Evaluation of stock structure for eastern Bering Sea pollock

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Summary

The stock structure for the Eastern Bering sea (EBS) pollock is evaluated using the template provided by the Stock Structure Working Group (SSWG) and follows from the Aleutian Islands analysis done in 2013 and the Gulf of Alaska in 2012. The original separation of pollock stocks for management were partly due to meristic differences identified in early morphological studies and general geographic characteristics between regions and fisheries. Stock separation is supported to some degree by the genetic isolation by distance (IBD) pattern along the Aleutian Island archipelago between North American and Asian populations and consistent seasonal spawning observed at distinct locales within the EBS. Size at age within the Eastern Bering Sea, Gulf of Alaska, and Aleutian Islands varies notably based on summer survey data which lends support to the current management units (Table 1). The fact that spawning concentrations occur in different locales within the EBS and follow a generally consistent pattern (i.e., adjacent to the northern area of Unimak island and eastward towards Amak Island and a generally later spawning group to the around the Pribilof Islands) suggests that at finer scales some population structuring is likely. However, given uncertainties of the relative contributions of these apparently different spawning events to overall EBS recruitment, close monitoring of fishing patterns relative to spawning conditions remains important.

Introduction

The eastern Bering Sea (EBS) management area is presently defined as the area inside the US Exclusive Economic Zone (EEZ) along the Aleutian Islands Archipelago west of 170° W longitude (Fig. 1). Walleye pollock (*Gadus chalcogrammus);* hereafter pollock) are semi-pelagic schooling gadoids that are widely distributed in the North Pacific Ocean ranging from the Sea of Japan in the west to Northern California in the East. The largest concentrations of pollock occur in the EBS. Pollock in this region reach maturity in about 4 years and grow to about 50 cm (~500 g) in about 5 years and live as long as 20 years though relative few pollock are found much older than age 10. Presently the North Pacific Fishery Management Council and NMFS manage four “stocks” within the US EEZ. In addition to the pollock within the EBS management area, the three other areas are the Gulf of Alaska (GOA), Bogoslof Island /Aleutian Basin, and the Aleutian Islands (AI). To supplement analysis of stock structure conducted for the AI and GOA (Barbeaux 2013, Dorn 2012), the work presented here examines possible pollock stock structure patterns within the EBS and contrasts those with pollock from other regions. The outline and structure of this document follows from the recommended format provided by the NPFMC groundfish Plan Teams.

Harvest and Trends

Pollock catches in the EBS has varied with peaks during the foreign and joint venture fisheries in the early 1970s (Fig. 1).

During the fully domestic period since 1991, spatial patterns in the catch has shifted following population trends and within the EBS, catch has varied between broad ares east and west of 170°W (Fig. 2). The lower overall abundances estimated during the period from 2008-2011 (due to below-average year classes from 2001-2005) caused the fishery to shift further to the northern regions during the B-season. From a biomass perspective, partitioning the B-season catches to east and west of 170°W (approximately coinciding with bottom trawl survey strata) and comparing these catches relative to the biomass shows that from 1991-2014 the area west of 170°W averages about 12% of the survey biomass during that period whereas east of that longitude, the ratio of B-season catch relative to the survey biomass estimates (from strata 1, 3, and 5) has averaged 24%. Since the American Fisheries Act was adopted, the period from 2000 – 2014 the ratios shifted to average 14% in the west and 22% in the east. The overall fishing intensity in the A and B seasons for the period 2012-2014 is show in Figures 3 and 4. Harvest rates within the EBS overall have varied but have generally been below the estimated value for natural mortality (0.3) for recruited fish (Fig 5).

Relative to biomass trends in the GOA and Aleutian Islands region, the patterns differ in a relative sense (Fig. 6) but with somewhat better correspondence in recruitment—particularly the 1978 year class (Fig. 7), while the late 1980s and early 1990s recruitments were generally poor (with the notable exception of the 1989 year class which was above average for all three stocks).

Barriers and phenotypic characters

Between the EBS and Bogoslof region, and on into the Aleutian Islands, physical barriers are limited. Oceanic conditions change with Bogoslof (and Aleutian basin) pollock typically residing in deeper waters (Mckelvey and Steinesson 2015).

Relative to the Aleutian Islands management region, the temperature, salinity, and nutrient load changes at Samalga Pass between 169° W and 170° W longitude (Ladd *et al.* 2005, Mordy *et al.* 2005) due to Aleutian-wide current patterns. This transition from the AI to the EBS poses a clear biophysical with respect to the management areas. At this pass surface waters change from coastal conditions in the east (warm, fresh, and nutrient-poor) to more oceanic conditions in the west (cold, salty, and nutrient-rich). Logerwell *et al.* (2005) found significant differences in demersal ichthyofauna assemblages, diets, and growth on the eastern and western sides of Samalga Pass consistent with a major biophysical transition zone. Logerwell *et al.* (2005) also identified step changes in ichthyofaunal characteristics at Buildir Island and Amchitka Pass, as well as some longitudinal trends in demersal fish characteristics that indicate continuous physical and biological variation along the length of the Aleutian Islands Archipelago.

To the north, along the U.S. – Russia convention line, the evidence for physical barriers are few. In fact, in most years when surveys are conducted there is evidence of continuous distributions extending north into the Russian zone (Figures 8 and 9; compiled from Kuznetsov and Syrovatkin, 2014 and Stepanenko 2015).

Morphometric and meristic studies on Bering Sea walleye pollock show equivocal results regarding stock delineations (Dawson 1994) and as summarized in Bailey *et al.* (1999, Table 2) and Macklin (1998; Table 2.2 page 34). Serobaba (1978) initially identified four subpopulations of pollock in the Bering Sea based on meristics; the eastern Bering Sea (EBS), western Bering Sea (WBS), northern Bering Sea (NBS), and a southern Bering Sea or Aleutian Island (AI) group. The Serobaba (1978) study lacked samples from the Aleutian Basin but for the stocks identified, suggested that all the groups intermingled at the margins of the zones they inhabit which precluded clear stock delineations. This study noted similar rates of parasite infestation for EBS and AI pollock and combined with weak evidence of differences based on meristic, suggested that the EBS and AI pollock exhibited exchange. The fact that the limited tagging data (mainly off of Japan; e.g., Tsuji 1989) suggests dispersed feeding migrations supports this difficulty.

Based on the comparison of morphometric measurements and size at age Dawson (1994) concluded that there were three distinguishable stocks in the Bering Sea. They found little difference between samples from northeastern and southeastern Bering Sea and concluded that western Bering Sea shelf shared characteristics whereas samples from the Aleutian Islands and Aleutian Basin suggested distinct stocks. Barbeaux (2013) reviewed the regional differences in growth patterns for pollock. Our updated examination (sample sizes shown in Tables 2, 3, and 4) confirm that differences in growth exist between regions (Fig. 10). Also, the general characteristics of the sizes of pollock available during summer surveys differs between regions with the Aleutian Islands showing a higher relative frequency of large pollock compared to the EBS which were generally smaller (Fig. 11). Latitude bins, the length frequencies from the GOA showed some similarities when aggregated over time with smaller pollock occurring furthest to the north in the survey data (Fig. 12). By age, and plotted to coincide with ADFG statistical grids, the size-at-age anomalies show that the smaller pollock (at age) are generally to the north and western part of the EBS (Fig. 13) consistent with the findings of Shuck (2000). To evaluate synchronicity in growth, the same data aggregated for means within regions shows periods with medians above and below but without any apparent similarities between regions (Fig. 14). Extending the length at age anomalies by latitude shows the differences between the GOA and EBS in a different way (Fig. 15).

Hinckley (1987) used distinct and consistent spawning locations as one metric for discerning pollock stocks. She was able to identify spawning locations in the EBS, GOA, and Aleutian basin. Shuntov et al. (1993) synthesized available information and show some hypothesized movement patterns (Fig. 16). Stepanenko and Gritsay (2015) provide pollock distribution patterns based on extensive investigations and experience. Their detailed view of age-specific patterns of pollock movement and spawning suggests a large number of discrete spawning sites but insights on the relative contributions of these sites (and to which fisheries they contribute) are limited (Fig. 17). Based on these studies and a workshop that was convened to address this topic, Quinn et al. (2011) developed a conceptual model for pollock movement and spawning (Fig. 18).

Genetics

Macklin (1998) provides evidence of distinct separation from pollock samples collected in the eastern and western Pacific (Fig. 19). Bailey et al. (1999; Table 4) provides a thorough synopsis of genetics studies conducted on pollock up to 1999. Mulligan et al. (1992) study showed discernible differences among samples collected in the Aleutian Islands, Gulf of Alaska, and Aleutian Basin using mtDNA and RFLP methods (Fig. 20). Subsequent work presented in Grant et al. (2010). The study used sequences of mitochondrial DNA cytochrome oxidase subunit I in nine samples (n = 433) from Japan to Puget Sound to evaluate genetic population structure. In their study two haplotypes varied clinally across the North Pacific (Fig. 21). They concluded that these clines were likely the result of the isolation of populations in ice-age refugia, secondary post-glacial contact, and restricted long-distance dispersal. Overall, Φ_{ST}= 0.030 ($p < 0.001$), but the greatest partition was attributable to differences between Asian and North American populations (Φ_{CT} = 0.058, p = 0.036). Isolation by distance was detected across the North Pacific, but differentiation among populations within regions was minimal (Φ_{SC}= 0.007, $p < 0.092$). They note:

> *"The analyses of phenotypic and demographic population traits in pollock are more important for identifying local populations, because these variables reflect the short-term environmental drivers of larval survival and recruitment. Hence, the combined results of genetic studies on pollock do not provide information that would alter the present practice of managing pollock on the scale of continental shelf regions."*

A Russian study used 10 microsatellite loci but found that discriminatory power was noted for only 3 of them (Shubina et al. 2009) *[Jim needs help interpreting this study…].*

Interpretation of the information regarding stock structure

Growth has known to vary geographically within the EBS and generally follows a latitudinal trend with smaller fish at a given age occurring in the north and larger towards the south. Physical features that appear unique include the areas north of Unimak pass near Amak Island and in the shelf break areas in general. Genetic studies have indicated a clinal trend across the North Pacific but to date have shown little differences within the EBS.

There is clear overlap of pollock between the US and Russian around the convention line as shown in the fall survey data above. Similar patterns have been noted in the NMFS summer acoustic-trawl surveys which have extended into the Russian zone (e.g., Honkalehto et al. 2014). These are possibly affected by the thermal structure of the EBS as well as the population structure and the relative contribution of different spawning aggregations to recruitment. For example, comparing available fall survey biomass estimates from the Russian research vessels with mean bottom temperatures in the EBS suggests there are climate-related mechanisms that affect subsequent pollock biomass distributions (Fig. 22).

Management implications

Evidence for discrete spawning events and locales indicate that consideration and monitoring of the population components is required. Within the current constraints placed on the EBS pollock fishery and adjacent areas (e.g., Bogoslof and Aleutian Islands region), additional area-specific management would likely require near real-time abundance data to adequately spatially allocate stocks that are complex in their organization and movements throughout the year. Relative to the survey biomass estimates by region, the B-season (June 10th-October 31st) catch east and west of 170°W, suggests that the regional harvest rates are relatively higher in the eastern portion of the EBS (closes to main shore-based processing plants). From a management perspective, this aspect is monitored and manifests changes over time in the way selectivity is modeled. Also, the eastern area generally comprises more old pollock which may have benefits by avoiding focus on younger fish recruiting to the spawning stock.

Hulson et al. (2011, 2013) evaluated the estimation properties of movement with and without tagging and found that regional biomass estimates were unbiased but had higher uncertainty when tagging data were unavailable.

Regionally, separation of the AI pollock from the AI Basin, GOA, EBS pollock seems warranted given growth and other differences highlighted in Barbeaux 2013 and from results presented here. Relative to the international shared boundary at the US-Russia Convention line to the north, collaboration among scientists is excellent and the ability to conduct surveys that straddle this border in summer (every other year with the NOAA/NMFS acoustic-trawl survey) and later in the year (extending into November typically) by the Russian research vessel. Environmental conditions likely play a role in structuring the pollock distribution in these areas and it is likely that some mixing of fish spawned in the western Bering Sea occurs and is vulnerable to fishing within the US zone. Similarly, it is also likely that fish arising from spawning aggregations in the US zone mix into the Russian zone in varying degrees. As more survey and fishery data accrue from both regions, analysis on potential drivers and cooperative management strategies can be developed.

References

Bailey, K. M., T. J. Quinn, P., Bentzen, and W. S. Grant. 1999. Population structure and dynamics of walleye pollock, *Theragra chalcogramma*. Advances in Marine Biology. 37:179-255

Buslov, a. V. (2009). Spawning of walleye pollock (*Theragra chalcogramma*) off the Southwestern coast of Kamchatka. Russian Journal of Marine Biology, 35(7), 549–557. doi:10.1134/S1063074009070049

Barbeaux, 2013. Pollock stock structure for the Aleutian Islands. Draft document presented to the BSAI Groundfish Plan Team. September 2013.

Barbeaux and Fraser (2009). Aleutian Islands cooperative acoustic survey study for 2006. U. S.Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-198, 91 p.

Barbeaux, S., J. Ianelli, and W. Palsson. 2012. Chapter 1A: Assessment of the pollock stock in the Aleutian Islands. In: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pac. Fish. Mgmt. Council, P.O. Box 103136, Anchorage, AK 99510.

Dawson, P. 1994. The stock structure of Bering Sea walleye pollock (*Theragra chalcogramma*). University of Washington. 220p.

Grant, W. S., I. Spies, and M. F. Canino. 2010. Shifting-balance stock structure in North Pacific walleye pollock (*Gadus chalcogrammus*). ICES J. Mar. Sci. 67:1687-1696

Hinckley, S. 1987. The reproductive biology of walleye pollock (*Theragra chalcogramma*) in the Bering Sea, with reference to spawning stock structure. Fish. Bull. 85: 481-498.

Honkalehto, T., A. McCarthy, P. Ressler, and D. Jones, 2013. Results of the acoustic-trawl survey of walleye pollock (*Theragra chalcogramma*) on the U.S., and Russian Bering Sea shelf in June–August 2012 (DY1207). AFSC Processed Rep. 2013-02, 60 p. Alaska Fish. Sci. Cent. NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115. Available from http://www.afsc.noaa.gov/Publications/ProcRpt/PR2013-02.pdf

Hulson, P.-J.F., Miller, S.E., Ianelli, J.N., and Quinn, T.J., II. 2011. Including mark–recapture data into a spatial age-structured model: walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea. Can. J. Fish. Aquat. Sci. 68(9): 1625–1634. doi:10.1139/f2011-060.

Hulson, P. F., Quinn, T. J., Hanselman, D. H., Ianelli, J. N. (2013). Spatial modeling of Bering Sea walleye pollock with integrated age-structured assessment models in a changing environment. Canadian Journal of Fisheries & Aquatic Sciences, 70(9), 1402-1416. doi:10.1139/cjfas-2013-0020.

Kotwicki, S., T.W. Buckley, T. Honkalehto, and G. Walters. 2005. Variation in the distribution of walleye pollock (*Theragra chalcogramma*) with temperature and implications for seasonal migration. Fish. Bull 103:574–587.

Kuznetsov, M. and E. Syrovatkin. 2014. Results Of The August-September 2013 Acoustic-Trawl Survey of Walleye Pollock (*Theragra chalcogramma*) Conducted In The Northwestern Bering Sea, R/V Tinro. Informal Report transmitted to AFSC, Seattle. 5 p. *In Russian.*

Ladd, C., G.L. Hunt Jr. C. Mordy, S. Salo, and P. Stabeno. 2005. Marine environment of the eastern and central Aleutian Islands.Fish. Oceanogr. 14(Suppl. 1):22–38.

Logerwell, E.A., K. Aydin, S. Barbeaux, E. Brown, M.E. Conners, S. Lowe, J.W. Orr, L. Ortiz, R. Reuter, and P. Spencer. 2005. Geographic patterns in the demersal ichthyofauna of the Aleutian Islands Fish. Oceanogr. 14(Suppl. 1): 93-112.

Lynde, C.M., Lynde, M.V.H., and Francis, R.C. 1986. Regional and temporal dif- ferences in growth of walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea and Aleutian Basin with implications for management. NMFS Northwest and Alaska Fisheries Science Center, Seattle, Wash.

Macklin, S. A. ed. (1998). Bering Sea FOCI Final Report. *NOAA Coastal Ocean Program Decision Analysis Series*, *13*, 167.

Mordy, C., P. Stabeno, C. Ladd, S. Zeeman, D. Wisegarver, and G. L. Hunt Jr. 2005. Nutrients and primary production along the eastern Aleutian Islands Archipelago. Fish. Oceanogr. 14(Suppl. 1): 55-76.

McKelvey, D., and S. Steinessen. 2015. Results of the March 2014 acoustic-trawl survey of walleye pollock (*Gadus chalcogrammus*) conducted in the southeastern Aleutian Basin near Bogoslof Island, Cruise DY2014-02. AFSC Processed Rep. 2015-06, 43 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Mulligan, P. J., W.W. Chapman, and B. L. Brown. 1992. Mitochondrial DNA analysis of walleye pollock,*Theragra chalcogramma*, from the eastern Bering Sea and Shelikof Strait, Gulf of Alaska. Can. J. Fish. Aquat. Sci. 49:319-326.

Quinn, T. J. II, J. N. Ianelli, S. X. Cadrin, V. Wespestad, and S. J. Barbeaux. 2011. Report on a workshop on spatial structure and dynamics of walleye pollock in the Bering Sea. AFSC Processed Rep. 2011-04, 46 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Rutecki, T. L. 2011. Feasibility of tagging walleye pollock, Theragrachalcogramma, captured with hook and line using external tags. AFSC Processed Rep. 2011-03, 20 p. Auke Bay Laboratories, Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 17109 Point Lena Loop Road, Juneau, AK 99801.

Shuck, C. J. 2000. Spatial and temporal differences in growth and productivity of walleye pollock in the eastern Bering Sea. Master's thesis. University of Washington, Seattle.

Shubina, E. a., Ponomareva, E. V., & Glubokov, a. I. (2009). Population genetic structure of walleye pollock *Theragra chalcogramma* (Gadidae, Pisces) from the Bering Sea and Sea of Okhotsk. Molecular Biology, 43(5), 855–866. doi:10.1134/S0026893309050161

Shuntov, V.P., et al. 1993. Population dynamics of the pollock In Pollock in the ecosystems of the Far Eastern seas. Vladivostok. TINRO. Transl. 53p. by Sarah Peyton. REPRINT FILE.

Shuntov, V. P. 1992. Functional structure of the distribution area of walleye pollock in the Bering Sea. Russian Journal of Marine Biology, 17: 189–198. (A translation from Biologia. Morya, 1991.)

Stepanenko, M. A., & Gritsay, E. V. (2014). Eastern Bering Sea pollock recruitment, abundance, distribution and approach to fishery management. *Fisheries Science*, *80*(2), 151–160. doi:10.1007/s12562-014-0719-9

Stepanenko, M. A. 2015. The R/V TINRO EI-MWT pollock survey in the northwestern Bering Sea, September 16-October 02, 2014. Informal report sent to AFSC Seattle WA. 5 pages.

Serobaba, I. I. 1978. Data on the population structure of the walleye pollock, *Theragra chalcogramma* (Pallas), from the Bering Sea.Russian Journal of Ichthyology (translation of Voprosy Ikhtiologii), 17: 219 –231.

Tsuji, S. (1989) Alaska pollock population, *Theragra chalcogramma*, off Japan and its adjacent waters: I. Japanese fisheries and population studies. Mar. Behav. Physiol. 15:147–205.

Tables

Table 1. Summary of available data on stock identification for EBS pollock.

Factor and criterion	Justification
Harvest and trends	
Fishing mortality	Fishing mortality rates (F; average over ages 3-10) and catch / age 3+ biomass values averaged 0.28 and 0.20, respectively, over the last five years.
Spatial concentration of fishery relative to abundance	Spatial concentration of fishery is affected by seasons (40% of quota allocated to winter and typically constrained by ice and weather) and in summer, at-sea processor quota (representing about 40% of quota) is restricted to fish outside of CVOA (see Figure 1)
Population trends	Recently stable to increasing population size characterized by highly variable recruitment. Within the EBS, absolute population trends vary slightly.
Barriers and phenotypic characters	
Generation time	Generation time is < 10 years
Physical limitations	Some possibly porous biophysical barriers along northern management area and to the south-and west. Dispersal potential during larval phase is high but retention within the EBS probable.
Growth differences	Growth differences apparent relative to other current management areas, changes with smaller size at age for northern region compared to southern part of EBS.
Age/size-structure	Some synchronicity with adjacent regions and variability within the EBS.
Spawning time differences	Timing of spawning differs between AI, GOA, EBS and AI Basin stocks and some clear seasonal patterns of different aggregations spawning within the EBS
Maturity-at-age/length differences	Mean maturity-at-age/ length within the EBS data unavailable
Morphometrics	Two studies identified morphometric differences from other stocks (Serobaba 1978, Dawson 1994).
Meristics	Meristic characteristics have a latitudinal trend with some non-statistically significant differences observed (Serobaba 1978). Low sample sized did not allow for good comparisons.
Behavior & movement	
Spawning site fidelity	Spawning individuals occur in same locations consistently
Mark-recapture data	Tagging studies from elsewhere show movement to feeding areas
Natural tags	Some limited data on parasites show no difference between AI and EBS pollock (Serobaba 1978).
Genetics	
Isolation by distance	Apparent weak IBD structure from Asia to North America using microsatellites
Dispersal distance	Dispersal based on advection remains within the current management area
Pairwise genetic differences	Consistent pairwise genetic differences between geographically discrete samples using microsatellite markers from Asia to North America. Shifts in local abundance at centennial and decadal scales due to climate variability likely reduce resolution of genetic stock detection

Table 2. Sample sizes of number of pollock measured by year and survey area.

Year	AI	BS	GOA
1982	6,256	117,248	18,380
1983	28,672	818,383	9,619
1984	NA	56,494	33,238
1985	NA	239,784	75,472
1986	25,400	137,677	13,882
1987	NA	39,666	37,745
1988	NA	341,339	NA
1989	NA	80,080	22,527
1990	NA	280,447	42,811
1991	15,601	411,636	NA
1992	NA	61,148	NA
1993	NA	167,246	35,445
1994	18,045	126,647	NA
1995	NA	133,385	NA
1996	NA	117,501	47,120
1997	10,983	152,566	NA
1998	NA	108,056	NA
1999	NA	103,411	24,926
2000	10,772	132,632	NA
2001	NA	154,848	25,723
2002	13,439	151,012	NA
2003	NA	54,144	25,329
2004	8,569	98,429	NA
2005	NA	37,026	26,945
2006	6,585	39,615	NA
2007	NA	29,801	24,851
2008	NA	116,957	NA
2009	NA	109,320	32,909
2010	9,762	112,185	NA
2011	NA	103,157	27,327
2012	7,944	209,105	NA
2013	NA	247,845	31,883
2014	10,305	314,039	NA

Table 3. Sample sizes by year of pollock aged as collected by NMFS scientists on bottom trawl surveys.

Year	AI	BS	GOA
1982	NA	1,472	388
1983	3,756	1,928	390
1984	NA	1,708	1,665
1985	NA	1,705	NA
1986	1,051	1,342	NA
1987	NA	1,548	425
1988	NA	1,341	NA
1989	NA	1,226	NA
1990	NA	1,704	347
1991	NA	1,746	NA
1992	NA	1,043	NA
1993	NA	1,347	1,817
1994	990	832	NA
1995	NA	1,046	NA
1996	NA	1,387	977
1997	1,032	1,086	NA
1998	NA	1,125	NA
1999	NA	1,333	1,135
2000	868	1,545	NA
2001	NA	1,612	758
2002	1,335	1,605	NA
2003	NA	1,625	1,102
2004	583	1,632	NA
2005	NA	1,548	1,459
2006	575	1,545	NA
2007	NA	1,488	1,151
2008	NA	1,247	NA
2009	NA	1,342	1,517
2010	432	1,385	NA
2011	NA	1,746	1,642
2012	535	1,777	NA
2013	NA	1,847	1,557
2014	NA	2,097	NA

Table 4. Sample sizes by age over all years from the NMFS bottom trawl surveys.

age	AI	BS	GOA
1	704	5875	3193
2	847	3804	1715
3	1008	3822	1841
4	800	3906	1921
5	2561	4791	2269
6	1374	5113	1954
7	748	4157	1298
8	779	3291	764
9	543	2987	579
10	422	2599	322
11	396	2129	234
12	320	2002	127
13	252	1397	60
14	173	939	32
15	105	671	6
16	54	494	12
17	32	329	2
18	19	245	1
19	9	164	NA
20	6	127	NA
21	2	63	NA
22	2	26	NA
23	1	20	NA
24	NA	9	NA

Figures

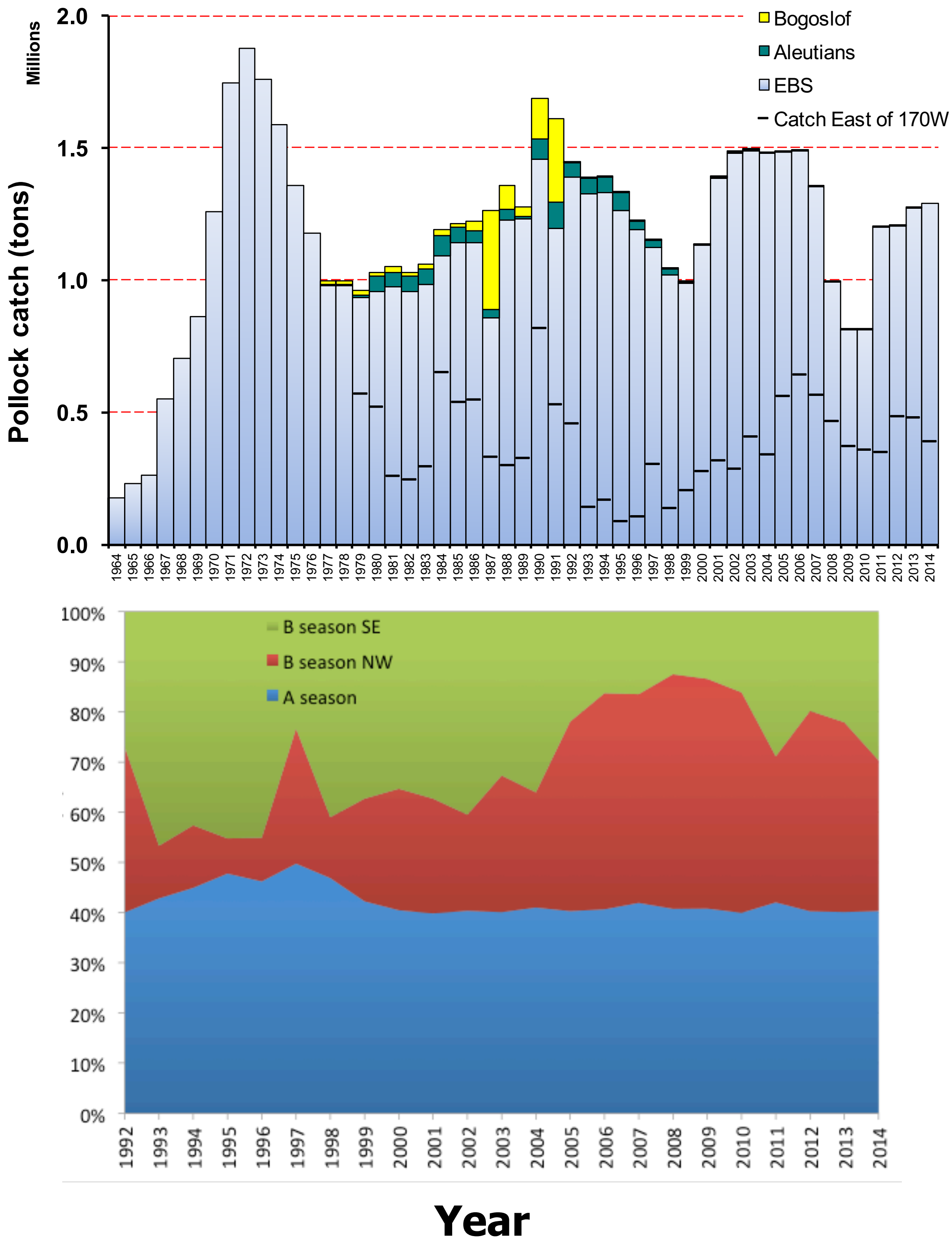

Figure 1. Pollock catch region (top; 1964-2014) and proportion within the EBS (bottom). The A-season is defined as from Jan-May and B-season from June-October, 1992-2014.

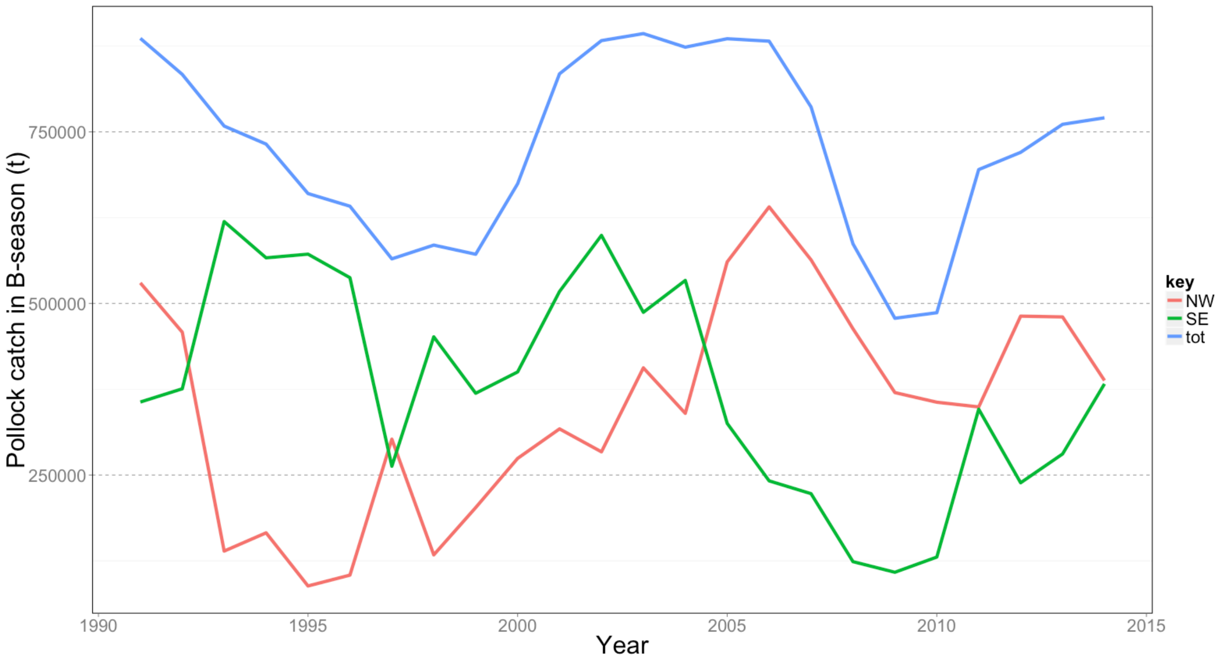

Figure 2. Pollock catch estimates from the Eastern Bering Sea B-season east (SE) and west (NW) of 170°W longitude; 1991-2014.

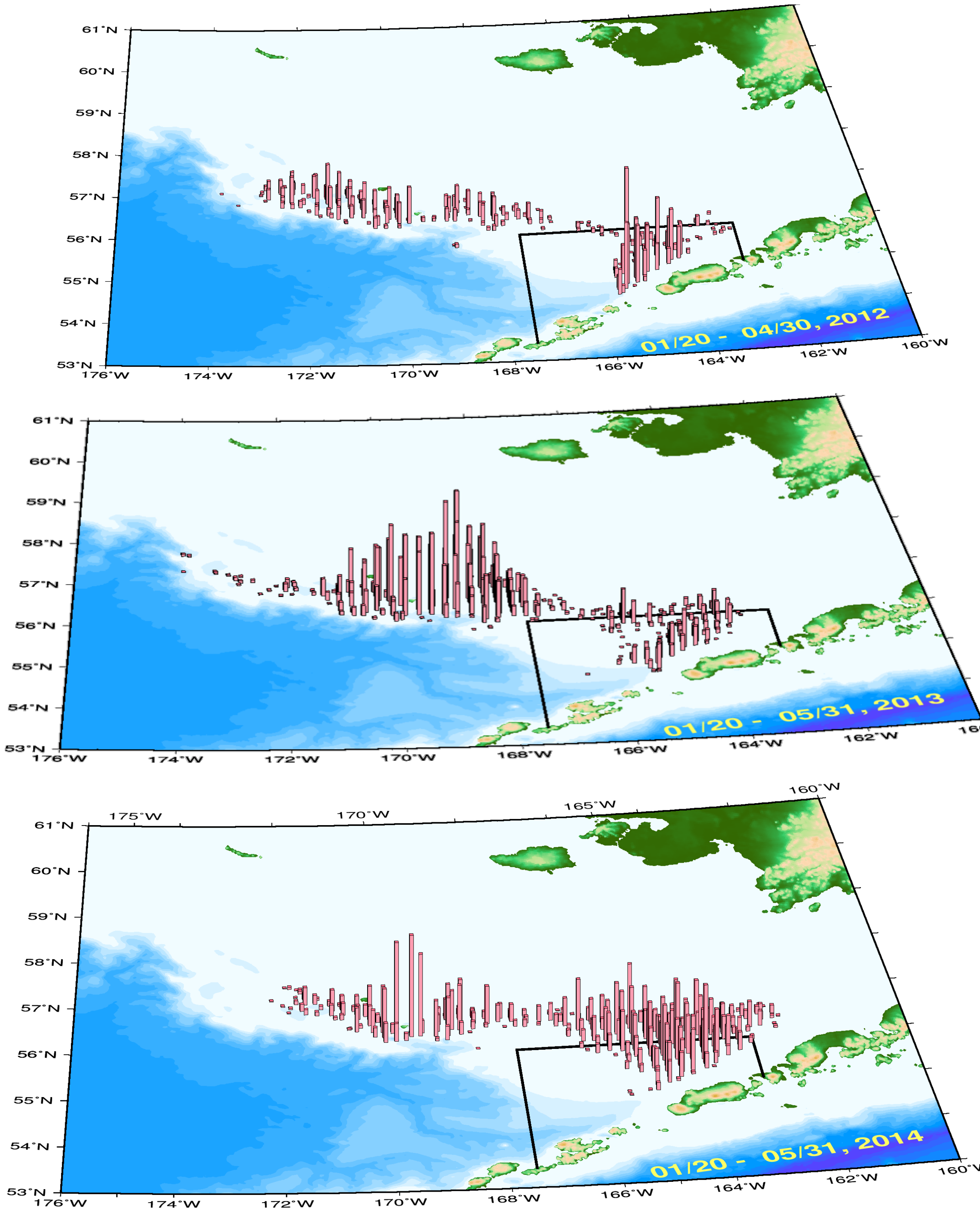

Figure 3. Pollock catch distribution 2012-2014, for the A-season on the EBS shelf. Line delineates catcher-vessel operational area (CVOA). The column height represents relative removal on the same scale in all years.

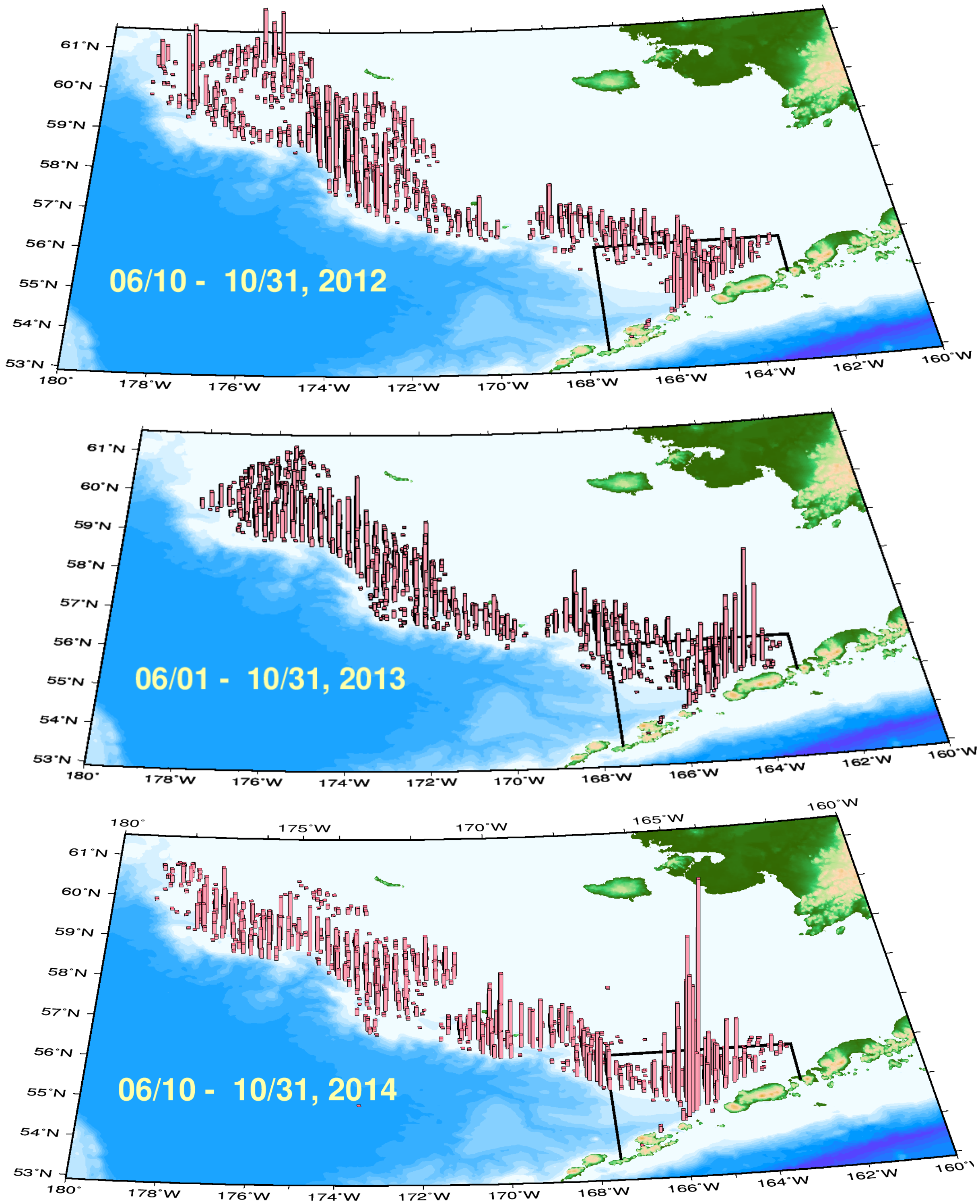

Figure 4. Pollock catch distribution during June – October 2012-2014. The line delineates the catcher-vessel operational area (CVOA) and the height of the bars represents relative removal on the same scale between years.

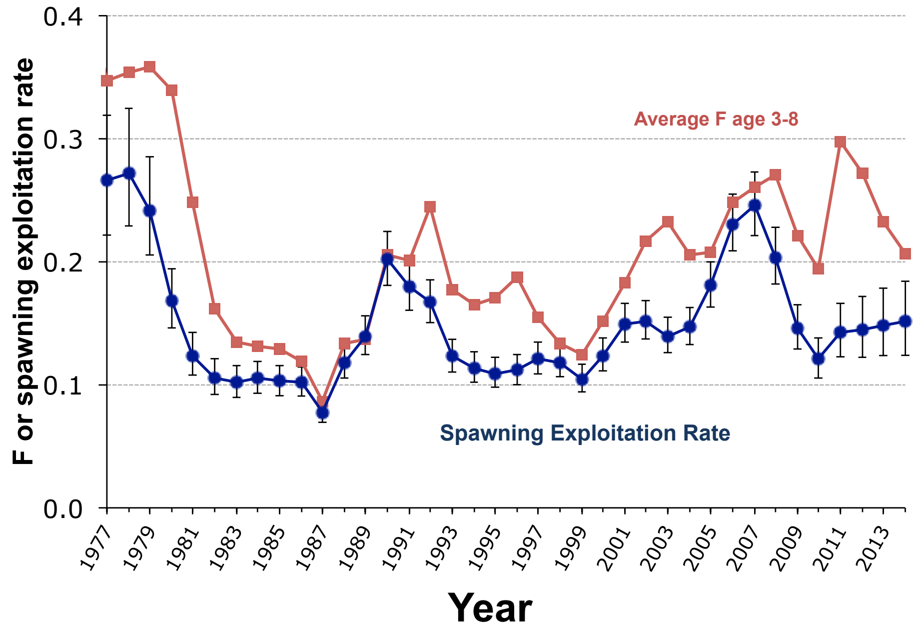

Figure 5. Estimated spawning exploitation rate (defined as the annual percent removals of spawning females due to the fishery) and average fishing mortality (ages 3-8) for EBS pollock, 1977-2014. Error bars represent two standard deviations from the estimates.

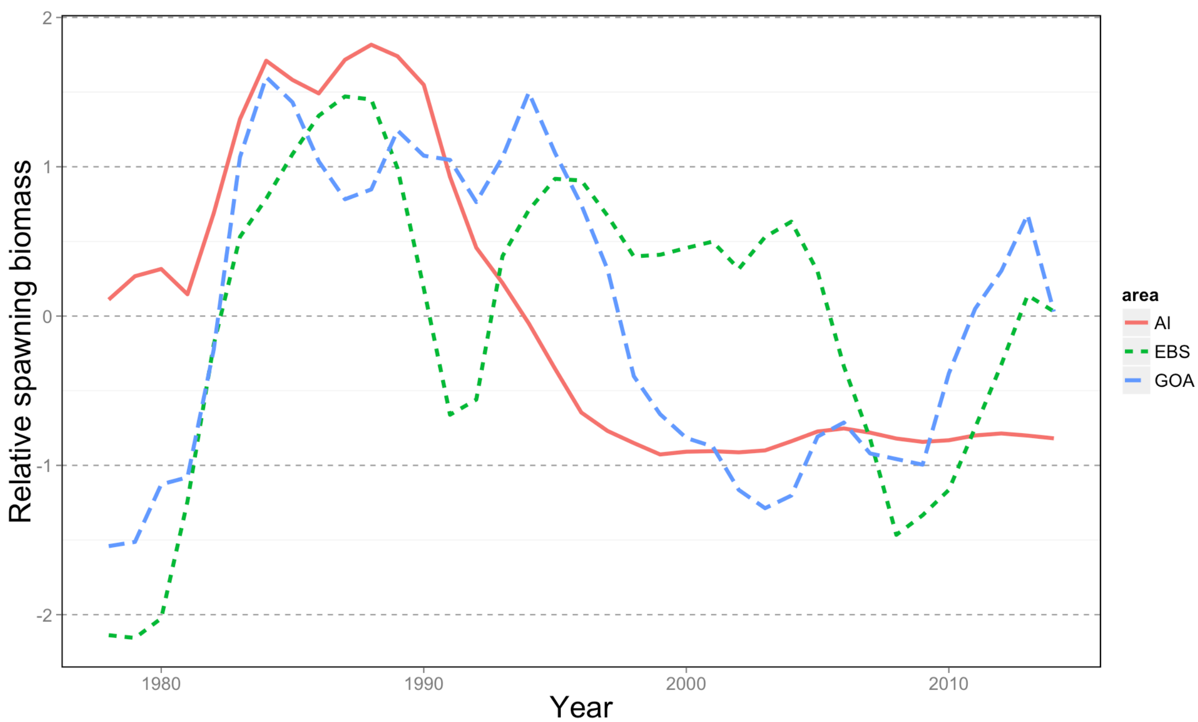

Figure 6. Relative female spawning biomass for the eastern Bering Sea, Gulf of Alaska, and Aleutian Islands pollock from the 2015 stock assessments, 1978-2014 (Barbeaux et al. 2014, Dorn et al. 2014, and Ianelli et al. 2014).

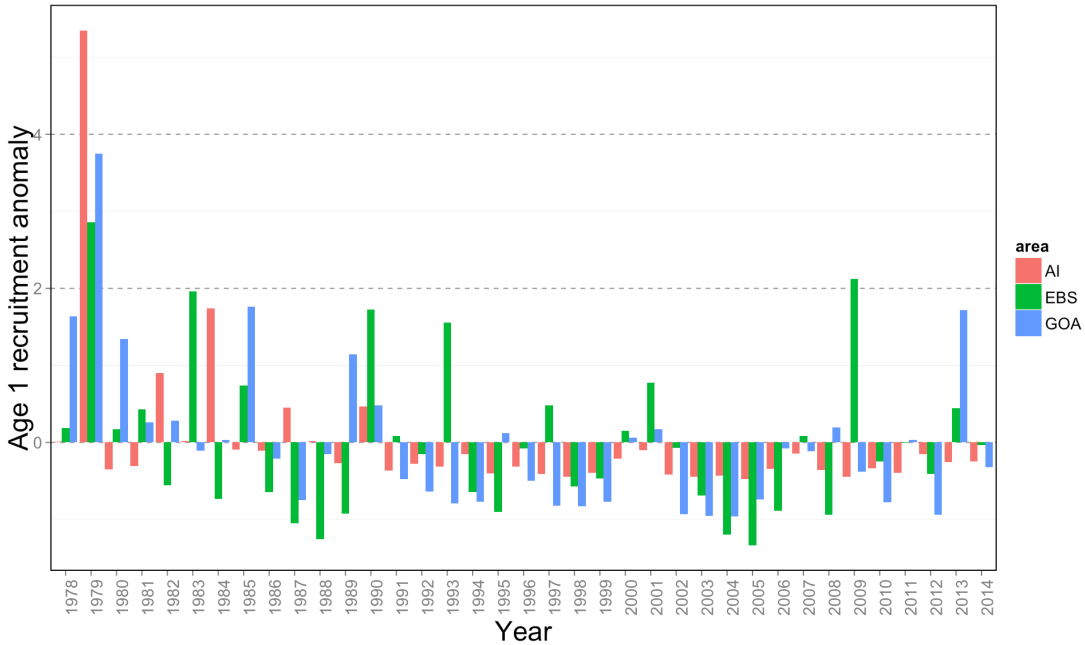

Figure 7. Normalized age-1 pollock recruitment from the Aleutian Islands (AI), eastern Bering Sea (EBS), and Gulf of Alaska (GOA) stock assessments, 1978-2014.

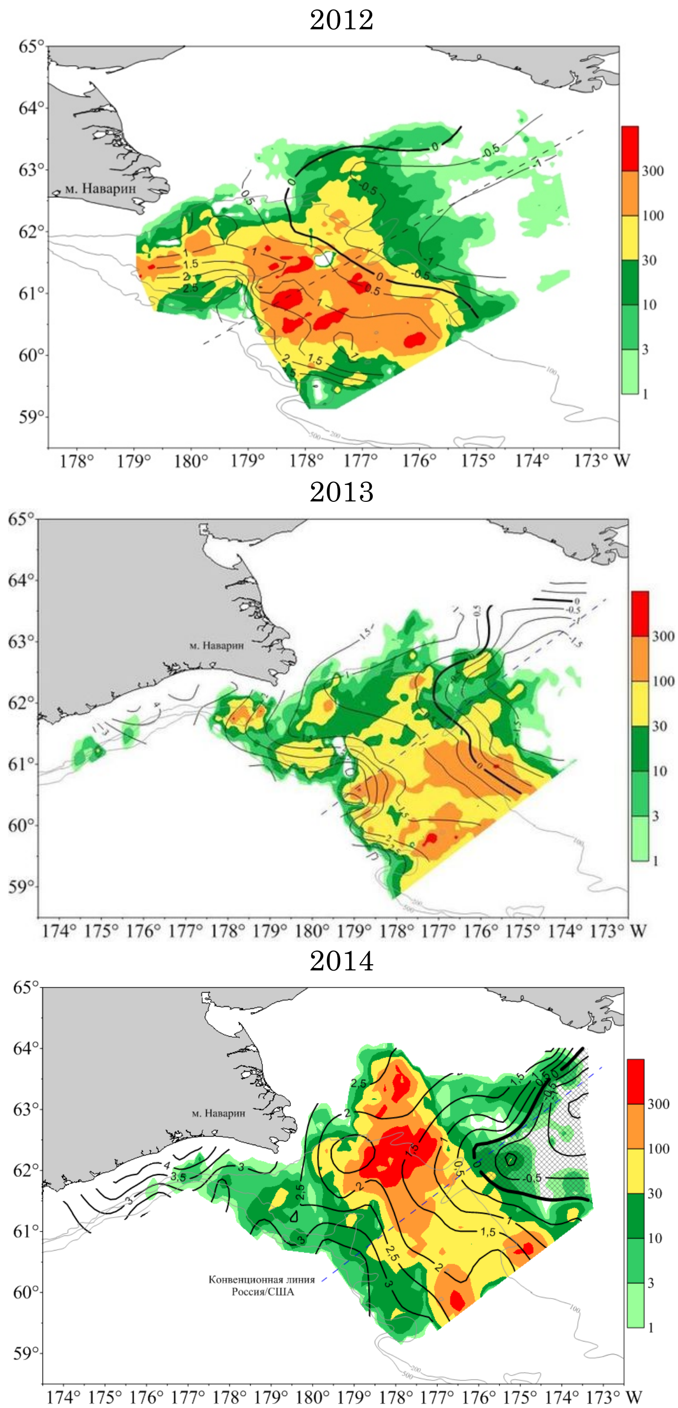

Figure 8. Pollock density distribution (t fish/nm²) (from depth 50 m to 05 m off bottom) and bottom temperature (°C) in the northwestern Bering Sea, September-October, 2012-2014 (compiled from Kuznetsov and Syrovatkin, 2014 and Stepanenko 2015).

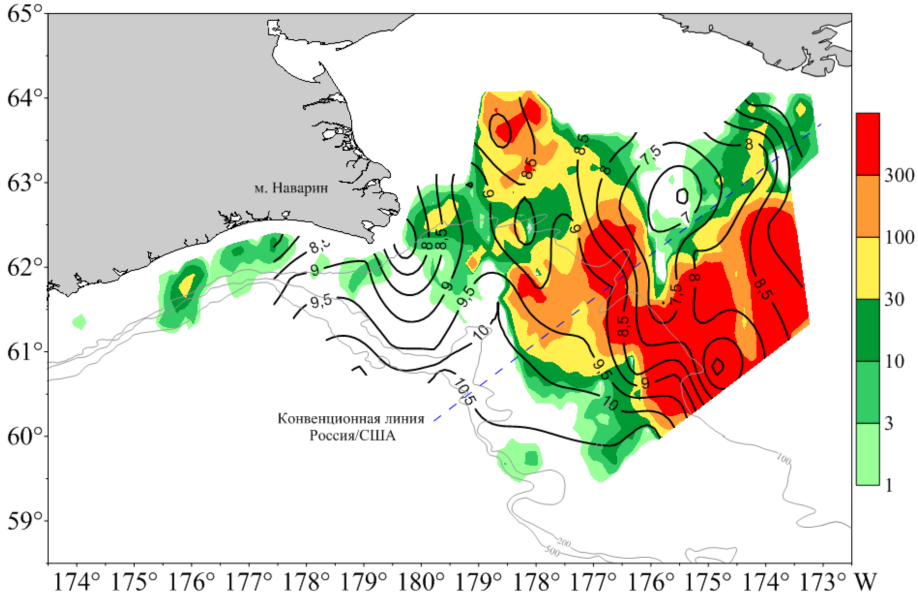

Figure 9. Young-of-the-year and immature pollock density distribution (th.fish./nm²) (from surface to depth 40 m) and temperature (°C) in the northwestern Bering Sea, September-October, 2014 (From Stepanenko 2015).

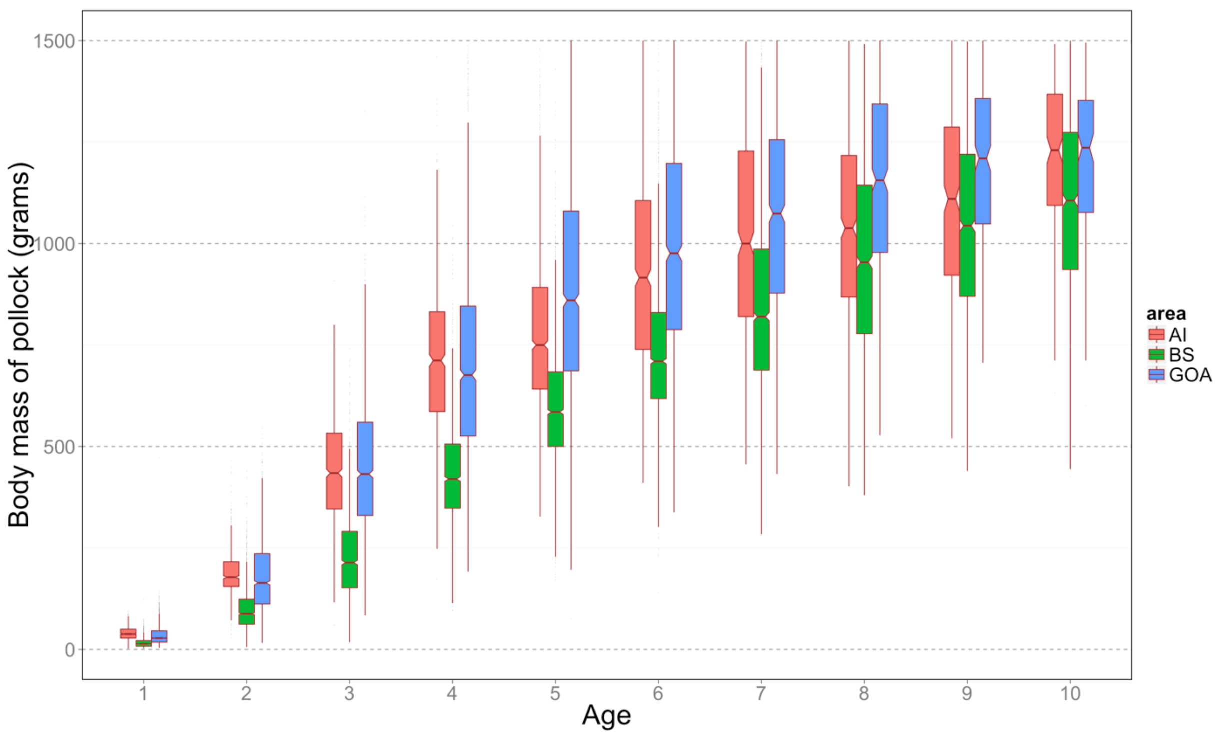

Figure 10. Pollock mean weight, for the Aleutian Islands (AI), Bering Sea (BS), and Gulf of Alaska (GOA) summer bottom trawl surveys 1982-2014.

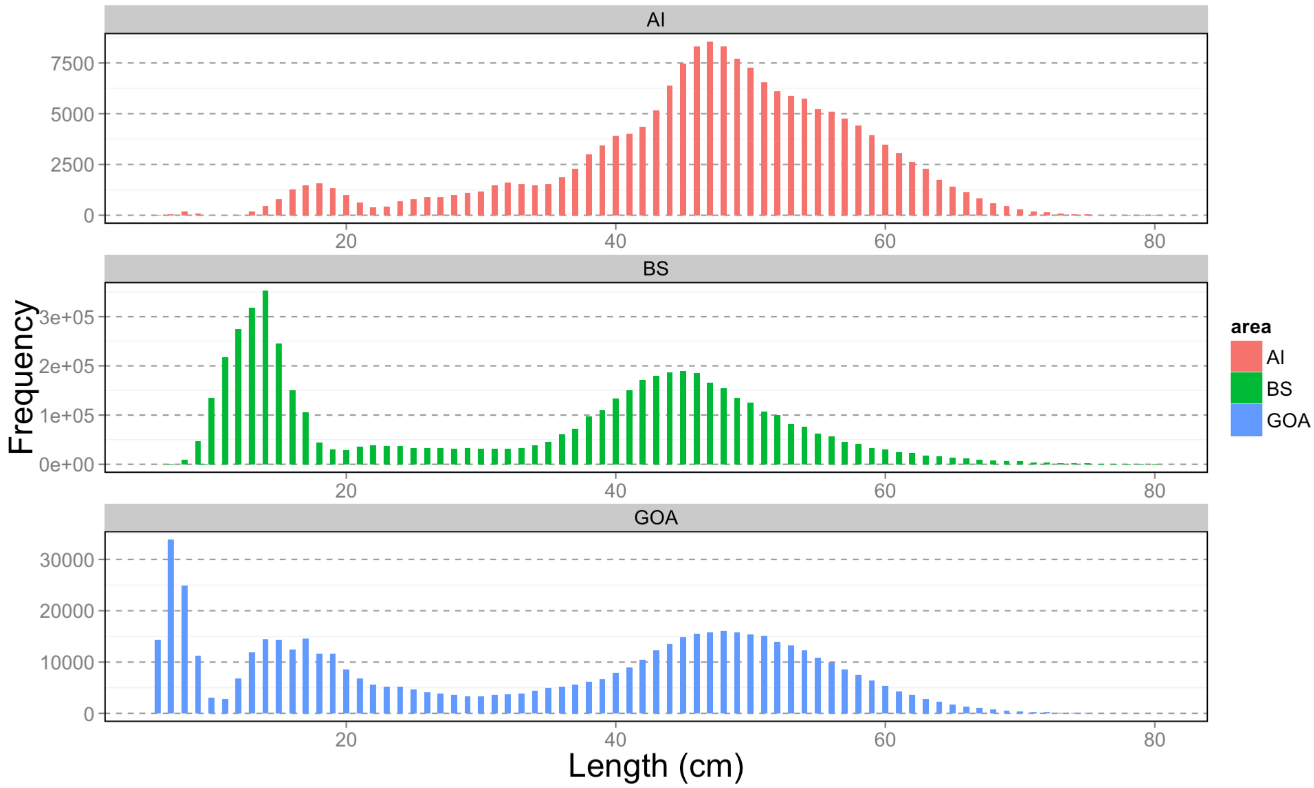

Figure 11. Pollock length frequencies by region (vertical scales differ and are in absolute numbers of fish measured) from NMFS bottom trawl surveys in the Aleutian Islands, GOA and EBS.

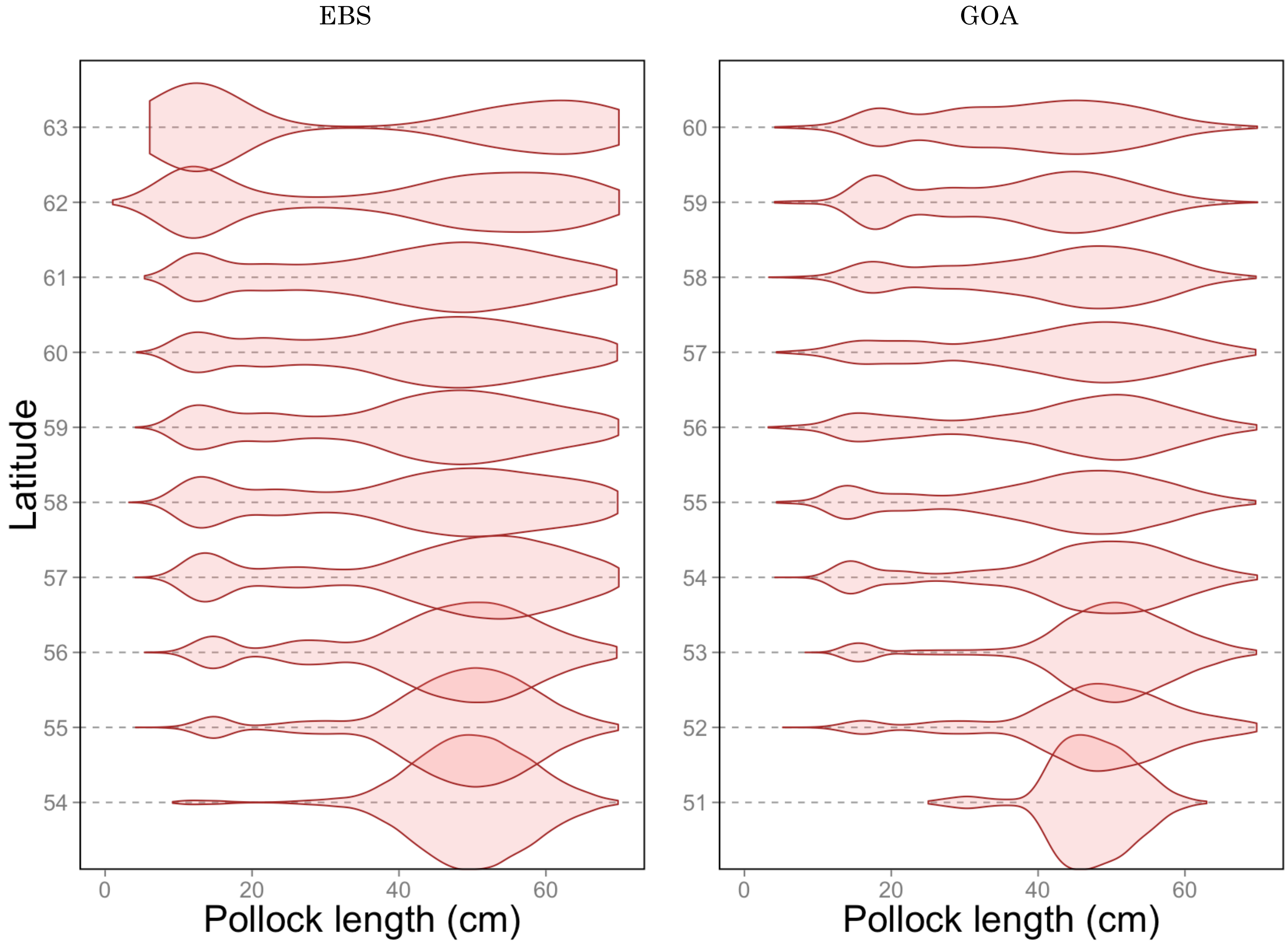

Figure 12. Length frequency by latitude (lower bound) for EBS and GOA pollock (note that the range of latitudes differ between the figures)

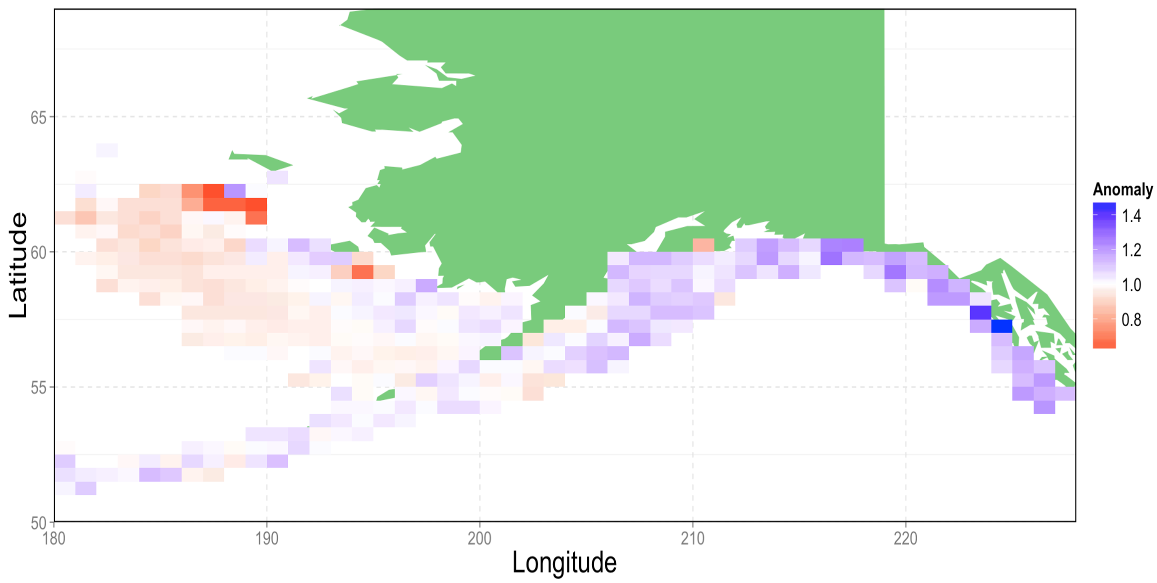

Figure 13. Pollock length-at-age anomalies (ages 2-15) relative to the global area-wide mean (each age is normalized by global mean value and shadings represent relative differences) based on NMFS bottom trawl surveys in the Aleutian Islands, GOA and EBS, 1982-2014

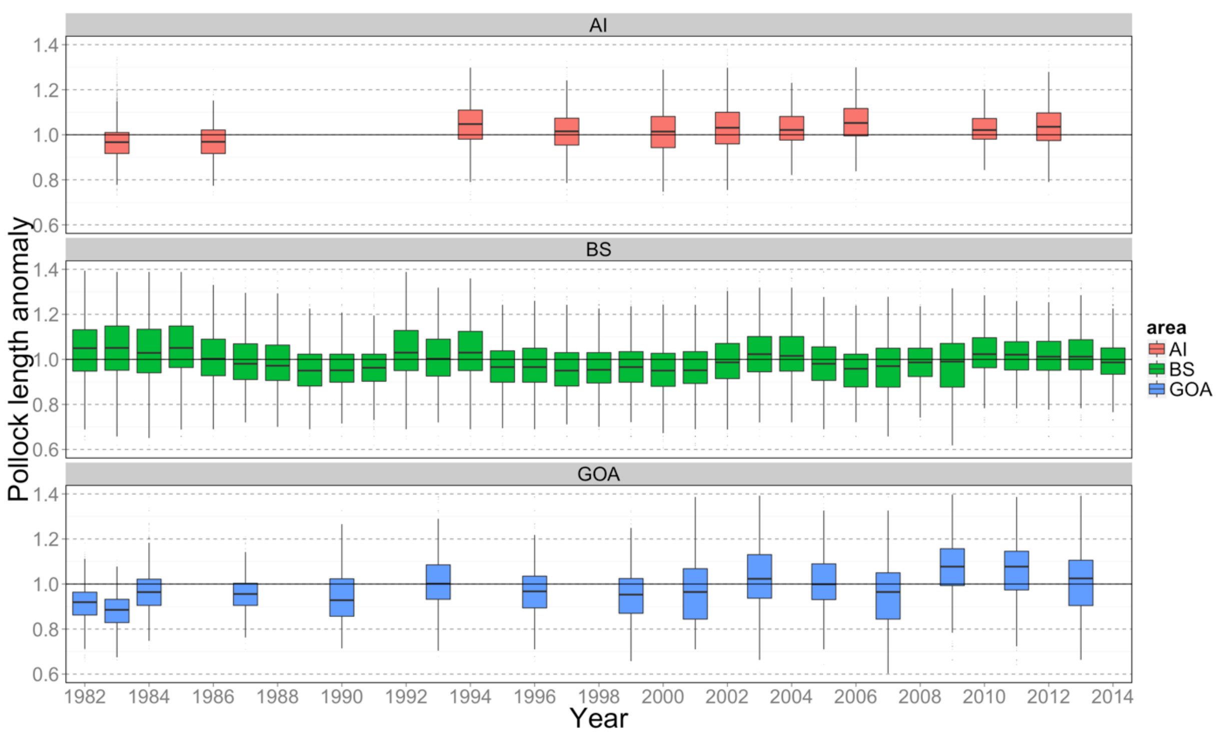

Figure 14. Mean length anomaly-at-age relative to the within-region means for all ages 2-15, 1982-2014.

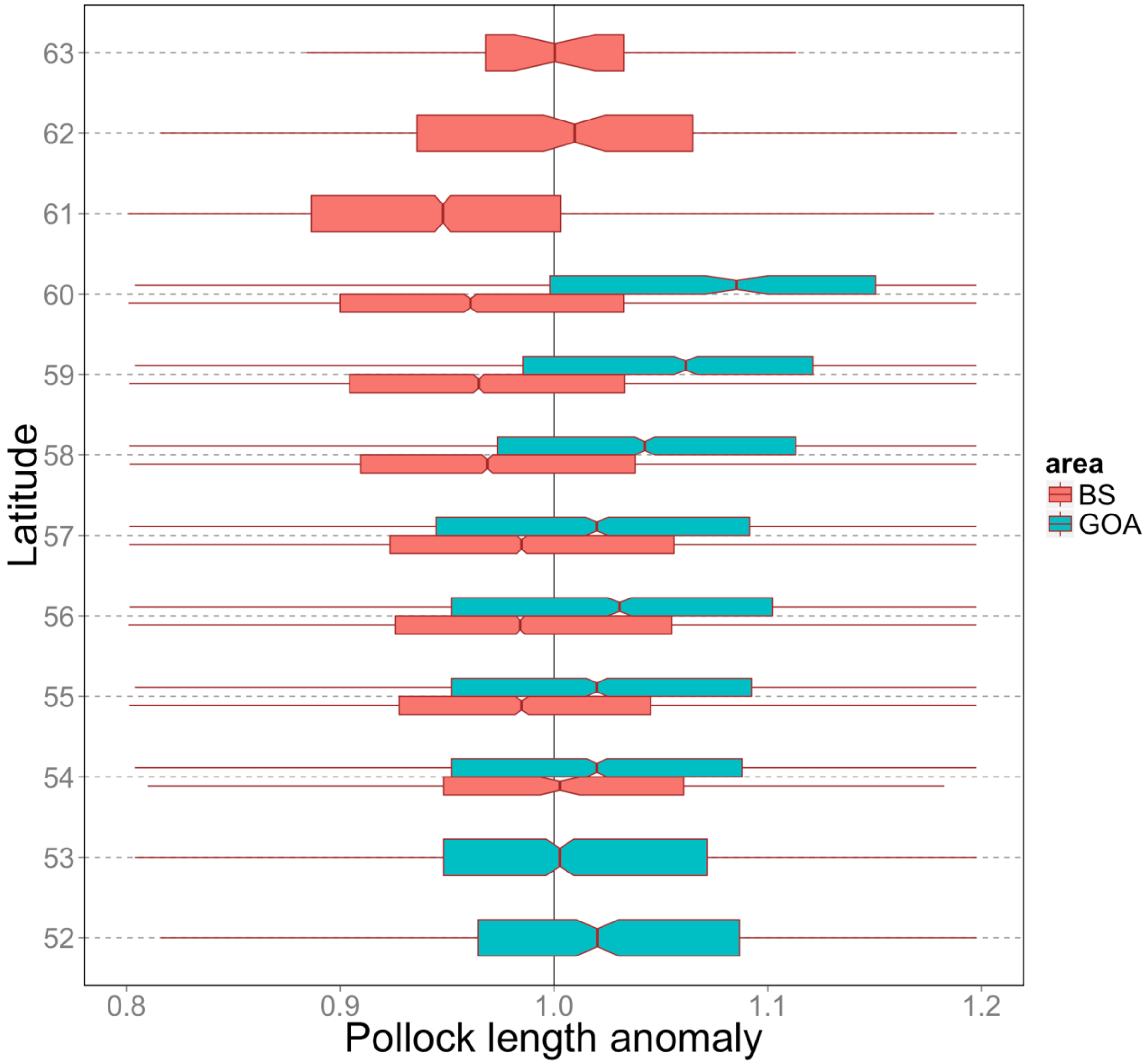

Figure 15. Comparison of mean length anomaly-at-age relative to the combined means for all ages 2-15, data from 1982-2014.

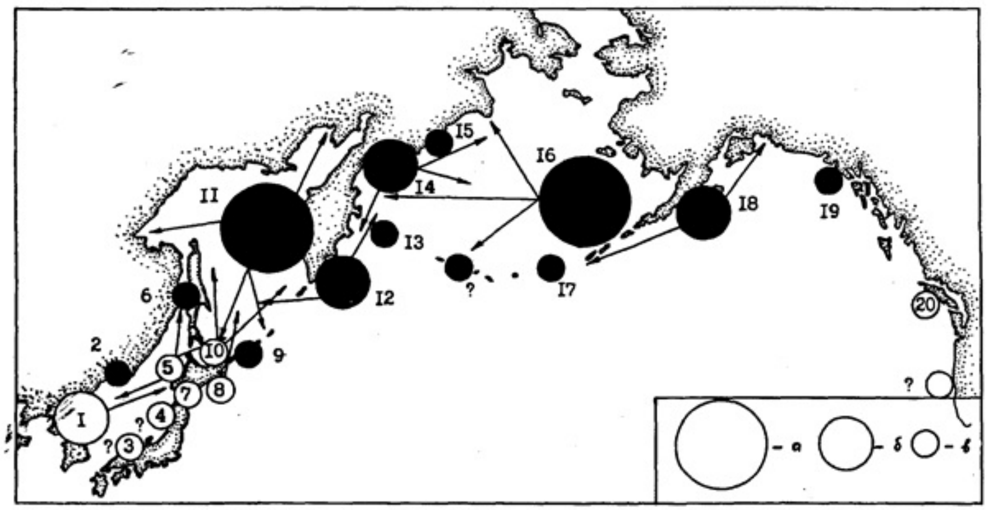

Figure 16. General diagram of pollock population structure (adapted from Shuntov et al, 1993): *"The summary biomass of populations: a– up to 10 million tons and more, b – from several hundred thousand to several million tons, c - from several ten thousand to several hundred thousand tons. The arrows show the pollock travel paths. The light circles are autumn or winter spawning and dark ones are the spring spawning. Populations: East Korean (1), Peter the Great Bay (2), Shimana (3), Toyama (4), West Hoккaido (5), Tatar Strait (6), South Hoккaido (7), East Hoккaido (8), South Kuril (9), North Hoккaido or Raus (10), North Okhotsk Sea super population (11), East Kamchatka (12), Commander (13), Olyutorsky-Karaginsky (14), Koryak (15), East Bering Sea super population (16), East Aleutian (17), West Alaska (18), East Alaska (19), Vancouver (20)"*

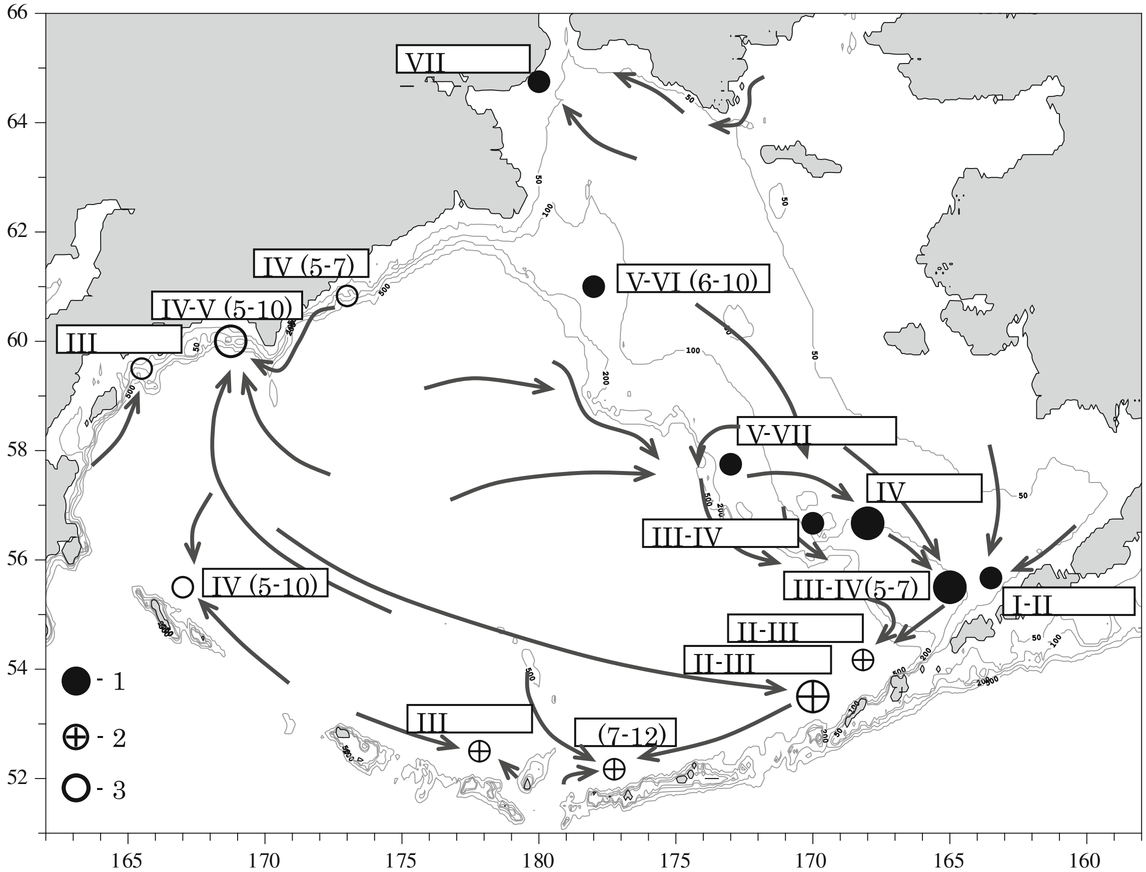

Figure 17. From Stepanenko and Gritsay (2015): Distribution of spawning concentrations and general direction of prespawning migrations of the Bering Sea pollock (1 eastern and northwestern Bering Sea; 2 area off Aleutian Islands; 3 western Bering Sea). Months of most intensive spawning indicated by Roman numerals and range of predominant ages of spawning pollock by Arabic numerals. Diameter of the circles reflects relative density of spawning concentrations

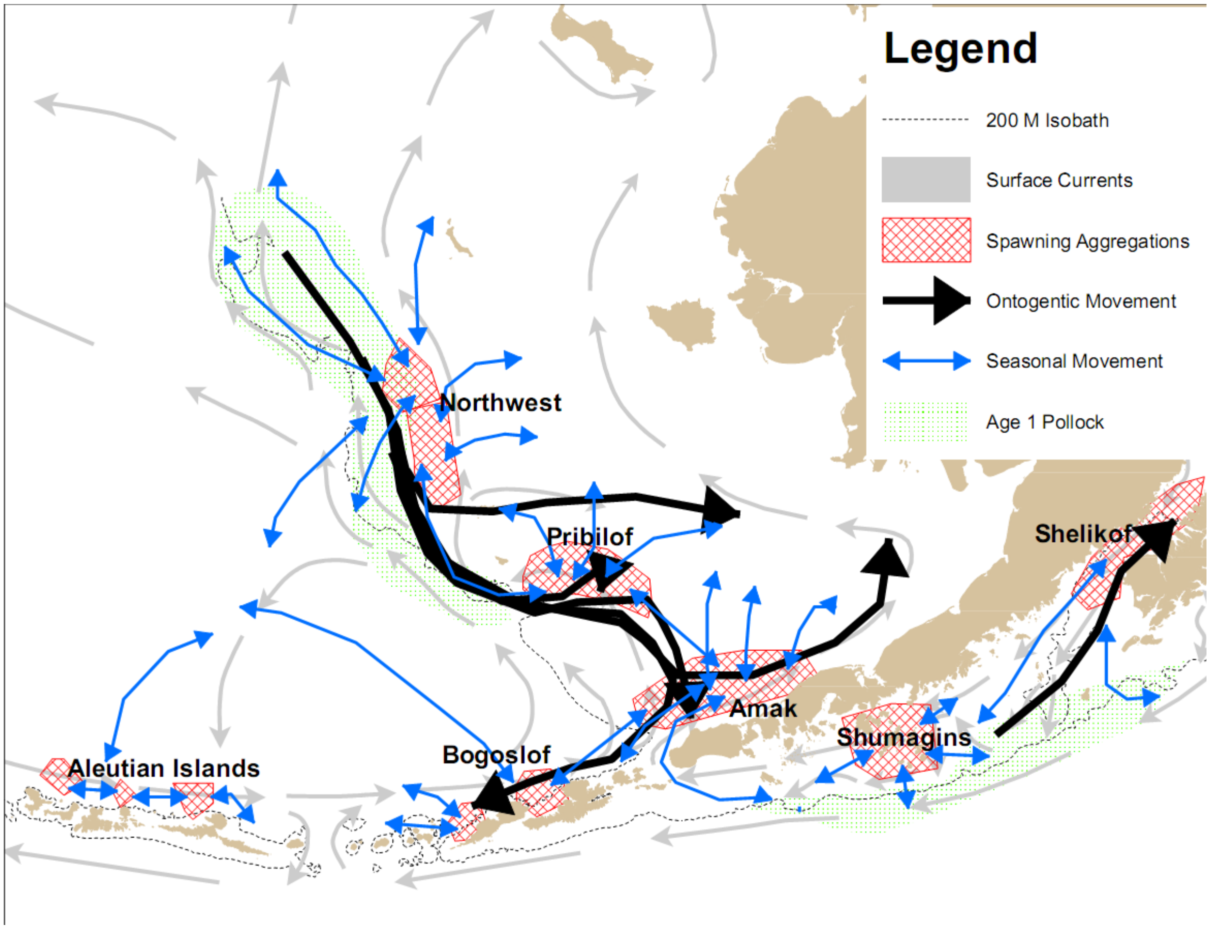

Figure 18. Conceptual model of walleye pollock seasonal and ontogenetic movements with shaded areas representing recent spawning locations (from Quinn et al. 2011).

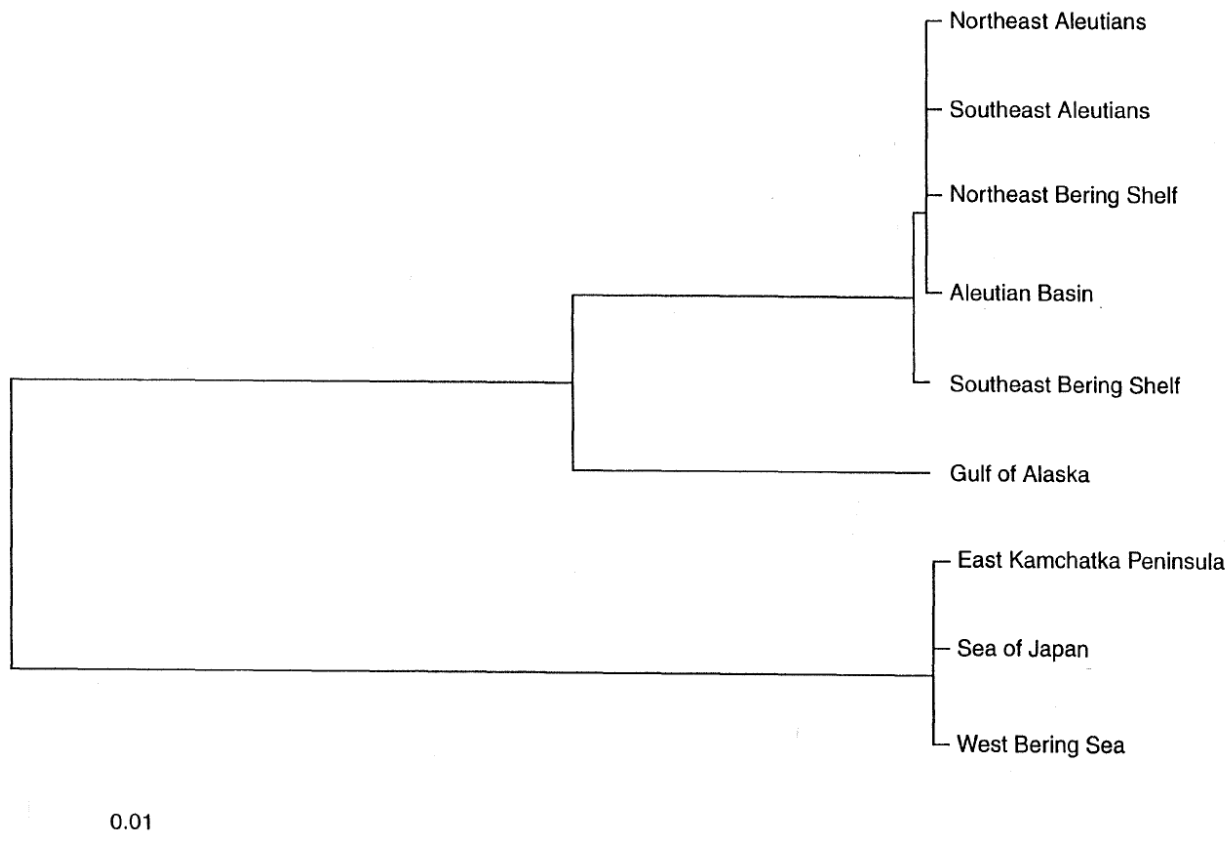

Figure 19. Dendogram results of genetics estimated from pollock samples as presented in Figure 2.20 of Macklin 1998.

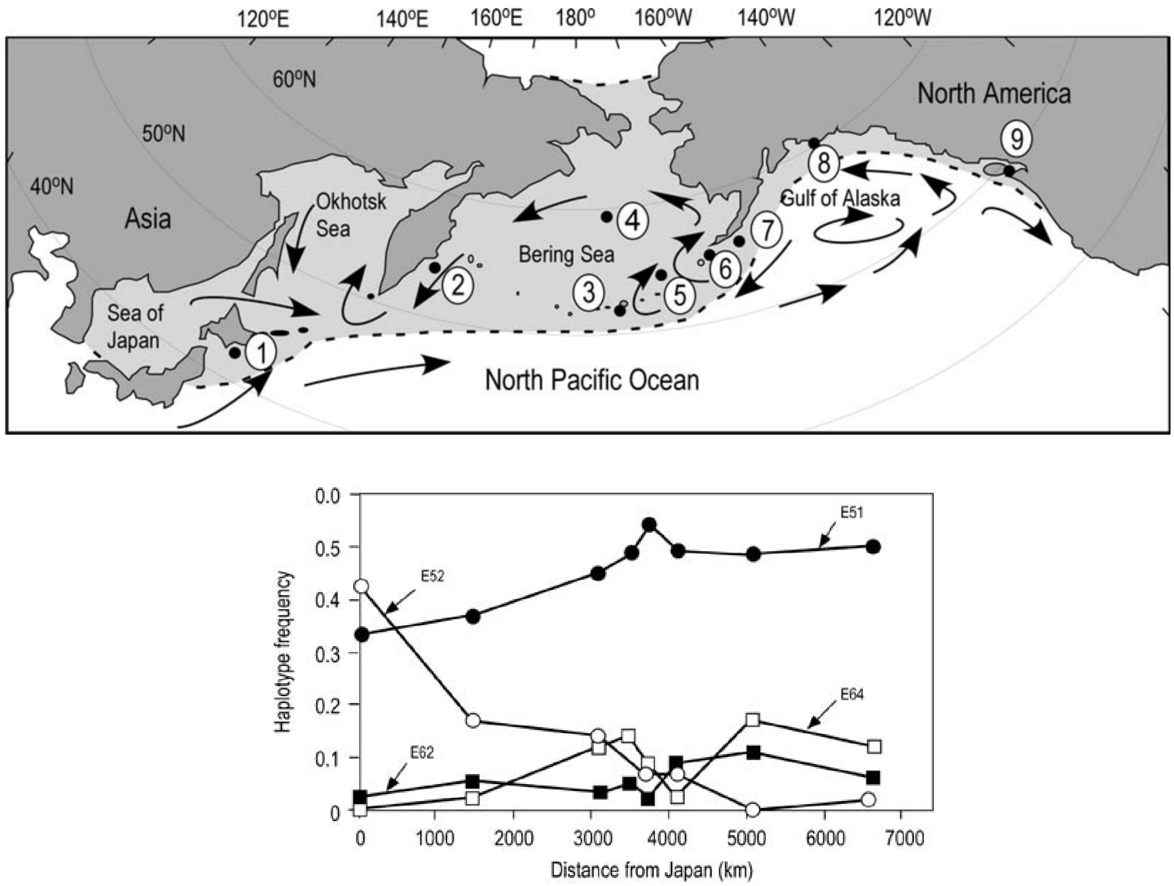

Figure 20. Map showing sample locations (and major currents; top) corresponding to frequencies of four haplotypes in samples of walleye pollock across the North Pacific and Bering Sea (bottom; from Grant *et al*. 2010).

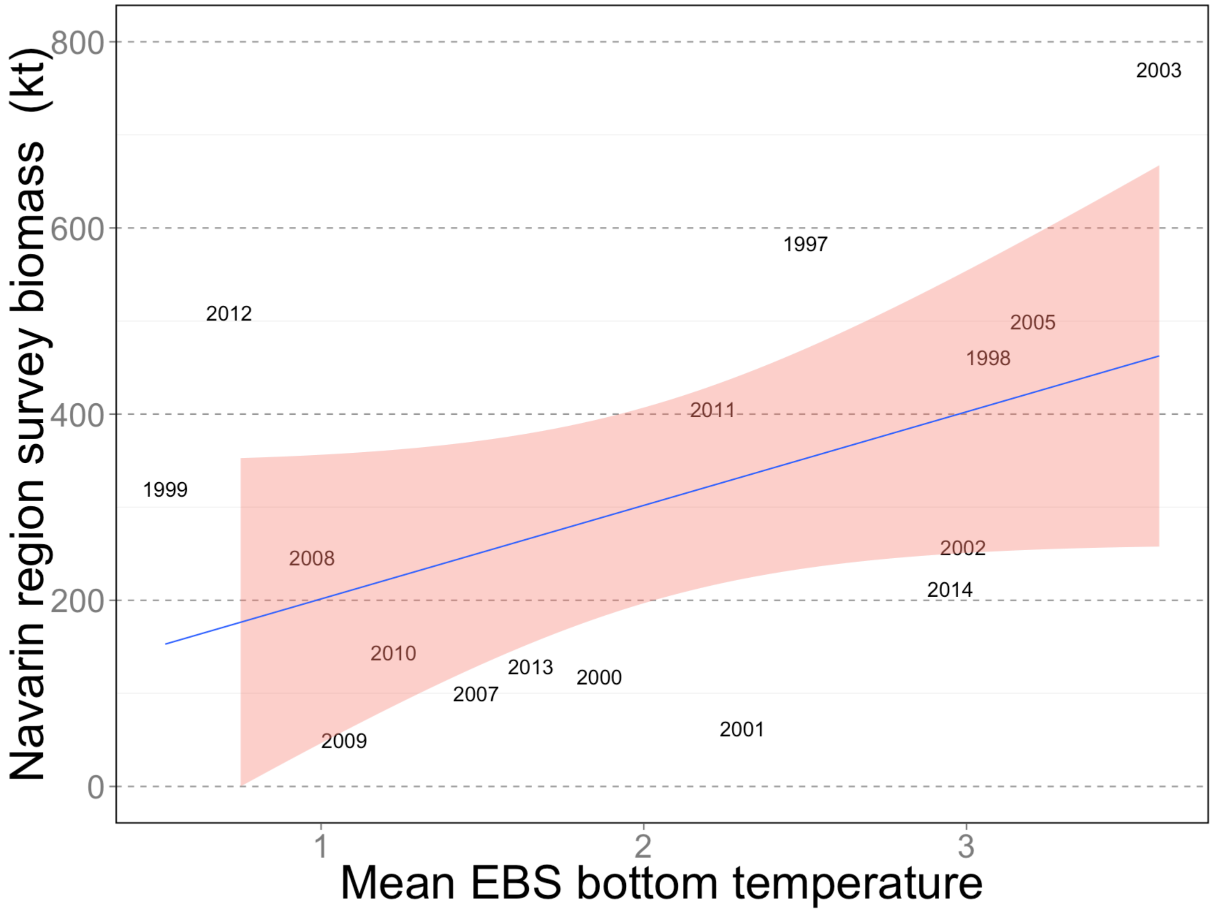

Figure 21. Pollock biomass estimates in the Navarin area of the Russian EEZ (kt) by Russian surveys compared to mean bottom temperatures within the NMFS summer survey area of the EBS.