimates
4) Added length composition data for squids caught in commercial fisheries during 2008

Harvest recommendations

The recommended allowable biological catch (ABC) for squids in 2010 and 2011 is calculated as 0.75 multiplied by the average catch from 1978-1995, or 1,970 t; the recommended overfishing level (OFL) for squid in the years 2010-2011 is calculated as the average catch from 1978-1995, or 2,624 t.

2010-2011 Tier 6 harvest recommendations for BSAI squids	
2010-2011 ABC	1,970 t
2010-2011 OFL	2,624 t

Responses to SSC Comments

The SSC requests that the sections on Alternative Approaches, Data Gaps, and Ecosystem Effects include impacts of removals on seabirds as well as seabird predation on squid, including the endangered short-tailed albatross.

A brief discussion of the role of squid in seabird diets has been added to the ecosystem considerations section, as well as a figure (Fig. 14) showing seabird diet composition.

Introduction

Description, scientific names, and general distribution

Squids are marine molluscs in the class Cephalopoda (Group Decapodiformes). Squids are considered highly specialized and organized molluscs, with only a vestigial mollusc shell remaining as an internal plate (the pen or gladius). They are streamlined animals with ten appendages (2 tentacles, 8 arms) extending from the head, and lateral fins extending from the rear of the mantle (Figure 1). Squids are active predators which swim by jet propulsion, reaching swimming speeds up to 40 km/hr, the fastest of any aquatic invertebrate. Squids also hold the record for largest size of any invertebrate (Barnes 1987).

In the Bering Sea/Aleutian Islands regions there are at least 15 species of squid (Table 1). The most abundant species is *Berryteuthis magister* (magistrate armhook squid). Members of these 15 species come from six families in two orders and can be found from 10 m to greater than 1500 m. All but one, *Rossia pacifica* (North Pacific bobtail squid), are pelagic but *Berryteuthis magister* and *Gonatopsis borealis* (boreopacific armhook squid) are often found in close proximity to the bottom. The vertical distribution of these three species is the probable cause of their predominance in the BSAI bottom trawl surveys relative to other squid species (Table 2), although no squid species appear to be well-sampled by BSAI surveys. Most species are associated with the slope and basin, with the highest species diversity along the slope region of the Bering Sea between 200 – 1500 m. Since most of the data come from groundfish survey bottom trawls, the information on abundance and distribution of those species associated with the bottom is much more accurate than that of the pelagic species.

Family Chiroteuthidae

This family is represented by a single species, *Chiroteuthis calyx*. *Chiroteuthis calyx* is a pelagic, typically deep water squid that is known to mate in the Aleutian Islands region. Larvae are common off the west coast of the US.

Family Cranchiidae

There are two species of this family found in the Bering Sea and Aleutian Islands, *Belonella borealis* (formerly *Taonius pavo*) and *Galiteuthis phyllura*. Mated *Galiteuthis phyllura* are known from the Bering Sea slope region and their larvae are common in plankton samples. Mature adults and larvae of *Belonella borealis* have not been identified in the region.

Family Gonatidae

This is the most speciose family in the region, represented by nine species: *Berryteuthis anonychus*, *Berryteuthis magister*, *Eogonatus tinro*, *Gonatus berryi*, *Gonatus madokai*, *Gonatus middendorffi*, *Gonatus onyx*, *Gonatopsis borealis*, and *Gonatopsis* sp. All are pelagic however, *B. magister*, *G. borealis*, and *Gonatopsis* sp. live very near the bottom as adults. Larvae of all species except the unknown *Gonatopsis* have been found in the Bering Sea. *Gonatus onyx* is known to brood its eggs to hatching, however no evidence of that behavior exists for other members of the family. *B. magister* is known to form enormous spawning aggregations in the Bering Sea, and large schools of late juvenile stages of *B. magister* have been observed elsewhere in the North Pacific Ocean.

Family Onychoteuthidae

Immature adults of two species from this family have been observed in the BSAI: *Moroteuthis robusta* and *Onychoteuthis borealijaponicus*, the latter of which is only known from the Aleutian Islands region. *Moroteuthis robusta* is the largest squid in the region, reaching mantle lengths of three feet. Mature adults, eggs, and larvae of either species have not been collected from the Bering Sea or Aleutian Islands regions.

Family Sepiolidae
This family is represented by a single species, *Rossia pacifica*. This small animal is found throughout the Bering Sea and Aleutian Islands regions to 1000 m. Eggs are deposited on substrate in the summer months and larva are benthic. Adults are believed to live 18 – 24 months and females may lay egg masses more than once in life time. Mature and mated females are common in the summer along the Bering Sea slope.

Life history and stock structure (general)
The life histories of squids in this area are almost entirely unknown. Of all the species, only *Rossia pacifica* has benthic larvae and only members of the family Gonatidae and Cranchiidae are known to spawn in the Bering Sea region. All other species are likely migrating to the area to feed and possibly mate.

Life history information for BSAI squids can be inferred from data on squid species elsewhere. Relative to most groundfish, squids are highly productive, short-lived animals. They display rapid growth, patchy distribution and highly variable recruitment (O'Dor, 1998). Unlike most fish, squids may spend most of their life in a juvenile phase, maturing late in life, spawning once, and dying shortly thereafter. Whereas many groundfish populations (including skates and rockfish) maintain stable populations and genetic diversity over time with multiple year classes spawning repeatedly over a variety of annual environmental conditions, squids have no such “reserve” of biomass over time. Instead, it is hypothesized that squids maintain a “reserve” of biomass and genetic diversity in space. Many squid populations are composed of spatially segregated schools of similarly sized (and possibly related) individuals, which may migrate, forage, and spawn at different times of year over a wide geographic area (Lipinski 1998; O’Dor 1998). Most information on squids refers to *Illex* and *Loligo* species which support commercial fisheries in temperate and tropical waters. Of North Pacific squids, life history is best described for western Pacific stocks (Arkhipkin et al., 1995; Osako and Murata, 1983).

The most commercially important squid in the north Pacific is the magistrate armhook squid, *Berryteuthis magister*. This species is distributed from southern Japan throughout the Bering Sea, Aleutian Islands, and Gulf of Alaska to the U.S. west coast as far south as Oregon (Roper et al. 1984). The maximum size reported for *B. magister* is 28 cm mantle length. Prior to 2008, most of the information available regarding *B. magister* was from the western Bering Sea. A study completed in 2008 investigated life history and stock structure of this species in the EBS (Drobny 2008). In the EBS, *B. magister* appear to have an approximately 1-year life cycle. This is half the longevity of *B. magister* in the western Bering Sea (Arkhipkin et al., 1995). *B. magister* in the EBS appear to grow and mature more quickly than their conspecifics in Russian and Japanese waters. Squid growth appears to be heavily influenced by ocean temperature (Forsythe 2004), which may account for some of the regional and temporal variability.

Populations of *B. magister* and other squids are complex, being made up of multiple cohorts spawned throughout the year. *B. magister* are dispersed during summer months in the western Bering Sea, but form large, dense schools over the continental slope between September and October. Three seasonal cohorts are identified in the region: summer-hatched, fall-hatched, and winter-hatched. Growth, maturation, and mortality rates vary between seasonal cohorts, with each cohort using the same areas for different portions of the life cycle. For example, the summer-spawned cohort used the continental slope as a spawning ground only during the summer, while the fall-spawned cohort used the same area at the same time primarily as a feeding ground, and only secondarily as a spawning ground (Arkhipkin et al., 1995). In the EBS, hatch dates of varied by year but were generally in the first half of the year (Drobny 2008). Analysis of statolith chemistry suggested that adult squids were hatched in at least three different locations, and these locations were different from the capture locations. Juvenile and adult *B. magister* also appear to be separated vertically in the water column.

Timing and location of fishery interactions with squid spawning aggregations may affect both the squid population and availability of squid as prey for other animals (Caddy 1983, O'Dor 1998). The essential position of squid as a forage species within North Pacific pelagic ecosystems, the high productivity of the species, combined with the limited knowledge of the abundance, distribution, and biology of many squid species in the FMP areas, make squid a good candidate for management distinct from that applied to other species (as has been done for forage species in the BSAI and GOA). Because fishery interactions with squid happen in predictable locations (see below), squid may be a good candidate for management by a bycatch cap that once breached would result in spatial restriction of target fisheries, rather than target and limit reference points for the entire EBS.

Much more research is necessary to determine exactly which species and life stages are present seasonally in the BSAI and GOA. Currently, our bottom trawl surveys do not adequately sample any of the squid species in the BSAI. Therefore, we do not have adequate data to produce spatial distribution maps of squid. Maps of fishery bycatch of squid (unidentified) are included in this assessment.

Management Units

While squids are currently considered a nontarget species, in the BSAI they are managed separately from the Other Species complex. Catch of all squid species in aggregate is limited by a total allowable catch (TAC) which is based on the average catch of squid between 1978 and 1995 (Fritz 1999, Gaichas 2003). In 2005, 100% of the squid TAC was caught, and in 2006 the squid TAC was exceeded by 10% or 129 t.

Historically, the squid catch in the BSAI was problematic within the management of the Community Development Quota (CDQ) program. Because each CDQ group receives an allocation of groundfish which is 7.5% of the TAC set for each species, the groups were required to restrict squid catch to a low level, potentially constraining target fisheries (NMFS 2000). This is more an example of the difficulties with managing very small TACs than with managing squid in particular, because the squid TAC is one of the smallest TACs in the BSAI (50 CFR Part 679, February 18, 2000). The NPFMC approved BSAI FMP amendment 66 to remove squid from the CDQ program in June 1999, and this rule was made final in 2001 (66 FR 13762, March 7, 2001). Under this rule, the catch of squid within the CDQ program is still monitored, and still counts against overall BSAI squid TAC, but CDQ groups will not be restricted to 7.5% of the squid quota.

Fishery

Directed fishery

In the BSAI, squids are generally taken incidentally in target fisheries for pollock. Historically squid were targeted by foreign vessels (from Japan and Korea) in the BSAI, but directed squid fisheries in Alaskan waters at this time. Squids could potentially become targets of Alaskan fisheries, however. There are many fisheries directed at squid species worldwide, although most focus on temperate squids in the genera *Ilex* and *Loligo* (Agnew et al. 1998, Lipinski et al 1998). There are fisheries for *B. magister* in the western Pacific, including Russian trawl fisheries with annual catches of 30,000 - 60,000 metric tons (Arkhipkin et al., 1995), and coastal Japanese fisheries with catches of 5,000 to 9,000 t in the late 1970's-early 1980's (Roper et al. 1982, Osaka and Murata 1983). Therefore, monitoring of catch trends for species in the squid complex is important because markets for squids exist and fisheries might develop rapidly.

Bycatch and discards

Catch

Reported catches since 1977 are shown in Table 3. Squid species can be difficult to identify, and fishery observers in the BSAI currently record all incidentally-caught squid as "Squid unidentified". After reaching 9,000 mt in 1978, total squid catches steadily declined to only a few hundred tons in 1987-1995. Since 2000, squid catches have fluctuated around an average of approximately 1,000 t, with anomalously high catches in some years. The 2001 estimated catch of squid, 1,761 t (Table 3), was the highest in the past ten years and high catches also occurred in 2002 and 2006. The 2008 catch was 1,459 t, the highest since 2001. As of October, the 2009 catch was relatively low at 262 t (Table 3). Retention rates of squid by BSAI groundfish fisheries have ranged between 12% and 84% from 1997-2009, with higher retention observed in recent years.

Catch size composition
In 2007, fishery observers began collecting data on the mantle length of squids captured in BSAI pollock fisheries. The 2007 data reveal two size modes of incidentally-caught squids, at approximately 13 and 21 cm, respectively (Figure 2). The two modes were visible in the 1st, 3rd, and 4th quarters of the year. In the 1st and 3rd quarters, the 21 cm mode was largest, while the 13 cm mode was largest in the 4th quarter. The length composition of squids caught during the 2nd quarter had a single mode at approximately 18 cm. The catch length composition in 2008 was similar (Figure 2), except that in the 1st quarter the largest size mode was at 13 cm. These patterns may be due to the species composition of the catch. The mean mantle length of *B. magister* caught during the 2008 AFSC slope survey was 21.2 cm (Table 4), and the mean mantle length of *Gonatopsis borealis* in the same survey was 13.7 cm (Table 4). Thus, the observed size composition may result from a mix of these two species. Alternatively, the different size modes and the variability among quarters may reflect the multiple yearly cohorts that are likely to occur in BSAI squid populations (Figure 2).

Catch distribution
Most squid are caught incidentally in the midwater trawl pollock fishery (Table 5), primarily over the shelf break and slope or in deep waters of the Aleutian Basin (subareas 515, 517, 519, 521 and 522; Table 6). Prior to 1997, catch in the Aleutian Islands statistical areas (541-543) contributed a measurable portion of the total squid catch (Table 6 and Figure 3). Since then, the observed squid catch has been almost exclusively from areas 517 and 519 (Table 6 and Figure 3). Some of this redistribution could be due to changes in observer coverage over time, but because the primary fisheries in these areas have high levels of observer coverage, this redistribution could also reflect changing fishing patterns and / or changes in squid distributions.

In the EBS, the distribution of squid catch appears to have remained fairly constant over time. From 1997-1999, squid catches were highly associated with the major canyons along the EBS slope (Figure 4). This result is supported by a more recent analysis of squid catch from 2000 to 2007 (Figure 5). While squids were caught throughout the EBS slope and outer domain of the EBS shelf, the highest catches consistently occurred near the major canyons. Bering Canyon, the southernmost, appears to have the highest catches. Large mean catches were also associated with Pribilof Canyon, and particularly the southern part of this canyon. In some years large catches also occurred in Zhemchug Canyon.

Overlaying some of the older catch and survey data suggests that *B. magister* is likely to be present in at least some fishery catches of squid (Figure 6). As is the case for most non-target species, identification of squids on past surveys has not been consistent and records labeled as “other squid” may or may not also represent *B. magister*.

Data

Fishery catch
The predominant species of squid in commercial catches in the EBS is believed to be the magistrate armhook squid, *B. magister*. *Onychoteuthis borealijaponicus*, the boreal clubhook squid, is likely the principal species encountered in the Aleutian Islands region. Because observers are not trained to identify individual species of squids, the majority (99%) of squid catch is reported as “squid unidentified”; the remainder is identified as *Moroteuthis* spp, or “giant squid unidentified”. Catch data from 1999-2009 are presented by target fishery (Table 4) and NMFS statistical area (Table 5). We assume complete mortality

of incidentally caught squids because squids are fragile and are almost certainly all killed in the process of being caught, regardless of gear type or depth of fishing.

Survey biomass in aggregate and by species

The AFSC bottom trawl surveys are directed at groundfish species, and therefore do not employ the appropriate gear or sample in the appropriate places to provide reliable biomass estimates for the generally pelagic squids. Squid records from these surveys tend to appear at the edges of the continental shelf, which is at the margin of the sampling strata defined for these surveys. This is consistent with results from 1988 and 1989 Japanese / U.S. pelagic trawl research surveys in the EBS that indicated that the majority of squid biomass is distributed in pelagic waters off the continental shelf (Sinclair et al. 1999), beyond the current scope of the AFSC surveys. We have included survey information in this assessment for general information only (Table 2), and the survey biomass estimates cannot be considered reliable measures of squid abundance. In 2008, *Rossia pacifica* was the only squid species observed in the EBS shelf survey (Table 2). The 2008 EBS slope survey, which samples the shelf break area and generally catches greater numbers of squids, caught seven identifiable squid species. *B. magister*, *G. borealis*, and *R. pacifica* were the most common squids in the slope survey. Catch rates of *B. magister* and *G. borealis* were highest in stratum 1 (Bering Canyon; Table 7 and Figure 7). *R. pacifica* were more most common in strata 5 & 6 (Table 7 and Figure 7). Size compositions for *B. magister*, corrected for differences in catch rates by stratum, are in Fig. 8. Uncorrected size compositions for *G. borealis* and *R. pacifica* are in Fig. 9.

Analytic Approach and Results

The available data do not support population modeling for squids in the BSAI, so most of the stock assessment sections are not relevant.

Harvest recommendations

Squids in the BSAI are currently managed under Tier 6, meaning that ABC and OFL are based on average commercial fishery catch between 1978 and 1995:

20010-2011 Tier 6 harvest recommendations for BSAI squids	
average catch 1978-1995	2,624 t
ABC (0.75 * avg. catch)	1,970 t
OFL (avg. catch)	2,624 t

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Alternative approaches

Tier 6 is problematic for BSAI squids because average catch is likely not indicative of the productivity of a lightly fished stock, and is a suboptimal tool for setting harvest policy. The traditional alternative to an average-catch based TAC is one based on biomass. For species in the squid complex we do not have a reliable estimate of biomass and therefore lack the information required to set a biologically derived TAC. Below, we briefly investigate problems associated with obtaining a biomass estimate for squids and discuss whether a biologically-derived TAC based on biomass or a traditional stock assessment would ever be a cost effective management tool. Then, we suggest alternative management measures which may be more appropriate to an ecologically important species with a spatially and temporally complex life history pattern.

In theory, a squid survey could be conducted with midwater trawls and/or hydroacoustics. We have such a survey for pollock, but the existing survey would need to extend out across shelf break, at least, which would greatly expand the scope of the current survey. There is currently some interest in developing a mesopelagic trawl survey index which might begin this process. In addition, researchers at the University of Washington (UW) are exploring the utility of hydroacoustics for surveying squids (J. Horne, UW, pers. comm.). Potential surveys for squids would be complicated by large seasonal changes in squid abundance and distribution. Squid appear in the catch data during all pollock seasons in the areas around the shelf break. According to fishery information from 1997-1999, a peak in squid CPUE occurs in January, but it is also all in one location (Pribilof canyon), so it is difficult to tell if the high CPUEs are seasonally or spatially related. The available data suggest that a formal assessment of squids would require a survey conducted over multiple seasons to fully assess the biomass available in a given year, as well as extensive information on squid life history and movement patterns as well as a sophisticated population model. Lacking this information, a survey to provide the biomass estimates necessary for squid TAC setting (i.e. through Tier 5) would require extensive spatial and temporal coverage that might be prohibitively expensive, especially considering that there is no target fishery for squids in the FMP areas at this time.

The complex population dynamics and rapid turnover that are characteristic of squid populations suggest that the temporal and spatial scales for assessment of squids are different from the annual and basin-wide scales we apply to most groundfish. Therefore, even if we had a reliable estimate of biomass, we would have to understand the relative composition of cohorts and their movements and different mortality rates in order to apply TAC management effectively. If we used a previous year's biomass estimate to set a TAC for the following year for squids (as we do for groundfish target species), it is possible that this TAC would be too high or low relative to the current year's biomass due to the great interannual variability of squid stocks (Caddy 1983). To avoid this problem, biomass would have to be estimated for a given species and TAC set and taken within a very short time period, potentially less than one year. Even this intensive management scenario would leave open the possibility that an entire seasonal cohort could be eliminated by fishing unless additional temporal or spatial management measures ensured that fishing pressure was distributed between cohorts.

Effort controls (i.e. time or area closures) may be more effective tools for squid management (Caddy 1983, O'Dor 1998). The observation that the majority of squid catches occur in a few clearly defined areas supports the consideration of such approaches. We have identified potential squid management areas based on areas with recurring high catches of squids (Figures 4-6). Management within these areas could be applied only to pelagic trawl gear in the Bering Sea (almost exclusively the pollock fishery). Year-round closures in these areas would be the most conservative measure, providing protection to all cohorts of each species that potentially occupies the area and minimizing incidental catches of squids overall, but a range of monitoring and management options are available. For example, a better understanding of seasonal squid movements could allow us to close areas only when high numbers of squids are likely to be present. Alternatively, temporary area closures may be an effective management tool for squids. In 2006, the pollock fleet voluntarily prohibited fishing by their members in areas of high squid catches on a temporary basis, which helped to reduce the amount by which the 2006 TAC was exceeded. Determining a threshold catch level that would close an area would still require some knowledge of squid abundance and life history. Given that squid populations do not appear threatened by the current level of fishing mortality, a different management priority may be to maximize prey availability during certain seasons for protected resources. Monitoring and management of squid catch could be focused on pinniped foraging areas (see below).

Ecosystem Considerations

Fishery management should attempt to prevent negative impacts on squid populations not only because of their potential fishery value, but because of the crucial role they play in marine ecosystems. Squid are important components in the diets of many seabirds, fish, and marine mammals, as well as voracious predators themselves on zooplankton and larval fish (Caddy 1983, Sinclair et al. 1999). The prey and predators of squids depend on their life stage. Adult squid of many species will actively prey upon fish, squid, and crustaceans, while the larvae likely share the same prey items as larval fish, including copepods, euphausiids, and larval fish. Adult squid will be preyed upon by marine mammals, fish, and other squid, whereas, larval and juvenile squids will be taken by fish, squid, and seabirds.

Squids are central in food webs in both the AI (Figure 10, upper panel) and the EBS (Figure 10, lower panel). These food webs were derived from mass balance ecosystem models assembling information on the food habits, biomass, productivity and consumption for all major living components in each system. The EBS and AI are physically very different ecosystems, especially when viewed with respect to available squid habitat and densities. While direct biomass estimates are unavailable for squids, ecosystem models can be used to estimate squid densities based upon the food habits and consumption rates of predators of squid. The AI has much more of its continental shelf area in close proximity to open oceanic environments where squid are found in dense aggregations, hence the squid density as estimated by predator demand in each system is much greater in the AI relative to the EBS (labeled “BS” in the figures) and GOA (Figure 11, upper panel).

In contrast with predation mortality, estimated fishing mortality on squid is currently very similarly low in all three ecosystems. Figure 11 (lower panel) demonstrates the estimated proportions of total squid mortality attributable to fishing vs. predation, according to food web models built based on early 1990’s information from the AI, EBS, and the GOA for comparison. Fishing mortality is so low relative to predation mortality that it is not visible in the plot, suggesting that current levels of overall fishery bycatch may be insignificant relative to predation mortality on squid populations. While estimates of squid consumption are considered uncertain, the ecosystem models incorporate uncertainty in partitioning estimated consumption of squid between their major predators in each system. The predators with the highest overall consumption of squid in the AI are Atka mackerel, which consume between 100 and 700 thousand metric tons of squid annually in that ecosystem, followed by “other large demersal species” (mostly grenadiers), which consume a similar range of squid annually (Figure 12, upper panel). In the EBS, estimated consumption of squid is dominated by “other large demersal species” (grenadiers) taking in the range of 200,000 to over a million metric tons annually, followed by pinnipeds which consume up to 500,000 tons annually (Figure 12, lower panel). Squid make up about 10% of the diet of AI Atka mackerel, 30% of the diet of EBS fur seals (both adults and juveniles), and between 45 and 50% of the diet of grenadiers in both systems (Figure 13). In addition, squids are important constituents of seabird diets (Figure 14). The input data for the AFSC ecosystem models suggests that squids make up nearly half the diet of fulmars, storm petrels, and the albatross/jaegers group (Figure 8; Aydin et al. 2007). These input data are largely based on diet composition and preference data reported by Hunt et al. (2000).

Diets of squids are poorly studied, but currently believed to be largely dominated by euphausiids, copepods and other pelagic zooplankton in the AI and EBS. Assuming these diets are assessed correctly, squids are estimated to consume on the order of one to five million metric tons of these zooplankton species in both systems annually. Squids are also reported to consume forage fish as a small portion of their diet, which could amount to as much as one million metric tons annually in the AI and EBS ecosystems. While there is much uncertainty surrounding the quantitative ecological interactions of squids, as is apparent in the wide ranges of these estimates from food web models, it is clear that squids are intimately connected with both very low trophic level processes affecting secondary production of zooplankton, and in turn they comprise a significant portion of the diet of both commercially important (Atka mackerel) and protected species (pinnipeds) in the AI and EBS.

While overall fishing removals of squid are very low relative to predation at the ecosystem scale, local-scale patterns of squid removals should still be monitored to ensure that fishing operations do not have significant impacts on squid and their predators. Many squid populations are composed of spatially segregated schools of similarly sized (and possibly related) individuals, which may migrate, forage, and spawn at different times of year (Lipinski, 1998). The timing and location of fishery interactions with squid spawning aggregations may affect the availability of squid as prey for other animals as well as the age, size, and genetic structure of the squid populations themselves (Caddy 1983, O'Dor 1998). Monitoring these fishery interactions with squid could be especially important within the foraging areas for the currently declining Northern fur seals, which rely on squids for a significant portion of their diets. The essential position of squids within North Pacific pelagic ecosystems combined with our limited knowledge of the abundance, distribution, and biology of squid species in the FMP areas make squids a good case study to illustrate management of an important nontarget species complex with little information.

Data gaps and research priorities

Clearly, there is little information for stock assessment of the squid complex in the BSAI. However, ecosystem models estimate that the proportion of squid mortality attributable to incidental catch in groundfish fisheries in the BSAI region is extremely small relative to that attributable to predation mortality. Therefore, improving the information available for squid stock assessment seems a low priority as long as the catch remains at its current low level.

However, investigating potential impacts of incidental removal of squids on foraging by protected species of concern (pinnipeds, specifically northern fur seals) seems a higher priority for research. Limited data suggest that squids may make up nearly a third of the diet (by weight) for northern fur seals in the EBS. Research should investigate whether the location and timing of incidental squid removals potentially overlap with foraging seasons and areas for northern fur seals (for example, as described in Robeson 2000), and whether the magnitude of squid catch at these key areas and times is sufficient to limit the forage available for these pinnipeds. This research would require a local estimate of squid abundance but would not require a full BSAI population assessment.

Ecosystem Effects on Stock and Fishery Effects on the Ecosystem: Summary

In the following table, we summarize ecosystem considerations for BSAI squids and the entire groundfish fishery where they are caught incidentally. The observation column represents the best attempt to summarize the past, present, and foreseeable future trends. The interpretation column provides details on how ecosystem trends might affect the stock (ecosystem effects on the stock) or how the fishery trend affects the ecosystem (fishery effects on the ecosystem). The evaluation column indicates whether the trend is of: *no concern, probably no concern, possible concern, definite concern,* or *unknown.*

Ecosystem effects on BSAI Squids ***(evaluating level of concern for squid populations)***

Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton Forage fish	Trends are not currently measured directly, only short time series of food habits data exist for potential retrospective measurement	Unknown	Unknown
Predator population trends			
Pinnipeds	Fur seals declining, Steller sea lions level	Possibly lower mortality on squids	No concern
Atka mackerel (AI)	Cyclically varying population with slight upward trend overall 1977-2005	Variable mortality on squids slightly increasing over time	Probably no concern
Grenadiers (BSAI)	Unknown population trend	Unknown	Unknown
Changes in habitat quality			
North Pacific gyre	Physical habitat requirements for squids are unknown, but are likely linked to pelagic conditions and currents throughout the North Pacific at multiple scales.	Unknown	Unknown

Groundfish fishery effects on ecosystem via squid bycatch ***(evaluating level of concern for ecosystem)***

Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Squid catch	Stable, generally <2000 tons annually	Extremely small relative to predation on squids	No concern
Forage availability for Atka mackerel (AI)	Minor pollock fisheries in AI so very little squid catch in Atka mackerel foraging areas	Little change in forage for Atka mackerel	Probably no concern
Forage availability for grenadiers (BSAI)	Squid catch overlaps somewhat with grenadier foraging areas along slope	Small change in forage for grenadiers	Probably no concern
Forage availability for pinnipeds (EBS)	Depends on magnitude of squid catch taken in pinniped foraging areas, most catch in fur seal foraging area at shelf break by Pribilofs	Mixed potential impact (fur seals vs Steller sea lions)	Possible concern
Fishery concentration in space and time	Bycatch of squid is mostly in shelf break and canyon areas, no matter what the overall distribution of the pollock fishery is	Potential impact to spatially segregated squid cohorts and squid predators	Possible concern
Fishery effects on amount of large size target fish	Effects of squid bycatch on squid size are not measured	Unknown	Unknown
Fishery contribution to discards and offal production	Squid discard an extremely small proportion of overall discard and offal in groundfish fisheries	Addition of squid to overall discard and offal is minor	No concern
Fishery effects on age-at-maturity and fecundity	Effects of squid bycatch on squid or predator life history are not measured	Unknown	Unknown

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Tables and figures

Table 1. Taxonomic grouping of squid species found in the BSAI.

Class Cephalopoda; Order Oegopsida	
Family Chiroteuthidae	
Chiroteuthis calyx	
Family Cranchiidae	"glass squids"
Belonella borealis	
Galiteuthis phyllura	
Family Gonatidae	"armhook squids"
Berryteuthis anonychus	minimal armhook squid
Berryteuthis magister	magistrate armhook squid
Eogonatus tinro	
Gonatopsis borealis	boreopacific armhook squid
Gonatus berryi	Berry armhook squid
Gonatus madokai	
Gonatus middendorffi	
Gonatus onyx	clawed armhook squid
Family Onychoteuthidae	"hooked squids"
Moroteuthis robusta	robust clubhook squid
Onychoteuthis borealijaponicus	boreal clubhook squid
Class Cephalopoda; Order Sepioidea	
Rossia pacifica	North Pacific bobtail squid

Table 2. Survey biomass estimates (t) for the EBS shelf, EBS slope, and AI. Biomass is shown for all squids and for the principal species caught in each survey.

	EBS shelf			EBS slope				AI
year	all squids	*R. pacifica*	*B. Magister*	all squids	*R. pacifica*	*B. Magister*	*G. borealis*	*B. Magister*
1982	127							
1983	94	94						9,571
1984	99	57	14					
1985	65	4	13					
1986	66	32						15,762
1987	39	39						
1988	101	97						
1989	639	3						
1990	5,751	5,680						
1991	12							28,934
1992	26							
1993	32							
1994	8							11,083
1995	14	6						
1996	6							
1997	1,297	3						2,677
1998	68	60						
1999	86	19						
2000	392	13	45					2,759
2001	313	20	280					
2002	33	33		1,270	52	1,198	2	2,087
2003	46	27	16					
2004	20	6		1,642	58	1,418	52	3,250
2005	14	13						
2006	56	9	47					1,467
2007	11	11						
2008	8	8		1,826	36	1,717	54	
2009	642	19	623					

Table 3. Estimated total (retained and discarded) catches of squid (t) in the eastern Bering Sea and Aleutian Islands by groundfish fisheries, 1977-2009, and estimated retention rates. JV=Joint ventures between domestic catcher boats and foreign processors.

	Eastern Bering Sea				Aleutian Islands				BSAI	%
Year	foreign	JV	domestic	total EBS	foreign	JV	domestic	total AI	total	retained
1977	4,926			4,926	1,808			1,808	6,734	
1978	6,886			6,886	2,085			2,085	8,971	
1979	4,286			4,286	2,252			2,252	6,538	
1980	4,040			4,040	2,332			2,332	6,372	
1981	4,178	4		4,182	1,763			1,763	5,945	
1982	3,833	5		3,838	1,201			1,201	5,039	
1983	3,461	9		3,470	509	1		510	3,980	
1984	2,797	27		2,824	336	7		343	3,167	
1985	1,583	28		1,611	5	4		9	1,620	
1986	829	19		848	1	19		20	868	
1987	96	12	1	109		23	1	24	131	
1988		168	246	414		3		3	417	
1989		106	194	300		1	5	6	306	
1990			532	532			94	94	626	
1991			544	544			88	88	632	
1992			819	819			61	61	880	
1993			611	611			72	72	683	
1994			517	517			87	87	604	
1995			364	364			95	95	459	
1996			1,083	1,083			84	84	1,167	
1997			1,403	1,403			71	71	1,474	51%
1998			891	891			25	25	915	50%
1999			432	432			9	9	441	51%
2000			375	375			8	8	384	12%
2001			1,761	1,761			5	5	1,766	45%
2002			1,334	1,334			10	10	1,344	60%
2003			1,171	1,171			36	36	1,206	55%
2004			879	879			14	14	893	48%
2005			1,086	1,086			17	17	1,103	76%
2006			1,389	1,389			15	15	1,404	79%
2007			1,171	1,171			13	13	1,184	75%
2008			1,459	1,459			49	49	1,508	84%
2009*			262*	262*			81*	81*	343*	51%+

* 2009 catch as reported through October 7, 2009.
+ based on partial 2009 fishery observer data

Data Sources: Foreign and JV catches-U.S. Foreign Fisheries Observer Program, AFSC Domestic catches before 1989 (retained only; do not include discards): Pacific Fishery Information Network (PacFIN). Domestic catches 1989-2002: NMFS Alaska Regional Office BLEND. Domestic catches 2003-present: NMFS AKRO Catch Accounting System. Retention rate estimates are from fishery observer data obtained from the AFSC Fishery Monitoring and Analysis program.

Table 4. Mean lengths (cm) for squid species and species groups caught during the 2008 EBS slope survey conducted by the AFSC. SE = standard error, N = sample size. Mean length for *B. magister* was calculated from extrapolated numbers based on length composition data, so no SE was calculated. Exact N for the *B. magister* data is unknown but is in excess of 1,000 individual measurements.

species	mean	SE	N
Gonatus pyros	6.0		1
Rossia pacifica	6.6	0.3	25
Gonatus onyx	8.0		1
Gonatopsis borealis	13.7	0.2	122
Gonatus berryi	19.0	7.0	3
Berryteuthis magister	21.2	N/A	N/A
Chiroteuthis calyx	25.0		2
Gonatus sp.	21.0	6.0	2
Gonatidae unidentified	4.5	2.5	2
squid unidentified	6.2	0.3	10

Table 5. Estimated catch (t) of all squid species combined by target fishery, 1999-2009. Data sources as in Table 3.

Target fishery	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009***
arrowtooth	3	3	7	11	7	6	10	4	3	46	93
Atka mackerel	5	3	3	7	21	7	9	9	6	12	11
flathead sole	2	9	10	5	0.2	4	1	0.2	0.2	0	0
Gr. turbot	0	>1	0	1	3	6	0.5	0	0	4	23
other flatfish	5	2	>1	1	3	2	6	0	2	1	0
other target	0	0	0	0	0	0.1	0	0	0	0	0
Pacific cod	0	0	0	5	8	5.3	2.5	1	.2	0	0
rock sole	0	0	1	>1	0.02	0.3	0.03	0	.4	0	0
rockfish	6	6	2	9	12	6	7	6	8	25	13
sablefish	0	0	0	0	0	0.1	0.1	0.01	0.1	1	0
yellowfin sole	>1	>1	>1	>1	1	0	0.01	0	0	0	0
pollock	475	379	1,776	1,702	1,151	855	1,066	1,384	1,165	1,418	203
BSAI total	**500**	**413**	**1,807**	**1,742**	**1,206**	**893**	**1,103**	**1,404**	**1,184**	**1,508**	**343***

* 2009 catch estimate as of October 7, 2009.

Table 6. Estimated catch (t) of all squid species combined by area, 2002-2009. Data sources as in Table 3.

FMP area	area	2002	2003	2004	2005	2006	2007	2008	2009*
AI	541	6	9	4	3	2	2	25	63
	542	5	10	7	2	6	3	6	4
	543	5	17	3	12	7	8	18	14
AI Total		**16**	**36**	**14**	**17**	**15**	**13**	**49**	**81***
EBS	509	1	2	7	5	162	13	25	1
	513	2	2	2	0	1	12	9	2
	516		0	0	0	0	0	0	0
	517	1,083	719	555	502	952	687	1,034	143
	518		0	0	0	0	0	23	39
	519	638	436	309	482	260	418	342	67
	521	2	12	5	95	15	26	25	9
	523	>1	0	0	2	0	0	1	0
	524	0	0	0	0	0	15	0	0
EBS Total		**1,726**	**1,171**	**879**	**1,087**	**1,389**	**1,171**	**1,459**	**262***
BSAI Total		**1,742**	**1,206**	**893**	**1,103**	**1,404**	**1,184**	**1,508**	**343***
BSAI ABC		1,970	1,970	1,970	1,970	1,970	1,970	1,970	1,970
BSAI TAC		1,970	1,970	1,275	1,275	1,275	1,970	1,970	1,970

*2009 catch estimate as of October 7, 2009.

Table 7. 2008 slope survey biomass estimates by stratum for three species of squids.

	biomass estimate (t)		
stratum	*B. magister*	*R. pacifica*	*G. borealis*
1	1,204.6	2.8	50.3
2	260.4	2.7	0.9
3	28.7	3.3	0.4
4	87.0	0.0	0.6
5	26.3	15.5	0.3
6	109.7	12.1	1.4

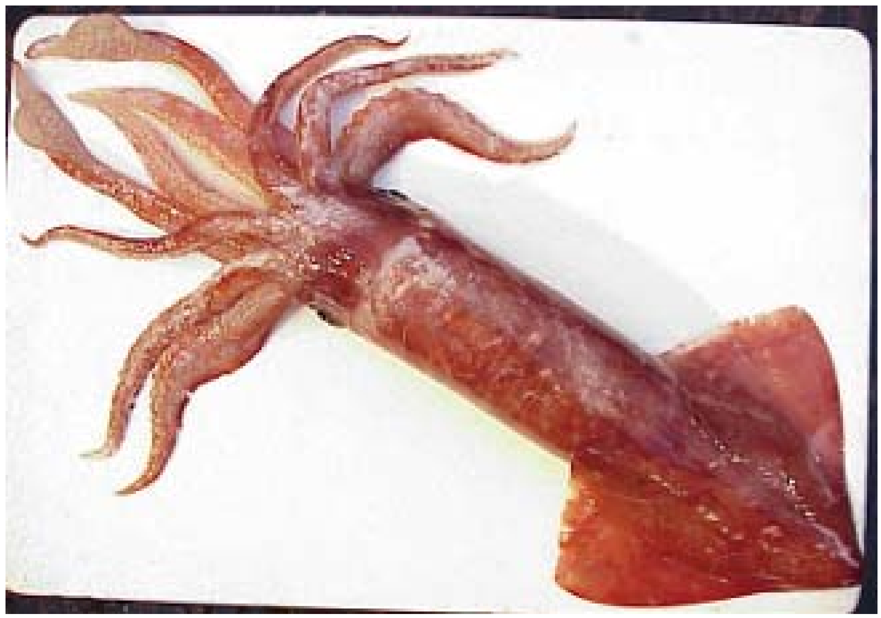


Figure 1. *Berryteuthis magister*, the magistrate armhook or red squid, is a common species in the BSAI and shows the general physical characteristics of species in the Order Teuthoidea.

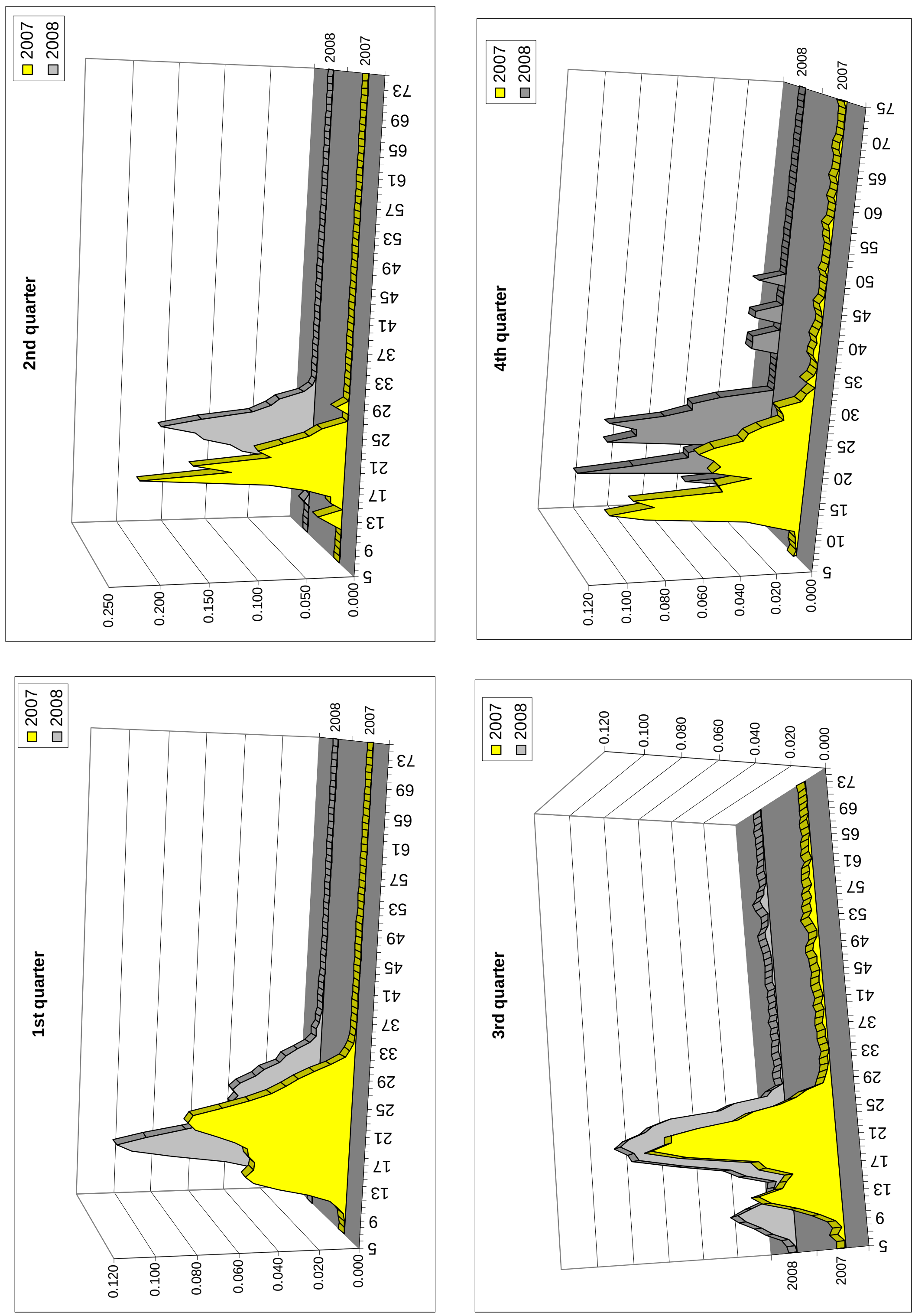


Figure 2. Length compositions from the 2007 and 2008 commercial fisheries in the BSAI. Composition are shown by quarter of the year: 1 = January-March, 2 = April-June, 3 = July-September, 4 = October- December.

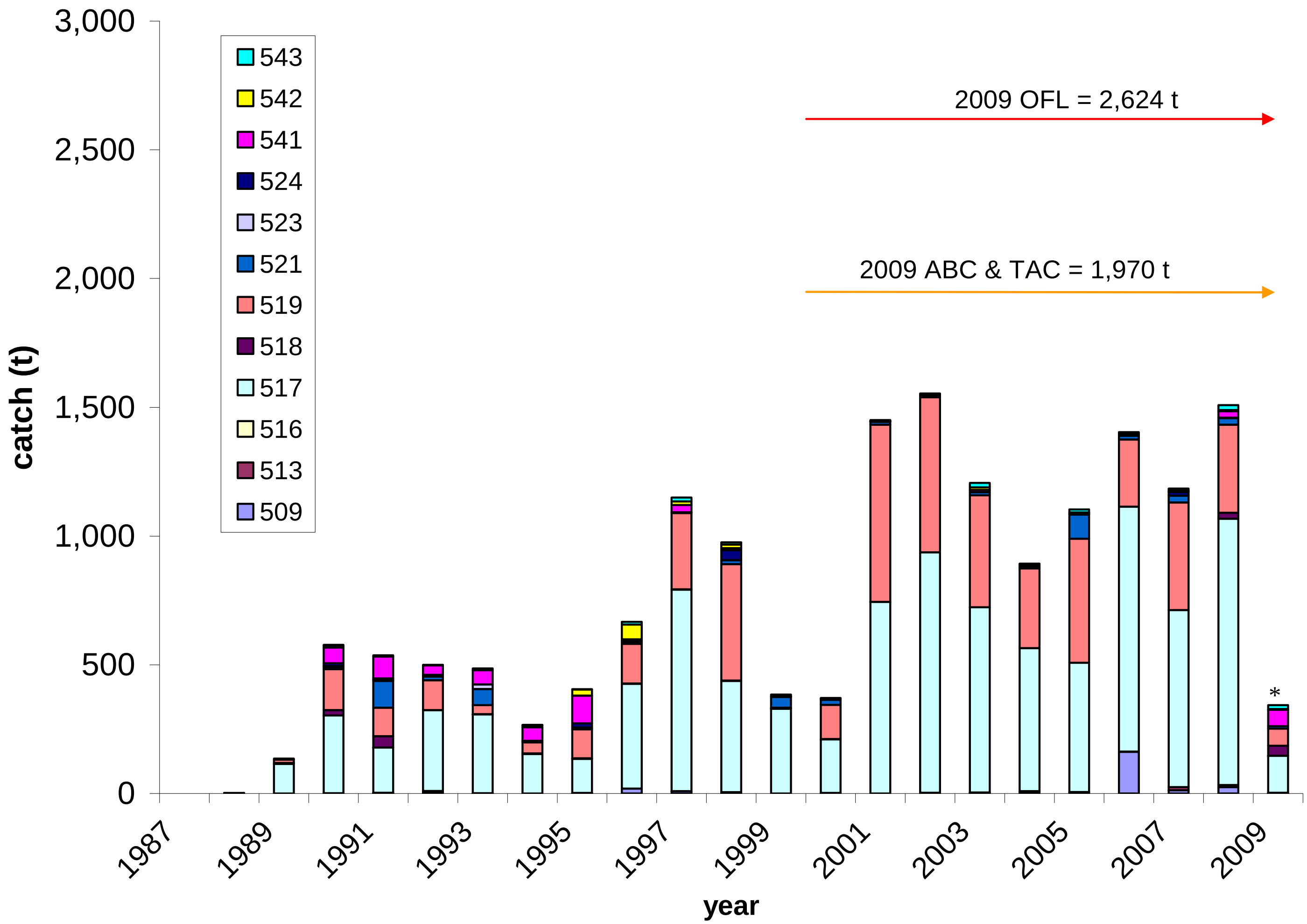


Figure 3. Estimated total fishery catch (t) of all squid species in NMFS management areas of the BSAI region, 1989-2009 (as of October 7, 2009). Numbers in legend refer to management area. OFL, ABC, and TAC specified for the 2009 fishing season are indicated on the plot. * 2009 catch estimate as of October 7, 2009.

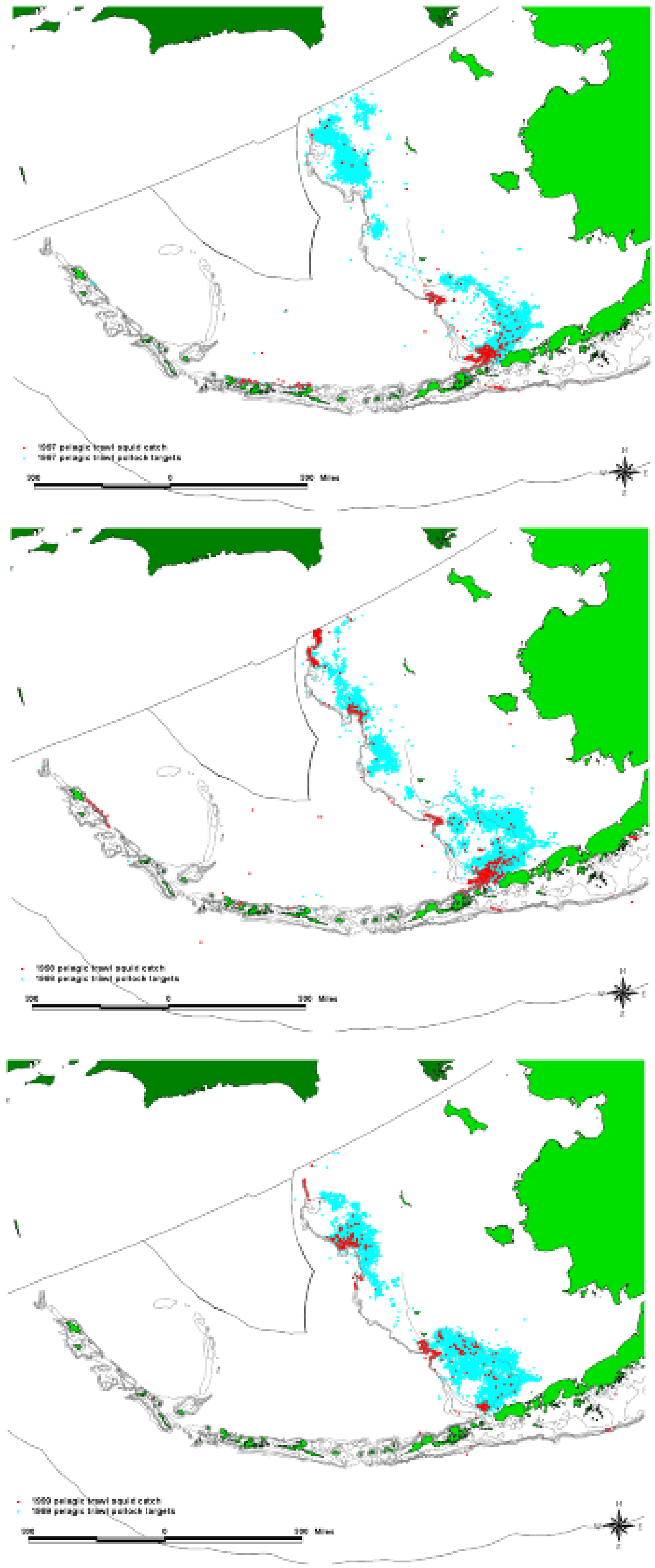
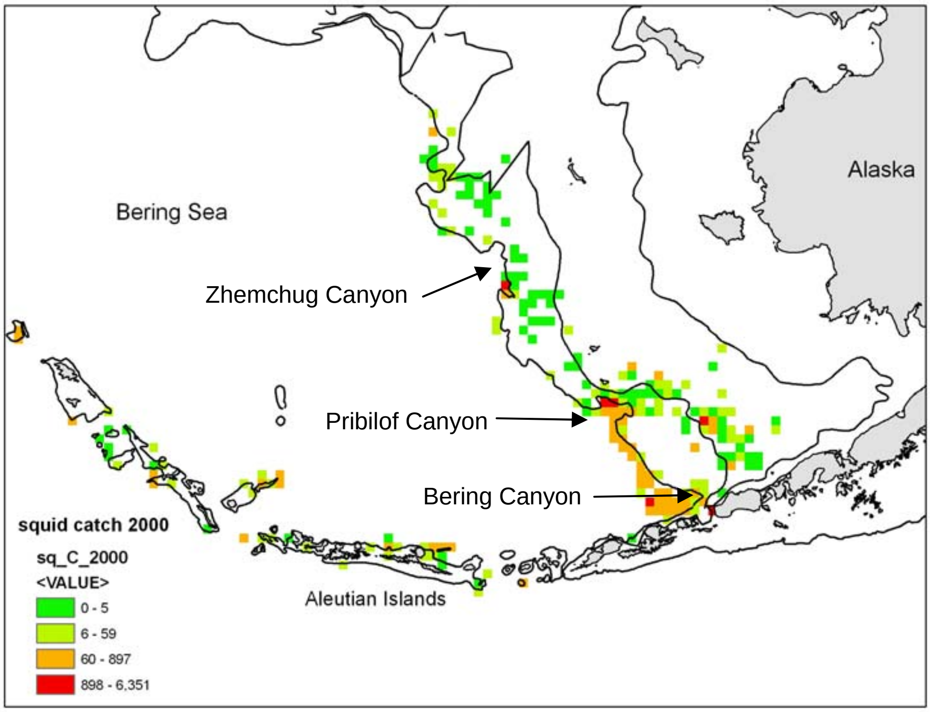


Figure 4. Eastern Bering Sea pollock fishery in light blue, areas of squid catch in dark red. Top--1997, center--1998, bottom--1999. Note that squid catches occur in the same places regardless of where the fishery operates.



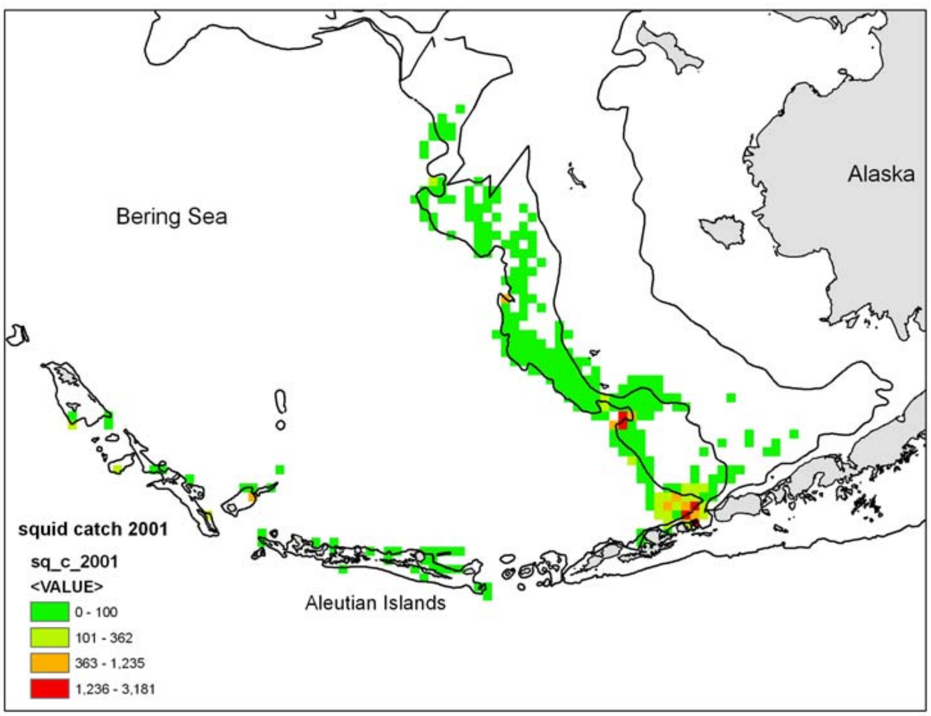
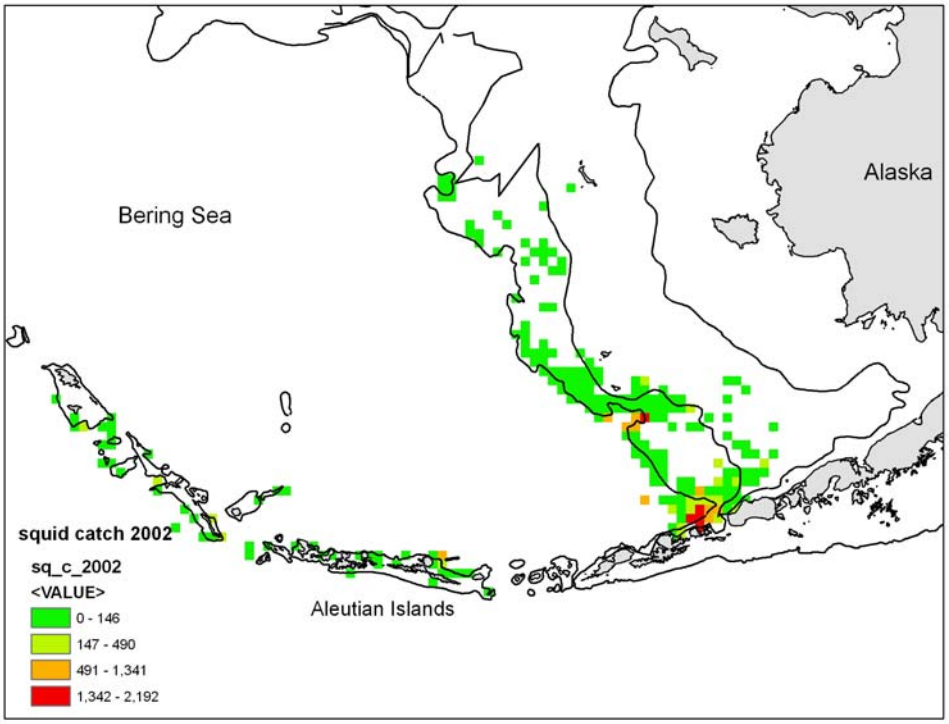


Figure 5. Distribution of squid catches from 2000-2007. Each grid cell (20 km x 20 km) depicts the mean observed catch in kg. Data are from the AFSC Fisheries Monitoring and Analysis program, and each grid cell contains at least three observed hauls. Mean catch values delineating color legend are not consistent among years. Black lines show the 50 m, 100 m, and 200m depth contours.



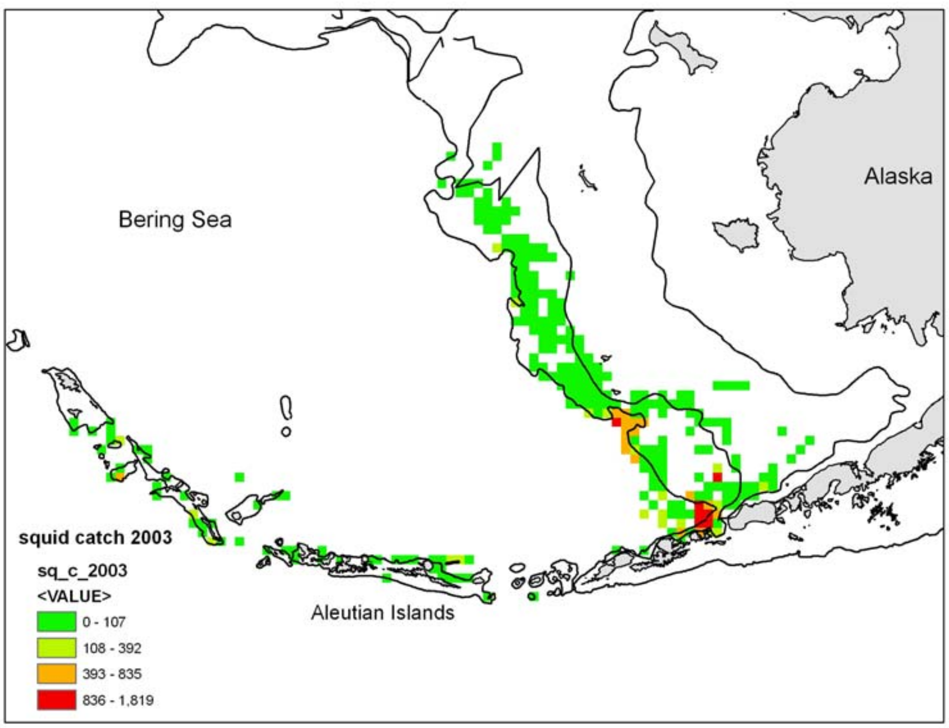
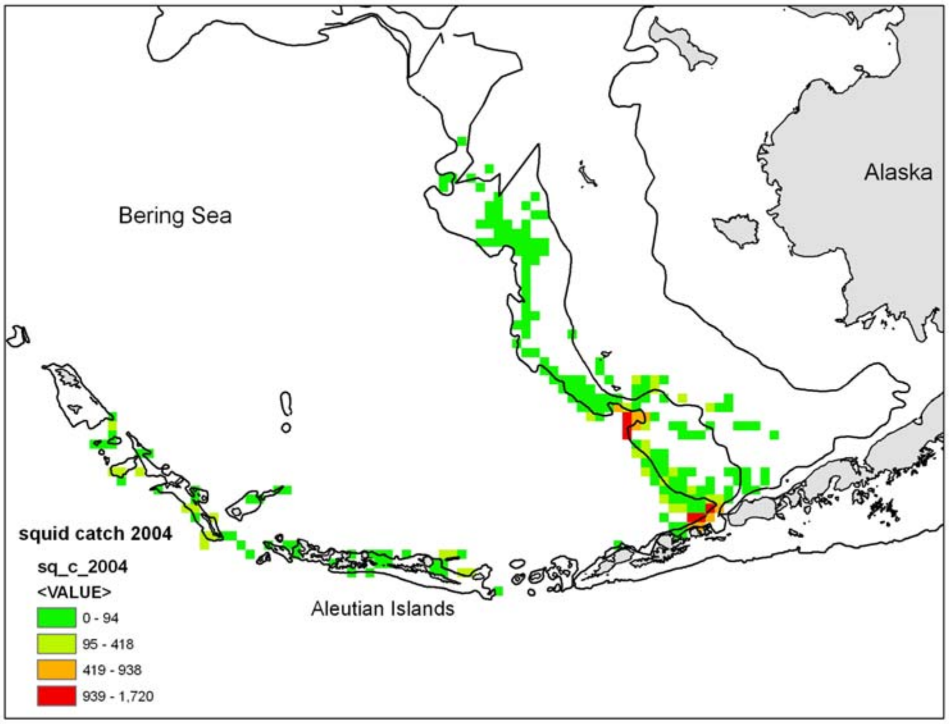


Fig. 5 continued.



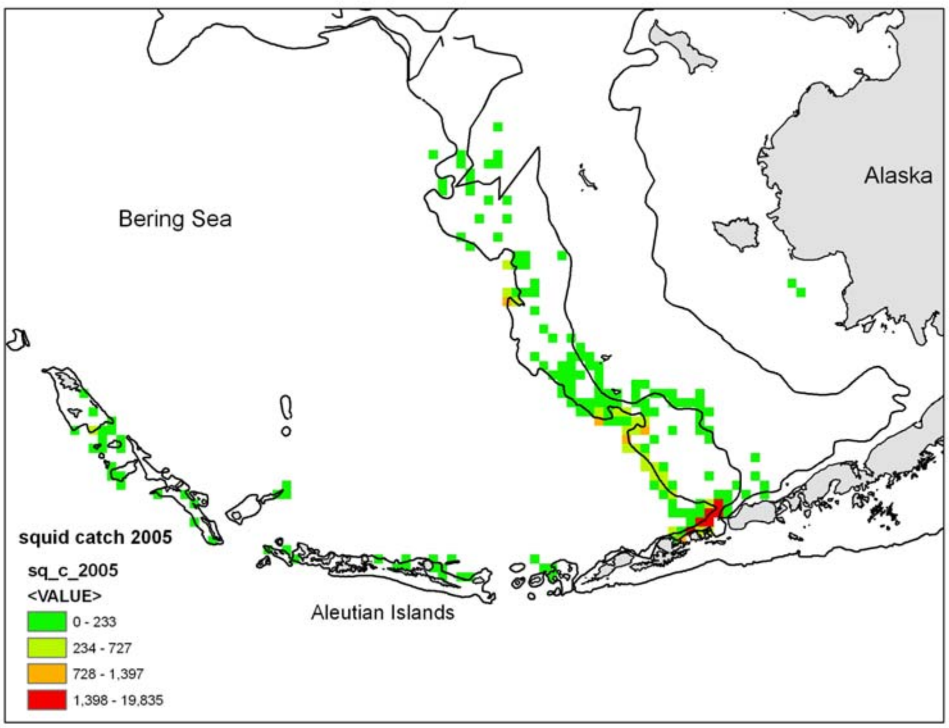
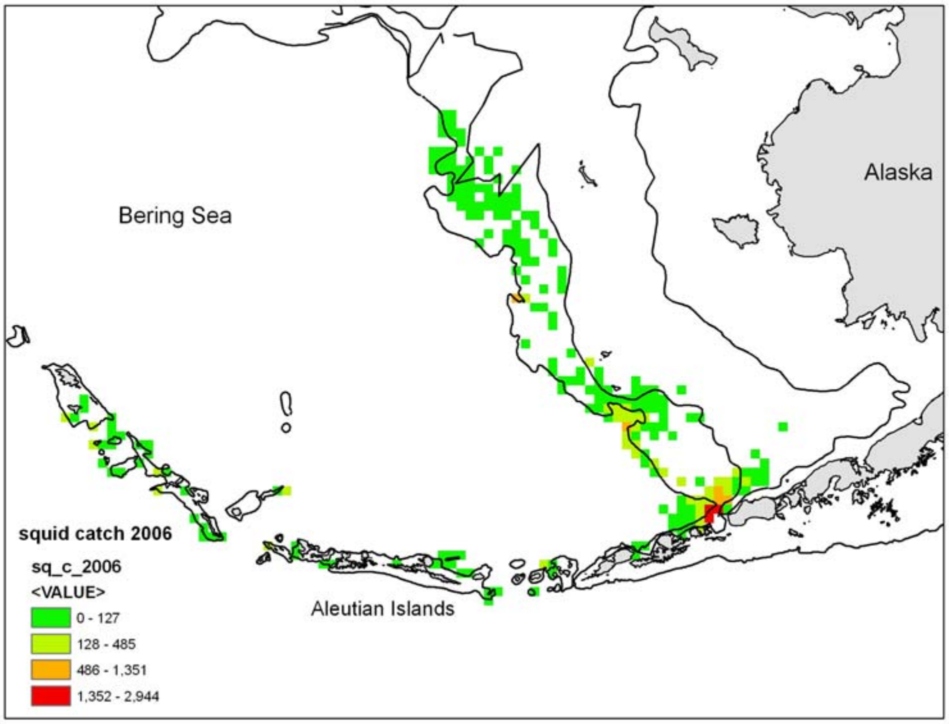
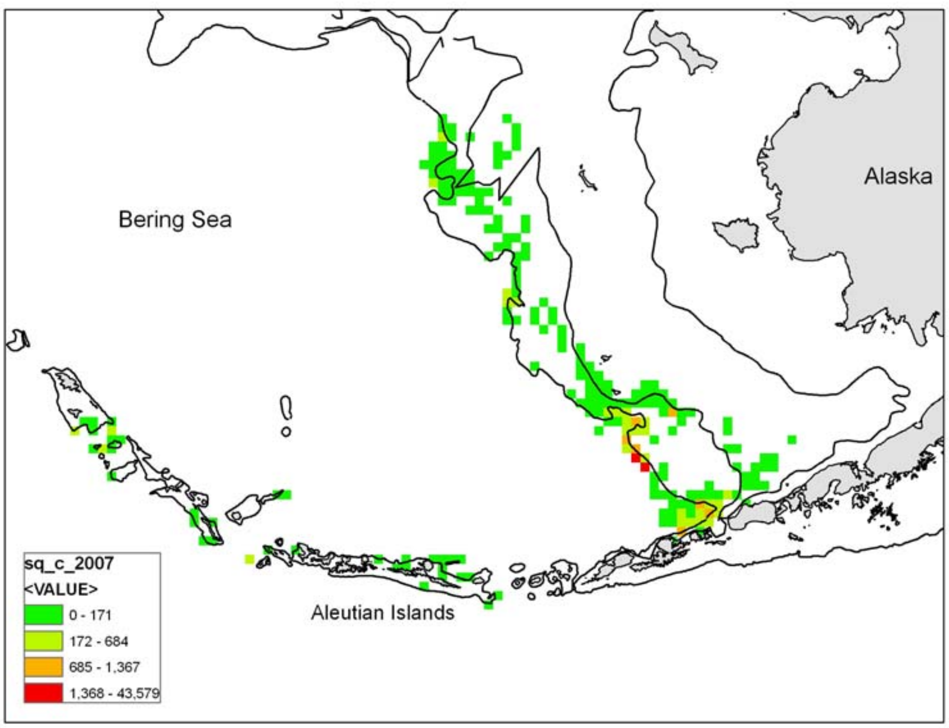


Figure 5 continued.





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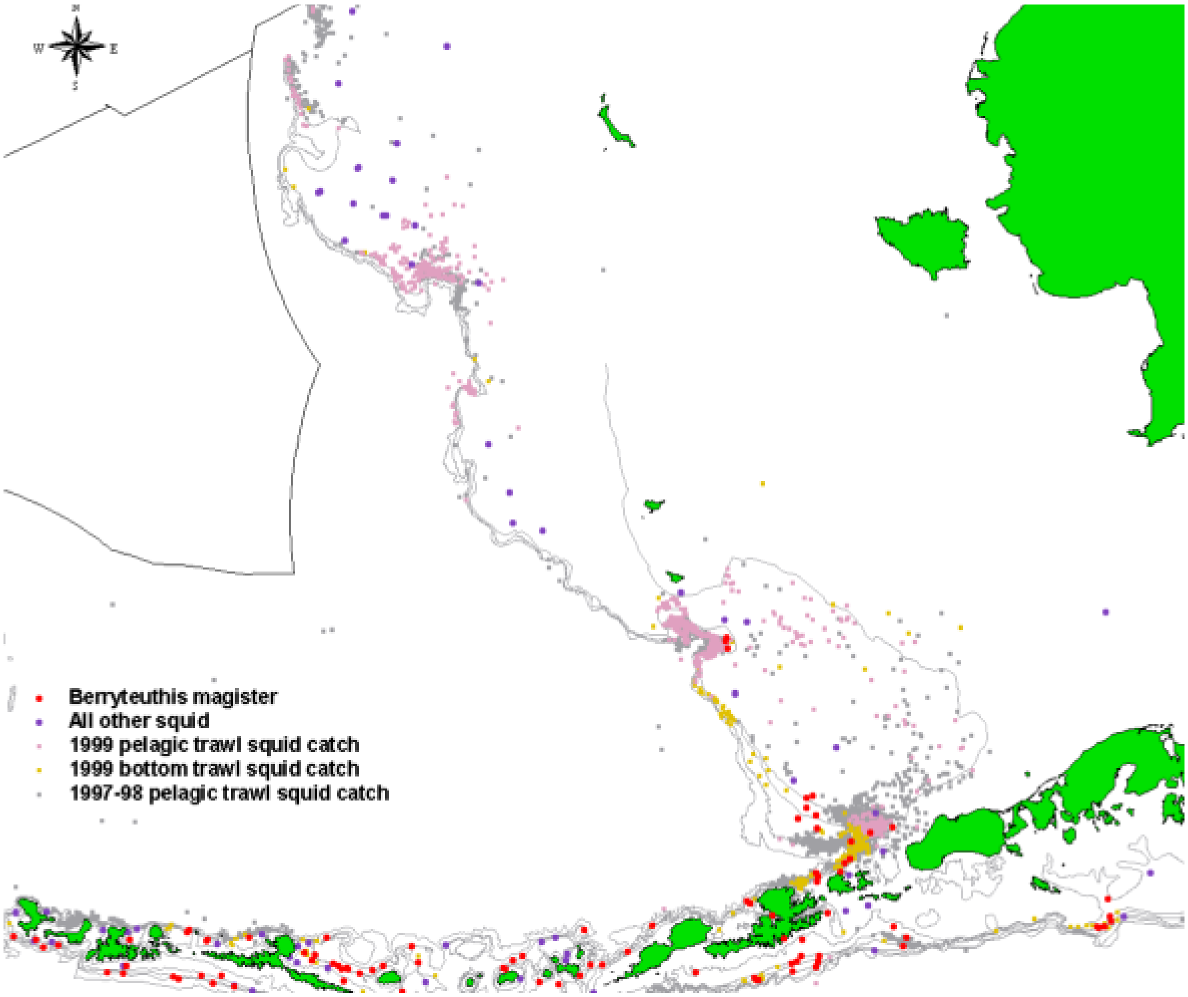

Figure 6. Distribution of squid species from bottom trawl surveys and catch, 1997-1999.

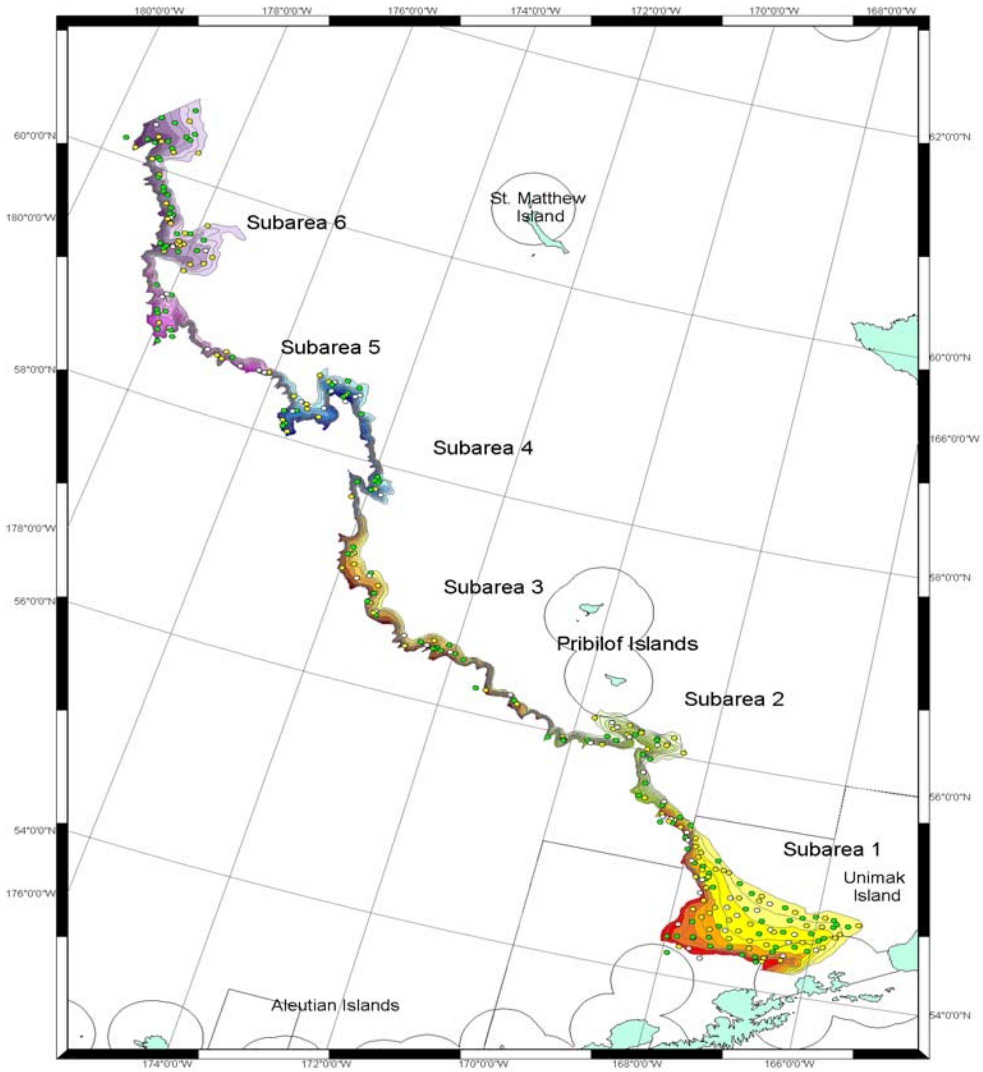

Figure 7. 2008 Eastern Bering Sea Upper Continental Slope Survey. All stations are indicated with colored dots. Figure is from G. Hoff, AFSC.

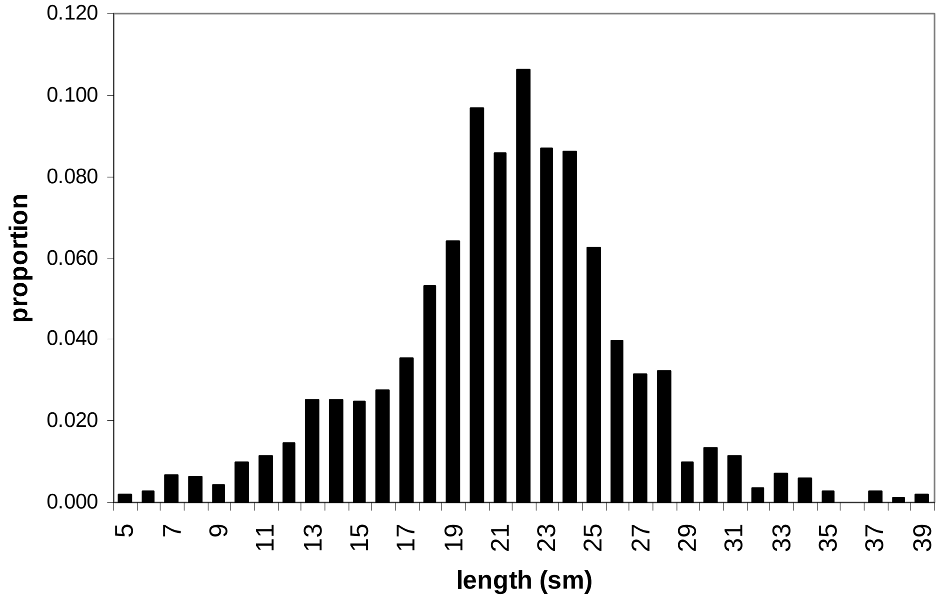

Figure 8. Length composition of *B. magister* caught during the 2008 EBS slope survey conducted by the AFSC. Proportions were calculated from extrapolated numbers at length.

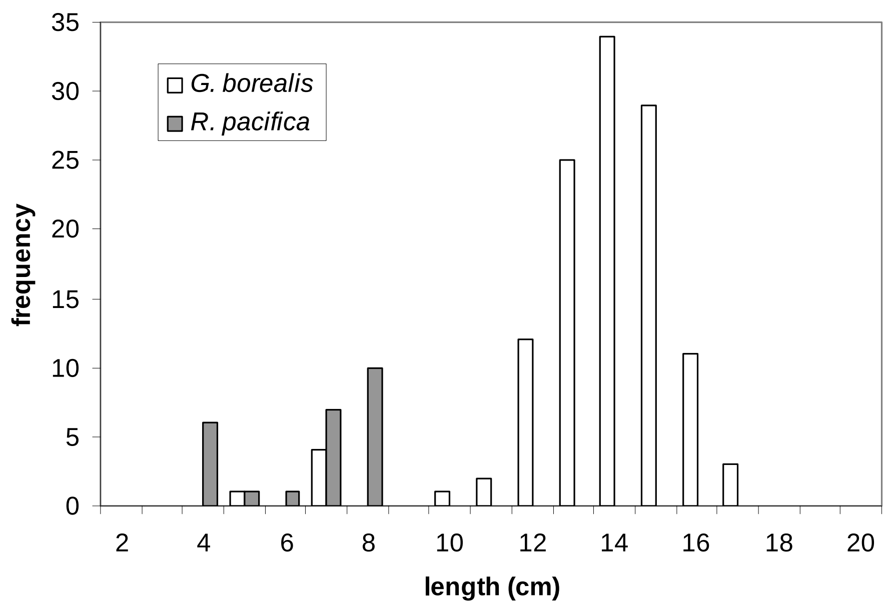

Figure 9. Length compositions of *G. borealis* and *R. pacifica* caught during the 2008 EBS slope survey conducted by the AFSC. Data shown are numbers of individuals observed at each length.

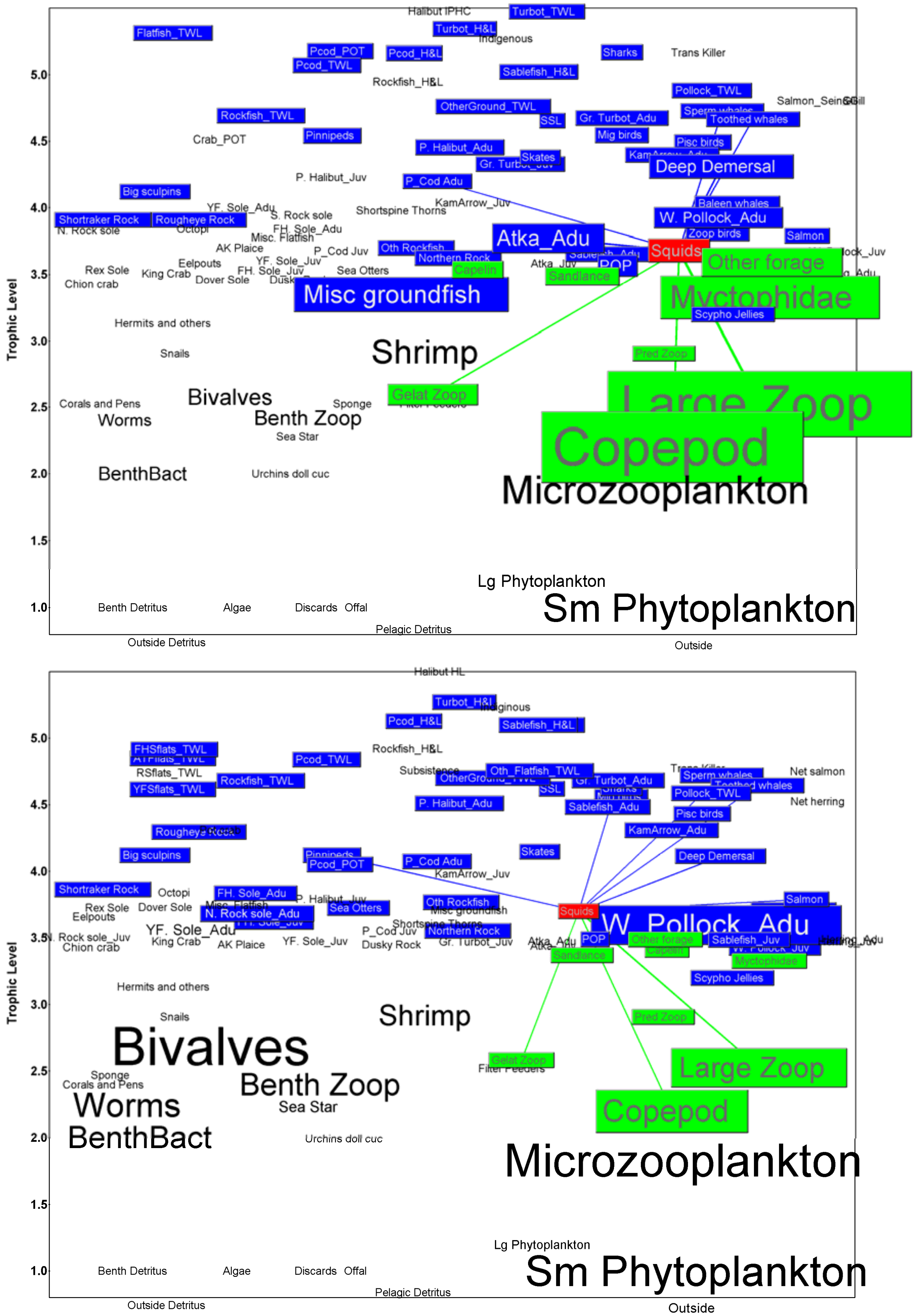

Figure 10. AI (upper) and EBS (lower) food webs of squids (red), predators (blue), and prey (green).

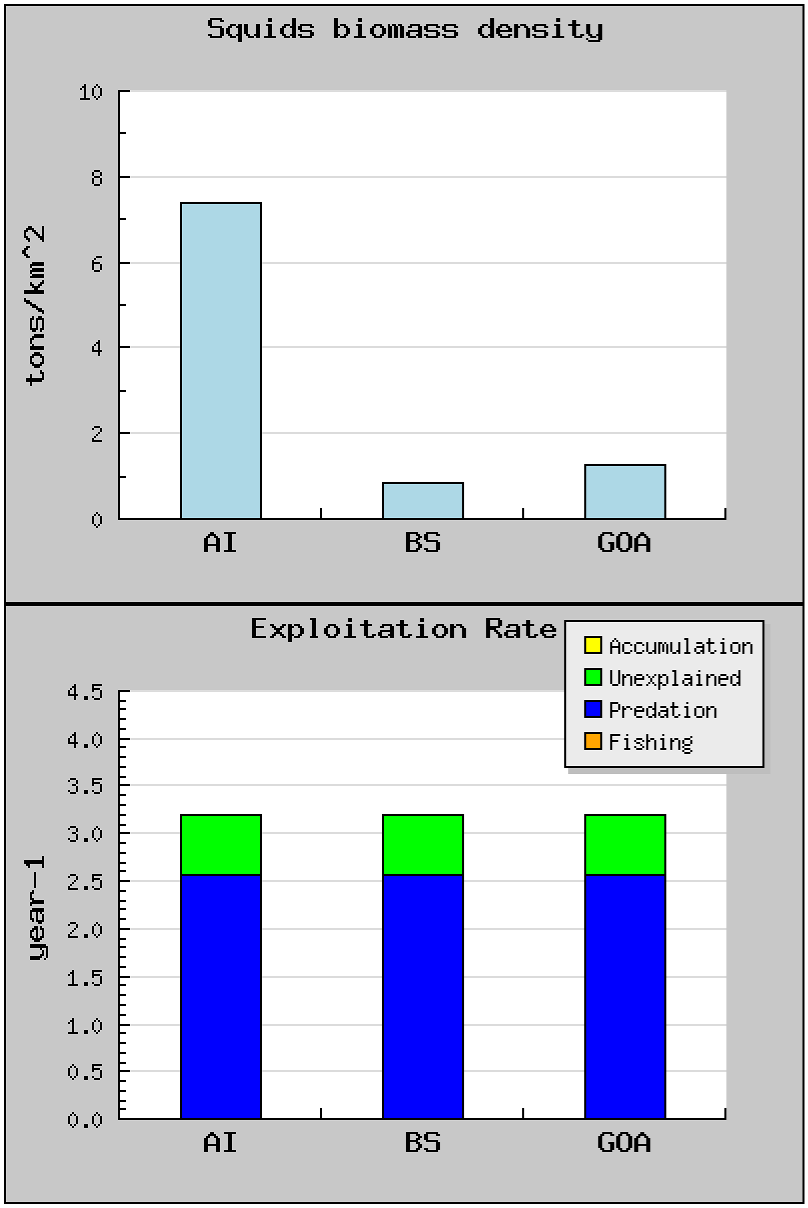

Figure 11. Biomass density (tons per square kilometer) come from direct estimates of consumption by groundfish of the AI, EBS, and GOA (upper panel), and exploitation rates partitioned into mortality due to predation, fishing, and unexplained sources (lower panel). Fishing mortality has been included in this calculation, but is too small to show on the plot.

Disclaimer: Figures generated in October 2005, we are currently awaiting updated figures. The calculation for this is Equation 1.1 in Appendix 1 of the Ecosystem Assessment (page 83).

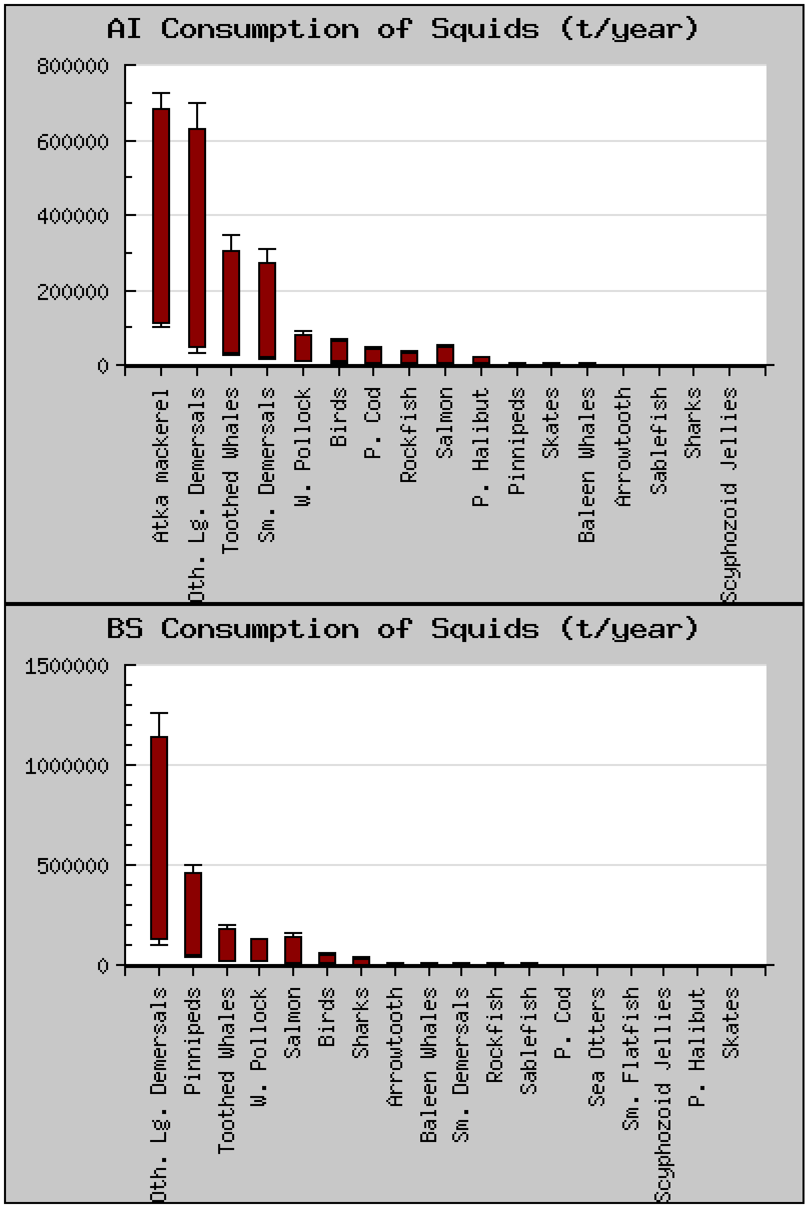

Figure 12. Consumption of squids estimated from ecosystem models for the AI (upper) and EBS (lower), based on early 1990's data and incorporating uncertainty. "Other large demersals" is primarily grenadiers (Macrouridae) in both ecosystems.
Disclaimer: Figures generated in October 2005, we are currently awaiting updated figures. Description of method is in an appendix of the Ecosystem considerations chapter.

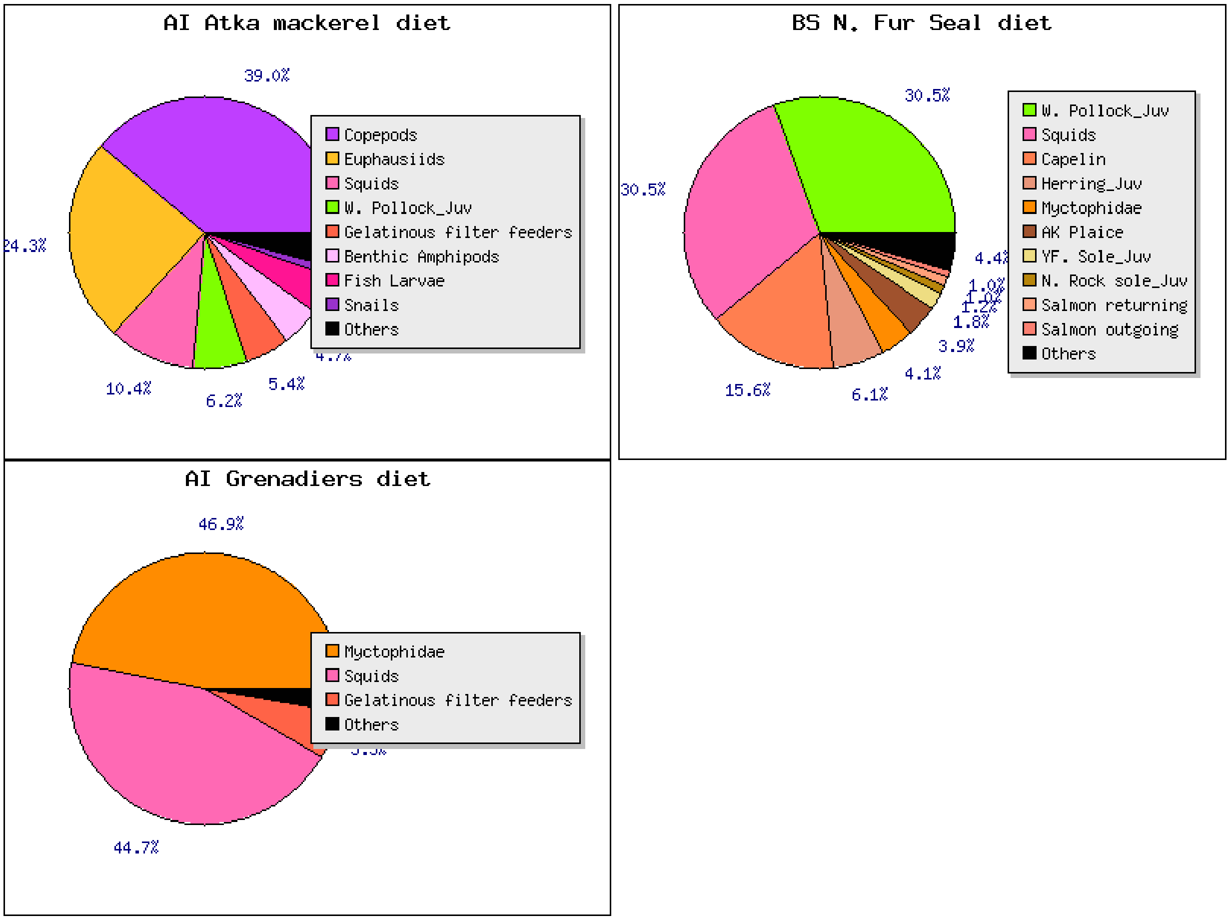

Figure 13. Proportion of squids in diets of major squid consumers in BSAI: Atka mackerel (top), northern fur seals (center), and grenadiers (bottom). EBS grenadier diets (not shown) are similar to AI.
Disclaimer: Figures generated in October 2005, we are currently awaiting updated figures. Description of method is in an appendix of the Ecosystem considerations chapter.

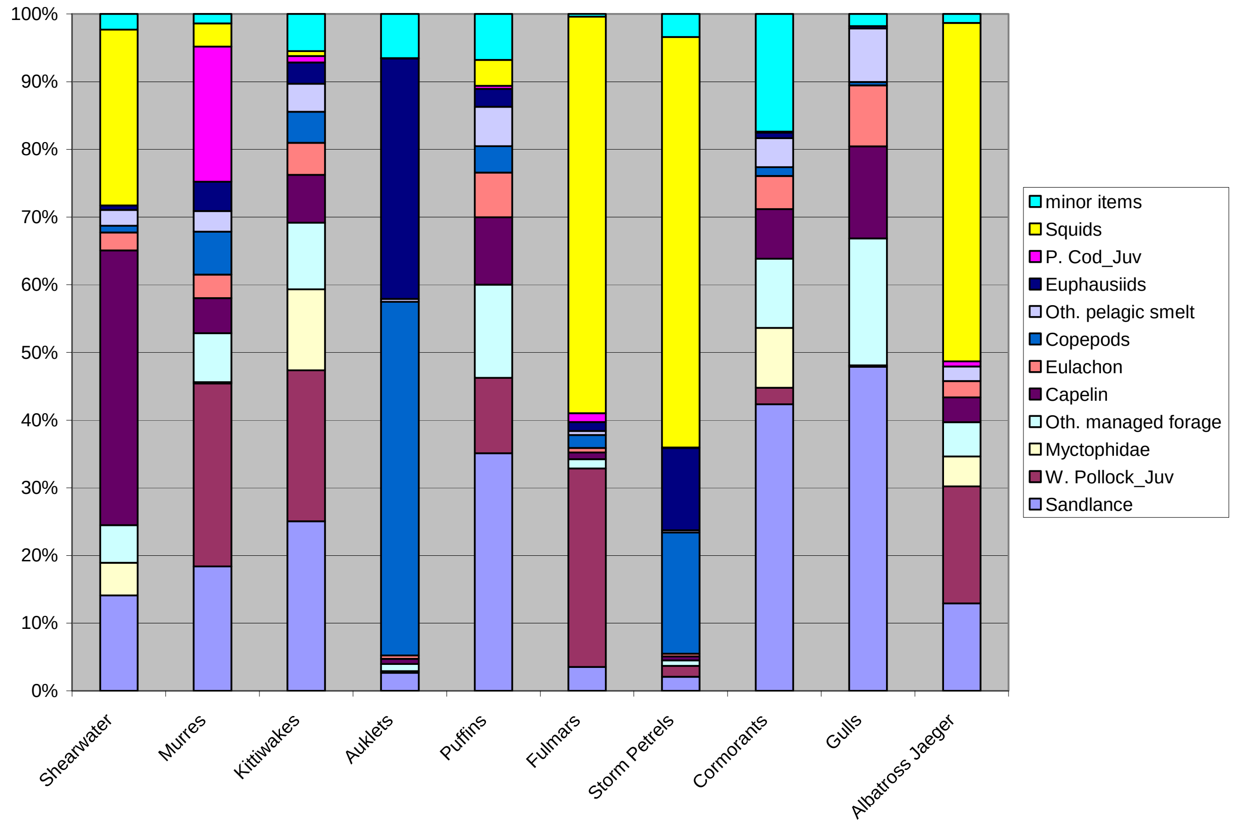

Figure 14. Estimated diet composition of seabirds in the GOA. Data are the inputs used in ecosystem modeling performed at the AFSC (Aydin et al. 2007) and are based largely on Hunt et al. (2000). Albatrosses and jaegers are considered a single functional group for modeling purposes.