21. Assessment of the squid stock complex in the Bering Sea and Aleutian Islands

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Executive Summary

Harvest recommendations for the Bering Sea and Aleutian Islands (BSAI) squid complex are currently made based on historical catch. Until the 2015 assessment cycle, the overfishing level (OFL) was set equivalent to the average historical catch during 1978-1995. In 2014 and 2015, squid catches increased and the current specifications acted as a constraint on the directed pollock fishery, where most squid are captured. As a result the Plan Teams and the SSC requested that the assessment author revisit the analytic approach and develop a set of harvest recommendations that better reflect a sustainable level of squid removals. A number of alternative approaches were examined and the historical period using for recommendations was limited to the earliest part of the time series, 1977-1981. This assessment discusses the various alternatives that have been considered for making BSAI harvest recommendations and also includes expanded information regarding historical catches and ecological differences among the squid species in the complex.

Summary of changes in assessment inputs

1) Catch data have been updated through October 16, 2016.
2) New survey biomass estimates are included from the 2015 and 2016 eastern Bering Sea (EBS) shelf survey, the 2016 EBS slope survey, and the 2016 Aleutian Islands (AI) trawl survey.
3) The introduction contains expanded information regarding the ecology of the different species in the complex.
4) The fishery section includes a discussion of fishing effort during the early part of the catch history and the implications for basing catch limits on historical catch.
5) The analytical approach section includes a discussion of alternative approaches to harvest recommendations that have been considered for BSAI squids.

Summary of results

The recommended overfishing level (OFL) for squid in the years 2017-2018 is calculated as the average catch from 1977-1981, or 6,912 t. The recommended allowable biological catch (ABC) for squids in 2017 and 2018 is calculated as 0.75 multiplied by the average catch from 1977-1981, or 5,184 t.

	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
Quantity	*2016*	*2017*	**2017**	2018
Tier	6	6	6	6
OFL (t)	6,912	6,912	**6,912**	6,912
maxABC (t)	5,184	5,184	**5,184**	5,184
ABC (t)	5,184	5,184	**5,184**	5,184
	As determined *last* year for:		As determined *this* year for:	
Status	2013	2014	2014	2015
Overfishing	no	n/a	no	n/a

Responses to SSC and Plan Team comments on assessments in general

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

Responses to SSC and Plan Team comments specific to this assessment

From the November 2015 Plan Team minutes:
The Team recommends that average catch over the period 1977-1981 be used to calculate the OFL, with 75% of the OFL as the recommended ABC. The Team also recommends that, in the next full assessment, the author examine historical data to verify that the decline in catch beginning in 1982 represents a decline in effort rather than a decline in biomass this in the next full assessment. The Team also recommends that, in the next full assessment, the author consider whether certain environmental conditions may be correlated with squid catch and abundance in the surveys.

> *Response*: The report now includes a comprehensive exploration of how CPUE and effort varied during the early part of the historical catch timeseries (1977-1990). In addition, discussion has been added regarding how squid populations may respond to environmental change, particularly increased ocean temperature.

From the December 2015 SSC report:
The SSC supports the PT recommendation to examine the cause behind the dramatic decline in catch in the early 1980s for the 2016 assessment. The SSC supports the PT recommendation for the author to consider whether certain environmental conditions may be correlated with squid catch and abundance in the surveys.

> *Response*: Please see above response to identical recommendations from the Plan Team.

Introduction

<u>Overall description and taxonomic groups</u>
Squids are marine molluscs in the class Cephalopoda (Group Decapodiformes). They are streamlined animals with ten appendages (2 tentacles, 8 arms) extending from the head, and lateral fins extending from the rear of the mantle. Squids are active predators which swim by jet propulsion, reaching swimming speeds up to 40 km/hr, the fastest of any aquatic invertebrate. Squids also hold the record for largest size of any invertebrate (Barnes 1987).

In the Bering Sea/Aleutian Islands regions there are at least 15 species of squid (Table 1). The most abundant species is *Berryteuthis magister* (magistrate armhook squid). Members of these 15 species come from six families in two orders and can be found from 10 m to greater than 1500 m. Most species are associated with the slope and basin, with the highest species diversity along the slope region of the Bering Sea between 200 – 1500 m. Since most of the data come from groundfish survey bottom trawls, the information on abundance and distribution of those species associated with the bottom is much more accurate than that of the pelagic species.

Family Chiroteuthidae
This family is represented by a single species, *Chiroteuthis calyx*. *Chiroteuthis calyx* is a pelagic, typically deep water squid that is known to mate in the Aleutian Islands region. Larvae are common off the west coast of the US.

Family Cranchiidae
There are two species of this family found in the Bering Sea and Aleutian Islands, *Belonella borealis* (formerly *Taonius pavo*) and *Galiteuthis phyllura*. Mated *Galiteuthis phyllura* have been observed along the Bering Sea slope region and their larvae are common in plankton samples. Mature adults and larvae of *Belonella borealis* have not been identified in the region.

Family Gonatidae
This is the most speciose family in the region, represented by nine species: *Berryteuthis anonychus*, *Berryteuthis magister*, *Eogonatus tinro*, *Gonatus berryi*, *Gonatus madokai*, *Gonatus middendorffi*, *Gonatus onyx*, *Gonatopsis borealis*, and *Gonatopsis* sp. All are pelagic however, *B. magister*, *G. borealis*, and *Gonatopsis* sp. live very near the bottom as adults. Larvae of all species except the unknown *Gonatopsis* have been found in the Bering Sea. *Gonatus onyx* is known to brood its eggs to hatching, however no evidence of that behavior exists for other members of the family. *B. magister* is known to form enormous spawning aggregations in the Bering Sea, and large schools of late juvenile stages of *B. magister* have been observed elsewhere in the North Pacific Ocean.

Family Onychoteuthidae
Immature adults of two species from this family have been observed in the BSAI: *Moroteuthis robusta* and *Onychoteuthis borealijaponicus*, the latter of which is only known from the Aleutian Islands region. *Moroteuthis robusta* is the largest squid in the region, reaching mantle lengths of three feet. Mature adults, eggs, and larvae of either species have not been collected from the Bering Sea or Aleutian Islands regions.

Family Sepiolidae

This family is represented by a single species, *Rossia pacifica*. This small animal is found throughout the Bering Sea and Aleutian Islands regions to 1000 m. Eggs are deposited on substrate in the summer months and larva are benthic. Adults are believed to live 18 – 24 months and females may lay egg masses more than once in life time. Mature and mated females are common in the summer along the Bering Sea slope.

Distribution and availability to predators and fisheries

Squids in the BSAI vary widely in their size and distribution, and these differences influence the extent to which they are susceptible to predation and how they are observed by trawl surveys and fisheries. Three species have vertical distributions that make them more susceptible to surveys and fisheries using bottom trawls: *R. pacifica*, *B. magister*, and *G. borealis* (Table 2 and Figure 1). *Rossia pacifica* is strictly benthic with behavior similar to octopus (Table 2) while adult *B. magister* and *G. borealis* are generally demersal. In addition to increasing their susceptibility to trawls, their association with the bottom makes these species less vulnerable to predators limited in their ability to access great depths (e.g. seabirds, salmon, and northern fur seals *Callorhinus ursinus*). The large size of adult *B. magister* and *G. borealis* similarly limits the number of animals that rely on these species for prey, and sperm whales *Physeter microcephalus* are thought to be the main predator on adults of these species. The remaining species, particularly members of the genus *Gonatus*, are truly pelagic (Table 2 and Figure 1) and their vulnerability is the inverse of the deeper species: they are much less likely to be observed in fishery and survey bottom trawls and are more likely to be predated by surface-oriented animals and those with relatively limited diving ability. In addition, the smaller sizes of many of these species makes them vulnerable to a wider range of predators. Juvenile *B. magister* and *G. borealis* have a pelagic distribution. This combined with their small size likely explains the abundance of these individuals in predator diets.

Management Units

Squids in the BSAI are currently managed as a stock complex that includes all known squid species in the management area. Although no directed fishery exists for squids, they are caught and retained in sufficiently large numbers for them to be considered as “in the fishery”.

Life history and stock structure

The life histories of squids in this area are almost entirely unknown. Of all the species, only *Rossia pacifica* has benthic larvae and only members of the family Gonatidae and Cranchiidae are known to spawn in the Bering Sea region.

Life history information for BSAI squids can be inferred from data on squid species elsewhere. Relative to most groundfish, squids are highly productive, short-lived animals. They display rapid growth, patchy distribution and highly variable recruitment (O'Dor, 1998). Unlike most fish, squids may spend most of their life in a juvenile phase, maturing late in life, spawning once, and dying shortly thereafter. Whereas many groundfish populations (including skates and rockfish) maintain stable populations and genetic diversity over time with multiple year classes spawning repeatedly over a variety of annual environmental conditions, squids have no such “reserve” of biomass over time. Instead, it is hypothesized that squids maintain a “reserve” of biomass and genetic diversity in space. Many squid populations are composed of spatially segregated schools of similarly sized (and possibly related) individuals, which may migrate, forage, and spawn at different times of year over a wide geographic area (Lipinski 1998; O’Dor 1998). Most information on squids refers to *Illex* and *Loligo* species which support commercial fisheries in temperate and tropical waters. Of North Pacific squids, life history is best described for western Pacific stocks (Arkhipkin et al., 1995; Osako and Murata, 1983).

The most commercially important squid in the north Pacific is the magistrate armhook squid, *Berryteuthis magister*. This species is distributed from southern Japan throughout the Bering Sea, Aleutian Islands, and Gulf of Alaska to the U.S. west coast as far south as Oregon (Roper et al. 1984). The maximum size reported for *B. magister* is 28 cm mantle length. Prior to 2008, most of the information available regarding *B. magister* was from the western Bering Sea. A study completed in 2008 investigated life history and stock structure of this species in the EBS (Drobny 2008). In the EBS, *B. magister* appear to have an approximately 1-year life cycle. This is half the longevity of *B. magister* in the western Bering Sea (Arkhipkin et al., 1995). *Berryteuthis magister* in the EBS appear to grow and mature more quickly than their conspecifics in Russian and Japanese waters. Squid growth appears to be heavily influenced by ocean temperature (Forsythe 2004), which may account for some of the regional and temporal variability in mean size.

Populations of *B. magister* and other squids are complex, being made up of multiple cohorts spawned throughout the year. *B. magister* are dispersed during summer months in the western Bering Sea, but form large, dense schools over the continental slope between September and October. Three seasonal cohorts are identified in the region: summer-hatched, fall-hatched, and winter-hatched. Growth, maturation, and mortality rates vary between seasonal cohorts, with each cohort using the same areas for different portions of the life cycle. For example, the summer-spawned cohort used the continental slope as a spawning ground only during the summer, while the fall-spawned cohort used the same area at the same time primarily as a feeding ground, and only secondarily as a spawning ground (Arkhipkin et al., 1995). In the EBS, hatch dates of *B. magister* varied by year but were generally in the first half of the year (Drobny 2008). Analysis of statolith chemistry suggested that adult squids were hatched in at least three different locations, and these locations were different from the capture locations. Juvenile and adult *B. magister* also appear to be separated vertically in the water column.

Fishery

Catch records for squids exist from 1977 (Table 3 and Figure 2) and can be broken into three overlapping periods: “foreign” (1977-1987; when foreign vessels dominated the Alaska fleet), “joint venture” (1981-1989; shared fishing activities between domestic and foreign partners), and “domestic” (1987-present). Since 1990, only domestic vessels have operated in Alaskan waters. The section below discusses temporal and spatial patterns in catch and effort during two eras: foreign/joint venture (1977-1989) and domestic (1990-present). Although captured squids have not been identified to species, anecdotal evidence and current observer data strongly suggest that the vast majority of catches consisted primarily of *B. magister*.

<u>Foreign/joint-venture era, 1977-1989</u>
Foreign vessels were active in Alaskan waters beginning in the 1960s, but detailed catch records are only available starting in 1977 as a result of increased observer efforts (Megrey and Wespestad 1990). Data from the AFSC’s “Foreign Blend” database, which contains all catches prior to 1990, were analyzed to characterize squid catch patterns and changes in fishing effort. Squid catch-per-unit-effort (CPUE) was highest along the outer edge of the EBS continental shelf, particularly near the heads of the multiple canyons that penetrate the shelf break (Figure 3). As a result, catches were highest in the Bering Sea 2 region which included the present-day statistical areas 521, 523, and 524 (Figure 4). Until 1983 there were also substantial catches in the AI. Most of the squid catch occurred aboard vessels classified as small or large trawlers. Catches were substantially higher in the small trawler sector (Figures 4 & 5), as was overall effort as measured by vessel days (Figure 6).

The temporal and spatial patterns of effort varied between small and large trawlers. Squid catches in small trawlers occurred mainly in the Bering Sea 2 region, while large trawlers captured squid primarily in Bering Sea 1 (Figure 6). Small-trawler effort peaked during 1981-1983 and decreased dramatically after

1983; effort by large trawlers peaked in 1979 and declined more gradually between 1979 and 1987 (Figure 6). Small trawlers were more active in the AI but this stopped abruptly as effort declined in 1984, while large trawlers continued a limited effort in the AI through 1985.

Because historical catch is used to estimate a sustainable level of fishery removals of squid in the present day, it is important to understand the basis for the substantial decline in squid catches during 1982-1987. If this decline resulted from overfishing the population prior to the decline, catches during the years 1977-1981 could not be considered sustainable fishing levels. Two approaches were taken to examine the relationship between catch levels and effort during the years 1977-1987. If the squid population had been reduced by fishing effort, it is likely that CPUE would have declined in a similar fashion to overall catch. The foreign observer database was used to generate haul-specific CPUEs (kg/hour of trawling) for small and large trawlers, and an average annual CPUE was estimated by weighting the haul-specific CPUEs by the total catch of squids in each haul. Average CPUE declined during 1980-1983, when catches were falling (Figure 5). However average CPUE increased from 1983 to 1986 even though total squid catches continued to decline.

Analysis of CPUE data is complicated by the potential for hyperstability, where animals continue to aggregate at similar densities despite overall population declines. Therefore a second analysis was performed focusing on changes in overall effort. The onset of the decline in squid catches (1982-1983) was paralleled by a reduction in effort by large trawlers although small-trawler effort remained high during these years (Figure 6). Conversely, the decline in catch during 1984-1987 was matched by a dramatic reduction in effort by small trawlers while large-trawler effort did not drop until 1986 (Figure 6). There were also spatial shifts in effort for both vessel classes, in particularly a reduction in effort in the Bering Sea 2 region where CPUEs were highest (Figure 3).

The results of these two analyses indicate that the reduction in squid catches during 1982-1987 resulted from a decrease in fishery effort, not overfishing of squids during 1977-1981. The average CPUE dropped during 1980-1983, but rose again during 1983-1986 when catches continued to decline. Reduced catches were paralleled by diminished effort by both small and large trawlers and a shift in effort away from areas where squid CPUE was highest. The temporal pattern of average CPUE during 1977-1987 is also similar to patterns observed in recent years where catches appear to fluctuate as a result in dramatic changes in squid abundance and/or spatial distribution.

<u>Domestic era, 1990-present</u>
Currently in the BSAI, squids are generally taken in target fisheries for pollock (Table 4). Squid species can be difficult to identify, and fishery observers in the BSAI currently record almost all incidentally-caught squid as “Squid unidentified”. The predominant species of squid in commercial catches in the EBS is believed to be the *B. magister*. Squids are often retained (Table 3), and even squids that are discarded are unlikely to survive..

Catch
After reaching 9,000 t in 1978, total squid catches steadily declined to only a few hundred tons in 1987-1995 (Table 2 & Figure 1). From 2000-2008 squid catches fluctuated around an average of approximately 1,000 t, with anomalously high catches in some years (Table 3 and Figure 2). From 2009 to 2013 catches were much smaller, ranging from 360 to 598 t. In 2014, the catch was the highest since 2001, greatly exceeding the TAC which had been set at a low level based on the low catch levels of recent years. The 2015 catch was even higher (2,364 t) and for the first time exceeded the ABC. The 2016 catch (1,277 t as of October 16, 2016) is similar to catches during 200-2008.

Most of the squid catch continues to be in the walleye pollock fishery (Table 4). In 2014 and 2015, the majority of the catches occurred in July at the start of the pollock B season (Figure 7). In both years catch rates declined dramatically after the pollock fleet adopted a voluntary special closure in the Bering Canyon area. Retention rates of squid by BSAI groundfish fisheries have ranged between 36% and 67% since 2008, with much of the retained squid being processed for bait (Table 3).

Catch distribution
The majority of catches occur in the Bering Canyon region of the southeastern Bering Sea (areas 517 & 519; Table 5 and Figures 8 & 9). Catches in the Aleutian Islands appear to have increased slightly since 2008. In the EBS, the distribution of squid catch appears to have remained fairly constant over time. While squids were caught throughout the EBS slope, the outer domain of the EBS shelf, and the Aleutian Islands, the highest catches consistently occurred near the major canyons (Figure 9).

A survey conducted in 2009 in the Bering Canyon region suggested that the density of *B. magister* increases considerably below 200 m (Horne and Parker-Stetter 2010). Incidental catches of squids may thus increase when fishing activity occurs at greater depths. These results suggest a possible mechanism for voluntary avoidance of squid bycatch by the pollock fishery.

Catch size composition
In 2007, fishery observers began collecting data on the mantle length of squids captured in BSAI pollock fisheries. Examination of past length compositions on a seasonal basis revealed two length modes that might indicate the presence of seasonal cohorts (e.g. Ormseth 2012). Aggregate length compositions from July of each year (the month of peak catch; Figure 10) suggest that the representation of the two modes in the annual catch (whether as a result of differences in species or age) varies among years, and that the primary mode occurs consistently at ~21 cm. In the western Bering Sea the size at 50% maturity is 25 cm (Arkhipin et al. 1996), so it is likely that the fishery is capturing mature squids that may soon be spawning.

Data

Fishery data

Current fishery data are maintained in the Catch Accounting System operated by the NMFS Alaska Regional Office. Catch data are presented in this assessment as complete time series from 1977-present (Table 3 and Figure 2) and are also partitioned by target fishery (Table 4) and statistical area (Table 5 and Figure 8).

Survey data

Distribution and abundance
The AFSC bottom trawl surveys are directed at groundfish species, and therefore do not employ the appropriate gear or sample in the appropriate places to provide reliable biomass estimates for the pelagic squids. Squid records from these surveys tend to appear at the edges of the continental shelf in the eastern Bering Sea and in the Aleutian Islands (Figure 11). This is consistent with results from 1988 and 1989 Japanese / U.S. pelagic trawl research surveys in the EBS that indicated that the majority of squid biomass is distributed in pelagic waters off the continental shelf (Sinclair et al. 1999), beyond the current scope of the AFSC surveys. It is also consistent with the observation that the largest biomass of squids is found at depths below 200 m (Horne and Parker-Stetter 2010). Catches of squids in the EBS shelf survey are highly variable and uncertain, and it is likely that few squid inhabit the bottom waters of the shelf (Table 6). The EBS slope survey, which samples the shelf break area and much deeper waters, generally catches greater numbers of squids. *B. magister, G. borealis*, and *R. pacifica* are the most common squids in the slope survey (Table 6). In the AI, *B. magister* is the only squid species captured in abundance (Table 6).

Survey size composition
The EBS slope and AI trawl surveys appear to capture slightly larger squid than does the fishery, and multiple length modes are more apparent. In the EBS slope survey, the dominant length mode for B. magister is at approximately 22 cm, slightly larger than in the fishery (Figure 12). There is also a second length mode at approximately 8 cm that was conspicuous in 2010 and 2012. This likely represents juveniles of a separate seasonal cohort. The dominant size mode in the AI trawl survey is similar to the EBS slope, but the smaller length mode is barely evident (Figure 13). The extent to which gear selectivity affects differences in size compositions among the fishery and the two surveys is unknown.

Analytic Approach

Harvest recommendations for the BSAI squid complex are currently made based on historical catch. Until the 2015 assessment cycle, the overfishing level (OFL) was set equivalent to the average historical catch during 1978-1995. In 2014 and 2015, squid catches increased and the current specifications acted as a constraint on the directed pollock fishery, where most squid are captured. In both years, a voluntary spatial closure in the Bering Canyon area where squid bycatch was particularly high was adopted by the pollock fleet. This limited fishing access to the fleet and may have interfered with the fleet's ability to avoid chinook and chum salmon (K. Hafflinger, Sea State, pers. comm., August 2015). As a result the Plan Teams and the SSC requested that the assessment author revisit the analytic approach and develop a set of harvest recommendations that better reflect a sustainable level of squid removals. A number of alternative approaches were examined, and the author, Plan Team, and SSC were in agreement that setting OFL as the average catch during the earliest part of the catch history (1977-1981) was the best alternative among a range of imperfect solutions. The advantages of using this earlier time period are (1) the fishery is consistent during this period (i.e. all fishing was by foreign fleets) and (2) catches during this era are more likely to reflect sustainable catches, either because there was targeting of squid or there was greater overlap between the fisheries and squid.

Overview of alternative approaches to harvest recommendations
Discussions during Plan Team and SSC meetings have often focused on the potential for alternative approaches to making harvest recommendations. To facilitate these discussions, a brief summary of the alternatives that have been explored is given below.

Historical catch: Numerous methods for using historical catch, including the use of different time periods and maximum vs. average catch, have been explored in previous assessments. The 2014 and 2015 assessments contain extensive detain regarding these alternatives.

Biomass-based approaches: Previous assessments have explored a wide range of alternatives based on the Tier 5 methodology where OFL is equal to M * biomass. These alternatives are problematic because biomass estimates for squids in the BSAI are highly uncertain, and because short-lived squids have extremely high mortality rates. In addition, squid life cycles are substantially different than most groundfish species for which the Tier 5 approach was developed. The 2015 assessment in particular explored many biomass-based approaches; all were considered to have flaws that barred their use in making harvest recommendations.

Consumption-based specifications: For several years the SSC and others have suggested exploring the possibility that consumption rates of squid by predators could be used a proxy for a sustainable fishing level as is done for BSAI octopus. This is problematic for two reasons. Diet data for predators consuming squid are highly uncertain. More importantly, there is a major difference between those species and life stages that are regularly consumed and those that are observed in surveys and captured in fisheries (see Introduction section). Adult B. magister are the main constituent of fishery catches, but it is juveniles of this species that are targets of numerous predators. Squid are terminal spawners and the mortality rate of juveniles consumed by predators is unlikely to be related to the mortality rate of the pre-spawning adults captured by fisheries.

Biomass estimates for acoustic surveys: The EBS acoustic survey samples areas that contain squid aggregations and thus serves as a potential source of information regarding squid abundance. A 2009 project in the Bering Canyon area confirmed that acoustic surveys can detect squids (Horne and Parker-Stetter 2010). However squids were often observed in association with other fish species and the species composition of echosign containing squid was difficult to establish. Therefore it is likely that the survey would need to be substantially redesigned to permit adequate ground-truthing of squid echosign. Additional survey time and increased expense would be required. Because squid are not targeted and do not appear to constitute a conservation concern, the author suggests this would not be an appropriate allocation of limited survey resources.

Results

The average catch during 1977-1981was 6,912 t. The alternatives discussed above produced OFLs ranging from 1,766 t to 8,971 t (Table 6). The average OFL among the alternatives was 5,504 t. These results suggest that using average catch 1977-1981 is a reasonable approach and the author recommends that this be used for developing harvest recommendations.

Harvest recommendations

The harvest recommendations are based on the average catch during 1977-1981, with OFL = average catch and ABC = 0.75x average catch:

2016-2017 Tier 6 harvest recommendations for BSAI squids

average catch 1977-1981	6,912 t
OFL (avg. catch)	6,912 t
ABC (0.75 * avg. catch)	5,184 t

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Literature Cited

Agnew, D.J., C.P. Nolan, and S. Des Clers. 1998. On the problem of identifying and assessing populations of Falkland Islands squid *Loligo gahi*. In Cephalopod biodiversity, ecology, and evolution (A.I.L. Payne, M.R. Lipinski, M.R. Clark and M.A.C. Roeleveld, eds.), p.59-66. S. Afr. J. mar. Sci. 20.

Arkhipkin, A.I., V.A. Bizikov, V.V. Krylov, and K.N. Nesis. 1996. Distribution, stock structure, and growth of the squid Berryteuthis magister (Berry, 1913) (Cephalopoda, Gonatidae) during summer and fall in the western Bering Sea. Fish. Bull. 94: 1-30.

Aydin, K., S. Gaichas, I. Ortiz, D. Kinzey, and N. Friday. 2007. A comparison of the Bering Sea, Gulf of Alaska, and Aleutian Islands large marine ecosystems through food web modeling. NOAA Tech. Memo. NMFS-AFSC-178

Barnes, R.D. 1987. Invertebrate Zoology, Third edition. Saunders College Publishing, Fort Worth, TX: 893 pp.

Brodziak, J. 1998. Revised biology and management of long-finned squid (*Loligo pealei*) in the northwest Atlantic. CalCOFI Reports 39: 61-70

Caddy, 1983. The cephalopods: factors relevant to their population dynamics and to the assessment and management of stocks. In Advances in assessment of world cephalopod resources (J.F. Caddy, ed.), p. 416-452. FAO Fish. Tech. Pap. 231.

Drobny, P. 2008. Life history characteristics of the gonatid squid Berryteuthis magister in the eastern Bering Sea. M.S. Thesis, University of Alaska Fairbanks.

Forsythe, J.W. 2004. Accounting for the effect of temperature on squid growth in nature: from hypothesis to practice. Mar Fresh Res 55: 331-339

Horne J and S Parker-Stetter (2010) Evaluating acoustics for squid assessment in the Bering Sea. NPRB Project 717 Final Report.

Hunt, G.L., H. Kato, and S.M. McKinnell. 2000. Predation by marine birds and mammals in the subarctic North Pacific Ocean. PICES Scientific Report No. 14, North Pacific Marine Science Organization, Sidney, British Columbia, Canada. 164 p.

Lipinski, M.R. 1998. Cephalopod life cycles: patterns and exceptions. In Cephalopod biodiversity, ecology, and evolution (A.I.L. Payne, M.R. Lipinski, M.R. Clark and M.A.C. Roeleveld, eds.), p.439-447. S. Afr. J. mar. Sci. 20.

Lipinski, M.R., D.S. Butterworth, C.J. Augustyn, J.K.T. Brodziak, G. Christy, S. Des Clers, G.D. Jackson, R.K. O'Dor, D. Pauly, L.V. Purchase, M.J. Roberts, B.A. Roel, Y. Sakurai, and W.H.H. Sauer. 1998. Cephalopod fisheries: a future global upside to past overexploitation of living marine resources? Results of an international workshop, 31 August-2 September 1997, Cape Town, South Africa. In Cephalopod biodiversity, ecology, and evolution (A.I.L. Payne, M.R. Lipinski, M.R. Clark and M.A.C. Roeleveld, eds.), p. 463-469. S. Afr. J. mar. Sci. 20.

Macfarlane, S.A., and M. Yamamoto. 1974. The squid of British Columbia as a potential resource–A preliminary report. Fisheries Research Board of Canada Technical Report No. 447, 36 pp.

Megrey, B.A. and V.G. Wespestad. 1990. Alaskan groundfish resources: 10 years of management under the Magnuson Fishery Conservation and Management Act. N. Am. J. Fish. Man. 10(2): 125-143

O'Dor, R.K. 1998. Can understanding squid life-history strategies and recruitment improve management? In Cephalopod biodiversity, ecology, and evolution (A.I.L. Payne, M.R. Lipinski, M.R. Clark and M.A.C. Roeleveld, eds.), p.193-206. S. Afr. J. mar. Sci. 20.

Osako, M., and M. Murata. 1983. Stock assessment of cephalopod resources in the Northwestern Pacific. In Advances in assessment of world cephalopod resources (J.F. Caddy, ed.), p. 55-144. FAO Fish. Tech. Pap. 231.

Roper, C.F.E., M.J. Sweeney, and C.E. Nauen. 1984. FAO Species Catalogue Vol. 3, Cephalopods of the world. FAO Fisheries Synopsis No. 125, Vol 3.

Sinclair, E.H., A.A. Balanov, T. Kubodera, V.I. Radchenko and Y.A. Fedorets, 1999. Distribution and ecology of mesopelagic fishes and cephalopods. Pages 485-508 in Dynamics of the Bering Sea (T.R. Loughlin and K Ohtani, eds.), Alaska Sea Grant College Program AK-SG-99-03, University of Alaska Fairbanks, 838 pp.

Tables

Table 1. Taxonomic grouping of squid species found in the BSAI.

Class Cephalopoda; Order Oegopsida	
Family Chiroteuthidae	
Chiroteuthis calyx	
Family Cranchiidae	"glass squids"
Belonella borealis	
Galiteuthis phyllura	
Family Gonatidae	"armhook squids"
Berryteuthis anonychus	minimal armhook squid
Berryteuthis magister	magistrate armhook squid
Eogonatus tinro	
Gonatopsis borealis	boreopacific armhook squid
Gonatus berryi	Berry armhook squid
Gonatus madokai	
Gonatus middendorffi	
Gonatus onyx	clawed armhook squid
Family Onychoteuthidae	"hooked squids"
Moroteuthis robusta	robust clubhook squid
Onychoteuthis borealijaponicus	boreal clubhook squid
Class Cephalopoda; Order Sepioidea	
Rossia pacifica	North Pacific bobtail squid

Table 2. Maximum size, habitat, and 2016 EBS slope survey biomass estimates for squid taxonomic groups in the BSAI.

taxonomic group	**maximum size (cm)**	**habitat**	**2016 EBS slope survey biomass estimate (t)**
squid unID			2.1
Rossia pacifica	10	benthic	29.4
Gonatidae unID			31.8
Gonatus sp			7.8
Gonatus onyx	13.5	pelagic, > 500 m	1.8
Gonatus berryi	19	pelagic, > 500 m	0.9
Gonatus pyros	12.5	pelagic, > 500 m	0.3
Gonatus madokai	39	pelagic, > 500 m	
Eogonatus tinro	12	pelagic, > 500 m	0.3
Gonatus middendorffi	35	pelagic, > 500 m	
Berryteuthis magister	34	demersal, 50-750 m	1,127
Gonatopsis sp			0.9
Gonatopsis borealis	20	demersal, 100-1000 m	6.8
Moroteuthis robusta	200	pelagic, > 500 m	
Galiteuthis phyllura	76	meso-, bathypelagic	0.4
Chiroteuthis calyx	24	epi- to bathypelagic	1.3
Cranchiidae		meso-, bathypelagic	
Belonella borealis		meso-, bathypelagic	

Table 3. Estimated total (retained and discarded) catches of squid (t) in the eastern Bering Sea and Aleutian Islands by groundfish fisheries, 1977-2016, and estimated retention rates. JV=Joint ventures between domestic catcher boats and foreign processors.

	Eastern Bering Sea				Aleutian Islands				BSAI	% retained
	foreign	JV	domestic	total EBS	foreign	JV	domestic	total AI	total	
1977	4,926			4,926	1,808			1,808	6,734	
1978	6,886			6,886	2,085			2,085	8,971	
1979	4,286			4,286	2,252			2,252	6,538	
1980	4,040			4,040	2,332			2,332	6,372	
1981	4,178	4		4,182	1,763			1,763	5,945	
1982	3,833	5		3,838	1,201			1,201	5,039	
1983	3,461	9		3,470	509	1		510	3,980	
1984	2,797	27		2,824	336	7		343	3,167	
1985	1,583	28		1,611	5	4		9	1,620	
1986	829	19		848	1	19		20	868	
1987	96	12	1	109		23	1	24	131	
1988		168	246	414		3		3	417	
1989		106	194	300		1	5	6	306	
1990			532	532			94	94	626	
1991			544	544			88	88	632	
1992			819	819			61	61	880	
1993			611	611			72	72	683	
1994			517	517			87	87	604	
1995			364	364			95	95	459	
1996			1,083	1,083			84	84	1,167	
1997			1,403	1,403			71	71	1,474	
1998			891	891			25	25	915	
1999			432	432			9	9	441	
2000			375	375			8	8	384	
2001			1,761	1,761			5	5	1,766	
2002			1,334	1,334			10	10	1,344	
2003			1,246	1,246			36	36	1,282	
2004			1,000	1,000			14	14	1,014	
2005			1,170	1,170			17	17	1,186	
2006			1,403	1,403			15	15	1,418	
2007			1,175	1,175			13	13	1,188	
2008			1,494	1,494			49	49	1,542	67%
2009			269	269			91	91	360	51%
2010			305	305			105	105	410	63%
2011			237	237			99	99	336	43%
2012			560	560			128	128	688	66%
2013			158	158			141	141	300	37%
2014			1,568	1,568			110	110	1,678	40%
2015			2,281	2,281			83	83	2,364	55%
*2016**			*1,229*	*1,229*			*49*	*49*	*1,277*	*36%*

* 2016 catch and retention data are incomplete; retrieved October 16, 2016.

Data Sources: Foreign and JV catches-U.S. Foreign Fisheries Observer Program, AFSC Domestic catches before 1989 (retained only; do not include discards): Pacific Fishery Information Network (PacFIN). Domestic catches 1989-2002: NMFS Alaska Regional Office BLEND. Domestic catches 2003-present: NMFS AKRO Catch Accounting System.

Table 4. Estimated catch (t) of all squid species combined by target fishery, 2003-2016. Data sources as in Table 2.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	*2016**
pollock	1,226	977	1,150	1,399	1,169	1,452	209	277	178	495	118	1,478	2,206	*1,160*
ATF	7	6	10	4	3	46	96	104	67	60	68	69	24	*29*
rockfish	12	6	7	6	8	25	18	12	37	33	60	56	66	*24*
Kamchatka	-	-	-	-	-	-	-	-	48	76	36	42	52	*22*
FHS	0.15	3.94	1.13	0.17	0.16	0.47	0.03	0.17	0.11	0.29	0.86	0.20	1.26	*17*
Atka	21	7	9	9	5	12	14	16	5	23	15	31	13	*15*
Other flatfish	2.89	1.76	6.05	0	2.09	0.85	0.45	0.09	0	0.18	1.16	0.43	1.09	*5.12*
Greenland turbot	3.46	6.05	0.42	0	0	4.18	22.66	0.88	0.00	0	0.06	0.60	0.00	*3.06*
Pacific cod	8.59	5.52	2.50	0.98	0.79	0.20	0.12	0.26	0.08	0.21	0.07	0.67	0.64	*1.66*
sablefish	0.01	0.11	0.12	0.02	0.10	0.96	0.11	0.00	0.00	0	0.07	0.23	0	*0.57*
YFS	1.40	0	0.01	0	0.01	0.28	0.01	0.06	0.24	0.05	0.43	0.07	0.25	*0.10*
Rock sole	0.02	0.26	0.03	0	0.37	0.04	0	0	0.13	0.02	0.16	0.00	0.04	*0.03*
total	**1,282**	**1,014**	**1,186**	**1,418**	**1,188**	**1,542**	**360**	**410**	**336**	**688**	**299**	**1,678**	**2,364**	***1,277***

* 2016 catch estimate as of October 16, 2016.

Table 5. Estimated catch (t) of all squid species combined by area, 2003-2016. Data sources as in Table 2.

		2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	***2016****
EBS	508	0	0.01	0	0	0	0	0	0	0	0	0	0	0	*0*
	509	2	7	5	162	13	25	1	5	3	16	5	19	9	*3*
	512	0	0	0	0	0	0	0	0	0	0	0	0	0.01	*0*
	513	2	2	0.25	1	12	9	2	0.11	1	2	1	0.13	1	*1*
	514	0	0	0.01	0.03	0	0	0	0	0.01	0	0	0.03	0	*0.08*
	516	0.04	0	0	0	0	0	0.01	0	0	0	0	0.04	0.02	*0*
	517	746	587	539	965	690	1,066	143	133	119	308	63	938	1,495	*887*
	518	0.04	0	0	0.00	0	23	40	17	30	17	2	43	42	*25*
	519	484	398	527	261	419	344	74	145	52	187	41	548	579	*179*
	521	12	5	95	15	26	25	9	5	17	20	33	12	59	*48*
	523	0.28	0.06	3	0.02	0	1	0	1	3	0.35	1	3	94	*83*
	524	0.01	0	0.30	0.02	15	0.49	0.34	0.05	12	9	11	5	2	*3*
AI	541	9	4	3	2	2	25	66	90	75	114	107	76	32	*24*
	542	10	7	2	6	3	6	5	4	8	6	5	13	12	*9*
	543	17	3	12	7	8	18	20	11	16	8	30	21	40	*16*
EBS total		**1,246**	**1,000**	**1,170**	**1,403**	**1,175**	**1,494**	**269**	**305**	**237**	**560**	**158**	**1,568**	**2,281**	***1,229***
AI total		**36**	**14**	**17**	**15**	**13**	**49**	**91**	**105**	**99**	**128**	**141**	**110**	**83**	***49***
BSAI total		**1,282**	**1,014**	**1,186**	**1,418**	**1,188**	**1,542**	**360**	**410**	**336**	**688**	**299**	**1,678**	**2,364**	***1,277***

* 2016 catch estimate as of October 16, 2016.

Table 6. Survey biomass estimates (“bio”, in metric tons) and coefficients of variation (CV) for the EBS shelf, EBS slope, and AI. Estimates are included for the principal species caught in each survey. Numerous species occur on the slope and are included in the “total squids” category for that region.

	EBS shelf				**EBS slope**								**AI**	
	R. pacifica		*B. magister*		*R. pacifica*		*B. magister*		*G. borealis*		misc. squids		*B magister*	
	bio	CV	bio	CV	bio	CV	bio	CV	bio	CV	bio	CV	bio	CV
1983	100	0.32	0	-									9,557	0.33
1984	61	0.30	14	0.94										
1985	4	0.75	13	1.00										
1986	34	0.35	0	-									15,761	0.51
1987	46	0.41	80	1.00										
1988	97	0.63	0	-										
1989	3	1.00	0	-										
1990	5,680	0.99	0	-										
1991	0	-	0	-									28,934	0.89
1992	0	-	0	-										
1993	0	-	0	-										
1994	0	-	0	-									11,084	0.84
1995	6	0.70	0	-										
1996	23	0.42	0	-										
1997	3	1.00	0	-									2,689	0.24
1998	60	0.46	0	-										
1999	19	0.48	0	-										
2000	13	0.45	42	0.82									2,758	0.18
2001	20	0.51	280	0.42										
2002	33	0.39	0	-	52	0.18	1,197	0.12	2	0.74	18	0.27	2,088	0.14
2003	27	0.37	16	1.00										
2004	6	0.82	0	-	58	0.19	1,418	0.14	52	0.37	114	0.78	3,250	0.37
2005	13	0.67	0	-										
2006	9	0.74	47	1.00									1,467	0.14
2007	11	0.71	0	-										
2008	8	0.52	0	-	35	0.33	1,675	0.10	52	0.41	22	0.26		
2009	19	0.41	623	1.00										
2010	42	0.60	9	1.00	67	0.25	1,831	0.10	8	0.32	17	0.36	2,444	0.22
2011	25	0.51	1	1.00										
2012	25	0.43	43	1.00	42	0.23	1,284	0.09	13	0.40	7	0.33	4,011	0.28
2013	146	0.84	28	1.00										
2014	21	0.49	0	-									6,178	0.30
2015	91	0.40	61	0.66										
2016	41	0.52	7	1.00	29	0.30	1,127	0.20	7	0.30	48	0.14	3,808	0.38

Figures

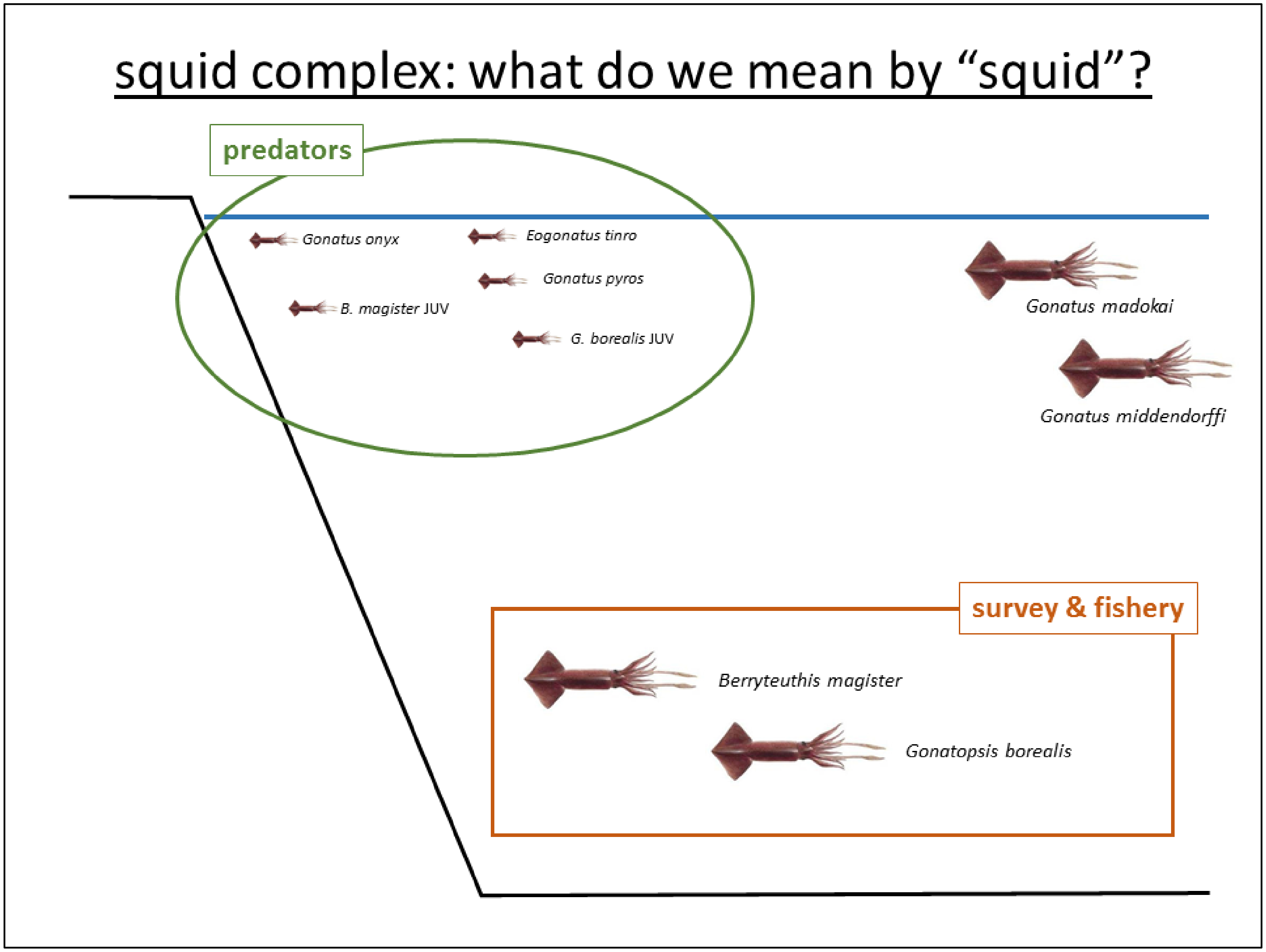

Figure 1. Schematic of vertical distribution of squid species in the BSAI and availability to predators, surveys, and fisheries.

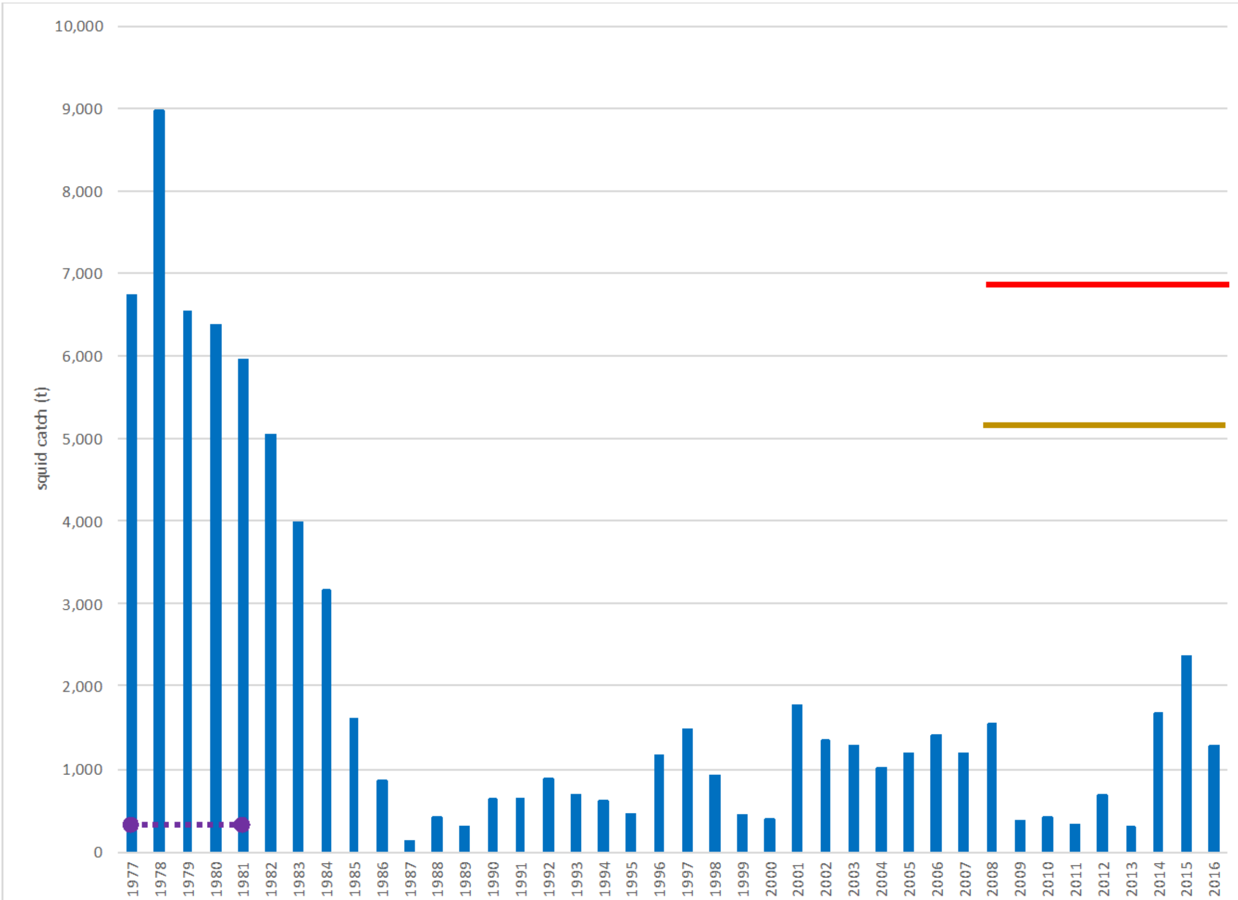

Figure 2. Historical catches of squids in the Bering Sea and Aleutian Islands, 1977-2016 (**2016 data as of October 16, 2016**). Red and brown horizontal lines indicate current OFL and ABC, respectively. Dashed purple line indicates period currently used for developing harvest recommendations.

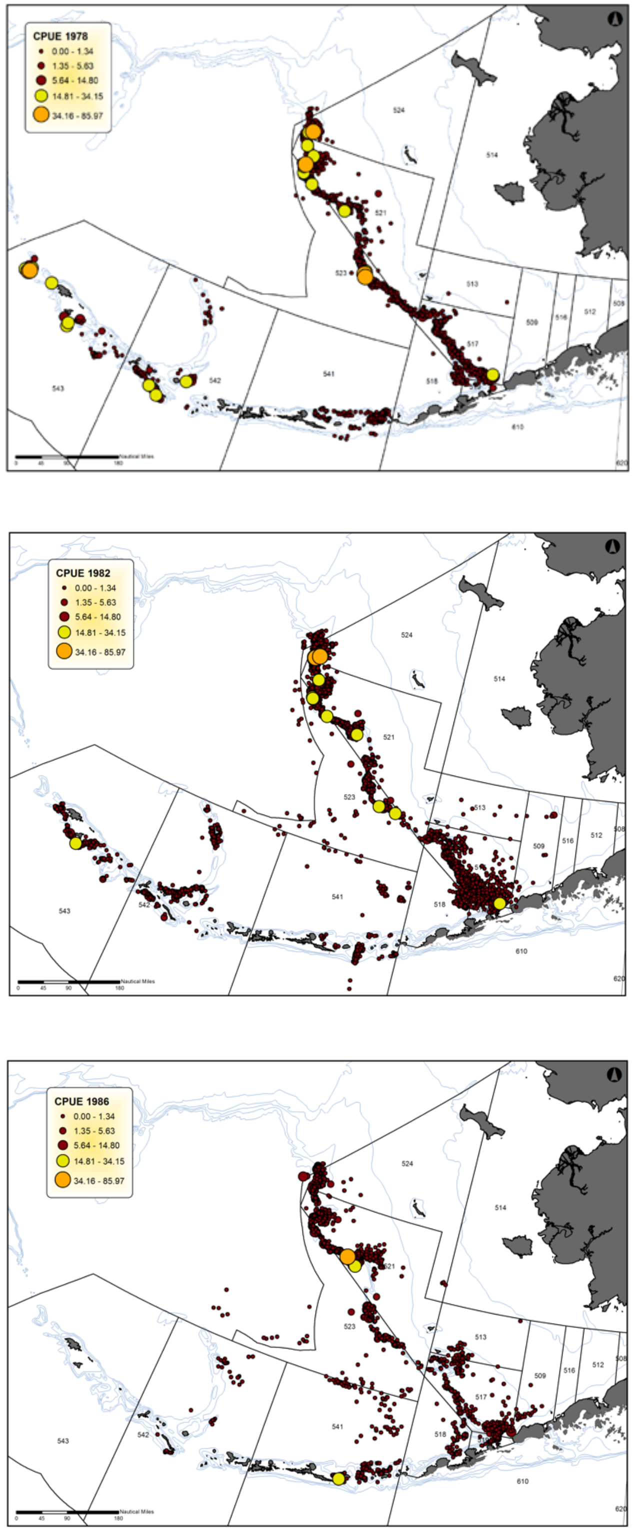

Figure 3. Distribution of squid catch-per-unit-effort (CPUE; kg/hour of trawling) in the BSAI in 1978, 1982, and 1986.

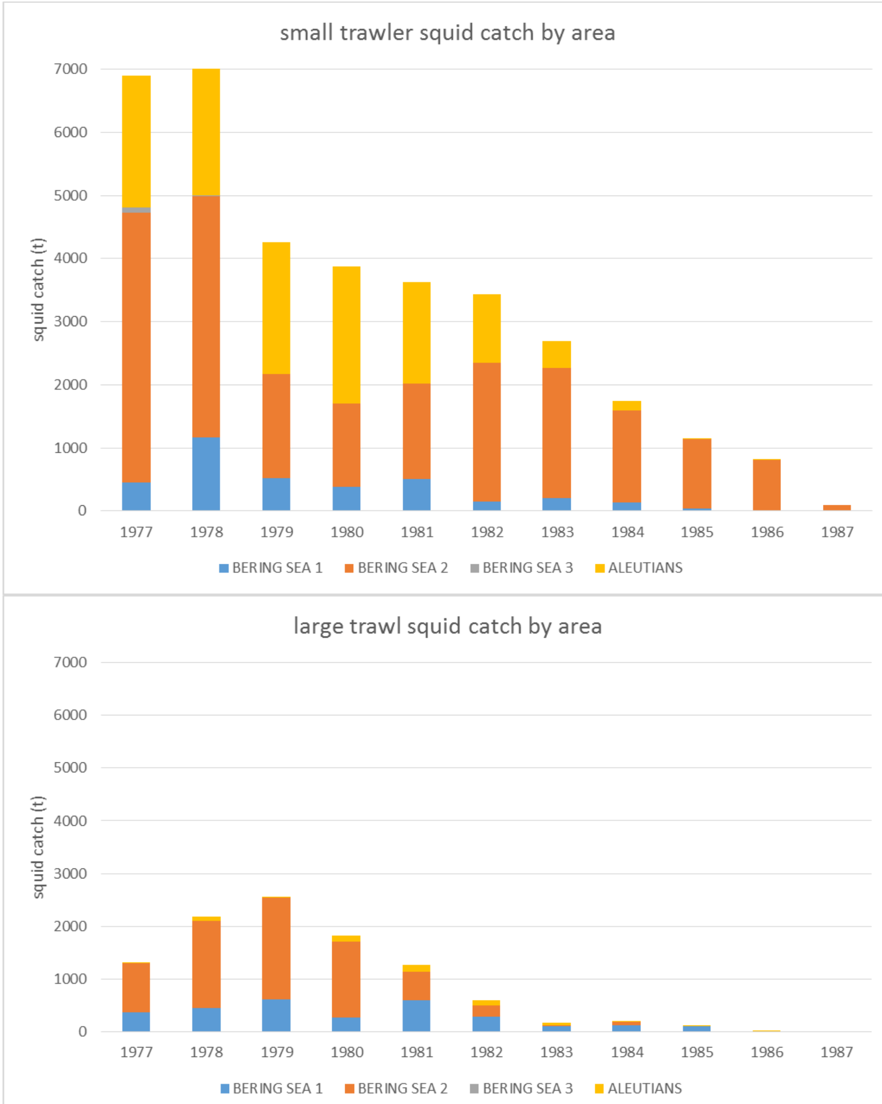

Figure 4. Squid catches in the BSAI during 1977-1987 by area for vessels classified as small trawlers (top panel) and large trawlers (bottom panel).

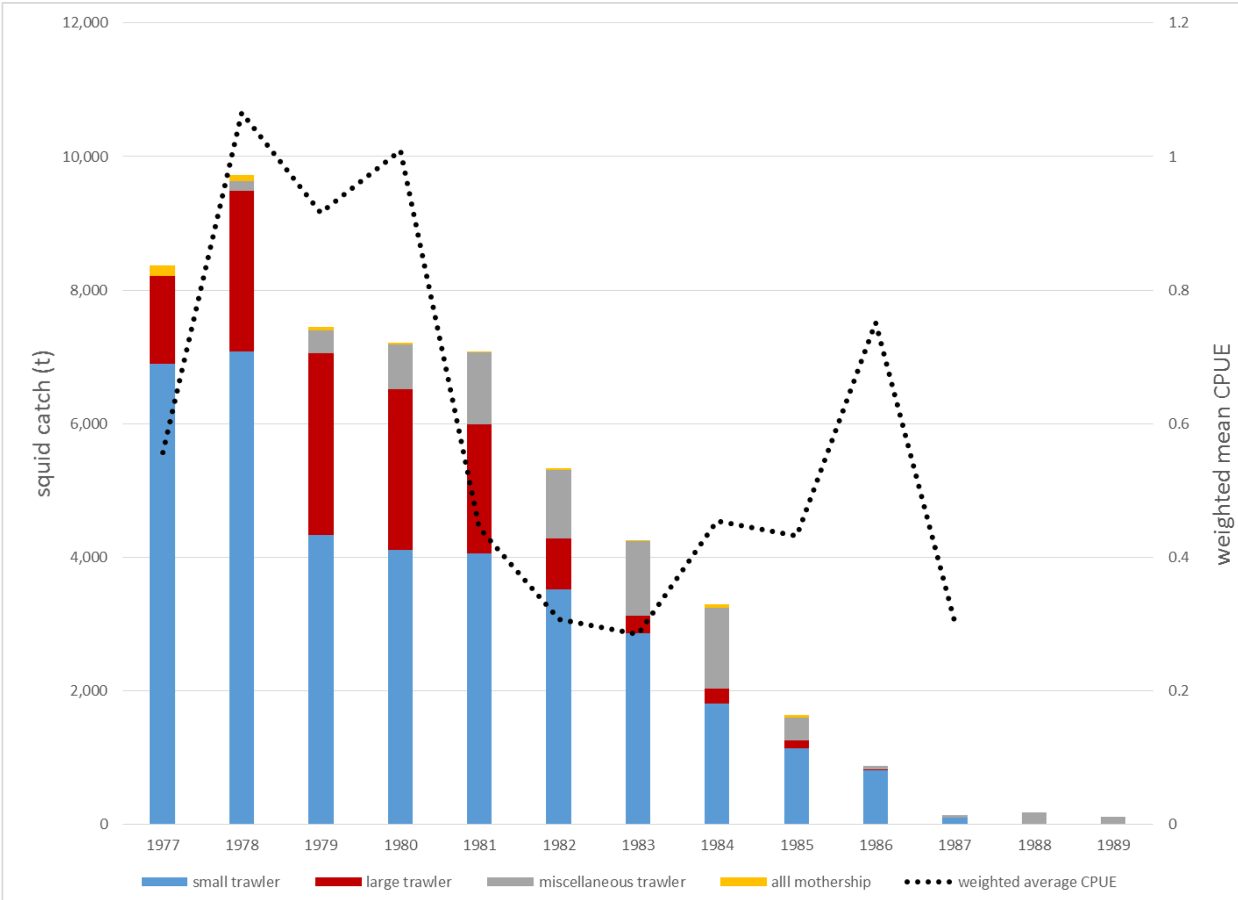

Figure 5. Catches of squid by vessel type and catch-weighted catch per unit effort (CPUE) in the Bering Sea and Aleutian Islands, 1977-1989.

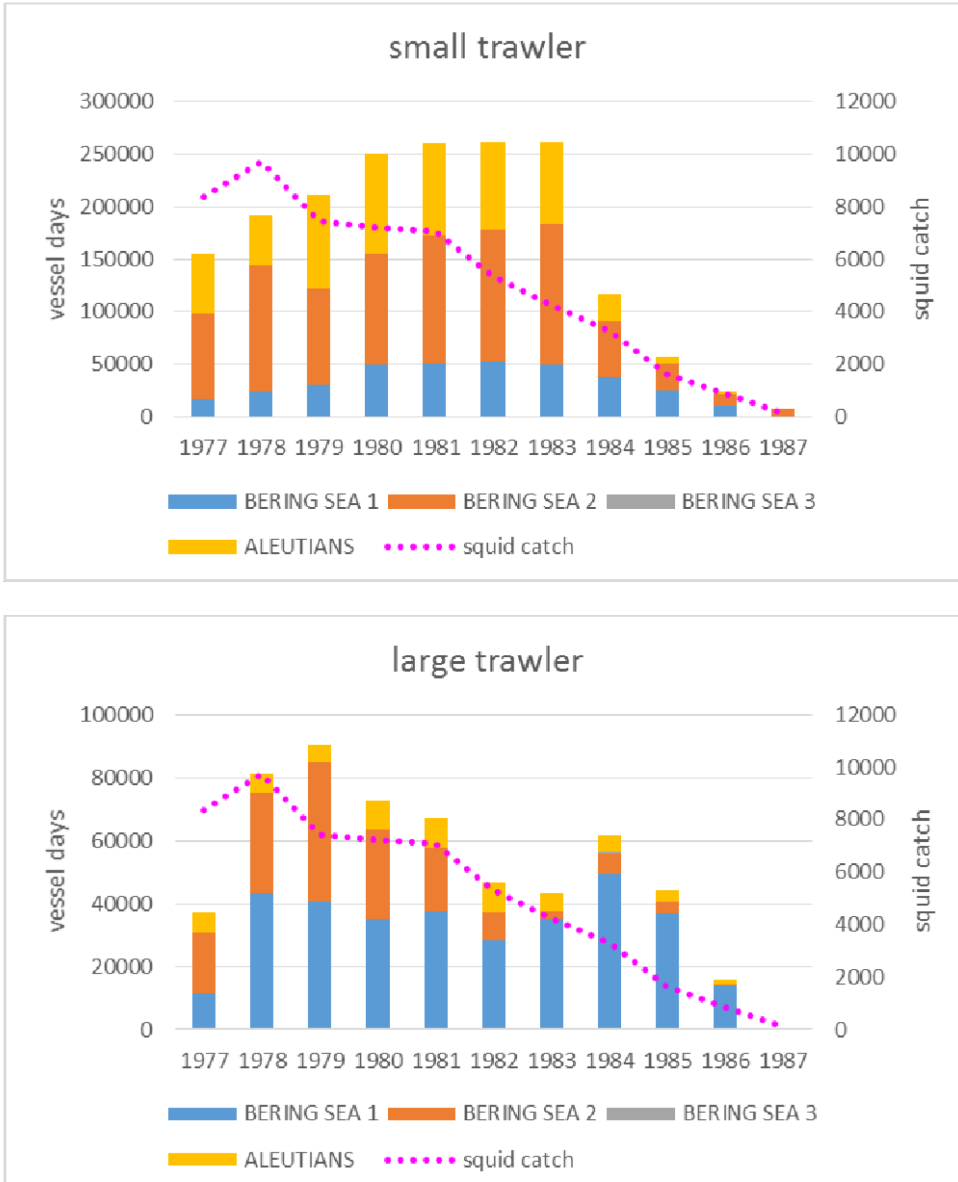

Figure 6. Total effort (vessel days) by region and total squid catch (t) during 1977-1987.

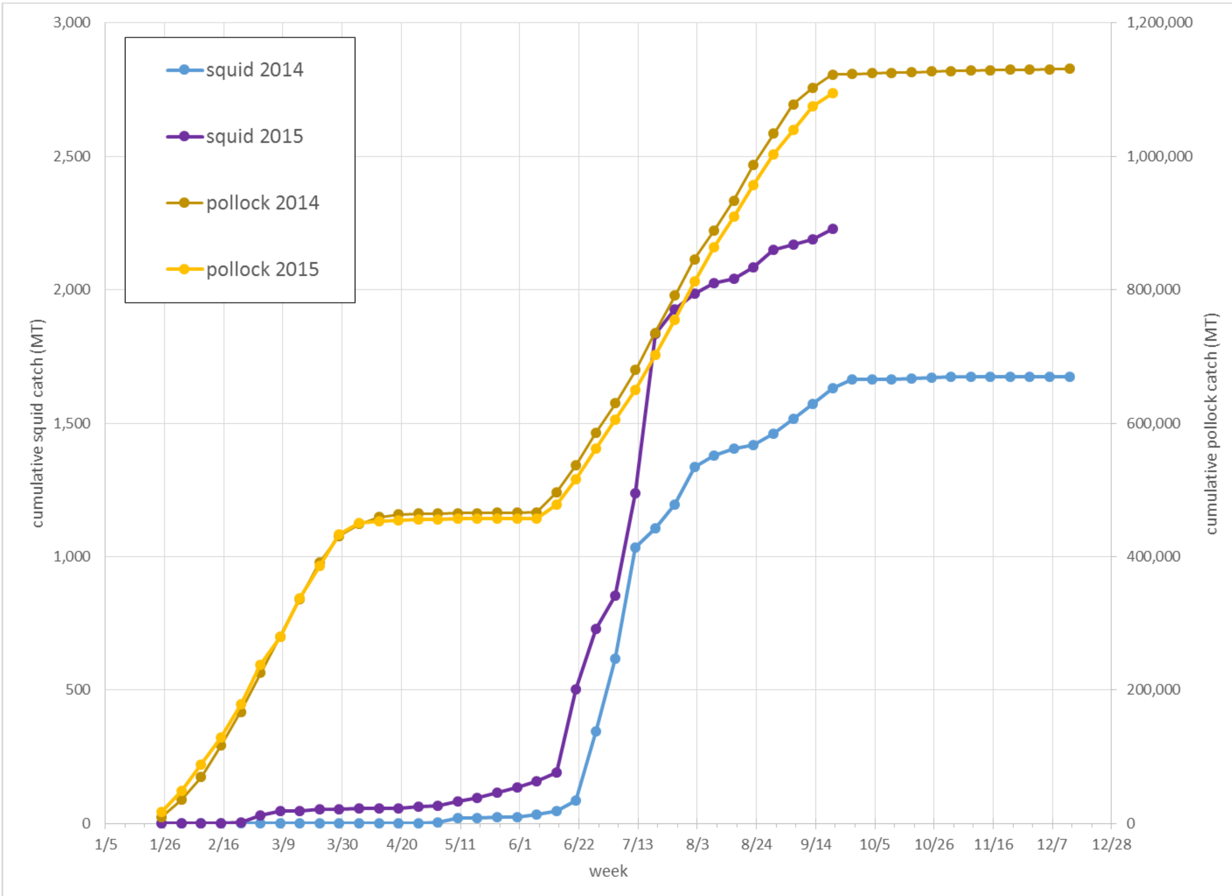

Figure 7. Cumulative catch of squids and pollock in the BSAI by week, 2014 & 2015.

Figure 8. Estimated total fishery catch (t) of all squid species in NMFS management areas of the BSAI region, 2003-2016 (**2016 data as of October 16, 2016**). Numbers in legend refer to management area. Blue and green colors indicate EBS areas; red indicates AI areas.

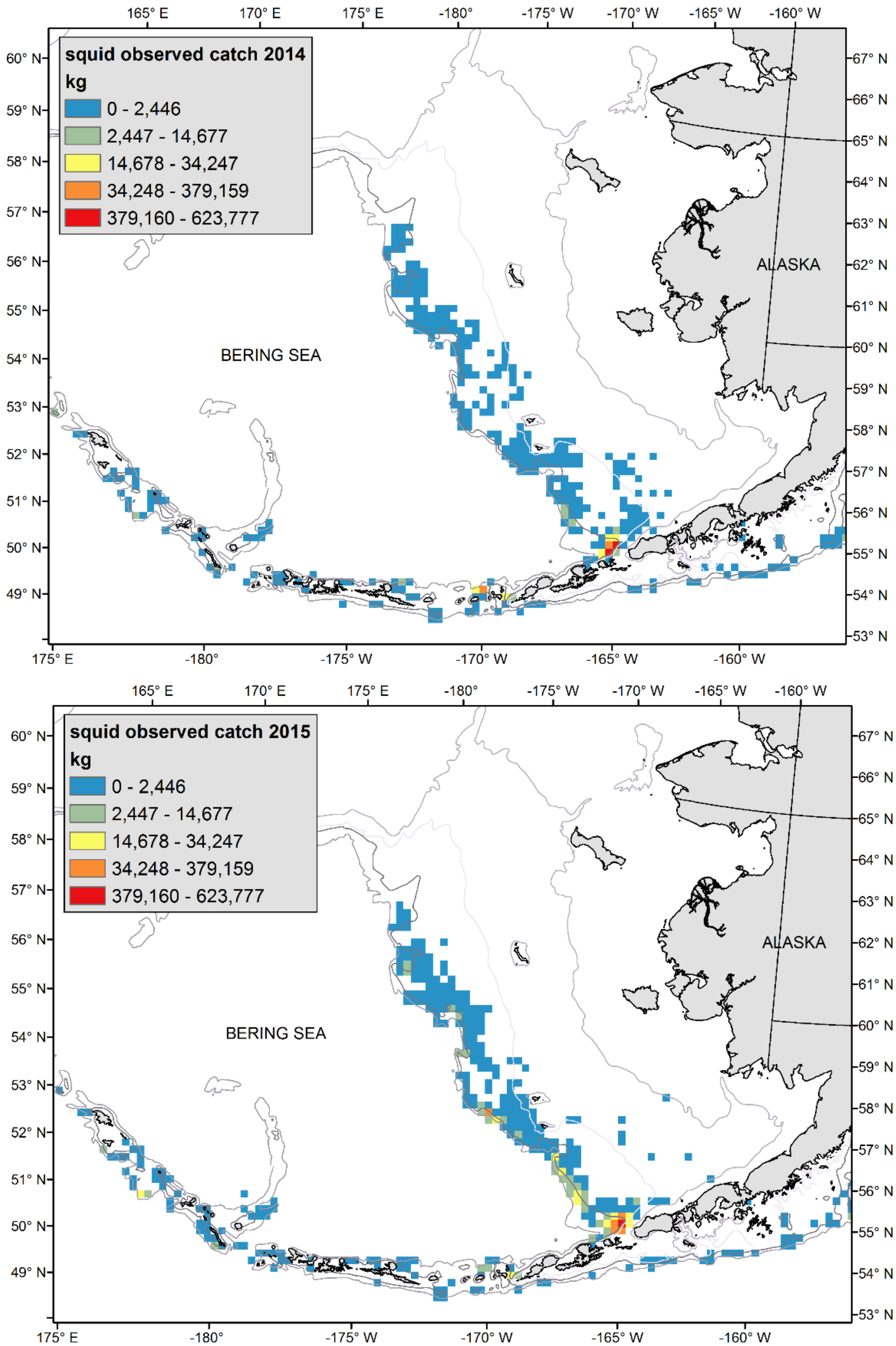

Figure 9. Distribution of observed annual squid catches during 2014 (top) and 2015 (bottom). Each 400 km^2 grid cell depicts the total observed catch in kg. Data are from the AFSC Fisheries Monitoring and Analysis program.

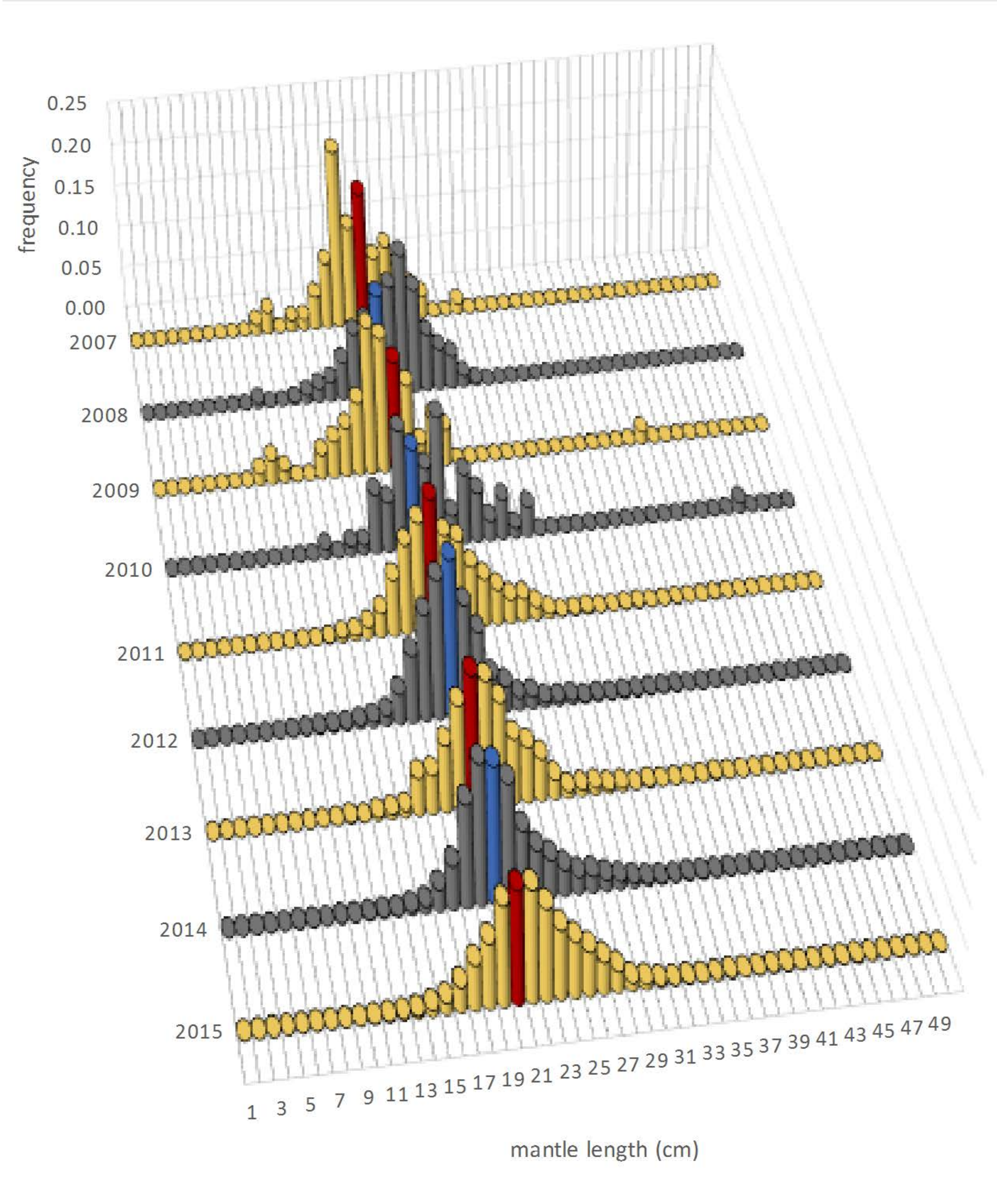

Figure 10. Length compositions (frequency at each cm) by year of squids captured during July in BSAI federal fisheries, 2007-2015. Data are from the AFSC's Fishery Monitoring and Analysis program. Individual colored bars (red and blue) indicate the 20-cm size bin.

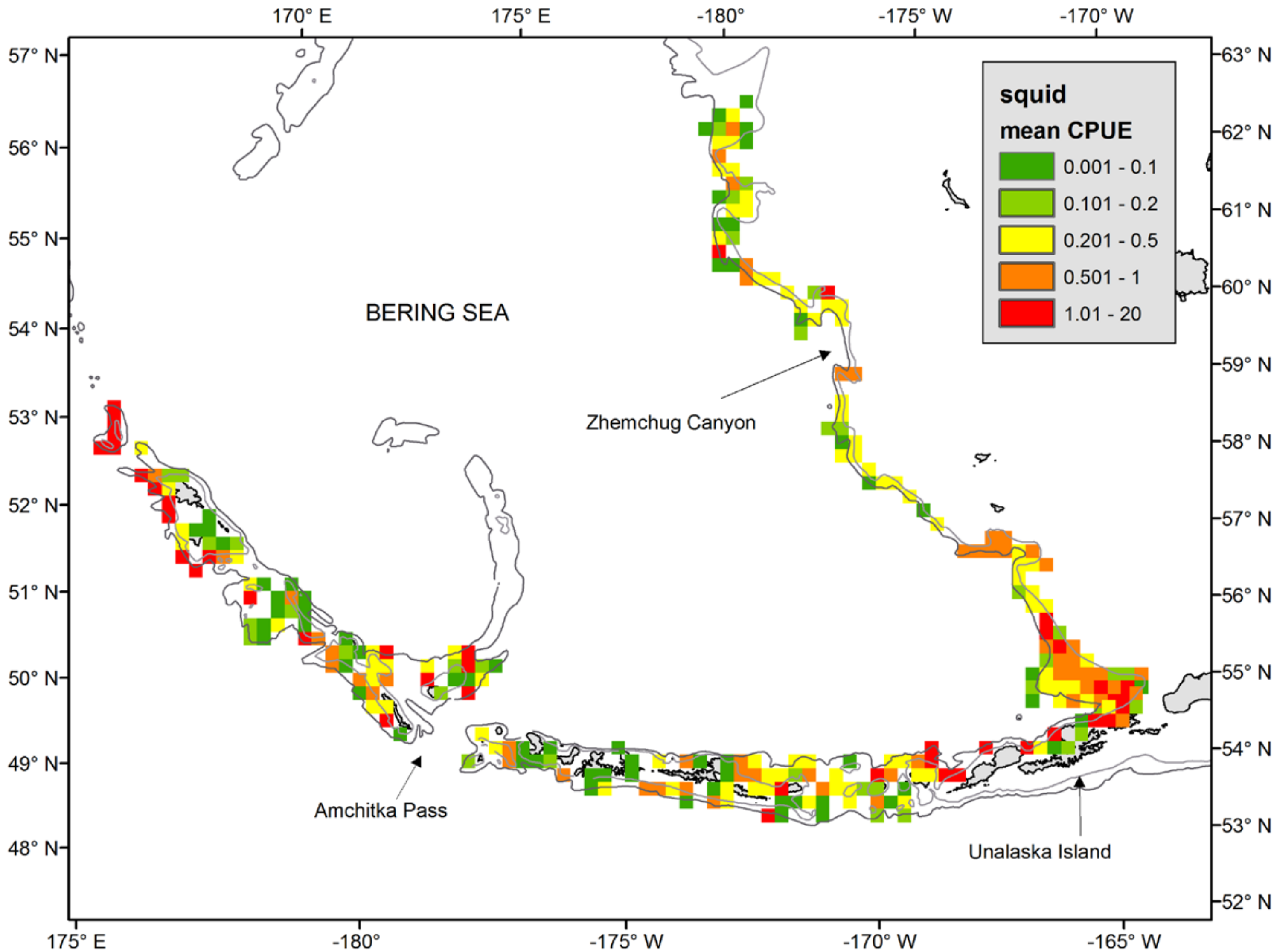

Figure 11. Mean trawl survey CPUE of all squid species combined in the BSAI, 2000-2012. Grid cells are 20 km X 20 km.

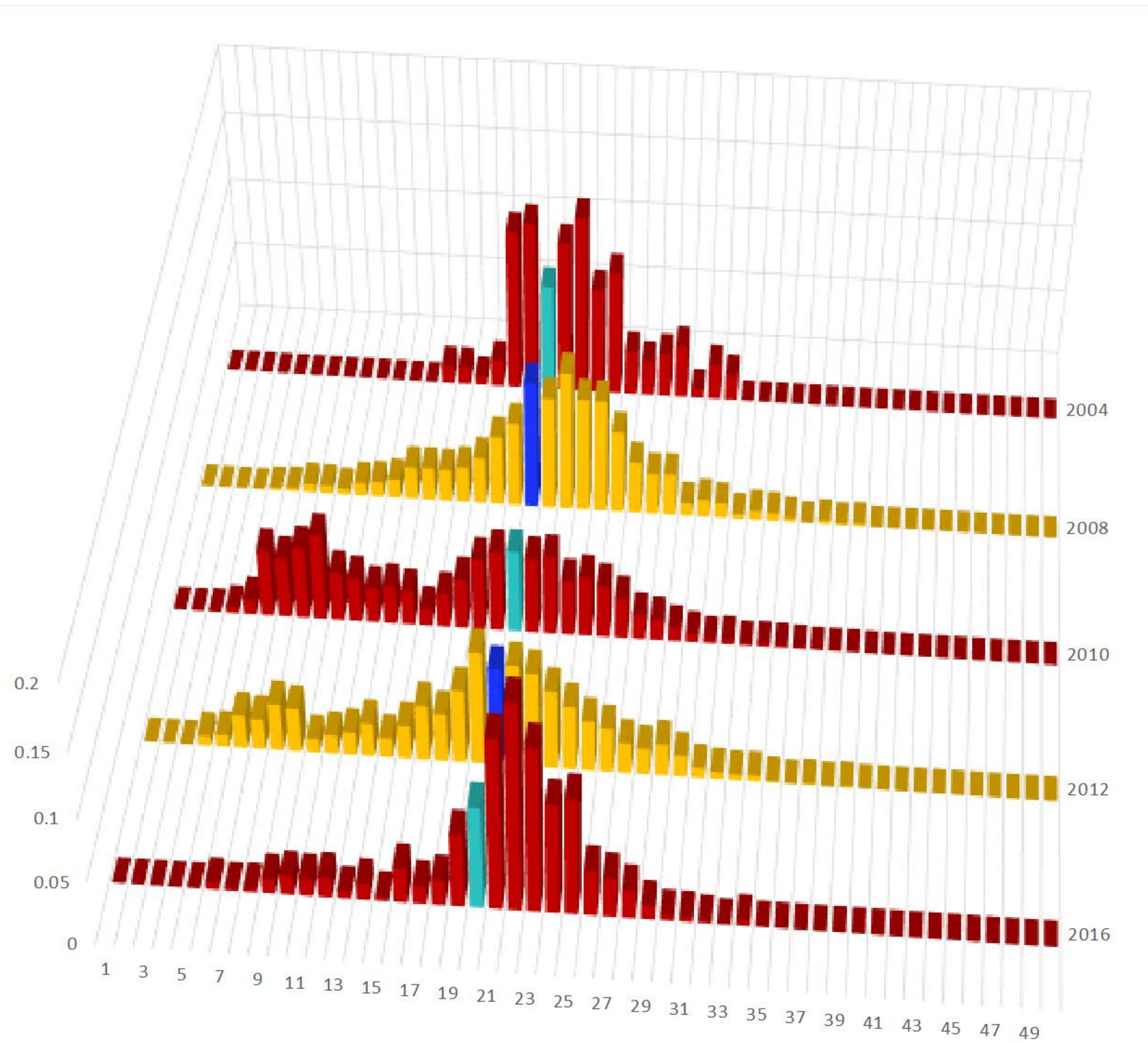

Figure 12. Size compositions of *B. magister* captured in EBS slope bottom trawl surveys conducted by the AFSC, 2004-2016. Off-color columns (teal and blue) indicate the 20-cm length bin in each year.

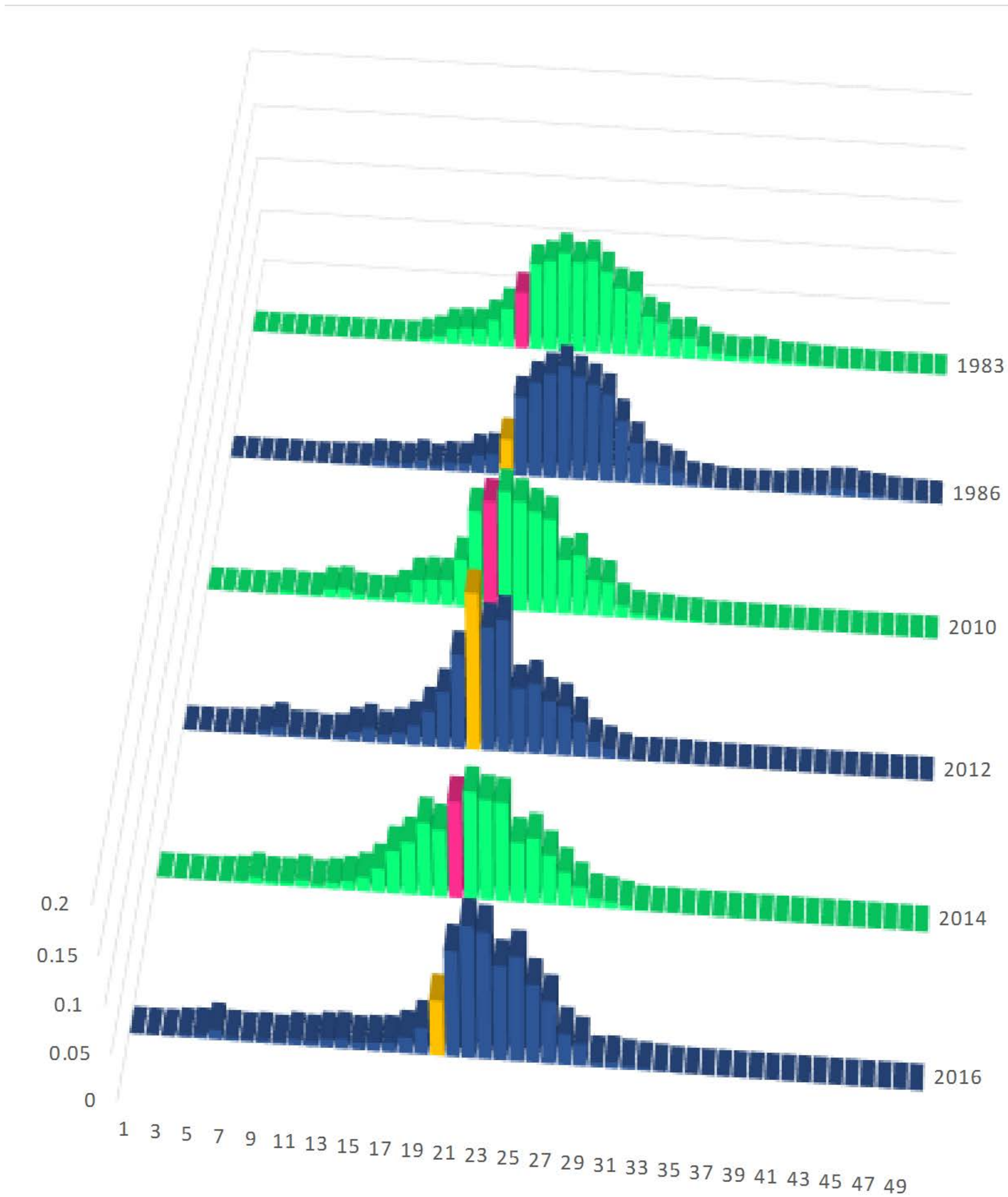

Figure 13. Size compositions of *B. magister* captured in Aleutian Islands bottom trawl surveys conducted by the AFSC, 1983-2016. Off-color columns (yellow and pink) indicate the 20-cm length bin in each year.

Appendix 1. Non-commercial catches (kg) of squids in the BSAI, 2018-2015. Data are from the Alaska Regional Office.

	2008	2010	2011	2012	2013	2014	2015
Aleutian Island Bottom Trawl Survey		2		4		30	
Aleutian Islands Cooperative Acoustic Survey	4						
Bering Sea Acoustic Survey		6					
Bering Sea Bottom Trawl Survey		1					
Bering Sea Slope Survey		16		9			
Bogoslof EIT Survey with/ N. Extensions				7			
Eastern Bering Sea Bottom Trawl Survey			1	1	5	1	3
Large-Mesh Trawl Survey				1	1		2
Pollock EFP 11-01				12,143			
total	**4**	**26**	**1**	**12,165**	**6**	**30**	**5**