# 22 Assessment of the Octopus Stock Complex in the Gulf of Alaska

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## Executive Summary

Through 2010, octopuses were managed as part of the "other species" complex, with catch reported only in the aggregate along with sharks, squids, and sculpins. Due to increasing market interest, retention of some other species complex members is increasing. Beginning in 2011, the GOA fisheries management plan has been amended to provide separate management for sharks, sculpins, and octopus. In compliance with the reauthorized Magnuson-Stevens act, each group will have its own annual catch limit. Catch limits for octopus for 2011 and 2012 were set based on using the average of the last 3 surveys as a minimum biomass estimate. Catch limits by this method would stay the same for 2013 and 2014, since there was not a new survey in 2012. A new methodology based on consumption of octopus by Pacific cod was introduced in the Bering Sea in 2011; this method has been applied to the GOA this year for the first time. This assessment presents recommendations under both methods for 2013-2014.

In this assessment, all octopus species are grouped into a single assemblage. At least seven species of octopus are found in the Gulf of Alaska (GOA). The species composition both of the natural community and the commercial harvest is not well documented, but research indicates that the Giant Pacific octopus *Enteroctopus dofleini* is the most abundant octopus species in shelf waters and makes up the bulk of octopus catches in commercial fisheries. Octopuses are taken as incidental catch in trawl, longline, and pot fisheries throughout the GOA; a portion of the catch is retained or sold for human consumption or bait. The highest octopus catch rates are from Pacific cod pot fisheries in the central and western GOA (NMFS statistical areas 610 and 630).

The GOA trawl surveys produce estimates of biomass for octopus, but these estimates are highly variable and may not reflect the same size 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 GOA 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 in Appendix A.

### *Summary of Changes in Assessment Inputs*

There are no new survey data for this year. Catch data have been updated through October 6, 2012. The estimated total catch for 2011 was the highest ever recorded at 918 tons. This is almost triple the catch amounts in preceding years. The majority of this high catch was from Pacific cod pot gear in statistical areas 610 and 630. Incidental catch through October 6, 2012 was more similar to past levels at 278 tons.

This assessment introduces a new approach for estimating octopus natural mortality and setting catch limits. This method was introduced in the Bering Sea last year and has been reviewed by the plan teams and SSC. This approach 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". Text summarizing recent studies and new research underway on octopus has been updated. 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 records of directed fishing for octopus. Estimates of incidental catch rate from 1997-2007 are available, and were selected as the baseline for assessments using historical catch methods. The authors and plan teams are concerned that the historical catch methods may result in an overly conservative catch limit. In 2010 and 2011, the plan team decided to use an approach where the average of the last 3 survey biomass estimates was used as a minimum biomass estimate, and a mortality factor applied. The OFL for octopus in 2012 was set at 1,940 tons and the TAC at 1,450 tons. The incidental catch of octopus in 2011 was 918 tons. This assessment provides recommendations for annual catch limits for 2013 and 2014, and presents several possible alternatives for setting new catch limits. The authors recommend the new method based on consumption estimates. There is insufficient data to determine whether the complex is being subjected to overfishing, is currently overfished, or is approaching a condition of being overfished.

| | 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) | 6(max) | 6(max) | 6(max) | 6(max) |
| OFL (t) | 298 | 298 | 298 | 298 |
| ABC (t) | 224 | 224 | 224 | 224 |
| Tier 6 (survey biomass * M) | 6(alt) | 6(alt) | 6(alt) | 6(alt) |
| OFL (t) | 1,940 | 1,940 | 1,940 | 1,940 |
| ABC (t) | 1,450 | 1,450 | 1,450 | 1,450 |
| Tier 6 (consumption-based estimate) | 6(alt) | 6(alt) | 6(alt) | 6(alt) |
| OFL (t) | ---- | ---- | 1,560 | 1,560 |
| ABC (t) | ---- | ---- | 1,170 | 1,170 |
| | As determined *last* year for: | | As determined *this* year for: | |
| **Status** | 2010 | 2011 | 2011 | 2012 |
| Overfishing | n/a | n/a | n/a | n/a |

### *Responses to SSC comments*

At the December 2011 meeting the SSC discussed the GOA octopus catch limits for 2012 and had the following comments:

*The modified Tier 6 approach involves averaging biomass estimates from the last three bottom trawl surveys in 2007, 2009 and 2011. This approach recognizes that the catch history is not appropriate for tier 6 management, and that the biomass estimates and M estimates are not sufficient for a Tier 5 approach. The author has also developed a method for estimating total mortality based on predation by*

*Pacific cod in the BSAI. The SSC agrees with the Plan Team that this approach be developed further for application and consideration for GOA octopus in 2012.*

Both the three-survey average and the new consumption-based approach are presented in this SAFE.

In discussing the consumption-based approach used in the BSAI SAFE, the SSC had the following comments and requests:

"*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 recommended in both the BSAI and GOA for 2013 catch limits. The authors agree that this method is still highly uncertain 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 A.

*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*
- *Contract 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; 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 were 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 are useful as a time trend and are included in this document, but they provide little 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. It is apparent that temporal and spatial catch patterns in the pot fishery are primarily determined by seasonal timing and locations of pot fishing for Pacific cod. Pot fishing in the GOA occurs primarily to the north and east of Kodiak (Chiniak Bay), in Kuprianof Strait, along the west side of Kodiak Island (statistical area 630), and in the western GOA between the Shumagin Islands and Sanak Island (area 610). Octopus catch occurs primarily in January-February and in September.

*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 molluscs 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, the octopus 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 paddle-shaped fins suitable for swimming in their deep oceanic 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). *Enteroctopus dofleini* is one of at least seven species of octopus (Table 1) found in the GOA. Members of these seven species represent six genera and can be found in depths from less than 10 m to greater than 1500 m. All but one, *Japetella diaphana*, are benthic octopuses. The state of knowledge of octopuses in the GOA, including the true species composition, is very limited.

In the GOA, octopuses are found from subtidal waters to deep areas near the outer slope (Figure1). The highest diversity is along the shelf break region of the GOA, although, unlike the Bering Sea, there is a high abundance of octopuses on the shelf. While octopuses are observed throughout the GOA, they are more commonly observed in the Central and Western GOA (stat areas 610-630) than in the Eastern GOA. The greatest numbers of observations are clustered around the Shumagin Islands and Kodiak Island. These observations are influenced by the distribution of fishing effort and may not reflect true spatial patterns. AFSC survey data also demonstrate the presence of octopus throughout the GOA and also indicate highest biomass in areas 610 and 630. Octopuses were caught at all depths ranging from shallow inshore areas (mostly pot catches) to trawl and longline catches on the continental slope at depths to nearly 1000 meters. The majority of octopus caught with pots in the GOA came from 70-110 meters;

catches from longline vessels tended to be in deeper waters of 200-400 fathoms (360-730 meters). Octopuses are also common in the eastern Bering Sea and throughout the Aleutian Island chain.

### Management Units

Through 2010, octopuses were managed as part of the "other species" complex in the GOA. Prior to 2003, catch of other species (squid, octopus, sharks, and sculpins) was reported only in the aggregate. Separate catch reporting for different components of the other species complex has been initiated, but octopus are still reported as an aggregate catch for all species. Increasing market value and a small directed fishery for skates in 2003-2004 caused this group to be broken out of the GOA other species complex and managed under a separate TAC. Catch of other species from 2005-2009 was limited by a Total Allowable Catch (TAC) set at $\leq$ 5% of the combined GOA target species TAC. In October 2009, the NPFMC voted unanimously to amend both the BSAI and GOA Fishery Management Plans to eliminate the 'other species' category. Plan amendments move species groups formerly included in 'other species' into the target species 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 2010.

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 GOA 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". *Enteroctopus 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, octopuses are fast growing with a life span generally less than 5 years. Life histories of seven of the eight species in the Gulf of Alaska are largely unknown. *Enteroctopus dofleini* has been studied extensively in Alaskan, Japanese and Canadian waters and its life history will be reviewed here; generalities on the life histories of the other seven species will be inferred from what is known about other members of the genus.

*Enteroctopus dofleini* within the Gulf of Alaska have been found to mature between 10 to 20 kg with 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 (conrath and conners, in prep). *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 but smaller size ranges (Kanamaru and Yamashita 1967, Mottet 1975). Within the Gulf of Alaska this species has a protracted reproductive cycle with a peak in spawning in the winter to early spring months. 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 an aquarium study of octopus in Alaska (Jared Gutheridge pers com) and British Columbia (Gabe 1975). Fecundity for this species ranges from 40,000 to 240,000 eggs per female with an average fecundity of 106,800 eggs per female. Fecundity is 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 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). Since the highest mortality occurs during the larval stage, it is probable that ocean conditions have a large impact on numbers of *E. dofleini* in the GOA and large fluctuations in numbers of *E. dofleini* should be expected.

*Enteroctopus dofleini* is found throughout the northern Pacific Ocean from northern Japanese waters, throughout the Aleutian Islands, the Bering Sea and the Gulf of Alaska and as far south down the Pacific coast 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) indicate the presence of a cryptic species of *E. dofleini* in Prince William Sound, Alaska and raises questions about the stock structure of this species. 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. Additional genetic and/or tagging studies are needed to clarify the stock structure of this species in Alaska waters.

*Octopus californicus* is a medium-sized octopus with a maximum total length of approximately 40 cm. Very little is known about this species of octopus. It is collected between 100 to 1,000 m depth in Alaska and has been reported in even deeper waters off the coast of California (Smith and Mackenzie 1948). It is believed to spawn 100 to 500 eggs. Hatchlings are likely benthic; hatchling size is unknown. The female likely broods the eggs and dies after hatching.

*Octopus rubescens* has been reported from Prince William Sound in the central GOA, but has not been verified in survey collections. *Octopus rubescens* appears to have a two year life cycle with egg laying occurring in July through September and hatching occurring 5 to 10 months later in February through March. Females of this species are terminal spawners estimated to lay approximately 3,000 eggs (Dorsey 1976). *Octopus rubescens* has a planktonic larval stage.

*Octopus sp. A* is a small-sized species with a maximum total length < 10 cm. This species has only recently been identified in the GOA and its full taxonomy has not been determined. *Octopus sp. A* is likely a terminal spawner with a life-span of 12 to 18 months. The eggs of *Octopus sp. A* are likely much larger than those of *O. rubescens*, as they appear to have larger benthic larvae. Females of *Octopus sp. A* lay between 80 to 90 eggs that take up to six months or more to hatch.

*Benthoctopus leioderma* is a medium sized species; its maximum total length is approximately 60 cm. Its life span is unknown. It occurs from 250 to 1400 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.

*Opisthoteuthis californiana* is a cirrate octopus; it has fins and cirri (on the arms). It is common in the GOA but is not likely to be confused with *E. dofleini*. It is found from 300 to 1,100 m and is 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 depth and brooding females near 800 m depth. Hatchlings have been observed to be about 3 mm mantle length (Young 2008). This is not a common octopus in the GOA and not likely to be confused with *E. dofleini*.

*Vampyroteuthis infernalis* is a cirrate octopus. It is not common in the GOA and 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 at least seven species of octopus present in the GOA, and the species composition both of natural communities and commercial harvest is unknown. At depths less than 200 meters, *E. dofleini* appears to have the highest biomass, but the abundances of *Octopus sp. A* and *B. leioderma* are also very high. The greatest difference in species composition between the Bering Sea Aleutian Islands (BSAI) and the GOA is the presence of *O. californicus* and the small *Octopus* sp. A.

# Fishery

## *Directed Fishery*

There is no federally-managed directed fishery for octopus in the GOA. One processor in Kodiak purchases incidentally-caught octopus, primarily for halibut bait. Ex-vessel prices for octopus in Kodiak are currently in the range of $0.50 /lb (Sagalkin and Spalinger, 2011). Recent increases in global market value have increased retention of incidentally-caught octopus in the BSAI and GOA. Because of the relatively large number of small boats in the GOA commercial fleet and recent changes to crab fishing seasons, there may be some interest in directed fishing for octopus in the GOA.

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. Two permits were issued in 2006 but no catch was taken on them. 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 GOA in both state and federally-managed bottom trawl, longline, and pot fisheries. From 1992-2002 total incidental catch of octopus in federal waters was estimated from observed hauls (Table 2) (Gaichas 2004). Since 2003 the total octopus catch in state and federal waters (including discards) has been estimated using the NMFS regional office catch accounting system. Minor updates and changes to this system have changed estimated catch numbers slightly from previous assessments. Incidental catch rates are presented in the data section. The majority of incidental catch of octopus comes from Pacific cod fisheries, primarily pot fisheries (Sagalkin and Spalinger, 2011). Some catch is also taken in trawl fisheries for cod and other species. The overwhelming majority of catch in federal waters occurred in the central and western GOA in statistical reporting areas 610, 620 and 630. In 2008-2011, there were high octopus catches in both the Shumagin and Kodiak regions (610 and 630). The species of octopus taken is not known, although size distributions suggest that the majority of the catch from pots is *E. dofleini*.

### Catch History

Since there has been only a limited market for octopus and no directed fishery in federal waters, there is limited data available for documenting catch history. Historical rates of incidental catch would not necessarily be indicative of future fishing patterns if octopuses were increasingly retained for market catch. Estimates of incidental catch based on observer data (Table 2) suggest substantial year-to-year variation in abundance, which would result in large annual fluctuations in harvest. This large interannual variability is consistent with anecdotal reports (Paust 1988, 1997) and with life-history patterns for *E. dofleini*. Incidental catch in 2011 was the highest ever observed, with a total catch over 900 tons.

### 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 t per year in the late 1960's and are currently in the range of 30,000 t (www.fao.org). Octopus are harvested with commercial bottom trawl and trap gear; hooks, lures, longlines, spears, and by hand. Primary markets are Japan, Spain, and Italy, and prices in 2004-2005 were near record highs (www.globefish.org). Prices were also high in 2011, due to a decrease in exports from tow 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 known 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). Caddy (2004) also suggests the use of surplus production models to protect minimum spawning biomass, if sufficient data are available. Perry et al. (1999) describe a framework for management of new and developing invertebrate fisheries; GOA and BSAI octopus fisheries are clearly in phase 0 of this scheme, where existing information is being collected and reviewed.

# Data

### *Incidental Catch Data*

From 1997-2001, total incidental catch of octopus in state and federal waters was generally between 100 and 200 t, with a high of 298 t in 2002 (Table2). Catches in 2007-2010 have been somewhat higher; between 250 and 350 t. Incidental catch in 2011 was the highest ever observed, with a total annual catch over 900 tons. The majority of this very large catch came during the fall Pacific cod pot fishery in statistical areas 610 and 630. Approximately half of the reported catch for 2011 was retained either for market or for use as bait. The incidental catch rate for the first portion of 2012 was much lower, with 287 tons caught through October 6, 2012. High rates of incidental catch in 2002, 2004, 2009, and 2011 correspond to high survey catches in 2003, 2009, and 2011 (Table 3). As in previous years, the majority of the 2011-2012 catch came from Pacific cod fisheries (Table 2), primarily pot fisheries in statistical reporting areas 610 and 630.

### *AFSC Survey Data*

Catches of octopus are recorded during the semi-annual NMFS bottom trawl survey of the GOA. In older survey data (prior to 2003), octopus were often recorded as Octopodidae or *Octopus* sp. and not identified further; other species may also have been sometimes misidentified as *E. dofleini*. Since 2003, increased effort has been put into cephalopod identification and species composition data are considered more reliable; species composition of octopus catch in recent GOA bottom trawl surveys is shown in Table 4. These catches are our only source of species-specific information within the species group. Based on available data, the species with the highest biomass in shelf waters is *E. dofleini*. The size distribution by weight of individual octopus collected by the bottom trawl surveys from 1999 through 2005 is shown in Figure 2. Survey-caught octopus ranged in weight from less than 0.1 kg up to 18 kg; 50% of all individuals were <0.5 kg. Larger octopus may be under-represented in trawl survey data because they are more adept at avoiding the trawl.

Survey catches of octopus occur throughout the GOA but are more frequent in the central and western GOA, and estimated biomass of octopus is higher in these regions. The survey catches octopuses at all depths from 25 to over 900 meters; the most frequent depth of survey catch is in the 100-300 meter range. The 2009 and 2011 GOA trawl surveys caught primarily *E dofleini*, *B. leioderma*, and *O. californiana*. The largest individual in the 2011 survey was an *E. dofleini* at 23 kg. Overall, the 2011 survey had octopus in 75 hauls out of a total of 704 survey hauls. A total of 95 octopus were caught, of which 75 were *E. dofleini.*

Biomass estimates for the octopus species complex based on bottom trawl surveys are shown in Table 3. These estimates show moderately strong year-to-year variability, but less so than in the BSAI surveys. Survey biomass estimates range from 994 t in 1999 and 2001 to 3,767 t in 2003 and 3,791 t in 2009. The biomass estimate from the 2011 survey is 4,897 tons, most of which was in the central gulf. The average of the most recent three survey biomass estimates is 3,661 tons. Because bottom trawls are not efficient for catching benthic octopus, the true biomass of octopus in the GOA is probably higher than the survey estimates (see discussion below under estimation of biomass). The estimate of octopus biomass from the Ecopath food-web model for the GOA is on the order of 200,000 t (Aydin et Al. 2008).

### *Federal Groundfish Observer Program Data*

Groundfish observers record octopus in commercial catches as either "octopus unidentified" or "pelagic octopus unidentified". Observer records do, however, provide a substantial record of catch of the octopus species complex. Figure 1 shows the spatial distribution of observed octopus catch in the GOA (aggregated over 400 $km^2$ blocks) for the years 1988-2005. The majority of GOA octopus caught by pot gear came from depths of 70-110 meters; catches from longline vessels tended to be in deeper waters (360-730 meters). Unlike the BSAI, the depth range of octopus catches in the GOA is similar between industry and survey data. The size distribution of octopus caught by different gears is variable (Figure 3); commercial cod pot gear clearly selects for larger individuals. Over 88% 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 of 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, especially *B. leioderma* or *Octopus* sp. A. It is apparent that temporal and spatial catch patterns in the pot fishery are primarily determined by seasonal timing and locations of pot fishing for Pacific cod. Pot fishing in the GOA occurs primarily to the north and east of Kodiak (Chiniak Bay), in Kuprianof Strait, along the west side of Kodiak Island (statistical area 630), and in the western GOA between the Shumagin Islands and Sanak Island (area 610). Octopus catch occurs primarily in January-February and in September. The size selectivity of different gear types in observer data is shown in Figure 3.

### *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. Larger individuals may also have high trawl mortality if either towing or deck 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 observed to be 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 5. 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 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 GOA 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. Estimated Tier 5 parameters 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 semi-annual GOA trawl surveys (Table 3) represent total weight for all species of octopus, and are formed using the sample procedures used for estimating groundfish biomass (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. 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 industry or observer data, are commonly reported as octopus sp., without full species identification. In surveys prior to 2003, most octopus collected were not identified to species. In more recent years, a greater fraction of collected octopus is identified to species, but some misidentification may still occur. Efforts to improve species identification and collect biological data from octopus are being made, but the survey is only beginning to provide species-specific information that could be used in a stock assessment model.

As noted earlier, the survey trawl may not be suitable gear for sampling octopus. The bottom trawl net used for the GOA survey has roller gear on the footrope to reduce snagging on rocks and obstacles and may allow benthic organisms, including octopus, to escape under the net. Given the tendency of octopus to spend daylight hours near dens in rocks and crevices, it is entirely likely that the actual capture efficiency for benthic octopus is poor (D. Somerton, personal communication, 7/22/05). Trawl sampling is not conducted 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 1989). 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 3 are based on a gear selectivity coefficient of one, which is probably not realistic for octopus. For this reason, these are probably conservative underestimates of octopus biomass in the regions covered by the survey. The large numbers of survey tows with no octopus also tend to increase the sampling variability of the survey estimates; in many years, octopus were present in only 5% of the survey tows.

There is a considerable difference in size selectivity between survey trawl gear and industry pot gear that catches most of the octopus harvested. The average weight for individual octopus in survey catches is 2.0 kg; over 50% of survey-collected individuals weigh less than 0.5 kg. Larger individuals are strong swimmers and may be more adept at escaping trawl capture. In contrast, the average weight of individuals from commercial pot gear was over 20 kg (Figure 3c). 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. Unlike the BSAI, the depth range of octopus catches in the GOA is similar between industry and survey data, although pot fisheries tend to be concentrated in shallower shelf waters**.** There is also a seasonal difference between summer trawl surveys and the fall and winter cod seasons, when most octopus are harvested. In general, it may be possible to use trawl survey data as an index of interannual variation in abundance, but the relationship between the summer biomass of individuals vulnerable to trawls and the fall or winter biomass available to pot fisheries will be difficult to establish.

If future management of the octopus complex is to be based on biomass estimates, then species-specific methods of biomass estimation should be explored. Octopus are readily caught with commercial or research pots. An index survey of regional biomass in selected areas of the Kodiak and Shumagin regions would be appropriate and is highly feasible. It may also be feasible to estimate regional octopus biomass using mark-recapture studies or depletion methods (Caddy 1983, Perry et al. 1999). If the species composition of commercial harvest can be verified, then it may be appropriate to use species-specific and/or depth-based biomass estimates.

### *Parameters Estimated Independently – Mortality Rate M*

It is important to note than not all species of octopus in the GOA have similar fecundity and life history characteristics. This analysis is based on *E. dofleini*, which probably make up the majority of the harvest. 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, Rikhter 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 (1983) discuss their use for invertebrate fisheries.

If we apply Hoenig's (1983) equation to *E. dofleini*, which have a maximum age of five years, we get an estimated M = 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 relationships for cephalopods needs further investigation, but these estimates represent the best available data at this time. The Rikhter and Evanov 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 GOA, based on either experimental fishing or tagging studies, is desirable.

### *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 little data on octopus biomass, we have good 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 highly conservative** estimate of the total natural mortality N for octopus, since it does not include mortality from other predators (*i.e*. marine mammals; Fig. 5) 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 be fisheries observers throughout the winter (Figure6). 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 6, 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, Figure6) 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 7, 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 7, 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 8-9. 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 8). In deeper water, for larger size classes of cod, octopus are up to 10% of prey by weight.

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 aren’t 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 size (hood length of both the upper and lower beaks). This year, we obtained whole octopus from fisheries samples and developed an initial regression between beak hood length and octopus weight (Figure 10, 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 10, bottom).

Results of these measurements indicate that the largest beaks eaten by cod generally correspond with the smallest (1-2 kg) octopus in the commercial samples, with the majority of octopus eaten by cod being smaller. 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 fuller weight frequency over the next 1-2 years.

### 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's important to note that, while this is a combined estimate of $C_y$ (octopus consumed by cod) is an estimate of a Tier 5-equivalent 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 GOA was divided into a total of 9 survey strata based on longitude and depth; longitudinally, the survey was dividing into east (area 640), central (620-630), and west (610). The three shelf depth zones were shelf, gully, and slope subareas as defined by RACE. There were insufficient diet data to perform calculations for the southeast region (650 and 680).

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. 2007). 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 $W_\infty$ (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 ($W_\infty$, *d*, *k*, and $t_0$) and the relationship between $W_\infty$ 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 (Fig. 12). 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 (Fig 7., bottom). **If a stratum, year, 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 the time being. 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 GOA is shown in Table 6. Figure 13 shows the total consumption and confidence intervals for consumption of all prey (top) and for octopus (bottom). 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 GOA cod on octopus range from 450 to almost 17,000 tons; the larger values have a high level of uncertainty. We used the harmonic 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 harmonic mean of the annual values to calculate a conservative long-term average predation rate over the 9 survey years of annual estimates. The harmonic mean of all of the annual estimates is 1,557 tons, which is an order of magnitude higher than most annual fishery catches of octopus. This method was presented in the 2011 stock assessment for the BSAI and has been reviewed by the plan team and SSC. We recommend that this approach be used to set catch limits for the 2013 fishery.

## Projections and Harvest Alternatives

None of the existing groundfish Tier strategies are well suited to the available information for octopus. We recommend that octopus be managed very conservatively due to the poor state of knowledge of the species, life history, distribution, and abundance of octopus in the GOA. Further research is needed in several areas before octopus could be managed by the methods used for commercial groundfish species. Regulatory limits under three different strategies are presented below.

Groundfish Tier 5 management is based on estimated overall biomass and natural mortality of the stock. It would be possible to manage GOA octopus complex under the Tier 5 model using trawl survey biomass estimates and estimates of mortality for *E. dofleini*. **If the average biomass from the three most recent surveys (2007, 2009, and 2011) of 3,661 tons and the conservative M estimate of 0.53 are used, the Tier 5 OFL and ABC for GOA octopus would be 1,941 and 1,455 tons, respectively. These figures have not changed since last year.** Trawl survey estimates of biomass for the species complex represent the best available data at this time. There are serious concerns, however, about both the suitability of trawl gear for accurately sampling octopus biomass and the extent to which the survey catch represents the population subject to commercial harvest. If future management of the octopus complex under Tier 5 is envisioned, then dedicated field experiments are needed to obtain both a more realistic estimate of octopus biomass available to the fishery and a more accurate estimate of natural mortality rates.

Another option presented in past reports is to set catch limits for the octopus assemblage under Tier 6 based on historical catch data. There is no historical catch data for the period specified under the usual application of Tier 6 (1975-1995). Available data are incidental catch rates from 1997-2009. Based on discussion at the September 2009 Plan team meetings, we used the full 12-year period of incidental catch data from 1997 through 2007 as the basis for Tier 6 catch estimates. The teams recommended that this period be fixed as the standard for use in all future assessments**.** Using this period, the average estimated incidental catch rate is 191 t. If this incidental catch rate was treated as the long-term average catch under **standard Tier 6 procedure, the OFL would be 191 t and the ABC would be 144 t. If the maximum incidental catch rather than the average is used, the OFL would be 298 tons and the ABC 224 tons.** Use of an upper percentile of the catch data would yield annual catch limits between these two values.

**Given that the survey and food web model biomass estimates are much greater than the historical-catch, we feel that the ABC and OFL alternatives based on incidental catch history are underestimates.** For most of this period there was very little market or directed effort for octopus. After review of the 2005 octopus SAFE, the Council's SSC concurred that neither Tier 5 nor the standard Tier 6 approach was satisfactory for this group, but supported use of Tier 6 until better methods could be found.

This assessment introduces a **new methodology** for examining population trends in octopus. This method has been approved by the SSC and Council for use in the BSAI in 2012. This approach is based on the use of diet data from Pacific cod to form a conservative estimate of the annual natural mortality of octopus (N). While this method involves some assumptions and uncertainties, these uncertainties are similar to those in stock assessment modeling and are quantified as part of the analysis. We feel that this conservative estimate of total mortality is based on observed data and is preferable to the alternative method based on catch history. This estimate of natural mortality 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 long-term 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 harmonic means both to form 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 =1,557 mt and ABC = 1,168 mt. This number is considerably higher than the rate of current or historical incidental octopus catch, but slightly less than the estimate based on survey biomass.**

The other decision that the teams and NMFS region 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 regional office.**

Because of the overall lack of biological data and the large uncertainty in abundance estimates, we do not recommend a directed fishery for octopus in federal waters at this time. We anticipate that octopus harvest in federal waters of the GOA will continue to be largely an issue of incidental catch in existing groundfish fisheries.

## Ecosystem Considerations

Very 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 habit data and ecosystem modeling of the GOA (Livingston et al. 2003, Aydin et al. in review) indicate that octopus diets in the GOA are dominated by epifauna such as snails and crabs and infauna such as mollusks. The Ecopath model (Figure 5) indicates that octopus in the GOA are preyed upon primarily by grenadiers, Pacific cod, halibut, and sablefish. **In the GOA, Steller sea lions and other marine mammals are not significant predators of octopus (Figure 14). Model estimates show octopus is less than 0.5% of the diet of both juvenile and adult Steller sea lions. In the Bering Sea, however, Stellar sea lions and other marine mammals are significant predators of octopus.** At least 20% of the estimated overall mortality of octopus in the GOA cannot be explained by the model.

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 Aleutian Islands, but much less so in the western GOA. 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. 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 octopus had among the lowest (1%).

Little is known about habitat use and requirements of octopus in Alaska. 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 (1989) reported increased trap catch rates in offshore areas during winter months. Octopus require secure dens in rocky bottom or boulders to brood their 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 (1989) 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 is having some effect on octopus, but data are not adequate to evaluate these effects. Survey data are not yet adequate to determine depth and spatial distributions of the different octopus species in the GOA, but the patterns may become more clear as data accumulate over future surveys.

## 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 industry or observers will be able to accurately determine species on a routine basis. A volume 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 analyses were available. Special projects and collections of octopus for identification and biology will be pursued as funding permits.

Because octopuses are semelparous, a better understanding of reproductive seasons and habits is needed to determine the best strategies for protecting reproductive output. *Enteroctopus dofleini* in Japan and off the US west coast reportedly undergo seasonal movements, but the timing and extent of migrations in Alaska is unknown. 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 would add greatly to our ability to appropriately manage a 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 1. Octopus species found in the Gulf of Alaska.

| | Scientific Name | Common Name | General Distribution | Age at Maturity | Size at Maturity |
|---|---|---|---|---|---|
| Class | Cephalopoda | | | | |
| Order | Vampyromorpha | | | | |
| Genus | *Vampyroteuthis* | | | | |
| Species | ***Vampyroteuthis infernalis*** | | GOA; > 300 m | unknown | unknown |
| Order | Octopoda | | | | |
| Group | Cirrata | | | | |
| Family | Opisthoteuthidae | | | | |
| Genus | *Opisthoteuthis* | | | | |
| Species | ***Opisthoteuthis californiana*** | flapjack devilfish | GOA; > 300 m | unknown | unknown |
| Group | Incirrata | | | | |
| | Bolitaenidae | | | | |
| | *Japetella* | | | | |
| | ***Japetella diaphana*** | pelagic octopus | Pelagic; over the shelf break | unknown | < 300 g |
| Family | Octopodidae | | | | |
| Genus | *Benthoctopus* | | | | |
| Species | ***Benthoctopus leioderma*** | smoothskin octopus | GOA; > 250 m | unknown | < 500 g |
| Genus | *Enteroctopus* | | | | |
| Species | ***Enteroctopus dofleini*** | giant octopus | all GOA; 10 - 1400 m | 3 - 5 yr | >10 kg |
| Genus | *Octopus* | | | | |
| Species | ***Octopus californicus*** | | E. GOA; 100 - 1000 m | unknown | 1 -2 kg |
| | ***Octopus rubescens*** | red octopus | N Pacific, Prince Wm. Sound | 1 yr | unknown |
| | ***Octopus* sp. A** | | GOA shelf , 10 - 300 m | unknown | < 250 g |

Table 2. Estimated state and federal catch (t) of all octopus species combined, by target fishery. Catch for 1997-2002 estimated from blend data. Catch for 2003-2012 data from AK region catch accounting. Due to updates and corrections in the catch accounting system, numbers for 2003-2010 differ slightly from previous assessments. *Data for 2012 are as of October 6, 2012; catch figures for flatfish targets have been revised to include the IFQ Halibut fishery.

| | Target Fishery | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **Pacific cod** | **Pollock** | **Flatfish*** | **Rockfish** | **Sablefish** | **Other** | **Total** |
| 1997 | 193.8 | 0.7 | 1.3 | 2.3 | 22.4 | | 232 |
| 1998 | 99.7 | 3.5 | 4.3 | 0.8 | 0.3 | | 112 |
| 1999 | 163.2 | 0.0 | 2.4 | 0.5 | 0.2 | | 166 |
| 2000 | 153.5 | - | 0.7 | 0.2 | 0.5 | | 156 |
| 2001 | 72.1 | 0.2 | 0.8 | 0.0 | 2.0 | | 88 |
| 2002 | 265.4 | 0.0 | 17.2 | 0.7 | 1.0 | | 298 |
| 2003 | 188.9 | - | 16.6 | 0.6 | 2.9 | 0.1 | 210 |
| 2004 | 249.8 | 0.0 | 2.8 | 0.4 | 0.1 | 16.5 | 270 |
| 2005 | 138.6 | 0.1 | 2.4 | 0.2 | 0.2 | 1.7 | 149 |
| 2006 | 151.0 | 3.4 | 1.9 | 0.5 | 0.3 | 0.2 | 166 |
| 2007 | 242.0 | 1.5 | 9.7 | 0.1 | 1.8 | - | 257 |
| 2008 | 326.0 | 0.0 | 5.2 | 2.9 | 0.2 | 0.1 | 339 |
| 2009 | 296.8 | 0.1 | 10.1 | 1.2 | 0.3 | 0.9 | 310 |
| 2010 | 263.7 | 0.8 | 15.4 | 3.7 | 0.5 | 41.9 | 326 |
| 2011 | 859.4 | 2.3 | 49.9 | 0.9 | 0.8 | 1.1 | 918 |
| 2012* | 272.4 | 0.0 | 3.5 | 0.9 | 0.8 | - | 278 |

**Average estimated catch 1997 - 2007 = 191.3 tons** 75% = **143.5 tons**
**Maximum estimated catch 1997 - 2007 = 298.1 tons** 75% = **223.6 tons**

Table 3. Biomass estimates for octopus (all species combined) from GOA bottom trawl surveys.

| Survey Year | Survey Hauls | Hauls with Octopus Num | % | Estimated Biomass (t) |
|---|---|---|---|---|
| 1984 | 929 | 89 | 9.6% | 1,498 |
| 1987 | 783 | 35 | 4.5% | 2,221 |
| 1990 | 708 | 34 | 4.8% | 1,029 |
| 1993 | 775 | 43 | 5.5% | 1,335 |
| 1996 | 807 | 34 | 4.2% | 1,960 |
| 1999 | 764 | 47 | 6.2% | 994 |
| 2001 | 489 | 29 | 5.9% | 994 |
| 2003 | 809 | 70 | 8.7% | 3,767 |
| 2005 | 839 | 56 | 6.7% | 1,125 |
| 2007 | 820 | 71 | 8.7% | 2,296 |
| 2009 | 824 | 172 | 20.9% | 3,791 |
| 2011 | 704 | 75 | 10.6% | 4,897 |

Table 4. Species composition of octopus (number or animals) from AFSC Gulf of Alaska bottom trawl surveys.

| | Year | | | | | | |
|---|---|---|---|---|---|---|---|
| **Species** | **1999** | **2001** | **2003** | **2005** | **2007** | **2009** | **2011** |
| *Octopodidae* | 33 | 22 | 36 | 38 | 10 | 2 | 2 |
| *Octopus sp.* | | | | | 13 | 1 | |
| *Benthoctopus sp.* | | | | | | 3 | 3 |
| *Enteroctopus dofleini* | 5 | 7 | 32 | 9 | 144 | 80 | 75 |
| *Benthoctopus leioderma* | 6 | 4 | 7 | 8 | 8 | 10 | 12 |
| *Opisthoteuthis californiana* | 18 | | 1 | 14 | 10 | 11 | 4 |
| *Japatella diaphana* | | | 2 | 2 | 8 | 1 | |
| *Octopus californicus* | | | | 4 | | | |
| *Vampyroteuthis infernalis* | 6 | | 3 | | | | 1 |

Table 5. Results of observer program special project (both BSAI and GOA) 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 6. Estimate of total octopus consumed by Pacific cod in the Gulf of Alaska.

| **Year** | **Octopus Consumed (t)** |
|---|---|
| 1990 | 16,979 |
| 1993 | 8,112 |
| 1996 | 4,661 |
| 1999 | 2,207 |
| 2001 | 2,271 |
| 2003 | 450 |
| 2005 | 644 |
| 2007 | 2,108 |
| 2009 | 4,113 |
| | ***HARMONIC MEAN (1990-2009)*** |
| | **1,557** |

Figure 1. Distribution of octopus (all species combined) in the Gulf of Alaska based on octopus recorded in observed hauls. Shading shows the numbers of octopus observed in 400 $km^2$ blocks over the period 1988-2005; darker colors (blue) are bocks with multiple observations.

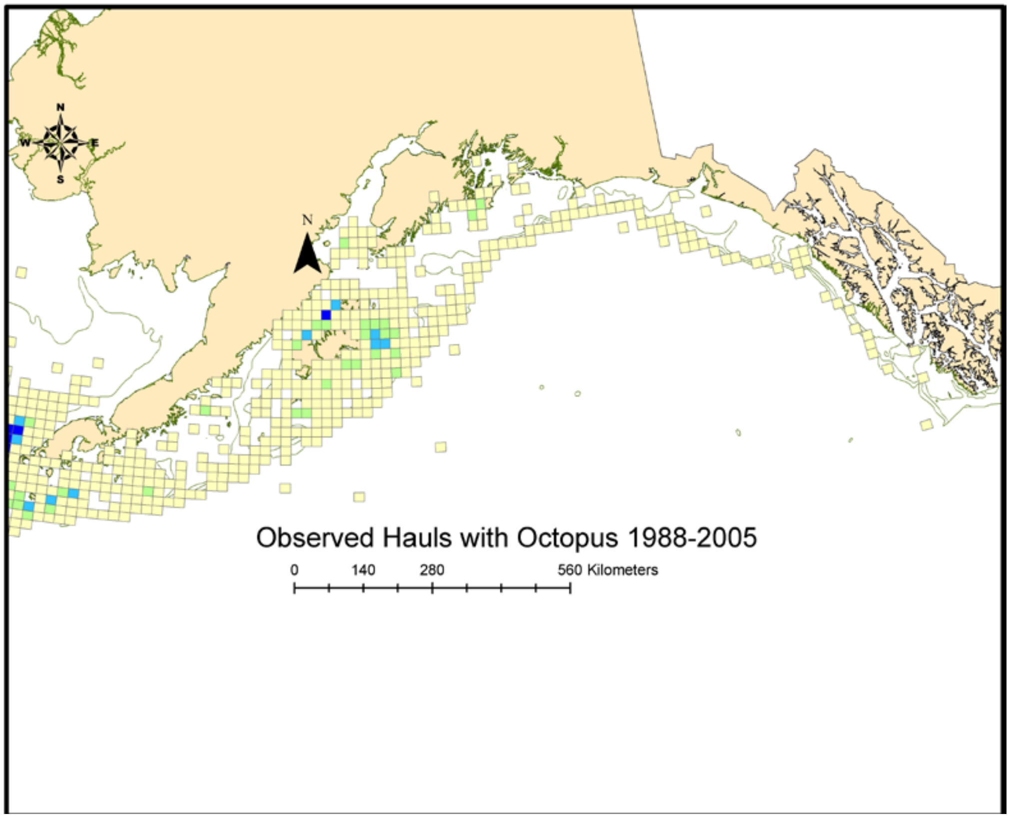



Figure 2. Size frequency of individual octopus (all species combined) from AFSC bottom trawl surveys in the GOA 1999-2005.

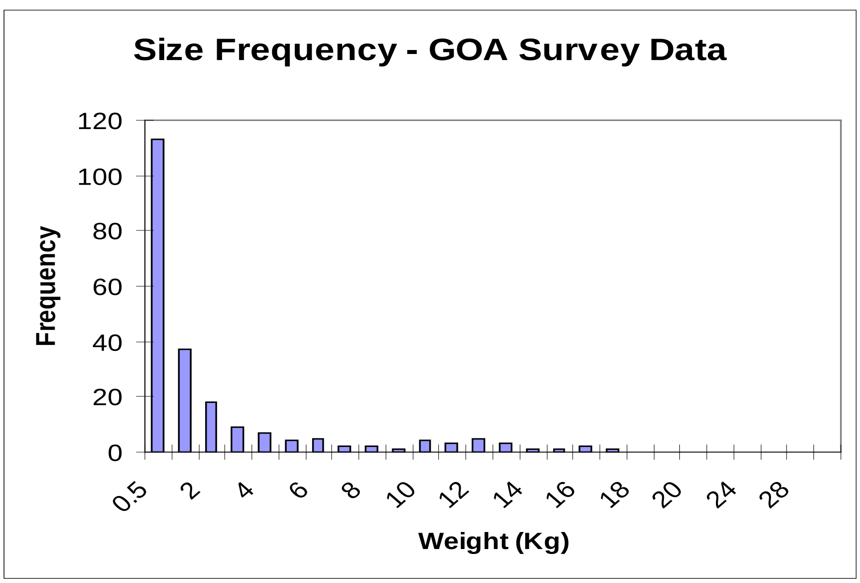
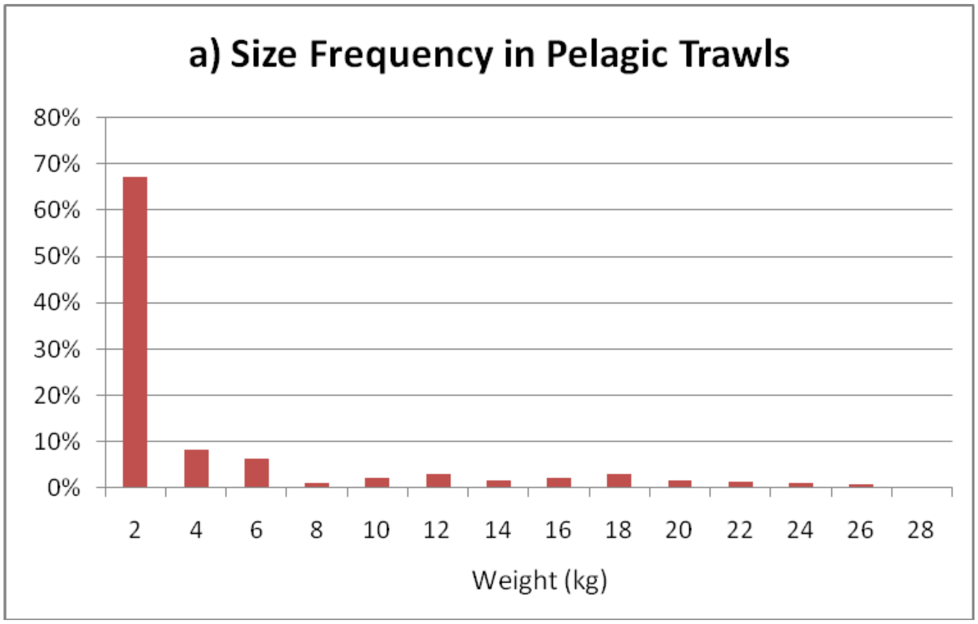


Figure 3. Size frequency of individual octopus from 2006-2011 observer special project by gear type: a) pelagic trawls, b) bottom trawls, c) pots, and d) longline.



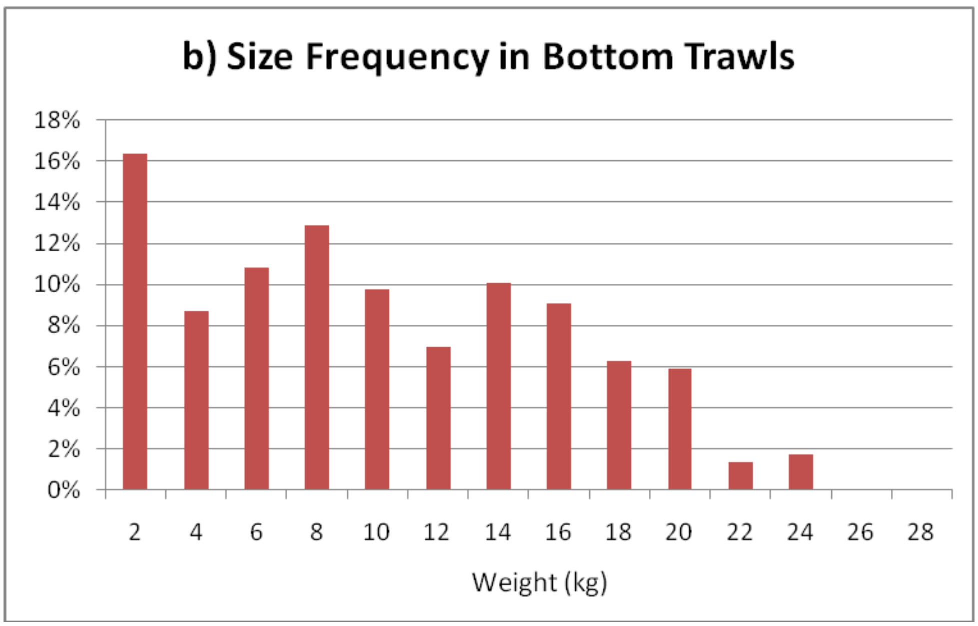
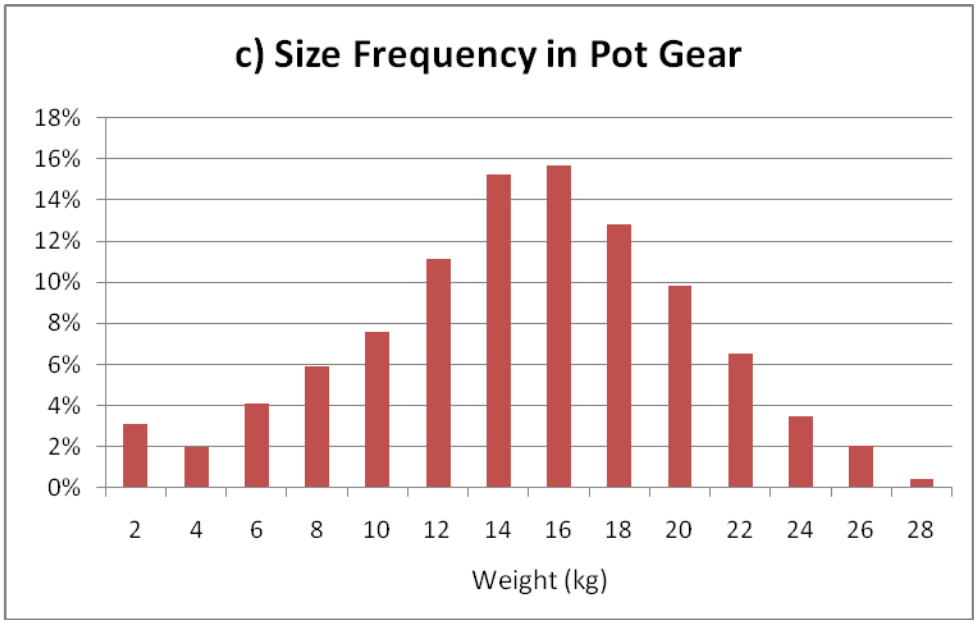



Figure 3. Continued.



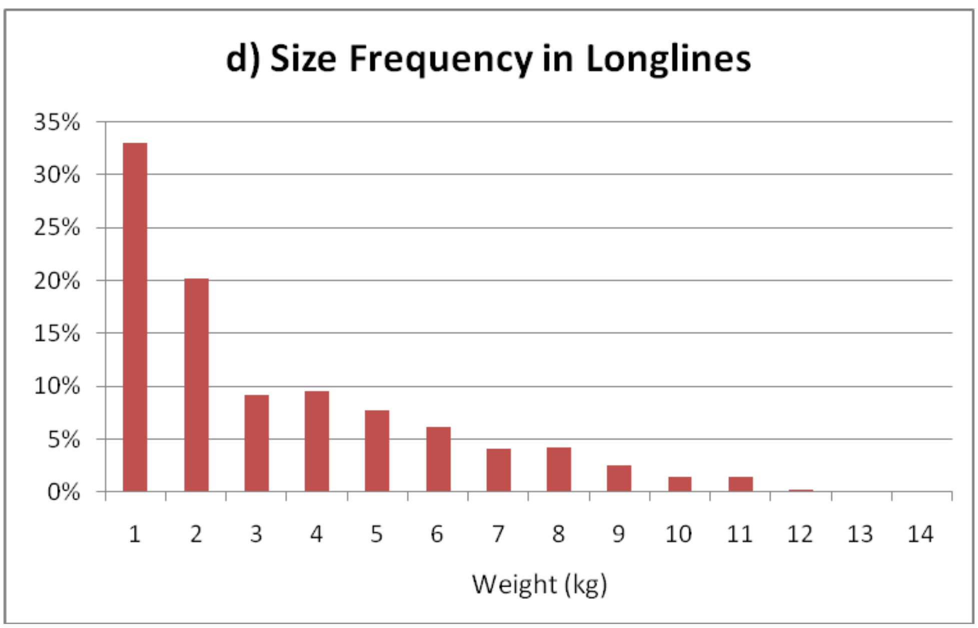



Figure 4. GOA octopus survey biomass estimates and confidence intervals.

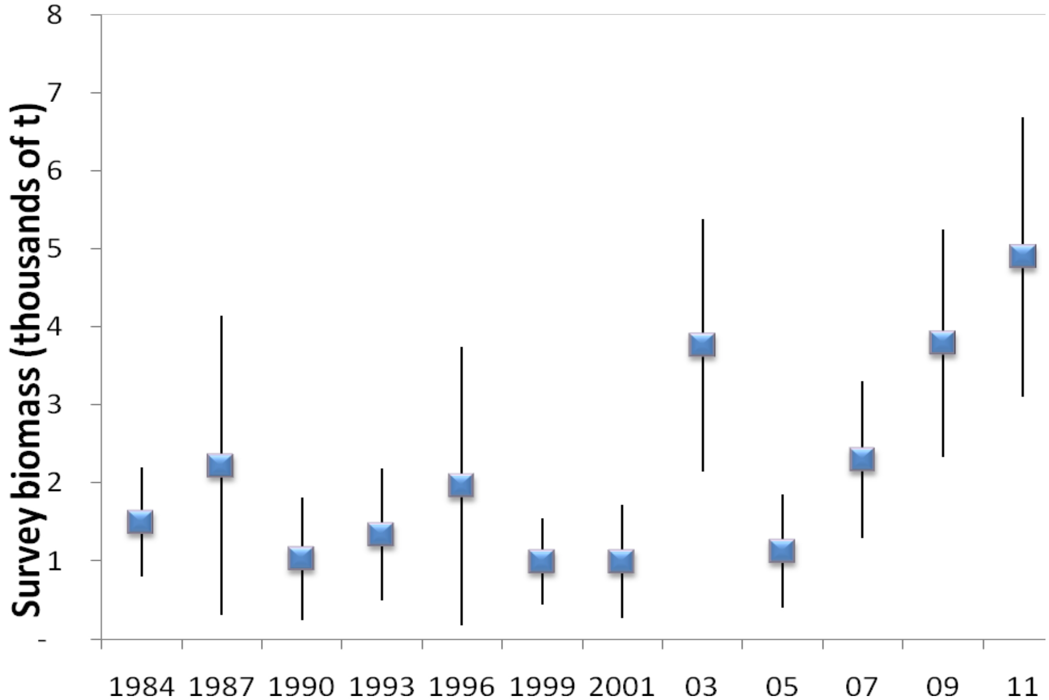



Figure 5. Ecopath model estimates of total consumption of octopus in the GOA (based on average 1990-1993 biomass and catch estimates).

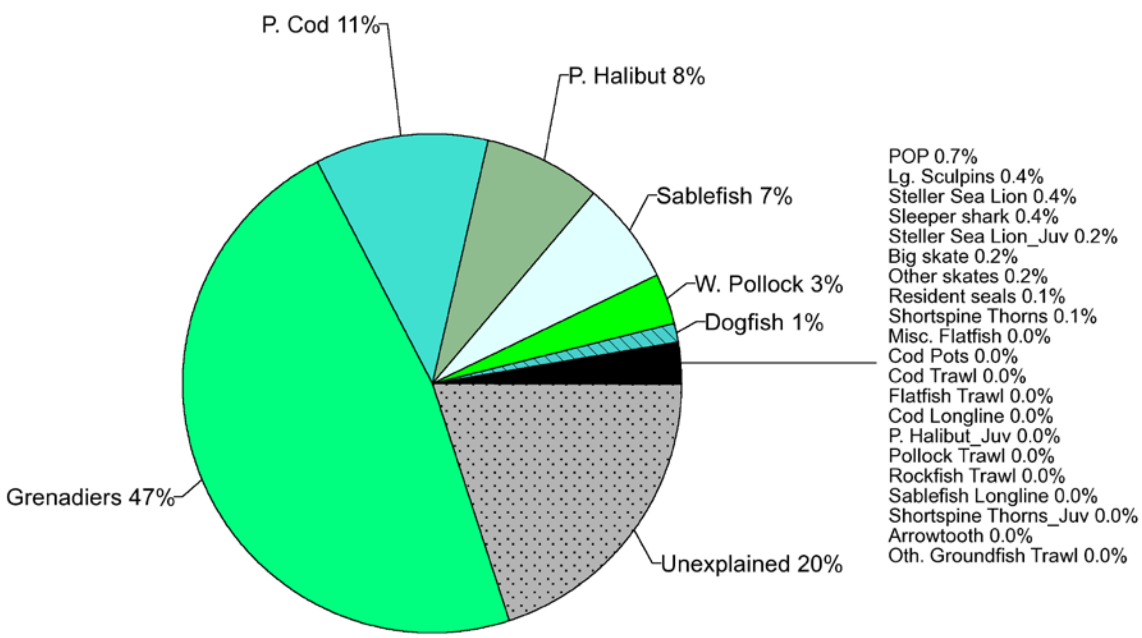


Figure 6. Locations of all sampled Pacific cod stomachs (black circles; N=62,393) and stomachs containing octopus (red circles), 1982-2011, for May-September (top panel) and October-April (bottom panel).

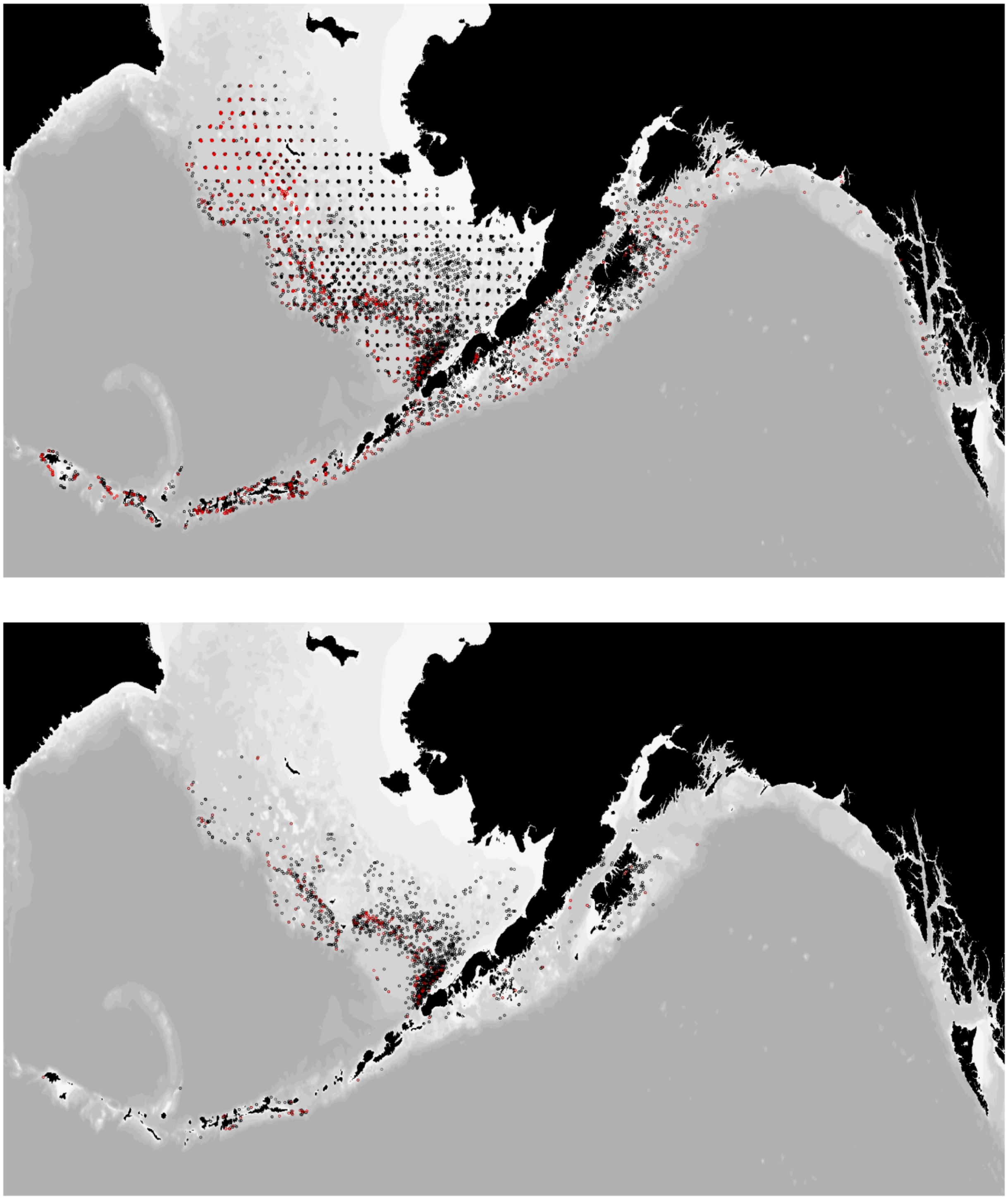


Figure 7. Frequency of occurrence of octopus in Pacific cod stomachs, all years, regions, and seasons, as a function of bottom depth (top panel) and Pacific cod fork length (bottom panel). Gray area shows the 95% confidence interval calculated from logit-transformed data (empirical logit transformation).

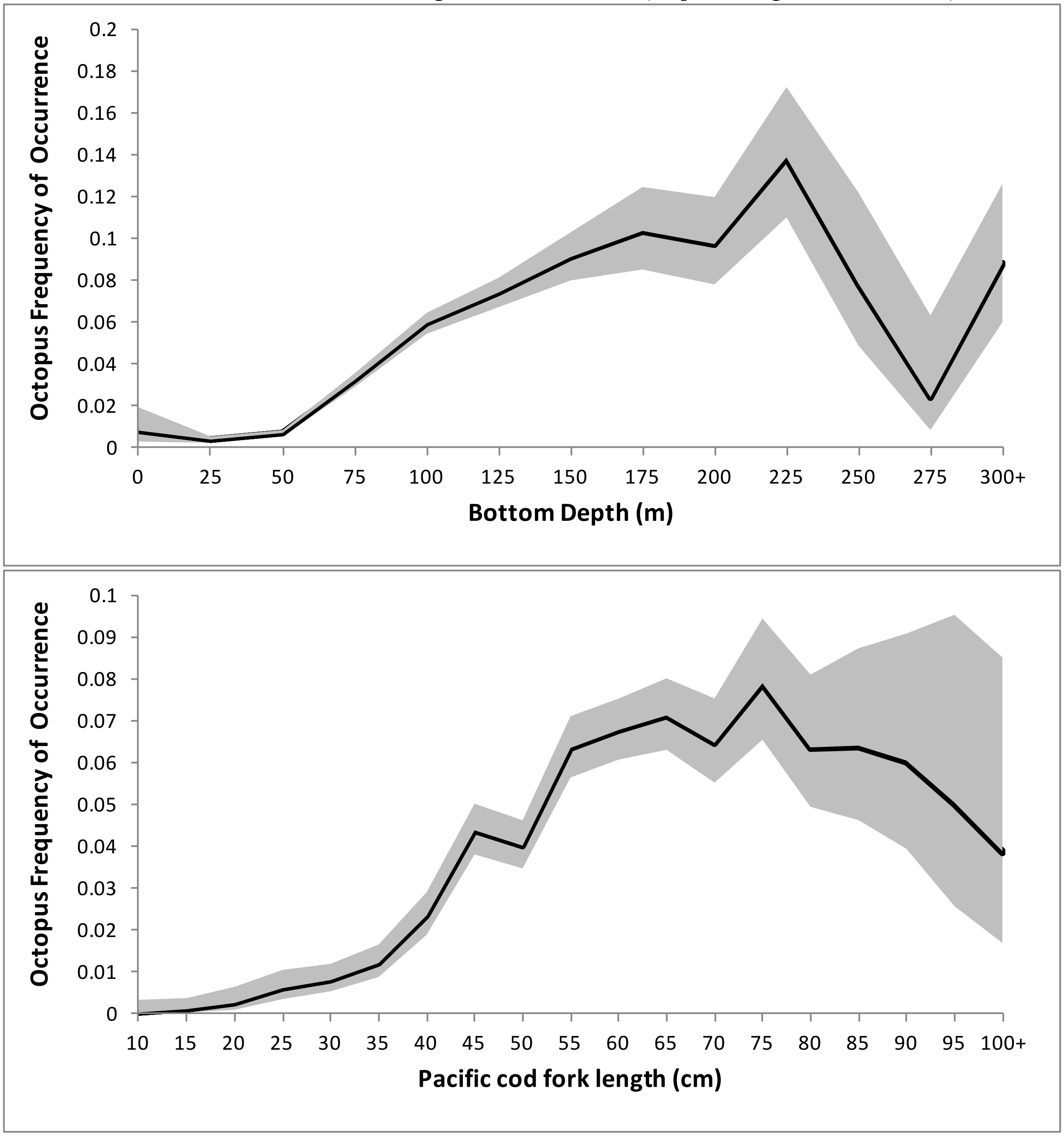


Figure 8. Percent diet by weight in Pacific cod stomachs sampled in water **<100m**, all years and seasons, for Aleutian Islands (top panel), Bering Sea (middle panel), and Gulf of Alaska (bottom panel).

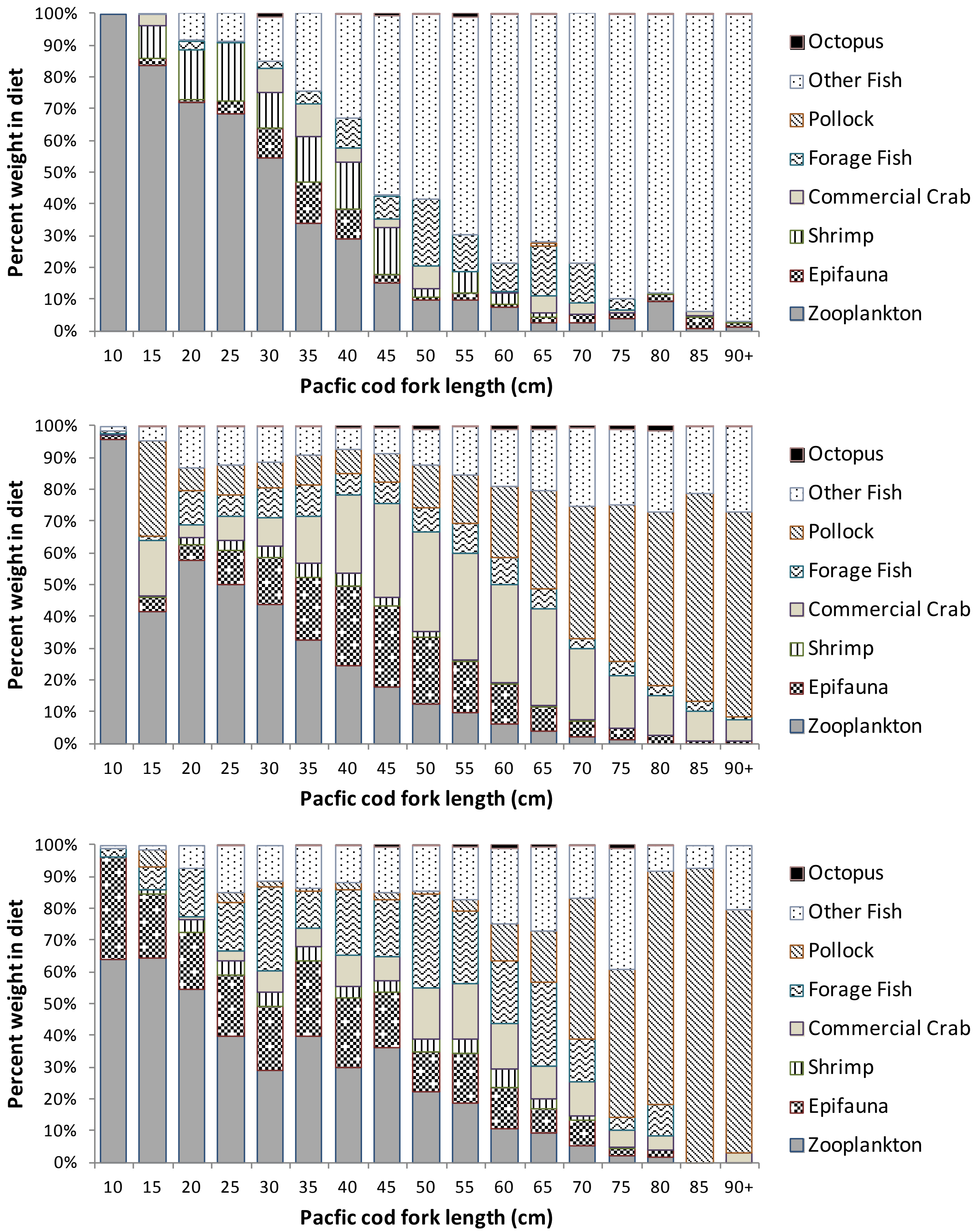


Figure 9. Percent diet by weight in Pacific cod stomachs sampled in water **≥100m**, all years and seasons, for Aleutian Islands (top panel), Bering Sea (middle panel), and Gulf of Alaska (bottom panel).

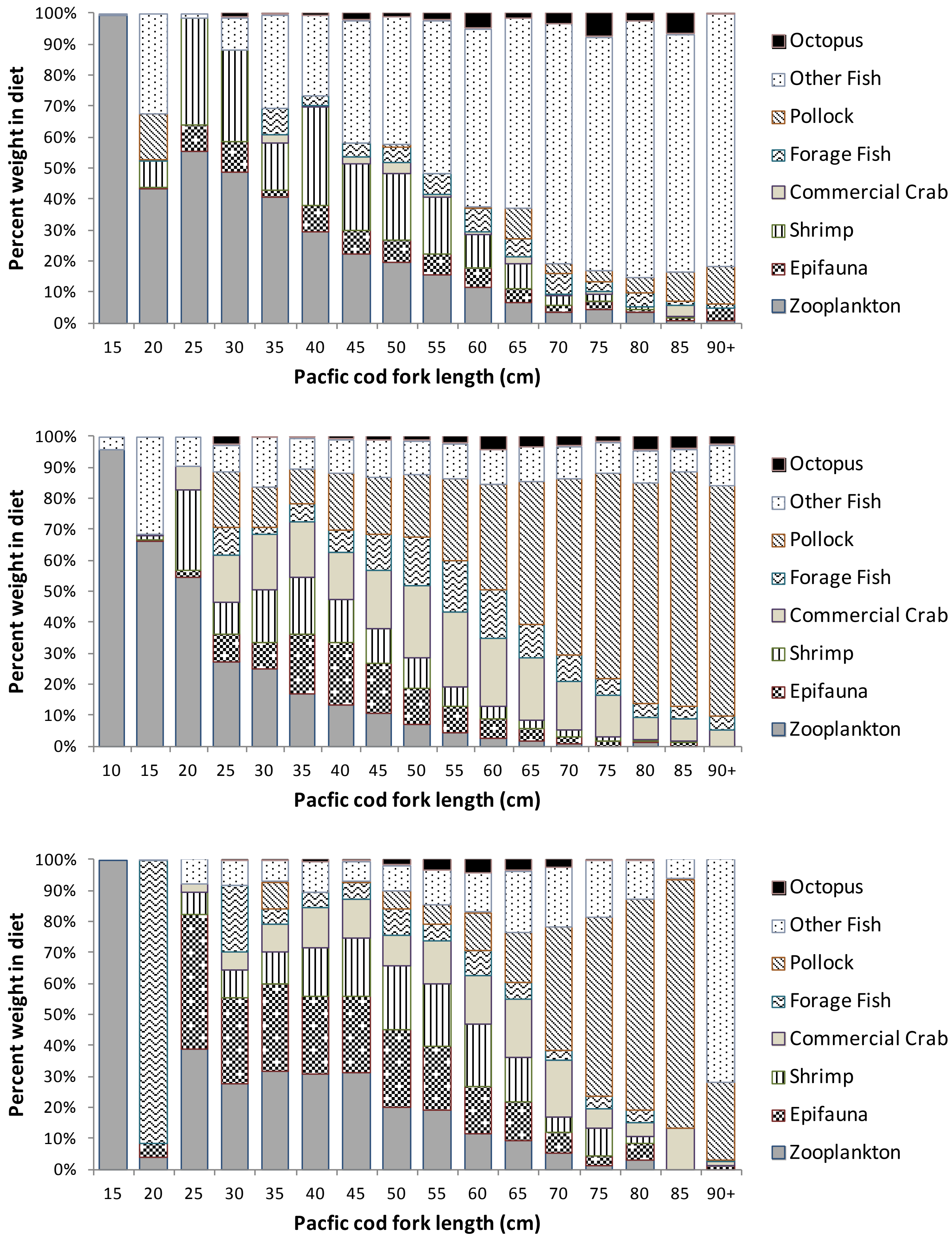
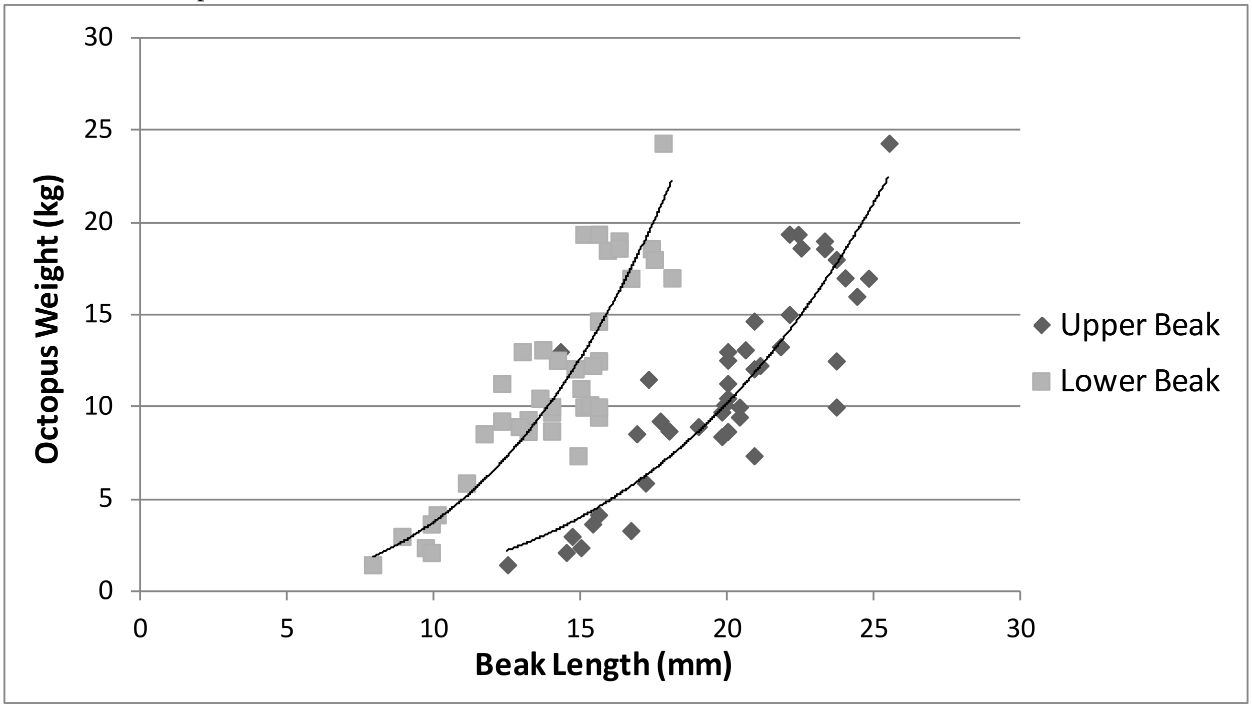


Figure 10. (Top panel): Relationship between upper and lower beak hood length and Pacific octopus total weight, measured from fisheries-sampled octopus. (Bottom panel): Length frequency of upper and lower beaks sampled from Pacific cod stomachs.



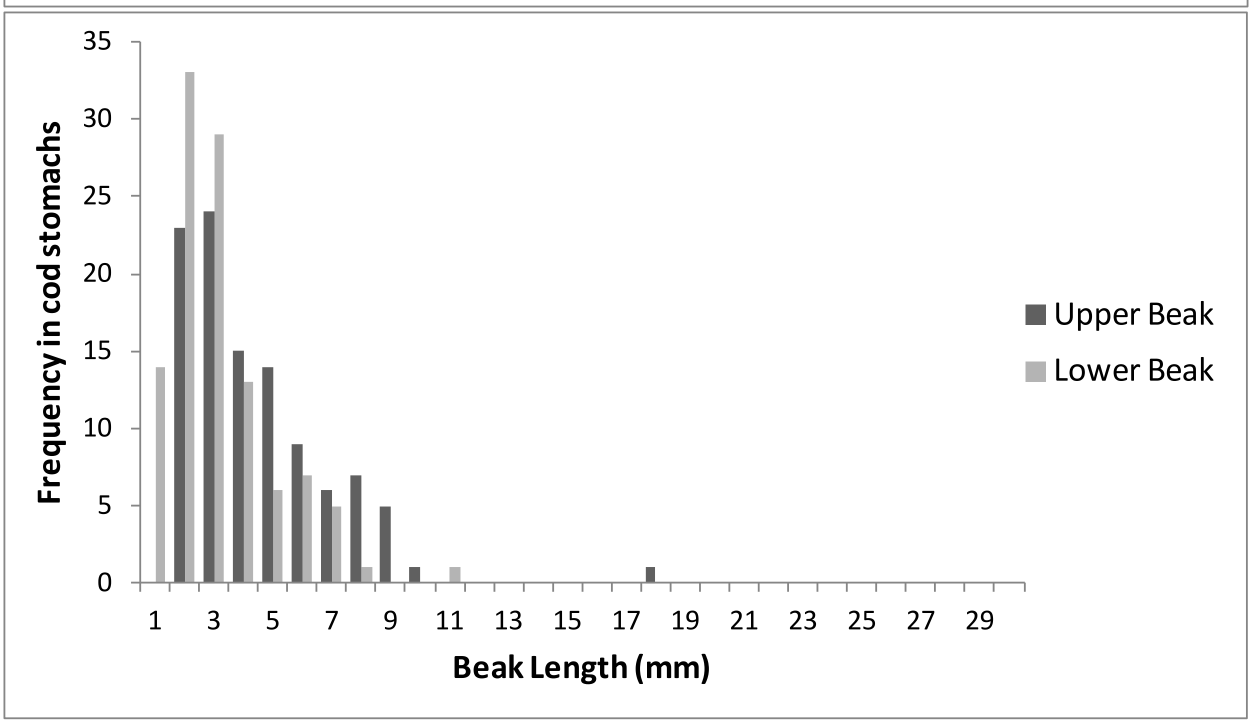



Figure 11. Beak hood lengths of octopus removed from Pacific cod stomachs as a function of cod fork length.

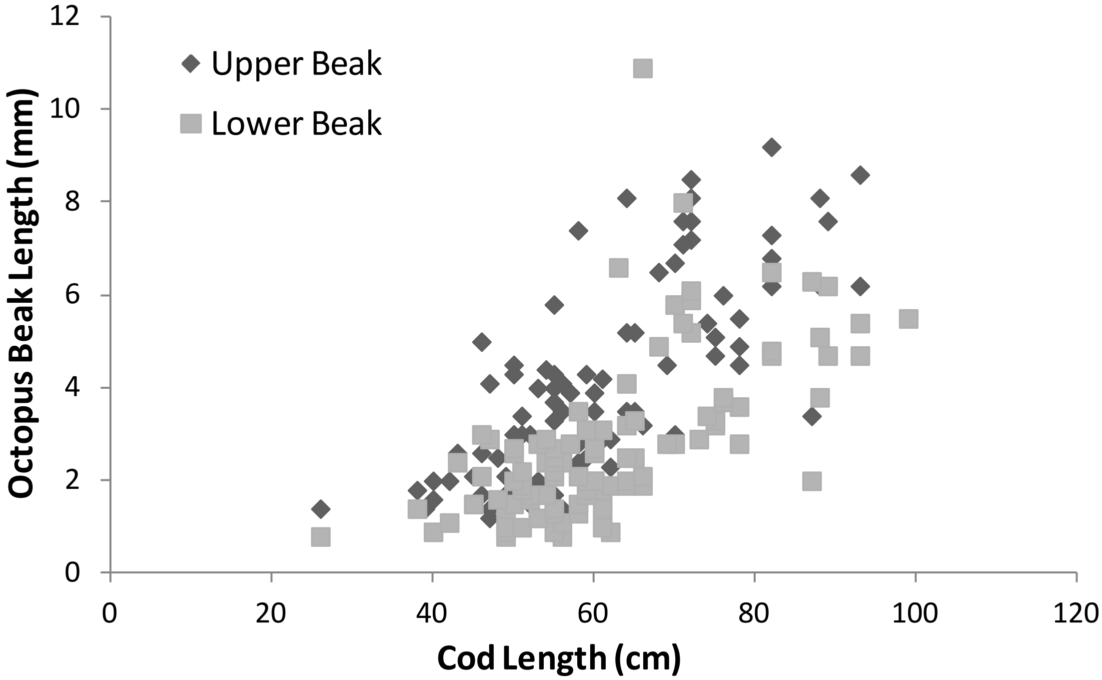



Figure 12. Annual ration of Pacific cod as a function of fork length, as estimated from fit von Bertalanffy parameters. Points indicate MCMC posterior distribution for fit; black and red lines show estimate and 95% confidence intervals.

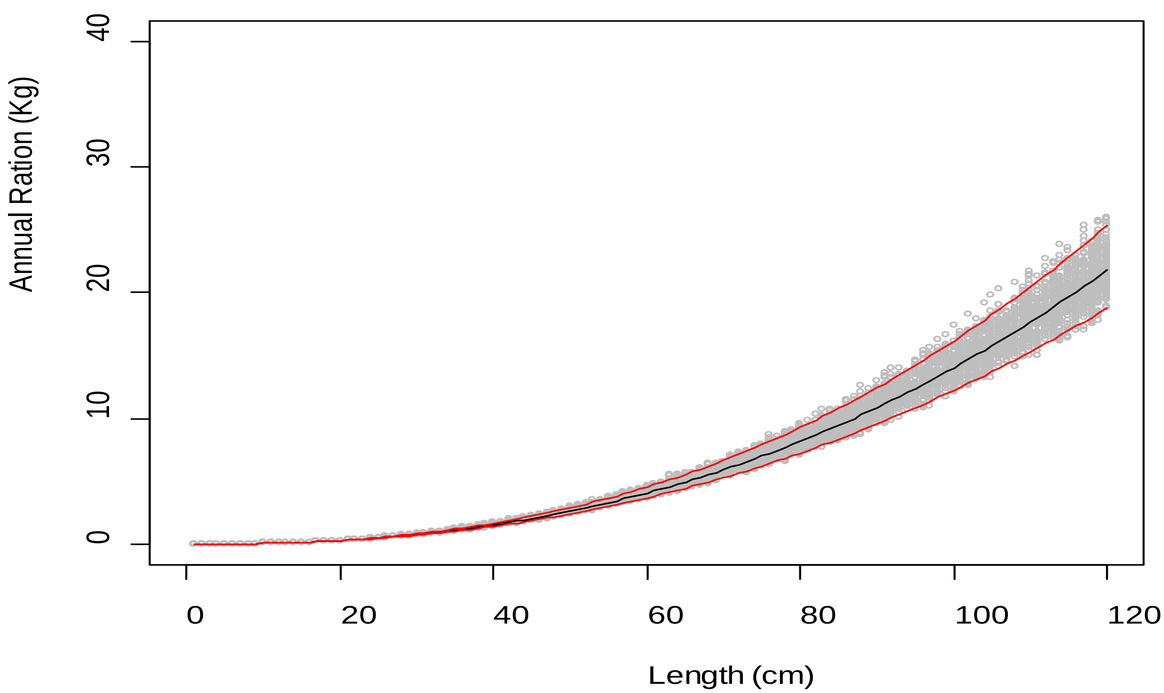


Figure 13. Estimated total consumption of food by Pacific cod in the GOA by year (top panel) and total consumption of octopus by cod (bottom panel). Box shows 50% confidence interval; bars show 95% confidence interval.

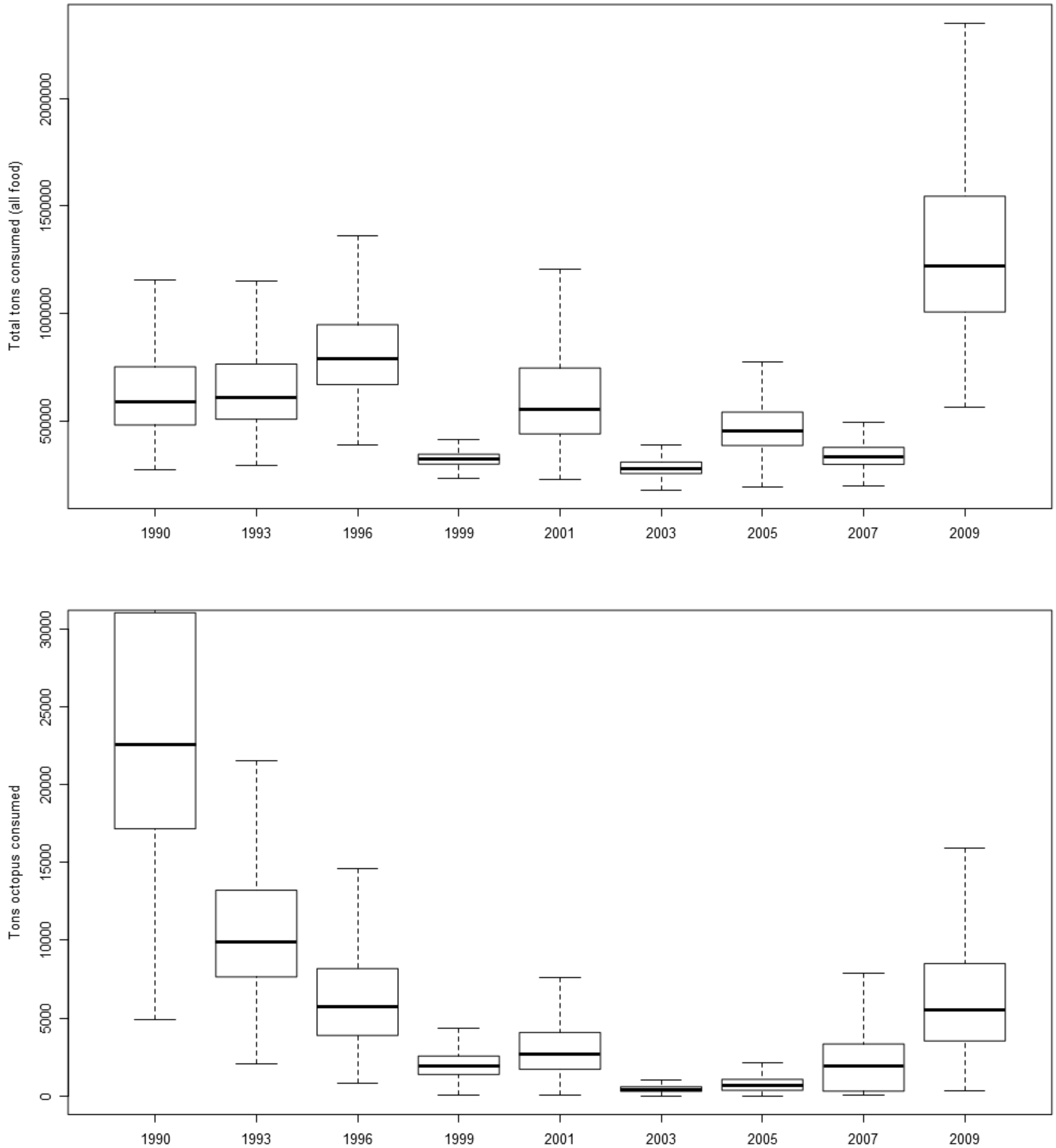
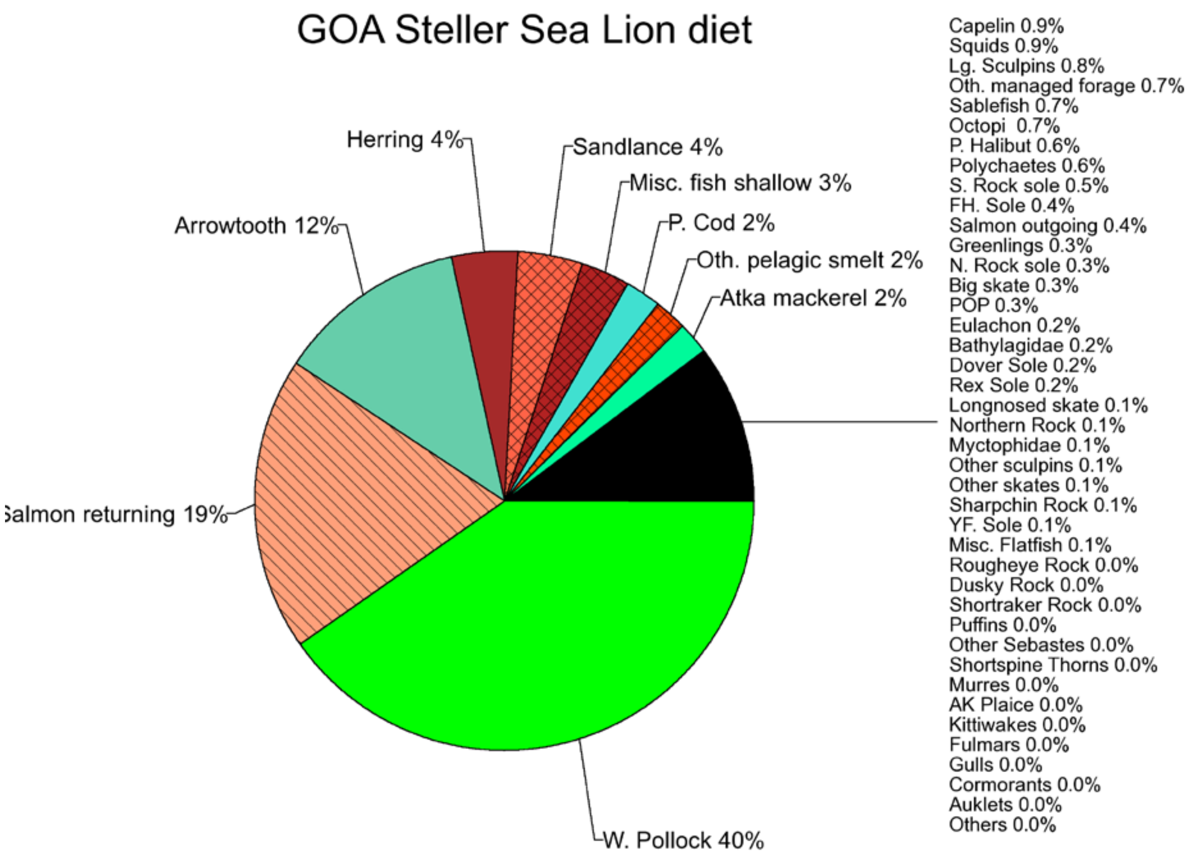


Figure 14. Ecopath model estimates of prey of Steller sea lions in the GOA (based on average 1990-1993 biomass and catch estimates).



## Appendix 22.A Summary of Octopus Research

### Observer Program 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 2011. Special project data include sampling at Alaska Pacific Seafoods in Kodiak and Trident Seafoods in Sand Point. All of the octopus data collected at these processors came from pot boats targeting Pacific cod.

The special project data reflect the size selectivity in gear as seen in Figure 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. As more data are acquired for this project we hope to use it to look at seasonal patterns in sex ratios in order to gain insight into reproductive timing. 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).

### Cooperative Research Program Project 2006

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 Kodiak ranged from 7.4 to 21.8 kg gutted weight with an average gutted weight of 14.8 kg.

### 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 is 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.

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.

Results from this study indicate that *E. dofleini* in the Gulf of Alaska has a protracted reproductive cycle with peak spawning occurring in the winter to early spring months. In the Gulf of Alaska, this species matures between 10-20 kg with 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 will look at 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. Coefficients of variation on the within-season population estimates were 12-22%. 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 strongly in different 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.

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