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

M. Elizabeth Conners, Christina Conrath, and Kerim Aydin
Alaska Fisheries Science Center
November 2013

Executive Summary

Through 2010, octopuses were managed as part of the BSAI "other species" complex, along with sharks, skates, and sculpins. Historically, catches of the other species complex were well below TAC and retention of other species was small. Due to increasing market values, retention of some other species complex members is increasing. Beginning in 2011, the BSAI fisheries management plan was amended to provide separate management for sharks, skates, sculpins, and octopus and set separate catch limits for each species group. Catch limits for octopus for 2011 were set using Tier 6 methods based on the maximum historical incidental catch rate. For 2012 and 2013, a new methodology based on consumption of octopus by Pacific cod was introduced; this method is also recommended for 2014 and 2015. The consumption estimate has not been revised from 2012; the authors recommend that this calculation be revisited once every five years.

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

Summary of Changes in Data

Survey data have been updated with the 2013 Bering Sea shelf survey results. Estimated survey biomass in 2013 was 1,810 tons, slightly lower than in 2011 and 2012. Species composition from the survey was similar to previous years, with *E. dofleini* making up 91% of the estimated total biomass.

The table of incidental catch rates has been updated to include estimated catch for the entirety of 2012 and for 2013 through September 18. The estimated total catch for 2012 was 138 tons and the catch for 2013 through September 18 was 134 tons. The estimated percent retention of BSAI octopus in 2013 was 21%.

Summary of Changes in Assessment

This assessment uses the approach introduced in 2012 that estimates the total mortality of octopus by the annual amount of octopus consumed by Pacific cod. This methodology is based on species composition of diet data for Pacific cod from the AFSC food habits database, and cod weight-at-age data fit to a generalized von Bertalanffy growth curve (Essington et al. 2001). The text describing this in detail has been retained from last year under “Analytical Approach”. **The consumption estimate and recommended catch levels have not been changed from last year.**

Summary of Results

The current data are not sufficient for a model-based assessment. From 2006 through 2010, preliminary stock assessments of octopus were prepared that presented both Tier 5 and Tier 6 estimates of OFL and ABC. A new alternative methodology, introduced in 2011, uses a predation-based estimate of total natural mortality and the logistic fisheries model to set the OFL equal to a highly conservative estimate of total natural mortality; the OFL and ABC from this approach are much higher than the historical incidental catch rate. This alternative Tier 6 approach was approved by the SSC in 2012 and used to set catch limits for 2012 and 2013 and is brought forward without change (consumption estimates have not been recalculated) for 2014/15. The authors and plan teams feel that the standard Tier 6 approach based on the incidental catch results in an overly conservative limit, because most of these data are from a period in which there was very little market or directed effort for octopus. The consumption methodology is based on extensive diet data and includes estimation of uncertainty in calculations.

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	2013	2014	2014	2015
Tier 6 (consumption estimate)				
OFL (t)	3,450	3,450	3,450	3,450
ABC (t)	2,590	2,590	2,590	2,590
	As determined *last* year for:		As determined *this* year for:	
Status	2012	2013	2013	2014
Overfishing	n/a	n/a	n/a	n/a

Bering Sea 2013 Survey and Catch Data

The Bering Sea Shelf survey was conducted in 2013, but not the slope survey. Biomass estimates for the octopus complex from AFSC survey data are shown in Table 1 and Figure 1. Estimated survey biomass for the shelf in 2013 was 1810 tons, slightly lower than in 2011 and 2012. Species composition from the survey was similar to previous years, with *E. dofleini* making up 91% of the estimated total biomass.

The table of incidental catch rates (Table 2) has been updated to include estimated catch for the entirety of 2012 and for 2013 through September 18. The estimated total catch for 2012 was 138 tons, much lower than the record-high catch of 528 tons that resulted in a closure of the fall Pacific cod pot fishery. The catch for 2013 through September 18 was 134 tons (total catch through October 26 was 188 tons). An estimated percentage of annual catch that was retained from 2003-2013 has been added to the catch table. The retained percentage was lower in 2011 and 2012 than in previous years due to a low TAC for octopus and better reporting of octopus discards; the percent retention rose to 21% in 2013.

Update on Current Research

Results from recent research studies on octopus reproductive biology, survey gear, and tagging have been published or are in final stages of preparation and review (Conrath et al. in press, Connners et al. 2012 and in prep, Brewer and Norcross 2012 and in prep). The octopus tagging study in the southeastern Bering Sea is complete and data analysis is underway; results are expected to be available for the 2014 stock assessment.

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. 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.

A cooperative research project is currently underway between ADF&G, AFSC, and two commercial vessel operators. The two vessels are directed fishing for octopus under an ADF&G commissioners permit, using the longlined plywood box pots tested in the initial gear study. The goal of this project is to further refine gear and fishing methods for possible use as an index survey tool. Catch and effort data from this project will provide data on variability in catch rates that would be needed to estimate the cost and scope of an index survey.

Analytic Approach, Model Evaluation, and Results

Pacific cod food habits analysis

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

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

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

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

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

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

Estimation of annual consumption of octopus by Pacific cod

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

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

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

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

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

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

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

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

Where W_∞ (asymptotic body mass) is equal to $(H/k)^{\frac{1}{1-d}}$, and t_0 is the weight of the organism at time=0. From measurements of body weight and age, equation 2 can be used to fit four parameters (W_∞, *d*, *k*, and t_0) and the relationship between W_∞ and the *H*, *k*, and *d* parameters can then be used to determine the consumption rate $H \cdot W_t^d$ for any given length class of fish.

For these calculations, weight-at-age data available and specific to the modeled regions were fit by minimizing the difference between log(observed) and log(predicted) body weights from Pacific cod survey weight-at-age data. Separate estimates were performed for the GOA and EBS using AD Model Builder; estimates included MCMC-generated confidence intervals for ration. Interannual differences in consumption were not calculated.

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

The **Total consumption of octopus (t/year)** estimated for the EBS is shown in Figure 2. There is no direct and evident relationship between total cod biomass and octopus consumption; a multivariate examination including differences in cod size composition and depth over time is planned. Estimates of annual predation mortality by Bering Sea cod on octopus range from <200 to almost 20,000 tons; the larger values have a high level of uncertainty. The majority of the annual estimates, however, lie in the range of 3,000 to 6,000 tons. We used the geometric mean of the boostrapped estimates to estimate annual predation for each year in the time series. The geometric mean is used rather than the arithmetic mean because the posterior distribution is right-skewed (higher values have higher uncertainty). We then used a geometric mean of the annual values to calculate a conservative long-term average predation rate over the 24 years of annual estimates. The geometric mean of all of the annual estimates is 3,452 tons, which is a full order of magnitude higher than the estimated rate of fishery catch of octopus. This calculation and mean value were presented in the 2011 stock assessment, and were selected by the plan team and SSC to set catch limits for the 2012 and 2013 fishery.

Projections and Harvest Alternatives

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

In 2011-12013, the Plan Team and SSC recommended using biological reference points derived from consumption estimates for Pacific cod. This estimate of natural mortality (N) can then be combined with the general logistic fisheries model that forms the basis of Tier 5 assessments (Alverson and Petreyra 1969, Francis 1974) to set OFL = N and ABC = 0.75*OFL. Because the logistic model assumes equilibrium, we propose using a mean over all of the years of available data to estimate N. Because the posterior distribution of the estimates is right-skewed (higher variability at higher values), we have used geometric means both to for m the annual estimates from the posterior distribution and to take the long-term average of the annual estimates. When this method is used, the resulting catch limits are OFL = 3,450 mt and ABC = 2,590 mt. This number is considerably higher than the rate of current or historical incidental octopus catch, and similar to the estimate based on survey biomass.

The other decision that the Plan Teams and NMFS Alaska Regional Office may want to consider is whether or not it is desirable to incorporate gear-specific discard mortality estimates into catch accounting for octopus. Based on data from the observer program special project (Table 3), 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%. A small field experiment conducted in 2013 confirmed that the octopus in excellent condition showed no delayed mortality in 24-60 hours after capture (Table 4). Longer-term delayed mortality experiments are currently underway. Whether the increased accuracy of catch accounting merits the increased complexity of introducing a separate calculation for this assemblage is a policy issue best decided through consultation between the Council, AKFIN, the AFSC, and the NMFS Alaska Regional Office.

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

Literature Cited

Alverson, D.L. and W.T. Pereyra. 1969, Demersal fish explorations in the northeastern Pacific ocean – an evaluation of exploratory fishing methods and analytical approaches to stock size and yield forecasts. J. Fish. Res. Board. Can. 26(8); 1985-2001.

Brewer, R.S. and B.L. Norcross. 2012. Long-term retention of internal elastomer tags in a wild population of North Pacific giant octopus (Enteroctopus dofleini), Fisheries Research 134-136: 17-20.

Brewer, R.S. and B.L. Norcross. In review. Seasonal changes in the sexual maturity and body condition of the North Pacific giant octopus (Enteroctopus dofleini).

Conners, M. E., C. L. Conrath, and P. Tscherich. (in prep) Use of habitat pot gear for fishing giant Pacific octopus in Alaska

Conners, M. E., C. L. Conrath, and R. Brewer. 2012. Field studies in support of stock assessment for the giant Pacific octopus *Enteroctopus dofleini*. NPRB Project 906 Final Report. North Pacific Research Board, Anchorage, AK.

Conners, M.E., Conrath, C.L. and Aydin, K. 2012. BSAI Octopus Complex. In: Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Management Council, Anchorage, AK.

Conrath, C.L. and M.E. Conners. In Press. Aspects of the reproductive biology of the giant Pacific octopus, *Enteroctopus dofleini*, in the Gulf of Alaska.

Essington, T.T., J.F. Kitchell, and C.J. Walters. 2001. The VonBertalanffy growth function, bioenergetics, and the consumption rates of fish. Can. J. Fish. Aquat. Sci. 58; 2129-2138.

Francis, R.C. 1974. Relationship of fishing mortality to natural mortality at the level of maximum sustainable yield under the logistic stock production model. J. Fish Res. Board Can. 31(9); 1539-1542.

Table 1. Biomass estimates in tons for octopus (all species) from AFSC bottom trawl surveys.

Year	EBS Shelf Survey Biomass	EBS Slope Survey Biomass	AI Survey Biomass
1982	12,442	180	
1983	3,280		440
1984	2,488		
1985	2,582	152	
1986	480		781
1987	7,834		
1988	9,846	138	
1989	4,979		
1990	11,564		
1991	7,990	61	1,148
1992	5,326		
1993	1,355		
1994	2,183		1,728
1995	2,779		
1996	1,746		
1997	211		1,219
1998	1,225		
1999	832		
2000	2,041		775
2001	5,407		
2002	2,435	979	1,384
2003	5,142		
2004	4,922	1,957	4,099
2005	9,560		
2006	1,568		3,060
2007	2,115		
2008	1,016	815	
2009	833		
2010	650	621	3,075
2011	2,844		
2012	2,087	1,421	2,779
2013	1,654		

Table 2. Estimated catch (mt) of all octopus species in state and federal waters. 1997-2002 estimated from blend data. 2003-2012 data from AK region catch accounting, as provided in September 2012. Catch is shown separately for the two target fisheries that have the highest rate of incidental octopus catch, Pacific cod and flatfish. The estimated percentage of total catch retained is shown for 2003-2013. *2013 data includes only part of the year, January –Sept 18, 2012.

	Target Species				
Year	**P cod**	**FlatF**	**Other**	**Total**	**% Retained**
1997	160	86	3	248	
1998	168	13	9	190	
1999	310	14	2	326	
2000	359	57	3	418	
2001	211	9	7	227	
2002	334	21	19	374	
2003	216	34	19	269	38%
2004	279	45	205	338	24%
2005	311	17	10	338	64%
2006	331	5	14	351	55%
2007	166	7	9	181	39%
2008	193	11	8	212	37%
2009	57	10	6	72	23%
2010	161	11	6	177	33%
2011	565	9	14	587	6%
2012	126	4	6	138	17%
2013*	129	1	3	134	21%

Table 3. 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 4. 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 hours (n)	**Condition code** Excellent	Poor	Dead	**Percent downgraded**
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. Biomass estimates of octopus (all species) from the Bering Sea shelf survey, with 95% confidence intervals shown.

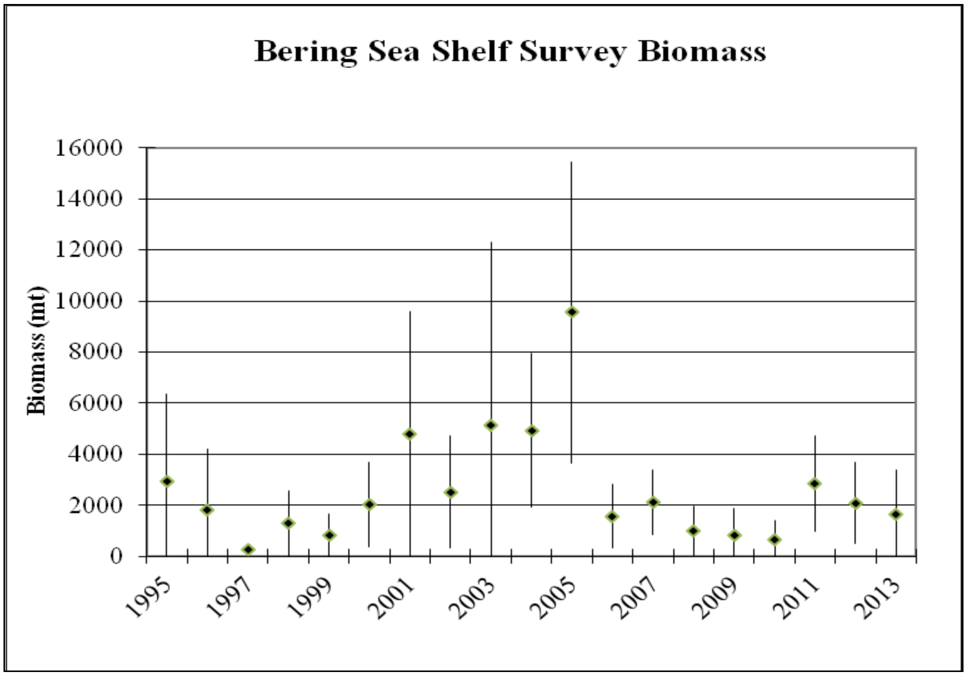

Figure 2. Estimated consumption of octopus by Bering Sea Pacific cod, 1984-2008. Error bars show 95% confidence intervals of posterior distribution; solid bars are annual hyperbolic means.