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

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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 Council 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 updates 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

Summary of updates

1) The format of the report has been altered to better reflect its purpose, and a "data gaps and research priorities" section has been added.
2) For three of the most important BSAI forage species (capelin, eulachon, Pacific herring) the analysis of temporal trends in abundance and spatial distribution has been greatly enhanced.
3) The bycatch section contains much more detail, especially regarding bycatch of Pacific herring.

Responses to Plan Team and SSC comments

<u>From the December 2013 SSC minutes:</u>
"Currently, the list of species included in the BSAI report is very similar to those in the GOA. While understanding the need to be broad in what is considered to be a "forage species", the differences in species compositions between the two regions should be explored in more detail."

> *Response: The report contains many species that are found in abundance in both areas, but also includes some species (e.g. rainbow smelt and Arctic cod) that are found only in the BSAI.*

"The overview of the different forage species or species groups could be substantially expanded, primarily with basic life history information. There are also several references in the overviews (e.g. with shrimps) where it is stated that additional information is available in the monitoring section. However, there is little or no information presented in that section. This information, if it exists, needs to be included or these references removed."

Response: Aside from Pacific herring, life-history information for the forage species described here is very limited and is not yet included in the report. The references in the overviews have been revised and the content of the later sections clarified.

"The information presented on the geographic distribution of forage species is very informative, particularly the figures from the bottom trawl and BASIS surveys. However, parts of this section are structured by survey (e.g. "bottom trawl survey data") while others are structured by species group (e.g. "euphausiids"). The SSC requests that this section be structured by species or species group, acknowledging that this would require synthesizing information from multiple data sources in some cases. Care should be taken to separate the apparent shifts in distribution due to the timing of surveys that may detect seasonal migrations from interannual variability and larger-scale shifts in distributions."

Response: This section has been completely redone, along with the structure of the report. Information on abundance, distribution, and catch are all structured by species or species group. The analysis has been greatly expanded and includes discussions of survey timing and species behaviors.

"Similar to the GOA forage species report, the SSC requests a "data gaps and research priorities" section."

Response: A "data gaps and research priorities" section has been added at the end of the report.

"On page 1040, there is larger herring PSC in 2012 and the herring PSC limit was exceeded for the first time in the dataset time series. Does this spike in herring show up in any other data sets? Are there additional data from ADF&G that could be pulled into the discussion of herring in this report?"

Response: The connection between herring PSC in federal fisheries and other information regarding herring has been greatly expanded.

<u>From the October 2015 SSC minutes:</u>

"The SSC had several suggestions for additions and clarifications to be addressed, to the extent possible, prior to the December meeting. 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 author was unable to conduct additional analysis in time for the November 2015 report submission. The suggested work will be a major focus of the next report.

"The SSC asked for additional clarification on the Togiak herring biomass estimates used in Figure 29, specifically whether these estimates were from aerial surveys or from age-structured model estimates, and what component of the population they represented (e.g., mature biomass, spawning biomass, mature and immature biomass combined). If the biomass estimates were from the aerial survey, it would be valuable to investigate the conditions during the surveys for each year, as this could affect whether the estimates are more or less likely to represent spawning or mature biomass. If the estimates were from the Togiak herring age-structured model, a four-year running average is not recommended."

Response: The original document used estimates that were a mixture of survey estimates and pre-season forecasts (model estimates). For the final version of the 2015 report, only the survey estimates were used except in those years where survey estimates were unavailable. The text also *now includes more detail regarding the source and uncertainty of the estimates. The author recognizes that more work is needed regarding the use of the herring biomass data and this will be included in the next report.*

"There were also two suggestions for additional research priorities for Pacific herring."

Response: The suggestions have been incorporated into the relevant research priorities.

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*

<u>Forage fish group in the FMP</u>

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 group is large and diverse, containing over fifty species from these 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) Definition. See Table 2c to this part.
(2) Applicability.
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, has 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).

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 are managed as "in the fishery" due to high levels of incidental catch, mainly in the fisheries for walleye pollock. 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 using 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 two large-scale surveys that are conducted regularly by the AFSC:

1) Bottom trawl surveys are conducted 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 earlier; the EBS slope and AI surveys have occurred consistently since the early 2000s. The surveys are conducted from May to August. The EBS shelf survey has also occasionally visited the northeastern Bering Sea.
2) Surface trawl surveys are conducted as part of the Bering Arctic Subarctic Integrated Survey (BASIS; http://www.afsc.noaa.gov/ABL/EMA/EMA_BASIS.php). 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 and is included here. 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 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.

<u>Regime classification</u>

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, data were aggregated according to five temperature regimes (Figure 3). 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 of <2° C temperatures known as the cold pool. Regimes were identified, specifically for this report, as series of consecutive years with either 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 began in 1975, the first year for which CPUE data are available:

1975-1976: cold 1
1977-1987: warm 1
1988-2000: cold 2
2001-2005: warm 2
2006-2013: cold 3

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 included in the 2015 report. There appears to be strong cross-shelf partitioning among the six species/ species groups studied (Figure 4). 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) was 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 5). The pattern of CPUE varies substantially between the surface and bottom trawl surveys, with catches in the BASIS survey occurring much further north than in the trawl survey. However, capelin were caught at only a small number of BASIS stations. 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 the length of the survey timeseries; this is discussed in greater detail below.

The distribution and abundance of capelin varied in a consistent manner with temperature regime, with one important exception. During cold regimes capelin had a larger distribution than during warm regimes, and the warm distributions were narrower and aligned more closely with the inner domain of the EBS shelf (Figure 6; capelin location data were not available for 1975-1976 so cold regime 1 was not included in the spatial analysis). In addition, mean survey CPUE was consistently higher during cold regimes (Figure 7), although the annual mean CPUE data indicate substantial interannual variability (Figure 8). The annual data from both surveys are consistent in displaying increased mean CPUEs during the late 2000s.

Warm-regime distributions were almost identical, while the later cold regime was associated with a northern shift in distribution. This northerly shift may be responsible for the difference in overall distribution between the two surveys. The BASIS survey has been conducted only since 2003, so most of the survey has occurred during the latest cold regime (2006-2013). The corresponding trawl-survey distribution (pale blue ellipse in Figure 6) has the greatest overlap with the BASIS distribution, with both standard deviational ellipses including St. Lawrence Island. The two surveys may actually be more consistent than implied by Figure 5.

The variation in capelin distribution between cold and warm regimes may be due to changes in capelin abundance, or may result from the interaction between capelin and other ecosystem components. Survey CPUE was higher during cold regimes, indicating greater population size. In many fish populations, spatial distribution is linked to population size: as numbers increase, individuals spread out to reduce competition for resources (MacCall 1990). The warm-regime distribution may reflect a core capelin habitat, with the population expanding into other areas as population size increases. Alternatively, changes in distribution may result from interactions with predators or competition with other species. Warm years in the EBS are associated with reduced extent of the cold pool. Retreat of the cold pool may allow Pacific cod increased access to the EBS shelf and greater opportunities for preying on capelin (Cianelli and Bailey 2005), and the shrinking of the capelin distribution during warm regimes may be an attempt to reduce spatial overlap with cod and other predators. The first warm regime (1977-1987) was also a period of high abundance of Pacific cod and walleye pollock, another potential predator. Capelin also appear to compete with age-1 walleye pollock, and the degree of spatial overlap between the two species is dependent on water temperatures over the shelf (Hollowed et al. 2012). Similar pollock-capelin interactions have been observed in the central GOA (Logerwell et al. 2007). Although the results presented here differ somewhat from Hollowed et al. (2012), the changes in distribution may reflect similar competitive interactions.

No clear explanation exists for the differences in the two cold-regime distributions. The two periods are of unequal length (13 years vs. 8 years), and temperatures were more anomalously cold during the later regime (Figure 3). Factors other than those discussed here may influence distributions. Regardless of the cause, the contrast between the regimes has implications for the analysis of capelin ecology and demonstrates the utility of long timeseries. The cod-capelin study (Cianelli and Bailey 2005) used data only through 2001 and suggested that in cold years (i.e. the 1988-200 cold regime) capelin distribution shifted to the south. The data through 2013 presented here indicate that responses to temperature are likely more complicated, with capelin in the later cold regime shifting to the north.

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 BASIS surface trawls. Only bottom trawl data are presented here. Eulachon are consistently distributed in the extreme southern portion of the outer EBS shelf (Figure 9). In addition, their distribution does not appear to shift over time, with little variation among the regime-specific deviational ellipses (Figure 10). The sole exception is a reduced distribution during the 1st warm regime (red ellipse in Figure 10). This shrinking is unexplained, but may result from similar dynamics to those discussed for capelin: populations of gadid fish predators were high during this period, and warm waters may have increased predator access.

Eulachon abundance also appears unrelated to temperature regime (Figures 11 & 12). 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 12), 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 occur rarely in the bottom trawl survey, so the BASIS survey is the primary source of information for this osmerid. Data from BASIS 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 13). 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 and BASIS survey suggest that they have a primarily inshore distribution in the EBS, particularly in areas such as Bristol Bay with extensive sandy bottom substrates (Figures 14 & 15). They also occur in the AI, particularly in the islands west of Amchitka Pass (Figure 16). 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 lances, 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 17 & 18). 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 in the BSAI survey data, where they occur on the EBS slope (Figure 19) and along the shelf break and slope in the AI (Figure 20).

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 since 2004 (Ressler et al. 2012). These results suggest that euphausiid distributions are variable but that the largest biomass is consistently found in the southeastern Bering Sea (Fig. 21).

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 distributions of herring in the BSAI described by the two surveys vary substantially and likely result from seasonal migrations. 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 22 top panel) are consistent with the movement patterns in Figure 2. The BASIS survey is conducted during September. 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 (Figure 22 bottom panel). The high CPUEs observed in the BASIS survey in the northeastern Bering Sea, particularly in Norton Sound, 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.

The distribution of herring in the BSAI varied with temperature regime (Figure 23). In contrast to capelin, there was not a consistent change in distribution with warm vs. cold regimes. However, similar to capelin, herring displayed a similar northward shift during the third (latest) cold regime (2006-2013). Mean CPUE showed no relation to regime and appears to have increased with each successive regime (Figure 24). The annual data reflect the high interannual variability of the data but also suggest increasing abundance over time, particularly since the mid-2000s.

It is unclear what influences the regime-specific distribution of herring. Herring that are returning to nearshore spawning areas are influenced by cold water and ice extent, returning later in the year if cold water is more widespread and persistent (Tojo et al. 2007). This behavior seems to contradict a northward shift during cold regime 3. The EBS cold pool normally exists as a “tongue”, with warmer waters offshore and inshore of the pool, so it could be that the summer distribution is sufficiently inshore that it is less influenced by temperature.

Bycatch and other conservation issues

FMP forage group

Data regarding incidental catches of this group exist from 2003 and are maintained by the Alaska Regional Office (ARO; 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 ARO database (eulachon, capelin, surf smelt, “other osmerid”) were combined into a single “osmerids” group.

The osmerid bycatch occurs primarily 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) yellowfin fishery catches are higher. During 2008-2014, total osmerid catch varied between 2.3 t and 18.8 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 2015 BSAI catch as of August 28, 2015 was 34.6 t (Table 2), intermediate to the high and low catch ranges. In 2006 & 2007 most of the osmerid catches occurred in February (Figure 26), with some additional catches in October, so it is unclear how much the August 28 total will increase during the rest of 2015.

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 27 & 28). Additional catch occurs in some years in area 514 in the northern part of the inner shelf, the location of intensive fishing for yellowfin sole.

Pacific herring

Data regarding the Prohibited Species Catch (PSC) of herring exist from 1991 and are maintained by the ARO (Table 4). During the 1990s herring bycatch was consistently high, but since 2000 herring catches have followed a pattern similar to osmerids, with relatively low catches interrupted by occasional extremely high catches. In 2012 the herring PSC was 2,376 t, an order of magnitude higher than catches in preceding years. The herring PSC quota was exceeded in that year. As of September 12, 2015 the herring PSC was 1,525 t and since herring catches tend to be greatest in September the 2015 catch is likely to increase.

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 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 years when peak biomass could not be determined and the pre-season forecasts were substituted. Herring bycatch is not related to annual variation in the Togiak spawning biomass (analysis not shown) but on a decadal scale there does seem to be some coherence between the two datasets (Figure 29). 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 (Figure 30). Because most of this catch occurred in September (Figure 31), 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 30), 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 (Figure 32). There is substantial annual variability, but most captured herring were between 24 cm and 32 cm. In 2010, average size for Togiak herring aged 5, 7, and 9 was 25, 29, and 31 cm, respectively (Buck 2012). In 2010, the ages 5-9 made up most of the Togiak harvest (72.3%) and age 6 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.

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 BASIS 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 whether the eulachon captured in the EBS survey and fishery also spawn in the EBS, or are GOA spawners, would be very useful for understanding the relationship of EBS eulachon to eulachon in other areas.
3) Similarly, it would be useful to have a clearer understanding of which herring are being captured in federal fisheries. Genetics studies 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. Of particular interest would be the reason for the high BASIS 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. – i.e. exactly how bad are the surveys at sampling forage species? This would allow us to make the most of the existing survey data.

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

Acknowledgments

Thanks to all survey personnel for gathering the various data. Thanks to Wes Strasburger and Ed Farley for the BASIS data, and Jerry Hoff for assistance with bottom trawl survey data.

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Table 1. Bycatch (t) of FMP forage fish groups in BSAI federal fisheries, 2003-2015. *2015 data are incomplete; retrieved October 18, 2015.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	*2015**
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*
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*
surf smelt					0.6	0.0							
other osmerids	16.2	7.0	4.7	6.8	73.5	12.4	1.1	2.9	2.4	4.9	1.2	9.6	*7.6*
total osmerids	**18.8**	**32.6**	**14.5**	**103.4**	**181.3**	**15.1**	**7.0**	**4.5**	**9.5**	**8.9**	**2.3**	**13.6**	***34.6***
myctophids	0.3	0.1	0.6	9.6	5.8	1.5	0.5	0.3	0.2	0.1	0.5	0.6	*0.6*
pricklebacks	0.2	0.1	0.1	0.2	0.8	0.3	0.1	0.2	0.4	0.3	0.2	0.8	*0.6*
Pacific sand lance	0.1	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.4	0.2	0.0	0.1	*0.2*
Pacific sandfish								0.0	0.1	0.0	0.0	0.2	*0.1*
gunnels		0.0	0.0		0.0	0.0			0.0	0.0	0.0	0.0	*0.0*
total FMP forage fish	**19.4**	**33.1**	**15.6**	**113.3**	**188.0**	**17.0**	**7.7**	**5.1**	**10.7**	**9.5**	**3.0**	**15.2**	***36.1***

Table 2. Total bycatch (t) of osmerids (eulachon, capelin, surf smelt, and “other osmerids) in the BSAI by target fishery, 2003-2015. Only fisheries with 0.1 t or greater catch in any year are included. *2015 data are incomplete; retrieved October 18, 2015.

	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	***2015****
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*
YFS	4.3	9.0	0.6	0.9	41.2	10.0	1.2	3.7	6.3	7.1	1.2	11.1	*6.8*
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*
Pacific cod	0.2	0.6	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*0.0*
arrowtooth	0.3	0.6	0.0	0.0			0.0	0.0	0.0	0.0	0.0	0.0	*0.0*
FHS	0.3	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	*0.0*
total	**18.8**	**32.6**	**14.5**	**103.4**	**181.3**	**15.1**	**7.0**	**4.5**	**9.5**	**8.9**	**2.3**	**13.6**	***34.6***

Table 3. Total bycatch (t) of osmerids (eulachon, capelin, surf smelt, and “other osmerids) in the BSAI by NMFS statistical area, 2003-2015. Only areas with 0.1 t or greater catch in any year are included. *2015 data are incomplete; retrieved October 18, 2015.

		2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	***2015****
EBS	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*
	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*
	514	7.4	8.9	1.2	1.0	41.2	10.5	1.1	3.4	5.4	6.6	1.1	10.9	*12.6*
	516	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.1	*0.0*
	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*
	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*
	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*
	524	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*0.0*
AI	541	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	*0.0*
total		**18.8**	**32.6**	**14.5**	**103.4**	**181.3**	**15.1**	**7.0**	**4.5**	**9.5**	**8.9**	**2.3**	**13.6**	***34.6***

Table 4. Bycatch (t) of Pacific herring in BSAI federal trawl fisheries, 1991-2015. Data are from the Prohibited Species Catch (PSC) database maintained by the NMFS Alaska Regional Office. *2015 data are incomplete; retrieved October 18, 2015.

	herring PSC	**herring 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
2004	1,208	1,876
2005	692	2,013
2006	485	1,770
2007	409	1,787
2008	216	1,726
2009	63	1,697
2010	356	1,973
2011	397	2,273
2012	2,376	2,094
2013	988	2,648
2014	186	2,179
*2015**	*1,530*	2,742

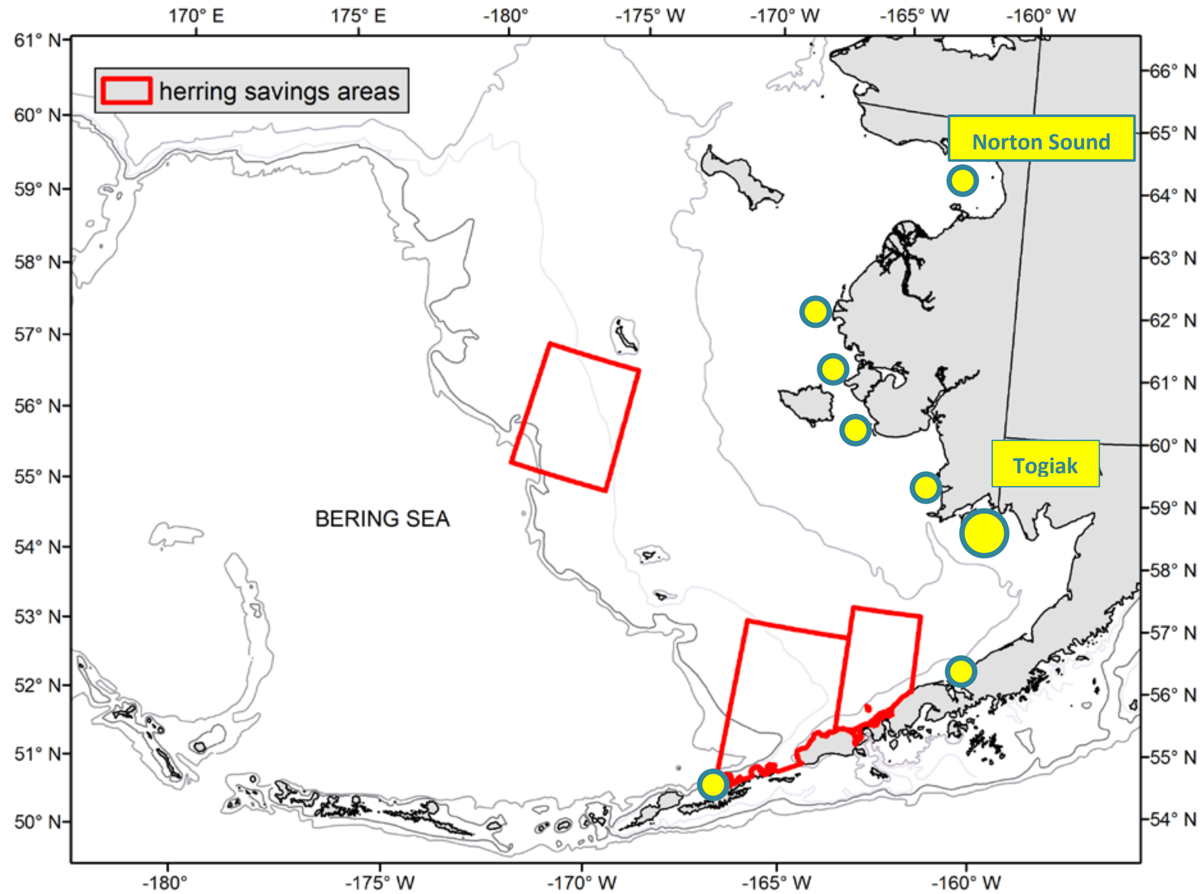

Figure 1. Locations of Pacific herring fisheries in the BSAI (yellow dots) and Herring Savings Areas (red-outlined polygons. The two largest herring fisheries are labeled by name; the larger dot at Togiak indicates that this is by far the biggest fishery.

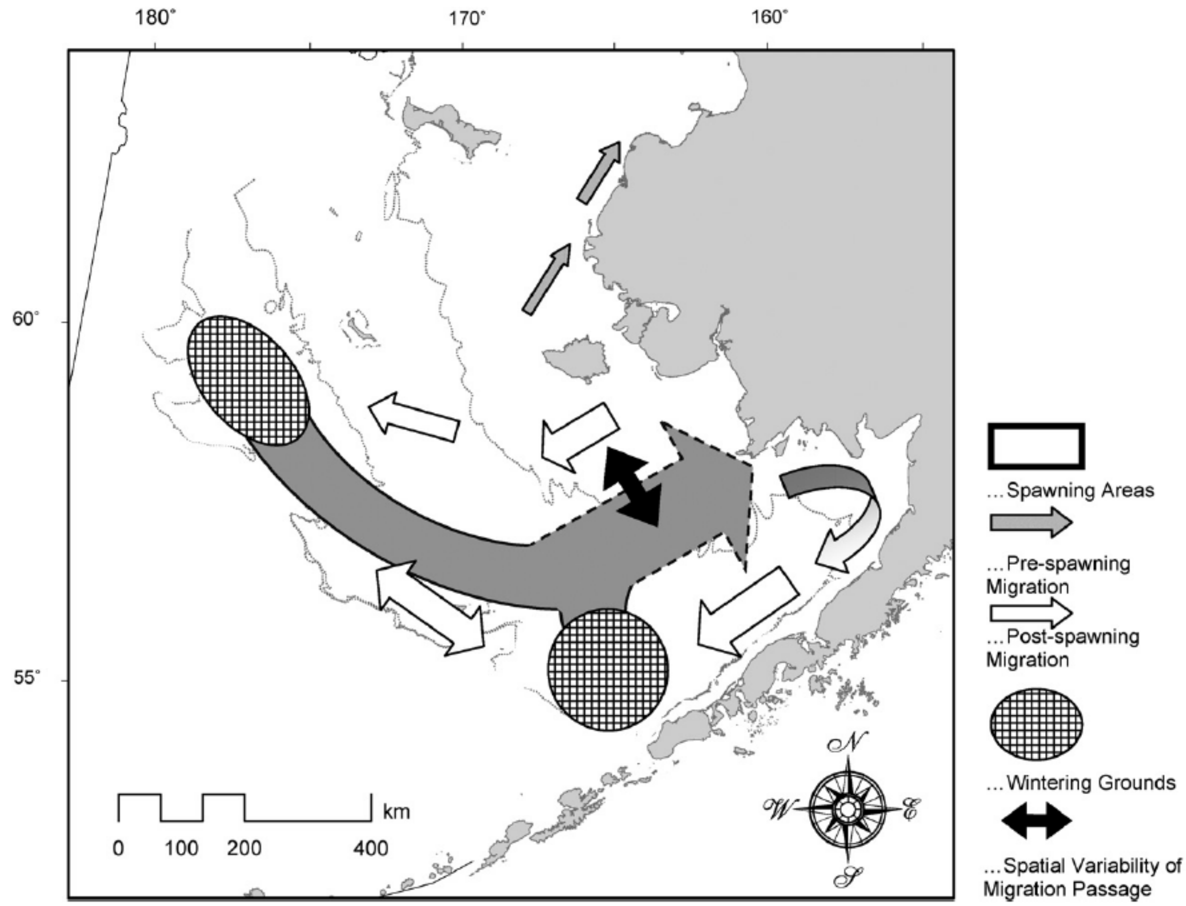

Figure 2. Hypothesized migration routes and seasonal distributions of Pacific herring in the EBS. Figure is from Tojo et al. 2007.

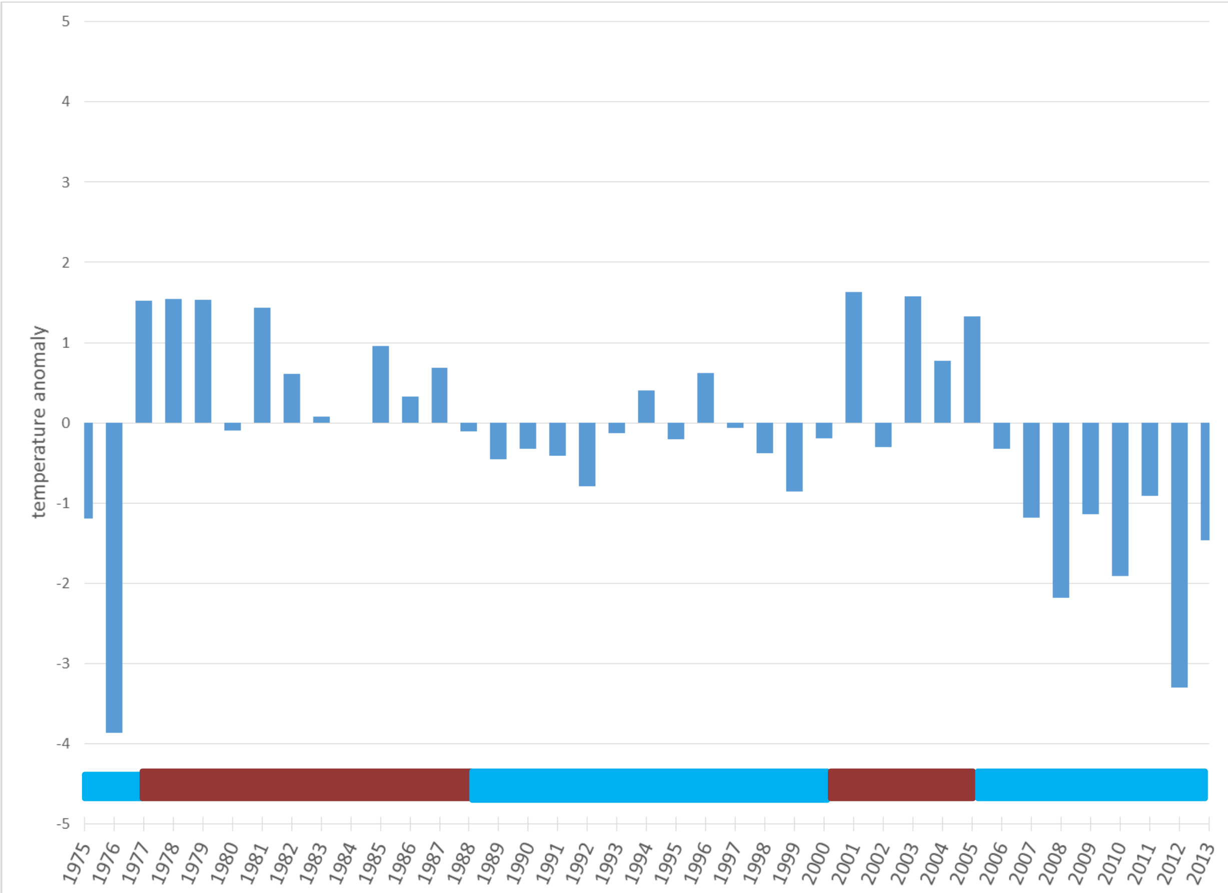

Figure 3. Annual reanalysis sea surface temperature anomalies at the M2 mooring site in the southeastern Bering Sea, 1975-2013. Temperature regimes used in the forage fish analysis are indicated in the horizontal bars (blue = cold regime, red = warm regime).

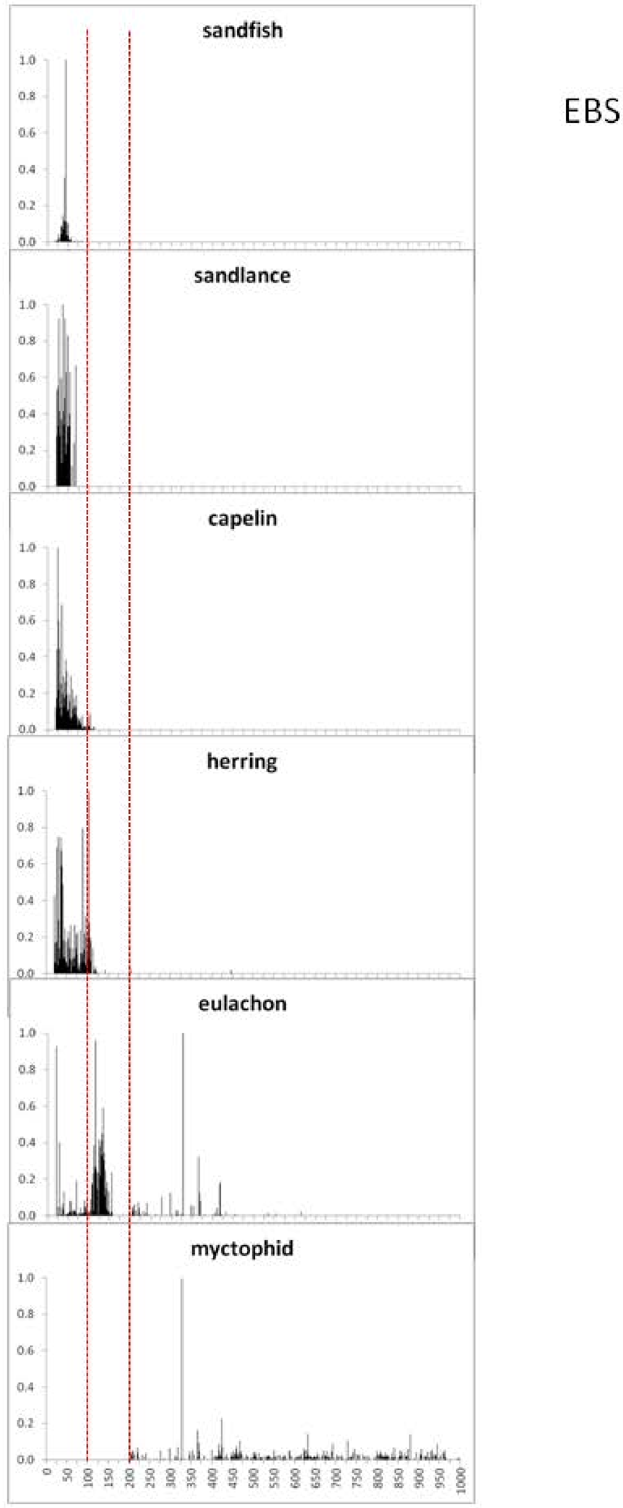

Figure 4. Mean bottom trawl survey CPUE versus bottom depth (m) of haul for six forage groups in the eastern Bering Sea.

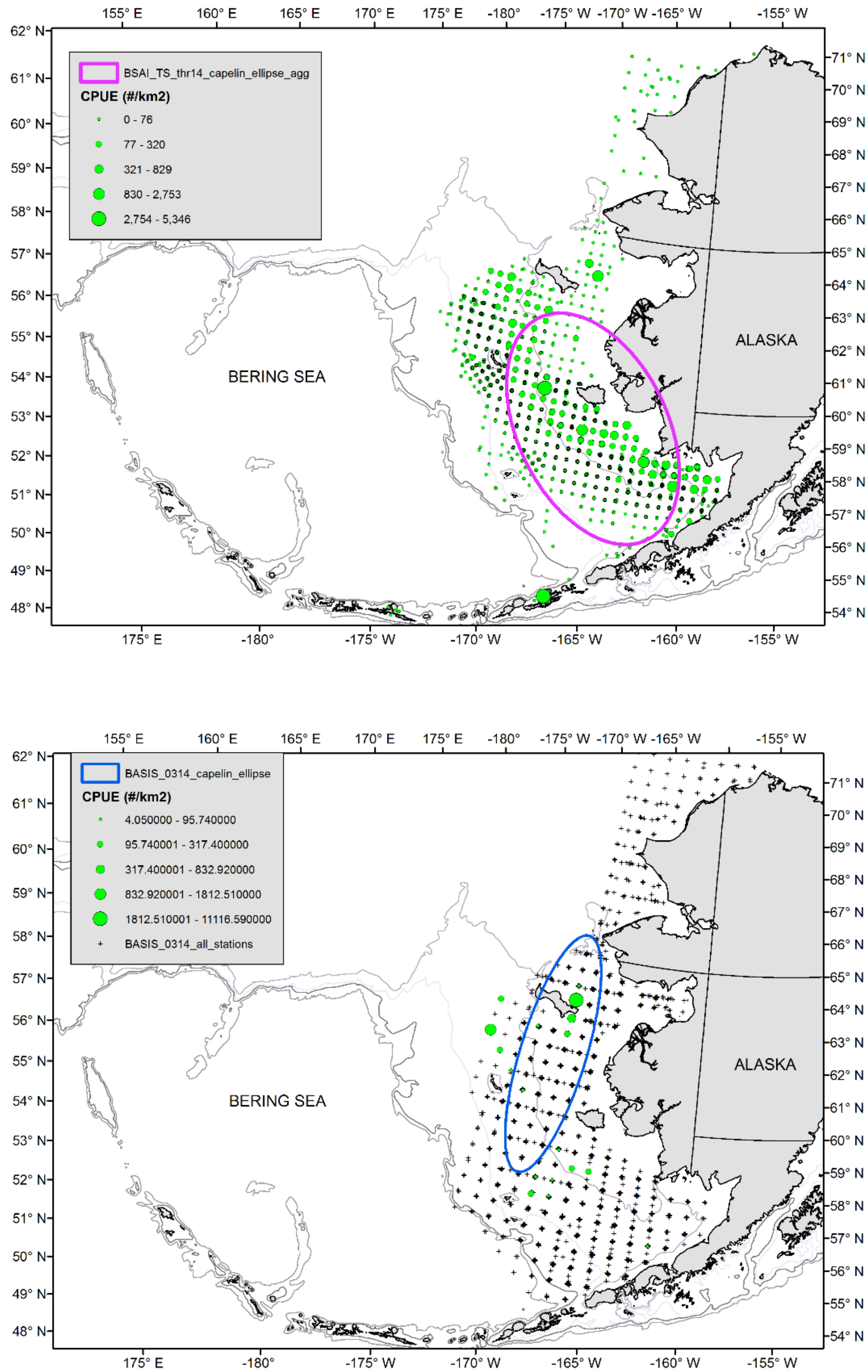

Figure 5. Mean CPUE (number/km^2) of capelin in the BSAI bottom trawl surveys 1982-2014 (top) and in BASIS surveys 2003-2014 (bottom). Ovals in each map indicate weighted standard deviational ellipses. Ellipses include all points within one standard deviation of the distribution's mean geographic center.

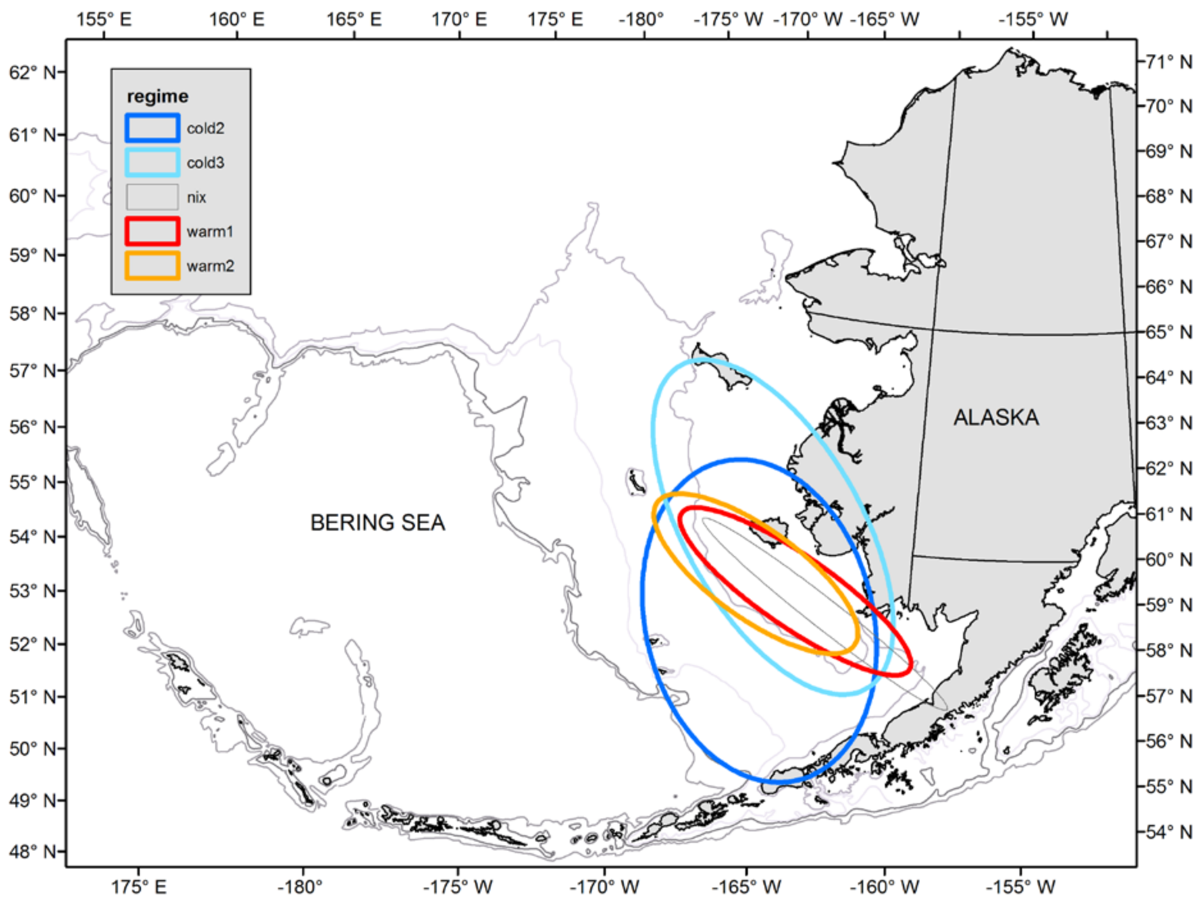

Figure 6. Weighted standard deviational ellipse by temperature regime for capelin CPUE in the AFSC bottom trawl survey. The "nix" ellipse is 2014 data and was not included in the rest of the analysis. Ellipses include all points within one standard deviation of the distribution's mean geographic center.

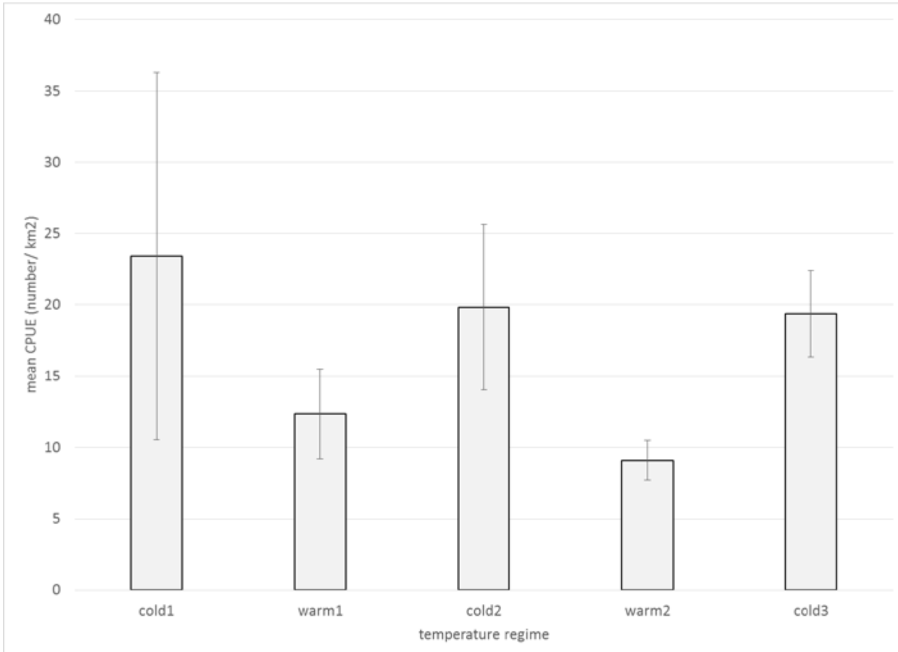

Figure 7. Mean CPUE (number/ km^2) of capelin in the Bering Sea shelf bottom trawl survey by temperature regime. Error bars indicate 95% confidence interval.

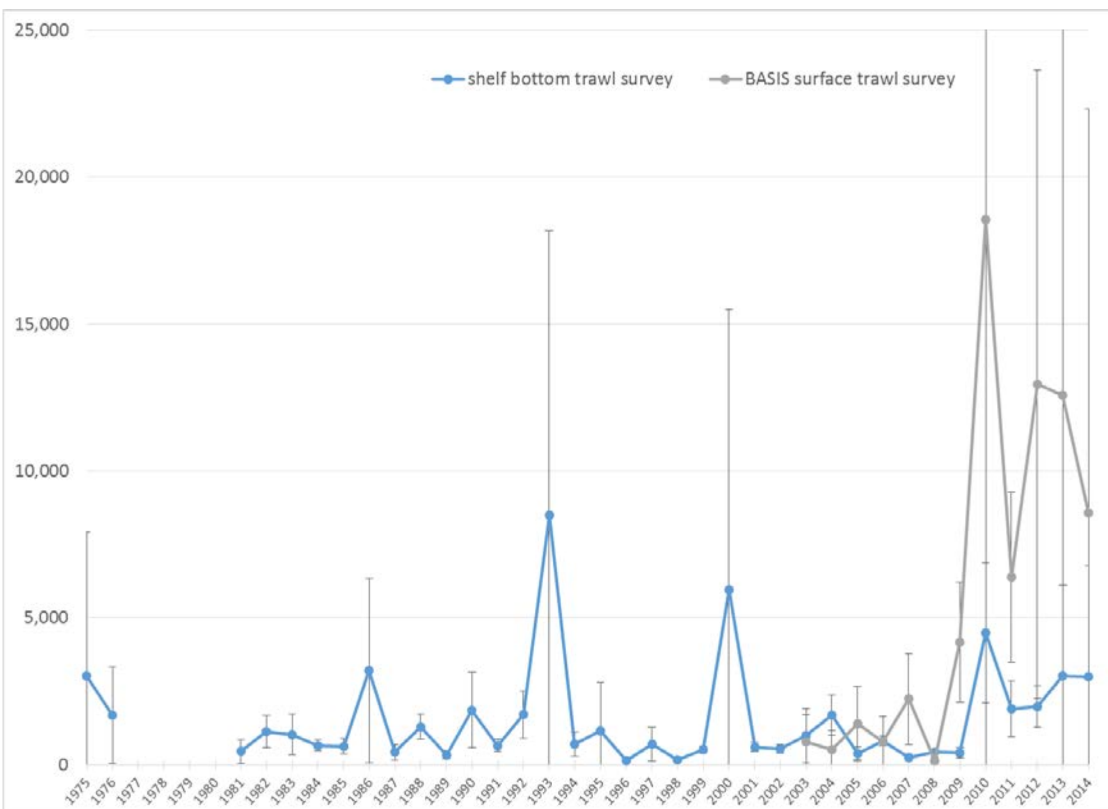

Figure 8. Annual mean CPUE (number/ km^2) of capelin in the Bering Sea bottom trawl and BASIS surveys. Error bars indicate 95% confidence interval.

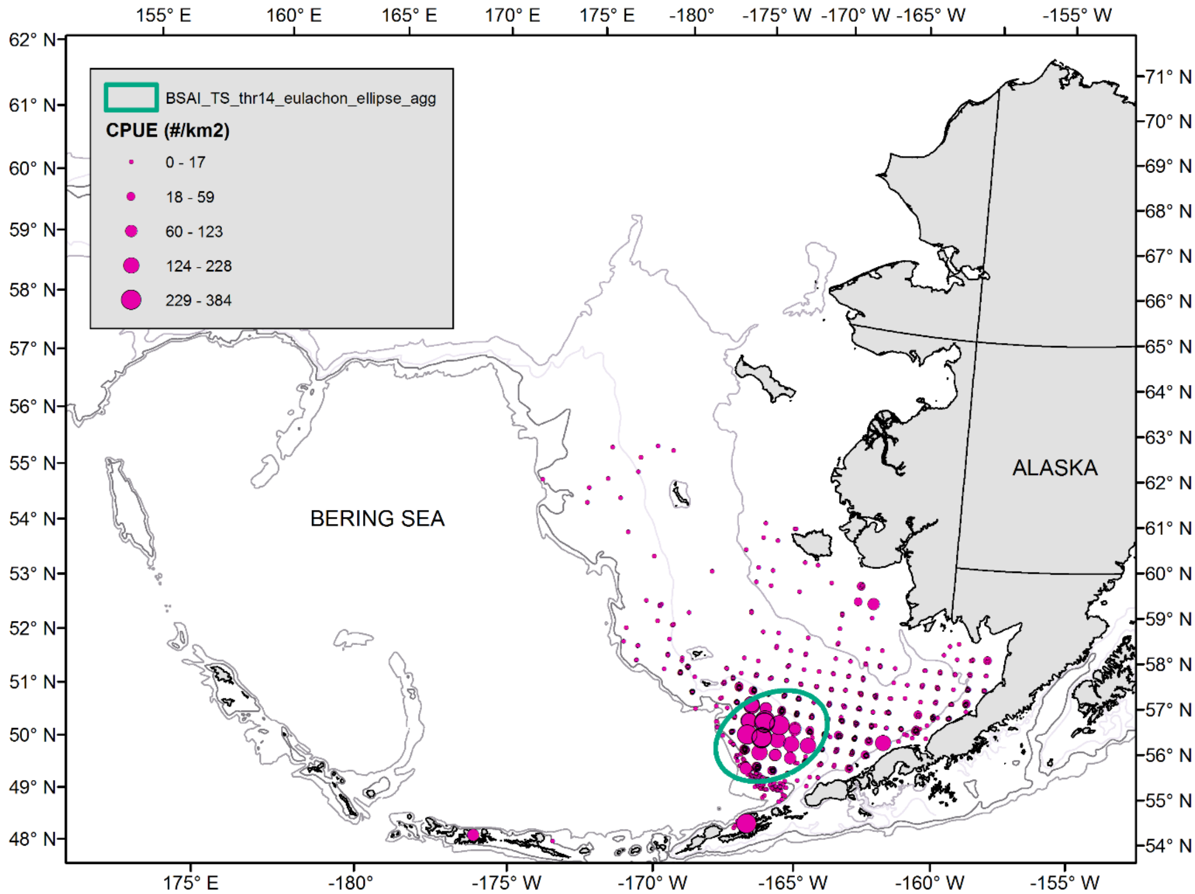

Figure 9. Bottom trawl survey CPUE (number/hec) of eulachon in the BSAI, 1982-2014. Green circle indicates weighted standard deviational ellipse. Ellipse includes all points within one standard deviation of the distribution's mean geographic center.

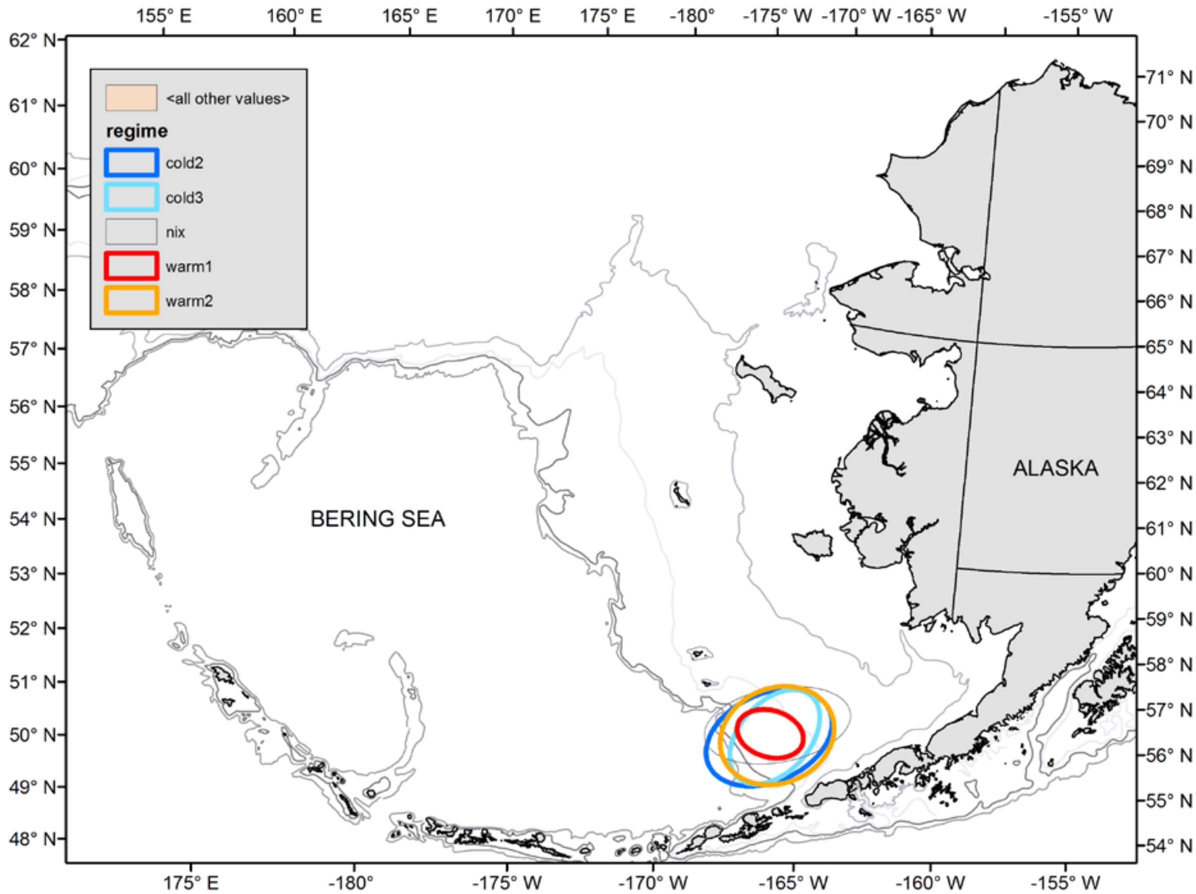

Figure 10. Weighted standard deviational ellipse by temperature regime for eulachon CPUE (number/hec) in the AFSC bottom trawl survey. The “nix” ellipse is 2014 data and was not included in the rest of the analysis. Ellipses include all points within one standard deviation of the distribution’s mean geographic center.

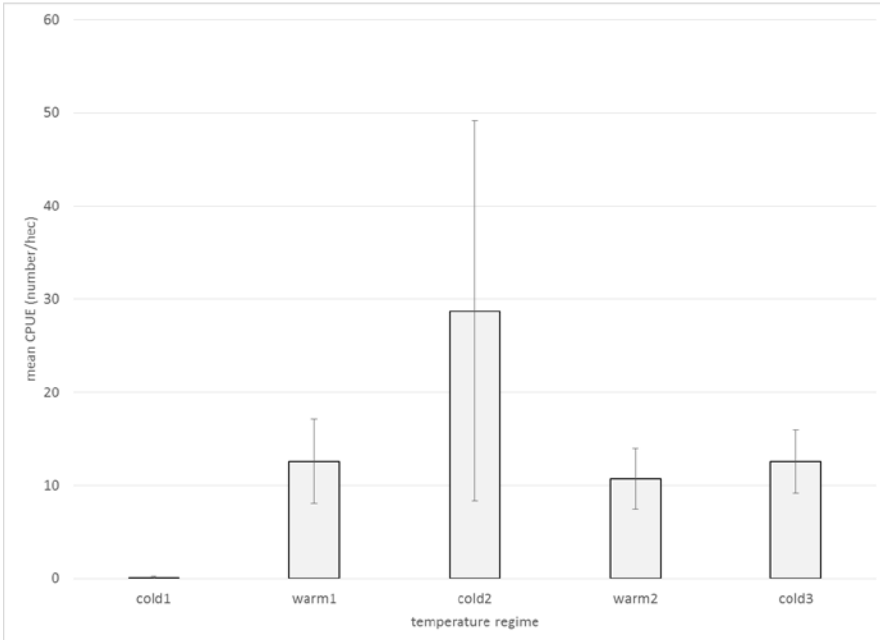

Figure 11. Mean CPUE (number/ hec) of eulachon in the Bering Sea shelf bottom trawl survey by temperature regime. Error bars indicate 95% confidence interval.

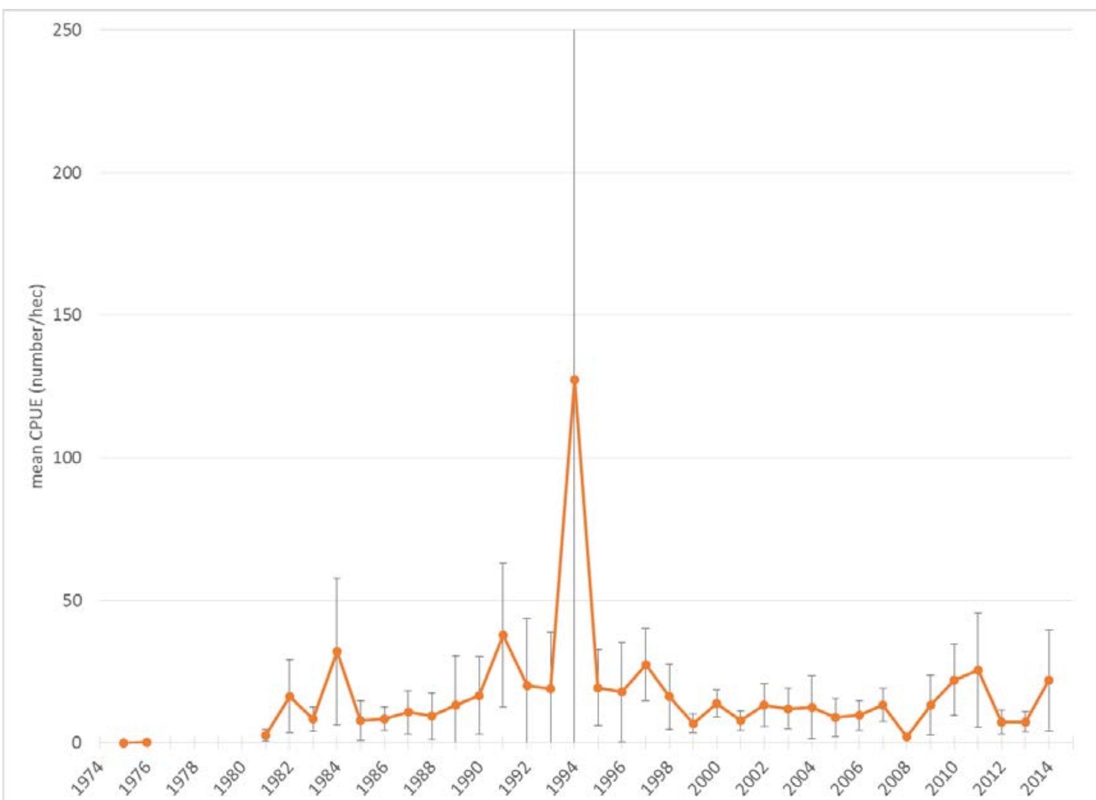

Figure 12. Annual mean CPUE (number/ hec) of eulachon in the Bering Sea bottom trawl survey. Error bars indicate 95% confidence interval.

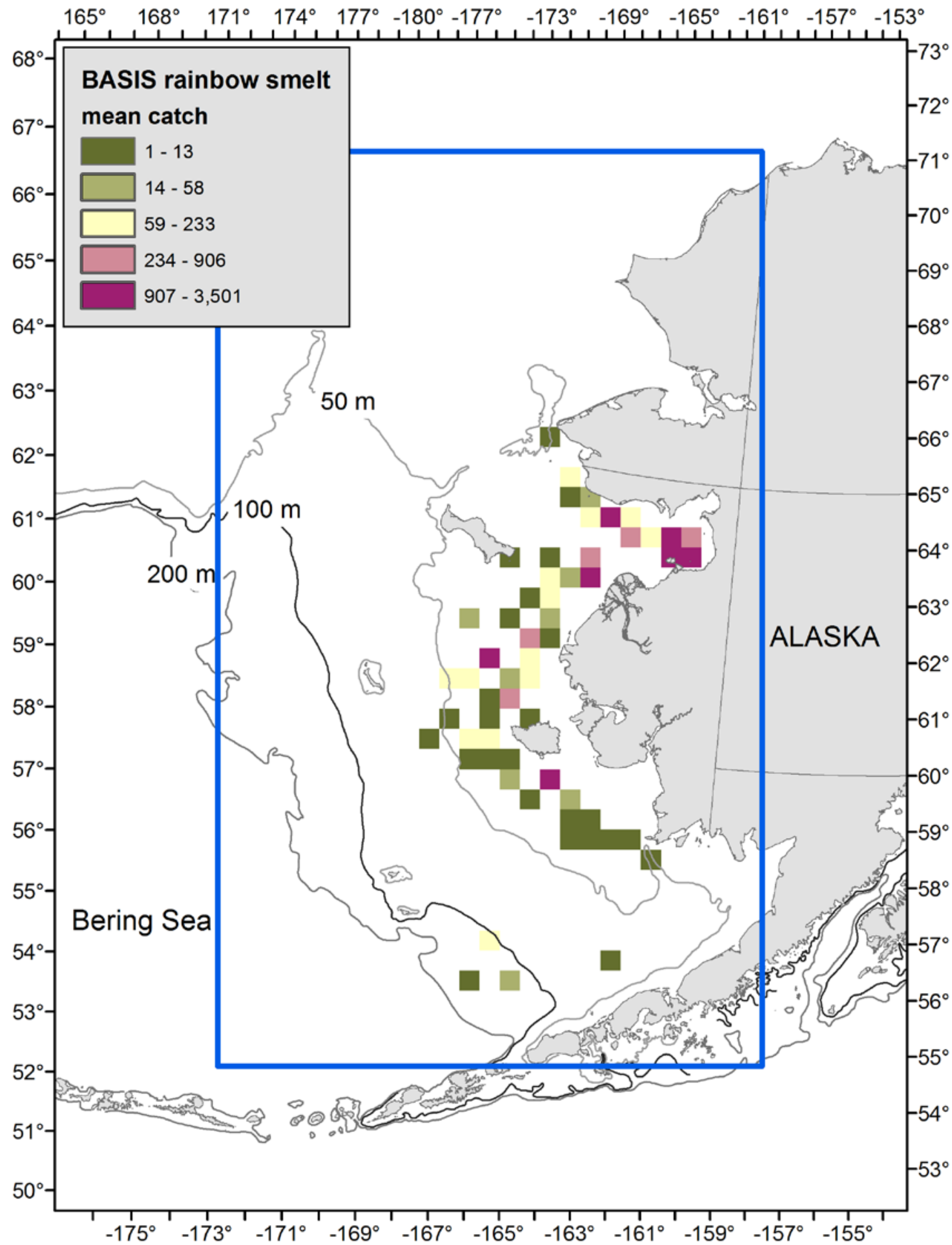

Figure 13. Mean catch (in numbers) of rainbow smelt in BASIS surveys in the eastern Bering Sea, 2002-2011. Grid cells are 20 km X 20 km. Blue box indicates approximate extent of survey hauls over the entire time period.

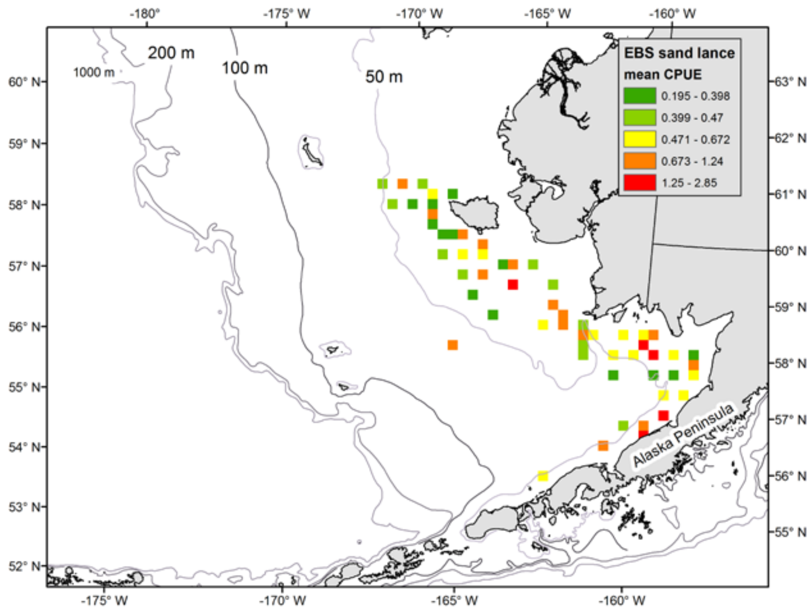

Figure 14. Mean bottom trawl survey CPUE (kg/hec) of Pacific sand lance in the eastern Bering Sea, 2000-2011. Grid cells are 20 km X 20 km.

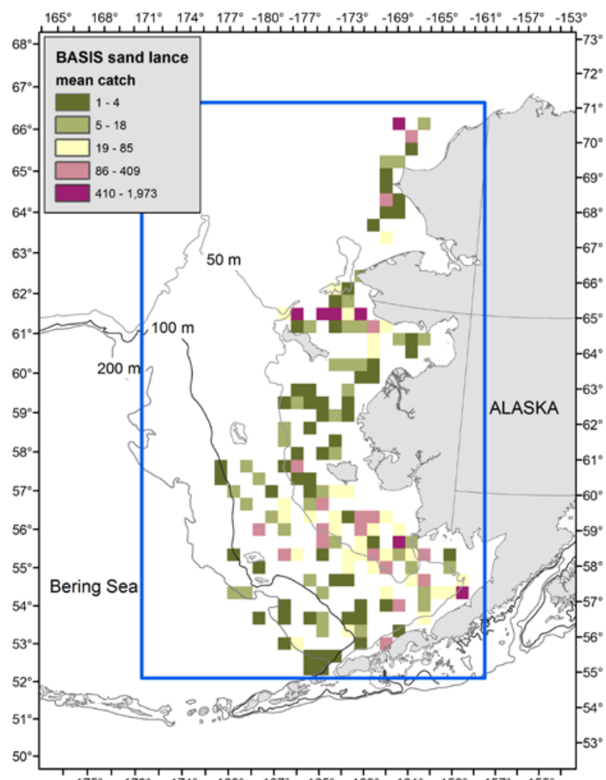

Figure 15. Mean catch (in numbers) of Pacific sand lance in BASIS surveys in the eastern Bering Sea, 2002-2011. Grid cells are 20 km X 20 km. Blue box indicates approximate extent of survey hauls over the entire time period.

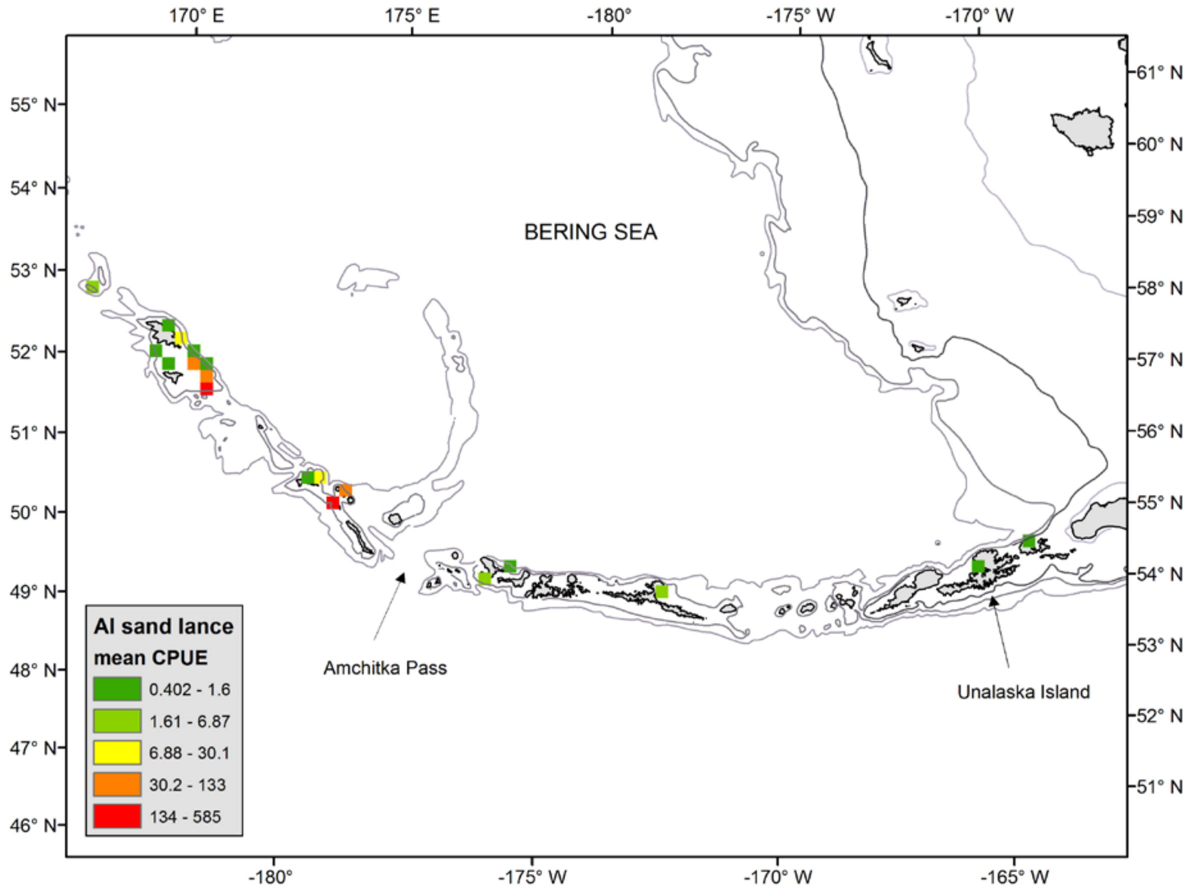

Figure 16. Mean bottom trawl survey CPUE (kg/hec) of Pacific sand lance in the Aleutian Islands, 2000-2011. Grid cells are 20 km X 20 km.

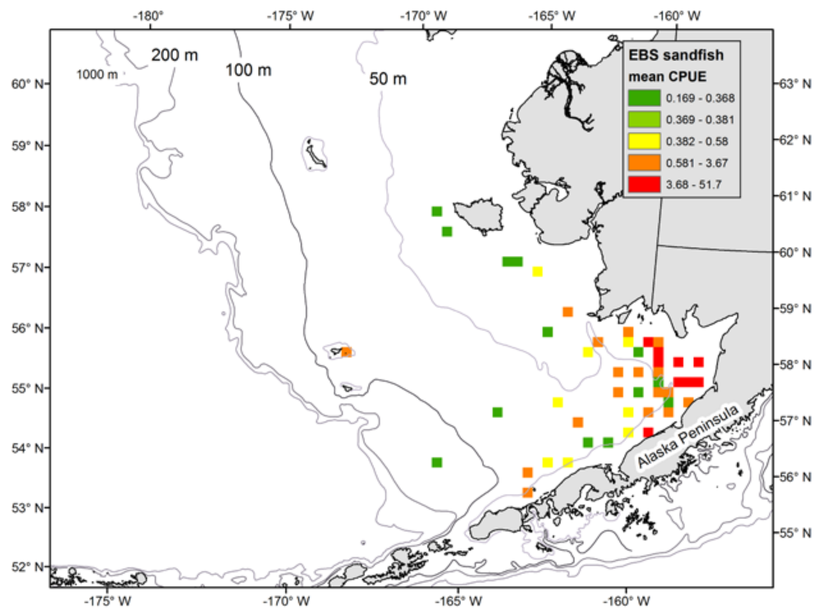

Figure 17. Mean bottom trawl survey CPUE (kg/hec) of Pacific sandfish in the eastern Bering Sea, 2000-2011. Grid cells are 20 km X 20 km.

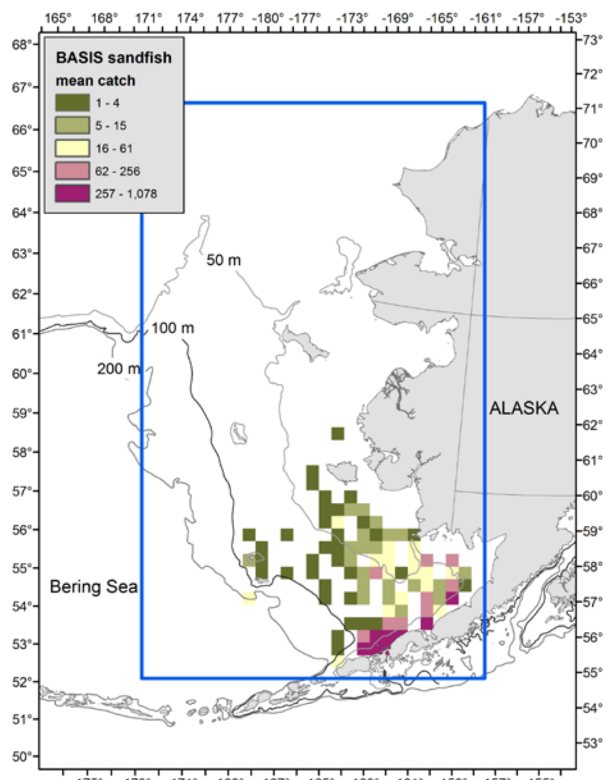

Figure 18. Mean catch (in numbers) of Pacific sandfish in BASIS surveys in the eastern Bering Sea, 2002-2011. Grid cells are 20 km X 20 km. Blue box indicates approximate extent of survey hauls over the entire time period.

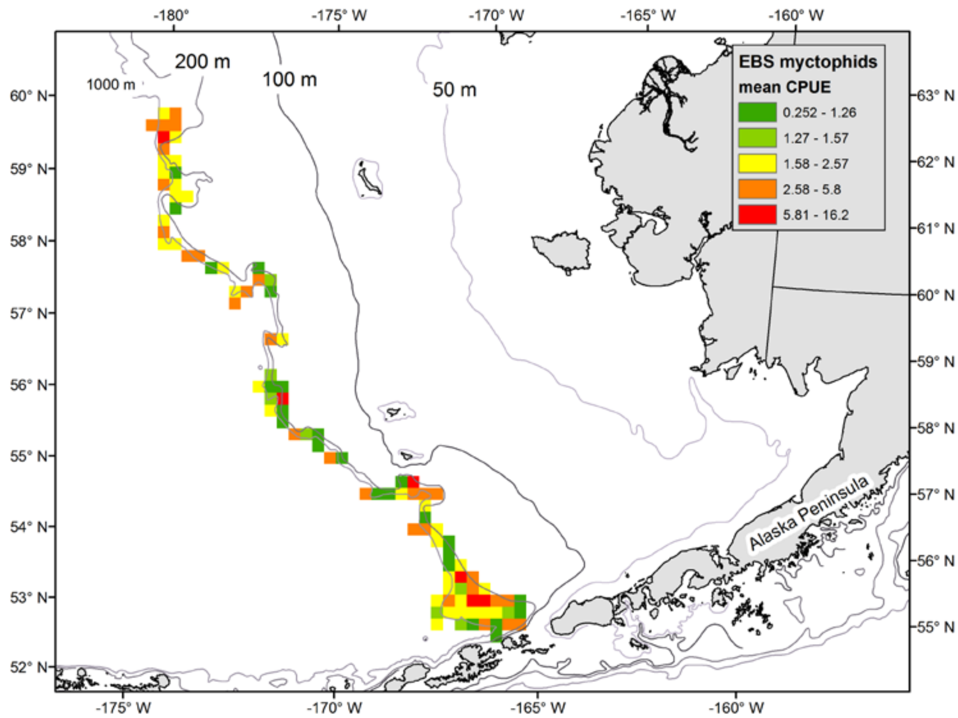

Figure 19. Mean bottom trawl survey CPUE (kg/hec) of myctophids in the eastern Bering Sea, 2000-2011. Grid cells are 20 km X 20 km.

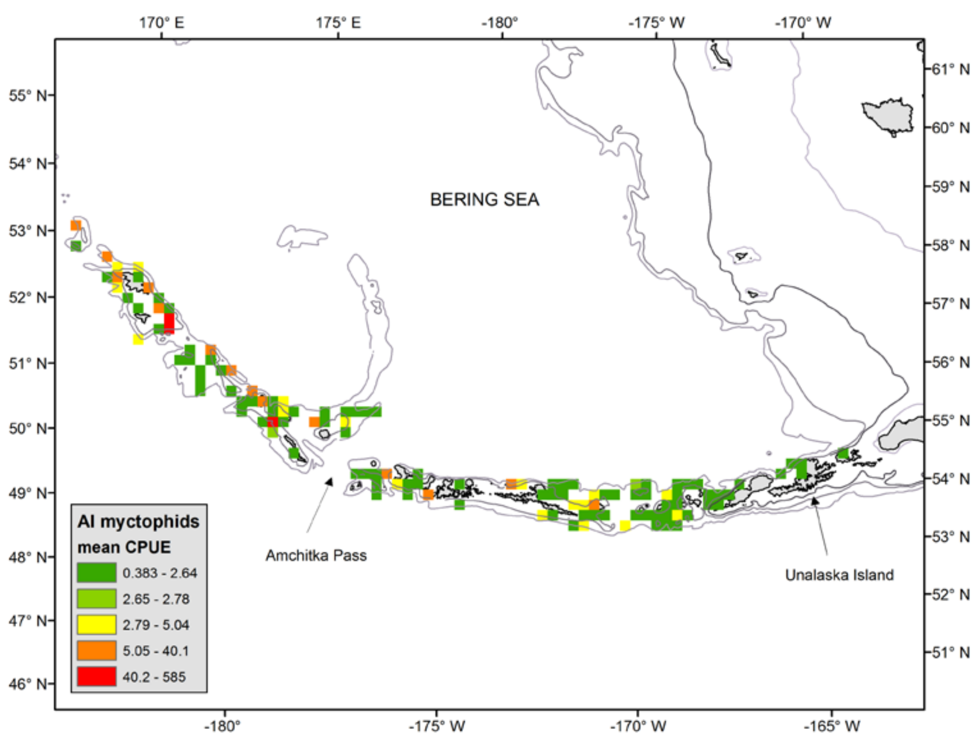

Figure 20. Mean bottom trawl survey CPUE (kg/hec) of myctophids in the Aleutian Islands, 2000-2011. Grid cells are 20 km X 20 km.

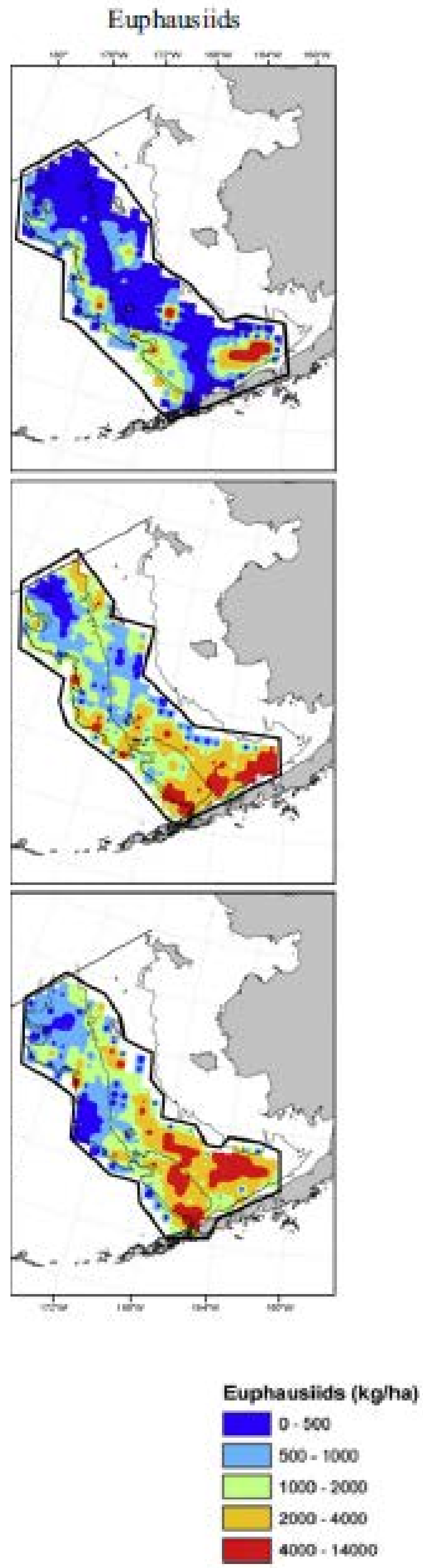

Figure 21. Spatial distribution of euphausiids as estimated using acoustic backscatter. Figure is taken from Ressler et al. 2012. Beginning with the top panel, data are from 2004, 2007, and 2010.

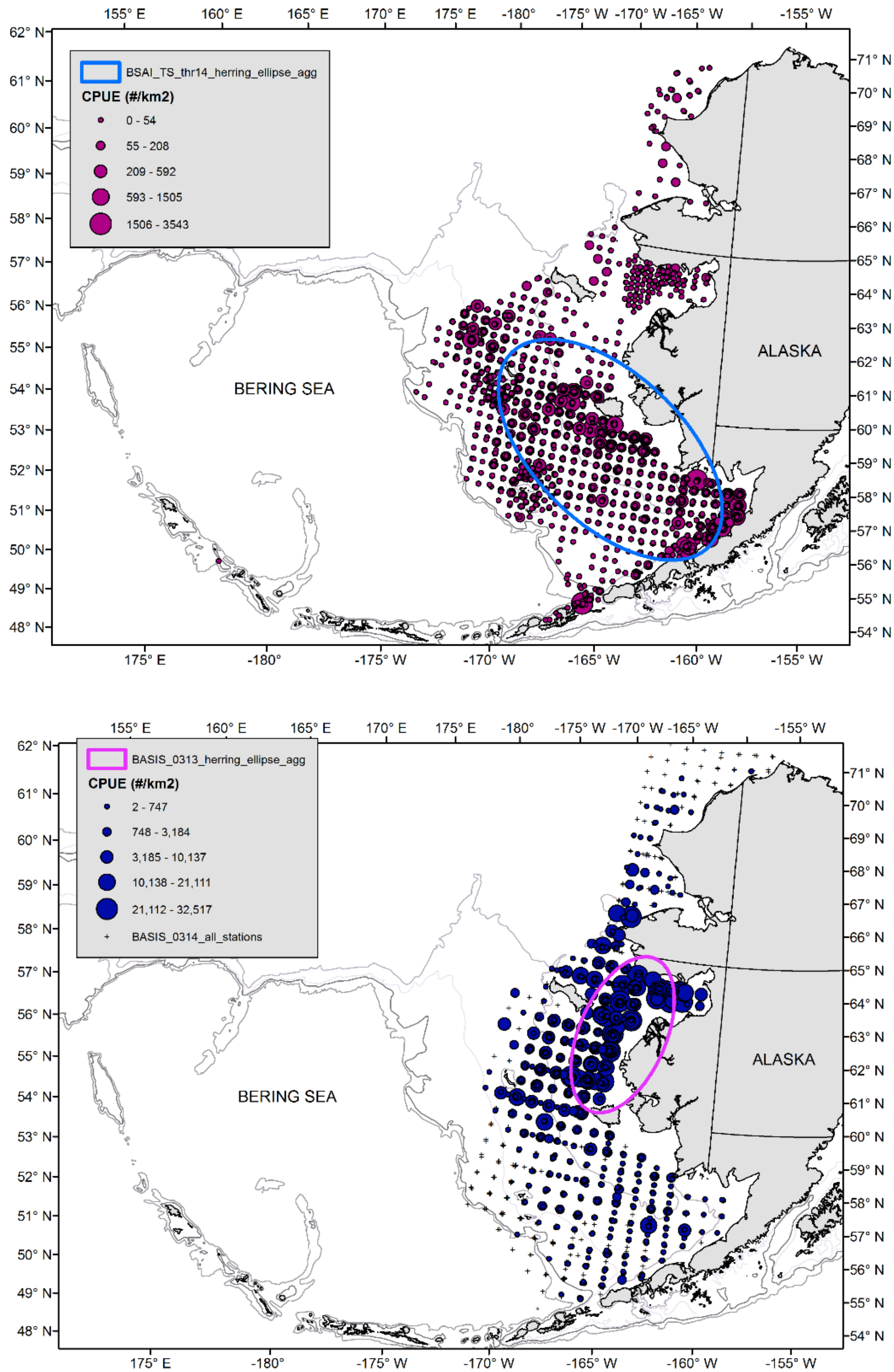

Figure 22. Mean CPUE (number/km^2) of Pacific herring in the BSAI bottom trawl surveys 1982-2014 (top) and in BASIS surveys 2003-2014 (bottom). Ovals in each map indicate weighted standard deviational ellipses. Ellipses include all points within one standard deviation of the distribution's mean geographic center.

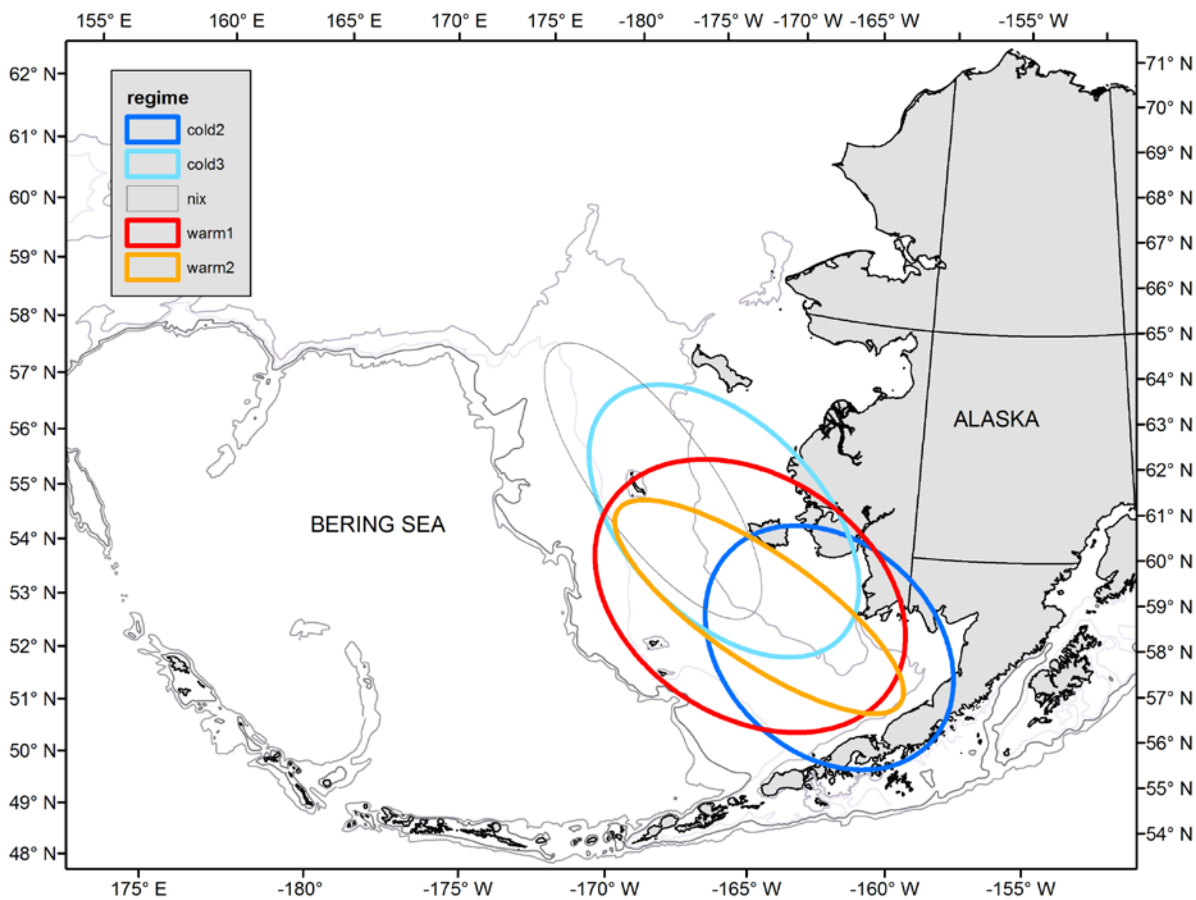

Figure 23. Weighted standard deviational ellipse by temperature regime for Pacific herring CPUE in the AFSC bottom trawl survey. The “nix” ellipse is 2014 data and was not included in the rest of the analysis. Ellipses include all points within one standard deviation of the distribution’s mean geographic center.

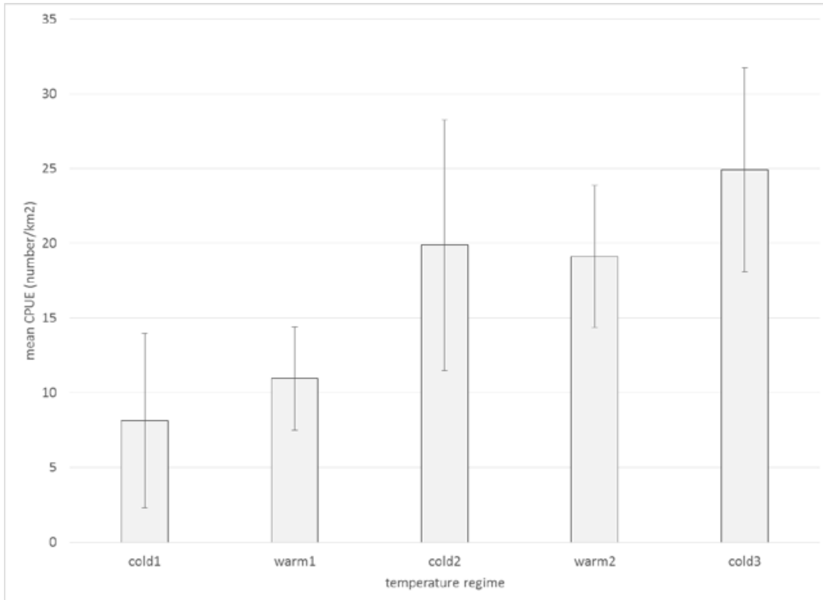

Figure 24. Mean CPUE (number/ km^2) of Pacific herring in the Bering Sea shelf bottom trawl survey by temperature regime. Error bars indicate 95% confidence interval.

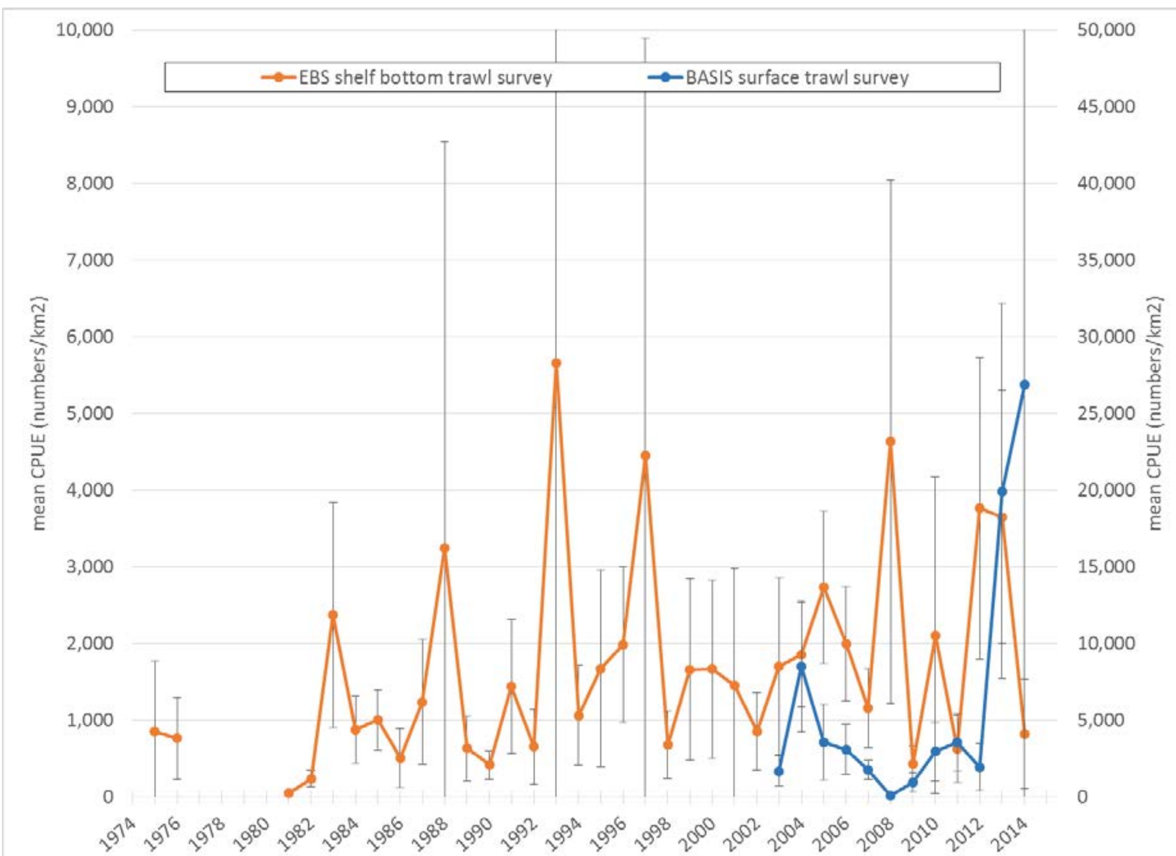

Figure 25. Annual mean CPUE (number/ km^2) of Pacific herring in the Bering Sea bottom trawl and BASIS surveys. Error bars indicate 95% confidence interval.

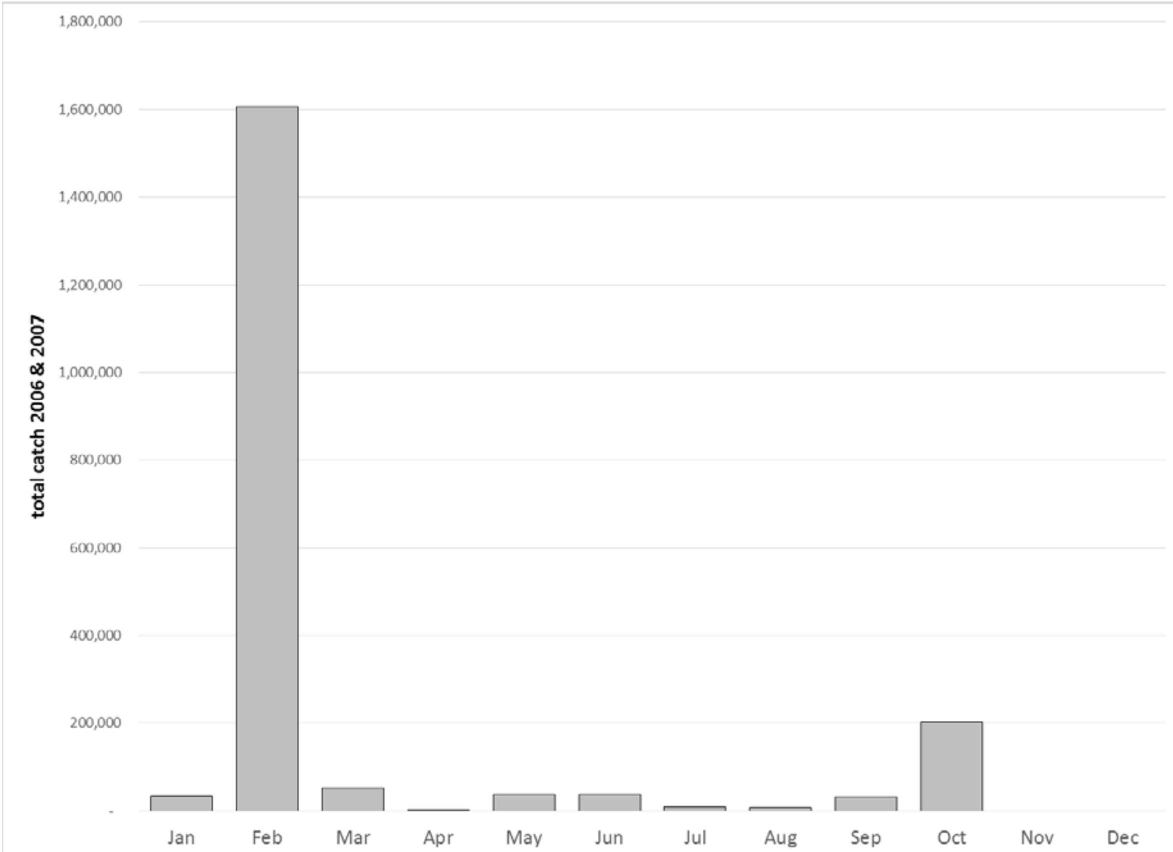

Figure 26. Seasonal pattern of observed eulachon catches (numbers) in the BSAI during 2006 & 2007.

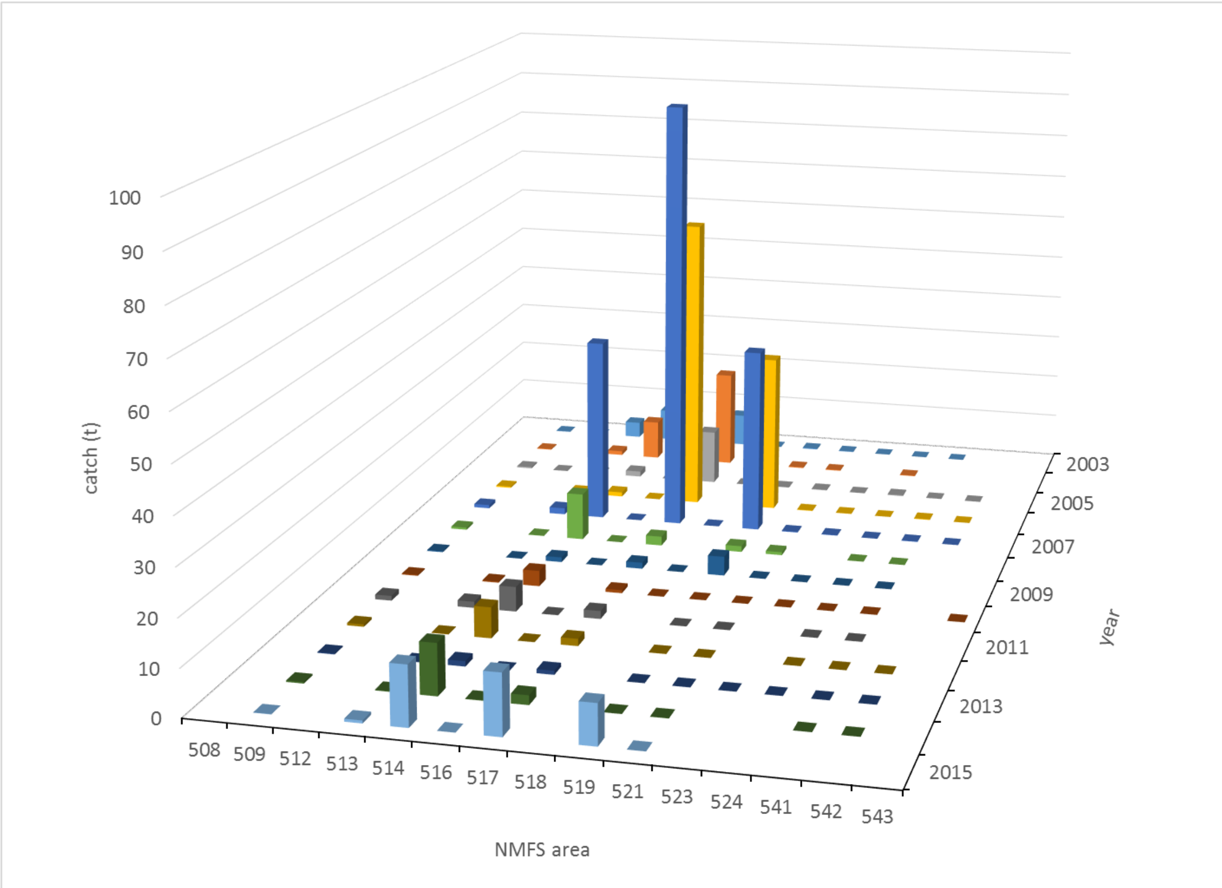

Figure 27. Incidental catches (t) of all osmerids (eulachon, capelin, surf smelt, "other osmerids") in the BSAI by NMFS statistical area, 2003-2015. 2015 data are incomplete; retrieved August 28, 2015.

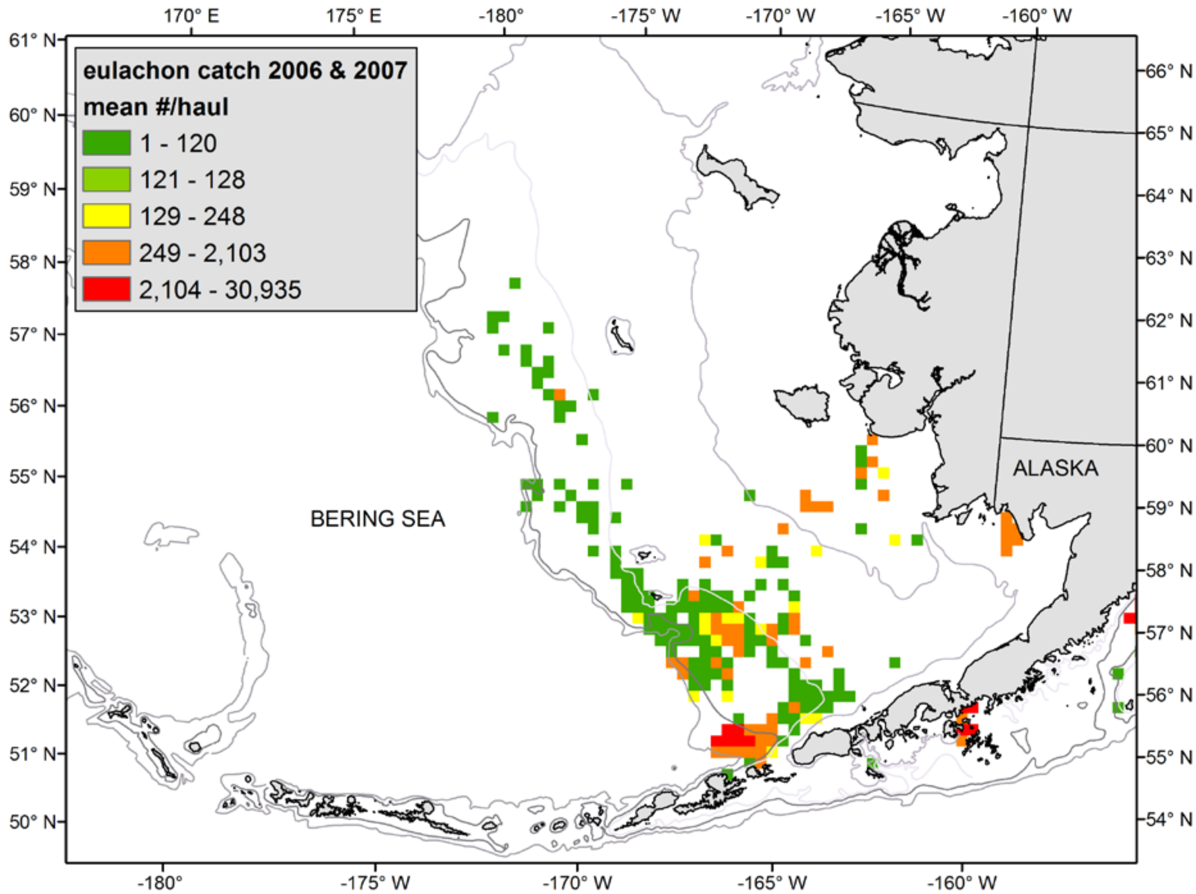

Figure 28. Catches (number/haul) of eulachon in the BSAI, 2006 & 2007.

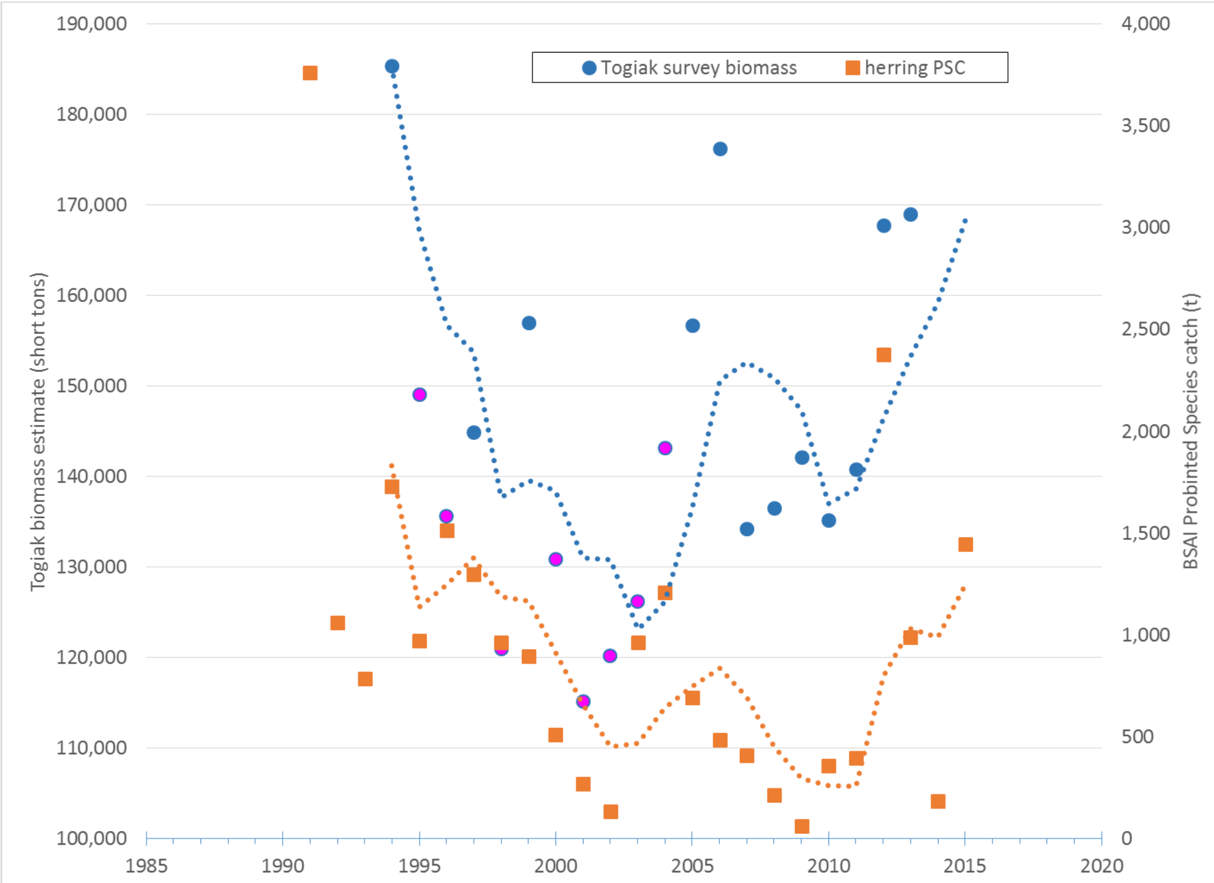

Figure 29. Prohibited Species catch of herring in BSAI federal fisheries, 1991-2015, and Togiak area herring biomass estimates, 1994-2013. Togiak biomass estimates are the peak biomass estimates from aerial surveys conducted in that year. Fuchsia-filled circles indicate years when biomass estimates were unavailable and data are preseason forecasts from an age-structured model. Dotted lines indicate 4-year moving averages for each data series. Data are from the NMFS Alaska Regional Office and the Alaska Dept. of Fish & Game, respectively.

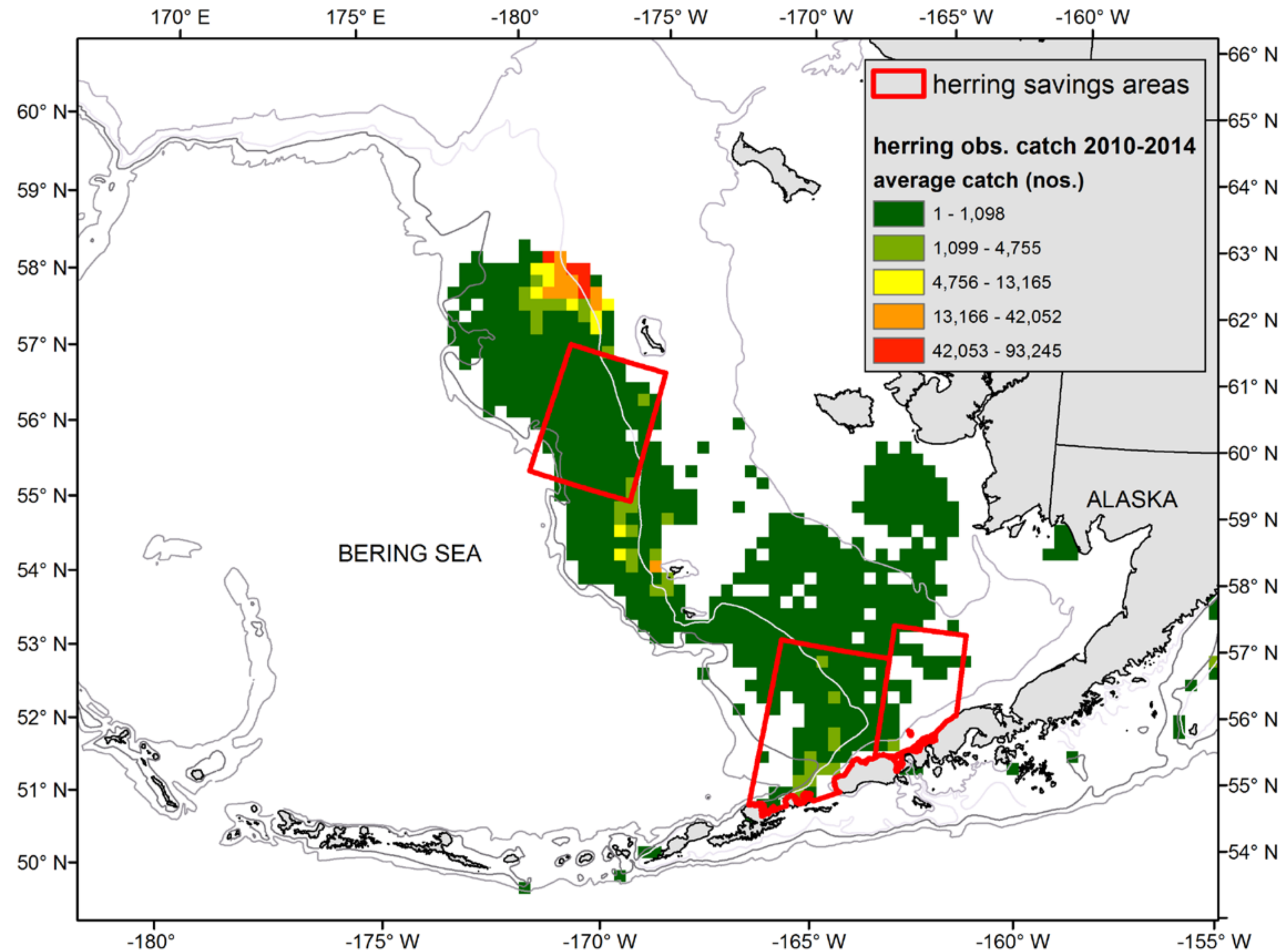

Figure 30. Average observed catch (number/haul) of Pacific herring in the BSAI, 2010-2014. Grid cells are 20 km X 20 km. Red-outlined polygons indicate Herring Savings Areas.

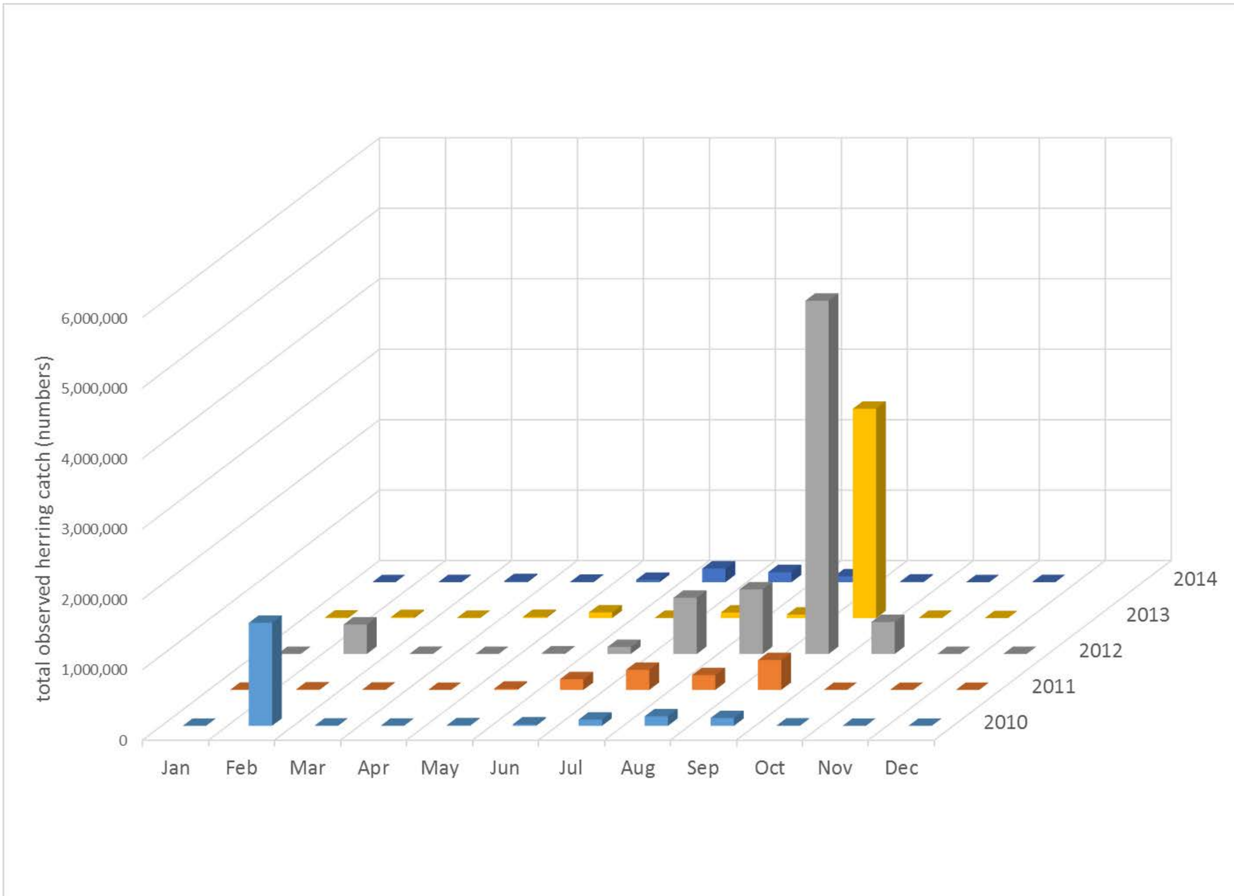

Figure 31. Seasonal patterns of observed Pacific herring catches in federal fisheries the BSAI, 2010-2014.

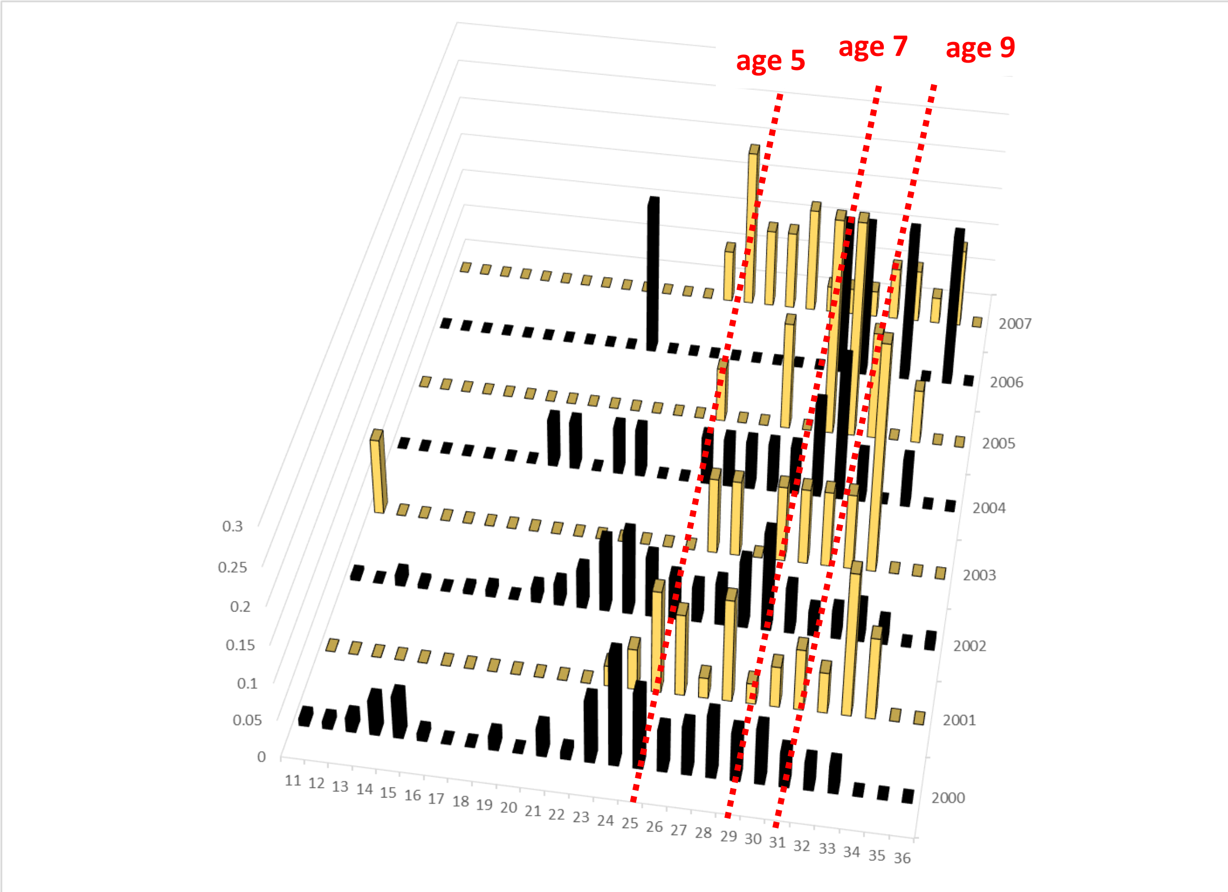

Figure 32. Length compositions of Pacific herring captured in observed federal fisheries, 2000-2007. Dashed red lines indicate mean size at age for ages 5, 7, and 9 in the Togiak fishery in 2010 (Buck 2012).

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

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