Status of forage species in the Bering Sea and Aleutian Islands region

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Executive Summary

A report on the status of forage species in the Bering Sea and Aleutian Islands (BSAI) region is prepared on a biennial basis and presented to the Plan Team and the North Pacific Fishery Management Council (NPFMC) in odd years. This report is not intended as a formal stock assessment, although forage populations are analyzed if data are available. The two main objectives of the report are to 1) investigate trends in the abundance and distribution of forage populations and 2) describe interactions between federal fisheries and species that make up the forage base (i.e. to monitor potential impacts of bycatch). The report's structure is as follows:

1) Summary of findings and response to Plan Team & SSC comments
2) Overview of forage species and their management
3) Trends in abundance and spatial distribution
4) Bycatch and other impacts of federal fisheries on forage species
5) Data gaps and research priorities
6) Appendix

Because forage species are a fundamental component of the ecosystems in the BSAI, there is potential for overlap between the data presented here and forage-related information reported in the Ecosystem Considerations report published annually by the NPFMC (https://access.afsc.noaa.gov/reem/ecoweb/index.php). To minimize duplication of efforts, this report relies mainly on data from the bottom trawl surveys in the BSAI as well as acoustic-survey results where applicable. The Ecosystem Considerations report contains results from the surface-trawl surveys conducted by the Ecosystem Monitoring and Assessment (EMA) program (Yasumiishi et al. 2017), as well as estimates of euphausiid abundance from acoustic surveys (Ressler 2016). Indirect indicators of forage species abundance and prey availability, such as seabird breeding success and groundfish predator diets, are also described in the Ecosystem Considerations report. A brief summary of relevant findings from that report are included in this document's "Summary of findings" section below, and in other relevant sections of the report.

Summary of findings

This report

1) Bycatch of FMP forage species continues to be dominated by osmerids, especially eulachon. The 2015 catch (36.1 t) was high relative to other catches during 2016-2017 but was much lower than the high catches that occurred in 2006 & 2007. The 2016 catch was 16.9 t.
2) Prohibited Species catches (PSC) of Pacific herring were relatively high during 2015-2017 but below the PSC limit.

3) The apparent relationship between ocean temperature regimes and capelin abundance observed in the 2015 report was disrupted when the warm years 2014-2017 were included in the analysis: survey CPUE of capelin did not decline during this period as it had for past warm temperature regimes.
4) Pacific herring and eulachon CPUE decreased slightly during the years 2014-2017.

Ecosystem Considerations report

1) Seabird breeding success was poor and the multivariate seabird breeding index was below the long-term mean in 2016 & 2017, suggesting that forage availability was low.
2) Abundance estimates for capelin from the EMA surface-trawl were lower in 2014-2016 than they were in 2012 & 2013. Pacific herring abundance estimates were also lower in 2015 & 2016 relative to 2014.
3) The acoustic survey-based estimate of euphausiid biomass reached its lowest point in 2016. This is supported by zooplankton net tow data, although these data also suggest a slight increase in 2017.

Responses to Plan Team and SSC comments

From the October 2015 SSC minutes:

"The SSC asks for exploration of alternatives to the temperature regimes that were developed and that additional information on how the timing of ice retreat could impact forage fish distribution and abundance be explored. The SSC suggested looking at the distribution of species bycatch in commercial catches over space and time in addition to those of the surveys."

> *Response:* The 2017 report does not include an exploration of patterns in the commercial catch, but it does include an additional temperature regime (2014-2017) in the analysis.

From the December 2016 SSC minutes:

"The SSC acknowledges the Plan Team's concern that forage fish information is contained in two places (the Forage Fish chapter and the Ecosystem chapter), but recommends that the Forage fish chapter be retained as a separate chapter due to (1) the different purposes of the two chapters and (2) concern over losing information if it is incorporated into the Ecosystem chapter (due to the brevity necessary for the Ecosystem chapter)… Recognizing that forage fish contributions are included in more than one SAFE document, the SSC recommends that authors state the types of information that are contained in each at the start of the chapter (e.g., this chapter includes distribution, abundance and catch information for forage fishes, this chapter includes summaries of interactions of forage fishes with other members of the ecosystem) and cross-list where other contributions are located. This would help make readers aware that there are several efforts to assess interannual forage fish information."

> *Response*: The author has made additional strides towards reducing duplication and confusion between this report and the Ecosystem chapter. For example, the document now cross-references information that is in the Ecosystem chapter.

Overview of forage species and their management

Defining "forage species" can be a difficult task, as most fish species experience predation at some point in their life cycle. A forage fish designation is sometimes applied only to small, energy-rich, schooling fishes like sardine and herring, but in most ecosystems this is too limiting a description. Generally, forage species are those whose primary ecosystem role is as prey and that serve a critical link between lower and upper trophic levels. For this report, the following species or groups of species are considered to be critical components of the forage base in the Bering Sea and Aleutian Islands (BSAI) area:

- members of the "forage fish group" listed in the BSAI Fishery Management Plan (FMP)
- Pacific herring *Clupea pallasii*
- juvenile groundfishes and salmon
- shrimps
- squids
- Arctic cod *Boreogadus saida*

Forage fish group in the FMP

Prior to 1998, forage fishes in the BSAI were either managed as part of the Other Species group (nontarget species caught incidentally in commercial fisheries) or were classified as "nonspecified" in the FMP, with no conservation measures. In 1998, Amendment 36 to the BSAI FMP created a separate forage fish category, with conservation measures that included a ban on directed fishing. Beginning in 2011, members of this forage fish group (the "FMP forage group" in this report) are considered "ecosystem components". The FMP forage fish group is large and diverse, containing over fifty species from the following taxonomic groups (see the appendix at the end of this report for a full list of species):

- Osmeridae (smelts; eulachon *Thaleichthys pacificus* and capelin *Mallotus villosus* are the principal species, with rainbow smelt *Osmerus mordax* locally abundant in some areas)
- Ammodytidae (sand lances; Pacific sand lance *Ammodytes hexapterus* is the only representative)
- Trichodontidae (sandfishes; Pacific sandfish *Trichodon trichodon* is the main species)
- Stichaeidae (pricklebacks)
- Pholidae (gunnels)
- Myctophidae (lanternfishes)
- Bathylagidae (blacksmelts)
- Gonostomatidae (bristlemouths)
- Euphausiacea (krill; these are crustaceans, not fish, but are considered essential forage)

The primary motivation for the creation of the FMP forage group was to prevent fishing-related impacts to the forage base in the BSAI; it was an early example of ecosystem-based fisheries management. The management measures for the group are specified in section 50 CFR 679b20.doc of the federal code:

50 CFR 679b20.doc § 679.20 General limitations
(i) Forage fish
(1) <u>Definition.</u> See Table 2c to this part.
(2) <u>Applicability.</u>

The provisions of § 679.20 (i) apply to all vessels fishing for groundfish in the BSAI or GOA, and to all vessels processing groundfish harvested in the BSAI or GOA.
(3) Closure to directed fishing.
Directed fishing for forage fish is prohibited at all times in the BSAI and GOA.
(4) Limits on sale, barter, trade, and processing.
The sale, barter, trade, or processing of forage fish is prohibited, except as provided in paragraph (i)(5) of this section.
(5) Allowable fishmeal production.
Retained catch of forage fish not exceeding the maximum retainable bycatch amount may be processed into fishmeal for sale, barter, or trade.

In sum, directed fishing for species in the FMP forage fish group is prohibited, catches are limited by a maximum retention allowance (MRA) of 2% by weight of the retained target species (Table 10 to 50 CFR part 679), and processing of forage fishes is limited to fishmeal production. While the basis for a 2% MRA is not entirely clear, it appears this percentage was chosen to accommodate existing levels of catch that were believed not to significantly impact prey availability (Federal Register, 1998, vol. 63(51), pages 13009-13012). The intent of amendment 36 was thus to prevent an increase in forage fish removals, not to reduce existing levels of catch. In 1999, the state of Alaska adopted a statute with the same taxonomic groups and limitations (5 AAC 39.212 of the Alaska administrative code), except that no regulations were passed regarding the processing of forage fishes. This exception has caused some confusion regarding the onshore processing of forage fishes for human consumption (J. Bonney, Alaska Groundfish Data Bank, pers. comm.).

Pacific herring

Herring are highly abundant and ubiquitous in Alaska marine waters. Commercial fisheries in the BSAI, mainly for herring roe, exist along the western coast of Alaska from Port Moller north to Norton Sound (Figure 1). These fisheries target herring returning to nearshore waters for spawning, and herring in different areas are managed as separate stocks. The largest stock in the BSAI spawns in Togiak Bay in northern Bristol Bay: the spawning biomass was estimated at 163,480 short tons in 2015. The next largest stock, in Norton Sound, had a 2015 biomass estimate of 53,786 short tons (data can be retrieved at www.adfg.alaska.gov). Herring are hypothesized to migrate seasonally between their spawning grounds and two overwintering areas in the outer domain of the eastern Bering Sea (EBS) continental shelf (Figure 2; Tojo et al. 2007). The herring fisheries are managed by the Alaska Department of Fish & Game (ADFG) which uses a combination of various types of surveys and population modeling to set catch limits. In federal fisheries, herring are managed as Prohibited Species: directed fishing is banned and any bycatch must be returned to the sea immediately. The amount of herring bycatch allowed is also capped and if the cap is exceeded the responsible target fishery is closed in special Herring Savings Areas (Figure 1) to limit further impacts. In the BSAI, the Prohibited Species Catch Quota for herring is calculated as 1% of the estimated annual biomass of herring in the eastern Bering Sea.

Juvenile groundfishes and salmon

Members of this group, particularly age-0 and age-1 walleye pollock, *Gadus chalcogrammus*, are key forage species in the BSAI. As they are early life stages of important commercially fished species, however, their status is dependent on the assessment and management of the recruited portion of the population. Detailed information regarding these species is available in NPFMC stock assessments (http://www.afsc.noaa.gov/refm/stocks/assessments.htm) and ADFG reports (www.adfg.alaska.gov). Further information is not included in this report.

Shrimps

A variety of shrimps occur in the BSAI. Members of the family Pandalidae are generally found in offshore waters while shrimps of the family Crangonidae are distributed mainly in nearshore waters. Commercial fisheries for shrimps are managed by ADFG and are currently closed in the BSAI. Further information on shrimps in Alaska waters is available from ADFG (www.adfg.alaska.gov). This report includes data regarding catches of pandalid shrimps in federal groundfish fisheries.

Squids

Squids are abundant along the EBS slope and in the Aleutian Islands. Up to 15 species exist in the BSAI. Although no directed fisheries currently exist for squids, they have historically been managed as "in the fishery" due to high levels of incidental catch, mainly in the fisheries for walleye pollock. In June 2017 the NPFMC moved to reclassify squid as an "Ecosystem Component" complex, meaning that once the Fishery Management Plan has been amended to reflect this decision there will no longer be annual catch limits for squids (see https://www.npfmc.org/squid-reclassification/ for more information). Detailed information regarding BSAI squids can be found in the relevant stock assessment report (http://www.afsc.noaa.gov/refm/stocks/assessments.htm).

Arctic cod

Arctic cod is not currently included in the FMP for the BSAI. It is primarily a cold-water species with a northern distribution in the EBS, generally captured in bottom trawl surveys north of 59°N latitude. In the Alaskan Arctic it is likely the dominant prey species, and the Arctic FMP prohibits directed fishing for Arctic cod due to ecosystem concerns. As fish distributions and fishing locations shift, conservation measures for Arctic cod in the BSAI may become necessary. Further information is available at http://www.npfmc.org/arctic-fishery-management/.

Trends in abundance and spatial distribution

Data sources

There are a number of research surveys conducted on a regular basis in the BSAI, but none are optimized for sampling forage fishes. The main drawbacks are that the sampled areas do not correspond to forage fish distributions (e.g. bottom trawls do not effectively sample pelagic species) and that sampling gears (e.g. net mesh size) are not suitable for small fishes. As a result, estimating abundance and analyzing trends and patterns in abundance and spatial distributions is difficult. To ameliorate this situation this report relies on the aggregation of data: either referring to multiple data sources (i.e. surveys) and looking for common trends, or aggregating data within a survey across a range of years. The rationale for the latter approach is that although catches in any one year may not be representative of the population (e.g. there may be a couple of hauls where a bottom trawl happened to encounter pelagic schools as the net was being retrieved), aggregating across multiple years reduces the influence of such events and provides a low-resolution but reasonable analysis of abundance and distribution.

For most of the species in this section, data are from bottom trawl surveys conducted by the AFSC on the EBS shelf (annual), the EBS slope (biennial) and in the AI (biennial; methods and data at: http://www.afsc.noaa.gov/RACE/groundfish/default.php). The standardized EBS shelf survey began in 1982 but some work using similar gear was conducted prior to 1982; the EBS slope and AI surveys have occurred biennially since the early 2000s. These surveys are conducted from May to August. The EBS shelf survey has also occasionally visited the northeastern Bering Sea.

This section also references information from surface trawl surveys conducted by the AFSC Ecosystem Monitoring and Assessment (EMA) program (Yasumiishi et al. 2017). This survey has been conducted every year since 2003, although the extent and density of stations sampled has varied among years. This survey regularly visits the northeastern Bering Sea. The survey occurs primarily in September, with sampling during August and October in some years. There is also a biennial acoustic survey for walleye pollock that covers the middle and outer domains of the EBS shelf. An index of euphausiid abundance and distribution has been created using the results of this survey (Ressler et al. 2012) and is included in the Ecosystem Considerations report (Ressler 2016). Acoustic surveys are effective at sampling capelin, but the EBS survey does not extend to the inner domain of the EBS shelf where the capelin population is centered. Pacific herring are assessed by ADFG, primarily using aerial surveys and test fishing; these data are included here where appropriate.

Spatial analysis of survey data was conducted within ArcGIS. Point data for each survey haul were either symbolized directly or aggregated into 20 km X 20 km cells with a mean catch-per-unit-effort (CPUE) calculated for each cell using data from all years. To better understand variability in distributions, standard deviational ellipses were created using geographic data weighted by CPUE (Lefever 1926; Gong 2002). Ellipses include all points within one standard deviation of the distribution's mean geographic center.

Temperature regime classification

To reduce the uncertainty that results from suboptimal surveys, and to understand how abundance and distribution might vary in response to changes in the environment, sea surface temperature anomaly data were aggregated according to six temperature regimes: cold 1 (1975-1976), warm 1 (1977-1987), …. Data on sea surface temperature anomalies at the M2 mooring site in the southeastern Bering Sea were obtained from the Pacific Marine Environmental Laboratory (http://www.beringclimate.noaa.gov/data/). These data are the mean NCEP/NCAR Reanalysis temperatures during January 15-April 15, and are indicative of the annual extent of a region experiencing temperatures <2° C, known as the cold pool. For this report, regimes were identified as series of years with consistent positive (warm) or negative (cold) anomalies; during most of the regimes there are 1-2 years with anomalies with an opposite sign. Division into regimes begins in 1975, the first year for which survey CPUE data are available:

forage report temperature regimes	
cold 1	1975-1976
warm 1	1977-1987
cold 2	1988-2000

warm 2	2001-2005
cold 3	2006-2013
warm 3	2014-2017

Spatial partitioning on the EBS shelf

The cross-shelf distribution of forage fishes in the BSAI (i.e. nearshore vs. offshore) was investigated for the 2013 report (Ormseth 2013), and the results for the EBS shelf are repeated here. There appears to be strong cross-shelf partitioning among the six species/species groups studied (Figure 3). The mean CPUE of sandfish and sand lance was highest at bottom depths below 50 m, indicating a nearshore distribution in the inner domain of the EBS shelf. Capelin CPUE was also highest at bottom depths of approximately 50 m, but their distribution extended out to beyond 100 m. The distribution of herring was more variable, existing at a range of depths from 0 to more than 100 m. Eulachon were concentrated in hauls with 100-200 m bottom depth, with some catch over the EBS slope, while myctophids were found only on the slope. This type of segregation is similar to segregation observed among capelin and juvenile pollock (Hollowed et al. 2012). Habitat preferences and competitive interactions are both likely to influence these distributions. For example, sandfish and sand lance both depend on sandy substrates for burrowing. Myctophids have a mesopelagic distribution, so are unlikely to be found on the shelf. Spatial partitioning among capelin and juvenile pollock in the Gulf of Alaska (GOA) is thought to be due to competition between the species (Logerwell et al. 2007).

Capelin

Capelin are distributed primarily in the inner domain of the EBS shelf (Figure 4). The pattern of CPUE varies substantially between the surface and bottom trawl surveys, with catches in the EMA survey occurring further north than in the trawl survey (Yasumiishi et al. 2017). The reason for these differences is not clear. Capelin occupy different parts of the water column depending on environmental factors such as light levels and prey availability. Surveys in the GOA using identical surface trawl gear have occasionally caught capelin, but simultaneous acoustic surveying on the same vessel indicates that capelin are often below the trawl's footrope (Dave McGowan, UW, pers. comm.). The contrast between the surveys may also arise from differences in survey timing: the EMA survey occurs in late summer after the trawl surveys have been completed.

In the 2015 forage species report (Ormseth 2015) the mean survey CPUE of capelin appeared to fluctuate consistently with temperature regime, with higher CPUEs observed during cold regimes (Figure 5). During the most recent warm period however (warm 3, 2014-2017), the mean capelin CPUE remained high (Figure 5). Interpretation of these results is complicated by the substantial interannual variability in capelin CPUE (Figure 6) and the large variance of the "warm 3" mean CPUE. The annual data suggest a decline in capelin CPUE after 2014. The EMA survey abundance index indicates lower capelin abundance during 2014-2016, although variances are large (Yasumiishi et al. 2017).

Eulachon

In contrast to capelin, eulachon dynamics in the BSAI appear to be fairly simple. Eulachon tend to occur deeper in the water column and are more likely to be associated with the bottom. As a result the bottom trawl surveys sample eulachon more effectively than other forage species, and eulachon are essentially absent from the EMA surface trawls. Eulachon are consistently distributed in the extreme southern portion of the outer EBS shelf (Figure 7).

Eulachon abundance also appears unrelated to temperature regime (Figures 8 & 9). Mean survey CPUE was highest during the second cold regime (1988-2000). While the magnitude of the increase was influenced by an exceptionally high CPUE in 1994 (Figure 9), the annual data display a similar decadal variation in abundance as do the regime-specific data. Decadal variation in eulachon abundance also occurs in the GOA (Ormseth 2014).

Rainbow smelt

Rainbow smelt are rare in the bottom trawl survey, so the EMA survey is the primary source of information for this osmerid. These data are included here because no rainbow smelt information is presented in the Ecosystem Considerations report. Data from EMA surveys were only available through 2011, and indicate that the highest abundance of rainbow smelt is in the northeastern Bering Sea and particularly Norton Sound (Figure 10). Rainbow smelt are often found in shallow nearshore waters, so this apparent distribution may not be fully representative. For example, nearshore studies in northern Bristol Bay (Nushagak and Togiak bays) captured large number of rainbow smelt in multiple size classes (Ormseth, unpublished data).

Ammodytidae: Pacific sand lance

Sand lances are extremely difficult to sample due to their patchiness and behavior, which entails spending much of their time burrowed into sand. As a result, information for Pacific sand lance in the BSAI is extremely limited. The bottom trawl survey suggests that they have a primarily inshore distribution in the EBS, particularly in areas such as Bristol Bay with extensive sandy bottom substrates (Figure 11). They also occur in the AI, particularly in the islands west of Amchitka Pass (Figure 12). Despite the difficulty of sampling them, after myctophids, they are the most commonly observed member of the FMP forage group in the AI bottom trawl survey.

Trichodontidae: Pacific sandfish

Similar to sand lance, sandfishes burrow into sandy substrates. This is reflected in their distribution which is centered in the shallow inshore waters of the EBS, in Bristol Bay and along the northern shore of the Alaska Peninsula (Figure 13). The EMA surveys suggest a similar distribution (Yasumiishi et al. 2017). Unlike most of the other forage species, neither survey has found them north of Cape Romanzof (61°47' N), so this is likely the northern extent of their range. This is confirmed by historical reports (Mecklenburg et al. 2002).

Myctophidae (lanternfishes)

Myctophids are generally deep-water fishes (> 200 m depth), although diel migrations can bring them into surface waters. This is consistent with their distribution observed in BSAI survey data, where they occur on the EBS slope (Figure 14) and along the shelf break and slope in the AI (Figure 15).

Euphausiacea

The AFSC's Midwater Assessment and Conservation Engineering (MACE) program has recently developed the ability to discriminate between acoustic backscatter associated with fish versus backscatter from euphausiids. They have applied this methodology to acoustic data from acoustic trawl surveys conducted on the outer EBS shelf and have produced information regarding distribution and abundance of euphausiids since 2004 (Ressler et al. 2012). These results suggest that the distribution of euphausiids is variable but that the largest biomass is consistently found in the southeastern Bering Sea. The index suggests that euphausiid abundance has declined during the last decade (Ressler 2016).

Stichaeidae (pricklebacks), Pholidae (gunnels), Bathylagidae (blacksmelts), Gonostomatidae (bristlemouths)

These species occur rarely in the AFSC surveys, either due to their small size or their preference for unsurveyed habitats (e.g. nearshore areas or deep pelagic waters). No information exists regarding their abundance, and information regarding distribution is not presented in this report.

Pacific herring

The spatial distribution of herring in the BSAI described by the bottom trawl survey and the EMA survey vary substantially and may result from seasonal herring movement. Herring spawn in nearshore areas in the spring, then migrate to overwintering areas on the outer EBS shelf (Figure 3; Tojo et al. 2007). Older studies suggest that this is primarily a clockwise migration along the southern edge of the EBS ending at a single overwintering area north of the Pribilof Islands (Barton and Wespestad 1980). A more recent analysis suggests a more complex series of movements, with an additional overwintering ground in the southern EBS and multiple migration routes (Figure 2; Tojo et al. 2007). The routes used in any one year may depend on environmental factors, particularly temperature. The bottom trawl survey occurs primarily in June and July and is likely capturing herring that are out-migrating from nearshore spawning areas; the areas of high CPUEs on the southern edge of the EBS and around Nunivak Island (Figure 16) are consistent with the movement patterns in Figure 2. The EMA survey is conducted primarily during September, and by this time herring may have moved out of the sampling area in the southeastern Bering Sea and are no longer available to the survey. The high CPUEs observed in the EMA survey in the northeastern Bering Sea, particularly in Norton Sound (Yasumiishi et al. 2017), are harder to explain. It is possible that those herring belong to the Norton Sound stock, which is the second-largest in the BSAI, but it is unclear whether they are migrating or have a different overwintering strategy.

Mean herring CPUE appeared to be increasing during the 3rd cold temperature regime (2006-2013; Figure 17). Since 2014, however, the mean CPUE has declined. The annual data (Figure 18) reflect the high interannual variability of the CPUE estimates but also suggest increasing abundance during the late 2000s and a subsequent decline.

Bycatch and other conservation issues

FMP forage group

Data regarding incidental catches of this group are available since 2003 and are maintained by the Alaska Regional Office (AKRO; Table 1). Osmerids are the only species group that is caught incidentally in appreciable numbers, with the exception of substantial myctophid catches in 2006 & 2007. The years 2006 & 2007 were also years of exceptionally high osmerid catches. Eulachon and myctophids are both abundant in the Bering Canyon area, so the high catches in those areas may have resulted from a change in fishing activity by the pollock fishery.

Prior to 2005, osmerid species identification by observers was unreliable and many catches were recorded as "other osmerid". While identification has improved since then, osmerids in catches are often too damaged for accurate identification and much of the catch is still reported as "other osmerid". Eulachon are the most abundant forage fish in catches, and it is likely that they make up the majority of the "other osmerid" catch. For this analysis, all osmerid categories in the AKRO database (eulachon, capelin, surf smelt, "other osmerid") were combined into a single "osmerids" group.

The osmerid bycatch primarily occurs in two trawl fisheries: walleye pollock and yellowfin sole (Table 2). Catches are generally greater in the pollock fishery, but in some years (e.g. 2008, 2012, 2016) the yellowfin sole fishery catches are higher. During 2008-2016, total osmerid catch varied between 2.3 t and 34.6 t. In 2006 and 2007, however, catches were an order of magnitude higher (103.4 and 181.3 t, respectively) with most of the additional catch occurring in the pollock fishery. A similar pattern is observed in the Gulf of Alaska, where a background level of eulachon bycatch is periodically interrupted by very high bycatch levels in midwater fisheries (Ormseth 2014). The 2017 BSAI catch of osmerids as of November 1 was 8.0 t (Table 1). In 2006 & 2007 most of the osmerid catches occurred in February (Figure 19), with some additional catches in October, so it is unclear how much the total catch will increase during the rest of 2017.

The spatial concentration of eulachon bycatch corresponds to their distribution in the bottom trawl survey and the location of the fisheries in which they are caught. Most catches occur in areas 517 and 519 in the southeastern EBS (Table 3; Figures 20 & 21). Additional catch occurs in some years in area 514 in the northern part of the inner shelf, an area of intensive fishing for yellowfin sole.

Pacific herring

Data regarding the Prohibited Species Catch (PSC) of herring are available since 1991 and are maintained by the AKRO (Table 4 & Figure 22). During the 1990s herring bycatch was consistently high, but from 2000-2011 catches were relatively low. In 2012 the herring PSC was 2,376 t, an order of magnitude higher than catches in preceding years, and the PSC quota was exceeded. After smaller catches in 2013 & 2014, catches during the last three years have been more substantial, on the order of 1,000 t.

The herring bycatch in federal fisheries is related to the BSAI herring population and the Togiak spawning stock in several ways. Annual biomass estimates for the Togiak herring area available from pre-season forecasts, which are based on an age-structured analysis, and from aerial surveys of the spawning grounds that are conducted prior to the onset of spawning (e.g. Elison et al. 2015). For analysis of the relation between bycatch and Togiak biomass, the survey estimates of peak biomass (Appendix B4 in Elison et al. 2015) were used, except for years when peak biomass could not be determined and the pre-season forecasts were substituted. Results show that there is no relation between herring bycatch and the annual variation in the Togiak spawning biomass (analysis not shown), however, there does seem to be some coherence between the two datasets on a decadal scale. Four-year moving averages of bycatch and Togiak biomass both show values dropping during the early 2000s and increasing since approximately 2010. This pattern is consistent with increased herring abundance resulting in generally higher herring bycatch, but with other factors (e.g. fishery behavior, environmental variability) influencing bycatch levels on an annual basis. An additional complication is the uncertainty of the aerial survey estimates, which can be hindered by bad weather and rely on a number of assumptions regarding herring density and other variables.

The spatial pattern of herring catches is consistent with the migration patterns discussed earlier and the presence of an overwintering area north of the Pribilof Islands. During 2010-2014 catches were highest at the northern end of the bycatch distribution, north of 60°N (Figures 23 & 24). Because most of this catch occurred in September (Figure 25), it is likely that these are herring that have arrived at overwintering grounds. The area of high catch is north of the winter Herring Savings Area (Figure 23), so closure of the Savings Area in 2012 may not have achieved much in reducing herring bycatch.

Data regarding the size of herring captured in federal fisheries are sparse and could only be located for the years 2000-2007. There is substantial annual variability, but most captured herring were between 24 cm and 32 cm. In 2010, the average size for Togiak herring aged 5, 7, and 9 was 25, 29, and 31 cm, respectively (Buck 2012). In 2010, herring between the ages of 5 and made up most of the Togiak harvest (72.3%), while age 6 herring was the most abundant age class harvested (Buck 2012). The harvest in other years is comprised of similar age ranges (Elison et al 2015), so herring bycatch in the federal fishery appears to consist mainly of potential spawners.

Pandalid shrimps

Bycatch of pandalid shrimps has ranged between 0.98 t and 4.12 t since 2003 (Table 4). Shrimps in observed hauls are not identified to species, and shrimp populations are poorly understood. The federal bycatch is much smaller than the commercial shrimp harvest in combined Alaska waters, which was approximately 230 t in 2016 (ADF&G Commercial Operator's Annual Reports; http://www.adfg.alaska.gov/index.cfm?adfg=fishlicense.coar_shrimpproduction)

Data gaps and research priorities

Information regarding BSAI forage fishes is very limited, so any increase in research activity would be beneficial. Areas of particular interest are:

1) Absolute abundance of capelin, eulachon, and rainbow smelt: In the GOA, the summer acoustic survey provides a reasonable estimate of capelin abundance. Unfortunately the corresponding survey in the EBS occurs outside of the main capelin distribution. Acoustic data collected during the EMA survey may provide useful information. Estimates exist from the ecosystem models but these are highly uncertain.

2) Spawning areas of BSAI eulachon: Eulachon spawning runs have been researched in the GOA but are not well known in the BSAI. Information on where eulachon spawn would be very useful for understanding the relationship of EBS eulachon to eulachon in other areas.

3) Stock structure of federally captured herring: Genetic studies to determine population structure, similar to those conducted for BSAI chinook and chum salmon, could be conducted and should include a comparison of the genetic composition of herring on overwintering grounds versus those on the spawning grounds.

4) Enhanced knowledge regarding seasonal migrations of herring: What is the reason for the high EMA survey CPUE in Norton Sound during September? A possible approach would be to use recent observer estimates of herring catches in the groundfish trawl fishery to continue the

analysis of Tojo et al., 2007 and explore the seasonal migration of herring in relation to variability in climate and oceanographic conditions.

5) Enhanced knowledge of survey selectivity and catchability for capelin, eulachon, etc.; Knowledge of the effectiveness of the surveys at sampling forage species would allow us to make the most accurate calculations using the existing survey data.

6) Continued studies of how climate variability influences the abundance, distribution, and energy content of forage species in the BSAI.

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Table 1. Bycatch (t) of FMP forage fish groups in BSAI federal fisheries, 2003-2017. *2017 data are incomplete; retrieved on November 1, 2017.

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	***2017****
eulachon	2.5	20.2	9.4	94.0	106.0	2.5	5.4	0.8	2.9	1.6	0.8	2.6	20.2	8.3	*3.6*
capelin	0.0	5.4	0.4	2.6	1.2	0.2	0.6	0.8	4.2	2.4	0.3	1.3	6.8	0.5	*0.2*
surf smelt	-	-	-	-	0.6	0.0	-	-	-	-	-	-	-	-	-
other osmerids	16.2	7.0	4.7	6.8	73.5	12.4	1.1	2.9	2.6	4.9	1.2	9.6	7.6	6.1	*4.2*
total osmerids	**18.8**	**32.6**	**14.5**	**103.4**	**181.3**	**15.1**	**7.0**	**4.5**	**9.7**	**8.9**	**2.3**	**13.6**	**34.6**	**14.9**	***8.0***
myctophids	0.29	0.08	0.63	9.59	5.78	1.53	0.49	0.25	0.19	0.10	0.49	0.56	0.58	0.73	*0.23*
pricklebacks	0.25	0.12	0.11	0.23	0.84	0.28	0.15	0.21	0.44	0.35	0.19	0.78	0.57	0.61	*0.10*
Pacific sand lance	0.05	0.32	0.28	0.07	0.07	0.09	0.12	0.06	0.40	0.18	0.02	0.07	0.20	0.28	*0.33*
Pacific sandfish	-	-	-	-	-	-	-	0.031	0.054	0.008	0.038	0.172	0.115	0.074	*0.015*
gunnels	-	0.003	0.012	-	0.002	0.0001	-	-	0.031	0.0001	0.005	0.023	0.052	0.218	*0.096*
deep sea smelts	0.0001	0.0004	-	0.001	0.004	-	-	-	-	-	0.017	-	0.027	0.120	*0.010*
total FMP forage fish	**19.4**	**33.1**	**15.6**	**113.3**	**188.0**	**17.0**	**7.7**	**5.1**	**10.8**	**9.5**	**3.1**	**15.2**	**36.1**	**16.9**	***8.8***

Table 2. Total bycatch (t) of osmerids (eulachon, capelin, surf smelt, and "other osmerids) in the BSAI by target fishery, 2003-2017. Fisheries with less than 0.1 t of catch in any year are combined into the "miscellaneous fisheries" group. *2017 data are incomplete; retrieved on November 1, 2017.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	*2017**
pollock	10.0	21.6	12.9	102.0	139.9	4.4	5.6	0.7	2.6	1.6	0.8	2.2	22.0	5.9	*3.7*
yellowfin sole	4.3	9.0	0.6	0.9	41.2	10.0	1.2	3.7	6.5	7.2	1.2	11.1	6.8	8.2	*2.9*
rock sole	3.7	0.5	0.7	0.3	0.2	0.7	0.1	0.2	0.5	0.1	0.1	0.1	5.7	0.7	*1.4*
Pacific cod	0.167	0.649	0.042	0.218	0.003	0.001	-	0.002	0.007	0.008	0.028	0.031	0.033	-	*0.001*
arrowtooth	0.344	0.572	0.046	0.008	-	-	0.001	0.002	0.006	0.002	0.006	0.011	0.029	0.037	*0.006*
flathead sole	0.253	0.264	0.177	0.069	0.014	0.024	0.020	0.010	0.079	0.002	0.140	0.044	0.004	0.032	*0.002*
misc. fisheries	0.021	0.014	0.029	-	-	0.003	-	0.004	0.007	0.002	0.008	0.003	0.027	0.001	*0.004*
total	18.78	32.62	14.55	103.43	181.27	15.11	6.98	4.54	9.73	8.89	2.29	13.59	34.59	14.90	*8.02*

Table 3. Total bycatch (t) of osmerids (eulachon, capelin, surf smelt, and "other osmerids) in the BSAI by NMFS statistical area, 2003-2017. Areas with less than 0.1 t of catch in any year are combined into the "all others" group. *2017 data are incomplete; retrieved November 1, 2017.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
517	7.4	22.1	12.3	65.9	96.2	2.0	1.4	0.7	1.7	1.5	0.8	2.0	12.8	2.0	1.9
514	7.4	8.9	1.2	1.0	41.2	10.5	1.1	3.4	5.6	6.7	1.1	10.9	12.6	8.8	4.1
519	0.2	0.2	0.1	35.5	41.4	1.3	4.2	0.0	0.0	0.1	0.0	0.0	8.5	3.7	1.8
513	3.7	0.9	0.3	0.5	1.4	0.1	0.0	0.2	1.4	0.1	0.1	0.2	0.6	0.3	0.0
509	0.1	0.2	0.3	0.3	0.8	0.5	0.2	0.2	1.0	0.5	0.2	0.3	0.1	0.2	0.2
521	0.1	0.2	0.1	0.1	0.1	0.7	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
all others	0.014	0.125	0.212	0.177	0.214	0.026	0.003	0.005	0.001	0.005	0.020	0.106	0.002	0.001	0.003
total	18.8	32.6	14.5	103.4	181.3	15.1	7.0	4.5	9.7	8.9	2.3	13.6	34.6	14.9	8.0

Table 4. Bycatch (t) of Pacific herring and pandalid shrimps in BSAI groundfish fisheries, 1991-2017. Data are from the Prohibited Species Catch (PSC) and nontarget catch databases, respectively, maintained by the NMFS Alaska Regional Office. *2017 data are incomplete; retrieved November 1, 2017.

	Pacific herring		**pandalid shrimp**
	groundfish fishery catch	**PSC limit**	
1991	3,761	834	-
1992	1,059	956	-
1993	784	2,122	-
1994	1,728	1,962	-
1995	970	1,861	-
1996	1,513	1,697	-
1997	1,298	1,579	-
1998	963	1,585	-
1999	895	1,685	-
2000	512	1,853	-
2001	270	1,526	-
2002	134	1,526	-
2003	962	1,525	0.98
2004	1,200	1,876	2.22
2005	676	2,013	1.74
2006	484	1,770	3.24
2007	417	1,787	2.08
2008	215	1,726	2.48
2009	88	1,697	2.63
2010	356	1,973	2.14
2011	397	2,273	4.12
2012	2,376	2,094	2.45
2013	988	2,648	4.01
2014	186	2,179	3.05
2015	1,531	2,742	2.22
2016	1,493	2,630	1.89
*2017**	*1,023*	*2,013*	*1.65*

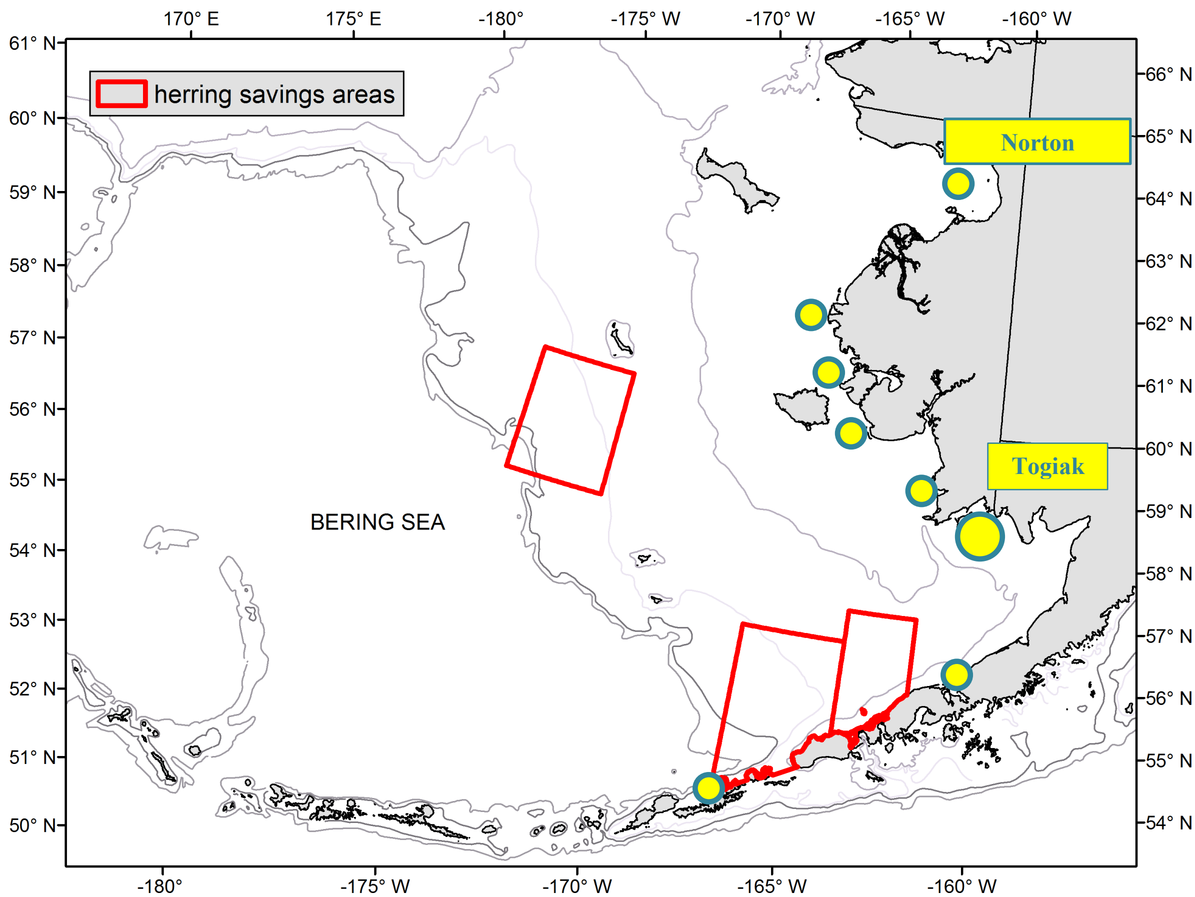

Figure 1. Locations of Pacific herring fisheries in the Bering Sea/Aleutian Islands region (yellow dots) and Herring Savings Areas (red-outlined polygons). The two largest herring fisheries are labeled by name; the larger dot at Togiak indicates that this is by far the biggest fishery.

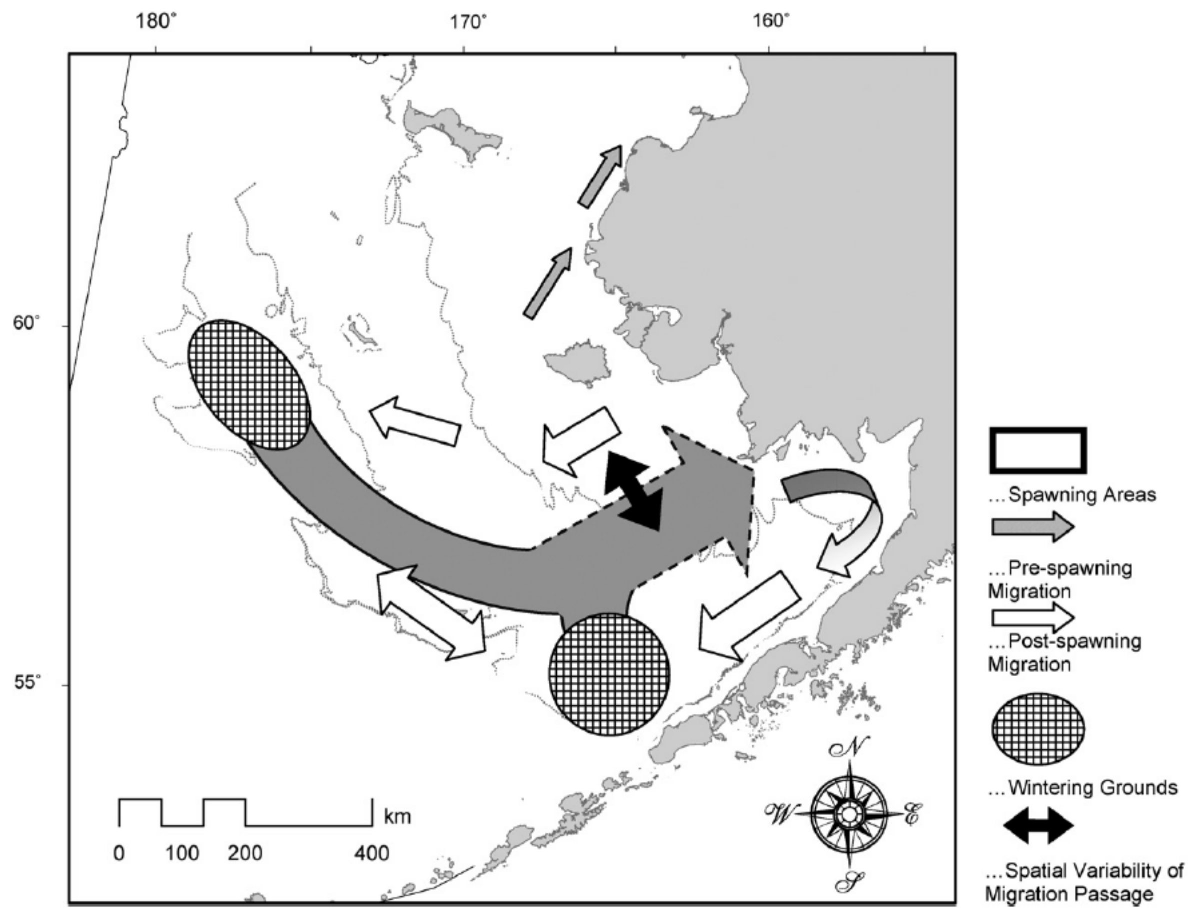

Figure 2. Hypothesized migration routes and seasonal distributions of Pacific herring in the eastern Bering Sea. Figure is from Tojo et al. 2007.

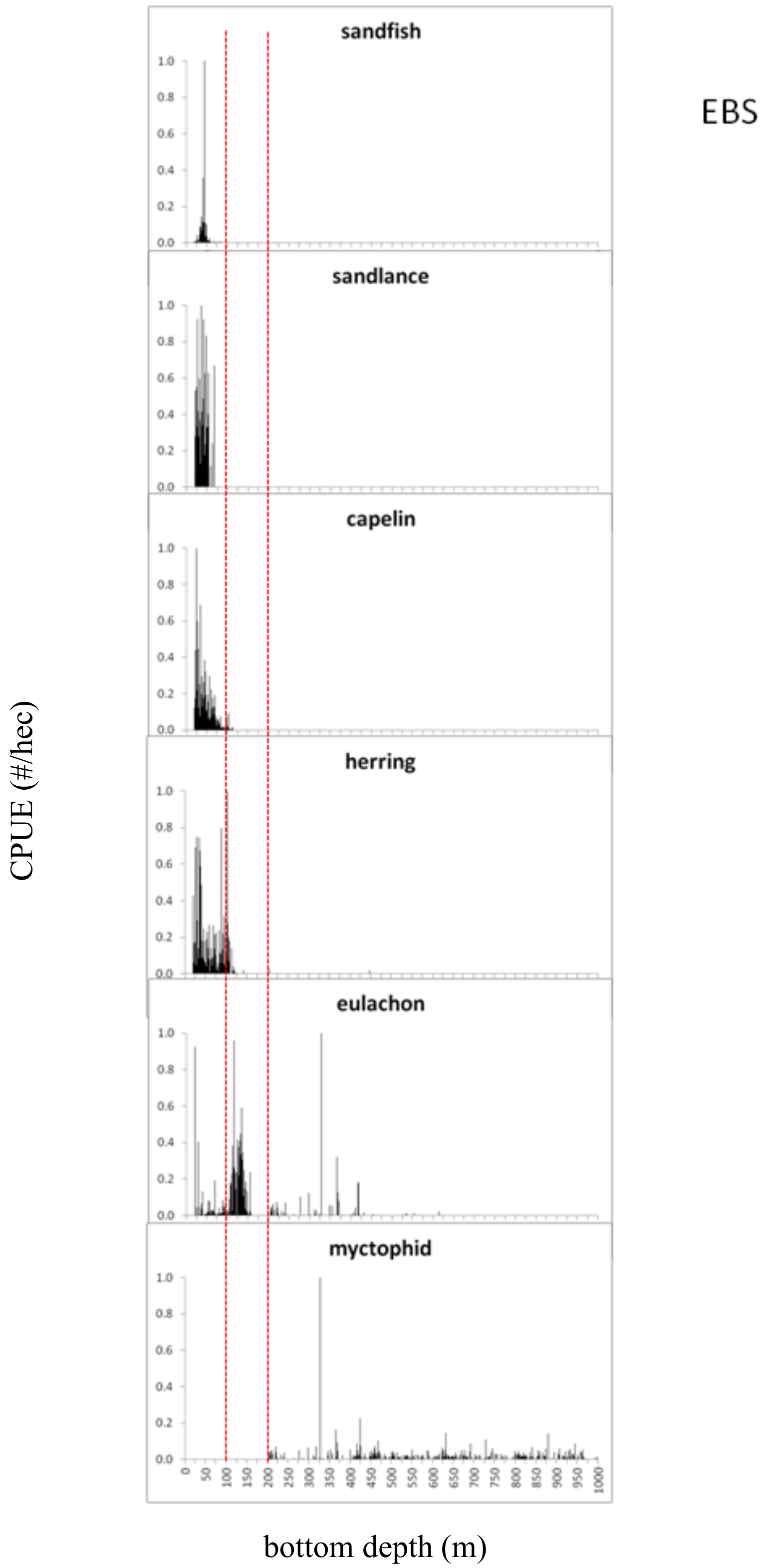

Figure 3. Mean bottom trawl survey catch-per-unit-effort (CPUE; number/ hec) versus bottom depth (m) of haul for six forage groups in the eastern Bering Sea.

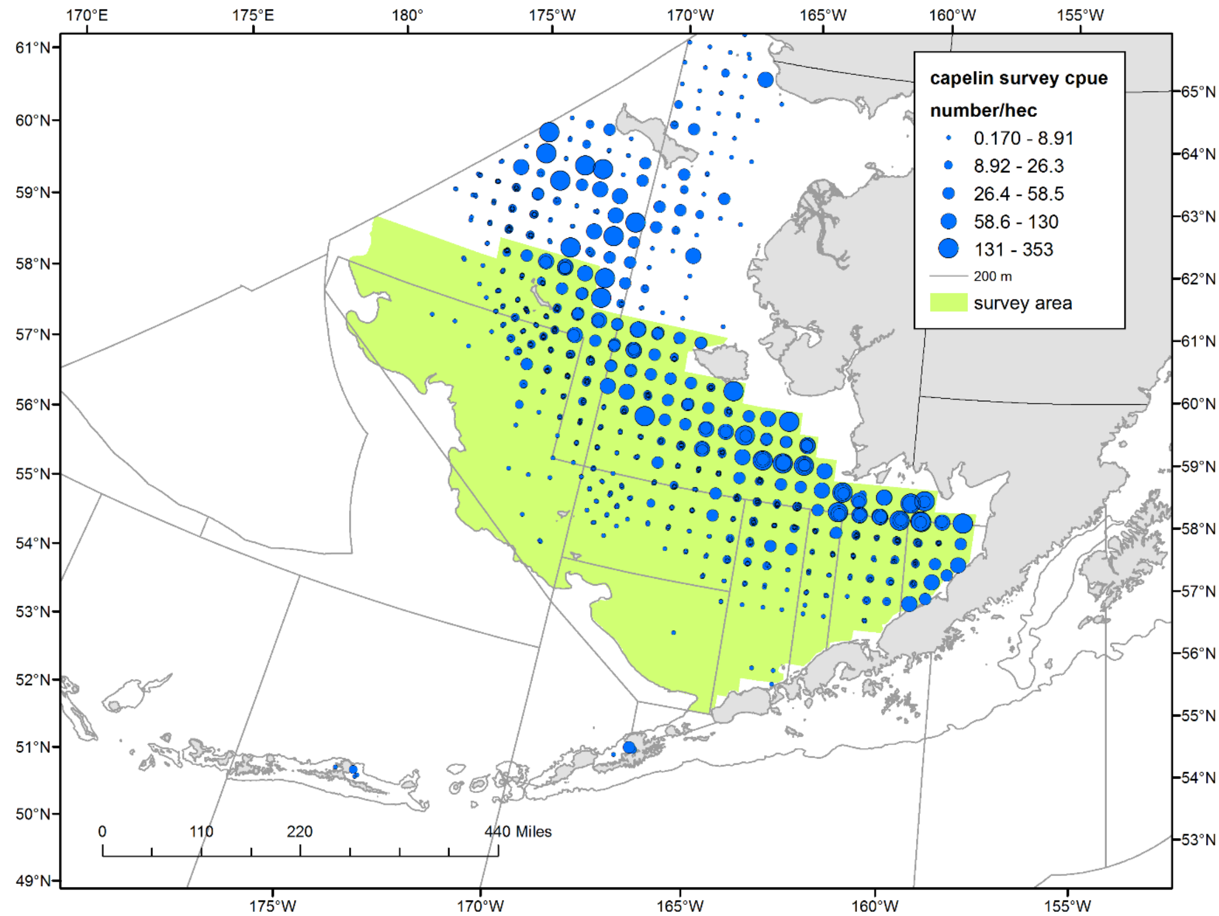

Figure 4. Mean catch-per-unit-effort (CPUE; number/km^2) of **capelin** in NMFS Bering Sea/Aleutian Islands bottom trawl surveys 2006-2017. Oval indicates weighted standard deviational ellipse, which includes all points within one standard deviation of the distribution's mean geographic center.

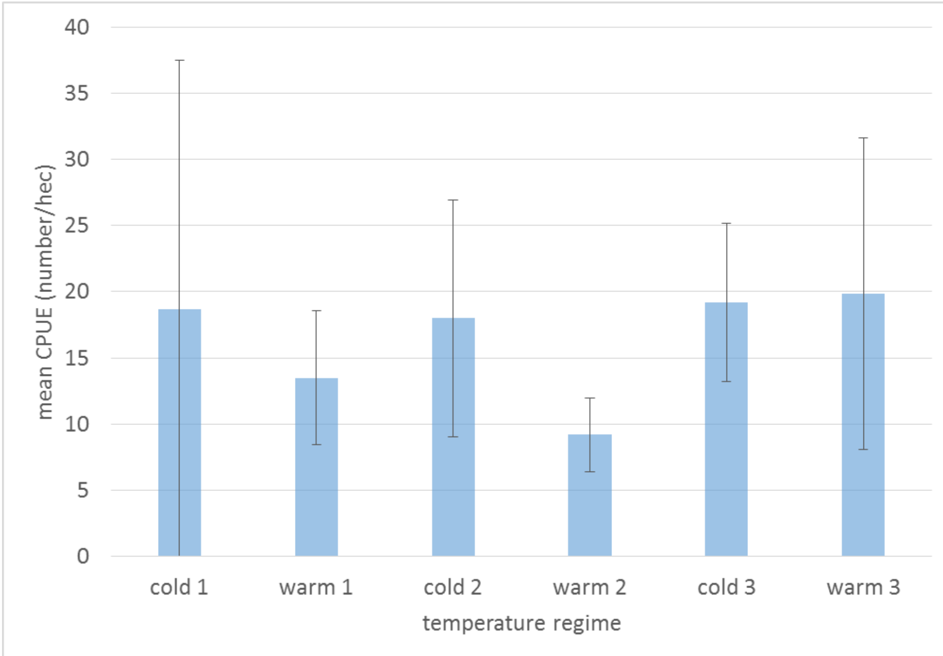

Figure 5. Mean catch-per-unit-effort (CPUE; number/ hec) of **capelin** in the eastern Bering Sea shelf bottom trawl survey by temperature regime. Error bars indicate 95% confidence interval.

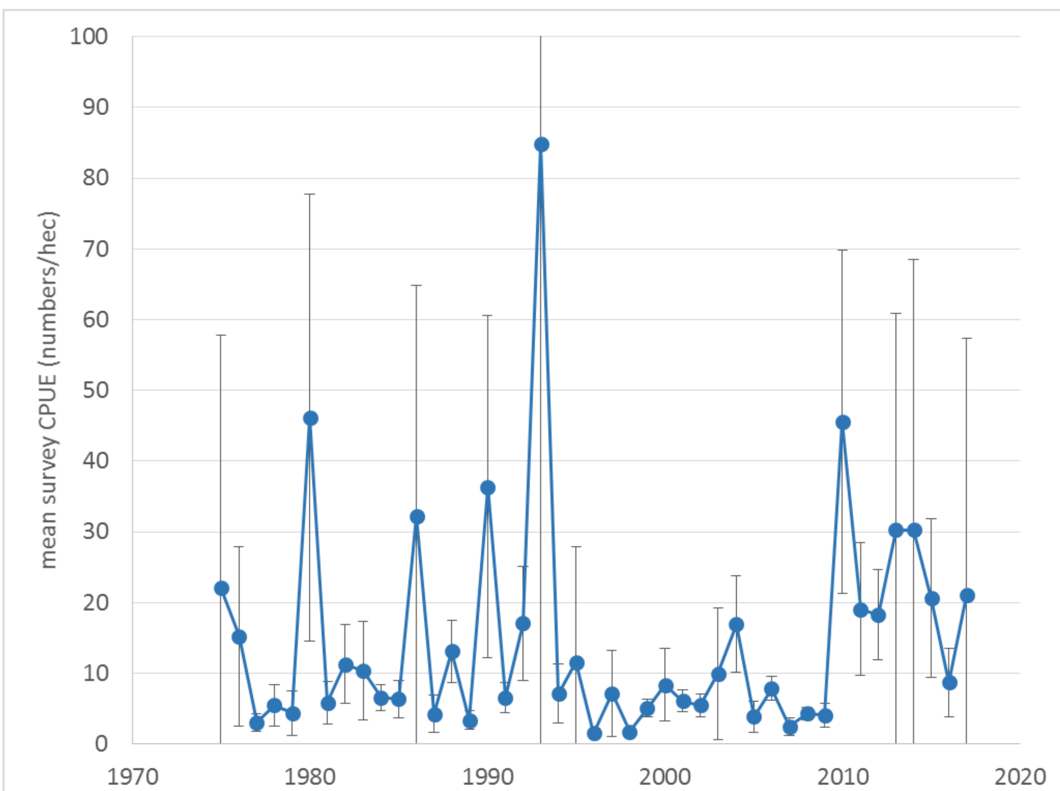

Figure 6. Annual catch-per-unit-effort (CPUE; number/ hec) of **capelin** in the eastern Bering Sea shelf bottom trawl survey. Error bars indicate 95% confidence interval.

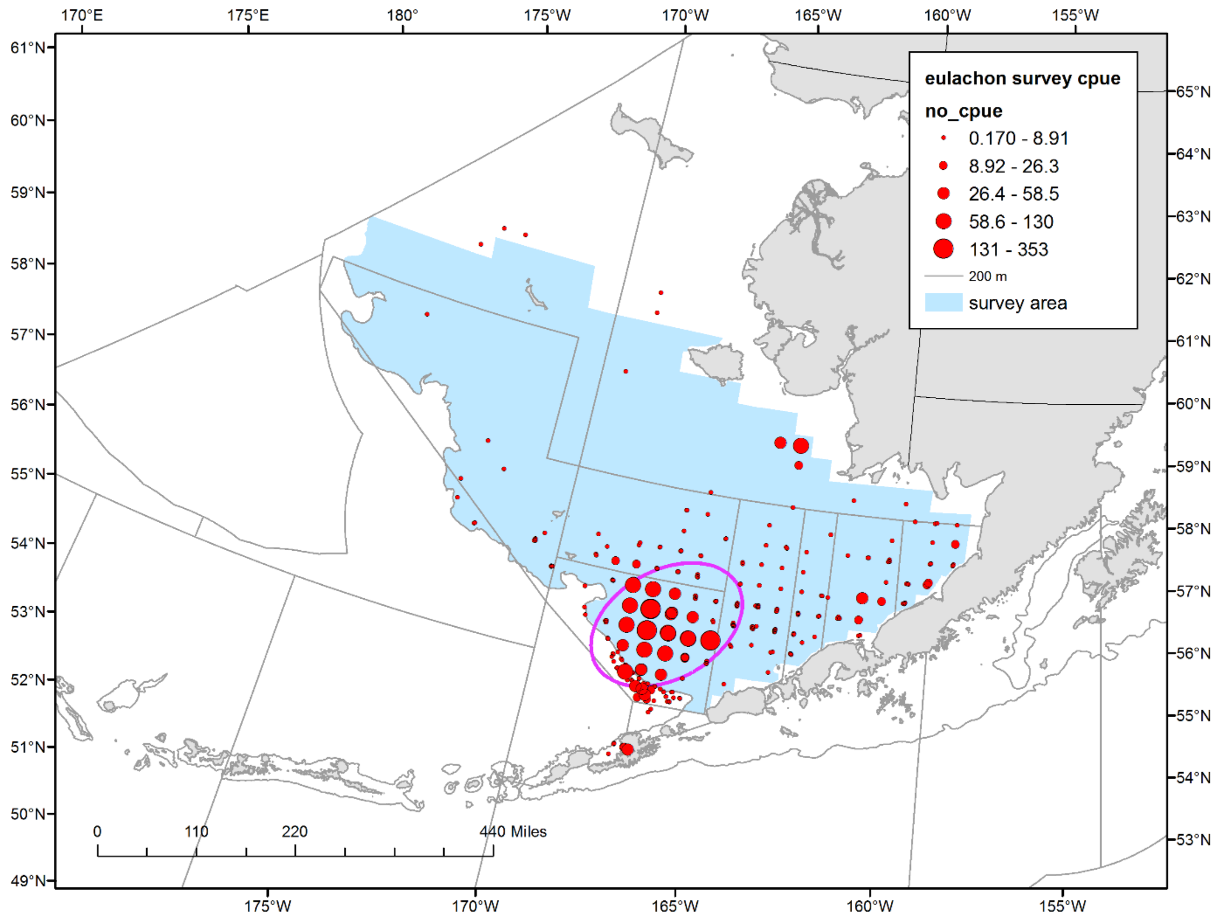

Figure 7. Mean catch-per-unit-effort (CPUE; number/km^2) of **eulachon** in NMFS Bering Sea/Aleutian Islands (BSAI) bottom trawl surveys, 2006-2017. Oval indicates weighted standard deviational ellipse, which includes all points within one standard deviation of the distribution's mean geographic center.

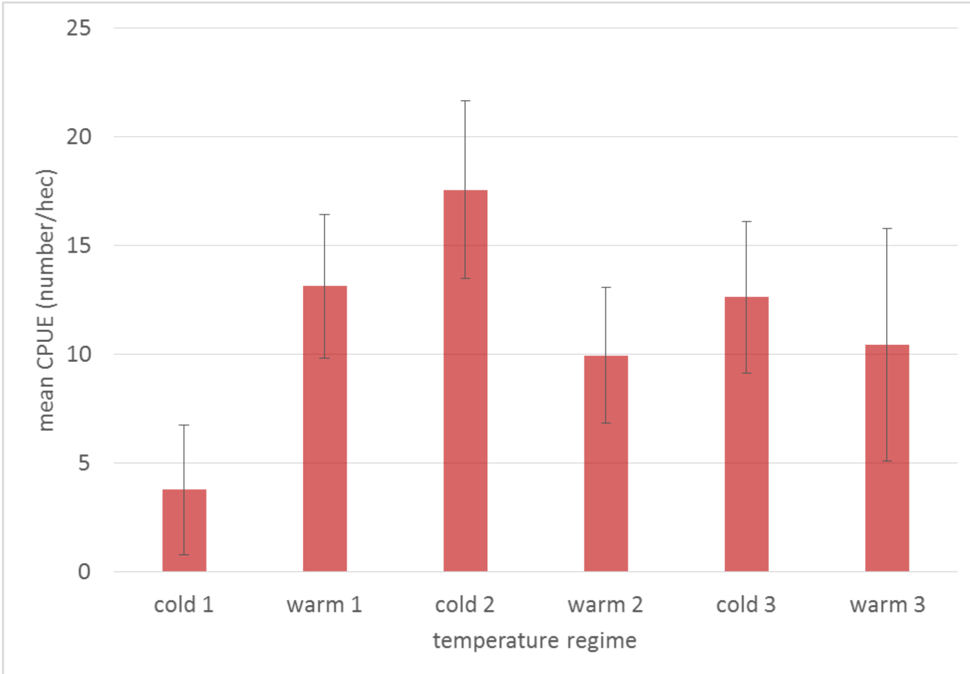

Figure 8. Mean catch-per-unit-effort (CPUE; number/ hec) of **eulachon** in the eastern Bering Sea shelf bottom trawl survey by temperature regime. Error bars indicate 95% confidence interval.

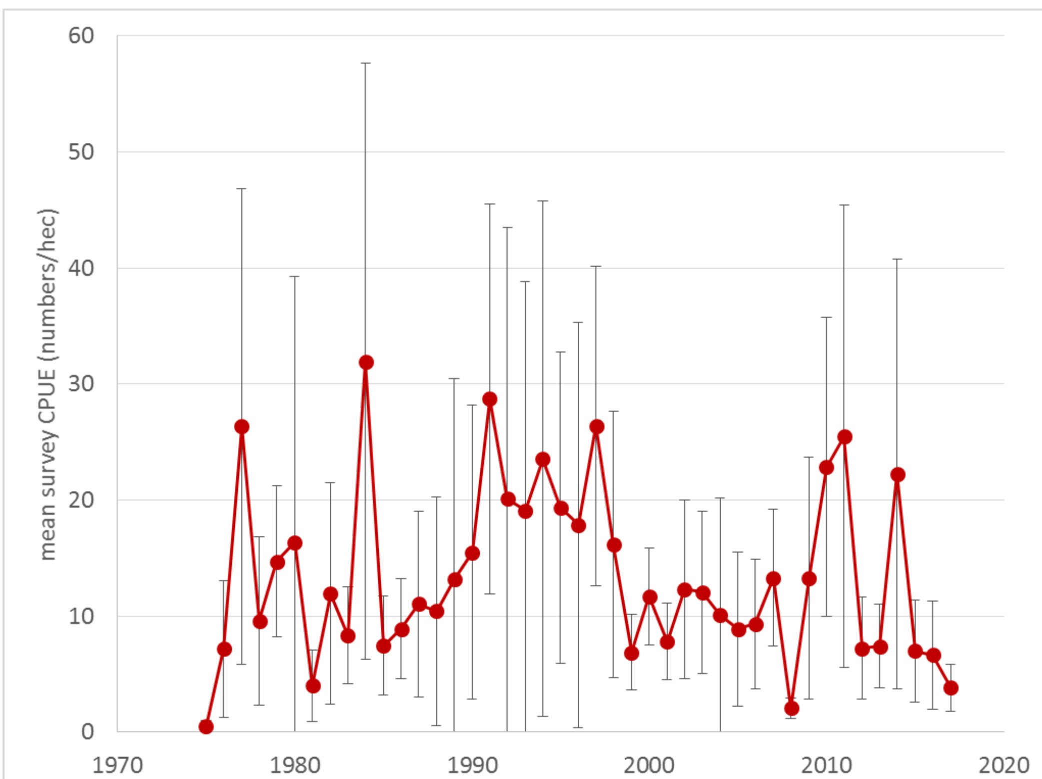

Figure 9. Annual mean catch-per-unit-effort (CPUE; number/ hec) of **eulachon** in the eastern Bering Sea shelf bottom trawl survey. Error bars indicate 95% confidence interval.

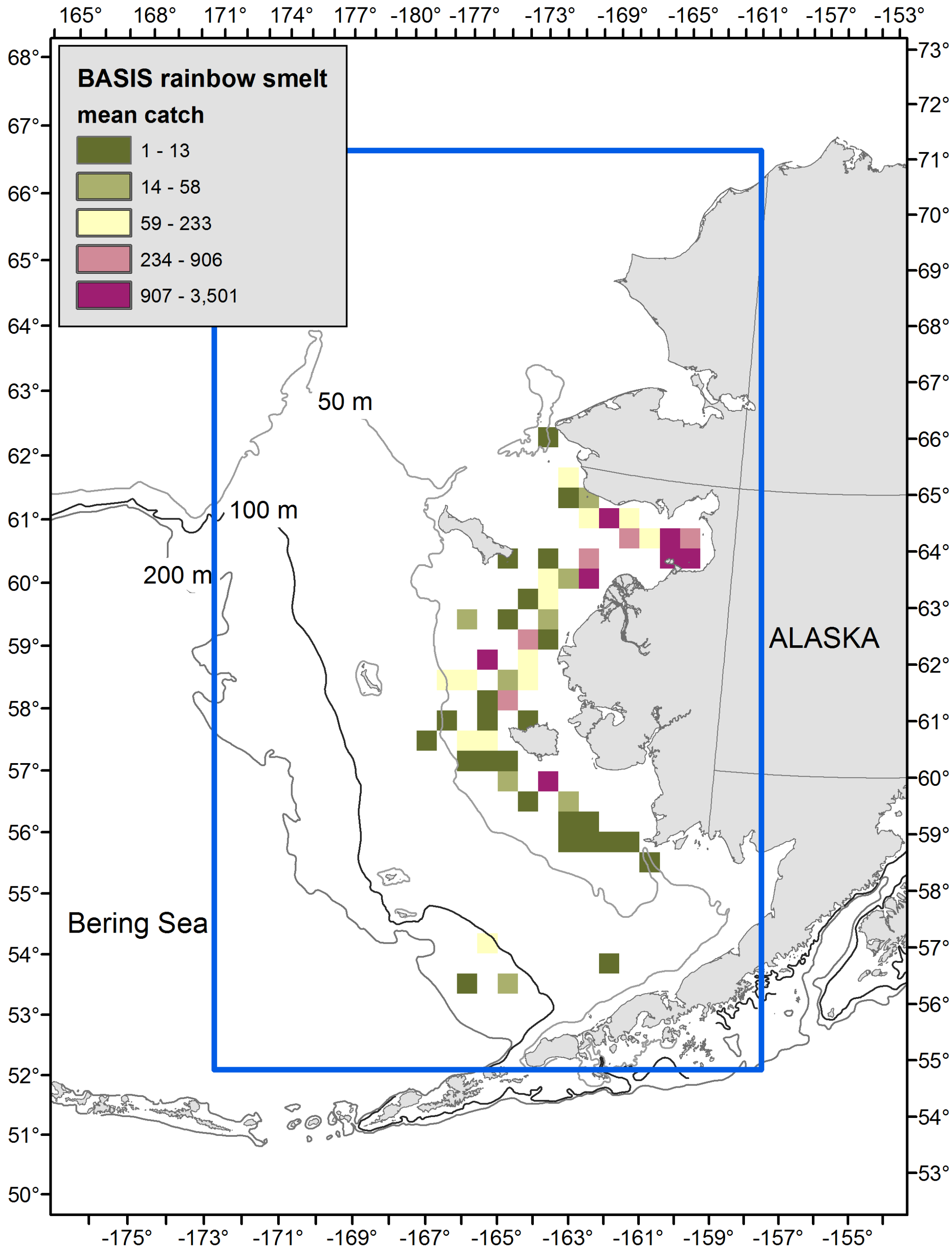

Figure 10. Mean catch (in numbers) of rainbow smelt in surface-trawl surveys conducted by the Ecosystem Monitoring and Assessment program in the eastern Bering Sea, 2002-2011. Grid cells are 20 km X 20 km. Blue box indicates approximate extent of survey hauls over the entire time period.

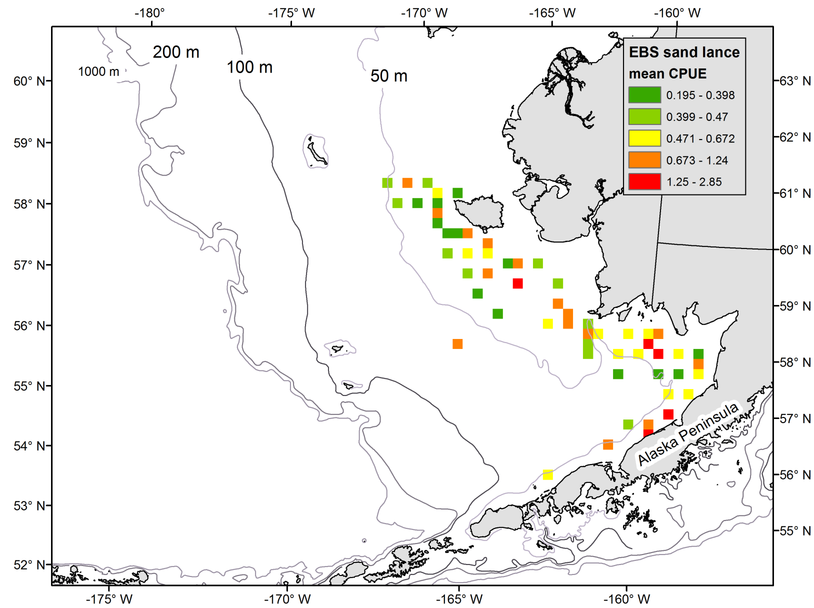

Figure 11. Mean catch-per-unit-effort (CPUE; kg/km^2) of Pacific sand lance in the NMFS eastern Bering Sea shelf survey, 2000-2017. Grid cells are 20 km X 20 km.

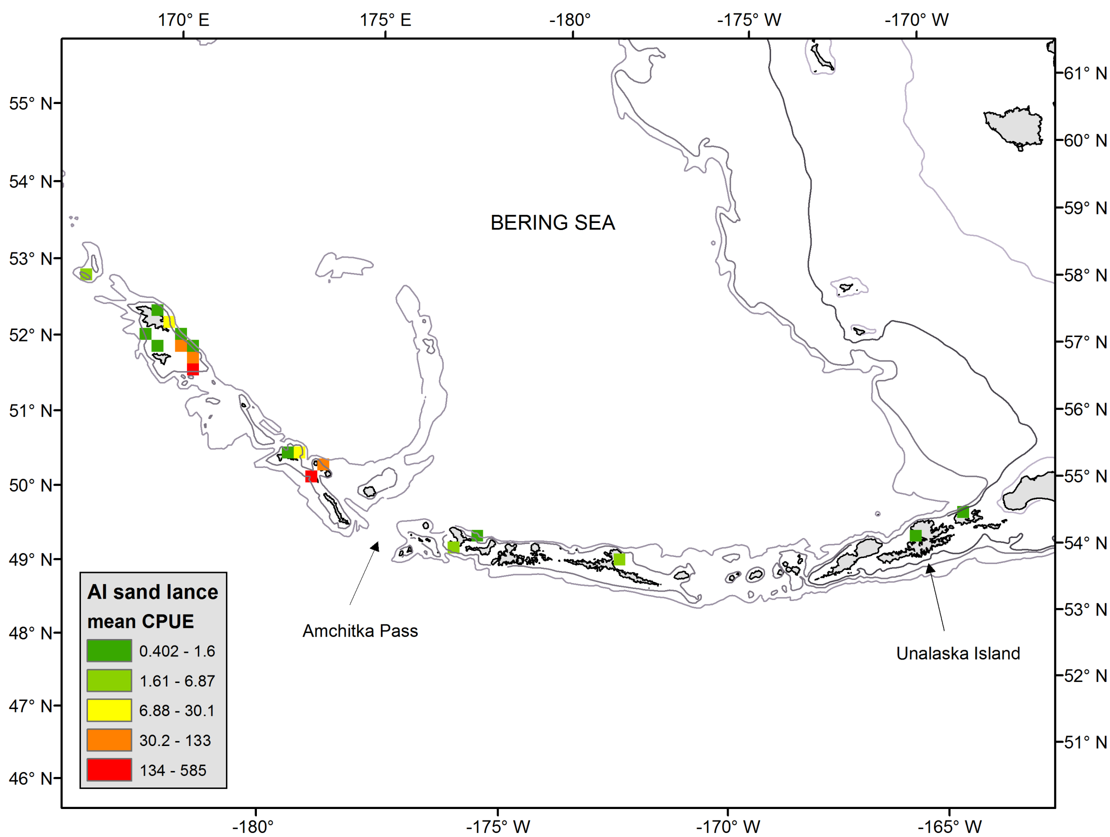

Figure 12. Mean catch-per-unit-effort (CPUE; kg/km^2) of Pacific sand lance in the NMFS Aleutian Islands bottom trawl survey, 2000-2016. Grid cells are 20 km X 20 km.

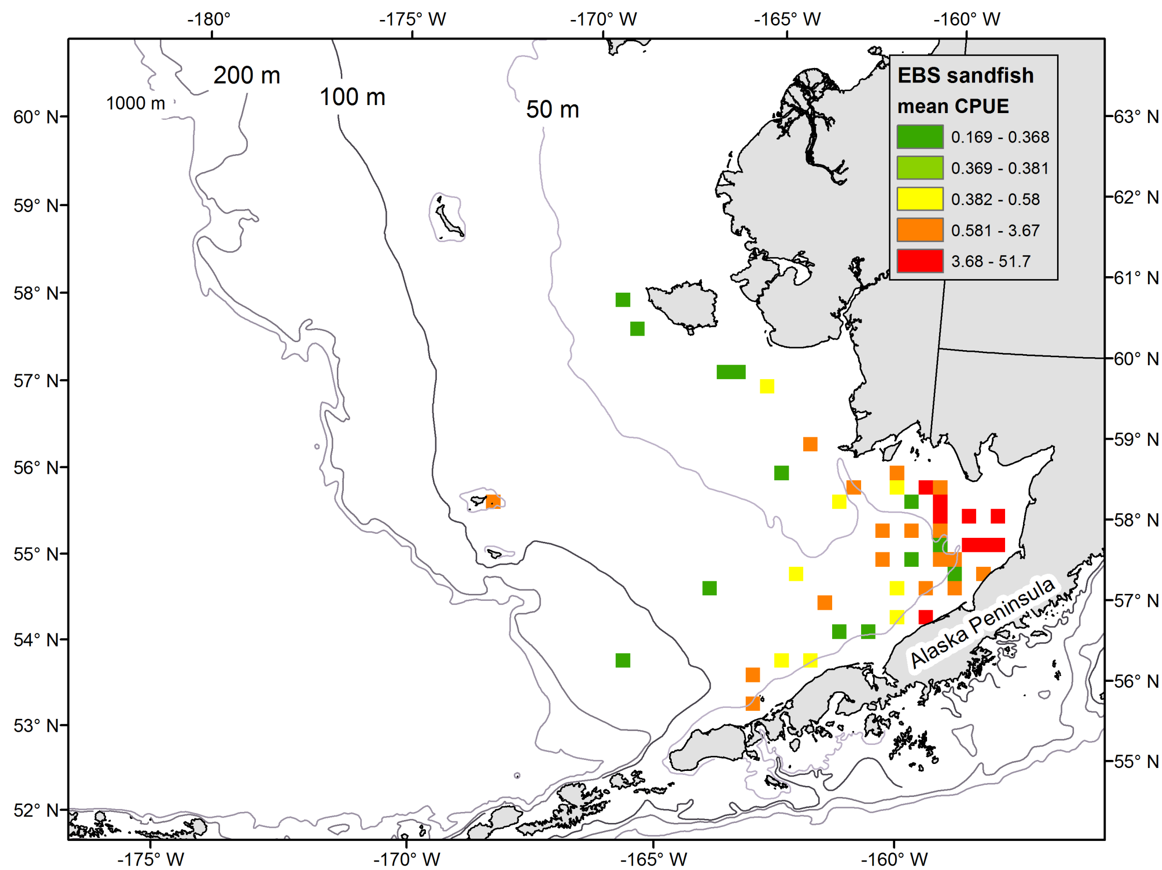

Figure 13. Mean catch-per-unit-effort (CPUE; kg/km^2) of Pacific sandfish in the NMFS eastern Bering Sea bottom trawl survey, 2000-2017. Grid cells are 20 km X 20 km.

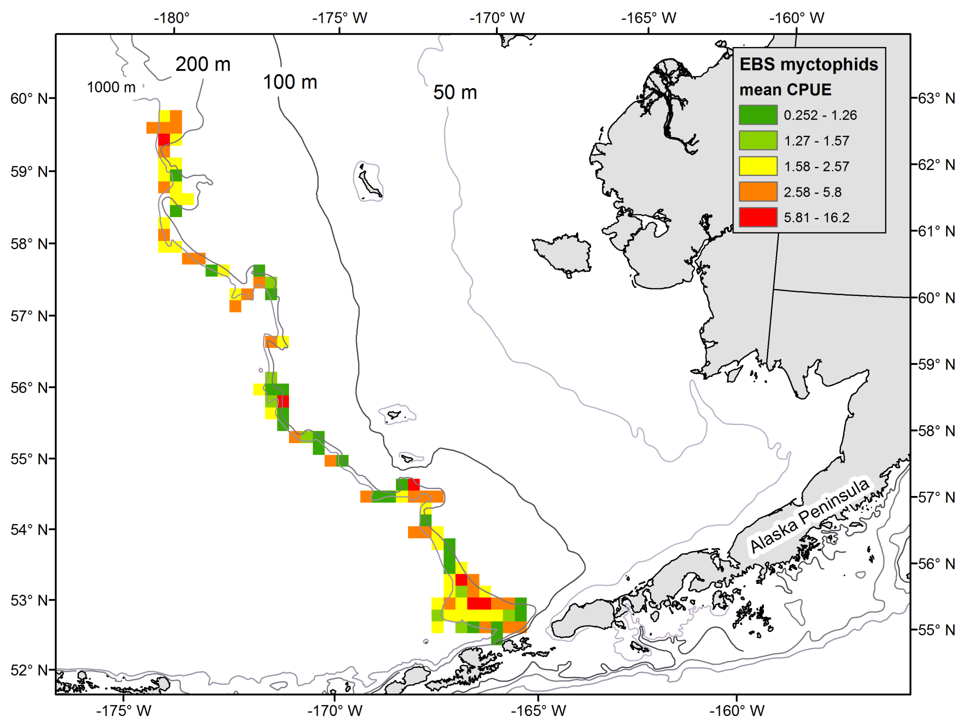

Figure 14. Mean catch-per-unit-effort (CPUE; kg/km^2) of myctophids in the NMFS eastern Bering Sea shelf and slope bottom trawl surveys, 2000-2017. Grid cells are 20 km X 20 km.

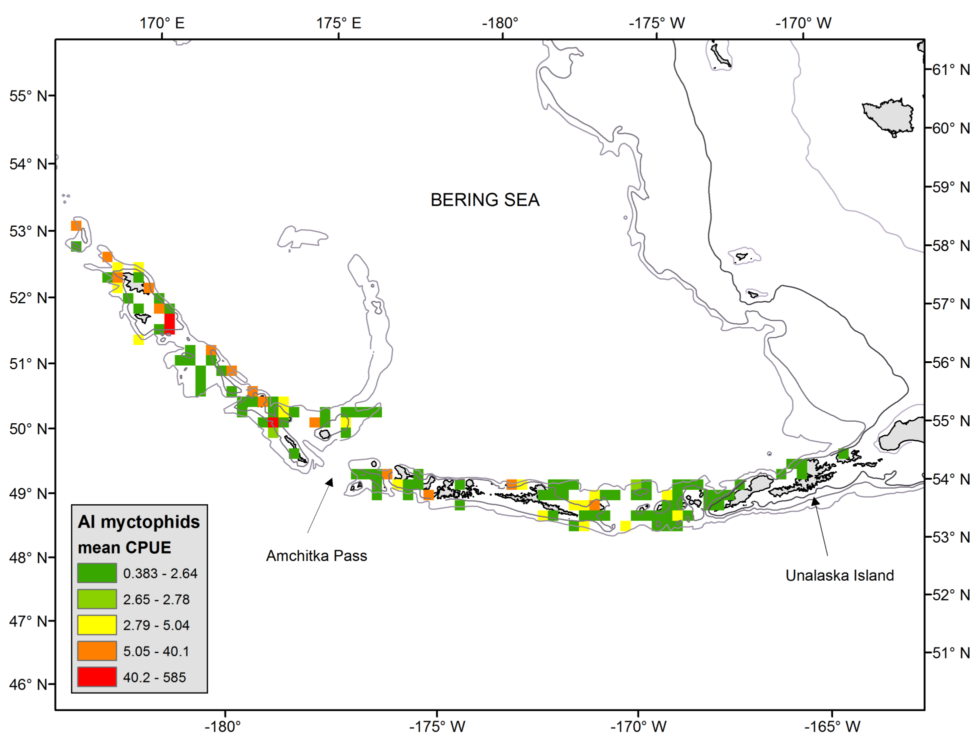

Figure 15. Mean bottom trawl survey catch-per-unit-effort (CPUE; kg/km^2) of myctophids in the NMFS Aleutian Islands bottom trawl survey, 2000-2016. Grid cells are 20 km X 20 km.

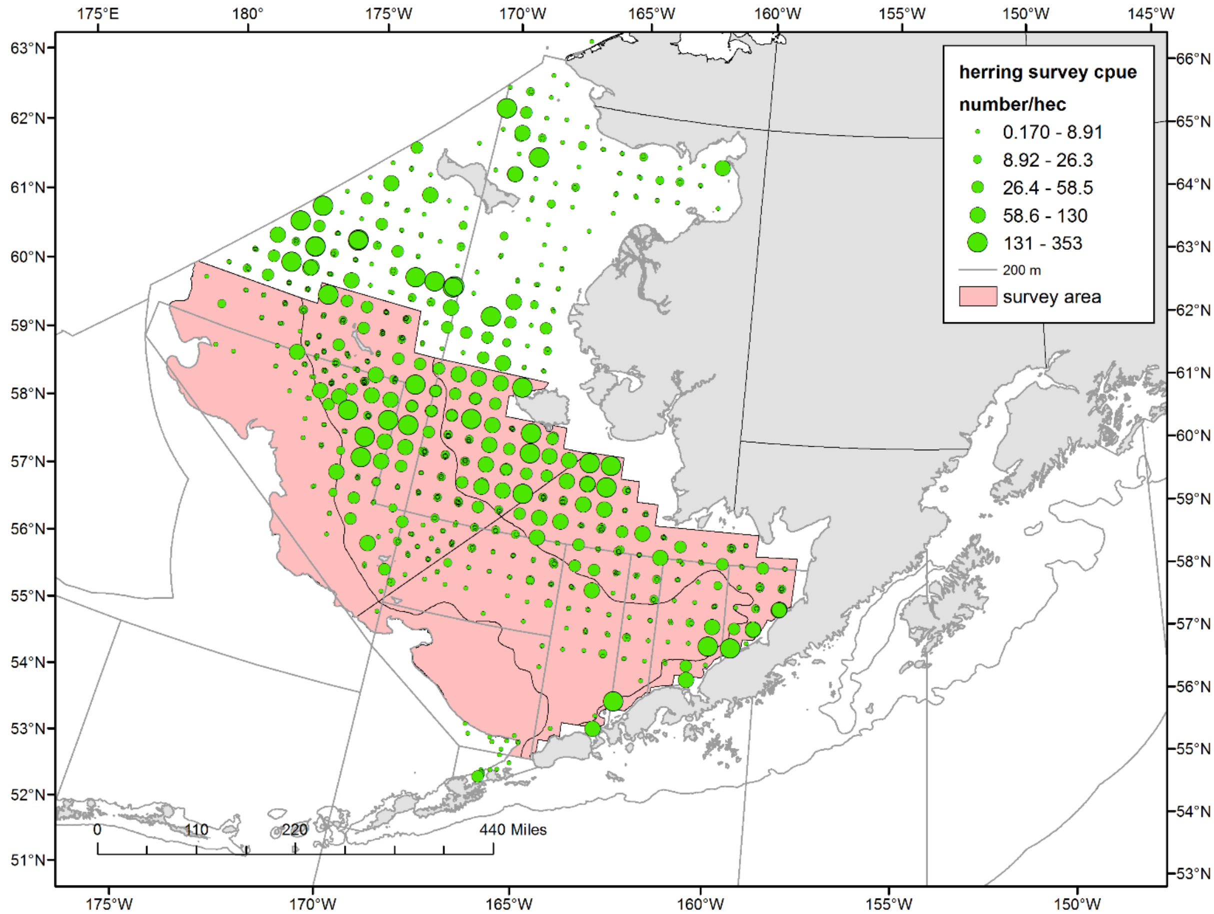

Figure 16. Mean catch-per-unit-effort (CPUE; number/km^2) of **Pacific herring** in the NMFS Bering Sea/Aleutian Islands bottom trawl surveys, 2006-2017.

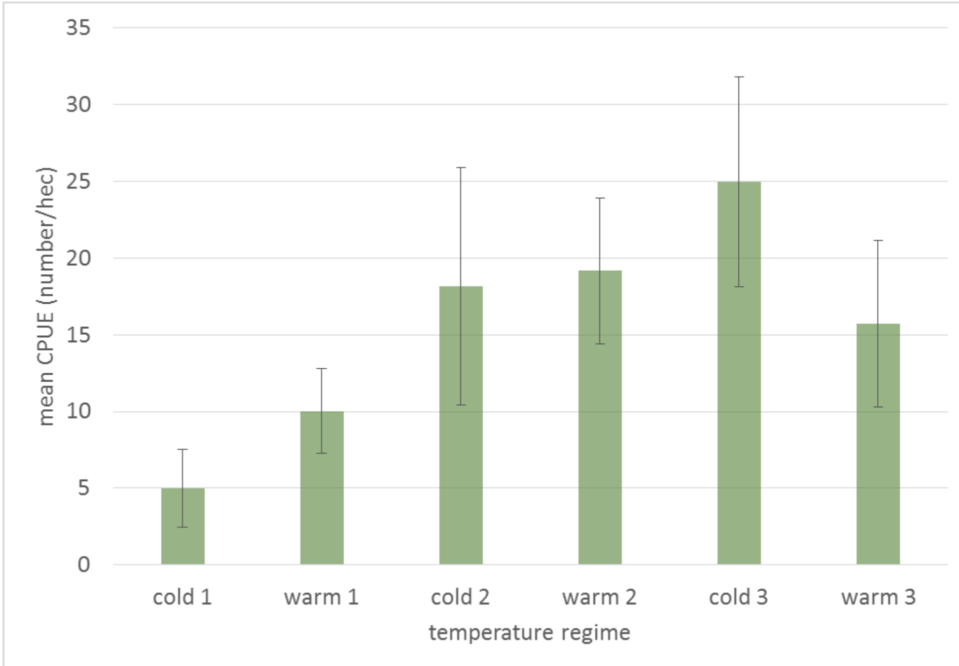

Figure 17. Mean catch-per-unit-effort (CPUE; number/ hec) of **Pacific herring** in the eastern Bering Sea shelf bottom trawl survey by temperature regime. Error bars indicate 95% confidence interval.

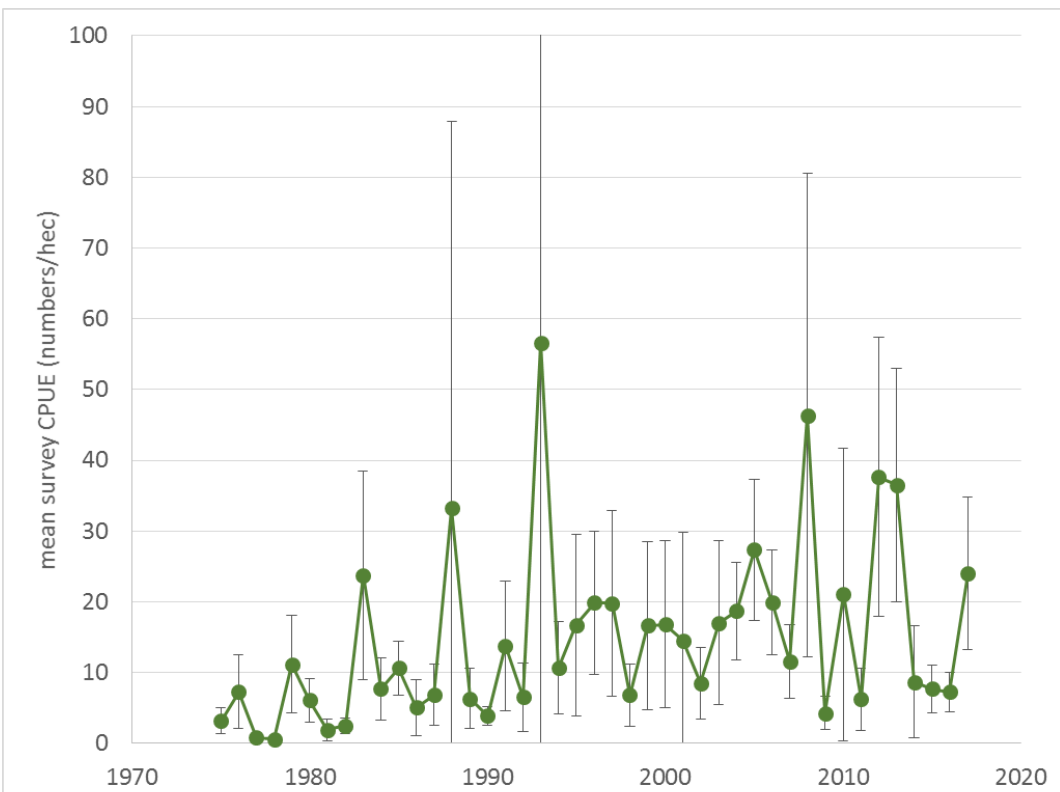

Figure 18. Annual mean catch-per-unit-effort (CPUE; number/ hec) of **Pacific herring** in the eastern Bering Sea shelf bottom trawl survey. Error bars indicate 95% confidence interval.

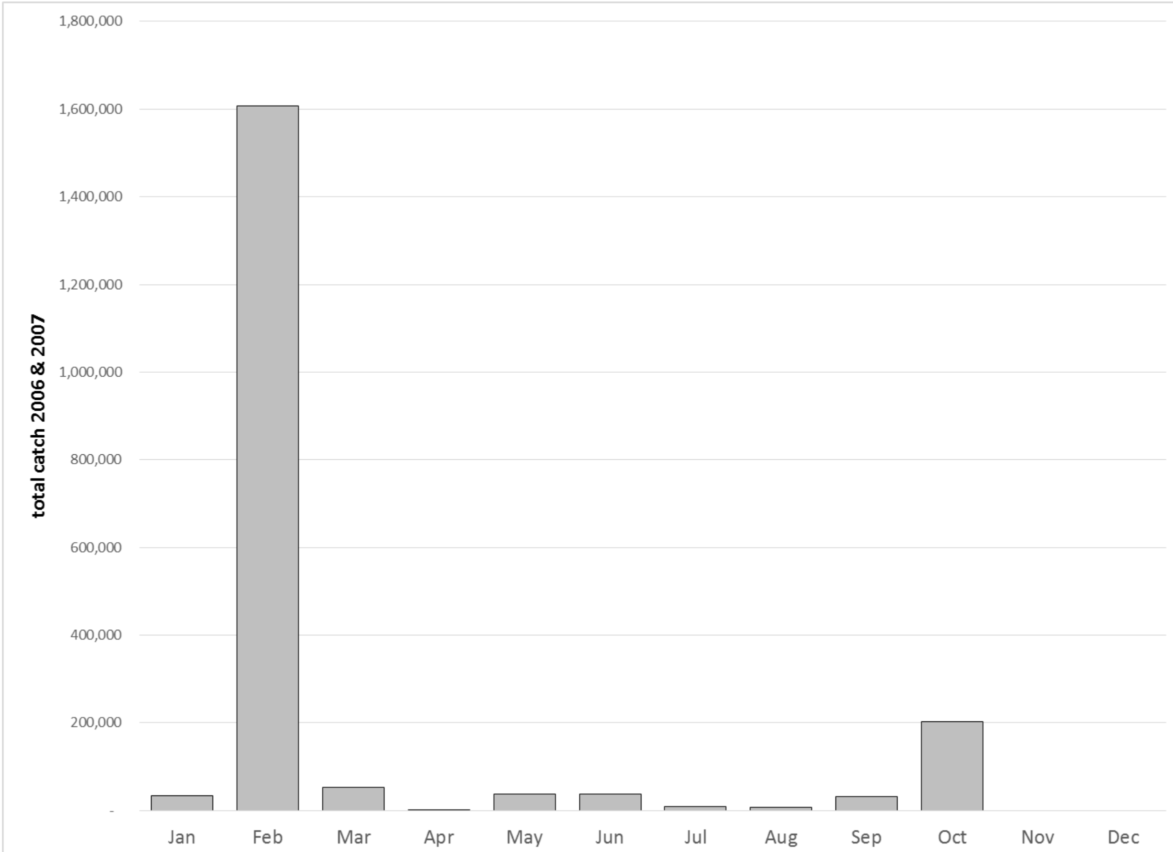

Figure 19. Seasonal pattern of observed eulachon catches (numbers) in the Bering Sea/Aleutian Islands region during 2006 & 2007.

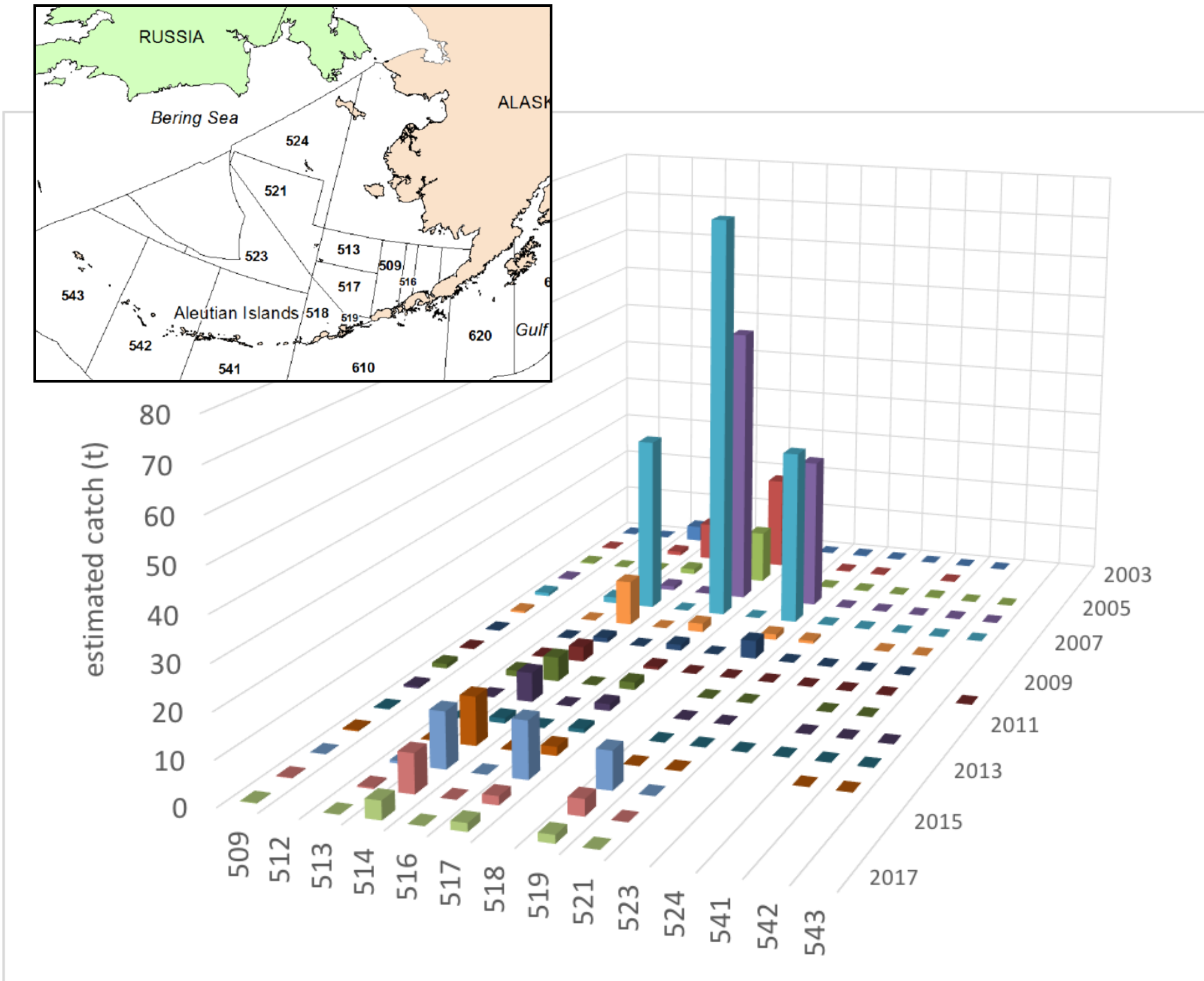

Figure 20. Incidental catches (t) of all osmerids (eulachon, capelin, surf smelt, "other osmerids") in the Bering Sea/Aleutian Islands (BSAI) by NMFS statistical area, 2003-2017. 2017 data are incomplete; retrieved on November 1, 2017. Inset map shows the boundaries of the statistical areas.

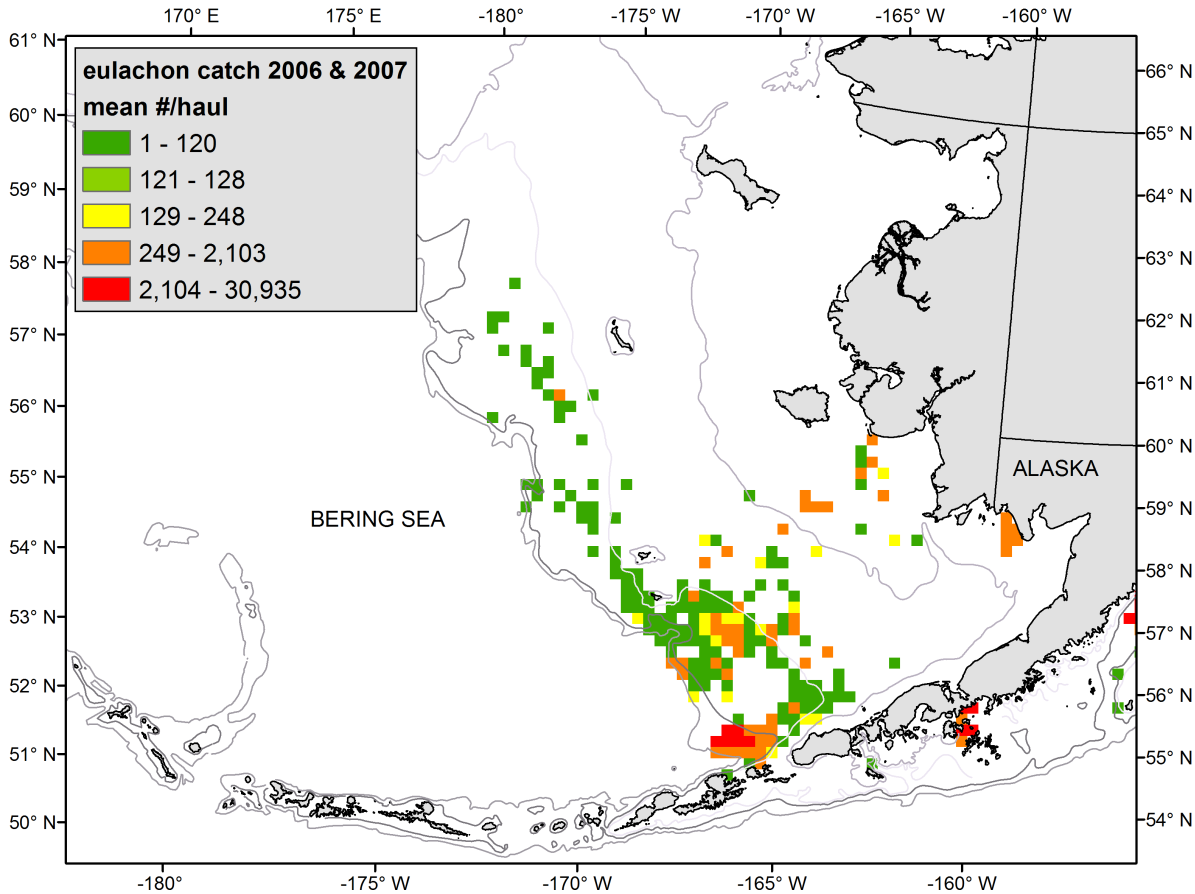

Figure 21. Mean catches of eulachon in observed fishery hauls (number/haul) in the Bering Sea and Aleutian Islands (BSAI) during 2006 & 2007.

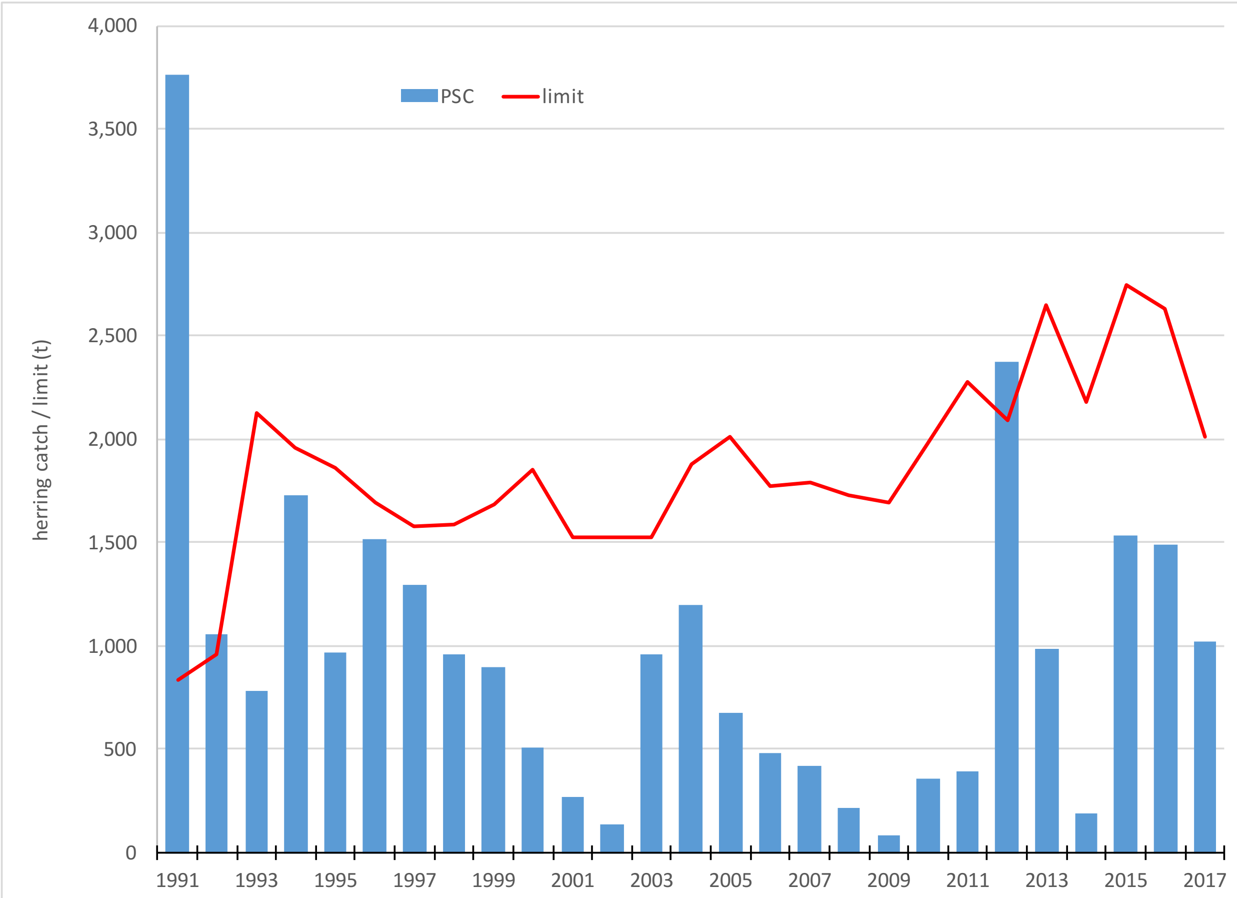

Figure 22. Catch (t) of Pacific herring in federally-managed groundfish fisheries in the Bering Sea and Aleutian Islands, 1991-2017 (blue bars). The annual limit on Prohibited Species Catch (PSC) of herring is indicated by a red line. Data are from the NMFS Alaska Regional Office. 2017 data are incomplete; retrieved on October 23, 2017.

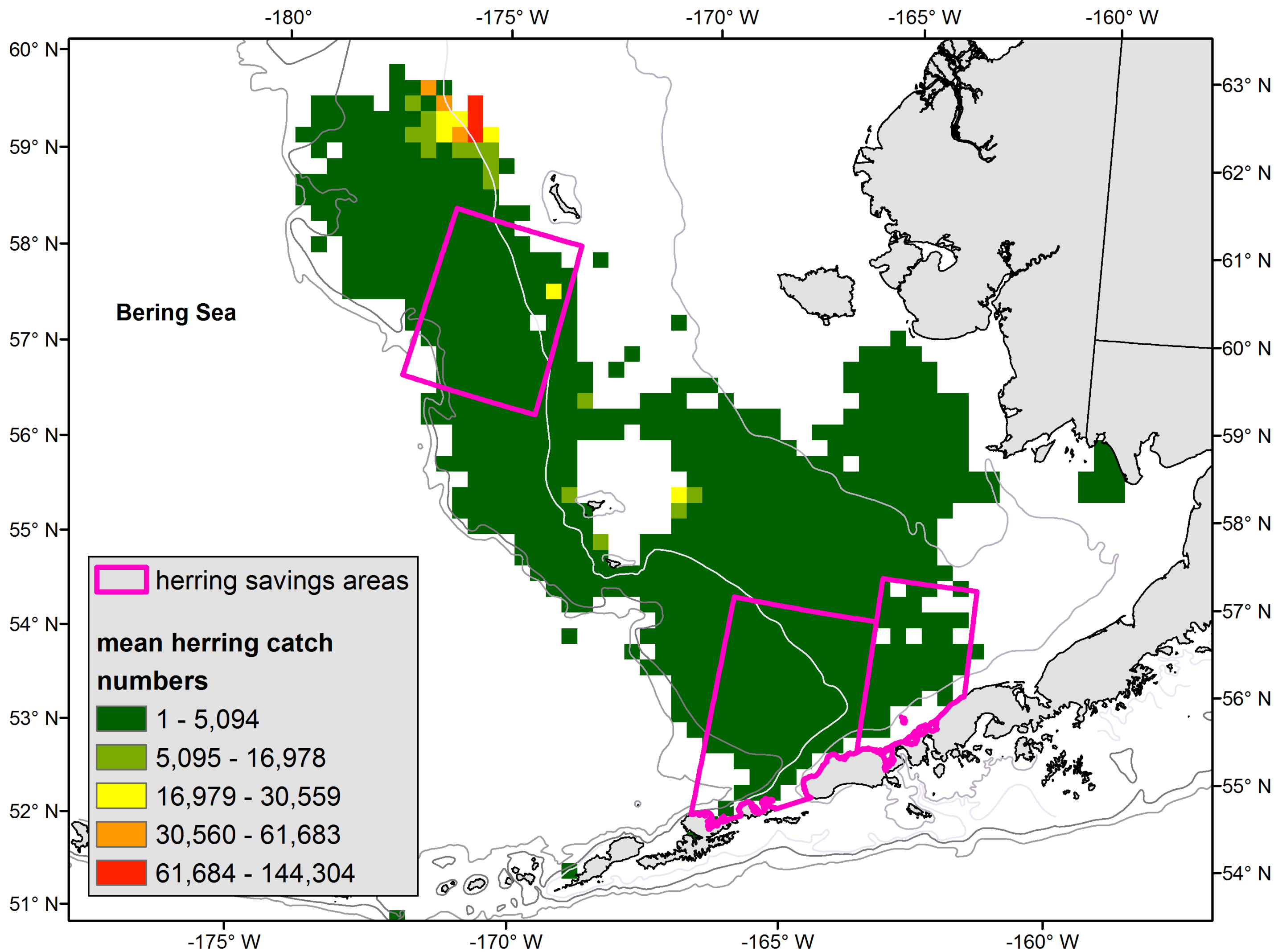

Figure 23. Mean observed catch (number/haul) of Pacific herring in commercial groundfish hauls in the Bering Sea/Aleutian Islands region, 2010-2017. Grid cells are 20 km X 20 km. Fuchsia-outlined polygons indicate Herring Savings Areas.

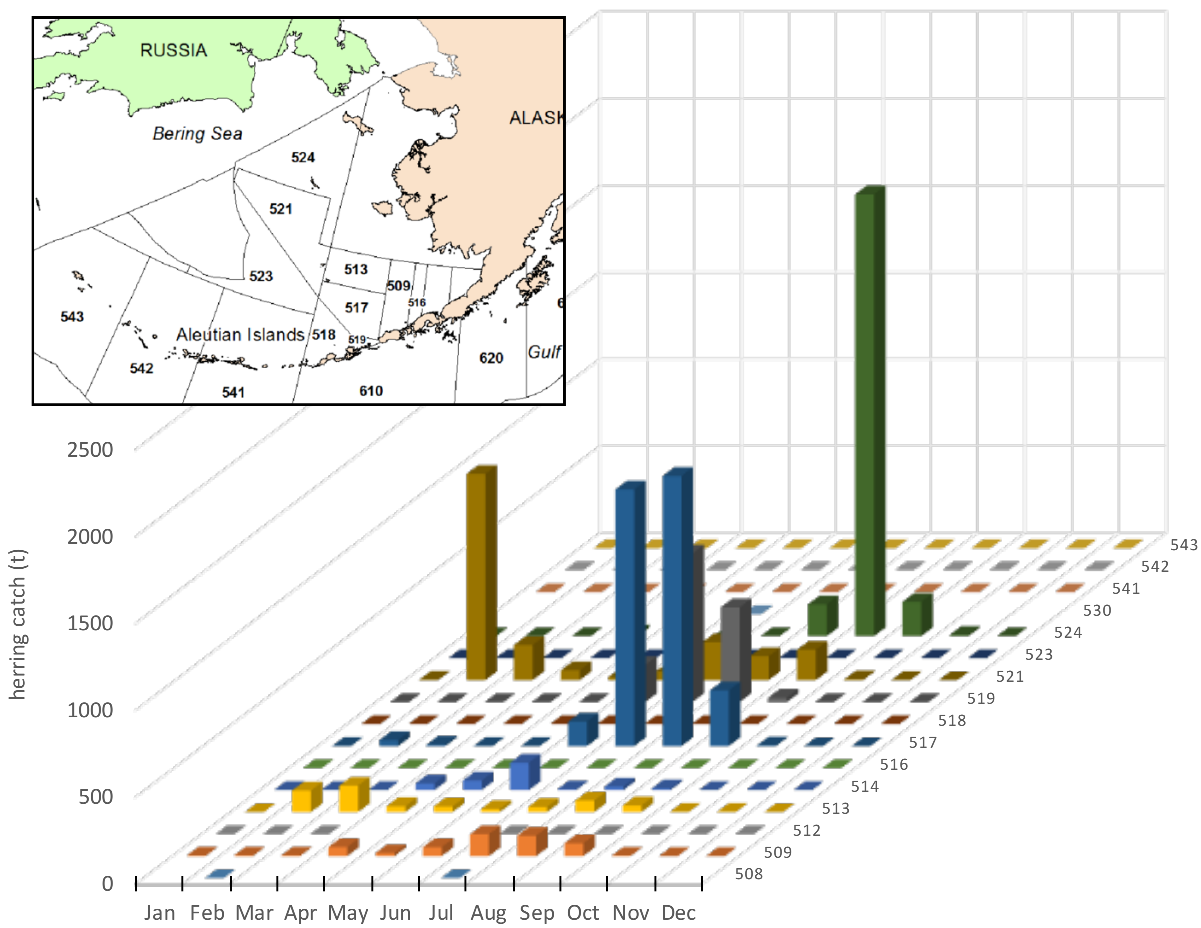

Figure 24. Seasonal and spatial patterns of observed Pacific herring catches (t) in federally-managed groundfish fisheries in the Bering Sea and Aleutian Islands, 2003-2017. Data are from the NMFS Alaska Regional Office. 2017 data are incomplete; retrieved on October 23, 2017. Numbers on the depth axis refer to the NMFS statistical areas outlined in the inset map.

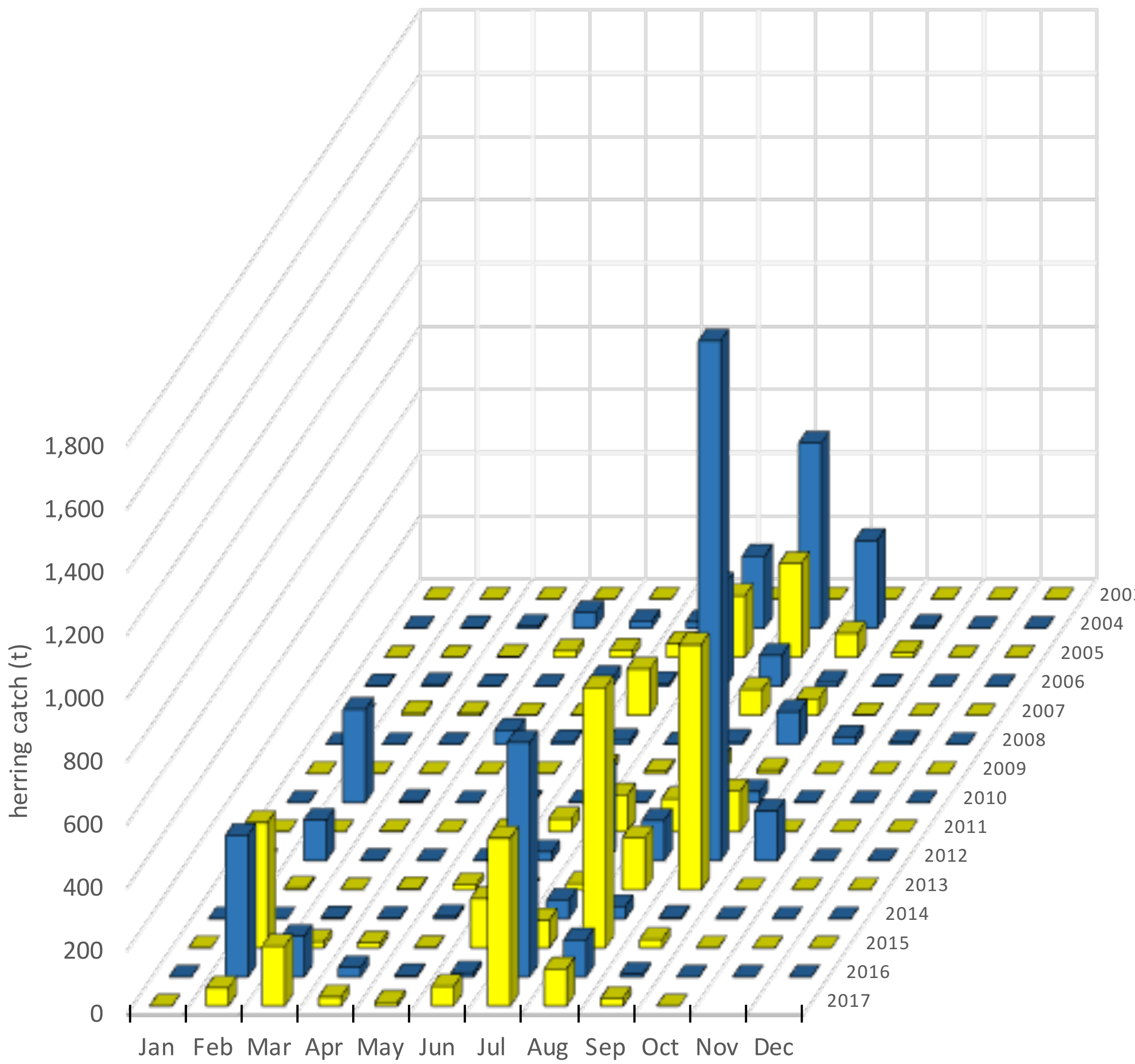

Figure 25. Seasonal and annual patterns of observed Pacific herring catches (t) in federally-managed groundfish fisheries in the Bering Sea and Aleutian Islands, 1991-2017. Data are from the NMFS Alaska Regional Office. 2017 data are incomplete; retrieved on October 23, 2017.

Appendix: List of scientific and common names of species contained within the "FMP forage fish" category. Data sources: BSAI FMP, "Fishes of Alaska" (Mecklenburg et al. 2002).

Scientific Name	Common Name
Family Osmeridae	smelts
Mallotus villosus	capelin
Hypomesus pretiosus	surf smelt
Osmerus mordax	rainbow smelt
Thaleichthys pacificus	eulachon
Spirinchus thaleichthys	longfin smelt
Spirinchus starksi	night smelt
Family Myctophidae	lanternfish
Protomyctophum thompsoni	bigeye lanternfish
Benthosema glaciale	glacier lanternfish
Tarletonbeania taylori	taillight lanternfish
Tarletonbeania crenularis	blue lanternfish
Diaphus theta	California headlightfish
Stenobrachius leucopsarus	northern lampfish
Stenobrachius nannochir	garnet lampfish
Lampanyctus jordani	brokenline lanternfish
Nannobrachium regale	pinpoint lampfish
Nannobrachium ritteri	broadfin lanternfish
Family Bathylagidae	blacksmelts
Leuroglossus schmidti	northern smoothtongue
Lipolagus ochotensis	popeye blacksmelt
Pseudobathylagus milleri	stout blacksmelt
Bathylagus pacificus	slender blacksmelt
Family Ammodytidae	sand lances
Ammodytes hexapterus	Pacific sand lance
Family Trichodontidae	sandfish
Trichodon trichodon	Pacific sandfish
Arctoscopus japonicus	sailfin sandfish
Family Pholidae	gunnels
Apodichthys flavidus	penpoint gunnel
Rhodymenichthys dolichogaster	stippled gunnel
Pholis fasciata	banded gunnel
Pholis clemensi	longfin gunnel
Pholis laeta	crescent gunnel
Pholis schultzi	red gunnel

Scientific Name	**Common Name**
Family Stichaeidae	pricklebacks
Eumesogrammus praecisus	fourline snakeblenny
Stichaeus punctatus	arctic shanny
Gymnoclinus cristulatus	trident prickleback
Chirolophis tarsodes	matcheek warbonnet
Chirolophis nugatory	mosshead warbonnet
Chirolophis decoratus	decorated warbonnet
Chirolophis snyderi	bearded warbonnet
Bryozoichthys lysimus	nutcracker prickleback
Bryozoichthys majorius	pearly prickleback
Lumpenella longirostris	longsnout prickleback
Leptoclinus maculates	daubed shanny
Poroclinus rothrocki	whitebarred prickleback
Anisarchus medius	stout eelblenny
Lumpenus fabricii	slender eelblenny
Lumpenus sagitta	snake prickleback
Acantholumpenus mackayi	blackline prickleback
Opisthocentrus ocellatus	ocellated blenny
Alectridium aurantiacum	lesser prickleback
Alectrias alectrolophus	stone cockscomb
Anoplarchus purpurescens	high cockscomb
Anoplarchus insignis	slender cockscomb
Phytichthys chirus	ribbon prickleback
Xiphister mucosus	rock prickleback
Xiphister atropurpureus	black prickleback
Family Gonostomatidae	bristlemouths
Sigmops gracilis	slender fangjaw
Cyclothone alba	white bristlemouth
Cyclothone signata	showy bristlemouth
Cyclothone atraria	black bristlemouth
Cyclothone pseudopallida	phantom bristlemouth
Cyclothone pallida	tan bristlemouth
Order Euphausiacea	krill