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 of the other species complex members increased. 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. In 2012, a new methodology based on consumption of octopus by Pacific cod was introduced; this method has been in use since 2012 and is recommended for 2019 and 2020.

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 large animals (10-20 kg). In general, the state of knowledge about octopus in the BSAI is increasing, but there is still no reliable estimate of octopus biomass.

Summary of Changes in Assessment Inputs

1) The assessment methodology and data availability have not changed from the 2016 assessment, so harvest recommendations are the same as in 2016.

2) Incidental catch data have been updated through November 3, 2018.

3) Biomass estimates from the 2017 & 2018 EBS shelf survey and 2018 Aleutian Islands survey have been added. The planned 2018 EBS slope survey did not occur due to problems with vessel availability.

Summary of Results

1) Catches of octopus were lower in 2017 and 2018 than in 2016 (281 t, 251 t, and 597 t, respectively) although 2018 catch data are partial (retrieved November 3, 2018).

2) The SSC and BSAI Plan Team have approved an alternative methodology for setting octopus catch limits in the BSAI under Tier 6. This method 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 the historical incidental catch. The annual consumption estimates for recent years have noticeably increased over the early part of the time series, both due to increasing numbers of Pacific cod and due to increased proportion of octopus in cod diets.

Quantity	As estimated or *specified in 2016* for: 2017	2018	As estimated or *recommended this* year for: 2019	2020
Tier 6 (consumption estimate)				
OFL (t)	4,769	4,769	4,769	4,769
ABC (t)	3,576	3,576	3,576	3,576
Status	As determined *in 2016* for: 2015	2016	As determined *this* year for: 2017	2018
Overfishing	n/a	n/a	n/a	n/a

Responses to SSC and Plan Team Comments on Assessments in General

From the October 2017 SSC minutes

"The SSC recommends that, for those sets of environmental and fisheries observations that support the inference of an impending severe decline in stock biomass, the issue of concern be brought to the SSC, with an integrated analysis of the indices in future stock assessment cycles. To be of greatest value, to the extent possible, this information should be presented at the October Council meeting so that there is sufficient time for the Plan Teams and industry to react to the possible reduction in fishing opportunity."

> *Response*: There were no environmental and fisheries observations that supported an inference of an impending severe decline in the BSAI octopus complex or individual species in the BSAI.

"The SSC also recommends explicit consideration and documentation of ecosystem and stock assessment status for each stock ... during the December Council meeting to aid in identifying stocks of concern….Implementation of these stock and ecosystem determinations will be an iterative process and will require a dialogue between the stock assessment authors, Plan Teams, ecosystem modelers, ESR editors, and the SSC."

> *Response*: The author supports this concept and looks forward to participating in the process.

From the November 2017 Joint and BSAI Plan Team minutes

The BSAI Plan Team did not make any comments on assessments in general.

From the December 2017 SSC minutes

"The SSC reminds authors of the need to balance the desire to improve model fit with increased risk of model misspecification….In the absence of strict objective guidelines, the SSC recommends that thorough documentation of model evaluation and the logical basis for changes in model complexity be provided in all cases."

> *Response*: Not relevant for this assessment.

"Report a consistent metric (or set of metrics) to describe fish condition among assessments and ecosystem documents where possible."

Response: This assessment does not incorporate data on fish (or octopus) condition.

"Projections ... clearly illustrate the lack of uncertainty propagation in the 'proj' program used by assessment authors. The SSC encourages authors to investigate alternative methods for projection that incorporate uncertainty in model parameters in addition to recruitment deviations. Further, the SSC noted that projections made on the basis of fishing mortality rates (Fs) only will tend to underestimate the uncertainty (and perhaps introduce bias if the population distribution is skewed). Instead, a two-stage approach that first includes a projection using F to find the catch associated with that F and then a second projection using that fixed catch may produce differing results that may warrant consideration."

Response: Not relevant for this assessment.

From the October SSC 2018 minutes

The SSC did not make any comments on assessments in general that were directed to authors. The general recommendations were for the Plan Teams.

Responses to SSC and Plan Team Comments Specific to this Assessment

There were no relevant comments from either the Plan Team or SSC.

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),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 eight 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 one, *Japetella diaphana* are benthic octopuses. The mesopelagic *Vampyroteuthis infernalis* is a cephalopod that shares similarities with both octopuses and squids. But is included in the octopus assessment. 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 species diversity is along the shelf break region between 200 – 750 m. The observed catches 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 is dependent primarily on the use of pot gear for Pacific cod and is concentrated in the three statistical areas near Unimak Pass.

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. The giant Pacific octopus *Enteroctopus dofleini* has been studied extensively, and its life history will be reviewed here. General life histories of the other octopus 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 indicate that *that this species is* reproductively active in the fall with peak spawning occurring in the winter to early spring months (Brewer 2016). Like most species of octopods, *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 (Brewer and Norcross 2012). *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, Mottet 1975). Within the Bering Sea, female *E. dofleini* show significantly larger gonad weight and maturity in the fall months (Brewer and Norcross 2012). 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 2014). 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 paralarvae 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 interannual 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.

Other Octopus Species

Sasakiopus salebrosus is a small benthic octopus recently identified from the Bering Sea slope in depths ranging from 200 to1200 m (Jorgensen 2010). It was previously identified in surveys as *Benthoctopus* sp. or as *Octopus* sp. 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 and a maximum weight of approximately 3 kg. 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 uncommon 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 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 of natural communities 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.*

Stock structure

The giant Pacific octopus is found throughout the northern Pacific Ocean from northern Japanese waters, throughout the Aleutian Islands, the Bering Sea, 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, but did not find substantial genetic differences between specimens from Dutch Harbor and Kodiak. 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.

Fishery

Management History

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, the Total Allowable Catch (TAC) of other species was 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 Alaska 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 species in the assemblage, however, do not necessarily share common patterns of distribution, growth, and life history. One avenue for possible future use is to split this assemblage by size, allowing retention of only larger animals. This would act to restrict harvest to the larger *E. dofleini* and minimize impact to the smaller animals which may be other octopus species. Under current fishery conditions, this size-based split is not needed, since commercial pot gear does not capture or retain small octopus.

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 Aleutian Islands existed from 1988-1995; catches from this fishery were reportedly less than 8 t 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 totaling 4,977 octopus (84.6 t). 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 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. 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).

Data

Incidental Catch Data

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 (Tables 22.2 and 22.3) 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*.

Reported harvest of octopus from incidental catch in state fisheries in the BSAI ranged from 18-69 t between 1996 and 2002 but was 100-300 t 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 t (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. 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 - 2018. 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 observed to that date, 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 528 t 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 (Table 22.3 and Figure 22.2).

Incidental catch rates were low for 2012 and 2013 but were over 400 t in 2014 through 2016. Catches have declined since 2016 (281 t in 2017 and 251 t in 2018). All catches were still nearly an order of magnitude below the recommended ABC. The percentage of BSAI octopus retained is variable and has increased since 2016 (34% in 2017).

AFSC Survey Data

Catches of octopus are recorded during the annual NMFS bottom trawl survey of the eastern 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 2010-2016 and from the three most recent Bering Sea slope and Aleutian Island surveys are shown in Table 22.4. These catches are our only source of species-specific information within the assemblage. 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 are *Sasakiopus salebrosus, E. dofleini,* and *Benthoctopus* *leioderma.* Because of their large body size, the estimated biomass of the slope is still dominated by *E. dofleini* (Table 22.4). 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. Octopuses 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. *Enteroctopus dofleini* have a peak frequency of occurrence 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 catches 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 22.3 (compared to size frequencies in commercial catch in Figure 22.4). 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 - 2016 slope survey show the marked difference in size distributions between the three most common species: *E. dofleini*, *B. leioderma*, and *S. salebrosus.* While *E. dofleini* ranges from <1 kg to >20 kg, the other species generally do not exceed 3 kg. 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 and Figure 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 t, 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). Biomass estimates for the EBS shelf and the AI declined slightly from 2016 levels during 2017 and 2018.

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 shows 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 22.4); 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 *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 Pribilof Islands. 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. 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”).

Analytic Approach

General Model Structure

The available data do not support quantitative catch-at-age modeling for either individual species of octopus in the BSAI or for the multi-species complex. Parameters for Tier 5 catch limits can be estimated from available data, but these estimates are not considered reliable. The alternative Tier 6 method, based on a predation-based estimate of total natural mortality (N), has been approved by the SSC and is recommended for use in 2017-2018.

The 2011 BSAI octopus assessment introduced a new methodology for examining population trends in octopus. This approach uses the underlying model from Tier 5, where MSY is obtained at ½ the total natural mortality (in tons). For Tier 5 stocks, the total natural mortality is usually estimated as the product of biomass (B) and an instantaneous mortality rate (M) $N=MB$. We use the letter N for the total natural mortality in tons to distinguish it from the M (continuous individual mortality rate) that is used widely in other stock assessment models. The new method uses a different approach to estimate total natural mortality that does not rely on being able to estimate biomass. The new method uses data from the AFSC’s food habits database to estimate the total amount of octopus consumed by their main predator in the BSAI: Pacific cod. Because Pacific cod is an important commercial species, the AFSC food habits group collects a large number of Pacific cod stomachs for diet analysis. The amount of octopus consumed by Pacific cod is a conservative estimate of the total natural mortality *N* for octopus, since it does not include mortality from other predators (*i.e*., marine mammals) or non-predation mortality. This approach has been reviewed by the Science and Statistical Committee and has been selected by the Bering Sea and Aleutian Islands Plan Team to set octopus catch limits for the BSAI fishery since 2012. This novel approach for setting annual catch limits for data-poor prey species has been presented at scientific conferences and is expected to be published next year. This analysis was originally performed in 2011 using stomach data through 2008 (Conners et al. 2011). The consumption estimator was updated for the 2016 assessment (Conners et al. 2016).

Parameter Estimates

Total Natural Mortality (N)

The consumption estimator was updated in 2016 to include additional samples (Table 22.6). The methodology used for this updated estimate is the same as used previously. The total consumption of octopus (t/year) estimated for the EBS is shown in Figure 22.6. We used the geometric mean of the posterior distribution to estimate annual predation for each year in the time series because the posterior distribution is right-skewed (higher values have higher uncertainty). Uncertainty of each annual estimate obtained by bootstrapping is also shown. Estimates of annual predation mortality by Bering Sea cod on octopus range from <200 to over 20,000 tons; the larger values have a higher level of uncertainty. The majority of the annual estimates prior to 2004 are in the range of 3,000 to 6,000 tons. The estimates for 2005 – 2015, however, show much higher levels of consumption, with several years in the 10,000-20,000 t range. This upward trend was initially assumed to be due to increasing abundance of Pacific cod, but there has also been an increase in the proportion of octopus in the diet of cod (Figure 22.7). Over the entire time series, this proportion shows large year-to-year variability and some periods of high consumption for several years followed by low consumption. Thus, it is unclear whether the recent upward trend is a permanent change (perhaps due to climate factors) or the peak of a periodic cycle.

We use a geometric mean of all the annual values to calculate a conservative long-term average predation rate over the 30 years of annual estimates. The use of the geometric mean is recommended because the distribution of the annual estimates is strongly right-skewed, with annual variance increasing in proportion to the annual mean. The geometric mean of all of the annual estimates in the updated data set is 4,770 tons, a substantial increase over the old estimate of 3,452 tons**.** Both estimates are a full order of magnitude higher than the current rate of fishery catch of octopus. The BSAI Plan Team requested clarification in September 2016 on whether the arithmetic mean, geometric mean, harmonic mean, or median of the annual values should be used to calculate the long-term average. These different approaches are shown in Table 22.7. At the November 2016 plan team meetings, use of the geometric mean was agreed upon.

Harvest Recommendations

We recommend that octopus be managed conservatively due to the poor state of knowledge of the abundance of octopus in the BSAI, and 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 be managed by the stock assessment models used for commercial groundfish species.

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 Conrath 2009, 2010). 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 6,999 t) and a mortality rate of 0.53 as described above; this estimate would set OFL at 3,709 tons. The BSAI plan team and SSC have previously rejected this option because of the high uncertainty associated with the estimates of both *B* and *M*.

Since 2011, the Plan Team and SSC have used an alternative method based on 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. **When this method is used, the resulting catch limits are OFL = 4,769 t and ABC = 3,576 t which are our recommended 2019 and 2020 ABCs and OFLs.**

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 (*Chionoecetes sp.*). The Ecopath model (Figures 22.8 and 22.9) 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), walrus, 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 are not a dominant predator of octopus, octopus are important prey item in the diet of Steller sea lions in the Bering Sea. According to diet information from Perez (1990; Figure 22.9), 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 (Figure 22.10). 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, was highest (11.5-18.2%) in the Aleutian Islands and was 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.

Ecosystem Effects on the Stock

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. A recent paper (Scheel, 2015) showed a negative correlation between annual beach counts of juvenile octopus in Prince William Sound and surface water temperatures in the eastern GOA during the preceding winter. Unusually warm surface temperatures have been occurring in the eastern North Pacific and appear to be causing some shifts in groundfish distributions. It is not clear whether trends in octopus populations are related to these climate shifts..

Fishery Effects on the Ecosystem

There is no directed fishery for octopus in the BSAI, but the majority of the incidental catch is taken in pot gear fished for Pacific cod. Catcher vessels have a limited time to deliver cod to processors (72-hour trip limit), so much of the cod pot effort in the BSAI is focused on areas near processors in Dutch Harbor and Akutan. To avoid gear conflicts with trawlers, cod pots are usually deployed inside of no-trawl zones or in rocky areas unsuitable for trawling. This results in most of the incidental octopus catch in the BSAI coming from specific areas near Unimak Pass. The effects of removal of Pacific cod and octopus from these specific areas is unknown. The low retention rate of octopus in the BSAI, and the high survival rate of discarded octopus suggest that effects on the octopus population is minor.

Data Gaps and Research Priorities

Recent efforts have improved collection of basic data on octopus, including catch accounting of retained and discarded octopus, full species identification of octopus during research surveys, and direct data on the life-history of *E. dofleini* in Alaskan waters. 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 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.

Aging methods for octopus are not in common use but have been developed for some species based on daily ring structure in beaks, stylets, or statoliths (Perales-Raya et al. 2010, Lepoarti 2015). Preliminary investigation confirmed that the statoliths of *E. dofleini* are too soft and chalky for use in aging analysis but showed definite structure in sections of beaks and stylets (Conners et al. 2012). Further research would be needed to examine these structures further and validate correlation between age and rings. If this research could develop a reliable aging protocol for *E. dofleini*, our understanding of its life cycle and growth patterns would be vastly improved.

We do not expect that either fishing industry employees or observers will be able to record accurate identification of octopus species on a routine basis. A publication on cephalopod taxonomy and identification in Alaska is available (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. 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. 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 planktonic paralarval 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 (Brewer 2016). These methods would require either extensive industry cooperation or funding for directed field research.

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Tables

Table 22.1. Octopus species found in the BSAI.

Scientific Name		Common Name	General Distribution	Age at Maturity	Size at Maturity
Class	Cephalopoda				
Order	Vampyromorpha				
Genus	*Vampyroteuthis*				
Species	***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				
Family	Bolitaenidae				
Genus	*Japetella*				
Species	***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*				
Species	***Sasakiopus salebrosus***	stubby octopus	BS shelf break, 200 - 1200 m	unknown	75 - 150 g

Table 22.2. Estimated catch (t) of all octopus species in state and federal waters. 1997-2002 estimated from Alaska Regional Office (AKRO) blend data. 2003-2018 data from AKRO catch accounting, as retrieved on November 3, 2018. Catch is shown separately for the two target fisheries that have the highest rate of incidental octopus catch, Pacific cod and flatfish (all species). The estimated percentage of total catch retained is shown for 2003-20168.

year	target fishery			total	% retained
	Pacific cod	flatfish	other		
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	209	34	19	262	38%
2004	278	45	246	569	24%
2005	311	17	10	339	64%
2006	331	5	14	350	55%
2007	156	7	9	171	39%
2008	196	11	8	215	37%
2009	58	10	6	73	23%
2010	168	12	5	184	33%
2011	565	8	14	587	6%
2012	126	3	8	137	17%
2013	218	2	4	224	21%
2014	406	17	7	429	25%
2015	411	19	12	442	17%
2016	553	16	27	597	16%
2017	263	7	11	281	34%
*2018**	*222*	*18*	*10*	*251*	*62%*

* 2018 data are incomplete; retrieved November 3, 2018.

Table 22.3. Estimated catch (t) of all octopus species in state and federal waters, 2003-2018, by NMFS statistical area. Data are from the Alaska Regional Office.

	EBS											AI			total
	509	512	513	514	516	517	518	519	521	523	524	541	542	543	
2003	81		7	0	1	42	0	77	31	3	1	10	9	1	262
2004	97	0	6		1	47	0	362	29	4	2	12	7	1	569
2005	81		3		3	33	0	190	13	0	2	12	0	0	339
2006	34		1		0	44	0	190	13	0	1	30	35	2	350
2007	70	0	3		1	12	0	46	8	0	1	23	4	4	171
2008	57	5	4		0	34	0	77	14	0	1	14	6	1	215
2009	18		0			7	0	20	6	0	0	7	11	2	73
2010	40		1		0	20	0	68	4	0	0	13	20	16	184
2011	180		3	0	13	136	1	228	15	0	0	6	5	0	587
2012	25		1		0	12	0	77	10	2	0	7	1	2	137
2013	26		1			18	0	130	8	2	0	19	19	1	224
2014	43	0	1	1	0	37	1	317	8	1	0	11	8	0	429
2015	70	1	2	1	0	56	3	270	20	0	0	11	7	2	442
2016	86	0	2	0	0	152	18	293	31	1	2	5	3	3	597
2017	72	1	3	0	1	54	1	96	15	0	4	27	7	1	281
*2018**	*43*	*0*	*1*	*0*	*1*	*19*	*4*	*25*	*13*	*0*	*4*	*110*	*30*	*2*	*251*

* 2018 data are incomplete; retrieved November 3, 2018.

Table 22.4a. Survey biomass estimates for octopus species in the Bering Sea and Aleutian Islands region. CV = coefficient of variation.

		B leioderma		*B oregonensis*		*E dofleini*		octopus unID		*S salebrosus*	
		biomass	CV	biomass	CV	biomass	CV	biomass	CV	biomass	CV
EBS shelf	2010	27	0.84	0		650	0.59	0.0		142	0.58
	2011	250	0.39	0		2,844	0.33	459.6	1.00	0	
	2012	479	0.37	0		2,087	0.39	0.1	1.04	0	
	2013	97	0.50	13	1.00	1,654	0.53	4.4	0.79	0	
	2014	157	0.60	93	1.00	2,095	0.54	2.0	0.80	4	1.00
	2015	113	0.63	0		5,248	0.31	1.7	0.77	0	
	2016	328	0.35	0		6,997	0.47	0.8	1.01	188	0.46
	2017	1,583	0.27	0		1,793	0.44	10.4	0.50	0	
	2018	604	0.37	0		4,638	0.29	0.0		0	
EBS slope	2010	87	0.21	28	0.99	216	0.33	0.0	1.00	32	0.17
	2012	146	0.32			647	0.43	1.3	0.80	28	0.16
	2016	133	0.20	151		566	0.31	5.3	0.89	51	
AI	2010					3,074	0.30	1.1	0.53		
	2012					2,739	0.42	40.8	0.52		
	2014					2,762	0.20	83.1	0.60		
	2016					3,752	0.24	80.6	0.94		
	2018					2,231	0.40	43.6	0.87		

Table 22.4b. Survey biomass estimates for octopus species in the Bering Sea and Aleutian Islands region. CV = coefficient of variation.

		J diaphana		*O californiana*		*G boreopacifica*		*Benthoctopus* sp		*V infernalis*	
		biomass	CV	biomass	CV	biomass	CV	biomass	CV	biomass	CV
EBS shelf	2010										
	2011										
	2012										
	2013										
	2014										
	2015										
	2016										
	2017										
	2018										
EBS slope	2010	0.5	1.00	85	0.24	96	0.46	77	0.22	0.09	1.00
	2012	5.1	0.61	342	0.22	248	0.27				
	2016	8.6	0.50	1,206	0.19	143	0.16				
AI	2010										
	2012										
	2014										
	2016										
	2018										

Table 22.5. Biomass estimates in tons for octopus (all species) and coefficients of variation (CV) of the estimates from AFSC bottom trawl surveys, 1982-2018.

year	EBS Shelf		EBS Slope		AI		BSAI
	biomass	CV	biomass	CV	biomass	CV	total biomass
1982	13,076		180				
1983	3,517				261	0.22	
1984	2,647						
1985	2,582		152				
1986	510				250	0.32	
1987	7,813	0.52					
1988	9,935	0.29	138				
1989	4,910	0.33					
1990	11,619	0.48					
1991	8,114	0.34	61		1,159	0.20	
1992	5,611	0.42					
1993	1,588	0.34					
1994	2,479	0.39			1,727	0.19	
1995	2,928	0.59					
1996	1,804	0.68					
1997	255	0.40			1,219	0.25	
1998	1,285	0.51					
1999	832	0.52					
2000	2,031	0.41			789	0.30	
2001	5,908	0.32					
2002	2,525	0.44	979	0.18	1,393	0.26	4,897
2003	8,244	0.46					
2004	4,957	0.31	1,957	0.14	4,095	0.34	11,010
2005	10,219	0.28					
2006	1,897	0.34			3,062	0.17	
2007	2,278	0.29					
2008	1,149	0.43	781	0.17			
2009	1,020	0.54					
2010	820	0.48	621	0.15	3,075	0.30	4,516
2011	3,554	0.30					
2012	2,567	0.32	1,419	0.21	2,779	0.42	6,765
2013	1,769	0.50					
2014	2,351	0.49			2,845	0.20	
2015	5,363	0.30					
2016	7,513	0.44	2,263	0.13	3,833	0.24	13,609
2017	3,387	0.26					
2018	5,242	0.26			2,274	0.39	

Table 22.6. Numbers of Pacific cod stomach samples analyzed for octopus consumption estimates.

year	# of samples
1984	636
1985	952
1986	1,338
1987	747
1988	551
1989	1,662
1990	1,121
1991	1,546
1992	1,876
1993	2,303
1994	2,381
1995	2,395
1996	1,314
1997	1,155
1998	1,262
1999	1,049
2000	1,101
2001	1,304
2002	1,334
2003	1,770
2005	408
2006	671
2007	578
2008	1,204
2009	1,312
2010	1,169
2011	1,511
2014	1,617
2015	1,893

Table 22.7. Results of different approaches for calculating a long-term mean value from annual consumption estimates. The geometric mean is recommended by the authors and accepted by the plan team.

Method:		**Value (t)**
Median		5,055
Arithmetic Mean		6,842
Geometric Mean		**4,769**
Harmonic Mean		2,653

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 have low immediate and short-term mortality.	No concern	No concern
Fishery effects on age-at-maturity and fecundity	Unknown	No concern at this time	Unknown

Figures

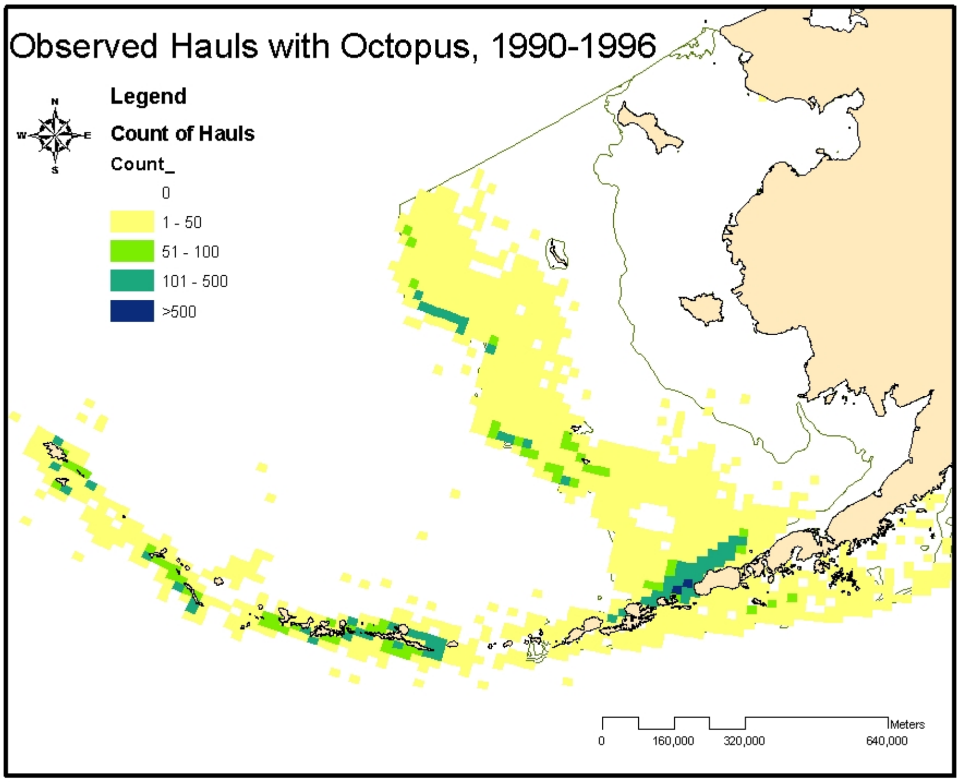


Figure 22.1. Distribution of octopus (all species) in the BSAI, based on octopus occurring in observed hauls during the period 1990-1996.

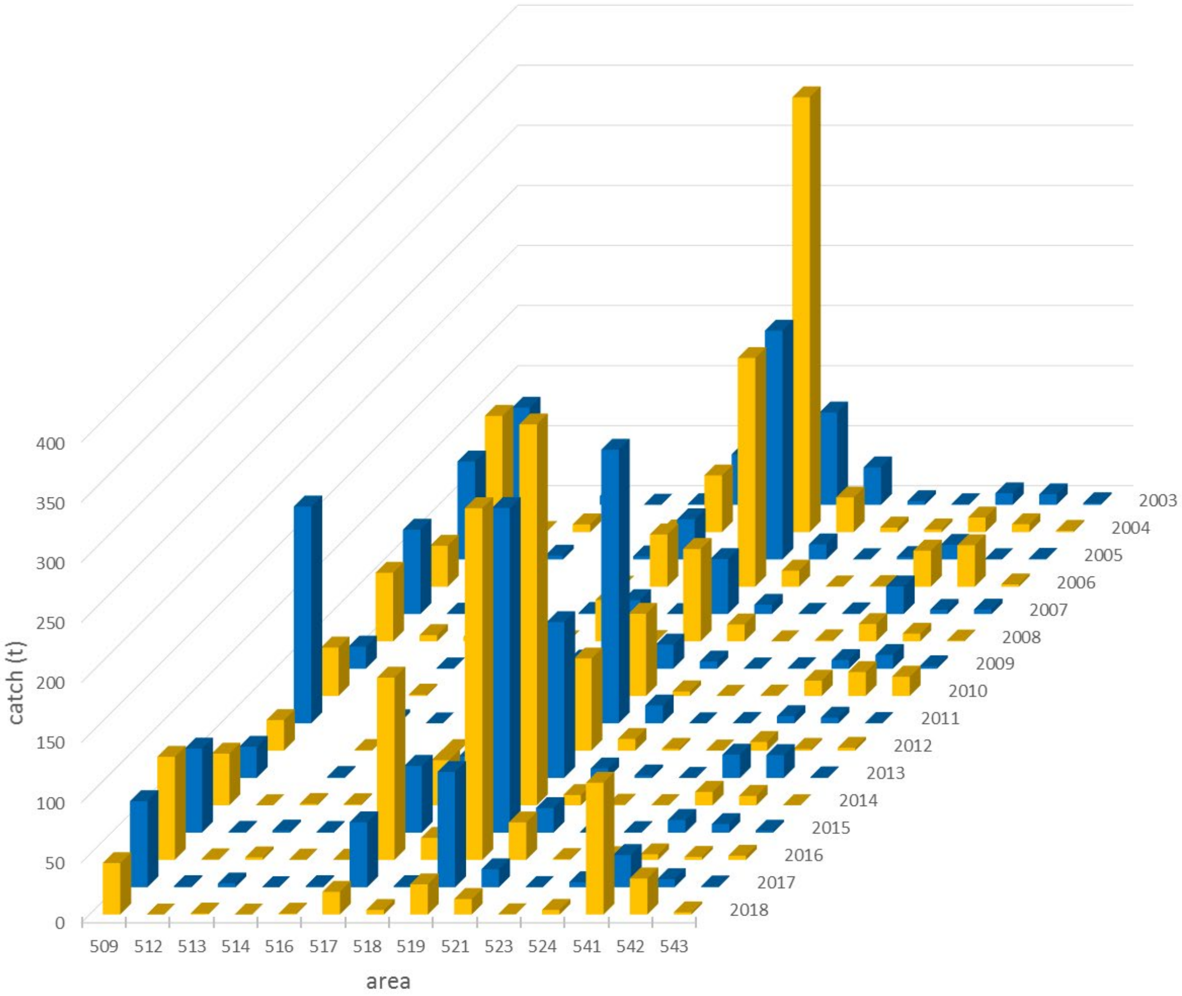


Figure 22.2. Incidental catches of octopus (t) in the Bering Sea and Aleutian Islands, 2003-2018, by NMFS statistical area. 2018 data are incomplete; retrieved November 3, 2018.

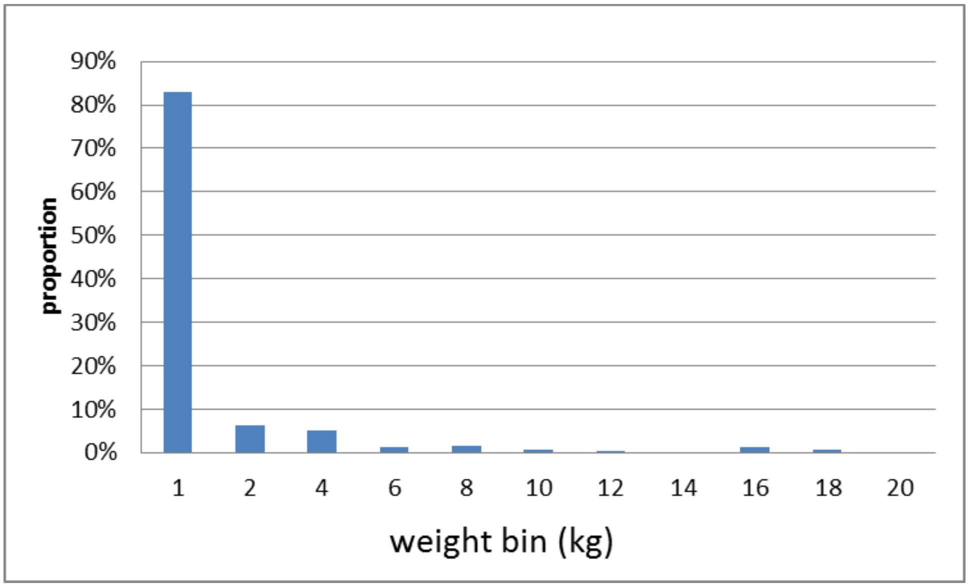
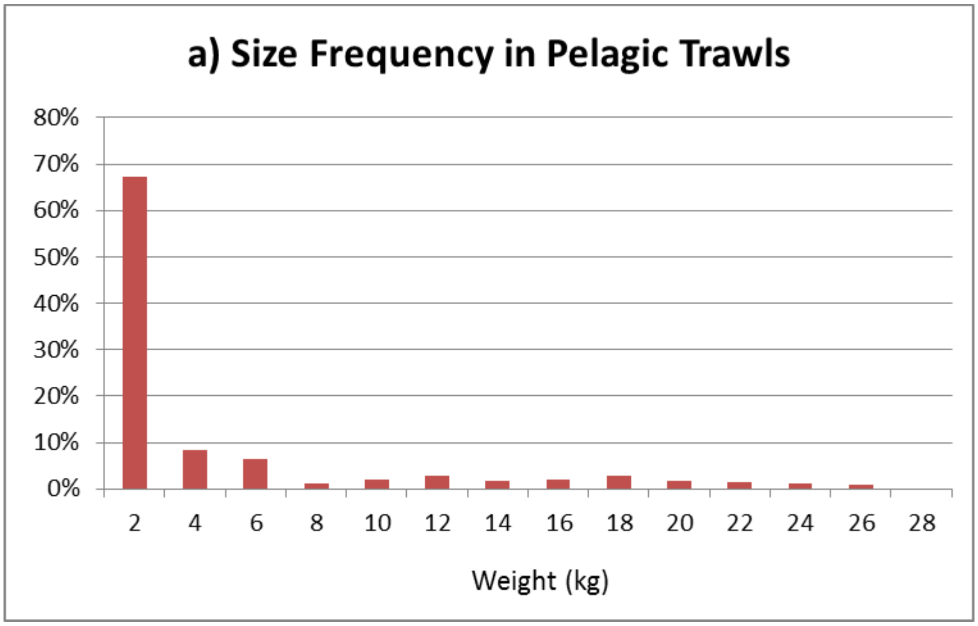


Figure 22.3. Size frequency of individual octopus (all species) from Bering Sea shelf bottom trawl surveys 2009 – 2018.



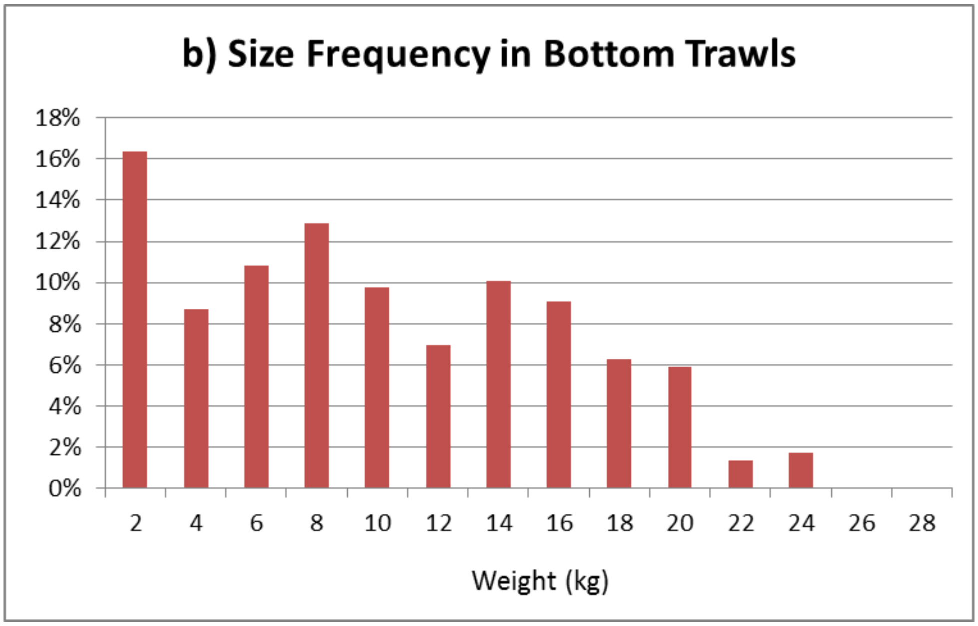
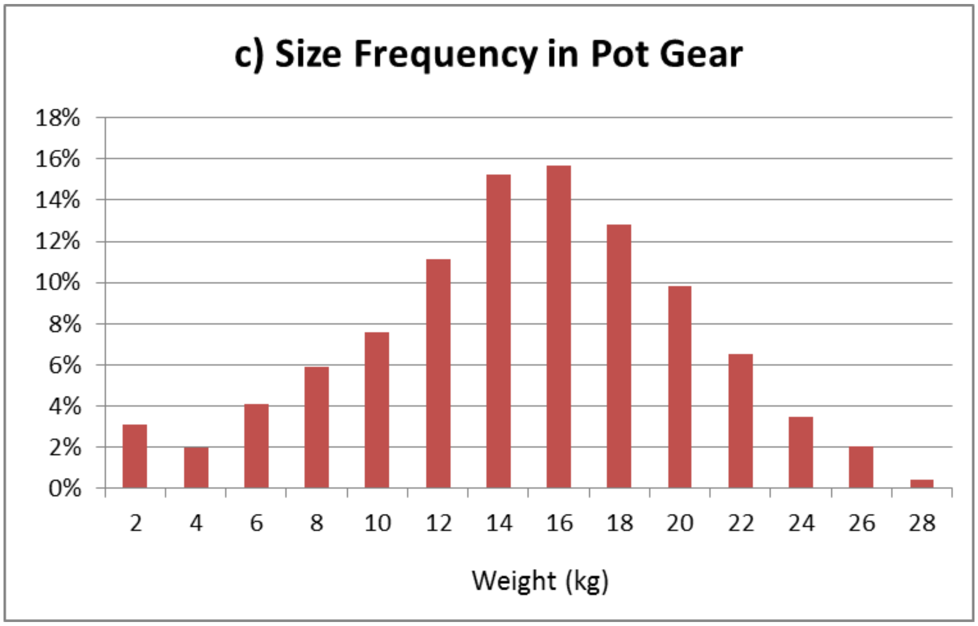


Figure 22.4a. Size frequency of individual octopus from observer special project 2006-2011 by gear type: a) pelagic trawl, b) bottom trawl, c) pots, d) longline.


c) Size Frequency in Pot Gear

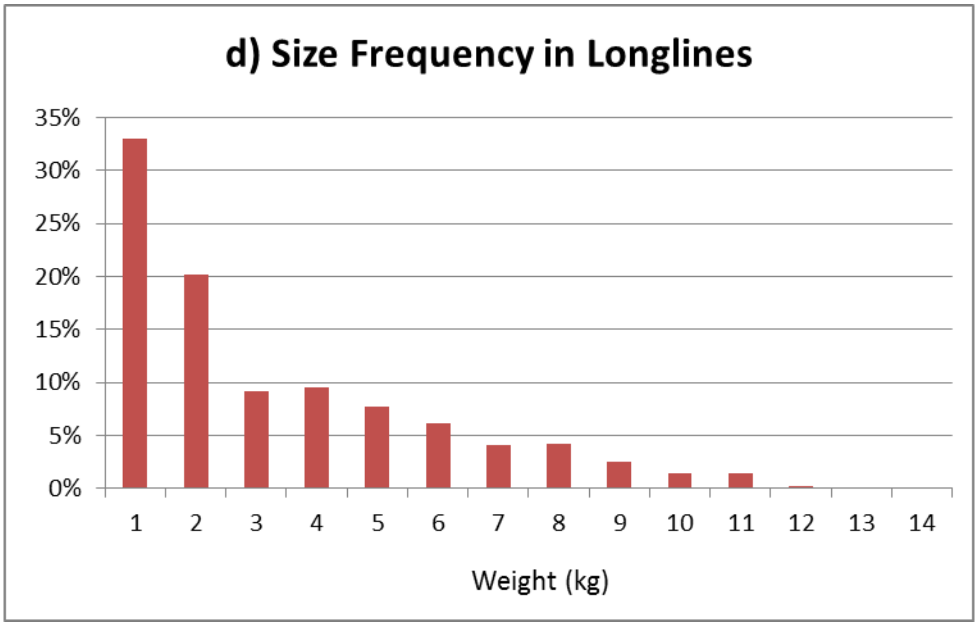

d) Size Frequency in Longlines

Figure 22.4b. Size frequency of individual octopus from observer special project 2006-2011 by gear type: a) pelagic trawl, b) bottom trawl, c) pots, d) longline.

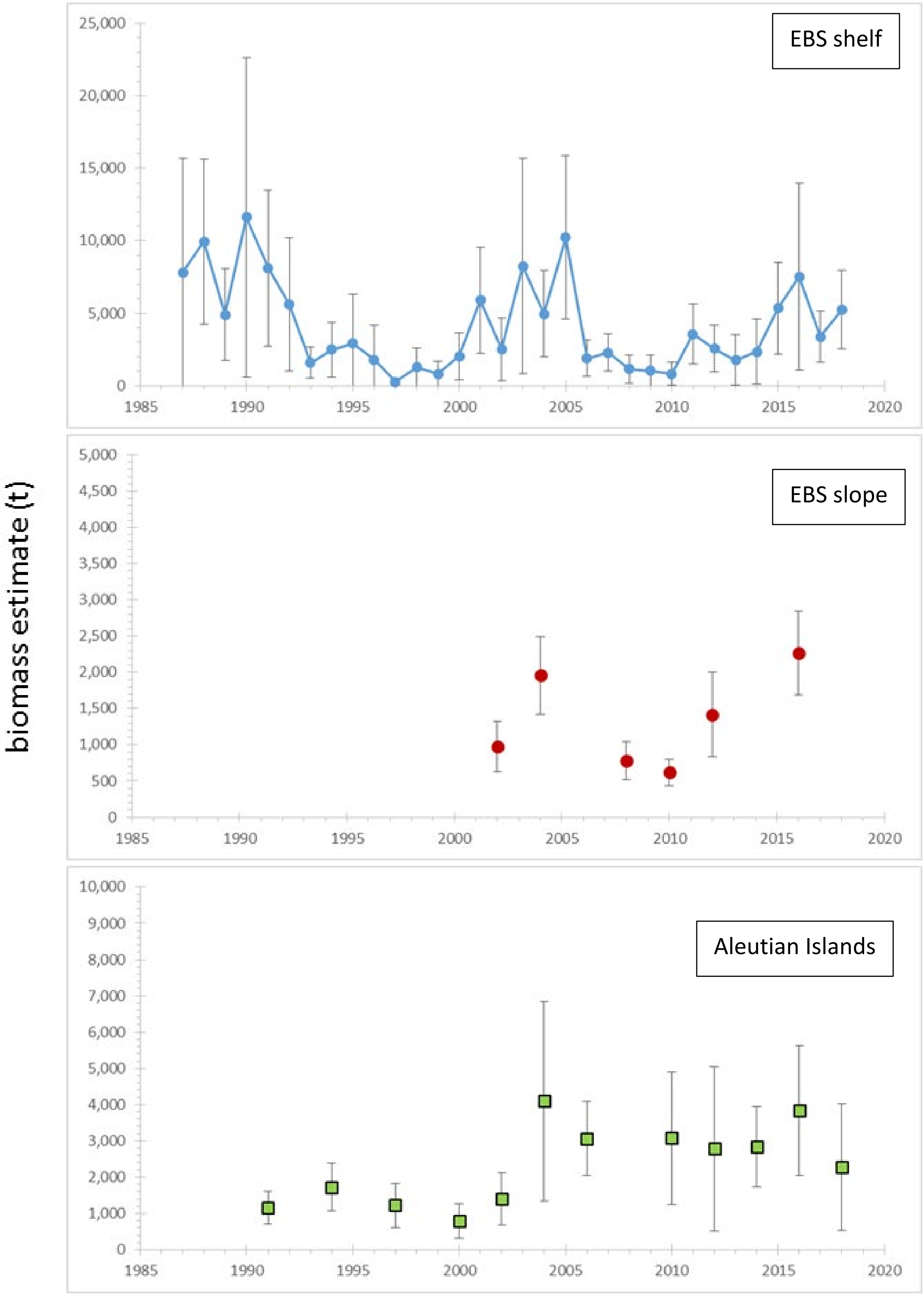


Figure 22.5. Biomass estimates (t) of octopus (all species) from AFSC bottom trawl surveys in three areas: EBS shelf (top), EBS slope (middle, and AI (bottom), 1987-2018. Error bars indicate 95% confidence intervals. Note that scale of y-axis varies among plots.

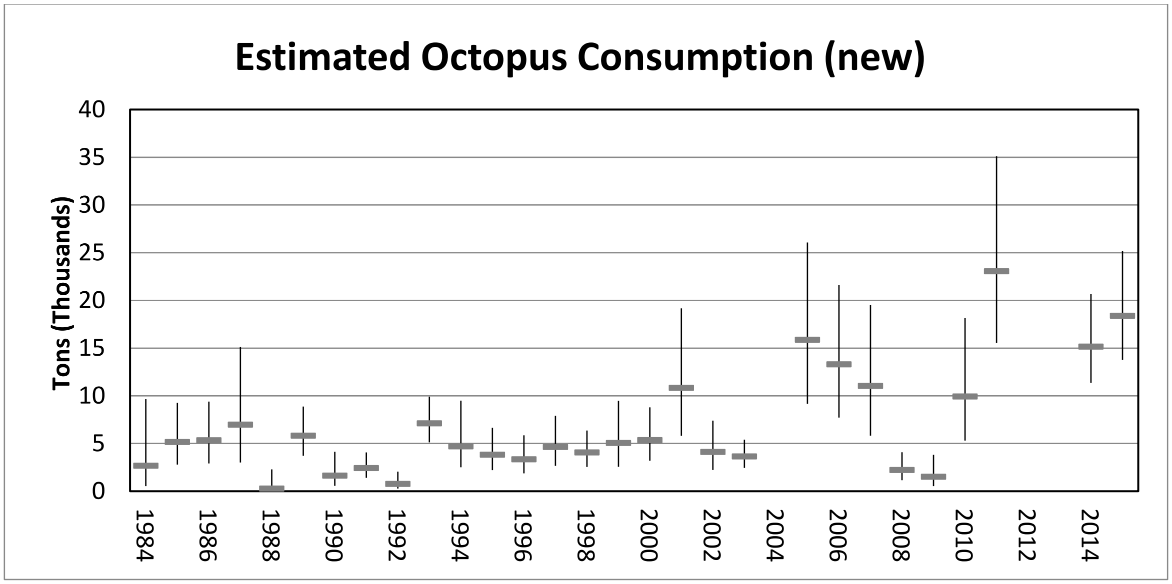


Figure 22.6. Estimated consumption of octopus by Bering Sea Pacific cod, 1984-2015. Error bars show 95% confidence intervals of posterior distribution; solid bars are annual hyperbolic means.

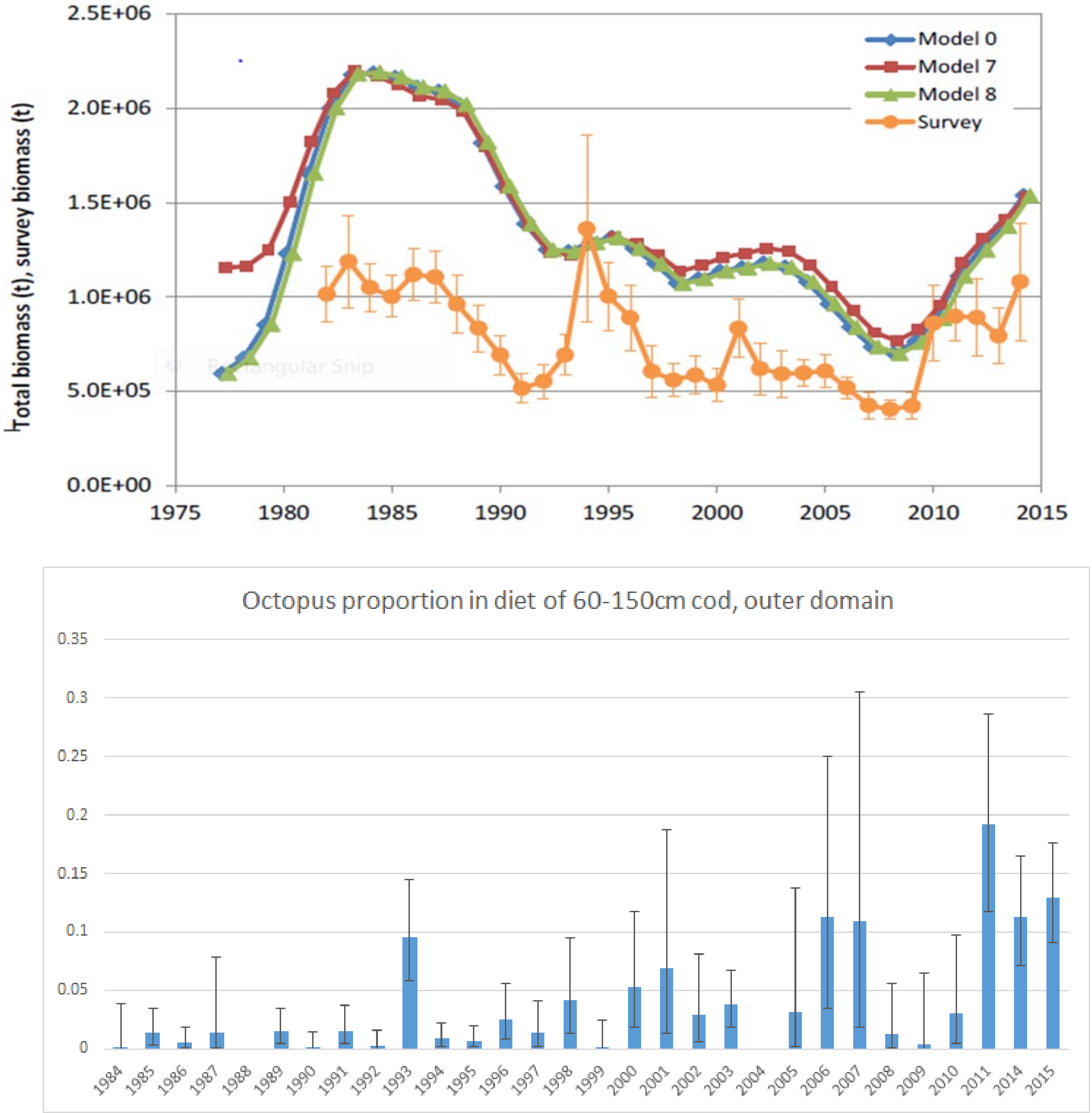
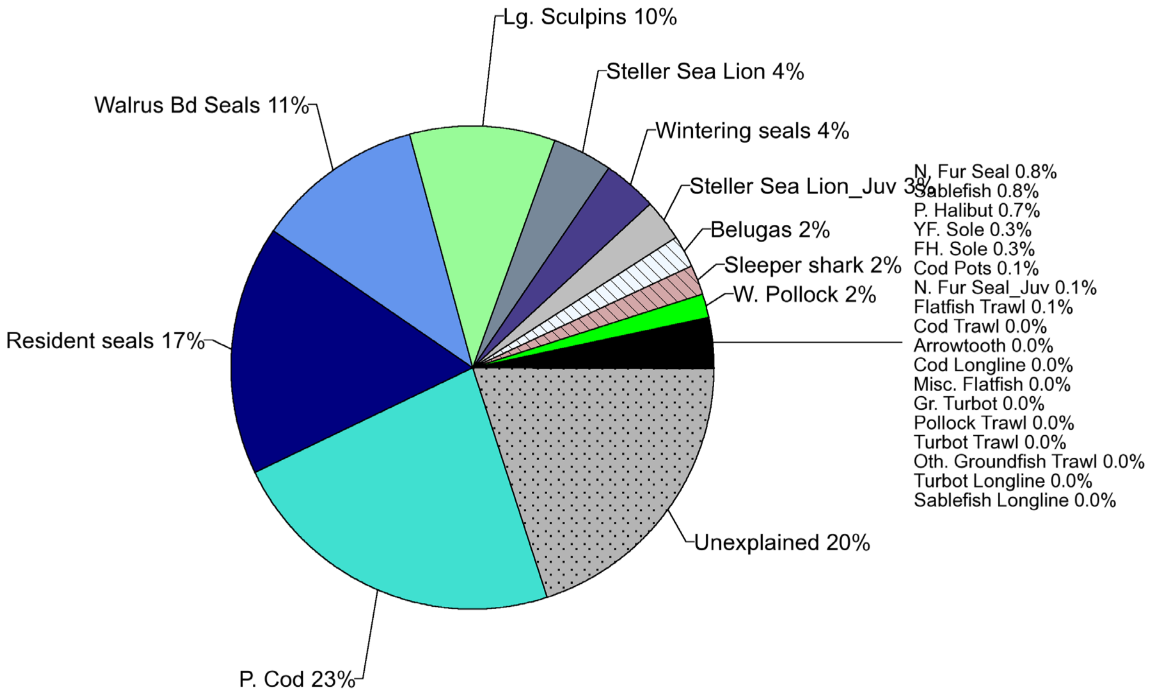


Figure 22.7 Time series trends in a) the biomass of Bering Sea Pacific cod and b) the proportion of octopus in cod diets.

.a) Bering Sea Ecosystem



b) Aleutian Islands Ecosystem

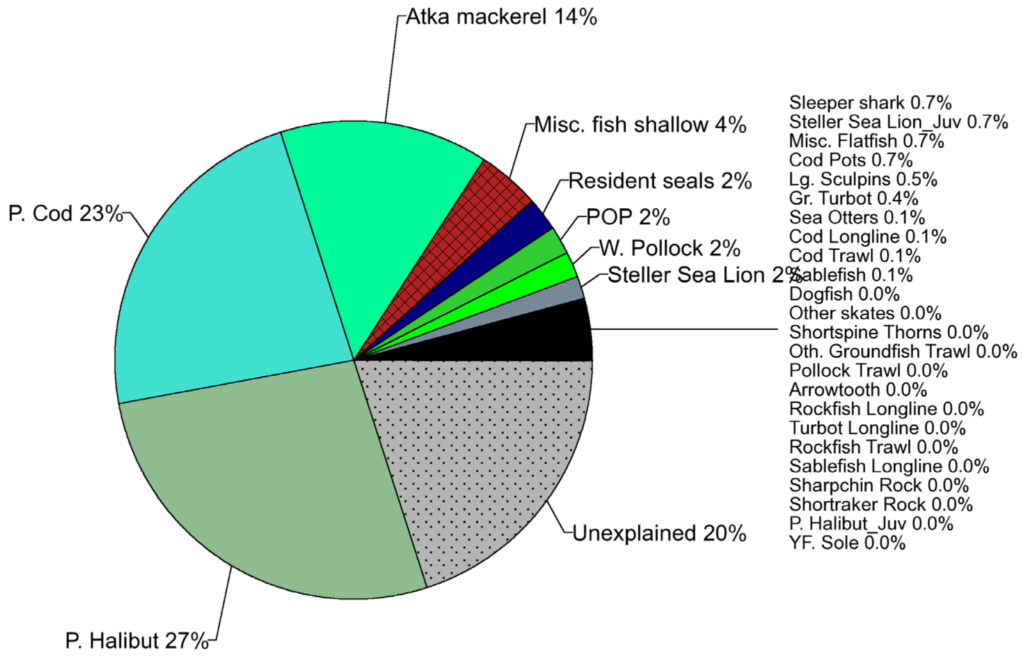


Figure 22.8. Ecopath model estimates of mortality sources of octopus in the BSAI

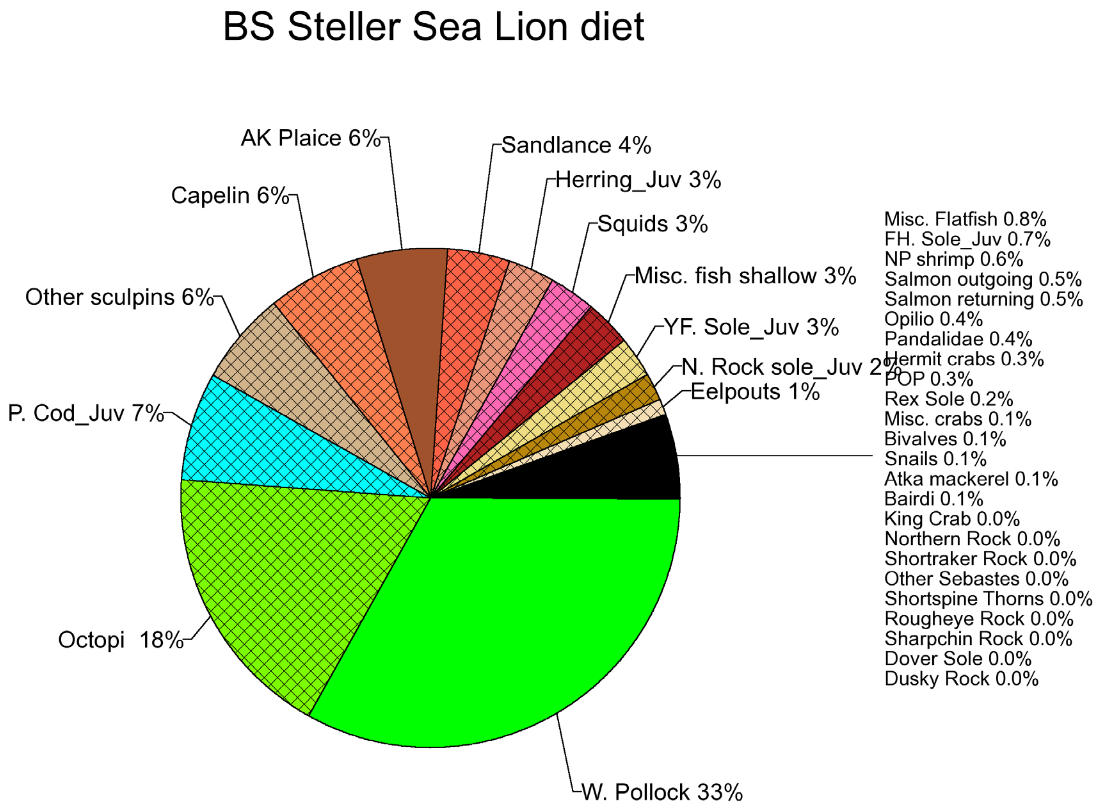


Figure 22.9. Literature-derived diets of Steller sea lions in the BS and AI.

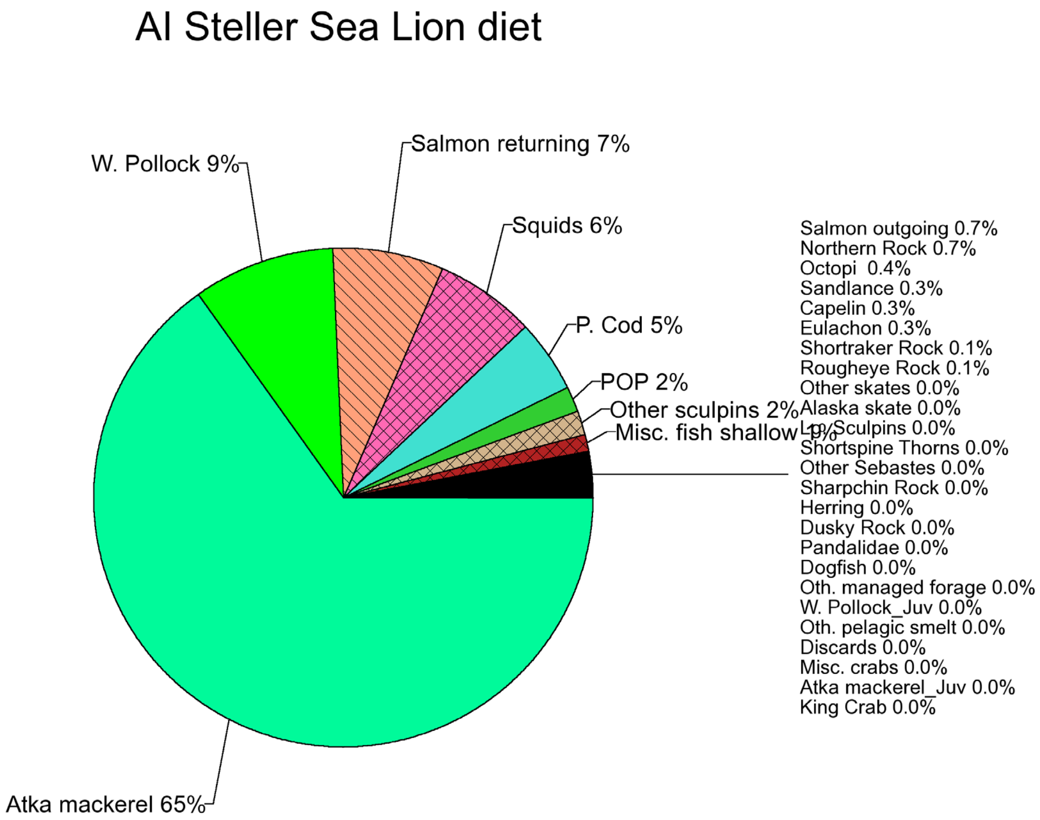


Figure 22.10. Literature-derived diets of Steller sea lions in the BS and AI.

Appendix

Table 1. Non-commercial catches (**kilograms**) of octopuses in the BSAI, 2014-2017.

agency	activity	2014	2015	2016	2017
ADFG	Kachemak Bay Large Mesh Trawl Survey				191
	Kodiak Scallop Dredge				5
	Large-Mesh Trawl Survey	1,307	1,574	736	94
	Prince William Sound Large Mesh Trawl Survey				8
	Scallop Dredge Survey			2	
	Small-Mesh Trawl Survey	68	15		
	Spot Shrimp Survey	32	33	17	
	Yakutat Scallop Dredge				1
IPHC	IPHC Annual Longline Survey	2,422	1,693	993	611
NMFS	Aleutian Island Bottom Trawl Survey	0		0	
	Annual Longline Survey	322	448	88	126
	Bait for Crab Fishery		133		772
	Bering Sea Slope Survey			2	
	Eastern Bering Sea Bottom Trawl Survey	0	0	0	0
	Gulf of Alaska Bottom Trawl Survey		0		0
	Salmon EFP 13-01	21			
	total	4,171	3,896	1,837	1,808