22. Assessment of the Octopus Stock Complex in the Bering Sea and Aleutian Islands

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Executive Summary

Through 2010, octopuses were managed as part of the BSAI "other species" complex, along with sharks, skates, and sculpins. Historically, catches of the other species complex were well below TAC and retention of other species was small. Due to increasing market values, retention of some other species complex members is increasing. Beginning in 2011, the BSAI fisheries management plan was amended to provide separate management for sharks, skates, sculpins, and octopus and set separate catch limits for each species group. Catch limits for octopus for 2011 were set using Tier 6 methods based on the maximum historical incidental catch rate. For 2012, a new methodology based on consumption of octopus by Pacific cod was introduced; this method is also recommended for 2013 and 2014. The consumption estimate has not been revised from last year; the authors recommend that this calculation be revisited once every five years.

In this assessment, all octopus species are grouped into one assemblage. At least seven species of octopus are found in the BSAI. The species composition of the octopus community is not well documented, but data indicate that the giant Pacific octopus *Enteroctopus dofleini* is most abundant in shelf waters and predominates in commercial catch. Octopuses are taken as incidental catch in trawl, longline, and pot fisheries throughout the BSAI; a portion of the catch is retained or sold for human consumption or bait. The highest octopus catch rates are from Pacific cod fisheries in the three reporting areas around Unimak Pass. The Bering Sea and Aleutian Island trawl surveys produce estimates of biomass for octopus, but these estimates are highly variable and do not reflect the same sizes of octopus caught by industry. Examination of size frequency from survey and fishery data shows that both commercial and survey trawls catch predominantly small animals (<5 kg), while commercial pot gear catches or retains only larger animals (10-20 kg). In general, the state of knowledge about octopus in the BSAI is poor. A number of research studies and special projects have been initiated in recent years to increase knowledge for this assemblage; results of these studies are summarized.

Summary of Changes in Assessment

This assessment uses the approach introduced last year that estimates the total mortality of octopus by the annual amount of octopus consumed by Pacific cod. This methodology is based on species composition of diet data for Pacific cod from the AFSC food habits database, and cod weight-at-age data fit to a generalized von Bertalanffy growth curve (Essington et al. 2001). The method is described in detail under "Parameters Estimated Independently". The consumption estimate has not been revised from last year. Text describing the methodology and its uncertainty has been expanded slightly from last year.

Survey data have been updated with the 2012 Bering Sea shelf survey, Bering Sea slope survey, and Aleutian Islands survey results. Estimated survey biomass was lower in 2012 than in the most recent surveys of the Bering Sea shelf and the Aleutian Islands, but much higher for Bering Sea slope survey than in recent years. Species composition and size frequencies from the surveys were similar to previous years.

The table of incidental catch rates has been updated to include estimated catch for the entirety of 2011 and for 2012 through October. The estimated total catch for 2011 was the highest ever observed: 584 tons. The octopus catch in 2011 exceeded the TAC of 150 tons by late August and was very high in the fall, reaching the OFL of 528 tons by early October, at which point pot fishing for Pacific cod was closed. The catch for 2012 through October 6 has been much lower at 86 tons. An estimated percentage of annual catch that was retained from 2003-2012 has been added to the catch table. The retained percentage was lower in 2011 and 2012 than in previous years due to a low TAC for octopus and better reporting of octopus discards. Text summarizing new research underway on octopus has been revised and the life history section has been updated with recent research. Other report sections are largely unchanged from the 2011 SAFE.

Summary of Results

The current data are not sufficient for a model-based assessment. From 2006 through 2010, preliminary stock assessments of octopus were prepared that presented both Tier 5 and Tier 6 estimates of OFL and ABC. The SSC and plan teams have discussed the difficulties in applying groundfish methodologies to octopus and have agreed to treat octopus as a Tier 6 species, owing to inadequate data for estimating Tier 5 parameters. There are no historical catch records for octopus. Estimates of incidental catch rate from 1997-2007 are used as a baseline for Tier 6 assessment. Based on previous discussion by the Plan Teams, the maximum incidental catch during this time period is used to set the OFL. Using the maximum incidental catch, the OFL and ABC would be 418 tons and 314 tons, respectively. A new alternative methodology, introduced in 2011, uses a predation-based estimate of total natural mortality and the logistic fisheries model to set the OFL equal to a highly conservative estimate of total natural mortality; the OFL and ABC from this approach are much higher than any of the historical-catch. This approach was used to set catch limits for 2012 and is brought forward without change (consumption estimates have not been recalculated) for 2013/14. The authors and plan teams feel that the standard Tier 6 approach based on the incidental catch results in an overly conservative limit, because most of these data are from a period in which there was very little market or directed effort for octopus. The new methodology is based on extensive diet data and includes estimation of uncertainty in calculations.

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2012	2013	2013	2014
Tier 6 (max of 1997-2007 catch)				
OFL (t)	418	418	418	418
ABC (t)	314	314	314	314
Tier 6 (consumption estimate)				
OFL (t)	3,452	3,452	3,452	3,452
ABC (t)	2,589	2,589	2,589	2,589
	As determined *last* year for:		As determined *this* year for:	
Status	2011	2012	2012	2013
Overfishing	n/a	n/a	n/a	n/a

Responses to SSC comments

At the December 2011 meeting the SSC discussed the SAFE for BSAI octopus. They had the following comments:

"*The Plan Team supported the author's predation-based estimate of octopus mortality from 1984-2008 survey data of Pacific cod diets as an alternate Tier 6 estimate. The Plan Team discussed the appropriateness of this approach and concluded that cod were a better sampler of octopuses than the survey and therefore represented an improved estimate of minimum biomass. The Plan Team thought that, in the case of BSAI octopus, the estimate resulting from the predation-based approach should be conservative.*

The SSC notes that estimates derived from the survey and consumption are both highly uncertain and should only be considered until more reliable estimates of biomass can be attained. The SSC would like to encourage development of alternative approaches or a survey."

Based on the SSCs approval of the consumption-based estimate, this approach has been used for this year's catch limit recommendations. The authors agree that this method is still highly approximate and research into more reliable estimation of biomass, including tagging research, is continuing. Research into fishery-independent survey methods and discard mortality rates is also continuing, as detailed inAppendix 22.1.

"The SSC requests the authors investigate:
- *Spatial and temporal patterns in consumption*
- *Compare size modes in code compared to what is captured in the fishery*
- *Provide details on stomach contents*
- *Analysis of AI Pacific cod diet*
- *Contrast observed consumption rates with cod abundance*
- *Consider information from other surveys and spatial-temporal catch patterns in the pot fishery."*

An expanded section on cod diets has been added, including spatial and temporal consumption patterns, size modes, and stomach contents details, in the section "Pacific cod food habits analysis". Of particular interest is the new data on size composition; we found that, **while many of the octopus consumed by cod were smaller than those in the fishery, larger (>60cm) cod eat octopus that overlap in beak length with the smaller octopus caught in the fishery (1-2 kg octopus), and larger cod contribute highly to the overall consumption estimate due to larger ration and larger proportion of octopus in stomachs.** It is not possible to make quantitative estimates of weight composition of consumption, although data collection is ongoing. While we examined AI diets, issues of both low diet sample sizes and narrow strata given depth-dependent consumption prevented us from making a quantitative estimate of consumption this year. We examined relationships between cod abundance and observed consumption rates and found no clear trend; this is possibly due to consumption variation being driven by cod size composition and location as well as straightforward abundance. Multivariate examinations are continuing.

For the last item, information from AFSC sablefish and IPHC halibut surveys was reviewed during the early stock assessments for octopus; neither of these surveys captures substantial amounts of octopus and the data from the surveys was not useful in determining spatial or depth distribution of octopus. Captures of octopus in the ADF&G inshore bottom trawl survey are rare; data from this survey is not useful for species-specific or spatial information.

Spatial and temporal patterns in the pot fishery have been reviewed through analysis of observer data; presentation of detailed results of this analysis is limited by observer data confidentiality rules. A summary table from screened observer data has been included in the Data section of this report, along with discussion. It is apparent that temporal catch patterns in the pot fishery are primarily determined by seasonal timing of pot fishing for Pacific cod and that spatial patterns in octopus catch are primarily determined by gear conflict considerations and proximity to processors. The data do suggest that the rate of octopus bycatch is higher during the fall cod season than in the winter, and that pot effort and octopus catch are both particularly high in the small statistical area 519, to the north of Akun and Akutan Islands, just west of Unimak Pass. This area also includes three Steller sea lion rookeries.

"The SSC also supports the Plan Team request for discussion of the data needed for a discard mortality rate analysis and additional research to estimate rates of non-spawning mortality and discard mortality."

Two studies of octopus discard mortality have been funded and are underway in 2013. A small field study will be conducted aboard a commercial pot boat, holding octopus in running seawater tanks to look for delayed mortality. A larger NPRB study will be conducted at the AFSC Kodiak laboratory, examining indicators of stress in giant Pacific octopus, longer-term delayed mortality rates, and growth rates. The tagging study being conducted by Reid Brewer of UAF should provide an independent estimate of natural mortality rate when it is completed.

Introduction

Description and General Distribution

Octopuses are marine mollusks in the class Cephalopoda. The cephalopods, whose name literally means head foot, have their appendages attached to the head and include octopuses, squids, and nautiluses. The octopuses (order Octopoda) have only eight appendages or arms and unlike other cephalopods, they lack shells, pens, and tentacles. There are two groups of Octopoda, the cirrate and the incirrate. The cirrate have cirri (cilia-like strands on the suckers) and possess paddle-shaped fins suitable for swimming in their deep ocean pelagic and epibenthic habitats (Boyle and Rodhouse 2005) and are much less common than the incirrate which contain the more traditional forms of octopus. Octopuses are found in every ocean in the world and range in size from less than 20 cm (total length) to over 3 m (total length); the latter is a record held by *Enteroctopus dofleini* (Wülker 1910). *E. dofleini* is one of at least nine species of octopus (Table 22.1) found in the Bering Sea, including one newly identified species. Members of these nine species represent seven genera and can be found from less than 10 m to greater than 1500 m depth. All but two, *Japetella diaphana* and *Vampyroteuthis infernalis*, are benthic octopuses. The state of knowledge of octopuses in the BSAI, including the true species composition, is very limited.

In the Bering Sea octopuses are found from subtidal waters to deep areas near the outer slope (Figure 22.1). The highest diversity is along the shelf break region between 200 – 750 m. The observed take of octopus from both commercial fisheries and AFSC RACE surveys indicates few octopus occupy federal waters of Bristol Bay and the inner front region. Some octopuses have been observed in the middle front, especially in the region south of the Pribilof Islands. The majority of observed commercial and survey hauls containing octopus are concentrated in the outer front region and along the shelf break, from the horseshoe at Unimak Pass to the northern limit of the federal regulatory area. Octopus have also been observed throughout the western GOA and Aleutian Island chain. The spatial distribution of commercial octopus catch and the distribution of trawl survey octopus by species are discussed in the data section of this report.

Management Units

Through 2010, octopuses were managed as part of the BSAI "other species" complex, with catch reported only in the aggregate with sharks, skates, and sculpins. In the BSAI, catch of other species was limited by a Total Allowable Catch (TAC) based on an Allowable Biological Catch (ABC) estimated by summing estimates for several subgroups (Gaichas 2004). Historically, catches of "other species" were well below TAC and retention of other species was small. Due to increasing market value of skates and octopuses, retention of other species complex members began to increase in the early 2000's. In 2004, the TAC established for the other species complex was close to historical catch levels, so all members of the complex were placed on "bycatch only" status, with retention limited to 20% of the weight of the target species. This status continued each year through 2009. In several years, the "other species" complex TAC was reached and all members of the complex were then placed on discard-only status, with no retention allowed, for the remainder of the year.

In October 2009, the North Pacific Fishery Management Council amended both the BSAI and GOA Fishery Management Plans to eliminate the "other species" category. Plan amendments moved species groups formerly included in "other species" into the "in the fishery" category and provide for management of these groups with separate catch quotas under the 2007 reauthorization of the Magnuson-Stevens Act and National Standard One guidelines. These amendments also created an 'Ecosystem Component' category for species not retained commercially.

Separate catch limits for groups from the former "other species" category, including octopus, were implemented in January 2011. Octopus remained on "bycatch only" status, with a TAC of 150 tons. As it happened, 2011 turned out to be an unusually high catch year for octopus in the BSAI. The TAC was reached in August 2011, and retention of octopus was prohibited for the remainder of the year. The OFL of 528 tons was reached in mid-October, 2011. To prevent further incidental catch of octopus, NMFS regional office closed directed fishing for Pacific cod with pots in the BSAI effective October 24, 2011.

Draft revisions to guidelines for National Standard One instruct managers to identify core species and species assemblages. Species assemblages should include species that share similar regions and life history characteristics. The BSAI octopus assemblage does not fully meet these criteria. All octopus species have been grouped into a species assemblage for practical reasons, as it is unlikely that fishers will identify octopus to species. Octopus are currently recorded by fisheries observers as either "octopus unidentified" or "pelagic octopus unidentified". *E. dofleini* is the key species in the assemblage, is the best known, and is most likely to be encountered at shallower depths. The seven species in the assemblage, however, do not necessarily share common patterns of distribution, growth, and life history. One avenue being explored for possible future use is to split this assemblage by size, allowing retention of only larger animals. This could act to restrict harvest to the larger *E. dofleini* and minimize impact to the smaller animals which may be other octopus species.

Life History and Stock Structure

In general, octopus life spans are either 1-2 years or 3-5 years depending on the species. Life histories of six of the seven species in the Bering Sea are largely unknown. *Enteroctopus dofleini* has been studied extensively, and its life history will be reviewed here. General life histories of the other six species are inferred from what is known about other members of the genus.

Giant Pacific Octopus

Enteroctopus dofleini samples collected during research in the Bering Sea (see Appendix 22.1) indicate that *E. dofleini* are reproductively active in the fall with peak spawning occurring in the winter to early spring months. Like most species of octopuds, E. dofleini are terminal spawners, dying after mating (males) and the hatching of eggs (females) (Jorgensen 2009). *Enteroctopus dofleini* within the Bering Sea have been found to mature between 10 to 13 kg with 50% maturity values of 12.8 kg for females and 10.8 kg for males (Appendix 1, Brewer and Norcross, in review). *Enteroctopus dofleini* are problematic to age due to a documented lack of beak growth checks and soft chalky statoliths (Robinson and Hartwick 1986). Therefore the determination of age at maturity is difficult for this species. In Japan this species is estimated to mature at 1.5 to 3 years and at similar size ranges (Kanamaru and Yamashita 1967, Mottet1975). Within the Bering Sea, female *E. dofleini* show significantly larger gonad weight and maturity in the fall months (Brewer and Norcross, in review). Due to differences in the timing of peak gonad development between males and females it is likely that females have the capability to store sperm. This phenomenon has been documented in aquarium studies of octopus in Alaska and British Columbia (Gabe 1975). Fecundity for this species in the Gulf of Alaska ranges from 40,000 to 240,000 eggs per female with an average fecundity of 106,800 eggs per female (Conrath and Conners, in review). Fecundity was significantly and positively related to the size of the female. The fecundity of *E. dofleini* within this region is higher than that reported for other regions. The fecundity of this species in Japanese waters has been estimated at 30,000 to 100,000 eggs per female (Kanamaru 1964, Mottet 1975, Sato 1996). Gabe (1975) estimated that a female in captivity in British Columbia laid 35,000 eggs. Hatchlings are approximately 3.5 mm. Mottet (1975) estimated survival to 6 mm at 4% while survival to 10 mm was estimated to be 1%; mortality at the 1 to 2 year stage is also estimated to be high (Hartwick, 1983). Large numbers of planktonic larvae of this species have been captured in offshore waters of the Aleutian Islands during June through August. These juveniles were assumed have hatched in the coastal waters along the Aleutian Islands and been transported by the Alaska Stream (Kubodera 1991). Since the highest mortality occurs during the larval stage it is likely that ocean conditions have the largest effect on the number of *E. dofleini* in the Bering Sea and large fluctuations in numbers of E. dofleini should be expected. Based on larval data, *E. dofleini* is the only octopus in the Bering Sea with a planktonic larval stage.

The giant Pacific octopus is found throughout the northern Pacific Ocean from northern Japanese waters, throughout the Aleutian Islands, the Bering Sea and the Gulf of Alaska and along the Pacific Coast as far south as northern California (Kubodera, 1991). The stock structure and phylogenetic relationships of this species throughout its range have not been well studied. Three sub-species have been identified based on large geographic ranges and morphological characteristics including *E. dofleini dofleini* (far western North Pacific), *E. dofleini apollyon* (waters near Japan, Bering Sea, Gulf of Alaska), and *E. dofleini martini* (eastern part of their range, Pickford 1964). A recent genetic study (Toussaint et al. 2012) indicated the presence of a cryptic species of *E. dofleini* in Prince William Sound, Alaska and raises questions about the stock structure of this group. There is little information available about the migration and movements of this species in Alaska waters. Kanamaru (1964) proposed that *E. dofleini* move to deeper waters to mate during July through October and then move to shallower waters to spawn during October through January in waters off of the coast of Hokkaido, Japan. Studies of movement in British Columbia (Hartwick et al. 1984) and south central Alaska (Scheel and Bisson 2012) found no evidence of a seasonal or directed migration for this species, but longer term tagging studies may be necessary to obtain a complete understanding of the migratory patterns of this species.

Other Octopus Species

Sasakiopus salebrosus is a small benthic octopus recently identified from the Bering Sea slope in depths ranging from 200 to1,200 m (Jorgensen 2010). It was previously identified in surveys as *Benthoctopus sp*. or as *Octopus sp. n.* In recent groundfish surveys of the Bering Sea slope this was the most abundant octopus collected; multiple specimens were collected in over 50% of the tows. *Sasakiopus salebrosus* is a small-sized species with a maximum total length < 25 cm. Mature females collected in the Bering Sea carried 100 to 120 eggs (Laptikhovsky 1999). Hatchlings and paralarvae have not been collected or described (Jorgensen 2009).

Benthoctopus leioderma is a medium sized species, with a maximum total length of approximately 60 cm. Its life span is unknown. It occurs from 250 to 1,400 m and is found throughout the shelf break region. It is a common octopus and often occurs in the same areas where *E. dofleini* are found. The eggs are brooded by the female but mating and spawning times are unknown. Members of this genus in the North Pacific Ocean have been found to attach their eggs to hard substrate under rock ledges and crevices (Voight and Grehan 2000). *Benthoctopus* tend to have small numbers of eggs (< 200) that develop into benthic hatchlings.

Benthoctopus oregonensis is larger than *B. leioderma*, with a maximum total length of approximately 1 m. This is the second largest octopus in the Bering Sea and based on size could be confused with *E. dofleini*. We know very little about this species of octopus. Other members of this genus brood their eggs and we would assume the same for this species. The hatchlings are demersal and likely much larger than those of *E. dofleini*. The samples of *B. oregonensis* all come from deeper than 500 m. This species is the least collected incirrate octopus in the Bering Sea and may occur in depths largely outside of the sampling range of AFSC surveys.

Graneledone boreopacifica is a deep water octopus with only a single row of suckers on each arm (the other benthic incirrate octopuses have two rows of suckers). It is most commonly collected north of the Pribilof Islands but occasionally is found in the southern portion of the shelf break region. This species has been shown to occur at hydrothermal vent habitats and prey on vent fauna (Voight 2000). Samples of *G. boreopacifica* all come from deeper than 650 m and this deep water species has not been found on the continental shelf. *Graneledone* species have also been shown to individually attach eggs to hard substrate and brood their eggs throughout development. Recently collected hatchlings of this species were found to be very large (55 mm long) and advanced (Voight 2004) and this species has been shown to employ multiple paternity (Voight and Feldheim 2009).

Opisthoteuthis californiana is a cirrate octopus with fins and cirri (on the arms). It is common in the Bering Sea but would not be confused with *E. dofleini*. It is found from 300 to 1,100 m and likely common over the abyssal plain. *Opisthoteuthis californiana* in the northwestern Bering Sea have been found to have a protracted spawning period with multiple small batch spawning events. Potential fecundity of this species was found to range from 1,200 to 2,400 oocytes (Laptikhovsky 1999). There is evidence that *Opisthoteuthis* species in the Atlantic undergo ‘continuous spawning’ with a single, extended period of egg maturation and a protracted period of spawning (Villanueva 1992). Other details of its life history remain unknown.

Japetella diaphana is a small pelagic octopus. Little is known about members of this family. In Hawaiian waters gravid females are found near 1,000 m and brooding females near 800 m. Hatchlings have been observed to be about 3 mm mantle length (Young 2008). This is not a common octopus in the Bering Sea and would not be confused with *E. dofleini*.

Vampyroteuthis infernalis is a cirrate octopus. It is not common in the BSAI, being reported only from the slope immediately north of the easternmost Aleutian Islands (Jorgensen 2009). It is easily distinguishable from other species of octopus by its black coloration. Very little is known about its reproduction or early life history. An 8 mm ML hatchling with yolk was captured near the Hawaiian Islands indicating an egg size of around 8 mm for this species (Young and Vecchione 1999).

In summary, there are eight species of octopus present in the BSAI, and the species composition both of natural communities and commercial harvest is not well known. It is likely that some species, particularly *G. boreopacifica*, are primarily distributed at greater depths than are commonly fished. At depths less than 200 meters *E. dofleini* appears to be the most abundant species, but could be found with *S. salebrosus*, or *B. leioderma.*

Fishery

Directed Fishery

There is no federally-managed directed fishery for octopus in the BSAI. The State of Alaska allows directed fishing for octopus in state waters under a special commissioner's permit. A small directed fishery in state waters around Unimak Pass and in the AI existed from 1988-1995; catches from this fishery were reportedly less than 8 mt per year (Fritz 1997). In 2004, commissioner's permits were given for directed harvest of Bering Sea octopus on an experimental basis (Karla Bush, ADF&G, personal communication). Nineteen vessels registered for this fishery, and 13 vessels made landings of 4,977 octopus totaling 84.6 mt. The majority of this catch was from larger pot boats during the fall season cod fishery (Sept.-Nov.). Average weight of sampled octopus from this harvest was 14.1 kg. The sampled catch was 68% males. Only one vessel was registered for octopus in 2005. Since 2006, few permits have been requested and all catch of octopus in state waters has been incidental to other fisheries (Bowers et al. 2010, Sagalkin and Spalinger, 2011).

Incidental Catch

Octopus are caught incidentally throughout the BSAI in both state and federally-managed bottom trawl, longline, and pot fisheries. Until around 2003, retention of octopus when caught was minor, because of a lack of commercial market. Retained octopus were used and sold primarily for bait. In 2004-2007 a commercial market for human consumption of octopus developed in Dutch Harbor, with ex-vessel prices running as high as $0.90/lb. The main processor marketing food-grade octopus went out of business in 2009, decreasing demand; other processors continue to buy octopus for bait at ex-vessel prices in the $0.40 - $0.60/lb range. The worldwide demand for food-grade octopus remains high (www.fao.org), so the possibility of increased future marketing effort for octopus exists.

From 1992-2002 total incidental catch of octopus in federal waters was estimated from observed hauls (Gaichas 2004). Since 2003 the total octopus catch in federal waters (including discards) has been estimated using the NMFS Alaska Regional Office catch accounting system. Minor updates and changes to this system in 2010 produced estimated catch numbers slightly different from previous assessments. Incidental catch rates are presented in the data section. The majority of both federal and state incidental catch of octopus continues to come from Pacific cod fisheries, primarily pot fisheries (Table 22.2; Bowers et al. 2010, Sagalkin and Spalinger, 2011). Some catch is also taken in bottom trawl fisheries for cod, flatfish, and pollock. The overwhelming majority of catch in federal waters occurs around Unimak Pass in statistical reporting areas 519, 517, and 509. The species of octopus taken is not known, although size distributions suggest that the majority of the catch from pots is *E. dofleini* (see below).

Catch History

Prior to 2003, there was little market for octopus and no directed fishery in federal waters; historical rates of incidental catch (prior to 2003) do not necessarily reflect fishing patterns where octopus are part of retained market catch. Estimates of incidental catch (Table 2) suggest substantial year-to-year variation in harvest, some of which is due to changing regulations and market forces in the Pacific cod fishery. A large interannual variability in octopus abundance is also consistent with anecdotal reports (Paust 1988, 1997) and with life-history patterns for *E. dofleini*. Incidental catch was particularly high in fall 2011 with a total catch rate over 500 tons. It is estimated that only about 35 tons of this catch was retained, the rest was discarded either at sea or during plant delivery. Some of this increase in catch may come from better recordkeeping and reporting as octopus was moved into its own regulatory category. Incidental catch rates during the first part of 2012 were low.

Fisheries in Other Countries

Worldwide, fisheries for *Octopus vulgaris* and other octopus species are widespread in waters off southeast Asia, Japan, India, Europe, West Africa, and along the Caribbean coasts of South, Central, and North America (Rooper et al.1984). World catches of *O. vulgaris* peaked at more than 100,000 tons per year in the late 1960's and are currently in the range of 30,000 tons (www.fao.org). Octopus are harvested with commercial bottom trawl and trap gear; with hooks, lures and longlines; and with spears or by hand. Primary markets are Japan, Spain, and Italy, and prices in 2004 were near record highs (www.globefish.org). Prices were also high in 2011, due to a decrease in exports from two of the major suppliers, Morocco and Mauritania. Declines in octopus abundance due to overfishing have been suggested in waters off western Africa, off Thailand, and in Japan's inland sea. Morocco has recently set catch quotas for octopus as well as season and size limits (www.globefish.org). Caddy and Rodhouse (1998) suggest that cephalopod fisheries (both octopus and squid) are increasing in many areas of the world as a result of declining availability of groundfish.

Fisheries for *E. dofleini* occur in northern Japan, where specialized ceramic and wooden pots are used, and off the coast of British Columbia, where octopus are harvested by divers and as bycatch in trap and trawl fisheries (Osako and Murata 1983, Hartwick et al. 1984). A small harvest occurs in Oregon as incidental catch in the Dungeness crab pot and groundfish trawl fisheries. In Japan, the primary management tool is restriction of octopus fishing seasons based on seasonal migration and spawning patterns. In British Columbia, effort restriction (limited licenses) is used along with seasonal and area regulation.

Descriptions of octopus management in the scientific literature tend to be older (before 1995) and somewhat obscure; formal stock assessments of octopus are rare. Cephalopods in general (both octopus and squid) are difficult to assess using standard groundfish models because of their short life span and terminal spawning. Caddy (1979, 1983) discusses assessment methods for cephalopods by separating the life cycle into three stages: 1) immigration to the fishery, including recruitment; 2) a period of relatively constant availability to the fishery; and 3) emigration from the fishery, including spawning. Assuming that data permit separation of the population into these three stages, management based on estimation of natural mortality (equivalent to Tier 5) can be used for the middle stage. He also emphasizes the need for data on reproduction, seasonal migration, and spawner-recruit mechanisms. General production models have been used to estimate catch limits for *O. vulgaris* off the African coast and for several squid fisheries (Hatanaka 1979, Sato and Hatanaka 1983, Caddy 1983). These models are most appropriate for species with low natural mortality rates, high productivity, and low recruitment variability (Punt 1995), which makes them difficult to apply to cephalopods. Another approach, if sufficient data are available, is to establish threshold limits based on protecting a minimum spawning biomass (Caddy 2004). Perry et al. (1999) suggest a framework for management of new and developing invertebrate fisheries. The BSAI octopus fishery is clearly in phase 0 of Perry's framework, where existing information is being collected and reviewed.

Data

Incidental Catch Data

Octopus are captured in both state and federal waters off Alaska. Reported harvest of octopus from incidental catch in state fisheries in the BSAI ranged from 18-69 mt between 1996 and 2002, but was 100-300 mt in 2003-2006 (Sagalkin and Spalinger 2011). From 1992-2002 total incidental catch of octopus in federal waters, estimated from observed hauls, was generally between 100 and 400 mt (Table 22.2). Since 2003 the total octopus catch in both state and federal waters (including discards) has been estimated using the NMFS Alaska Regional Office catch accounting system. Minor updates and changes to this system in 2010 changed estimated catch numbers slightly from previous assessments. Total incidental catch during this period has continued to be 200-400 tons in most years, with very high year-to year variation from 2006 - 2011. Total catch was generally high (300-500 tons) in 2003-2006 and low (<200 tons) in 2007-2010, with only 72 tons caught in 2009. The low octopus catch during this period may be a result of a decline in processor demand and a drop in cod pot-fishing effort due to a decline in the market price of cod and increased fuel prices. Catch in 2011 was the highest ever observed, reaching 534 tons by mid-October. On September 1, 2011 the NMFS regional office prohibited retention of octopus because the TAC of 150 tons had been reached. Catch rates for Pacific cod and incidental catch rates for octopus were both very high during fall 2011 and the octopus OFL of 428 mt was reached; the NMFS closed directed fishing for Pacific cod with pot gear in the BSAI on October 21, 2011. As in previous years, the majority of the 2011 catch came from Pacific cod fisheries, primarily pot fisheries in statistical reporting areas 519, 517, and 509. The incidental catch of octopus in the Aleutian Islands (statistical areas 541, 542, and 543) was low in 2011. The majority of the BSAI octopus catch in 2011 was not retained, but discarded either at sea or at processing plants. Of the 534 tons caught by Oct 15, only 35 tons were retained. Catch for 2012 has been low, with only 86 tons caught through October 2, 2012.

AFSC Survey Data

Catches of octopus are recorded during the annual NMFS bottom trawl survey of the Bering Sea shelf and biennial surveys of the Bering Sea slope and Aleutian Islands. In older survey data (prior to 2002), octopus were often not identified to species; other species may also have been sometimes misidentified as *E. dofleini*. Since 2002, increased effort has been put into cephalopod identification and species composition data are considered more reliable. Species composition data from the summer Bering Sea shelf surveys in 2007-2012 and from the three most recent Bering Sea slope and Aleutian Island surveys are shown in Tables 22.3 and 22.4. These catches are our only source of species-specific information within the species group. In general, the shelf survey rarely encounters octopus (less than 15% of the tows contain octopus), while the slope survey finds octopus in over half the tows. The dominant species on the shelf is *E. dofleini*, accounting for over 80% of the estimated shelf octopus biomass. The slope survey, which covers deeper waters, encounters a much wider variety of octopus species. The species most abundant numerically in the slope survey is the newly identified *Sasakiopus salebrosus* (previously thought to be a *Benthoctopus* species). Numerous tows contained several individuals of this species. As this species is very small-bodied, however, the estimated biomass of the slope is still dominated by *E. dofleini* (Table 4). Recent slope surveys also included substantial catches of *Opisthoteuthis californiana, Benthoctopus leioderma, and Graneledone boreopacifica.* The Aleutian Islands survey encounters octopus in about a quarter of the tows, primarily *E. dofleini.*

Survey data are beginning to provide information on the spatial and depth distribution of octopus species. Octopues are rarely caught in Bristol Bay and the inner front. Survey catches of octopus in the Bering Sea shelf are most frequent on the outer shelf adjacent to the slope and in the northernmost portions of the survey. The majority of survey-caught octopuses are caught at depths greater than 60 fathoms (110 meters), with roughly a third of all survey-caught octopuses coming from depths greater than 250 fathoms (450 meters). Biomass estimates from the slope surveys suggest that *Opisthoteuthis californiana,* and *Benthoctopus leioderma* are distributed primarily toward the southern portion of the slope, while *Granoledone boreopacifica* and *Benthoctopus oregonensis* are found primarily at the northern end. *E. dofleini* were found throughout the slope survey.

Species are stratified by size and depth with larger (and fewer) animals living deeper and smaller animals living shallower. *E. dofleini* have a peak frequency of occurence at 250 m, *Sasakiopus salebrosus* peaks at 450 m, *B. leioderma* peaks at 450 and 650 m, and *G. boreopacifica* peaks at 1,050 m. At depths less than 200 m, *E. dofleini* is the most common species. The Aleutian Island survey in 2010 caught octopus throughout the Aleutian Island chain, primarily at depths of 75-200 m. It is important to note that survey data only reflect summer spatial distributions and that seasonal migrations may result in different spatial distribution in other seasons.

The size distribution by weight of individual octopus collected by the Bering Sea shelf bottom trawl surveys from 2008 through 2011 is shown in Figure 22.2 (compared to size frequencies in commercial catch in Figure 22.3). Survey-caught octopus ranged in weight from less than 5 g up to 25 kg; 50% of all individuals captured in the shelf survey were <0.5 Kg. This pattern continues into the most recent shelf survey data. The slope survey captures more *E. dofleini* in the 0.5-3 kg range than the shelf survey; both surveys collect the occasional animal over 10 kg. In the 2008 surveys, the largest octopus caught were 4.5 kg for the shelf survey and 16.6 kg for the slope survey, both of which were *E. dofleini*. Data from the 2008 - 2012 slope survey show the marked difference in size distributions between the three most common species: *E. dofleini*, *B. leioderma*, and *S. salebrosus* (Figure 22.4, note x-axis scales are different). In general, the large individuals of *E. dofleini* typically seen in pot gear may be under-represented in trawl survey data because of increased ability to avoid the trawl.

Biomass estimates for the octopus species complex based on bottom trawl surveys are shown in Table 22.5. These estimates show high year-to-year variability, ranging over two orders of magnitude. There is a large sampling variance associated with estimates from the shelf survey because of a large number of tows that have no octopus. It is impossible to determine how much of the year to year variability in estimated biomass reflects true variation in abundance and how much is due to sampling variation. In 1997, the biomass estimate from the shelf survey was only 211 mt, approximately equal to the estimated BS commercial catch (Table 22.2). This suggests that the 1997 biomass estimate was unreasonably low. In general, shelf survey biomass was low in 1993-1999; high in 1990-1992 and in 2003-2005, and low again in 2006 -2010 (Figure 22.5). Shelf survey biomass increased to 3,554 mt in 2011 and was 2,567 mt in 2012. The estimated total biomass from the 2012 slope survey was double the 2010 catch at 1,421 mt, due in part to large catches of *O. californiana* and *G. boreopacifica.* The 2012 estimate of biomass in the Aleutian Islands was 2,779 mt, slightly lower than the 2010 estimate.

Federal Groundfish Observer Program Data

Groundfish observers record octopus in commercial catches as either “octopus unidentified” or “pelagic octopus unidentified”. Therefore, we do not know which species of octopus are in the catch. Observer records do, however, provide a substantial record of catch of the octopus species complex. Figure 22.1 show the spatial distribution of observed octopus catch in the BSAI. The majority of octopus caught in the fishery come from depths of 40-80 fathoms (70-150 m). This is in direct contrast to the depth distribution of octopus caught by the survey. This difference is probably reflective of the fact that octopus are generally taken as incidental catch at preferred depths for Pacific cod. The size distribution of octopus caught by different gears is very different (Figure 22.3); commercial cod pot gear clearly selects for larger individuals. Over 86% of octopus with individual weights from observed pot hauls weighed more than 5 kg. Based on size alone, these larger individuals are probably *E. dofleini*. Commercial trawls and longlines show size distributions more similar to that of the survey, with a wide range in sizes and a large fraction of octopus weighing less than 2 kg. These smaller octopuses may be juvenile *E. dofleini* or may be any of several species, including the newly identified *Sasakiopus salebrosus*.

Temporal catch patterns in the pot fishery are primarily determined by seasonal timing of pot fishing for Pacific cod; the overwhelming majority of octopus incidental catch comes during the primary cod seasons January-March and September-October. There is very little pot fishing effort, and very little octopus catch, during May-August and November-December. Spatial patterns in octopus catch are primarily determined by gear conflict considerations and proximity to processors. The majority of pot boats are catcher boats with a 72-hour limit for delivery of Pacific cod, so the pot effort is concentrated close to processing ports in the southeast Bering Sea and the Pribilov Islands (Figure 22.6). Most pot fishing and most octopus catch is concentrated in the regulatory no-trawl zones around Unimak Pass, where gear conflict with trawlers is avoided and trip duration is brief (Table 22.6). It is unlikely that either of the predominant temporal or spatial patterns represents significant seasonal or spatial trends of the octopus population. What is apparent from the available data is that octopus catch rates are often notably higher in the fall cod season than in the winter; this may reflect seasonal movements of octopus related to mating. Both pot effort and octopus catch rates are consistently highest in NMFS statistical reporting area 519, on the north side of Akutan and Akun Islands, just west of Unimak Pass. This area is heavily fished in part because the regulatory no-trawl zones around Steller sea lion rookeries and haulouts make it easy to avoid conflicts with trawlers, and cod catches are consistent. Since octopus are an item in Steller sea lion prey in the BSAI, however, the proximity of the major incidental catch to rookeries is a factor that should be noted (see discussion under "Ecosystem Considerations".

Observer Special Project Data

Since 2006, some fishery observers have also been collecting data for a special project on octopus. These observers record the individual weights of all octopus caught to improve size frequency distribution data. The observers also determine and record the sex of each octopus from external characters (male octopus have one arm especially adapted for mating). Octopus are also sampled in processing plants. Data collection for this project continues through 2012.

The special project data reflect the size selectivity in gear as seen in Figure 22.3. Octopus collected on cod pot boats were generally in the range of 5-20 kg, while octopus caught in trawl gear were often less than 2 kg. All of the octopus observed at the processing plants were over 3 kg gutted weight, with average gutted weights of 13.3 and 13.4 kg for males and females respectively. Male octopus predominated in pot catch and processing plant deliveries in both years by a factor of at least 2:1. Sex ratios from octopus observed on vessels differed between the two years, in part because the 2007 data includes both winter 2007 and fall 2006 data. In the first year of the study, males predominated in pot catch but females dominated in other gear types. In 2007, males were more common in bottom trawl catch; the sex ratio in pot catch was near even, and females predominated in pelagic trawl and longline observations. The reason that pot catch seems to include more males than other gear types is not known, but probably reflects the fact that pots select for larger animals and draw catch by scent. It is possible that male octopus move around more than females in searching for mates, and so have a higher chance of encountering pots (Roland Anderson, Seattle Aquarium, personal communication Oct 2007).

Species Composition of the Catch

A NOAA Cooperative Research Program project was conducted in 2006 and 2007 by AFSC scientist Elaina Jorgensen. Processing plants buying octopus were visited in Dutch Harbor and Kodiak in October 2006 and February-March 2007. A total of 282 animals were examined at Harbor Crown Seafoods in Dutch Harbor and 102 animals at Alaska Pacific Seafoods in Kodiak. Species identification of octopus observed in plant deliveries confirmed that all individuals were *E. dofleini*. All animals delivered to the plants came from the Pacific cod pot fishery. Octopus in Dutch Harbor ranged from 4.5 to 27.7 kg gutted weight with an average gutted weight of 13.6 kg.

Discard Mortality for Octopus

Mortality of discarded octopus is expected to vary with gear type and octopus size. Mortality of small individuals and deep-water animals in trawl catch is probably high due to compression in the cod end. Larger individuals may also have high trawl mortality if either towing or sorting times are long. Octopus caught with longline and pot gear are more likely to be handled and returned to the water quickly, thus improving the probability of survival. Octopuses have no swim bladder and are not affected by depth changes, and can survive out of water for brief periods. Large octopus caught in pots were very active during AFSC field studies and are expected to have a high survival rate. Octopus survival from longlines is probably high unless the individual is hooked through the mantle or head. Observers report that octopus in longline hauls are often simply holding on to hooked bait or fish catch and are not hooked directly. At present, catch accounting for octopus uses the conservative assumption of 100% mortality for all octopus caught, whether retained or discarded.

Data collected by the observer special project in 2006 and 2007 included a visual evaluation of the condition of the octopus when it was processed by the observer. In 2010 and 2011, the special project was modified so that observers recorded the condition of octopus at the point of discard from the vessel. The 2010-11 project included a three-stage viability coding (Excellent, Poor, or Dead) based on the color and mobility of octopus and the presence of visible wounds. Data from both projects are presented in Table 22.7. The table shows the number of observations and the proportion of observed octopus alive or dead for each gear type. These results provide partial data on the nature of discard mortality for octopus. In particular, the observed mortality rate for octopus caught in pot gear in 2006-2007 was less than one percent (two octopus out of 433, one coded as dead and the other as injured). In 2010-11, only 4 percent (30 out of 536) of the octopus caught in pot gear were in poor condition or dead at the point of discard. Mortality rates in both time periods were roughly 20% for longline gear; observers report that most animals seen on longlines are not actually hooked but are holding on to bait or hooked fish. Bottom trawl mortality rates were variable at 58-74 %, variable conditions may be expected since this category includes several different target fisheries. Mortality rates were highest for pelagic trawl gear, for which 85% of the observed octopus in both periods were dead.

These data suggest that a gear-specific discard mortality factor could be estimated for octopus, similar to approach currently used for Pacific halibut. If a discard mortality factor were included in catch accounting for octopus, the fraction of discarded octopus that are assumed to survive would not be counted toward the total “take” for the assemblage. Similar to the current practice used in Bering Sea crab assessments, the estimated catch for octopus would include all retained and dead animals, but only a percentage of those discarded alive. Estimated or assumed mortality rates would be assigned to each condition level, and combined with the observer data for a gear-specific estimate of the percentage mortality of discarded octopus. For example, if we assumed 75% survival for octopus discarded in excellent condition, then 96% * 75% = 72% of octopus discarded from pot vessels could be assumed to survive (mortality = 1- survival = 28%).

Research is currently underway to quantify the total mortality of discarded octopus in relation to condition coding. While many of the octopus in the observer study were rated in “Excellent” condition at discard, it is not known whether there is some delayed mortality due to handling stress or temperature changes during capture and discard. Laboratory and field experiments have been funded for 2012-2013 to examine delayed mortality in octopus caught by commercial cod pots. The goal of these projects is to develop measures to assess stress in captured octopus and to estimate the proportion of octopus that are alive at discard but later die due to being caught and handled. Results from these studies could be combined with the observer data into overall gear-specific estimates of discard mortality for octopus.

In October of 2012, a brief field study was conducted by Reid Brewer of UAF. In this study, 15 *E. dofleini* captured as part of the Bering Sea pot cod fishery were fitted with video cameras and released. Go Pro HD video cameras were attached to each of the 15 *E. dofleini* and were retrieved using heavy duty fishing poles. The mean depth was 50.2 m with a range of 40.2 to 66.7m and the mean time to the sea floor was 5 min 32 seconds with a range of 2 min 3seconds to 9 min 50 seconds. Each of the 15 *E. dofleini* actively swam to depth and showed color and body positioning changes upon reaching the sea floor. Though this project does not determine the survival of *E. dofleini* beyond reaching the sea floor, Brewer and Norcross (2012) recaptured 243 tagged *E. dofleini* at least 24 hours after release. Together, these two studies also suggest that a large portion of discarded *E. dofleini* are making it to the sea floor and surviving capture and handling. More work with video cameras is planned for 2013.

Analytic Approach, Model Evaluation, and Results

The available data do not support population modeling for either individual species of octopus in the BSAI or for the multi-species complex. As better catch and life-history data become available, it may become feasible to manage the key species *E. dofleini* through methods such as general production models, estimation of reproductive potential, seasonal or area regulation, or size limits. Parameters for Tier 5 catch limits can be estimated (poorly) from available data and are discussed below. Catch limits under Tier 6 have also been calculated. An alternative Tier 6 method, based on predation mortality, is also proposed.

Parameters Estimated Independently – Biomass B

Estimates of octopus biomass based on the annual Bering Sea trawl surveys (Table 22.5, Figure 22.5) represent total weight for all species of octopus, and are formed using the sample procedures used for estimating groundfish biomass based on the area-swept method (National Research Council 1998, Wakabayashi et al 1985). The positive aspect of these estimates is that they are founded on fishery-independent data collected by proper design-based sampling. The standardized methods and procedures used for the surveys make these estimates the most reliable biomass data available for many groundfish and invertebrate species. The survey methodology has been carefully reviewed and approved in the estimation of biomass for other federally-managed species. There are, however, some serious drawbacks to use of the trawl survey biomass estimates for octopus.

Older trawl survey data, as with fishery or observer data, are commonly reported as octopus sp., without full species identification. In surveys from 1997 – 2001, from 50 to 90% of the total biomass of octopus collected was not identified to species. In more recent years up to 90% of collected octopus are identified to species, but some misidentification may still occur. Efforts to improve species identification and collect biological data from octopus are being made, and biomass estimates by species are available from the most recent surveys, but the variability associated with these estimates is very high. In most survey strata, over 90% of the hauls do not contain any octopus at all, so the estimation of biomass is based on only a few tows where octopus are present. This leads to high uncertainty in the biomass estimate, especially in years when the estimate is large (Figure 22.5).

Secondly, a trawl is probably not the most appropriate gear for sampling octopus. The bottom trawl net used for the Bering Sea shelf survey has no roller gear and tends the bottom fairly well, especially on the smooth sand and silt bottoms that are common to the shelf. The nets used in the Bering Sea slope, Aleutian Island, and GOA surveys, however, have roller gear on the footrope to reduce snagging on rocks and obstacles. Given the tendency of octopus to spend daylight hours near dens in rocks and crevices, it is entirely likely that both types of net have poor efficiency at capturing benthic octopus (D. Somerton, personal communication, 7/22/05). Trawl sampling is not feasible in areas with extremely rough bottom and/or large vertical relief, exactly the type of habitat where den spaces for octopus would be most abundant (Hartwick and Barringa 1997). The survey also does not sample in inshore areas and waters shallower than 30m, which may contain sizable octopus populations (Scheel 2002). The estimates of biomass in Table 22.5 are based on a gear selectivity coefficient of one, which is probably not realistic for octopus. For these reasons, the survey biomass estimates are likely much less than the true octopus biomass in the regions covered by the survey. In addition, the sampling variability of survey biomass estimates is very high, which may mask year-to-year variability or trends in octopus abundance.

Finally, there is considerable lack of overlap between the trawl survey and fishery data in the size range of octopus caught, the depth distribution of octopus catch, and the timing of catch. The average weight for individual octopus in survey catches is less than 2 kg; over 50% of survey-collected individuals weigh less than 0.5 kg. Larger individuals are strong swimmers and may disproportionately escape trawl capture. In contrast, the average weight of individuals from experimental pot gear was 18 kg. Pot gear is probably selective for larger, more aggressive individuals that respond to bait, and smaller octopus can easily escape commercial pots while they are being retrieved. The trawl survey also tends to catch octopus in deeper waters associated with the shelf break and slope; in 2002-2004 less than 30% of the survey-caught octopus came from depths less than 100 fathoms, where nearly all of the observed commercial catch is taken. Both rapid growth of individual octopus and possible seasonal movements make it difficult to compare the summer trawl survey with octopus vulnerable to fall and winter cod fisheries. Given the large differences in size and depth frequency, it is difficult to presume that the survey accurately represents the part of the octopus population that is subject to commercial harvest.

If future management of the octopus complex is to be based on biomass estimates, then species-specific methods of biomass estimation should be explored. Octopuses are readily caught with commercial or research pots. The recent NPRB project has shown that a species-specific index survey using habitat pot gear is feasible. Given the strong spatial focus of the harvest, an index survey of regional biomass in the Unimak Pass area would give useful information on population trends in the portion of the population most susceptible to harvest. It may also be feasible to estimate regional octopus biomass based on mark-recapture studies currently being conducted.

Parameters Estimated Independently

Mortality Rate M

Since *E. dofleini* are terminal spawners, care must be taken to estimate mortality for the intermediate stage of the population that is available to the fishery but not yet spawning (Caddy 1979, 1983). If detailed, regular catch data within a given season were available, the natural mortality could be estimated from catch data (Caddy 1983). When this method was used by Hatanaka (1979) for the west African *O. vulgaris* fishery, the estimated mortality rates were in the range of 0.50-0.75. Mortality may also be estimated from tagging studies; Osako and Murata (1983) used this method to estimate a total mortality of 0.43 for the squid *Todarodes pacificus*. Empirical methods based on the natural life span (Hoenig 1983, Richter and Efanov 1976) or von Bertalanffy growth coefficient (Charnov and Berrigan 1991) have also been used. While these equations have been widely used for finfish, their use for cephalopods is less well established. Perry et al. (1999) and Caddy (1996) discuss their use for invertebrate fisheries.

We attempted to estimate mortality for Bering Sea octopus from survey-based estimates of biomass and population numbers, however the values were too variable to allow accurate estimation. If we apply Hoenig's (1983) equation to *E. dofleini*, which have a maximum age of five years, we obtain an estimated M of 0.86. Rikhter and Efanov's (1976) equation gives a mortality value of 0.53 based on an age of maturity of 3 years for *E. dofleini*. The utility of maturity/ mortality relationship for cephalopods needs further investigation, but these estimates represent the best available data at this time. The Rikhter and Efanov estimate of M**=0.53** represents the most conservative estimate of octopus mortality, based on information currently available. If future management of octopus is to be based on Tier 5 methods, a direct estimate of octopus mortality in the Bering Sea, based on either experimental fishing or tagging studies, is desirable. The tagging study currently underway in the Bering Sea, when completed, should provide natural mortality rate estimates for the octopus that are vulnerable to commercial pot gear.

Parameters Estimated Independently – Natural Mortality N

The 2011 BSAI octopus is assessment introduced a **new methodology** for examining population trends in octopus. This approach uses the underlying model from Tier 5, where fishing catch is equated to a total natural mortality (in tons). For Tier 5 stocks, the total natural mortality is usually estimated as the product of biomass and instantaneous mortality rate N=MB. The new method uses a different approach to estimate total natural mortality that does not rely on being able to estimate biomass.

While we have unreliable data on octopus biomass, we have reliable data on one of the octopus' major predators – Pacific cod. The new method uses data from the AFSC's food habits database to estimate the total amount of octopus consumed by Pacific cod. This number could be considered **a conservative** estimate of the total natural mortality N for octopus, since it does not include mortality from other predators (*i.e*. marine mammals; Fig. 22.7) or non-predation mortality.

Pacific cod food habits analysis

Since 1982, the Alaska Fisheries Science Center has collected and analyzed the stomachs of 48,665 Pacific cod stomachs from the Bering Sea, 9,200 from the Gulf of Alaska, and 4,528 from the Aleutian Islands. Stomachs are primarily collected on RACE groundfish surveys during the summer, but substantial additional samples have been collected by fisheries observers throughout the winter (Figure 22.8). For these estimates, we have used samples collected during the summer groundfish survey only, as winter samples, associated with observed fishing operations, do not provide full geographic coverage for making population-level estimates (Figure 22.8, bottom panel). Stomachs are analyzed on shipboard or preserved in formalin and analyzed in the lab, where the weight composition of each prey type in the stomach is measured. Prey are identified to the lowest possible taxonomic resolution; to date, octopus are not generally identified to species.

Octopus occur in cod stomachs in both the summer and the winter (red circles, Figure 22.8) and so represent a regular, but not majority diet item for Pacific cod. Pooling across all years and regions, octopus is considerably lower in diets in water shallower than 75m, increasing to approximately 10% occurrence in cod captured between 100-250m depth (Figure 22.9, top). Octopus consumption also shows a strong relationship with Pacific cod length, being rare in cod with fork lengths less than 30cm, increasing to 7% for 50cm+ cod (Figure 22.9, bottom). Initial exploration with Generalized Additive Models (GAMs) suggests that the depth and length relationships are relatively independent and not a function of season or year.

The diets of Pacific cod for all years and seasons combined, broken out by region (AI, BS, and GOA) and depth (<100m and ≥100m) are shown in Figures 22.10-22.11. Generally, small cod feed on zooplankton, transitioning to benthos and shrimp, and finally to fish, primarily pollock in the BS and GOA and Atka mackerel (part of "other fish") in the AI. Octopus are nearly absent from the diet of cod in shallower water (Figure 22.10). In deeper water, for larger size classes of cod, octopus are up to 10% of prey by weight (Figure 22.11).

The weight (and therefore age or life stage) of octopus consumption is an important consideration when comparing to fisheries data. Octopus specimens recovered from Pacific cod stomachs are not directly measureable to individual weight, due to digestion. However octopus beaks are hard parts that are frequently recovered whole. To measure the size of consumed octopus, in 2012 we worked to obtain data to calibrate regressions between octopus weight and octopus beak hood length (both the upper and lower beaks). This year, we obtained whole octopus from fisheries samples and developed an initial regression between beak size and octopus weight (Figure 22.12, top); the regressions showed a strong relationship.

Further, we are currently measuring all octopus beaks found in Pacific cod stomachs, the initial data (from 2011 samples) are shown in Figure 22.12, bottom).

Results of these measurements indicate that the largest beaks eaten by cod generally correspond with the smallest (1-2kg) octopus in the commercial samples, with the majority of octopus eaten by cod being smaller (Figure 22.12, compare top and bottom graphs). However, an exact weight frequency is not obtainable at this time, both due to limited sampling to date, and the lack of smaller octopus in the regression set. We have obtained samples of smaller whole octopus to extend the regression, and expect to develop better weight frequency over the next 1-2 years.

However, it is also important to note that there is a strong relationship between size of octopus beak and size of cod, with larger cod feeding on larger octopus (Figure 22.13); the larger cod, with higher ration and larger percentage of octopus in diet, do overlap in size composition with the smaller octopus in the fisheries, although insufficient data exists for a quantitative weight frequency or weight-specific mortality calculation.

Estimation of annual consumption of octopus by Pacific cod

Cod predation on octopus was estimated using the following formula: $C_y = \sum_{s,l} N_{y,s,l} \cdot R_l \cdot DC_{y,s,l}$, where C_y is the total consumption (t/year) of octopus by cod in a given year y; $N_{y,s,l}$ is the number of cod in the bottom trawl survey for year y, survey stratum s, and length l; R_l is the annual ration for a cod (t prey/cod), and $DC_{y,s,l}$ is the proportion by weight of octopus in the diet of cod by year, stratum, and cod length. Therefore, the units of t/year octopus are the same as the units of the combined **M·B** caused by cod, while not relying on separate estimates of M or B for octopus. **It is important to note that, while this combined estimate of C_y (octopus consumed by cod) replaces the usual Tier 5 M·B reference point, it is neither possible nor necessary for this method to provide separate estimates for either of M or B.** Further, it should be noted that the quantity **M·B is an equilibrium reference quantity, so multiple years of estimates should be treated as improving the single reference point, rather than used as a moving average for catch.** This is especially important to the extent interannual variation is driven by predator fluctuations (cod); changing the reference point to track changing annual estimates would have the effect of increasing catch limits when predation is higher overall, leading in theory to greater fluctuations in the stock.

The EBS was divided into a total of 6 (standard areas 1-6) survey strata based on NW/NE orientation and depth. Each of the quantities N, R, and DC were estimated as follows:

1. Predator numbers $N_{y,s,l}$ were directly estimated from trawl survey numbers of Pacific cod for 1cm increments of cod, including 95% confidence intervals from the survey for each stratum and length bin. Since a comparison between survey biomass and stock assessment biomass of Pacific cod indicates that survey catchability is less than 1, using survey numbers therefore leads to a conservative estimate of overall cod numbers, and therefore a conservative estimate for predation.

2. Ration R_l was estimating following the methods of Essington et al. (2001) by fitting the generalized von Bertalanffy growth equation to weight-at-age data for GOA Pacific cod. The generalized Von Bertalanffy growth equation assumes that both consumption and respiration scale allometrically with body weight, and change in body weight over time (dW/dT) is calculated as follows:

$$\frac{dW_t}{dt} = H \cdot W_t^d - k \cdot W_t^n \qquad (1)$$

Here, W_t is body mass, t is the age of the fish (in years), and H, d, k, and n are allometric parameters. The term $H \cdot W_t^d$ is an allometric term for "useable" consumption over a year, in other words, the consumption (in wet weight) by the predator after indigestible portions of the prey have been removed and assuming constant caloric density between predator and prey. Total consumption is calculated as $(1/A) \cdot H \cdot W_t^d$, where A is a scaling fraction between predator and prey wet weights that accounts for indigestible portions of the prey and differences in caloric density (A=0.6 was used as an approximation from bioenergetics calculations; Aydin et al. 2008). The term $k \cdot W_t^n$ is an allometric term for the amount of biomass lost yearly as respiration.

Based on an analysis performed across a range of fish species, Essington et al. (2001) suggested that it is reasonable to assume that the respiration exponent n is equal to 1 (respiration linearly proportional to body weight). In this case, the differential equation above can be integrated to give the following solution for weight-at-age:

$$W_t = W_\infty \cdot \left(1 - e^{-k(1-d)(t-t_0)}\right)^{\frac{1}{1-d}} \qquad (2)$$

Where W_∞ (asymptotic body mass) is equal to $(H/k)^{\frac{1}{1-d}}$, and t_0 is the weight of the organism at time=0. From measurements of body weight and age, equation 2 can be used to fit four parameters (W_∞, d, k, and t_0) and the relationship between W_∞ and the H, k, and d parameters can then be used to determine the consumption rate $H \cdot W_t^d$ for any given length class of fish.
For these calculations, weight-at-age data available and specific to the modeled regions were fit by minimizing the difference between log(observed) and log(predicted) body weights from Pacific cod survey weight-at-age data. Separate estimates were performed for the GOA and EBS using AD Model Builder; estimates included MCMC-generated confidence intervals for ration (Figure 22.14). Interannual differences in consumption were not calculated.

2. Ration $DC_{y,s,l}$ was calculated for each year and stratum for three size classes of Pacific cod: (0-40cm, 40-60cm, and 60cm+). These size classes were determined based on sample size, and the size dependence of octopus consumption (Figure 22.9, bottom). **If a stratum, year, and size class combination contained less than 10 samples, the consumption of octopus in that stratum was assumed to be 0.** This was done to represent a conservative effort; methods of smoothing from neighboring strata were attempted but the noise of the data led to low confidence in such smoothed estimates. For each fish in the sample, stomach content weight was normalized by predator body weight; the total normalized octopus weight for all the fish in that stratum, and the normalized sum of all prey items, was converted into a percentage by weight. Confidence intervals were calculated by performing 10,000 Monte Carlo simulations for each stratum.

The **Total consumption of octopus (t/year)** estimated for the EBS is shown in Figure 22.15. There is no direct and evident relationship between total cod biomass and octopus consumption; a multivariate examination including differences in cod size composition and depth over time is planned. Estimates of annual predation mortality by Bering Sea cod on octopus range from <200 to almost 20,000 tons; the larger values have a high level of uncertainty. The majority of the annual estimates, however, lie in the range of 3,000 to 6,000 tons. We used the geometric mean of the posterior distribution to estimate annual predation for each year in the time series. The geometric mean is used rather than the arithmetic mean because the posterior distribution is right-skewed (higher values have higher uncertainty). We then used a geometric mean of the annual values to calculate a conservative long-term average predation rate over the 24 years of annual estimates. The geometric mean of all of the annual estimates is 3,452 tons, which is a full order of magnitude higher than the estimated rate of fishery catch of octopus. This calculation and mean value were presented in the 2011 stock assessment, and were selected by the plan team and SSC to set catch limits for the 2012 fishery.

Projections and Harvest Alternatives

We recommend that octopus be managed conservatively due to the poor state of knowledge of the species, life history, distribution, and abundance of octopus in the BSAI, and due to their important role in the diet of Steller sea lions. Continued monitoring and catch accounting for the octopus complex is essential. Efforts to set appropriate overfishing limits for octopus will continue to be limited by poor information on octopus abundance. Further research is needed in several areas before octopus could even begin to be managed by the stock assessment models used for commercial groundfish species.

Despite the lack of good information about octopus, the recent reauthorization of the Magnuson-Stevens act mandates that annual catch limits be set for all species and species complexes within the fishery management plan, even those that are not targets. Several possible methods for setting catch limits for octopus have been proposed in previous assessments (Conners and Jorgensen 2007, 2008; Conners and Conrath 2009, 2010). The OFL and ABC limits that would result from each of these approaches are summarized below. It would be possible to form a Tier 5 estimate based on survey biomass (an average of the most recent 3 surveys from Table 22.5 is 6,238 mt) and a mortality rate of 0.53 as described above; this estimate would set OFL at 3,306 tons. The plan teams and SSC have previously rejected this option because of the high uncertainty associated with the estimates of both B and M.

In 2011, the Plan Team and SSC recommended using biological reference points derived from consumption estimates for Pacific cod. This estimate of natural mortality (N) can then be combined with the general logistic fisheries model that forms the basis of Tier 5 assessments (Alverson and Petreyra 1969, Francis 1974) to set OFL = N and ABC = 0.75*OFL. Because the logistic model assumes equilibrium, we propose using a mean over all of the years of available data to estimate N. Because the posterior distribution of the estimates is right-skewed (higher variability at higher values), we have used geometric means both to for m the annual estimates from the posterior distribution and to take the long-term average of the annual estimates. When this method is used, the resulting catch limits are OFL = 3,452 mt and ABC = 2,589 mt. This number is considerably higher than the rate of current or historical incidental octopus catch, and similar to the estimate based on survey biomass.

The other decision that the Paln Teams and NMFS Alaska Regional Office may want to consider is whether or not it is desirable to incorporate gear-specific discard mortality estimates into catch accounting for octopus. Based on data from the observer program special project, the vast majority of octopus discarded at sea from pot vessels are alive and in excellent condition, which would argue for a discard mortality rates substantially lower than 100%. Although we do not at present have any experimental data on which to base a quantitative estimate of the delayed mortality of discarded octopus, conservative assumptions (e.g. assume 25% mortality of octopus in “excellent” condition, 100% for those in “poor” or “dead” condition) could be used as an interim measure until experimental data are available. Including a gear-specific mortality factor would make the estimate of octopus “taken” more consistent with actual fishing mortality. Since the majority of octopus incidental catch is with gears that have low mortality rates, this would minimize the likelihood of closure of groundfish fisheries due to high octopus bycatch. While the numbers of octopus retained would still be controlled by the TAC, the low mortality rate of discarded octopus would slow progress toward OFL for the assemblage. Whether the increased accuracy of catch accounting merits the increased complexity of introducing a separate calculation for this assemblage is a policy issue best decided through consultation between the Council, AKFIN, the AFSC, and the NMFS Alaska Regional Office.

We do not recommend a directed fishery for octopus in federal waters at this time, because data are insufficient for adequate management. We anticipate that octopus harvest in federal waters of the BSAI will continue to be largely an issue of incidental catch in existing groundfish fisheries.

Ecosystem Considerations

Little is known about the role of octopus in North Pacific ecosystems. In Japan, *E. dofleini* prey upon crustaceans, fish, bivalves, and other octopuses (Mottet 1975). Food habits data and ecosystem modeling of the Bering Sea and AI (Livingston et al 2003, Aydin et al 2008) indicate that octopus diets in the BSAI are dominated by other benthic invertebrates such as mollusks, hermit crabs (particularly in the AI), starfish, and snow crabs (*Chinoecetes sp.*). The Ecopath model (Figures 22.7 and 22.16) uses diet information on all predators in the ecosystem to estimate what proportion octopus mortality is caused by which predators and fisheries. Results from the early 1990s indicate that octopus mortality in the Bering Sea comes primarily from Pacific cod, resident seals (primarily harbor seal, *Phoca vitulina richardsi*), walrus and bearded seals, and sculpins; in the AI principal predators are Pacific cod, Pacific halibut, and Atka mackerel. Adult and juvenile Steller sea lions account for approximately 7% of the total mortality of octopus in the Bering Sea, but cause insignificant octopus mortality in the GOA and AI. Modeling suggests that fluctuations in octopus abundance could affect resident seals, Pacific halibut, Pacific cod, and snow crab populations. Modeling suggests that primary and secondary productivity and abundance of hermit crabs, snow crabs, resident seals, Pacific cod, and Pacific halibut affect octopus production.

While Steller sea lions (*Eumetopias jubatus*) are not a dominant predator of octopus, however, octopus are important prey item in the diet of Stellers in the Bering Sea. According to diet information from Perez (1990; Fig. 22.16) octopus are the second most important species by weight in the sea lion diet, contributing 18% of adult and juvenile diets in the Bering Sea. Diet information from Merrick et al (1997) for the AI, however, do not show octopus as a significant item in sea lion diets. Analysis of scat data (Sinclair and Zeppelin 2002) shows unidentified cephalopods are a frequent item in Steller sea lion diets in both the Bering Sea and Aleutians, although this analysis does not distinguish between octopus and squids. The frequency of cephalopods in sea lion scats averaged 8.8% overall, and was highest (11.5-18.2%) in the Aleutian Islands and lowest (<1 – 2.5%) in the western GOA. Based on ecosystem models, octopus are not significant components of the diet of northern fur seals (*Callorhinus ursinus*). Proximate composition analyses from Prince William Sound in the GOA (Iverson et al 2002) show that squid had among the highest high fat contents (5 to 13%), but that the octopus was among the lowest (1%).

Little is known about habitat use and requirements of octopus in Alaska (Table 22.8). In trawl survey data, sizes are depth stratified with larger (and fewer) animals living deeper and smaller animals living shallower. However, the trawl survey does not include coastal waters less than 30 m deep, which may include large octopus populations. Hartwick and Barriga (1997) reported increased trap catch rates in offshore areas during winter months. Octopus require secure dens in rocky bottom or boulders to brood its young until hatching, which may be disrupted by fishing effort. Activity is believed to be primarily at night, with octopus staying close to their dens during daylight hours. Hartwick and Barriga (1997) suggest that natural den sites may be more abundant in shallow waters but may become limiting in offshore areas. In inshore areas of Prince William Sound, Scheel (2002), noted highest abundance of octopus in areas of sandy bottom with scattered boulders or in areas adjacent to kelp beds.

Distributions of octopus along the shelf break are related to water temperature, so it is probable that changing climate and ice cover in the Bering Sea is having some effect on octopus, but data are not adequate to evaluate these effects.

Data Gaps and Research Priorities

Recent efforts have improved collection of basic data on octopus, including catch accounting of retained and discarded octopus and species identification of octopus during research surveys. Both survey and observer efforts provide a growing amount of data on octopus size distributions by species and sex and spatial separation of species. Studies currently underway are expected to yield new information on the life-history cycle of *E. dofleini* in Alaskan waters, and may lead to development of octopus-specific field methods for capture, tagging, and index surveys. The AFSC has kept in communication with the state of Alaska regarding directed fisheries in state waters, gear development, octopus biology, and management concerns.

Identification of octopus to species is difficult, and we do not expect that either fishing industry employees or observers will be able to accurately determine species on a routine basis. A publication on cephalopod taxonomy and identification in Alaska has recently been published (Jorgensen 2009). Efforts to improve octopus identification during AFSC trawl surveys will continue, but because of seasonal differences between the survey and most fisheries, questions of species composition of octopus incidental catch may still be difficult to resolve. Octopus species could be identified from tissue samples by genetic analysis, if funding for sample collection and lab analysis were available. Special projects and collections in octopus identification and biology will be pursued as funding permits.

Because octopuses are semelparous (breeding only once), a better understanding of reproductive seasons and habits is needed to determine the best strategies for protecting reproductive output. *E. dofleini* in Japan and off the US west coast reportedly undergo seasonal movements, but the timing and extent of migrations in Alaska is unknown. While many octopus move into shallower coastal waters for egg-laying, it is probable that at least some BSAI octopus reproduction occurs within federal waters. The distribution of octopus biomass and extent of movement between federal and state waters is unknown and could become important if a directed state fishery develops. Tagging studies to determine seasonal and reproductive movements of octopus in Alaska are underway and will enhance our ability to appropriately manage commercial harvest. If feasible, it would be desirable to avoid harvest of adult females following mating and during egg development. Larger females, in particular, may have the highest reproductive output (Hartwick 1983).

Factors determining year-to year patterns in octopus abundance are poorly understood. Octopus abundance is probably controlled primarily by survival at the larval stage; substantial year-to-year variations in abundance due to climate and oceanographic factors are expected. The high variability in trawl survey estimates of octopus biomass make it difficult to depend on these estimates for time-series trends; trends in CPUE from observed cod fisheries may be more useful.

Fishery-independent methods for assessing biomass of the harvested size group of octopus are feasible, but would be species-specific and could not be carried out as part of existing multi-species surveys. Pot surveys are effective both for collecting biological and distribution data and as an index of abundance; mark-recapture methods have been used with octopus both to document seasonal movements and to estimate biomass and mortality rates. These methods would require either extensive industry cooperation or funding for directed field research.

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Table 22.1. Species of Octopodae found in the BSAI.

	Scientific Name	Common Name	General Distribution	Age at Maturity	Size at Maturity
Class	Cephalopoda				
Order	Vampyromorpha				
Genus	*Vampyroteuthis*				
Specie	***Vampyroteuthis infernalis***	vampire squid	Southeast BS Slope >300 m	unknown	unknown
Order	Octopoda				
Group	Cirrata				
Family	Opisthoteuthidae				
Genus	*Opisthoteuthis*				
Species	***Opisthoteuthis*** cf ***californiana***	flapjack devilfish	BS deeper than 200 m	unknown	unknown
Group	Incirrata				
	Bolitaenidae				
	Japetella				
	Japetella diaphana	pelagic octopus	Pelagic	unknown	< 300 g
Family	Octopodidae				
Genus	*Benthoctopus*				
Species	***Benthoctopus leioderma***	smooth octopus	Southern BS deeper than 250 m	unknown	< 500 g
	Benthoctopus oregonensis	none	BS shelf break	unknown	> 2 kg
Genus	*Enteroctopus*				
Species	***Enteroctopus dofleini***	giant octopus	all BSAI, from 50 - 1400 m	3 - 5 yr	>10 kg
Genus	*Graneledone*				
Species	***Graneledone boreopacifica***	none	BS shelf break 650 - 1550 m	unknown	unknown
Genus	*Sasakiopus*				
	Sasakiopus salebrosus	stubby octopus	BS shelf break, 200 - 1200 m	unknown	75 - 150 g

Table 22.2. Estimated catch (mt) of all octopus species in state and federal waters. 1997-2002 estimated from blend data. 2003-2012 data from AK region catch accounting, as provided in October 2012. Catch is shown separately for the two target fisheries that have the highest rate of incidental octopus catch, Pacific cod and flatfish. Note that slight revisions to the catch accounting database in 2010 have slightly changed the 2003-2008 number from preceding assessments. The estimated percentage of total catch retained is shown for 2003-2012. *2012 data includes only part of the year, January – October 6, 2012.

	Target Species				
Year	**P cod**	**FlatF**	**Other**	**Total**	**% Retained**
1997	160	86	3	248	
1998	168	13	9	190	
1999	310	14	2	326	
2000	359	57	3	418	
2001	211	9	7	227	
2002	334	21	19	374	
2003	216	34	19	269	38%
2004	279	45	205	338	24%
2005	311	17	10	338	64%
2006	331	5	14	351	55%
2007	166	7	9	181	39%
2008	193	11	8	212	37%
2009	57	10	6	72	23%
2010	161	11	6	177	33%
2011	565	9	14	587	6%
2012*	76	3	6	86	17%

Table 22.3. Species composition of octopus from recent AFSC Bering Sea and Aleutian Islands bottom trawl surveys: numbers of hauls containing octopus and numbers of octopus caught by species.

	Bering Sea Shelf Survey						Slope Survey			A.I. Survey		
	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2008**	**2010**	**2012**	**2006**	**2010**	**2012**
Number of Hauls	376	375	376	376	422	376	200	200	187	358	418	420
No. Hauls w/ Octopus	32	26	37	47	43	39	113	110	114	86	99	80
Species	**Count of Octopus Caught**											
Enteroctopus dofleini	61	51	47	124	69	48	57	63	76	124	162	69
Sasakiopus salebrosus				17			73	94	72			3
Benthoctopus leioderma	5	7	35	4	14	29	89	62	66	1		3
Graneledone boreopacifica							41	33	57			
Opisthoteuthis californiana							39	39	190	3		1
Benthoctopus oregonensis							8	3				
Japetella diaphana							16	1	3			
Octopus sp.	8	1	2				1		3	6		
Benthoctopus sp.		2	2				1	18			1	
octopus unident.	6				11	1		1		6	6	4
All species	80	61	86	145	94	78	325	315	467	140	169	162

Table 22.4. Species composition of octopus from recent AFSC Bering Sea bottom trawl surveys: biomass estimates by species.

	Estimated Biomass (mt)						
	BS Slope Survey			**BS Shelf Survey**			
Species	**2008**	**2010**	**2012**	**2008**	**2010**	**2011**	**2012**
Enteroctopus dofleini	356.8	216.3	659.2	1,017	653.2	2,844	2,087
Graneledone boreopacifica	84.0	96.1	248.1				
Benthoctopus leioderma	155.8	86.6	134.7				
Benthoctopus sp.	0.44	76.9					
Opisthoteuthis californiana	156.1	70.4	342.4				
Sasakiopus salebrosus	23.6	32.2	28.6				
Benthoctopus oregonensis	28.1	27.8					
Opisthoteuthis sp.		14.6					
Japetella diaphana	10.0	0.5	6.4				
Vampyroteuthis infernalis		0.1					
octopus unident.	0.01	0.0	1.3				
All species	814.9	621.4	1,421	1,179	823.2	3,554	2,567
Pecentage *E. dofleini*	44%	35%	46%	86%	79%	80%	81%
Percentage *Benthoctopus*	23%	31%	9%				

Table 22.5. Biomass estimates in tons for octopus (all species) from AFSC bottom trawl surveys.

Year	EBS Shelf Survey Biomass	EBS Slope Survey Biomass	AI Survey Biomass	Total BSAI
1982	12,442	180		
1983	3,280		440	
1984	2,488			
1985	2,582	152		
1986	480		781	
1987	7,834			
1988	9,846	138		
1989	4,979			
1990	11,564			
1991	7,990	61	1,148	
1992	5,326			
1993	1,355			
1994	2,183		1,728	
1995	2,779			
1996	1,746			
1997	211		1,219	
1998	1,225			
1999	832			
2000	2,041		775	
2001	5,407			
2002	2,435	979	1,384	
2003	8,264			
2004	4,902	1,957	4,099	
2005	9,562			
2006	1,877		3,060	
2007	2,192			
2008	1,179	815		
2009	1,031			
2010	823	621	3,075	
2011	3,554			
2012	2,567	1,421	2,779	
Average All	4,031	703	1,863	6,597
Most Recent	2,567	1,421	3,075	7,063
Avg Last 3	2,315	952	2,971	6,238
OFL 3 survey average * M= 0.53				3,306
ABC 3 survey OFL * 75%				2,480

Table 22.6. Spatial and temporal distribution of pot fishing effort and incidental octopus catch for different gear types: POT – commercial pot, HAL – longline, NPT – non-pelagic trawl. A season is January 1 – June 9, B season is June 10-Dec 31. All data were screened to preserve confidentiality. Small catches from pelagic trawl and jig fisheries are not shown.

a) Incidental Octopus Catch in tons

Gear	Season	2003	2004	2005	2006	2007	2008	2009	2010	2011
POT	A seas	55	62	78	54	85	33	39	47	106
	B seas	85	89	179	220	46	130	2	78	400
HAL	A seas	18	17	19	25	13	9	4	7	19
	B seas	32	40	10	5	8	6	10	24	20
NPT	Year	27	70	25	27	14	15	2	5	19

b) 2011 Octopus Catch (t)

	NMFS Stat Area				
	509	517/519	521	Other	Total
A Season 2011					
POT Gear	60.0	45.2	-----	1.1	106.2
NPT Gear	15.2	2.5	-----	1.6	19.4
HAL Gear	8.4	11.0	4.6	2.4	26.4
B Season 2011					
POT Gear	81.8	301.3	-----	16.4	399.6
NPT Gear	-----	-----	-----	-----	-----
HAL Gear	3.2	5.5	4.3	7.4	20.4
	168.7	365.5	8.9	28.8	572.0

c) Number of Pots Fished in Observed Hauls (Thousands)

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
A SEASON										
Area 509	19.5	17.3	14.4	28.3	35.7	13.4	21.0	22.6	19.8	30.8
Area 519	19.2	28.0	21.3	15.0	9.7	13.7	7.4	11.6	19.4	13.7
Area 517	14.5	10.3	6.4	9.8	6.7	7.0	7.6	14.8	13.7	9.2
Other BS	15.7	32.6	27.2	27.7	23.2	20.3	21.6	20.3	17.1	8.6
All AI	21.1	14.5	36.7	42.3	40.2	19.0	-----	17.6	19.6	-----
B SEASON										
Area 509	3.9	-----	3.0	2.7	8.9	6.6	-----	-----	3.1	6.9
Area 519	22.2	18.0	17.5	25.0	9.2	13.1	13.0	20.9	24.3	4.3
Area 517	3.5	-----	5.4	4.9	2.0	9.1	2.0	5.5	9.6	-----
Other BS	14.6	12.2	13.3	13.0	17.9	14.4	18.6	9.2	9.4	2.7
All AI	8.6	-----	-----	-----	-----	-----	-----	-----	7.2	-----

Table 22.7. Results of observer program special project data on condition of octopus when observed (2006-2007) and at point of discard (2010-2011).

2006-2007	Observer Special Project Data Condition Reported for Observed Octopus			
Gear	**No. Alive**	**No. Dead**	**Total**	**Alive**
Bottom Trawl	32	43	75	42.7%
Pelagic Trawl	28	161	189	14.8%
Pots	431	2	433	99.5%
Longline	132	36	168	78.6%

2010-2011

Gear	Excellent	Poor	Dead	Total	%Excellent
Bottom Trawl	16	11	35	62	25.8%
Pelagic Trawl	8	7	42	58	13.8%
Pots	506	14	16	536	94.4%
Longline	122	7	16	146	83.6%

Table 22.8. Analysis of ecosystem considerations for the octopus complex.

Ecosystem effects on *BSAI octopus*			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Zooplankton	Stomach contents, ichthyoplankton surveys, changes mean wt-at-age	Stable, data limited	Unknown
Non-pandalid shrimp and other benthic organism	Trends are not currently measured directly, only short time series of food habits data exist for potential retrospective measurement	Benthic bivalves and crustaceans principal prey for all sizes	Unknown
Sandlance, capelin, other forage fish	Trends are not currently measured directly, only short time series of food habits data exist for potential retrospective measurement	Prey of larger octopus	Unknown
Salmon	Populations are stable or slightly decreasing in some areas	Unlikely to be important in octopus diet	No concern
Flatfish	Increasing to steady populations currently at high biomass levels	May be part of adult diet	No concern
Pollock	High population levels in early 1980's, declined to stable low level at present	Unlikely to be important in octopus diet	No concern
Other Groundfish	Stable to low populations	May be part of adult diet	No concern
Predator population trends			
Marine mammals	Fur seals declining, Steller sea lions increasing slightly	Both prey on octopus; importance unknown	Unknown
Birds	Stable, some increasing some decreasing	Unlikely to affect octopus	Unknown
Fish (Pollock, Pacific cod, halibut)	Stable to increasing	Possible increases to mortality	Unknown
Sharks	Stable to increasing	Predation on octopus unknown	Unknown
Changes in habitat quality			
Temperature regime	Warm and cold regimes	May shift distribution, depth selection, or growth rates	Unknown

***BSAI octopus* effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Not Targeted	Some market value, retention of incidental catch. Current level of fishery catch small in relation to estimated predation mortality.	No concern	No concern
Fishery concentration in space and time	Octopus catch concentrated in areas of Pacific cod pot fishing, esp. around Unimak pass.	Possible overlap of fishery with two SSL rookeries	Unknown
Fishery effects on amount of large size target fish	Pot fishing catches predominantly large males, unknown seasonal timing of fishing vs. mating	No concern at this time	Unknown
Fishery contribution to discards and offal production	None. Discards from pot vessels probably have low mortality.	No concern	No concern
Fishery effects on age-at-maturity and fecundity	Unknown	No concern at this time	Unknown

Figure 22.1. Distribution of octopus (all species) in the BSAI, based on octopus occurring in observed hauls during the period 1990-1996.

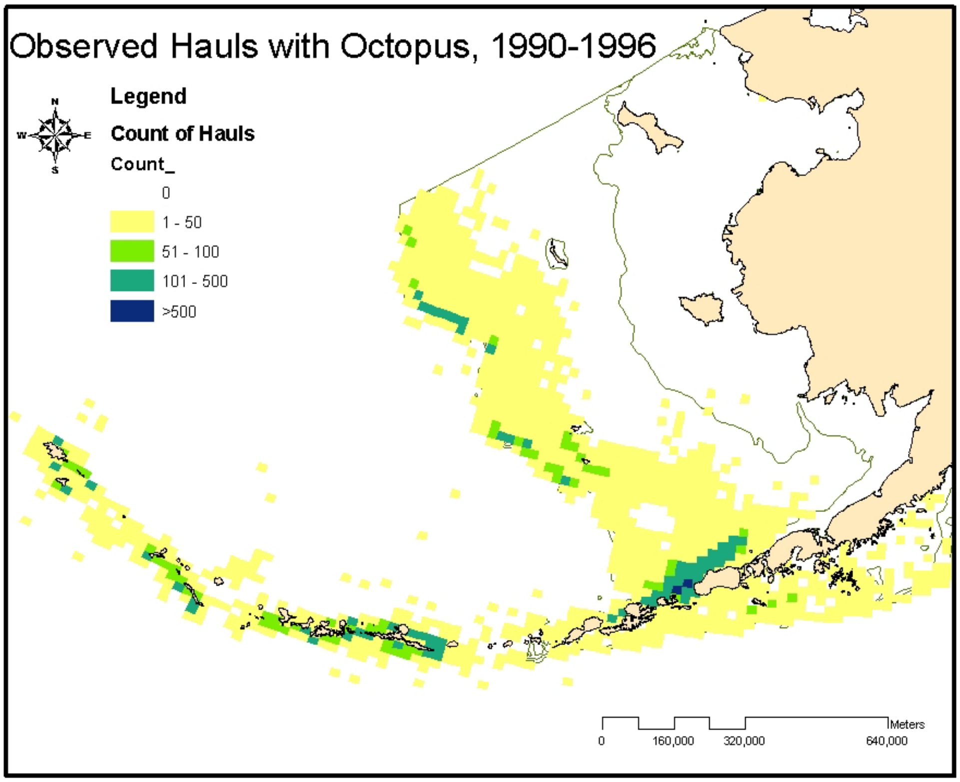


Figure 22.2. Size frequency of individual octopus (all species) from Bering Sea shelf bottom trawl surveys 2009 - 2011.

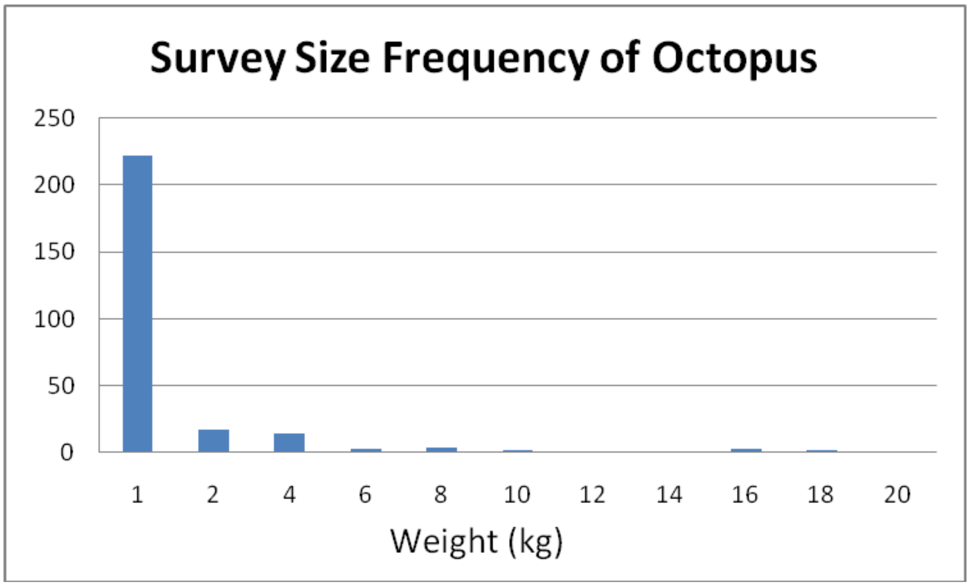
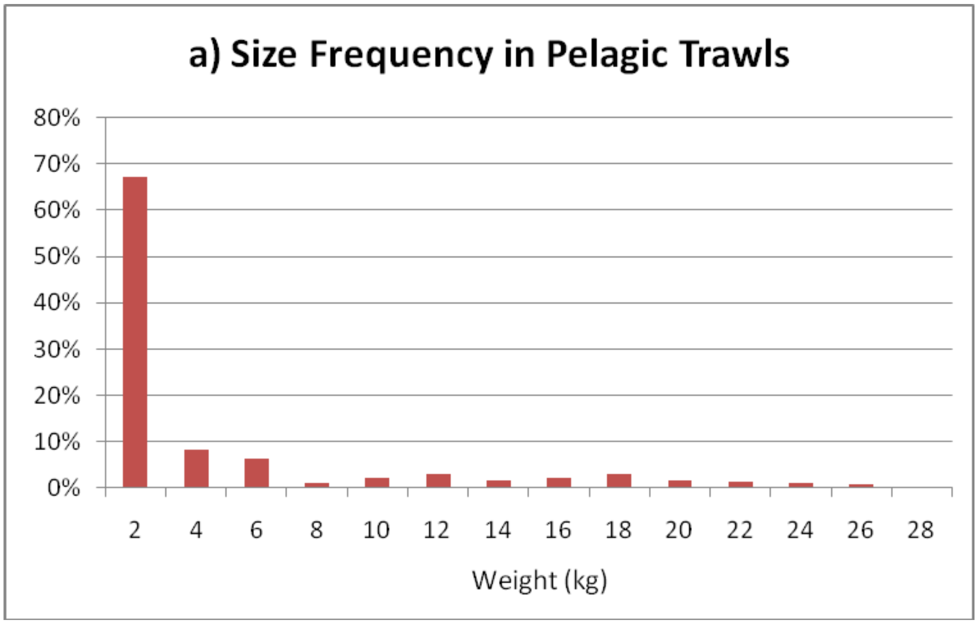


Figure 22.3. Size frequency of individual octopus from observer special project 2006-2011 by gear type: a) pelagic trawl, b) bottom trawl, c)pots, d) longline.



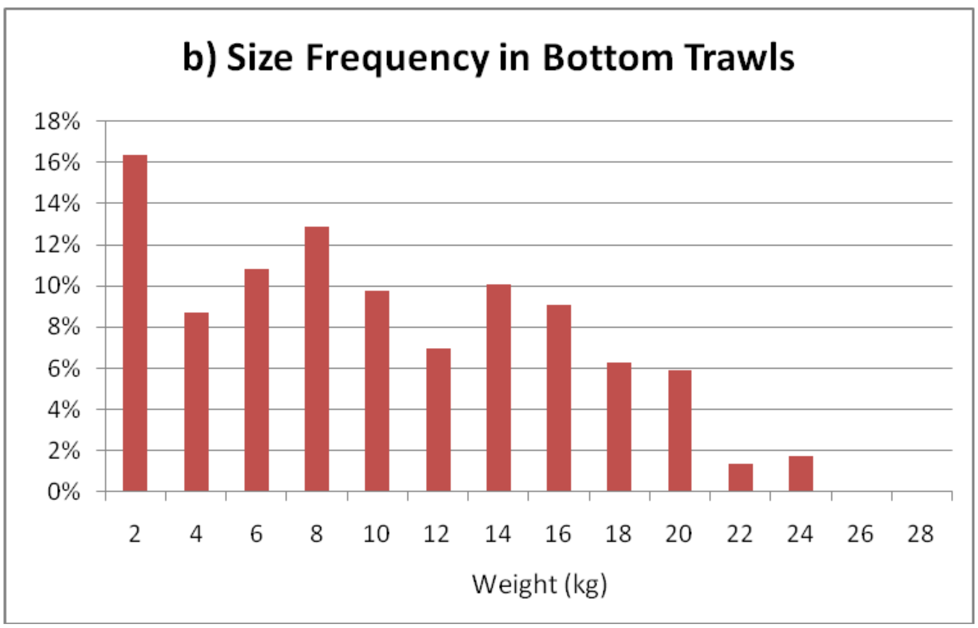
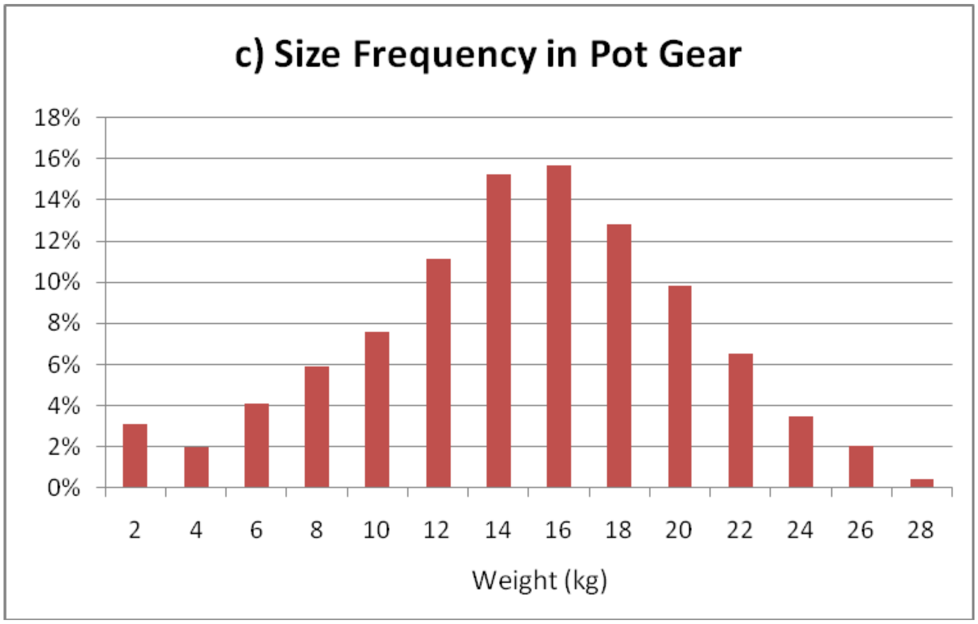


Figure 22.3. Continued.



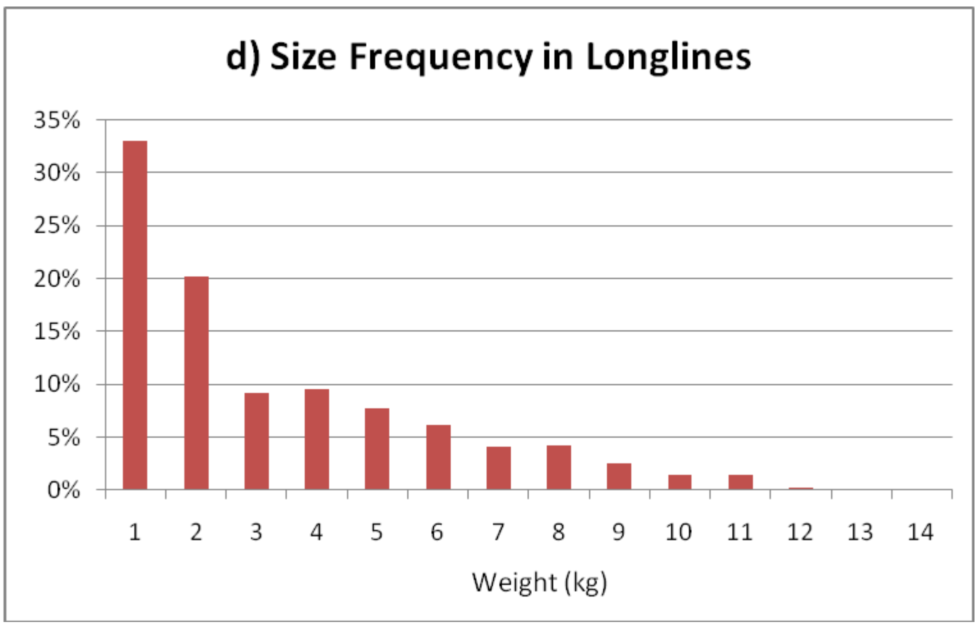


Figure 22.4. Size frequency of octopus by species from the 2008-2012 Bering Sea slope surveys.

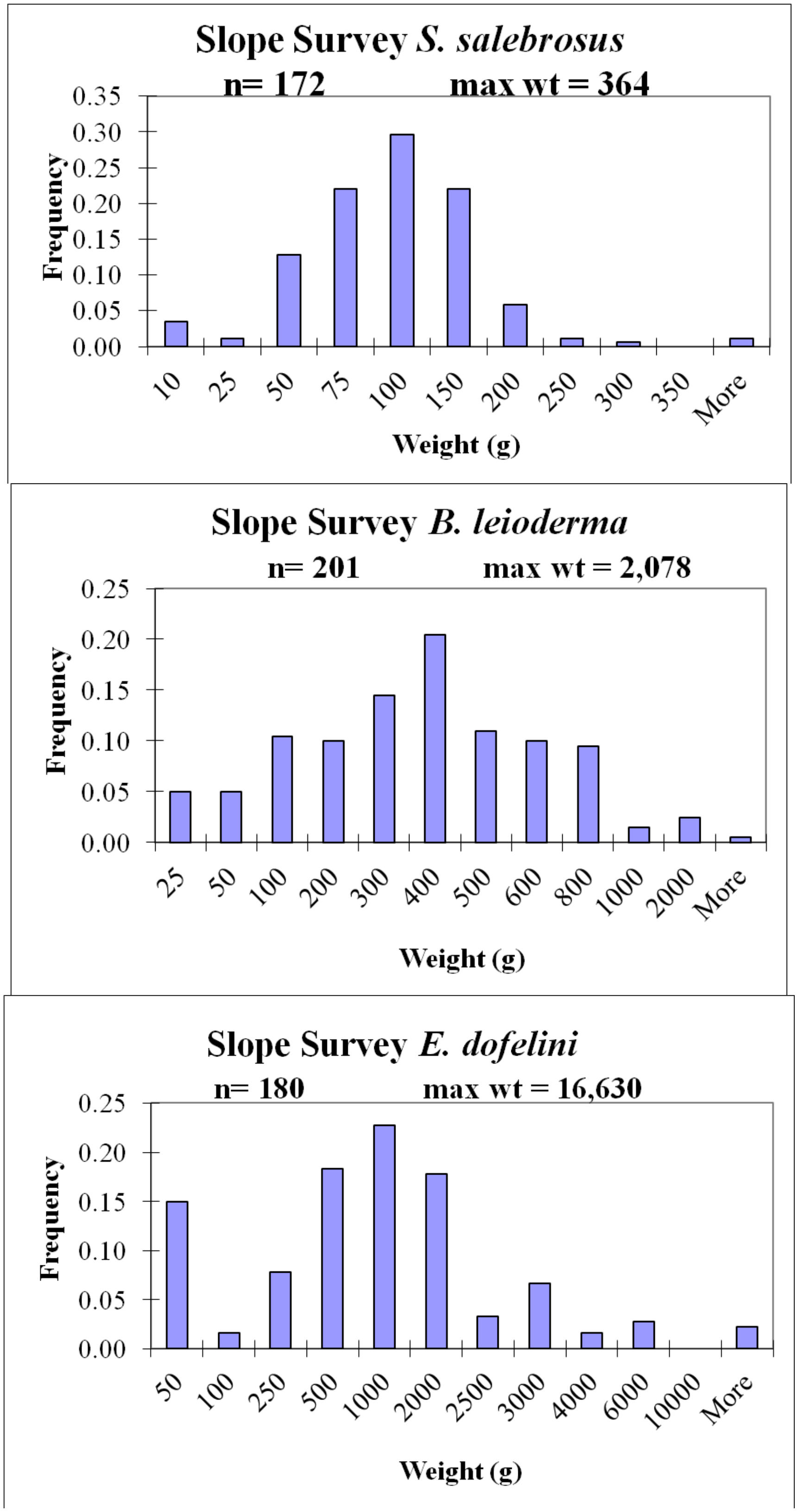


Figure 22.5. Biomass estimates of octopus (all species) from the Bering Sea shelf survey, with 95% confidence intervals shown.

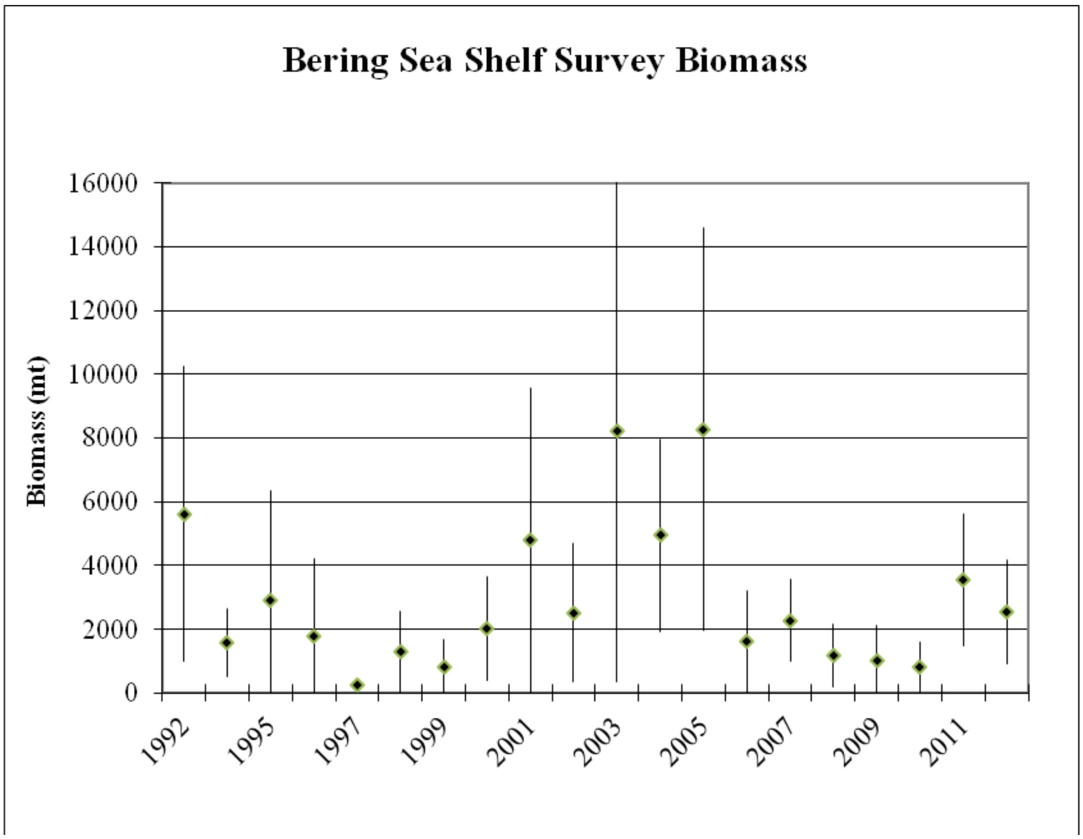


Figure 22.6. Spatial distribution of observed octopus catch from pot gear 2001-2010. Screened non-confidential observer data from AFSC FMA web site; each symbol represents catch in a 20x20 km grid cell. Cells with no symbol shown had less than three vessels with observed catch in that area. Also shown are boundaries of NMFS statistical reporting areas and 20 nm zones around Steller sea lion rookeries.

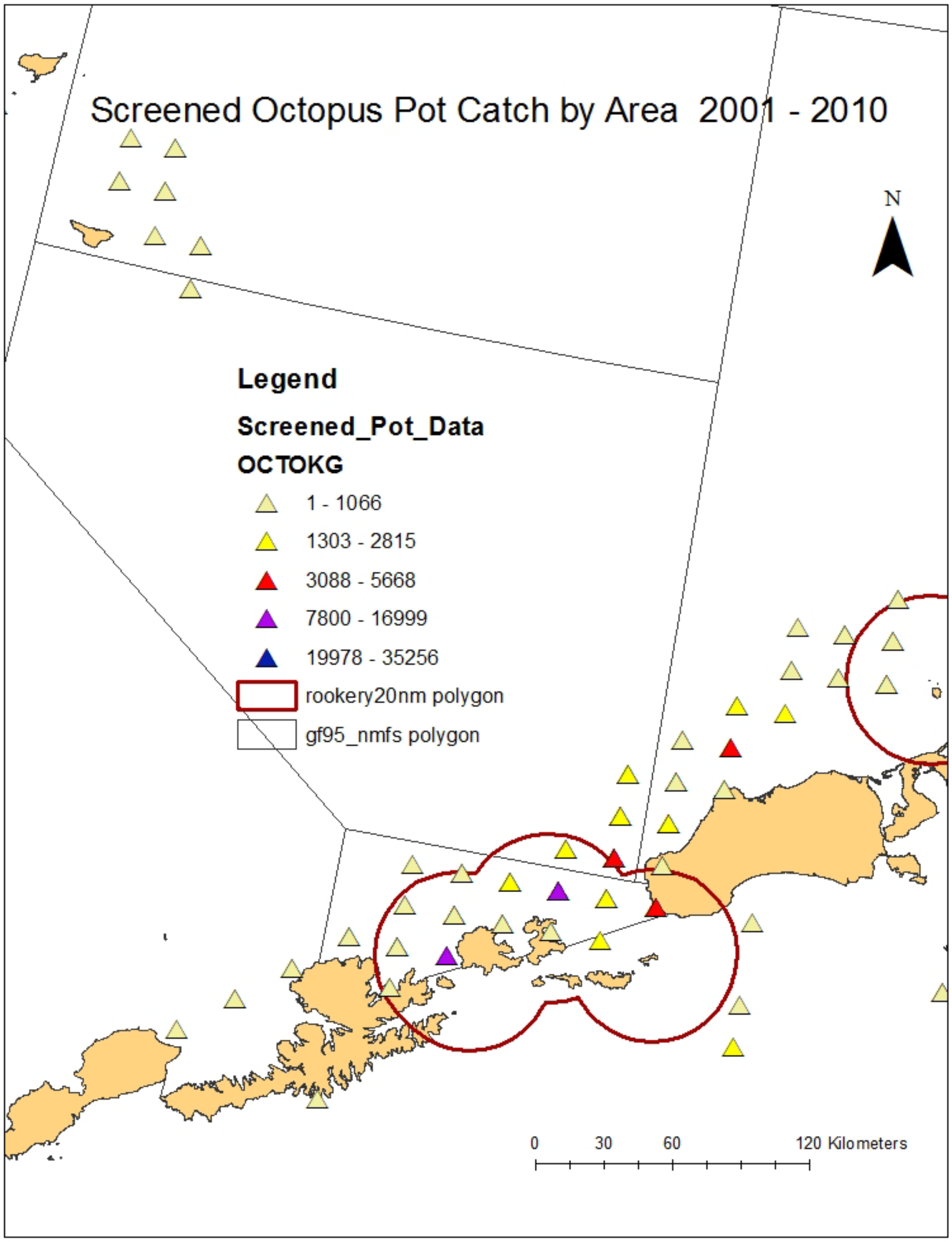
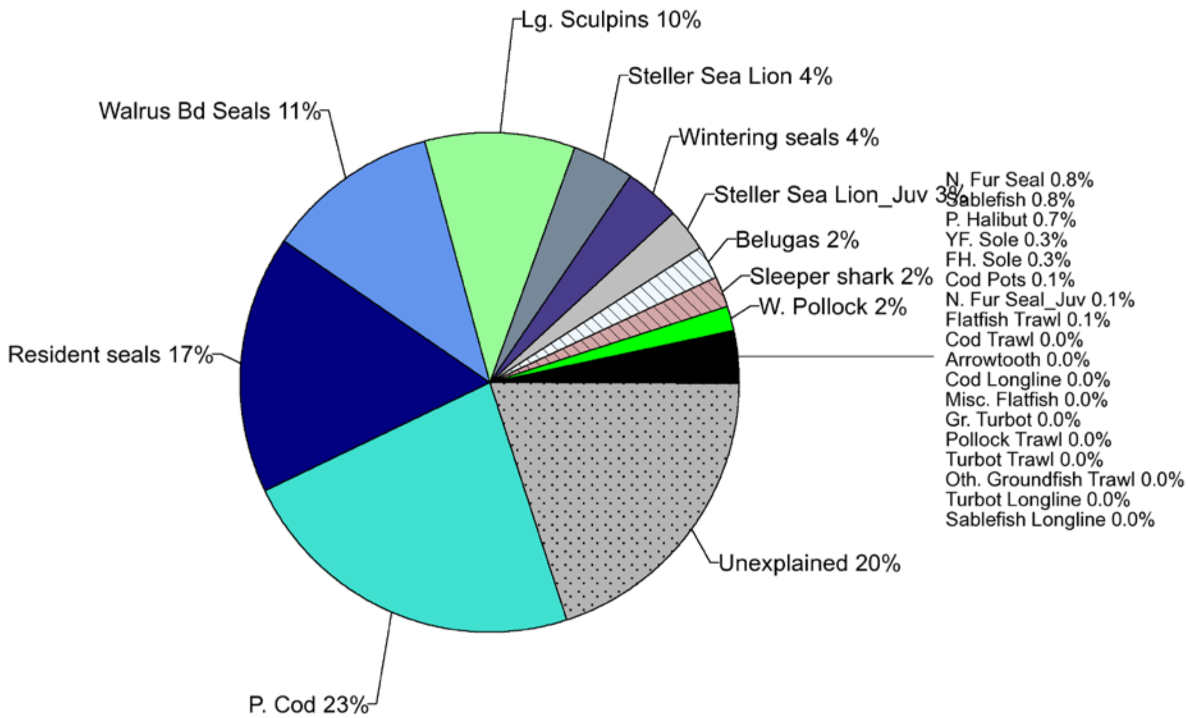


Figure 22.7. Ecopath model estimates of mortality sources of octopus in the BSAI.

a) Bering Sea Ecosystem



b) Aleutian Islands Ecosystem

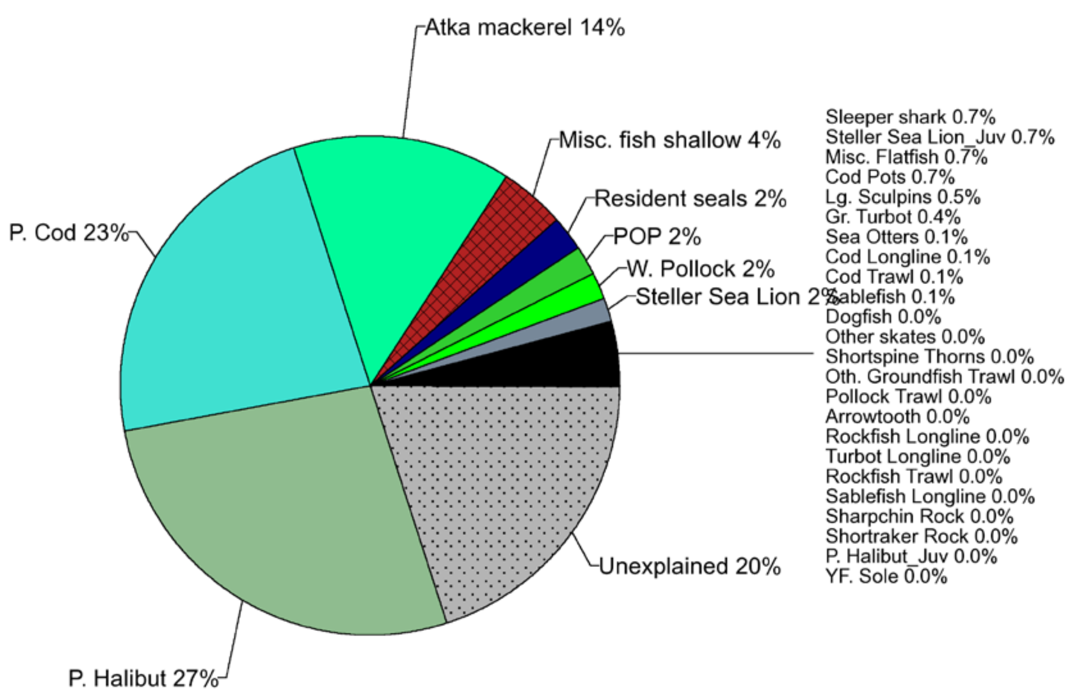


Figure 22.8. Locations of all sampled Pacific cod stomachs (black circles; N=62,393) and stomachs containing octopus (red circles), 1982-2011, for May-September (top panel) and October-April (bottom panel).

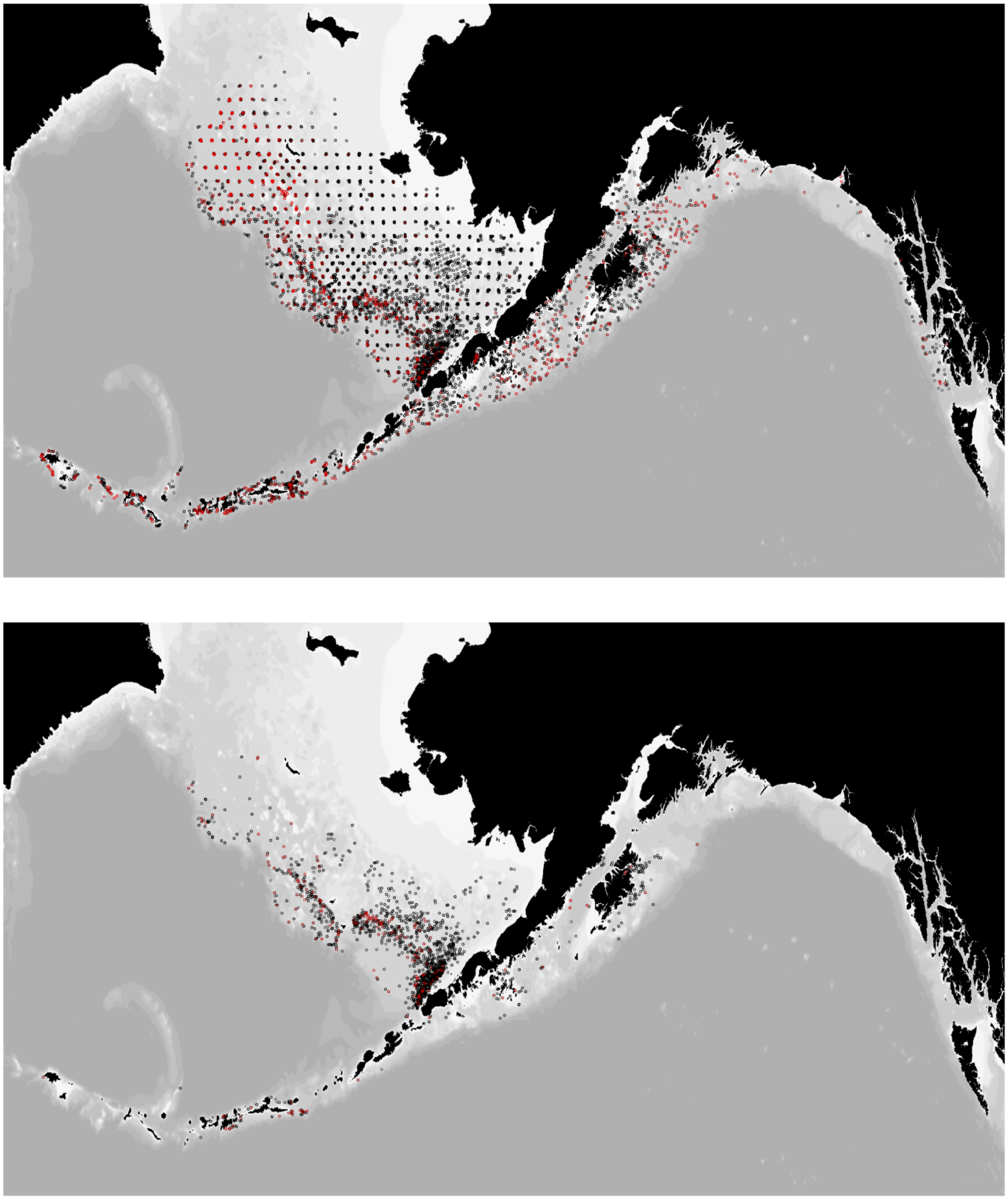


Figure 22.9. Frequency of occurrence of octopus in Pacific cod stomachs, all years, regions, and seasons, as a function of bottom depth (top panel) and Pacific cod fork length (bottom panel). Gray area shows the 95% confidence interval calculated from logit-transformed data (empirical logit transformation).

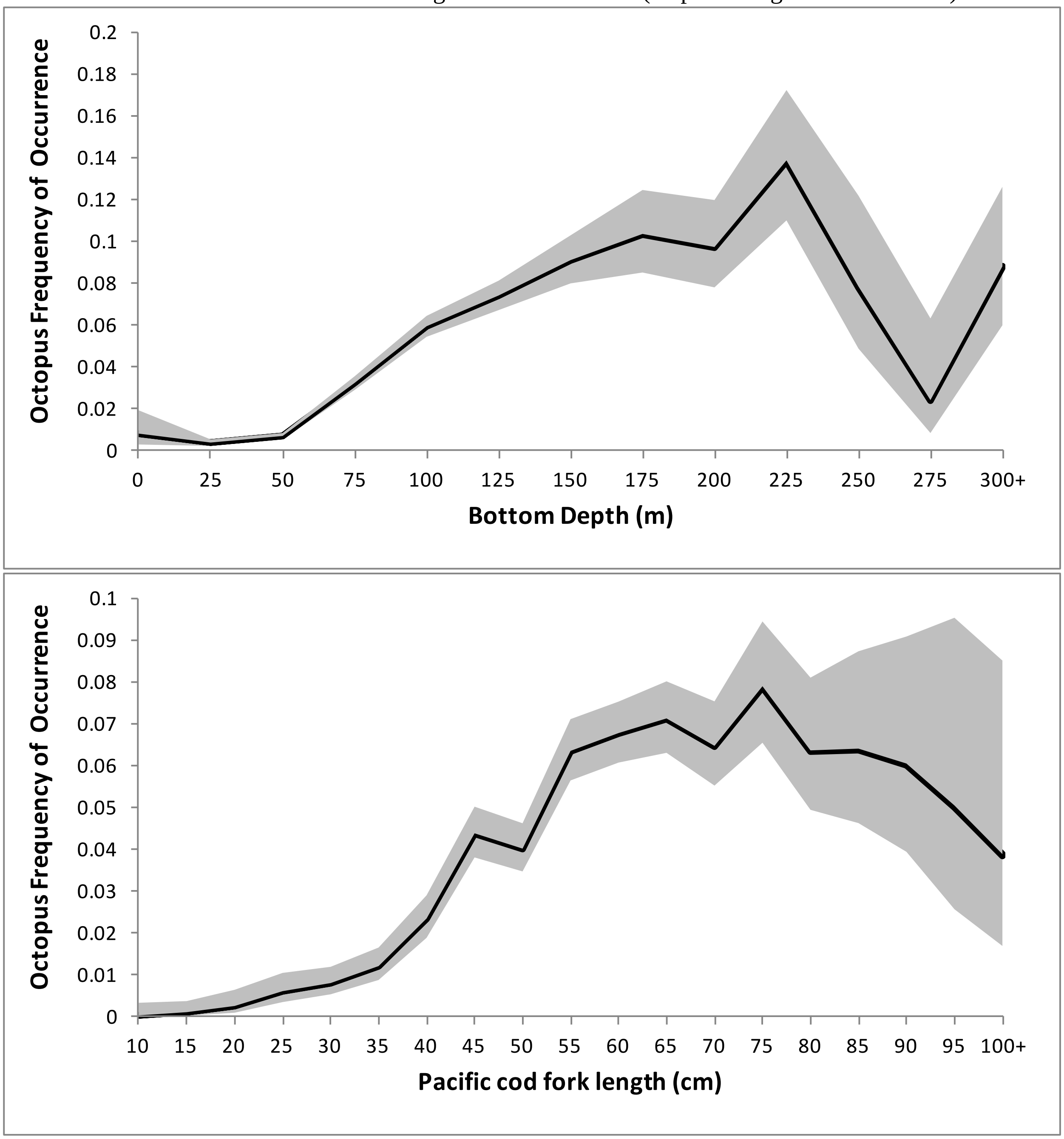


Figure 22.10. Percent diet by weight in Pacific cod stomachs sampled in water **<100m**, all years and seasons, for Aleutian Islands (top panel), Bering Sea (middle panel), and Gulf of Alaska (bottom panel).

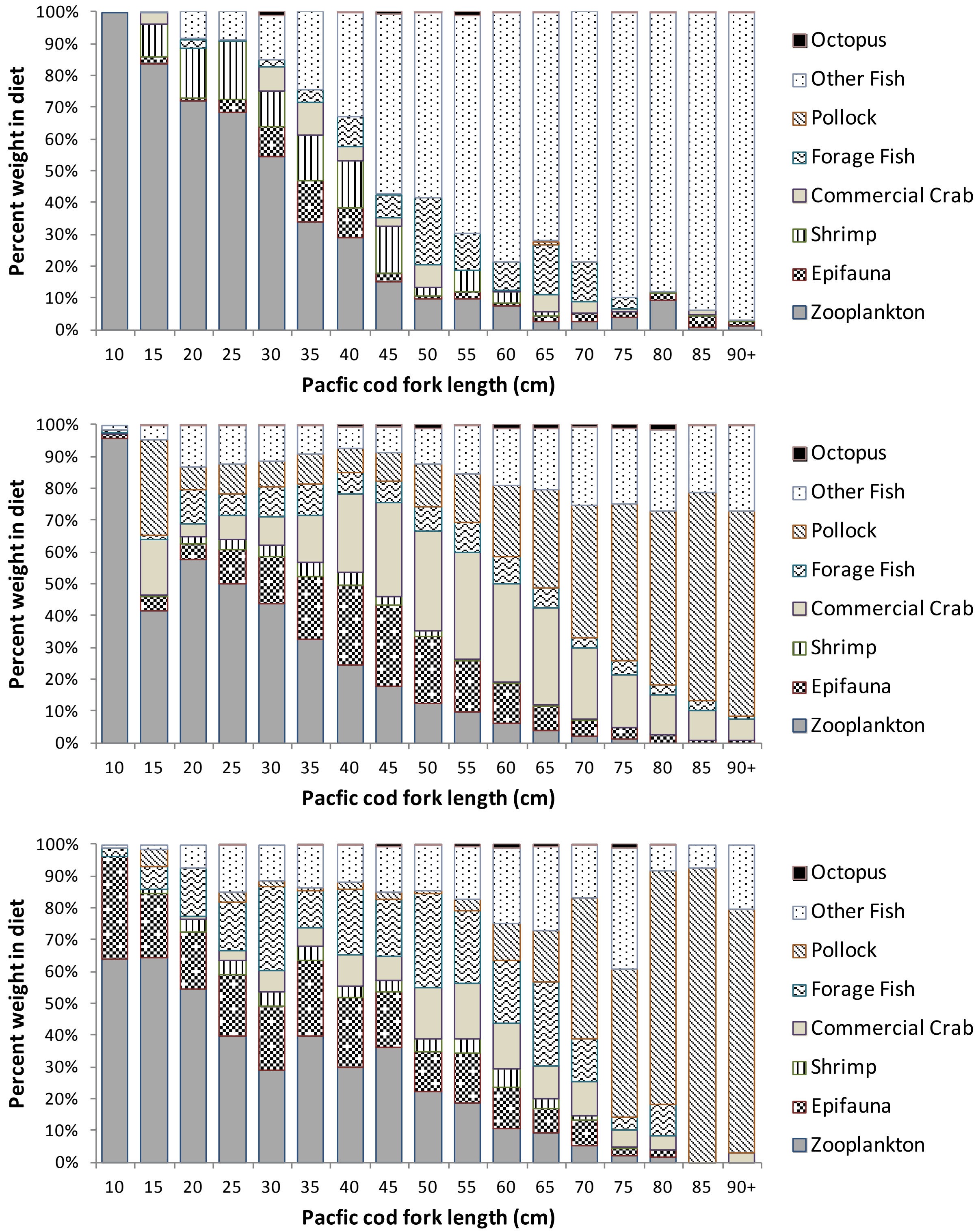


Figure 22.11. Percent diet by weight in Pacific cod stomachs sampled in water **≥100m**, all years and seasons, for Aleutian Islands (top panel), Bering Sea (middle panel), and Gulf of Alaska (bottom panel).

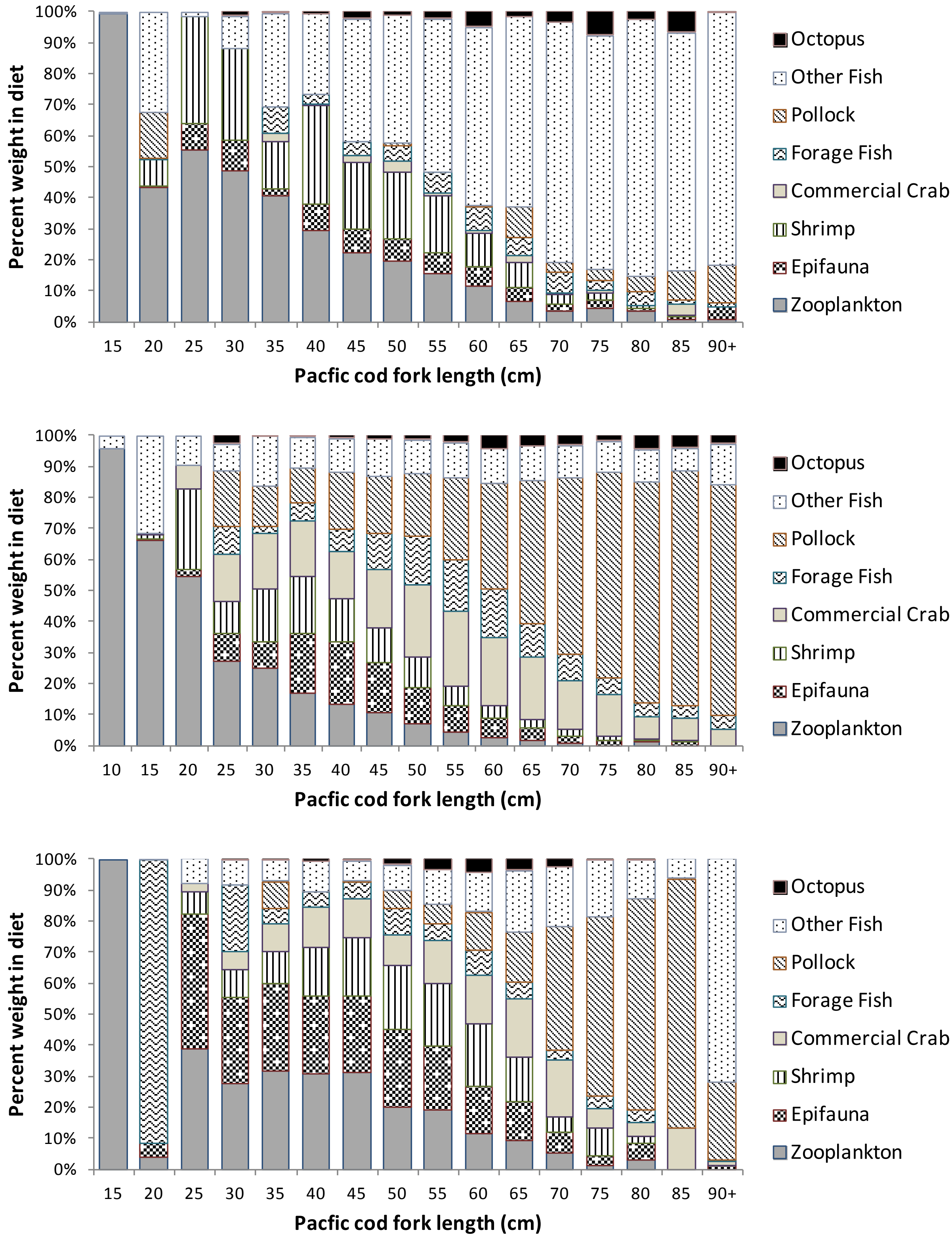


Figure 22.12. (Top panel): Relationship between upper and lower beak hood length and Pacific octopus total weight, measured from fisheries-sampled octopus. (Bottom panel): Length frequency of upper and lower beaks sampled from Pacific cod stomachs.

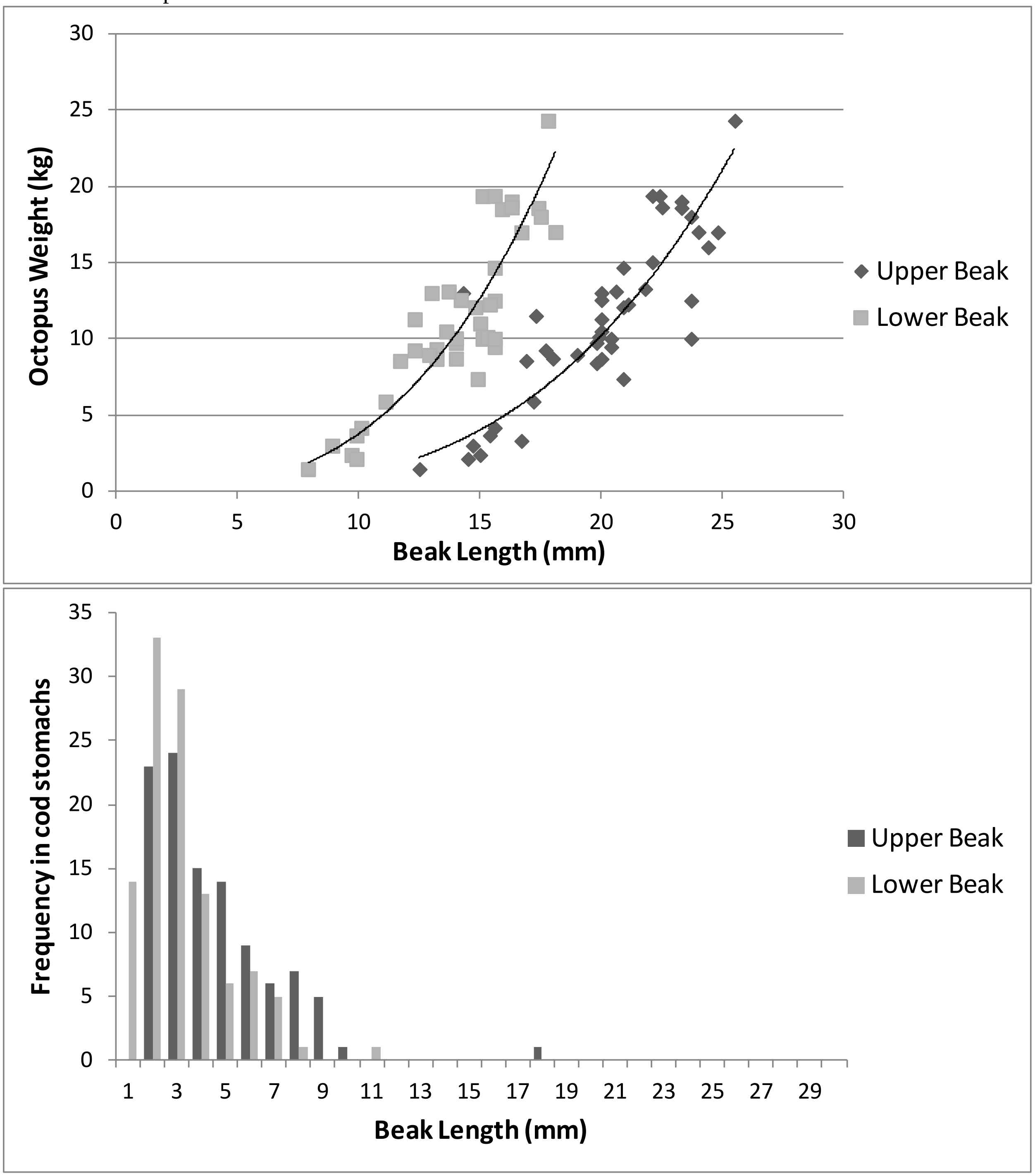


Figure 22.13. Beak hood lengths of octopus removed from Pacific cod stomachs as a function of cod fork length.

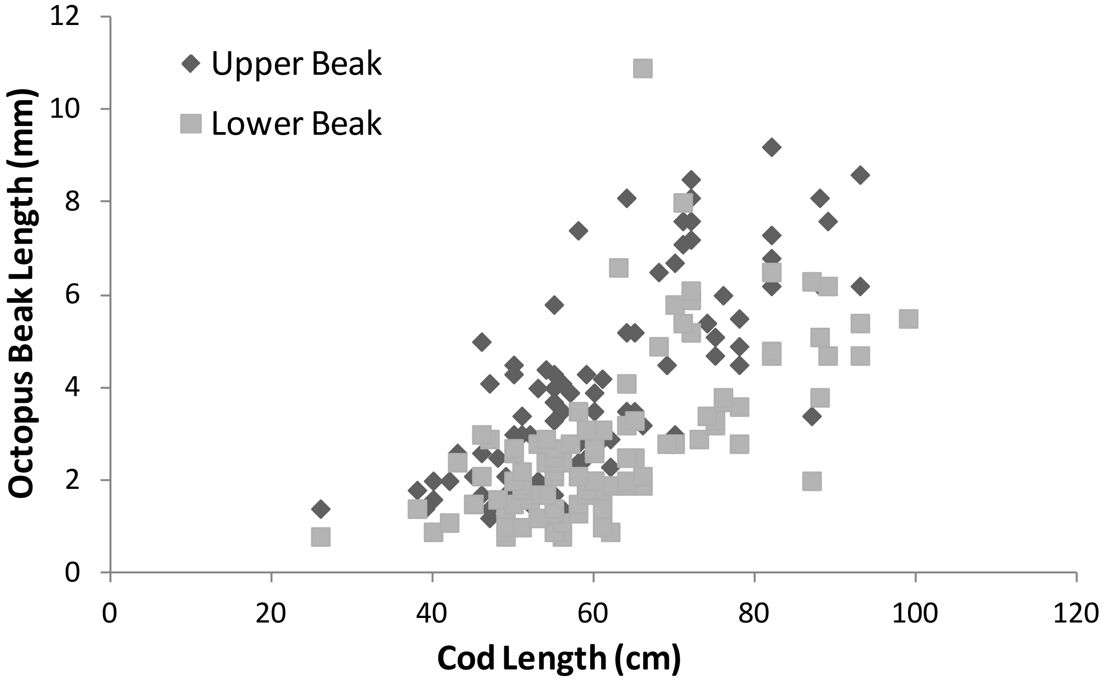


Figure 22.14. Annual ration of Pacific cod as a function of fork length, as estimated from fit von Bertalanffy parameters. Points indicate MCMC posterior distribution for fit; black and red lines show estimate and 95% confidence intervals.

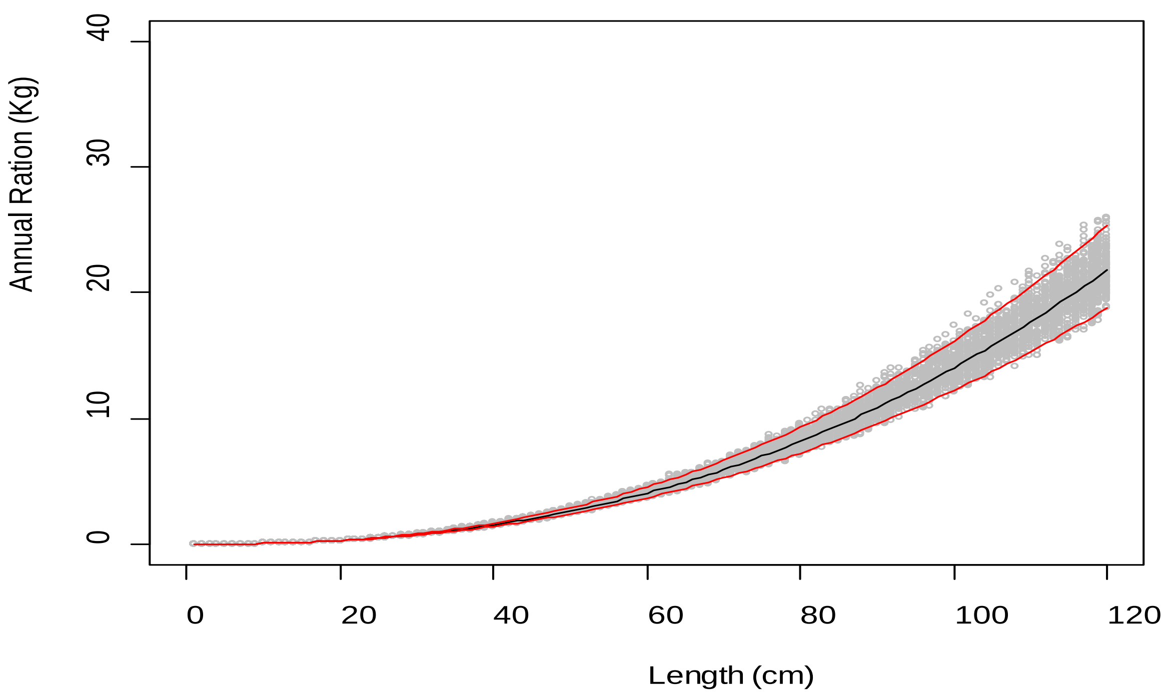


Figure 22.15. Estimated consumption of octopus by Bering Sea Pacific cod, 1984-2008. Error bars show 95% confidence intervals of posterior distribution; solid bars are annual hyperbolic means.

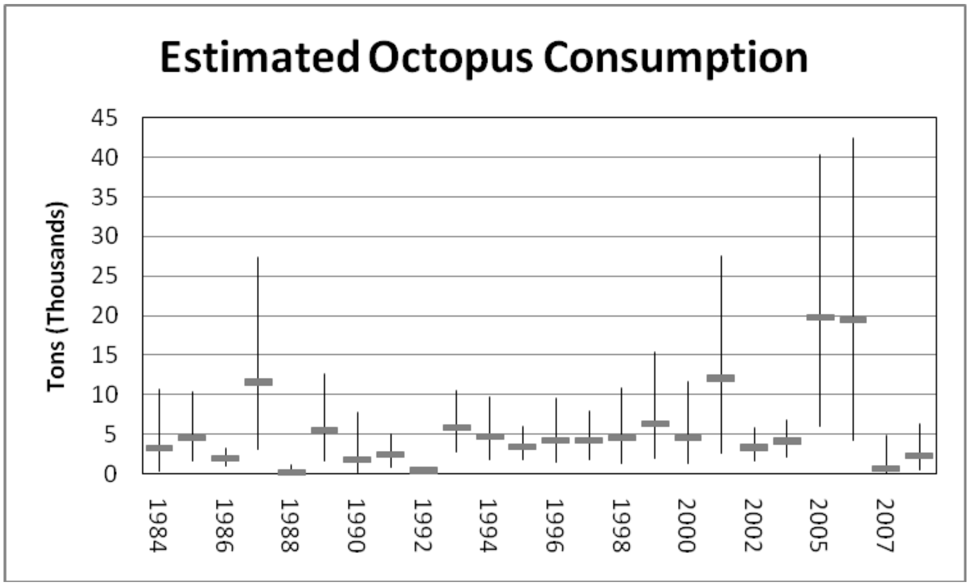
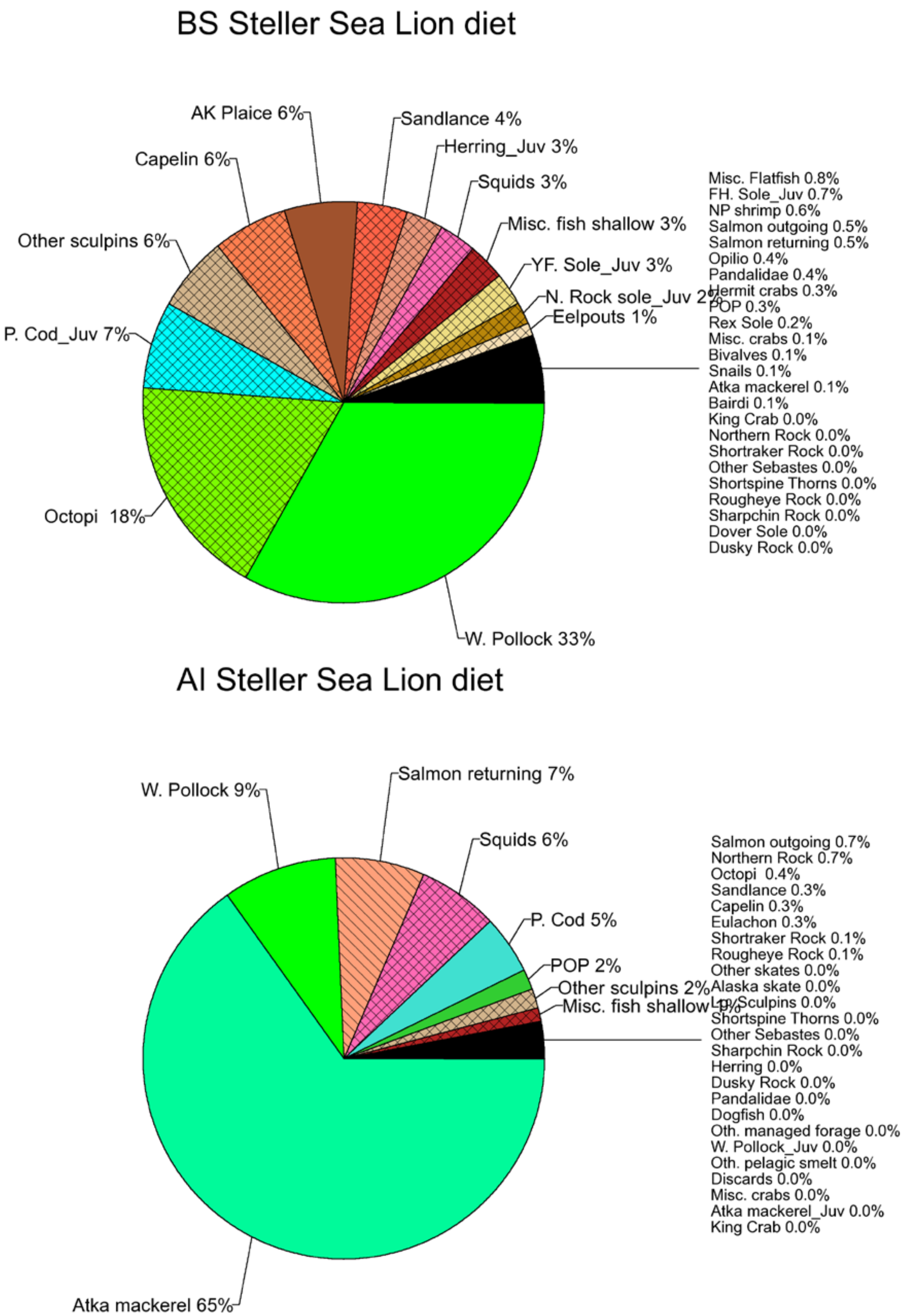


Figure 22.16. Literature-derived diets of Steller sea lions in the BS and AI.



Appendix 22.1 Summary of Octopus Research

NPRB Projects 2009-2012

The North Pacific Research Board has funded field studies in support of stock assessment for octopus, beginning in fall 2009. The studies are being conducted by AFSC and UAF researchers in both the Gulf of Alaska near Kodiak and in the southeast Bering Sea near Dutch Harbor. The main focus of the 2009-2011 study was to increase knowledge of reproductive biology of E. dofleini, in particular to document the seasonality of mating and egg incubation in Alaskan waters. Specimens were collected from a variety of sources throughout the calendar year for dissection and examination of the gonads; a gonad maturity coding system was developed and samples collected for laboratory analysis of fecundity and weight at sexual maturity. In addition to the reproductive work, this project also included a pilot tagging study near Dutch Harbor and testing of habitat pot gear for use in octopus studies (Conners et al. 2012).

Octopus specimens for reproductive study were obtained from Kodiak waters during each season of the year from charter operations, the AFSC GOA and AI bottom trawl surveys, and from commercial cod pot fishermen. All octopus sampled were weighed, sexed, the mantle length was measured and the reproductive tract was removed and weighed. The weight and diameter of the gonad was measured and the condition of the reproductive tract was noted. For male specimens the presence and number of fully or partially formed spermatophores was noted. For female specimens the presence of visible eggs within the ovary was noted. For all specimens, all or part of the gonad was preserved. Thin sections of these tissues were embedded in paraffin, thin sectioned, and stained utilizing standard histological techniques. A three stage maturity classification system was derived for both male and female *E. dofleini* based on reproductive tract characteristics and the presence/absence of well developed eggs or spermatophores.

Enteroctopus dofleini samples collected during research in the Bering Sea were found to have size at 50% maturity values of 12.8 kg for females and 10.8 kg for males (Brewer and Norcross, in review). Results from this study indicate that *E. dofleini* are reproductively active in the fall with peak spawning occurring in the winter to early spring months. In the Gulf of Alaska, this species was found to mature between 10-20 kg with size at 50% maturity values of 13.7 kg (95% CI 12.5-15.5 kg) for females and 14.5 kg (95% CI = 12.5-16.3 kg) for males. Size at maturity was highly variable for this species, particularly for male octopus. *Enteroctopus dofleini* smaller than 10 kg tended to be immature but male and female mature members of this species in the size range between 10 – 20 kg were found to be immature, maturing, and mature. Fecundity for this species in the Gulf of Alaska was found to range from 41,600 to 239,000 with an average fecundity of 106,800 eggs/female. Fecundity was significantly and positively related to the weight of the female (n = 33, $P < 0.001$).

The pilot tagging study conducted in fall 2009-winter 2010 near Dutch Harbor was highly successful. Tagging studies target the local dynamics and seasonal movement of octopus, and may eventually allow estimation of parameters for Tier 5 management of the octopus species group. The results from initial tagging efforts have shown that the tagging method using Visual Implant Elastomers (VIE tags) is feasible, and that the tags are readily visible in recaptured animals and have no associated tissue damage (Brewer and Norcross 2012). Based on these results, NPRB has funded continued tagging effort through 2012. The goal of the extended effort is to collect enough tag recapture data to fit a Jolly-Seber or similar quantitative model that will allow estimation of natural mortality rates and local abundance of octopus in the study area.

Tagged octopus are weighed at each recapture and release to assess in-situ growth rates. Of the *E. dofleini* recaptured thus far, change in weight for octopus appears to be variable; no apparent pattern in weight change can be observed. When a larger data set has been collected, we will attempt to fit growth information from tagged octopus to a von Bertalanffy growth curve. Parameter estimates from a fitted curve may be used to compare to literature values for other species and regions and in estimation of population growth for general production models.

As of October 2011, five seasons of tag and recapture efforts have occurred 20km north of Unalaska Island in depths ranging from 50 to 200m. From October 2009 through October 2011, 1,730 E. dofleini were tagged and 243 recaptured. While most of the recaptures have occurred within a few weeks after tagging, 32 octopus have been recaptured between seasons after 60 days. Preliminary within-season abundance estimates give densities of 200-600 octopus per km^2 in the study area. If a density of 200 octopus/km^2 with an average weight of 15 kg were applied to the approximately 3,500 km^2 of shelf area around Unimak Pass, this would represent over 10,000 tons of octopus.

The initial study also included a vessel charter for testing and developing a specialized gear for octopus fishing that may eventually be useful for scientific studies and index surveys of octopus abundance. The unbaited gear consists of small "habitat pots" that act as artificial den space for octopus. Similar gear is used in octopus fisheries in other parts of the world. A variety of pot designs and materials were tested for use in Alaska. An initial trial of habitat pot gear was conducted in spring and fall 2010, and more work was conducted during summer and fall 2011. Captured octopus ranged in size from smaller than 2 kg to over 20 kg. In all, a total of 319 octopus were captured in 1,901 pot lifts. In all trials, plywood box pots and scrap ATV tires captured octopus much more effectively than pots made of various plastic materials. Overall capture rates for boxes and tires was roughly 25%, but plastic pots had less than 10% catch rate. Capture rates varied between seasons, ranging from less than ten percent to over 50% occupancy (Conners et al, in review). Results of this study indicate that longlined plywood box pots are an economical and feasible method for capturing octopus.

Appendix 22.2 —Supplemental catch data

In order to comply with the Annual Catch Limit (ACL) requirements, two new datasets have been generated to help estimate total catch and removals from NMFS stocks in Alaska. The first dataset, non-commercial removals, estimates total removals that do not occur during directed groundfish fishing activities. This includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but does not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System estimates. Additional sources of significant removals are bottom trawl surveys and the International Pacific Halibut Commissions longline survey. These removals are not substantial relative to the incidental catch from commercial fisheries. Total removals of octopus from activities other than directed fishery were only 5 tons in 2011.

The second dataset, Halibut Fishery Incidental Catch Estimation (HFICE), is an estimate of the incidental catch of groundfish in the halibut IFQ fishery in Alaska, which is currently unobserved. The HFICE estimates of octopus catch by the halibut fishery are in the range of 25 mt/yr for 2001-2003, but are < 10 tons in 2005 – 2010. To estimate removals in the halibut fishery, methods were developed by the HFICE working group and approved by the Gulf of Alaska and Bering Sea/Aleutian Islands Plan Teams and the Scientific and Statistical Committee of the North Pacific Fishery Management Council. A detailed description of the methods is available in Tribuzio et al. (2011). These estimates are for total catch of groundfish species in the halibut IFQ fishery and do not distinguish between "retained" or "discarded" catch. These estimates should be considered a separate time series from the current CAS estimates of total catch. Because of potential overlaps HFICE removals should not be added to the CAS produced catch estimates. The overlap will apply when groundfish are retained or discarded during an IFQ halibut trip. IFQ halibut landings that also include landed groundfish are recorded as retained in eLandings and a discard amount for all groundfish is estimated for such landings in CAS. Discard amounts for groundfish are not currently estimated for IFQ halibut landings that do not also include landed groundfish. For example, catch information for a trip that includes both landed IFQ halibut and sablefish would contain the total amount of sablefish landed (reported in eLandings) and an estimate of discard based on at-sea observer information. Further, because a groundfish species was landed during the trip, catch accounting would also estimate discard for all groundfish species based on available observer information and following methods described in Cahalan et al. (2010). The HFICE method estimates all groundfish caught during a halibut IFQ trip and thus is an estimate of groundfish caught whether landed or discarded. This prevents simply adding the CAS total with the HFICE estimate because it would be analogous to counting both retained and discarded groundfish species twice. Further, there are situations where the HFICE estimate includes groundfish caught in State waters and this would need to be considered with respect to ACLs (e.g. Chatham Strait sablefish fisheries). Therefore, the HFICE estimates should be considered preliminary estimates for what is caught in the IFQ halibut fishery. Improved estimates of groundfish catch in the halibut fishery will become available following restructuring of the Observer Program in 2013, when all vessels >25 ft will be monitored for groundfish catch.

Table 22.2.1 Total removals of octopus (mt) from activities not related to directed fishing in 2010 and 2011. Trawl survey sources are a combination of the NMFS echo-integration, small-mesh, GOA, AI, and BS Slope bottom trawl surveys, and occasional short-term research projects.

Source	Catch (mt)
2010 Aleutian Island Bottom Trawl Survey	0.0002
2010 Bering Sea Slope Survey	0.0000
2010 Shelikof Acoustic Survey	0.0005
IPHC Survey	2.2280
large-mesh trawl survey	0.9252
NMFS_LL	0.2350
NPRB Octopus study	2.2032
small-mesh trawl survey	0.0362
Spot shrimp survey	0.0000
Grand Total	5.6282

Table 22.2.2. Estimates of BSAI octopus catch (mt) from the Halibut Fishery Incidental Catch Estimation (HFICE) working group.

YEAR	Numbers (1000's)	Weight (mt)
2001	3.91	27.39
2002	3.78	23.90
2003	2.56	25.96
2004	2.06	13.63
2005	2.19	9.74
2006	0.95	5.68
2007	0.12	0.92
2008	0.21	1.01
2009	0.30	1.50
2010	1.58	7.95

References:

Cahalan J., J. Mondragon., and J. Gasper. 2010. Catch Sampling and Estimation in the Federal Groundfish Fisheries off Alaska. NOAA Technical Memorandum NMFS-AFSC-205. 42 p.

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