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. In 2011, the GOA Fishery Management Plan was amended to provide separate management for sharks, sculpins, and octopus. In compliance with the reauthorized Magnuson-Stevens Act, each group has its own annual catch limit. Catch limits for octopus for 2011-2014 were set based on the average of the last 3 surveys as a minimum biomass estimate. For 2015-2016 two methods of estimating minimum biomass 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.

Summary of Changes in Data

The catch of octopus in the 2015 AFSC bottom trawl survey was unusually large, including several tows with multiple individuals of *Enteroctopus dofleini* and *Opisthoteuthis californiana*. The estimated biomass for the octopus assemblage in 2015 is 12,990 t, nearly an order of magnitude larger than previous estimates. The confidence bounds on this estimate, however, are also very large. Octopus were present in more than 15% of the survey tows in 2015, which is a higher frequency than in all past years except 2009. The estimated survey biomass was 97% *E. dofleini*. Survey-caught octopus ranged in size from 20 kg to 19 kg. Commercial catch data for the octopus complex have been updated through October 11, 2015. The estimated total catch shows a sharp increase in the last 2 years, with a total catch for 2014 of 1,298t, and a catch through September 2015 of over 800 t. The majority of the catch was taken with Pacific cod pot gear in statistical areas 610, 620 and 630. Overall, only 37% of the 2015 catch was retained, but a large fraction (79%) of the catch from area 630 was retained.

Summary of Changes in Assessment 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 2012-2014. 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 Plan Team Survey Averaging Work Group. The 2015 biomass estimated by this model and the resulting catch limit estimates are also presented.

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 2010-2014, 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 2014 and 2015 was set at 2,009 tons. By using an average of the 2011, 2013, and 2015 survey biomass estimates with this approach, the estimated biomass is 6,858 t and the new OFL for octopus would be 3,634 tons. If only the smoothed 2015 value from the random effects is used as the biomass estimate, the OFL would be much higher at 6,504 tons. Because of the large uncertainty in this year's survey biomass, the Plan Team may wish to consider setting the ABC at a lower fraction of the OFL, rather than the usual 75%. Since catches have remained below OFL, this complex has not been overfished. There is insufficient data to determine whether the complex is being subjected to overfishing or is approaching a condition of being overfished. In 2013, a review of AFSC non-target species assessments was held by the Center of Independent Experts. Responses to this review are included in an appendix.

Summary of Harvest Recommendations

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2015	2016	2016	2017
Tier 6 (3 survey biomass * M)	6(alt)	6(alt)	6(alt)	6(alt)
OFL (t)	2,009	2,009	3,634	3,634
ABC (t)	1,507	1,507	2,726	2,726
Tier 6 (model biomass * M)			6(alt)	6(alt)
OFL (t)			6,504	6,504
ABC (t)			4,878	4,878
	As determined *last* year for:		As determined *this* year for:	
Status	2013	2014	2014	2015
Overfishing		n/a	n/a	n/a

Responses to SSC and Plan Team Comments on Assessments in General

Meetings of the Plan Teams in September 2015 and the SSC in December 2014 and October 2015 had no general comments that apply to the octopus assessment.

Responses to SSC and Plan Team Specific to this Assessment

Meetings of the plan teams in September 2015 and the SSC in October 2015 had no comments specific to the octopus assessment.

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 species diversity is along the shelf break region of the GOA, although 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. 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). AFSC survey data also demonstrate the presence of octopus throughout the GOA and also indicate highest biomass in areas 610 and 630. 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 in 2003, but octopus was still reported as an aggregate catch for all species. 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 were initiated to 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 2011.

National Standard One Guidelines 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 possible approach for future use is to split this assemblage by size, allowing retention of only larger animals. This would 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, 2014). *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 and 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, AKFIN 2015). Recent increases in global market value have increased retention of incidentally-caught octopus in the BSAI and GOA. Overall, only 37% of the 2015 catch in the GOA was retained, but a large fraction (79%) of the catch from area 630 was retained. 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 t per year (Fritz 1997). In 2004, Commissioner's permits were given for directed harvest of Bering Sea octopus on an experimental basis (Karla Bush, ADF&G, personal communication). Nineteen vessels registered for this fishery, and 13 vessels made landings of 4,977 octopus totaling 84.6 t. The majority of this catch was from larger pot boats during the fall season Pacific 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. Two boats fished for octopus on Commissioners permits in 2014, their total catch was roughly 1.5 tons. The majority of octopus catch in state waters is 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 Table 2 and discussed below in the data section.. The majority of incidental catch of octopus comes from Pacific cod fisheries, primarily pot fisheries. Some catch is also taken in trawl fisheries for Pacific cod and other species and in longline fisheries. The overwhelming majority of catch in federal waters occurred in the central and western GOA in statistical reporting areas 610, 620 and 630. In 2014-2015, there were particularly high octopus catches not only in the Shumagin and Kodiak regions (610 and 630), but also in the Chirikof region (620). The species of octopus taken is not recorded, 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 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*.

Data

Fishery

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 (Table 2). Catches in 2007-2010 have been somewhat higher; between 250 and 350 t. Incidental catch in 2011 was much higher that previously 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, and approximately half of this catch was retained either for market or for use as bait. The estimated total catch for 2012 was 415 t and the catch for 2013 was 442 t.

Catches of octopus in the GOA have increased dramatically in the last 2 years. Incidental catch in 2014 was the highest ever observed, with a total catch over 1,200 tons. Catch remains high in 2015, exceeding 800 tons by October 11. In general the amount of catch retained has been in the range of 200-300 t since 2003, but 530 t was retained in 2014. In 2015, the overall retention rate is estimated at 37% but a large fraction (97%) of octopus caught in area 630 (Kodiak) was retained.

High rates of incidental catch in 2002, 2004, 2009, 2011, and 2014-15 correspond to high survey catches in 2003, 2009, 2011, and 2015 (Table 3). As in previous years, the majority of the 2014-2015 catch came from Pacific cod fisheries. While catches in areas 610 (Shumagin) and 630 (Kodiak) remained high, in 2014-15 area 620 (Chirikof) also saw large octopus catches (Table 2).

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 2006-2015. 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; total observed pot fishing effort varies widely from year to year. 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.

In order to check the recent increases in octopus survey biomass and total catch, observer data was used to construct a rough estimate of incidental catch per unit effort of octopus (Figure 2). For this time series, all observed hauls using pot gear in statistical reporting area 603 were used. The total extrapolated catch of octopus from observed hauls in each calendar year was divided by the total numbers of pots fished on observed hauls in the reporting area, and the results expressed as kg per 100 pots. This index shows a somewhat cyclic pattern with peaks in many of the same years that show high total incidental catch; 2003, 2009, 2011, and 2014. Both time series show a period of fairly stable catch rates from 1998-2006, and a general increasing trend from 2008 – 2015.

Survey

AFSC Survey Data

Catches of octopus are recorded during the semi-annual NMFS bottom trawl survey of the GOA. In historical 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 2006 through 2015 is shown in Figure 3. Survey-caught octopus ranged in weight from less than 0.1 kg to over 22 kg; 38% 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 through 2015 GOA trawl surveys caught primarily *E dofleini*, *B. leioderma*, and *O. Californiana*. The majority of the biomass, however, is *E dofleini*; in 2015 this species made up 82% of the total estimated biomass. The largest individual in the 2015 survey was an *E. dofleini* at 23 kg. Overall, the 2015 survey had octopus in 119 hauls out of a total of 772 survey hauls; this is a higher percentage than seen in previous survey (Table 3). A total of 1956 octopus were caught in the 2015 survey.

The estimated 2015 survey biomass of all octopus species for the GOA was very high, nearly an order of magnitude higher than historical catches (Table 3). Past survey biomass estimates range from 994 t in 1999 and 2001 to 4,897 t in 2011. **The estimate from the 2015 survey is 12,990 t.** The large biomass estimate results from several survey hauls that contained more than one large *E. dofleini*; one haul in the western GOA contained six octopus with a combined weight of 58 kg. However, 85% of the hauls contained no octopus. The averaging of hauls with large octopus weight and those with zero octopus results in a large degree of variability in the biomass estimate; the approximate 90%

confidence interval for the 2015 estimate ranges from 6,500 t to 20,000 t. When the three most recent survey biomass estimates are averaged together, the result is 6,858 tons.

The increases in numbers of octopus caught and in the estimated biomass from the 2015 survey are consistent with the higher incidental catch rates observed in 2014 and 2015. While the large jump in estimated biomass may be exaggerated by sampling variance, it appears that there has been some recent increase in the octopus population of the GOA. This may be related to strong patterns in upwelling and surface temperature observed in the eastern Gulf in recent years, or to warmer bottom temperatures measured throughout the Gulf during the 2015 survey. The paralarvae of *E. dofleini* spend several months in the plankton, and several studies have related cephalopod abundance to upwelling and productivity measures (Vidal et al. 2010, Robert et al. 2010). Recent work (Scheel, 2015) has shown a negative correlation between beach counts of octopuses in Prince William Sound and winter surface water temperatures in the eastern GOA.

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).

Analytic Approach

Model Structure

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 modified approach under Tier 6, which uses a minimum biomass estimate and a natural mortality rate based on life history parameters, assuming the logistic model used for Tier 5.

Parameter Estimates

Biomass B

Estimates of octopus biomass based on the biennial GOA trawl surveys (Figure 5) represent total weight for all species of octopus, and are calculated 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, an increasing fraction of collected octopus have been identified to species, but some misidentification may still occur. AFSC surveys are currently working toward complete species identification of octopus, and providing species-specific size and biomass information.

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, AFSC, 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 30 m, 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 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 from 2006–2016 was 3.8 kg; 38% of survey-collected individuals over this period weighed 0.5 kg or less. 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 12 kg (Figure 4). 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 and the true catchability is probably less than 100%. 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. When this approach is used, the average biomass is 6,858 t.

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 1990 through 2015 was fitted with the random effects model developed by this group, with the results shown in Figure 6. The smoothed value of annual biomass follows the trends in the survey estimates, but tends to moderate the more extreme highs and lows of the individual estimates. Because the very high 2015 estimate is the last data point in the series, the random effects model still predicts very high biomass for 2015. The model-estimated biomass for 2015 is 12,270 tons, only slightly lower than the raw survey 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, if funding were available. It may also be feasible to estimate regional octopus biomass using mark-recapture studies or depletion methods (Caddy 1983, Perry et al. 1999). These options could be explored with a small experimental fishery and industry support. A size-based stage-structured model is currently being explored, but will need a sufficient time-series index of abundance and size frequency data to be predictive.

Natural 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 from a directed fishery are 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 rate 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 natural mortality, based on information currently available. If future management of octopus is to be based on Tier 5 methods, a direct estimate of octopus natural 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 natural mortality rate for large octopus, but have not yet been published.

Results

Harvest Recommendations

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 composition, life history, distribution, and abundance of octopus in the GOA. The recent large increase in apparent octopus abundance should be monitored closely. Further research is needed in several areas before octopus could be appropriately managed by the methods used for commercial groundfish species. Harvest recommendations 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 modified approach under Tier 6, which uses a minimum biomass estimate and a natural 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 (2011, 2013 and 2015) of 6,858 t and the conservative *M* estimate of 0.53 are used, the OFL and ABC for GOA octopus would be 3,634 t and 2,726 t, respectively.** If the random effects smoothing model applied to the full survey time series is used, the predicted biomass for the most recent year (2015) is

12,271 t. **Using the model results as the minimum biomass estimate** with a natural mortality rate of 0.53, **the OFL would be 6,504 t and the ABC would be 4,878 t.**

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. If interest in a directed octopus fishery increases, we recommend using an experimental fishery to obtain depletion-based regional biomass estimates and to develop an octopus-specific index survey using habitat pot gear.

Ecosystem Considerations

Ecosystem Effects on the Stock

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 minor octopus species; spatial patterns about the most abundant species (*E. dofleini*) may be inferred only by combining data over several years.

Fishery Effects on the Ecosystem

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) 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 7) 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 8). 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 octopuses 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%).

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 lifehistory cycle of *E. dofleini* in Alaskan waters (Conrath and Conners 2014) and octopus-specific field methods for capture, tagging, and index surveys (Conners et al. 2012). The AFSC consults 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 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 catch (t) of octopus (all species) in state and federal fisheries and approximate percentage of catch retained. Catch for 1997-2002 was estimated from blend data. Catches for 2003-2015 are from Alaska Regional Office Catch Accounting System.

	Statistical Reporting Areas					GOA		
	610	620	630	640	650	Total	Retained	% Ret
1997						232		
1998						112		
1999						166		
2000						156		
2001						88		
2002						298		
2003	149	13	48	0.3	2.0	212	44	20.7%
2004	200	6	76	0.1	0.5	283	161	56.9%
2005	58	3	88		0.0	149	102	68.5%
2006	37	9	119	0.3	0.2	166	144	86.4%
2007	64	22	179	0.0	0.1	266	239	89.8%
2008	125	28	186		0.1	339	278	82.0%
2009	141	33	146	0.2	0.3	321	267	83.3%
2010	142	49	139	0.2	0.1	330	272	82.2%
2011	565	92	268	0.8	1.9	927	387	41.7%
2012	177	25	212	0.1	0.0	415	275	66.3%
2013	239	29	142	17.1	14.8	442	215	48.8%
2014	494	170	627	3.5	3.0	1298	530	40.8%
2015*	202	352	314	0.9	2.0	871	323	37.1%

*Data for 2015 are as of October 11, 2015.

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)	STD Err of Biomass (t)
1984	929	89	9.6%	1,498	347
1987	783	35	4.5%	2,221	959
1990	708	34	4.8%	1,029	393
1993	775	43	5.5%	1,335	422
1996	807	34	4.2%	1,960	892
1999	764	47	6.2%	994	279
2001	489	29	5.9%	994	365
2003	809	70	8.7%	3,767	810
2005	837	58	6.9%	1,125	362
2007	816	73	8.9%	2,314	503
2009	823	81	9.8%	3,791	724
2011	670	67	10.0%	4,897	894
2013	548	67	12.2%	2,686	496
2015	**772**	**119**	**15.4%**	**12,990**	**1,849.44**

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

		Year												
Species	**1990**	**1993**	**1996**	**1997**	**1998**	**1999**	**2001**	**2003**	**2005**	**2007**	**2009**	**2011**	**2013**	**2015**
octopus unid.	21	46	37	6	20	65	15	1		3	2	2	1	1
Enteroctopus dofleini	8	8	7			6	17	67	43		82	75	62	156
Octopus sp.								10	17	5	1		2	4
Opisthoteuthis californiana	4	2	1		17	25		1	15	10	11	4	4	26
Benthoctopus leioderma	16	3				8	5	7	11	3	11	10	22	3
Octopus californicus									9					
Benthoctopus sp.								4	9		3	3		
Japetella diaphana								2	2	8			1	5
Japetella sp.										1	1			
Benthoctopus oregonensis														1
Vampyroteuthis infernalis						7		3				1		
All Octopus	49	59	45	6	37	111	37	96	106	31	111	95	92	196

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 2006-2015; darker colors (blue) are blocks with multiple observations.

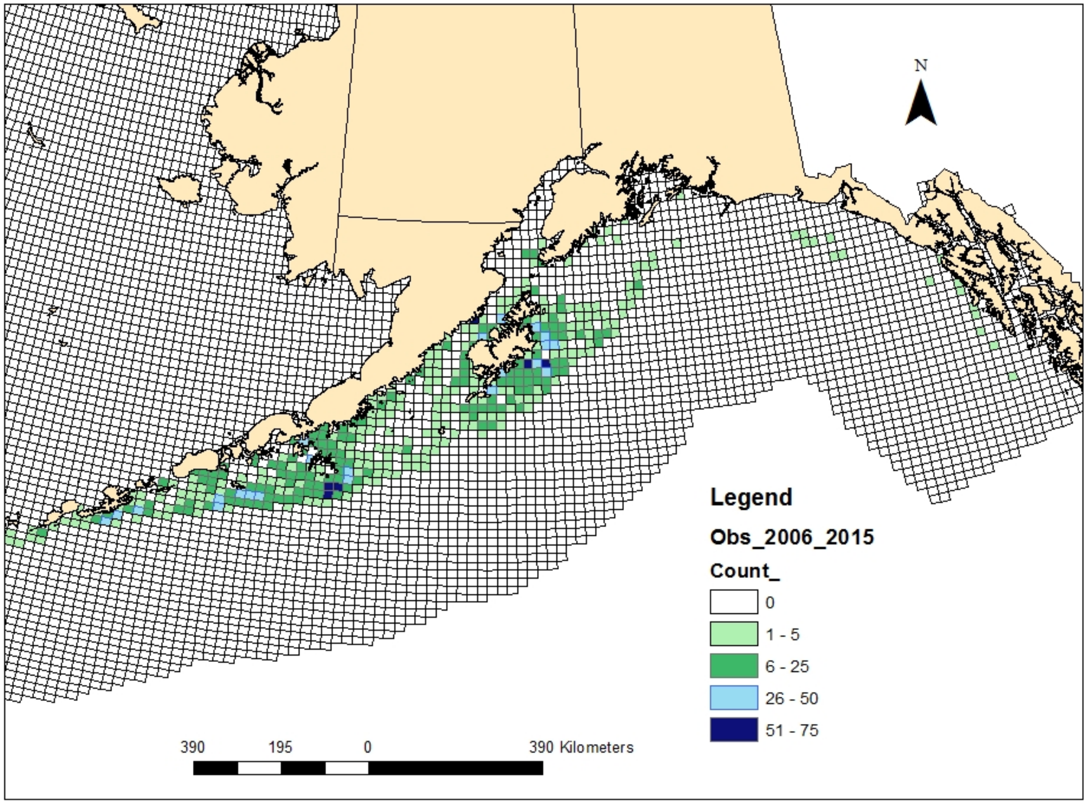


Figure 2. Time series of catch per unit effort (kg octopus per 100 pots) in observed hauls in statistical reporting area 630 (central Gulf of Alaska).

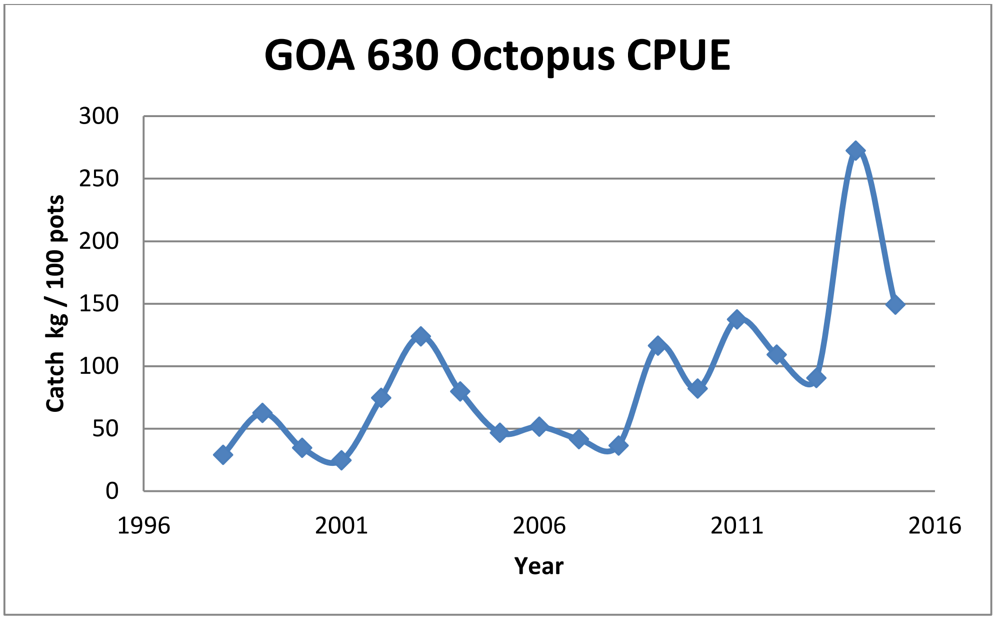


Figure 3. Size frequency of individual octopus (all species combined) from AFSC bottom trawl surveys in the GOA 2006-2015.

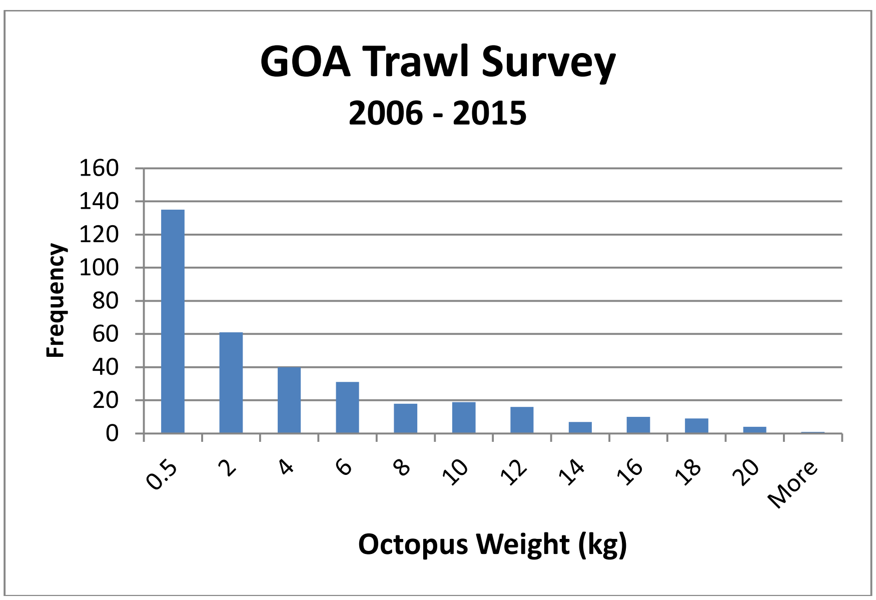
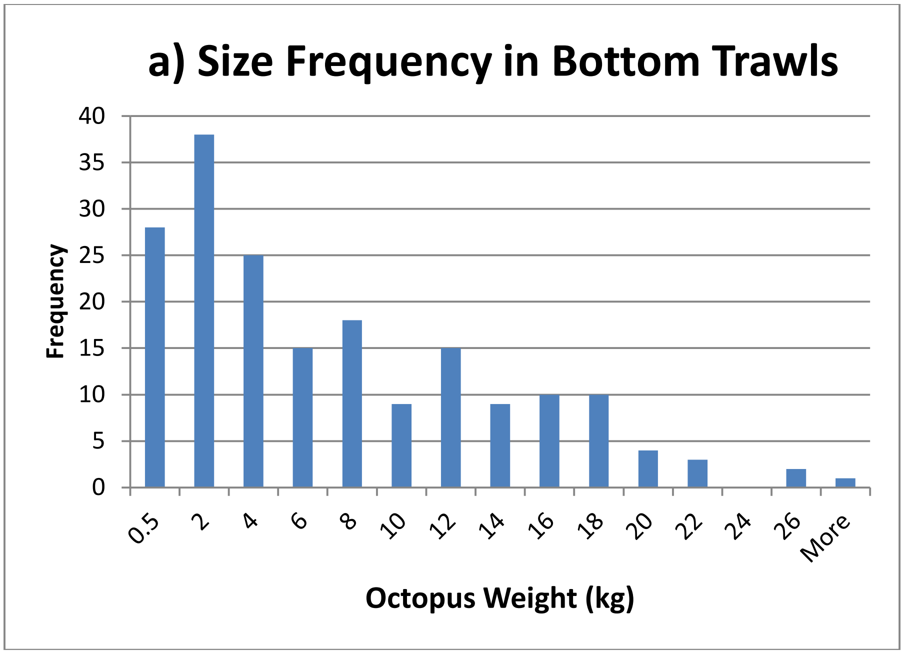


Figure4. Size frequency of individual octopus from observed hauls in GOA fisheries 2010 – 2015 by gear type: a) bottom trawls, b) pots, and c) longline.



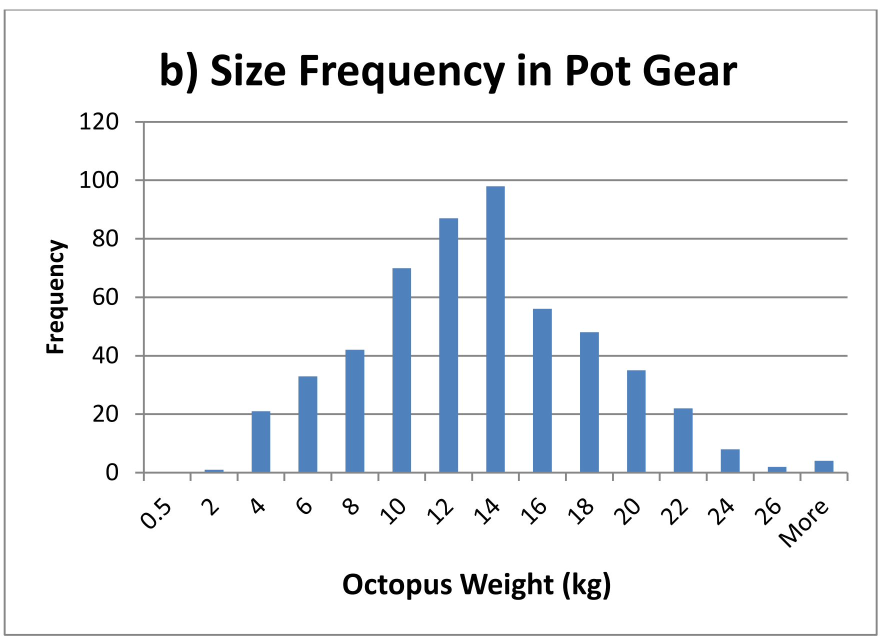


Figure 3. Continued.

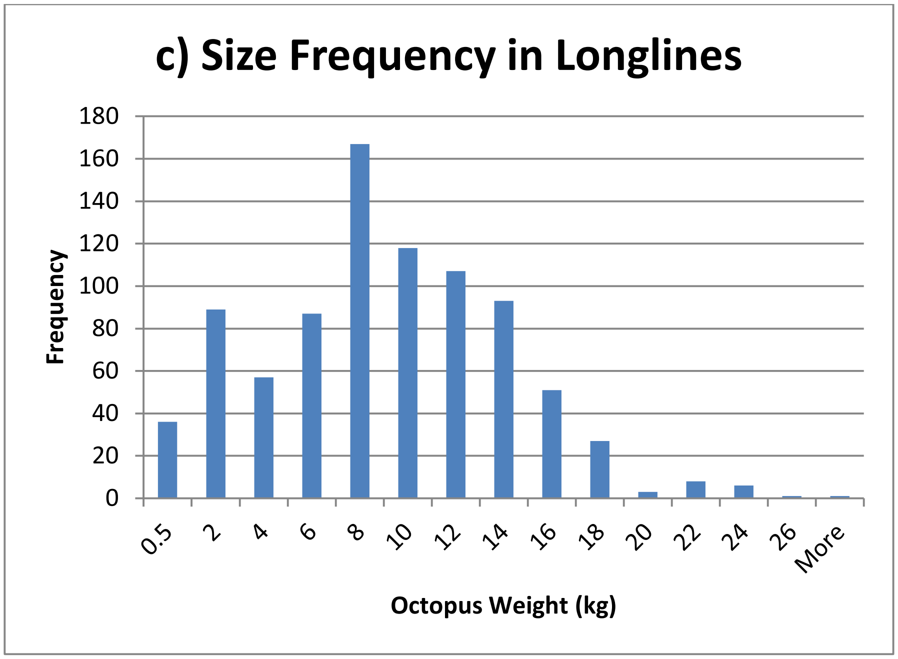


Figure 5. GOA octopus survey biomass estimates and approximate 95% confidence intervals.

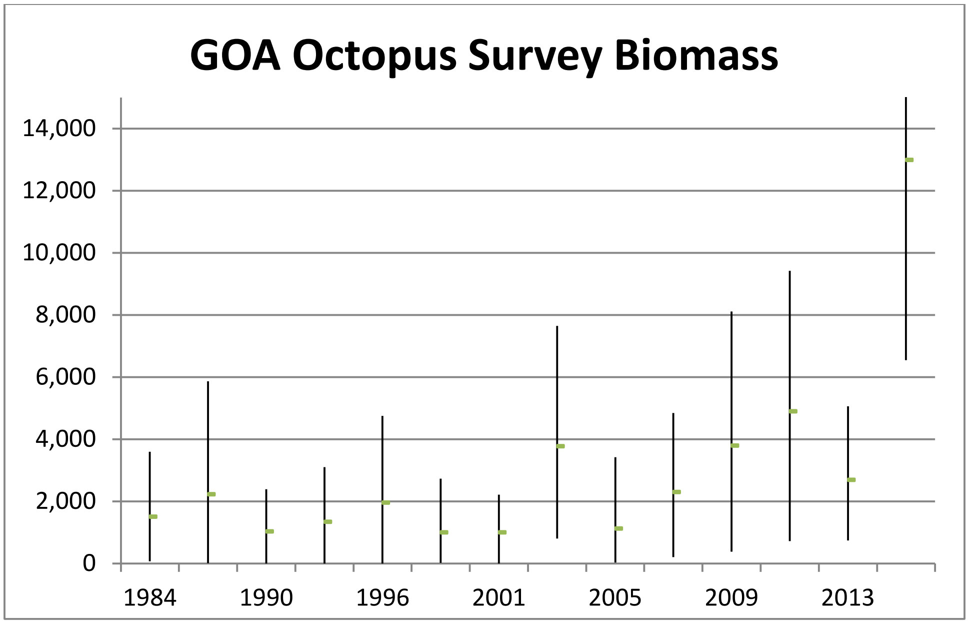


Figure 6. Random effects model results for GOA octopus survey biomass. Solid line shows model estimates of biomass, dashed lines show 90% confidence interval for the model estimates, markers show individual survey biomass estimates.

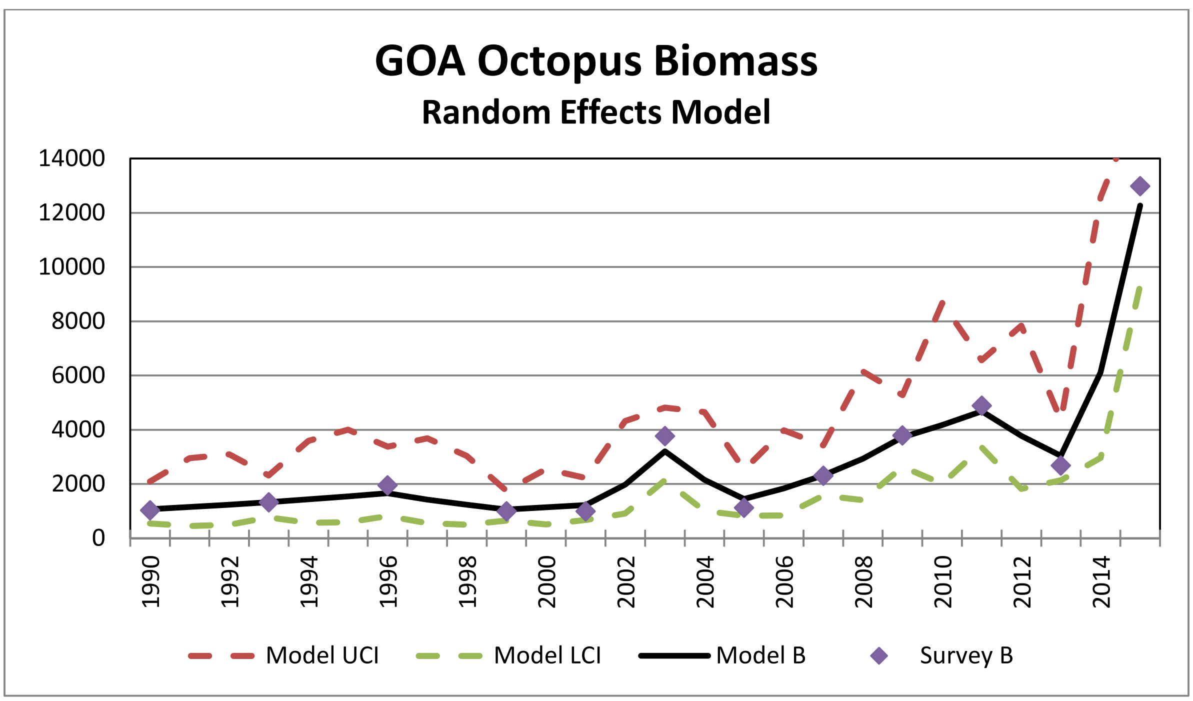


Figure 7. Ecopath model estimates of total consumption of octopus in the GOA (based on average 1990-1993 biomass and catch estimates).

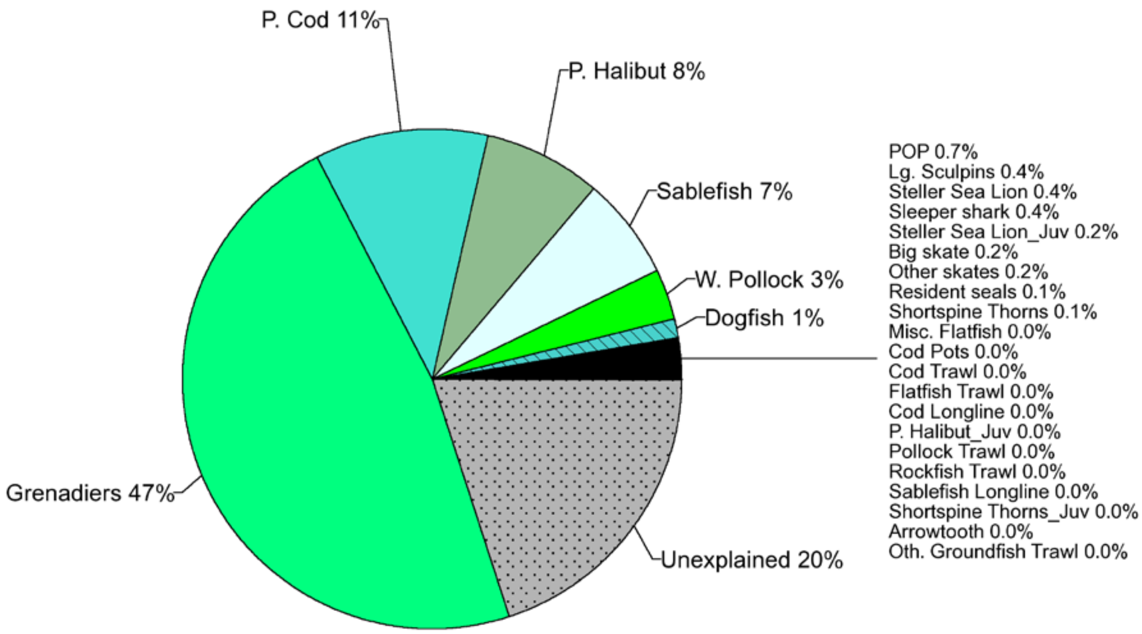
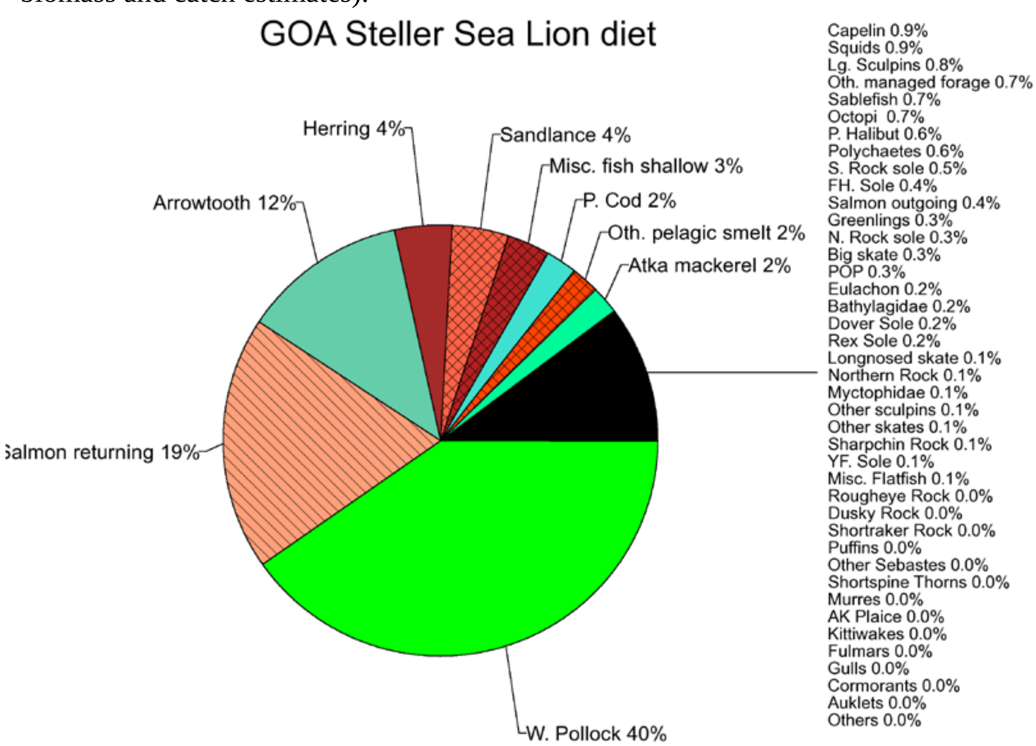


Figure 8. Ecopath model estimates of prey of Steller sea lions in the GOA (based on average 1990-1993 biomass and catch estimates).



Appendix: Response to 2013 CIE review for Non-Target Species

A review of AFSC assessments for several non-target species groups, including octopus, was conducted in May 2013. Three independent reviewers met with assessment authors and AFSC staff and provided written review of data and procedures used for non-target species assessments. The principal recommendations from this review and their relevance to the octopus assessment are discussed below.

1. Use of area-swept estimates from bottom trawl survey as absolute estimates of abundance. The issue that received the most discussion during the review was the use of survey biomass estimates as measures of absolute abundance. This is particularly important for many Tier 5 and 6 non-target species, including GOA octopus, that rely on survey biomass estimates directly for setting catch limits, without modifying effects of age-frequency data and age-structured models. The primary concern raised is that these estimates assume 100% catchability (q=1) for all species and size ranges, which is rarely true. For octopus, in particular, it is likely that the true catchability is less than 100% and that catchability is very different for different size classes. Other concerns raised were that the AFSC bottom trawl surveys do not cover all habitats (rocky, steep or otherwise untrawlable ground, inshore habitats in state waters, and areas < 30 ft deep), and it is difficult to estimate how much of a stock is contained in these areas, or if the fish density is the same between surveyed and unsurveyed habitats.

While these criticisms are true and are always present in fisheries management, the assessment authors do not see that there is any reasonable alternative to use of trawl survey biomass estimates. Where there is real information about catchability, this could be used to modify the swept-area estimates, as suggested by one reviewer. This type of information is, however, rarely available for non-target species. For octopus, while the differences in size ranges between trawl and pot gear suggest that there is strong gear size selectivity, it does not provide information to suggest appropriate estimations of the actual q for different size ranges.

2. Use of Tier 5 model where M is used as a proxy for FMSY. The reviewers also expressed concerns about applying the Tier 5 model to a wide variety of stocks. It was felt that this model is a “general rule of thumb” that may not reflect the true dynamics of all species groups, and that efforts should be made to develop species-specific reference points for setting catch limits. As an example, reviewer Phillip Cordue wrote a simple age-based model of octopus, with parameter values based on general assumptions of a 5-year life span, Beverton-Holt Stock-Recruitment, and terminal spawning. Using this model, he simulated population size relative to initial biomass (B/B0) and a range of fishing levels, measuring yield and spawning stock biomass. He concluded that FMSY was very sensitive to the assumed steepness of the spawner-recruit curve, and showed that F40%B0 was a more stable exploitation level.

The assessment author agrees that modeling of octopus population dynamics based on available life-history information will be interesting, and is developing a size-structured model similar to that proposed by Dr. Cordue. Choosing some regulatory measure other than FMSY, however, does not solve the principal problem with the stock assessment, which is accurate estimation of biomass. The author recommends that the standard Tier 5 model be retained until there exists a more accurate age- or stage-based model that can be calibrated to a time series of abundance of at least two of the size stages and a reliable measure of absolute abundance.

3. Use of a fixed buffer of ABC = 75%OFL for non-target species. The reviewers commented in several places that the NPFMC’s approach of using a fixed value for this buffer for species in Tiers 5-6 was not necessary, and that a better alternative would be to use a variable buffer between ABC and OFL that would reflect the uncertainty in the estimation of OFL. Reviewer Cieri endorsed the P* approach. Reviewer Cordue suggested that for Tier 5 models, the lower 95% confidence interval for the biomass estimate be used to calculate the ABC.

This is a broad-scale policy issue that should be considered at the SSC and Council levels, rather than within an assessment. For octopus, both survey biomass estimates and the Random Effects model generate confidence intervals that could be used in this manner, but the uncertainty in natural mortality rates is harder to quantify. The consumption model used for octopus in the Bering Sea also generates estimates of uncertainty.

4. Use of historical catch data for Tier 6 assessments. All three of the CIE reviewers concurred that use of historical catch data for non-target species is a very poor method of assessment and should be reserved as a last resort when no other method is feasible. In particular, incidental catch rates for species that were not targeted are unlikely to have much resemblance to sustainable catch levels. The reviewers also felt that when used, time periods for historical catch data should be selected on a species- specific basis, accounting for changes in structure of fisheries and gear.

For the octopus assessment, the plan teams and SSC have already agreed that the use of historical incidental catch data is inappropriate and likely to unnecessarily constrain target fisheries.

5. Use of age data in non-target assessments. There was considerable discussion of the quality and utility of age-frequency data for some of the non-target species, most notably sculpins. One reviewer was very concerned that samples collected for age data may not be collected in a manner that allows inference of age frequency, since the otolith collections are not necessarily balanced over the spatial range of the survey.

This is not relative to octopus assessment, as no age structures are collected.

6. Use of survey averaging and/or smoothing models. The reviewers felt in general that application of smoothing models to time series of survey biomass might be a good idea, but did not endorse a specific approach. They did not feel that averaging of a specific number of recent surveys (weighted or non-weighted) was supported by any scientific rationale.

For short-lived species such as octopus, the reviewers felt that recent biomass data would be more appropriate than long-term averages in managing stocks.

7. Best method for determining catch limits for the octopus assemblage. The reviewers agreed that none of the various methods that have been examined for setting octopus catch limits are very good, but did not agree on which of the available methods was best. Reviewer Cieri reluctantly supported the food-web approach used in the BSAI, but suggested several modifications that should be considered in application of this approach. Reviewer Volstadt strongly supported development of an octopus index survey using habitat pot gear. Reviewer Cordue, as described above, advocated use of a simulation model to select appropriate fishing levels but did not suggest any ways to improve biomass estimation.

The primary assessment author feels that the food-web consumptions estimation approach that is currently used in the BSAI is the method best supported by available data. The modifications suggested by reviewer Cieri will be examined when the consumption estimator is re-calculated in 2016. Future development of the octopus assessment will include development of a size-based model similar to Dr. Cordue's, and the author agrees that a habitat- pot survey could provide both a more accurate time series of abundance and improved data on size frequency of octopus populations in index areas. The next step in improvement of the octopus assessment could be an experimental fishery to determine overall catch rates (and possible economic support from sale of survey catch), best index areas and methods for an index survey, and estimates of absolute abundance for surveyed areas based on depletion, sex-ratio, or tagging methods.