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 - 2013 were set based on using the average of the last 3 surveys as a minimum biomass estimate. For 2014- 2015 two methods of estimating minimum biomass are presented: the average of three surveys or the random effects model applied to survey biomass estimates. Both methods give similar results.

For management purposes, 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).

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; these include studies of delayed mortality of discarded octopus and development of an octopus-specific fishing gear for possible scientific use. A review by the Center for Independent Experts of the stock assessments for North Pacific non-target species was conducted in May 2013. Suggestions and recommendations from this review will be incorporated into the 2014 stock assessment.

Summary of Changes in Data

The AFSC conducted a bottom trawl survey of the GOA in summer 2013; octopus were present in only 11% of the survey tows. The estimated survey biomass of all octopus species for the GOA was 2,686 t, 90% of which was identified as *E. dofleini*. This biomass is lower than seen in the 2009 and 2011 surveys, but similar to other historical surveys. Survey-caught octopus ranged in size from 4 g to 10.9 kg. Commercial catch data for the octopus complex have been updated through October 12, 2013. The estimated total catch for 2012 was 421 t and the partial catch for 2013 was 257 t. These are substantially below the estimated 2011 catch of 918 tons. The majority of the catch was from Pacific cod pot gear in statistical areas 610 and 630

Summary of Changes in Asessment Methods

The 2012 assessment included an estimation of octopus natural mortality based on consumption of octopus by Pacific cod in the GOA. Since the Plan Teams rejected this method in 2012, it has not been brought forward. Assessment methods consist of the "minimum biomass" method used in 2012. Two estimates of minimum biomass are presented. Catch limits based on the average of the 3 most recent survey biomass estimates, as used in previous years, are presented. In addition, the GOA survey biomass time series was run through the random effects smoothing model developed by the survey averaging committee. The 2013 biomass estimated by this model and the resulting catch estimates are also presented. In response to a request from the Council, the area apportionment of octopus biomass within the GOA are also presented, both for the three most recent trawl surveys and for incidental catch data.

Summary of Results

The current data are not sufficient for a model-based assessment. 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. There are no historical records of directed fishing for octopus, and the authors and Plan Teams are concerned that historical catch methods may result in an overly conservative catch limit. In 2010 - 2013, the GOA Plan Team chose to use an approach where the average of three most recent survey biomass estimates is used as a minimum biomass estimate, and a mortality factor applied. The OFL for octopus in 2013 and 2014 was set at 1,940 tons. By using an average of the 2009, 2011, and 2013 survey biomass estimates with this approach, the OFL for octopus would be 2,009 tons. If the smoothed 2013 value from the random effects is used as the biomass estimate, the OFL would be 1,539 tons. 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.

Summary of Harvest Recommendations

Quantity	As estimated or *specified last* year for: 2013	2014	As estimated or *recommended this* year for: 2014	2015
Tier 6 (3 survey biomass * M)	6(alt)	6(alt)	6(alt)	6(alt)
OFL (t)	1,940	1,940	2,009	2,009
ABC (t)	1,450	1,450	1,507	1,507
Tier 6 (model biomass * M)			6(alt)	6(alt)
OFL (t)			1,539	1,539
ABC (t)			1,154	1,154
Status	As determined *last* year for: 2011	2012	As determined *this* year for: 2012	2013
Overfishing		n/a	n/a	n/a

Apportionment by Statistical Area

	Western	Central	Eastern
2009 Survey Biomass	46%	52%	1.9%
2011 Survey Biomass	25%	73%	1.6%
2013 Survey Biomass	35%	61%	4.5%
3 Survey Total	35%	63%	2.4%

Introduction

Description and General Distribution

Octopuses are marine mollusks in the class Cephalopoda. The cephalopods, whose name literally means head foot, have their appendages attached to the head and include octopuses, squids, and nautiluses. The octopuses (order Octopoda) have only eight appendages or arms and unlike other cephalopods, 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 (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 was 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 possible for 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 five 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 press). *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 interannual 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 southern California (Kubodera, 1991, Jorgensen 2009). 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 is common along the U.S. west coast and has been reported from Prince William Sound, but its presence in the GOA has not been verified by 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 high. The greatest difference in species composition between the Bering Sea Aleutian Islands (BSAI) and the GOA is the presence of *O. californicus* in the GOA.

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 typically around $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 is 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 (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. Incidental catch rates are presented in the data section (Table 2). The majority of incidental catch of octopus comes from Pacific cod fisheries, primarily pot fisheries. 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 2008-2013, 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 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.

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. High rates of incidental catch in 2002, 2004, 2009, and 2011 correspond to high survey catches in 2003, 2009, and 2011 (Table 3). Commercial catch data for the octopus complex have been updated through October 12, 2013. The estimated total catch for 2012 was 421 t and the partial catch for 2013 was 257 t. 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. Apportionment of incidental catch data by statistical areas is presented in Table 3a.

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 5. 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* (79%). In the summer 2013 survey, octopus were present in 11% of the survey tows. The estimated 2013 survey biomass of all octopus species for the GOA was 2,686 t, 90% of which was identified as *E. dofleini*. Survey-caught octopus ranged in size from 4 g to 10.9 kg in 2013.

Biomass estimates for the octopus species complex based on bottom trawl surveys are shown in Table 4. 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 2013 biomass is lower than seen in the 2009 and 2011 surveys, but similar to other historical surveys. The average of the most recent three survey biomass estimates is 3,791 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).

The regional distribution of estimated octopus biomass from the three most recent bottom trawl surveys is shown in Table 3b. Approximately two-thirds of the estimated biomass came from the Central gulf (areas 620 and 630). Biomass in the Western gulf (area 610) varied from year to year, between 25% and 45% of the total. Octopus were consistently less common in survey hauls from the Eastern gulf (areas 640 and 650), with biomass estimates for this region less than 5% of the GOA total.

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 4); 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.

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 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 obviously 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. In the 2013 IPHC longline survey, only 13% of the octopus seen were actually hooked (Tracee Geernaert, pers comm.). 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 6. 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.

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. 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.

A small field project was conducted in January 2013 aboard the commercial pot vessel *Aleutian Mariner*. Small insulated seawater tanks were installed on the vessel during their winter cod pot season, and incidentally caught octopus were examined for condition at the normal point of discard from fishing operations. These octopus were then held in the onboard seawater tanks for at least 24 hours to look for delayed mortality or decline in condition. Some of the octopus were held and re-evaluated after longer time periods from 36-60 hours. All but one of the octopus were in excellent condition just after capture. None of the 36 octopus showed any overall decline in condition during holding (Table 7). One octopus, in poor condition at capture, actually improved in condition during the first 24 hours, but then declined again to poor condition by 48 hours. Two octopus held in the air on deck were still in excellent condition after more than two hours.

Another project is being conducted at the AFSC Kodiak laboratory, where octopus will be held in running seawater tanks for extended periods to assess growth and delayed mortality over longer time periods. Results from both of these studies could be combined with the observer data into overall gear-specific estimates of discard mortality for octopus, if the Council chooses to do so.

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 a size-based model. For the last few years, the GOA plan team has elected to use a special approach under Tier 6, which uses a minimum biomass estimate and a mortality rate based on life history parameters, assuming the logistic model used for Tier 5.

Parameters Estimated Independently – Biomass B

Estimates of octopus biomass based on the semi-annual GOA trawl surveys (Figure 4) 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 4 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 less than 10% 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.

The biomass of octopus estimated by the trawl survey is expected to be a minimum estimate of octopus biomass, as the larger octopus are not well represented. Survey estimates could be used as a minimum biomass estimate using several methods. One approach that is used for a number of groundfish assessments is to average the three most recent survey biomass estimates. Recently, a working group of Plan Team members have been investigating using smoothing models to reduce some of the year-to-year variability in biomass estimates. The time series of GOA survey estimates of octopus biomass from 1984 through 2013 was fitted with the random effects model developed by this group, with the results shown in Figure 5. The smoothed value of annual biomass follows the trends in the survey estimates, but does not hit the more extreme highs and low of the individual estimates. The smoothed biomass value for 2013 is 2,903 tons, slightly higher than the raw estimate.

Species-specific methods of biomass estimation are needed for octopus and are being 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). For the 2014 assessment, a size-based stage-structure model is being explored.

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. Tagging studies of octopus in the Bering Sea are expected to produce an estimated mortality rate for large octopus by the 2014 stock assessment.

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 two different strategies are presented below.

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.

For the last few years, the GOA plan team has elected to use a special approach under Tier 6, which uses a minimum biomass estimate and a mortality rate based on life history parameters, assuming the logistic model used for Tier 5. **If the average biomass from the three most recent surveys (2009, 2011, and 2013) of 3,791 tons and the conservative M estimate of 0.53 are used, the OFL and ABC for GOA octopus would be 2,009 and 1,507 tons, respectively.** If the random effects smoothing model applied to the full survey time series is used, the predicted biomass for the most recent year is 2,901 tons. **Using the model results as the minimum biomass estimate** with a mortality rate of 0.53, **the OFL would be 1,539 tons and the ABC would be 1,154 tons.**

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%. 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, 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 6) 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 7). 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. Recent studies have increased information on the life-history cycle of *E. dofleini* in Alaskan waters and 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.

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

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 have recently been concluded and results are expected within the next year.

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 are currently being researched; questions of funding and staffing for a dedicated octopus survey would still need to be addressed.

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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 2003-2013 data from AK region catch accounting. *Data for 2013 are as of September18, 2013; 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	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	2		88
2002	265.4	0	17.2	0.7	1		298
2003	188.9	-	17.2	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	8.7	0.2	0.2	1.7	149
2006	151.0	3.4	10.7	0.5	0.3	0.2	166
2007	242.0	1.5	12.1	0.1	1.8	-	257
2008	326.0	0.0	9.5	2.9	0.2	0.1	339
2009	296.7	0.1	10.4	1.2	2.3	0.9	312
2010	265.2	0.8	16.6	3.7	1.1	41.9	329
2011	859.6	2.3	53.2	0.9	0.8	1.1	918
2012	413.9	0.4	4.6	0.9	0.8	-	421
2013*	122.9	0.2	75.6	1.4	13.5	0.0	214

Table 3. Apportionment of incidental octopus catch and survey biomass by GOA subregions:

a) Incidental catch data from 2003-2013* (partial data through Sept 2013).

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013*
Western	69%	69%	39%	23%	25%	37%	45%	43%	61%	42%	32%
Central	29%	30%	61%	77%	75%	63%	55%	57%	38%	58%	58%
Eastern	1.1%	0.2%	0.0%	0.3%	0.1%	0.0%	0.2%	0.1%	0.3%	0.0%	9.2%
Total Catch (t)	210	270	149	166	257	339	312	329	918	421	214

b) Estimated biomass from three most recent AFSC trawl surveys.

	Western	Central	Eastern
2009 Survey Biomass	46%	52%	1.9%
2011 Survey Biomass	25%	73%	1.6%
2013 Survey Biomass	35%	61%	4.5%
3 Survey Average	35%	63%	2.4%

Table 4. Biomass estimates for octopus (all species combined) from GOA bottom trawl surveys.

Survey	Survey	Hauls with Octopus		Estimated
Year	Hauls	Num	%	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
2013	**548**	**62**	**11.3%**	**2,685**

Table 5. 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 6. Results of observer program special project data on condition of octopus when observed (2006-2007) and at point of discard (2010-2011).

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

2010-2011					
Gear	**Excellent**	**Poor**	**Dead**	**Total**	**%Excellent**
Bottom Trawl	16	11	35	62	25.8%
Pelagic Trawl	8	7	42	58	13.8%
Pots	506	14	16	536	94.4%
Longline	122	7	16	146	83.6%

Table 7. Results of 2013 field study of pot-caught octopus in the BS. Octopus condition was recorded at capture (0 hours, n = 36), after being held in flow-through seawater tanks for ≥24 hours, 25-36 hours, 37-48 hours, and 60 hours. The number of octopus removed from holding at each time is shown in parentheses. Percent downgraded refers to the percentage of octopus showing a downgrade from their condition at capture.

Holding time	**Condition code**			**Percent downgraded**
hours (n)	Excellent	Poor	Dead	
0	35	1	0	-
24 (20)	20	0	0	0
25-36 (5)	5	0	0	0
37-48 (10)	9	1	0	0
60 (1)	1	0	0	0

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.

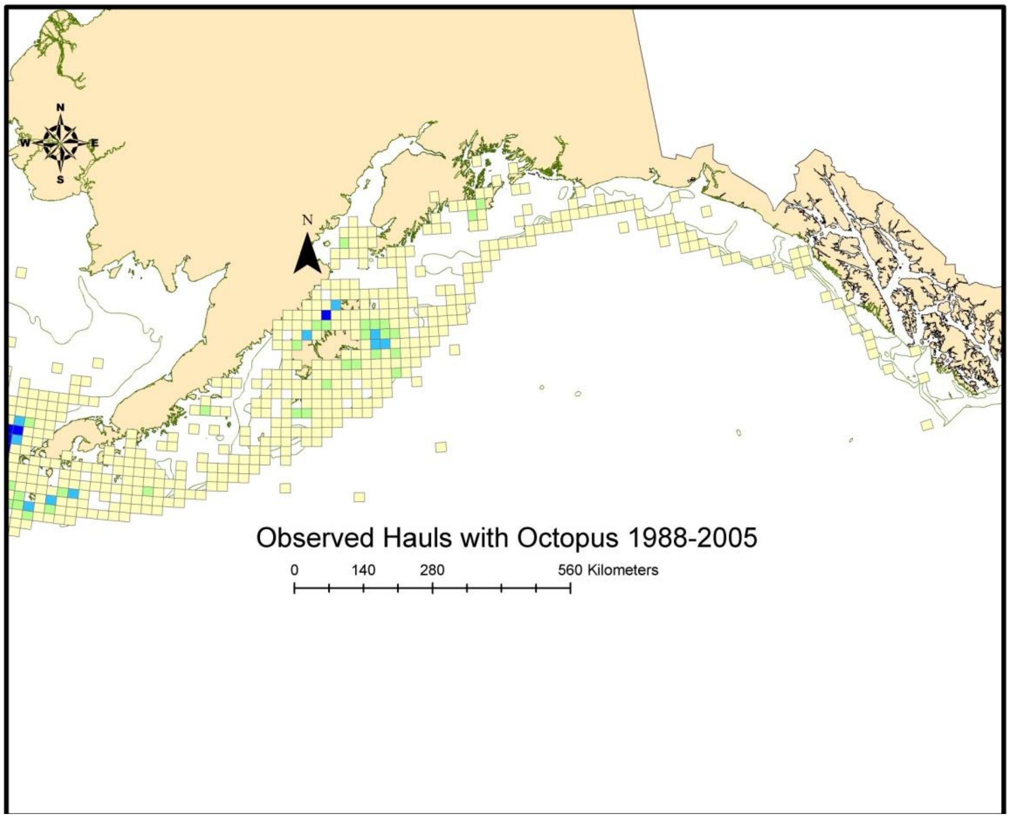


Figure 2. Size frequency of individual octopus (all species combined) from AFSC bottom trawl surveys in the GOA 1999-2005.

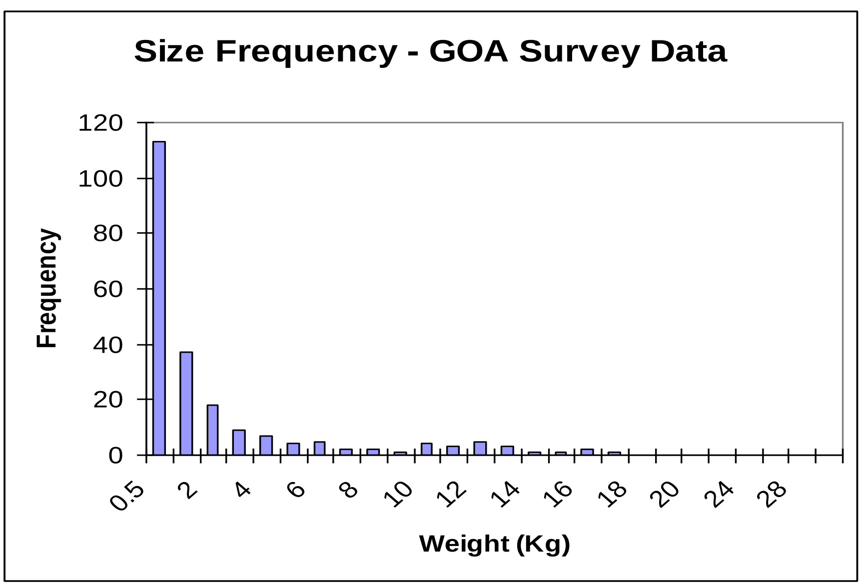
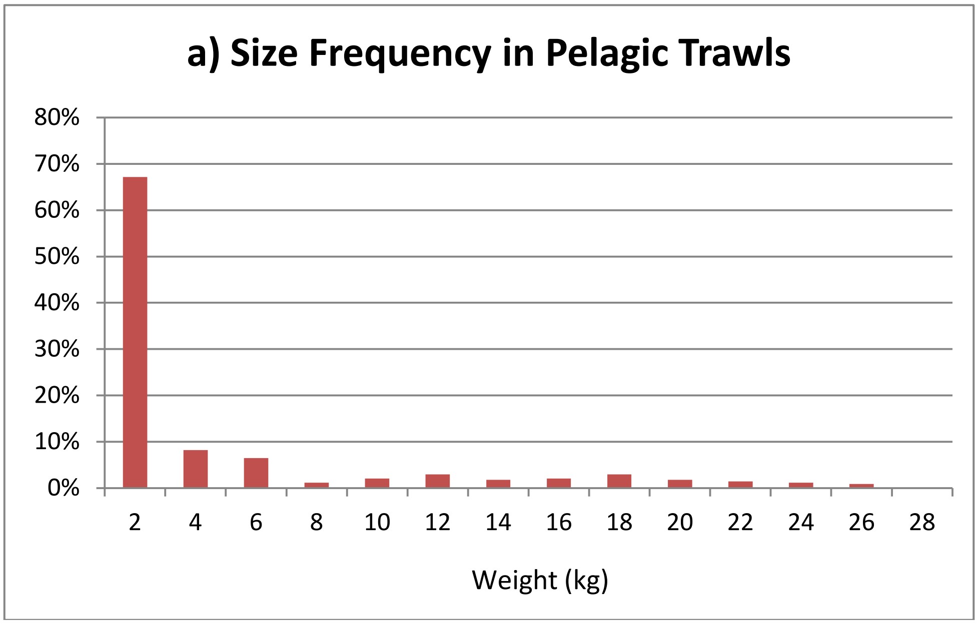


Figure 3. Size frequency of individual octopus from 2006-2011 observer special project by gear type: a) pelagic trawls, b) bottom trawls, c) pots, and d) longline.



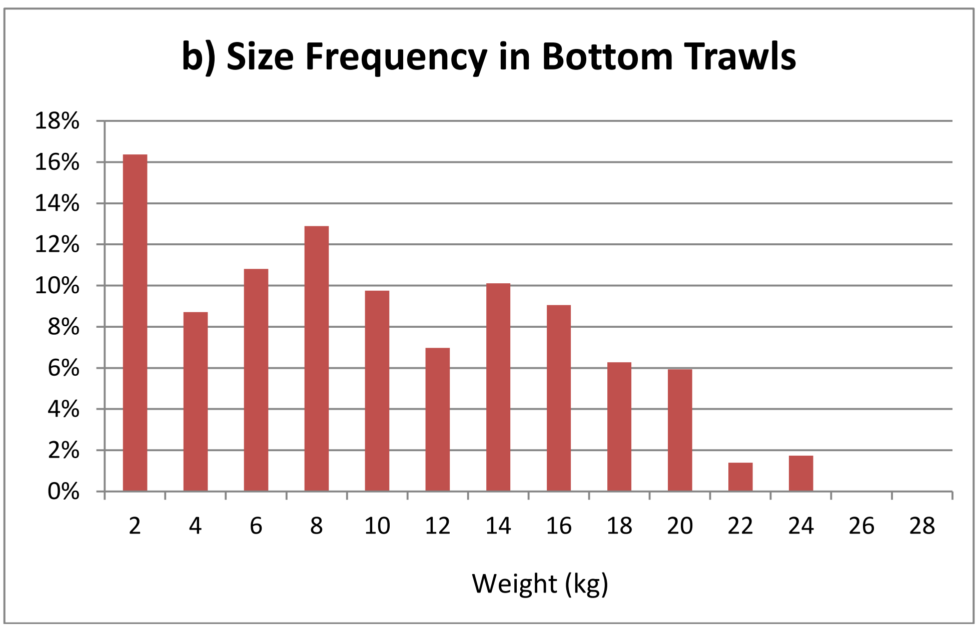
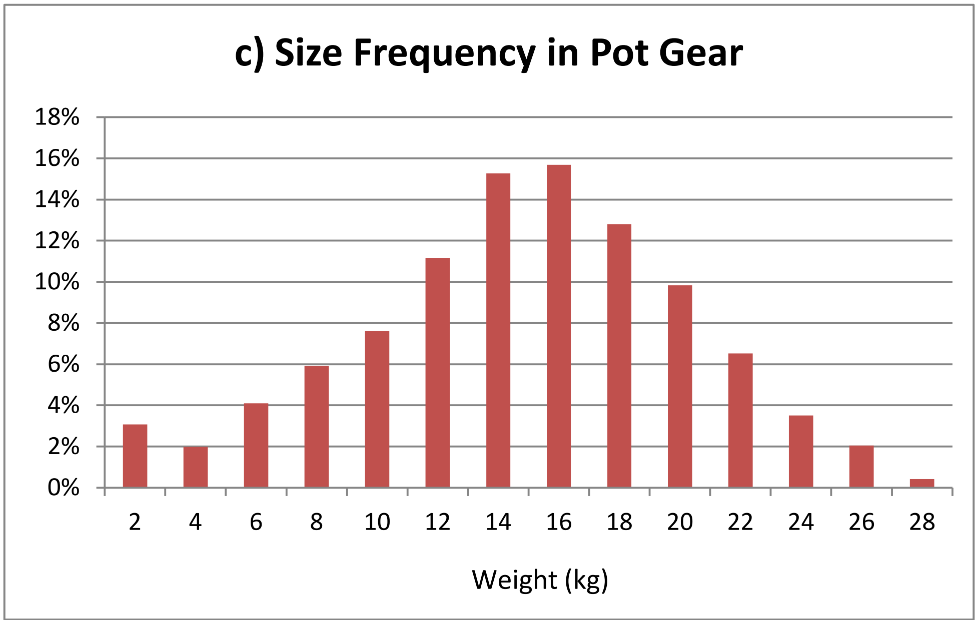


Figure 3. Continued.



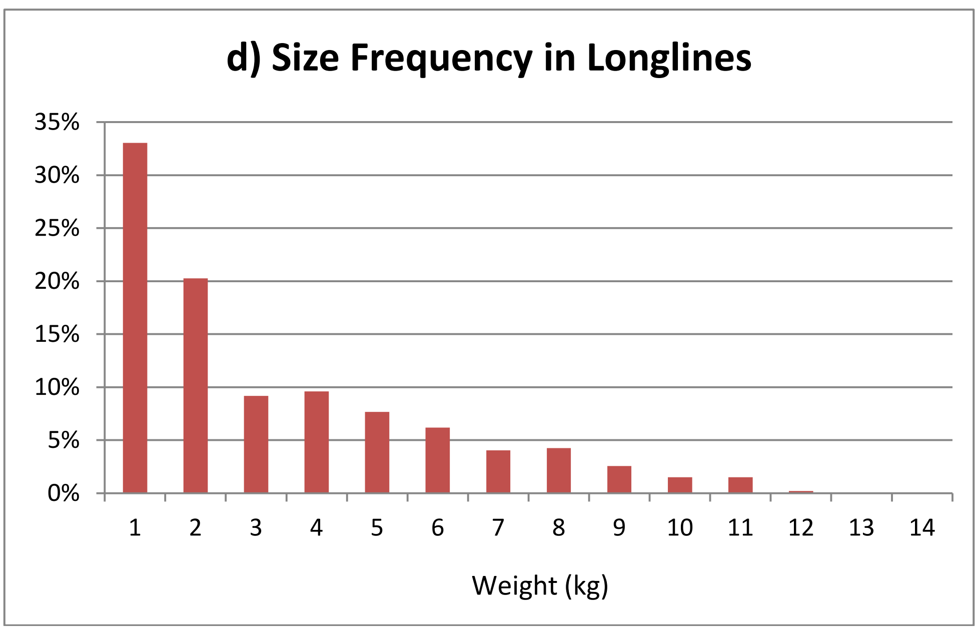


Figure 4. GOA octopus survey biomass estimates and confidence intervals.

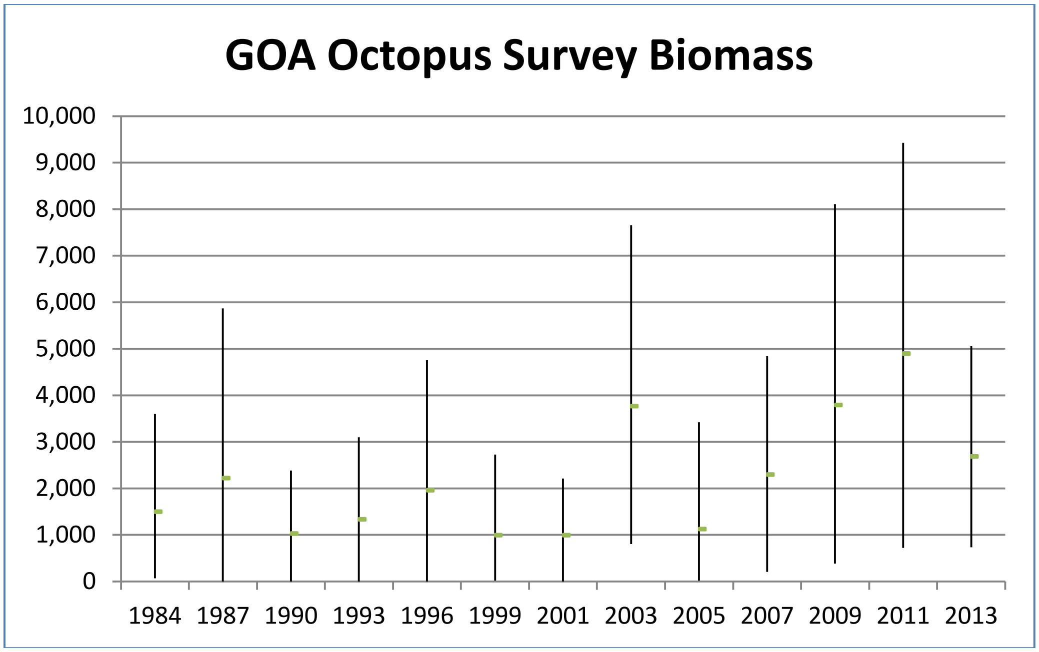


Figure 5. Random effects model on GOA octopus survey biomass. Solid line shows model estimates of biomass, dashed lines show 90% confidence interval on the model, markers show individual survey biomass estimates.

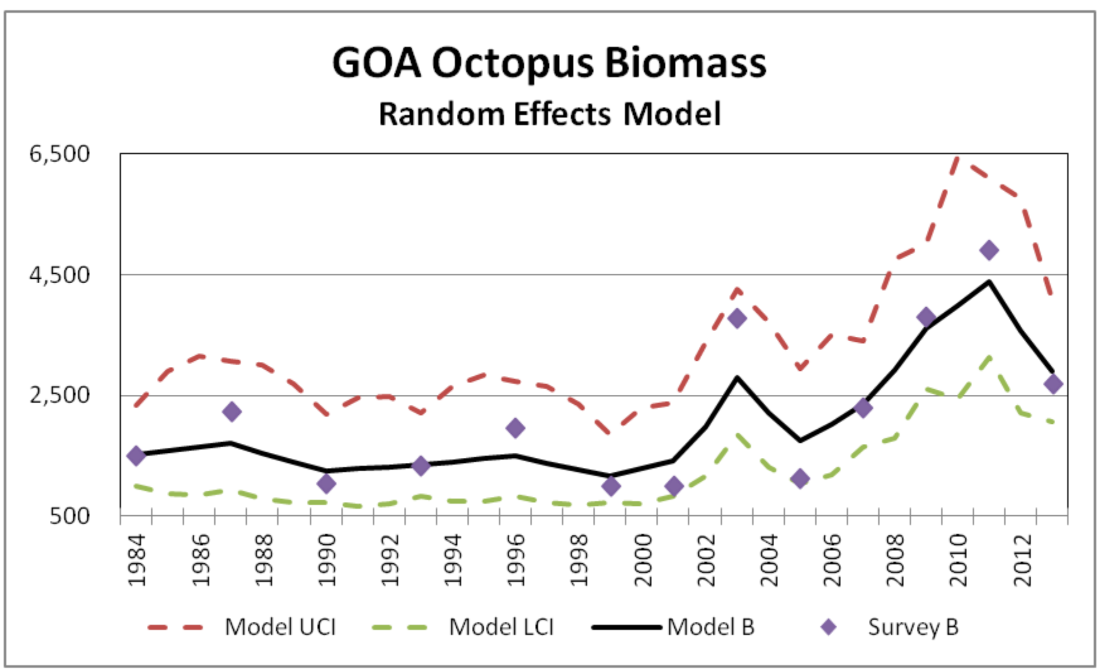


Figure 6. Ecopath model estimates of total consumption of octopus in the GOA (based on average 1990-1993 biomass and catch estimates).

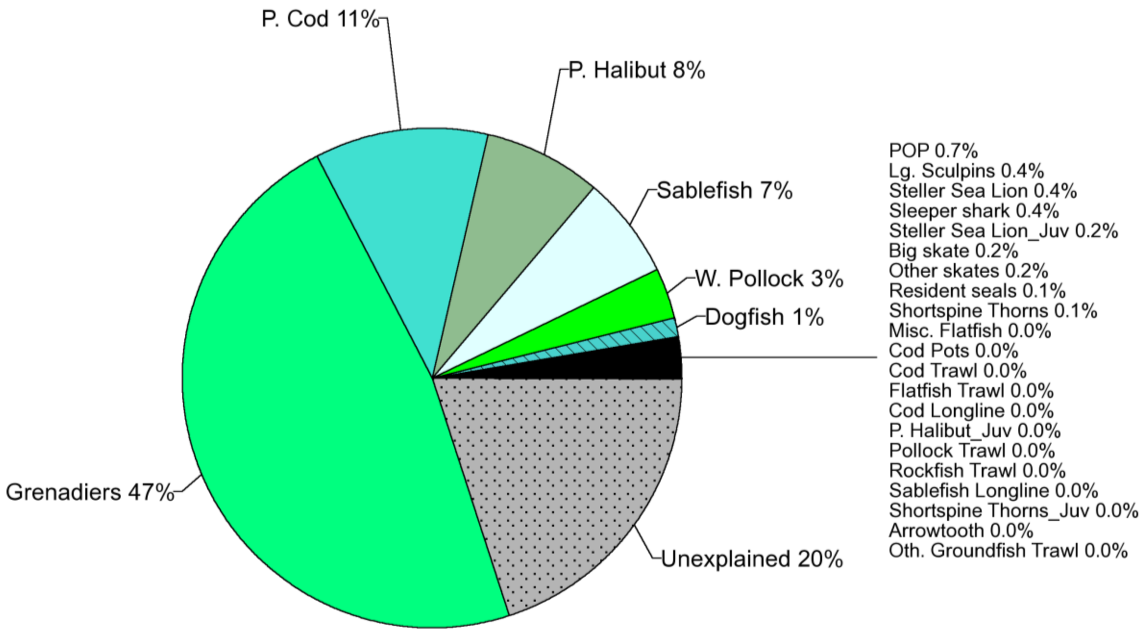


Figure 7. Ecopath model estimates of prey of Steller sea lions in the GOA (based on average 1990-1993 biomass and catch estimates).