Bering Sea and Aleutian Islands Greenland turbot stock structure

Meaghan D. Bryan

Introduction

In 2009 the Stock Structure Working Group (SSWG), consisting of members of the North Pacific Fisheries Management Council's (NPFMC) Scientific and Statistical Committee, Groundfish Plan Teams, geneticists, and assessment scientists, was formed to develop a set of guidelines to promote a rigorous and consistent procedure for making management decisions on stock structure for Alaska stocks. The committee produced a report, originally presented at the September 2009 meeting of the joint Groundfish Plan Team and updated for the September 2010 meeting (Spencer et al. 2010), which contains a template (Table 1) that identifies various scientific data from which we may infer stock structure. At the November 2017 meeting of the joint Groundfish Plan Team, the Team recommended application of the template to the Bering Sea and Aleutian Islands (BSAI) Greenland turbot (*Reinhardtius hippoglossoides*) stock to evaluate the appropriateness of existing stock categorizations and management boundaries. Very little research has been done pertaining to stock structure on Greenland turbot. Several categories listed in the SSWG template (Table 1) are addressed in this report and summarized in Table 2.

Spatial concentration of fishery relative to abundance and population trends

Greenland turbot catch (in tons) is generally higher in the Eastern Bering Sea (EBS) than in the Aleutian Islands (AI, Table 2, Figure 1). The one exception was in 2009 when the catch was evenly split between the EBS and AI (Figure 1). Catch in the EBS is higher on the slope than the shelf and in the AI catch is mainly taken in the eastern and central areas (Table 2). The trends in catch are similar to the trends in biomass as measured by the NOAA RACE Eastern Bering Sea Shelf and Slope surveys and the Aleutian Island survey. Biomass is higher in the EBS than the AI and generally higher on the EBS slope than EBS shelf (Table 3, Figure 2). Exceptions to this include 2010 and 2012 when the shelf survey biomass estimates were higher than the slope survey estimates. Biomass estimates in the AI are generally highest in the eastern AI followed by the central and western areas (Table 4).

The biomass estimates from the EBS shelf and slope surveys and the AI survey are shown in Figure 2. Biomass on the EBS shelf increased between 1987 and 1994, generally declined between 1994 and 2009, increased in 2010 and has been relatively stable since. Biomass on the EBS slope increased between 2002 and 2004, declined in 2008, and shows a slight increasing trend between 2008 and 2016. The biomass estimates from the AI survey have varied over time and have been at their lowest between 2012 and 2016.

Fishing mortality

Area-specific exploitation rates are defined here as the yearly catch within a subarea divided by an estimate of the subarea biomass. Area-specific exploitation rates are generated to assess

whether subarea harvest is disproportionate to biomass, which could result in reductions of subarea biomass for stocks with spatial structure.

Exploitation rates are generally low compared to the target fishing mortality rates (Table 5). Exceptions to this include the overall and eastern AI harvest rates in 2010 and 2012. It should be noted that the maximum depth fished by the NOAA's RACE Aleutian Islands survey is 500m. This covers a portion of Greenland turbot's depth range and likely represents an underestimate of Greenland turbot biomass. This helps explain the high exploitation rates when comparing catch and biomass in the Aleutian Islands.

Growth differences

Greenland turbot length- and weight-at-age data are available from the EBS shelf and slope surveys. The resulting growth curves are similar between the two areas (Figures 3 and 4). The exceptions to this are that the EBS slope survey generally does not capture 1- and 2-year olds and at around age 29 the length of male Greenland turbot captured by the EBS shelf survey is skewed towards larger individuals than the EBS slope survey. The differences between the shelf and slope is due to the ontogeny of the species, where larger and older individuals migrate from the shelf to the slope.

Length and weight data are available from the EBS shelf and slope surveys and the Aleutian Islands survey. The length-weight relationship is similar among the areas and over time (Figure 5).

Size structure

There is an obvious difference in the EBS shelf and EBS slope length distributions (Figures 6 and 7). The EBS shelf length distributions are generally skewed towards smaller individuals, whereas the EBS slope length distributions are skewed towards larger individuals. Greenland turbot are known to make ontogenetic movements. Juveniles settle on the EBS shelf (Alton *et al.* 1988, Sohn 2009) and move to the slope as they grow larger and older (Barbeaux *et al.* 2015). The length structure of the AI is similar to the EBS slope and represents the larger/older segment of the population (Figures 6 and 7). It is unknown if the fish found in the AI originate from the EBS or elsewhere.

Spawning, and maturity-at-age

Little is known about Greenland turbot reproduction in the EBS. Larval surveys indicate that spawning likely occurs in December-January along the continental slope near Pribilof and Akun Islands (Sohn 2009). Data indicate that the eggs hatch at depth, larvae vertically rise, and are horizontally transported to the continental shelf by way of the Bering Slope Current from March through May. Juveniles spend some time in the EBS shelf pelagic zone from June through August before settling along the northwestern slope (Sohn 2009).

Greenland turbot maturity-at-age studies are numerous for the North Atlantic, but rare for the North Pacific. Estimates of the age at 50% maturity estimates from the North Atlantic range from approximately 5 years to 10 years for males and 8 years to 13 years for females (Morgan et al. 2003). An analysis using NOAA's Groundfish Trawl survey data estimated the age at 50% maturity for Greenland turbot in the EBS to be 7.1 years and the age at full maturity to be approximately 10 years (Ten Brink, pers. comm.).

Genetics

Genetic information and genetic studies of Greenland turbot in the North Pacific are lacking. Several studies from the northeast Atlantic generally indicate that there is little genetic differentiation in this large area (Reiss *et al.* 2009 and reference therein). One study found weak genetic differentiation between the Greenland turbot from east Greenland and the Faroe Islands (Knutsen *et al.* 2007). It is difficult to make any conclusions about whether Greenland turbot in the EBS and AI would be genetically different; however, it would not be inconceivable that they are a single stock given the results from the NE Atlantic.

Conclusions

An evaluation of the available data for Greenland turbot does not suggest any differentiation between the EBS or Aleutian Islands and no studies on genetic population structure of Greenland turbot have been undertaken to date. Genetic population structure of this species may exist in the NE Atlantic, but this information does not imply that this stock structure exists for Greenland turbot in the EBS and Aleutian Islands.

References

Alton, M.S., R.G. Bakkala, G.E. Walters, and P.T. Munro. 1988. Greenland turbot *Reinhardtius hippoglossoides* of the eastern Bering Sea and Aleutian Islands region. NOAA Tech. Rep., NMFS 71, 31 p.

Barbeaux, S. J., J. Ianielli, D. Nichol, and J. Hoff. 2015. Assessment of the Greenland turbot (*Reinhardtius hippoglossoides*) in the Bering Sea and Aleutian Islands. *In* Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 2015. Section 5. North Pacific Fishery Management Council, Anchorage, AK.

Knutsen, H., Jorde, P.E., Albert, O.T., Hoelzel, A.R., Stenseth, N.C. 2007. Population genetic structure in the North Atlantic Greenland halibut (Reinhardtius hippoglossoides): influenced by oceanic current systems? Canadian Journal of Fisheries and Aquatic Sciences 64: 857–866.

Morgan, M.J., Bowering, W.R., Gundersen, A.C., Hoines, A. Morin, B., Smirnov, O., Hjorleifsson, E. 2003. A comparison of the maturation of Greenland halibut (*Reinhardtius hippoglossoides*) from populations throughout the North Atlantic. Journal of the Northwest Atlantic Fisheries Science 31: 99-11.

Reiss, H. Hoarau, G., Dickey-Collas, M. Wolff, W.J. 2009. Genetic population structure of marine fish: mismatch between biological and fisheries management units. Fish and Fisheries 10: 361-395.

Sohn D. 2009. Ecology of Greenland Halibut (*Reinhardtius hippoglossoides*) during the Early Life Stages in the Eastern Bering Sea and Aleutian Islands. Master's thesis. College of Oceanic and Atmospheric Sciences, Oregon State University, Oregon, USA (June, 2009).

Spencer,P., Canino, M., DiCosimo, J., Dorn, M., Gharrett, A.J., Hanselman, D., Palof, K., Sigler, M. 2010. Guidelines for determination of spatial management units for exploited populations in Alaskan groundfish fishery management plans. North Pacific Fisheries Management Council.

Table 1. Framework of types of information to consider when defining spatial management units (from Spencer et al. 2010).

Factor and criterion	Justification
Fishing mortality (5-year average percent of Fabc or Fofl)	If this value is low, then conservation concern is low
Spatial concentration of fishery relative to abundance (Fishing is focused in areas << management areas)	If fishing is focused on very small areas due to patchiness or convenience, localized depletion could be a problem.
Population trends (Different areas show different trend directions)	Differing population trends reflect demographic independence that could be caused by different productivities, adaptive selection, differing fishing pressure, or better recruitment conditions
Barriers and phenotypic characters	
Generation time (e.g., >10 years)	If generation time is long, the population recovery from overharvest will be increased.
Physical limitations (Clear physical inhibitors to movement)	Sessile organism; physical barriers to dispersal such as strong oceanographic currents or fjord stocks
Growth differences (Significantly different LAA, WAA, or LW parameters)	Temporally stable differences in growth could be a result of either short term genetic selection from fishing, local environmental influences, or longer-term adaptive genetic change.
Age/size-structure (Significantly different size/age compositions)	Differing recruitment by area could manifest in different age/size compositions. This could be caused by different spawning times, local conditions, or a phenotypic response to genetic adaptation.
Spawning time differences (Significantly different mean time of spawning)	Differences in spawning time could be a result of local environmental conditions, but indicate isolated spawning stocks.
Maturity-at-age/length differences (Significantly different mean maturity-at-age/ length)	Temporally stable differences in maturity-at-age could be a result of fishing mortality, environmental conditions, or adaptive genetic change.
Morphometrics (Field identifiable characters)	Identifiable physical attributes may indicate underlying genotypic variation or adaptive selection. Mixed stocks w/ different reproductive timing would need to be field identified to quantify abundance and catch

Table 1. continued

Barriers and phenotypic characters	
Meristics (Minimally overlapping differences in counts)	Differences in counts such as gillrakers suggest different environments during early life stages.
Behavior & movement	
Spawning site fidelity (Spawning individuals occur in same location consistently)	Primary indicator of limited dispersal or homing
Mark-recapture data (Tagging data may show limited movement)	If tag returns indicate large movements and spawning of fish among spawning grounds, this would suggest panmixia
Natural tags (Acquired tags may show movement smaller than management areas)	Otolith microchemistry and parasites can indicate natal origins, showing amount of dispersal
Genetics	
Isolation by distance (Significant regression)	Indicator of limited dispersal within a continuous population
Dispersal distance (<<Management areas)	Genetic data can be used to corroborate or refute movement from tagging data. If conflicting, resolution between sources is needed.
Pairwise genetic differences (Significant differences between geographically distinct collections)	Indicates reproductive isolation.

Table 2. Information used to examine the stock structure of Greenland turbot.

Factor and criterion	Justification
Fishing mortality (5-year average percent of Fabc or Fofl)	See Fishing mortality section
Spatial concentration of fishery relative to abundance (Fishing is focused in areas << management areas)	See Spatial concentration and population trends section
Population trends (Different areas show different trend directions)	See Spatial concentration and population trends section
Barriers and phenotypic characters	
Generation time (e.g., >10 years)	Maximum age is 30 year and the $A_{50\%}$ range: 5 – 13 years. This indicates the generation time is relatively short.
Physical limitations (Clear physical inhibitors to movement)	Unknown
Growth differences (Significantly different LAA, WAA, or LW parameters)	See Growth differences section
Age/size-structure (Significantly different size/age compositions)	See Size structure section
Spawning time differences (Significantly different mean time of spawning)	Unknown
Maturity-at-age/length differences (Significantly different mean maturity-at-age/ length)	See Spawning and maturity-at-age section
Morphometrics (Field identifiable characters)	Unknown
Meristics (Minimally overlapping differences in counts)	Uknown
Behavior & movement	
Spawning site fidelity (Spawning individuals occur in same location consistently)	Unknown
Mark-recapture data (Tagging data may show limited movement)	Unpublished tagging data indicate adults move between the EBS slope and shelf (Coutre et al., unpublished)
Natural tags (Acquired tags may show movement smaller than management areas)	Unknown
Genetics	
Isolation by distance (Significant regression)	Information is lacking for the North Pacific. See Genetics section
Dispersal distance (<<Management areas)	Information is lacking for the North Pacific.
Pairwise genetic differences (Significant differences between geographically distinct collections)	Information is lacking for the North Pacific.

Table 2. Catch (t) by area and subarea from 1991-2017 (as of August 9, 2018). Eastern Aleutian Islands (AI) is National Marine Fisheries Service (NMFS) area 541, Central AI is 542, Western AI is 543, and Other AI is area 540. Allowable Biological Catch (ABC) and percent of ABC caught are also shown. Blacked out data are confidential in at least one area. Source: NMFS AKRO BLEND/Catch Accounting System.

	Catch (t)								ABC			Percent ABC		
	Aleutian Islands				EBS			BSAI						
Year	Eastern	Central	Western	Total	Shelf	Slope	Total	Total	AI	EBS	Total	AI	EBS	BSAI
1991	-	-	-	3465	440	3957	4397	7862	-	-	7000	-	-	112
1992	-	-	-	1290	837	1624	2461	3751	-	-	7000	-	-	54
1993				2137	190	6143	6333	8470	-	-	7000	-	-	121
1994	2720	404	7	3131	286	6855	7141	10272	-	-	7000	-	-	147
1995	1969	350	19	2338	351	5446	5856	8194	2331	4669	7000	100	125	117
1996	1186	493	33	1712	291	4553	4844	6556	3400	6900	10300	50	70	64
1997	544	194	26	764	386	6049	6435	7199	4075	8275	12350	19	78	58
1998	328	320	35	683	485	7591	8075	8758	4950	10050	15000	14	80	58
1999	275	181	11	467	269	5117	5386	5853	4686	9514	14200	10	57	41
2000	513	540	33	1086	236	5653	5889	6975	3069	6231	9300	35	95	75
2001	733	310	17	1060	255	3999	4254	5314	2772	5628	8400	38	76	63
2002	304	149	32	485	158	2993	3150	3635	2673	5427	8100	18	58	45
2003	401	282	17	700	265	2146	2411	3111	1960	3920	5880	36	62	53
2004	128	297	9	434	256	1570	1826	2260	1578	3162	4740	28	58	48
2005	240	196	31	467	257	1883	2140	2607	1210	2720	3930	39	79	66
2006				537	203	1249	1452	1989	850	1890	2740	63	77	73
2007				524	252	1230	1482	2006	760	1680	2440	69	88	82
2008	675	143	4	822	251	1838	2089	2911	790	1750	2540	104	119	115
2009	2170	88	6	2264	158	2094	2252	4516	2290	5090	7380	99	44	61

Table 2. Continued

	Catch (t)								ABC			Percent ABC		
	Aleutian Islands				EBS			BSAI						
Year	Eastern	Central	Western	Total	Shelf	Slope	Total	Total	AI	EBS	Total	AI	EBS	BSAI
2010	1687	178	4	1869	90.7	2177.3	2268	4137	1900	4220	6120	98	54	68
2011	426	103	6	535	94.2	3045.8	3140	3675	1550	4590	6140	35	68	60
2012	1532	120	6	1658	91.7	2966.3	3058	4716	2430	7230	9660	68	42	49
2013	226	56	16	298	86.9	1361.1	1448	1746	450	1610	2060	66	90	85
2014	128	46	5	179	133.2	1346.8	1480	1659	465	1659	2124	38	89	78
2015	83	24	6	113	146.4	1945.6	2092	2205	724	2448	3172	16	85	70
2016				124	42.3	2073.7	2116	2240	789	2673	3462	16	79	65
2017				122	81.3	2629.7	2711	2833	844	5800	6644	10	45	43

Table 3. Greenland turbot survey biomass estimates in tons by area: Aleutian Islands, Eastern Bering Sea Shelf (EBS Shelf), Eastern Bering Sea Slope (EBS slope). Data area from the Aleutian Islands, EBS Shelf, and EBS Slope surveys. Values in parentheses represent the percentage of total biomass, which is defined as the summed biomass of the three surveys.

Year	AI	EBS Shelf	EBS Slope
1980	3,598	-	-
1983	9,684	-	-
1986	31,759	-	-
1987	-	11,787	-
1988	-	13,353	-
1989	-	13,209	-
1990	-	16,199	-
1991	10,122	12,484	-
1992	-	28,638	-
1993	-	35,692	-
1994	22,269	57,181	-
1995	-	37,636	-
1996	-	40,611	-
1997	27,984	35,303	-
1998	-	34,885	-
1999	-	21,536	-
2000	8,893	23,184	-
2001	-	27,280	-
2002	9,447 (16)	24,000 (40)	27,029 (44)
2003	-	31,010	-
2004	8,100 (11)	28,287 (39)	36,557 (50)
2005	-	21,302	-
2006	19,652	20,933	-
2007	-	16,723	-
2008	-	13,511	17,426
2009	-	10,953	-
2010	6,272 (13)	23,414 (47)	19,873 (40)
2011	-	26,156	-
2012	2,502 (6)	21,792 (52)	17,922 (42)
2013	-	24,907	-
2014	2,031	28,028	-
2015	-	25,240	-
2016	1,394 (3)	22,429 (47)	23,573 (50)
2017	-	21,519	-

Table 4. Greenland turbot survey biomass by area within the Aleutian Islands. Eastern, Central, and Western AI correspond to NMFS reporting areas 541, 542, and 543 and Total is the sum of the three areas. Data are from the NMFS Aleutian Islands Survey.

Year	Eastern	Central	Western	Total
1980	2,720	799	0	3,519
1983	5,737	2,328	525	8,590
1986	19,580	2,495	1,747	23,821
1991	4,607	3,320	2,195	10,122
1994	15,862	4,007	2,401	22,269
1997	22,708	3,130	2,146	27,984
2000	5,703	2,351	839	8,893
2002	6,996	1,658	793	9,448
2004	2,564	2,948	2,588	8,100
2006	15,742	1,937	1,973	19,652
2010	3,695	1,507	1,071	6,272
2012	181	1,231	1,091	2,502
2014	490	989	553	2,031
2016	970	424	0	1,394

Table 5. Exploitation rates (catch/biomass) in the Eastern Bering Sea (EBS) and the Aleutian Islands by area. Eastern, Central, and Western AI correspond to NMFS reporting areas 541, 542, and 543 and AI Total represents all three areas. F_{OFL} = 0.22 and F_{ABC} = 0.18.

	Aleutian Islands				Eastern Bering Sea		
Year	Eastern	Central	Western	Total	Shelf	Slope	Total
1991				0.34	0.035		
1992					0.029		
1993					0.005		
1994	0.17	0.10	0.00	0.14	0.005		
1995					0.009		
1996					0.007		
1997	0.02	0.06	0.01	0.03	0.011		
1998					0.014		
1999					0.013		
2000	0.09	0.23	0.04	0.12	0.010		
2001					0.009		
2002	0.04	0.09	0.04	0.05	0.007	0.11	0.06
2003					0.009		
2004	0.05	0.10	0.00	0.05	0.009	0.04	0.03
2005					0.012		
2006				0.03	0.010		
2007					0.015		
2008					0.019	0.11	0.07
2009					0.014		
2010	0.46	0.12	0.00	0.30	0.004	0.11	0.05
2011					0.004		
2012	8.46	0.10	0.01	0.66	0.004	0.17	0.08
2013					0.003		
2014	0.26	0.05	0.01	0.09	0.005		
2015					0.006		
2016				0.09	0.002	0.09	0.05
2017					0.004		

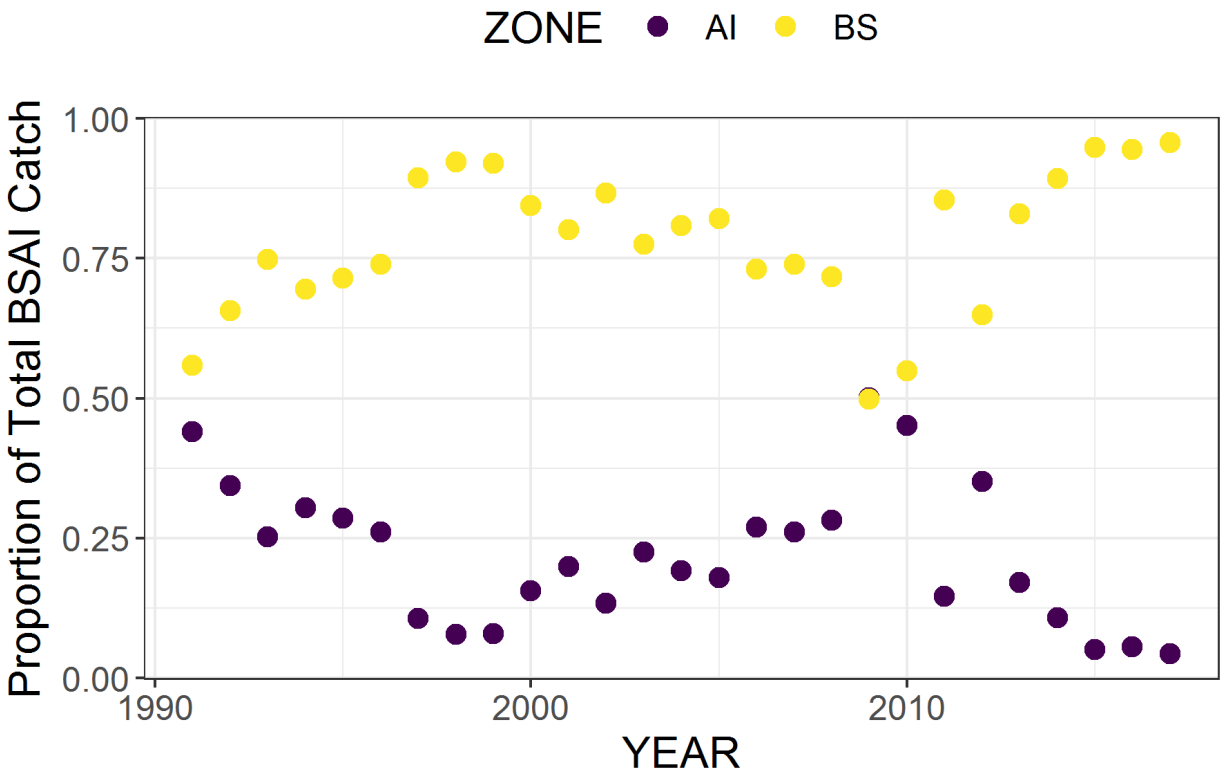


Figure 1. Proportion of the total catch from the Aleutians Islands and the Eastern Bering Sea.

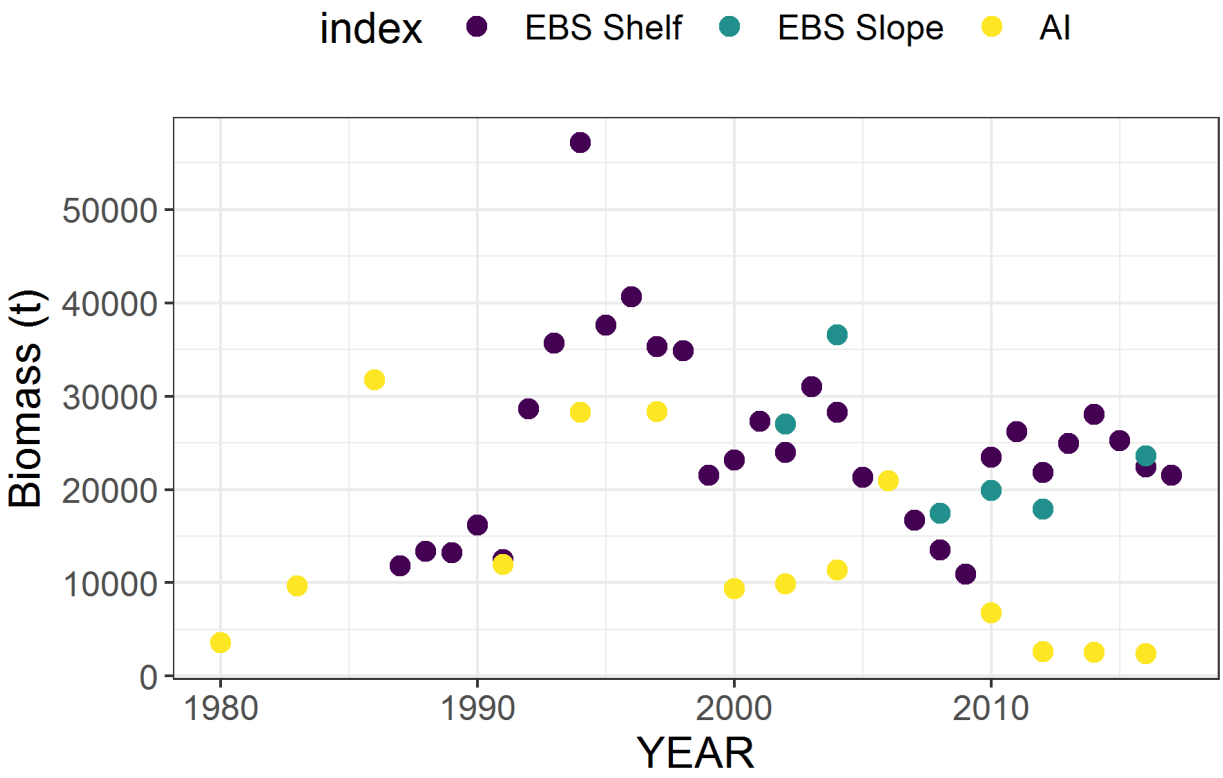


Figure 2. Survey biomass estimates. Data are from the EBS Shelf, EBS Slope, and Aleutian Islands (AI) surveys.

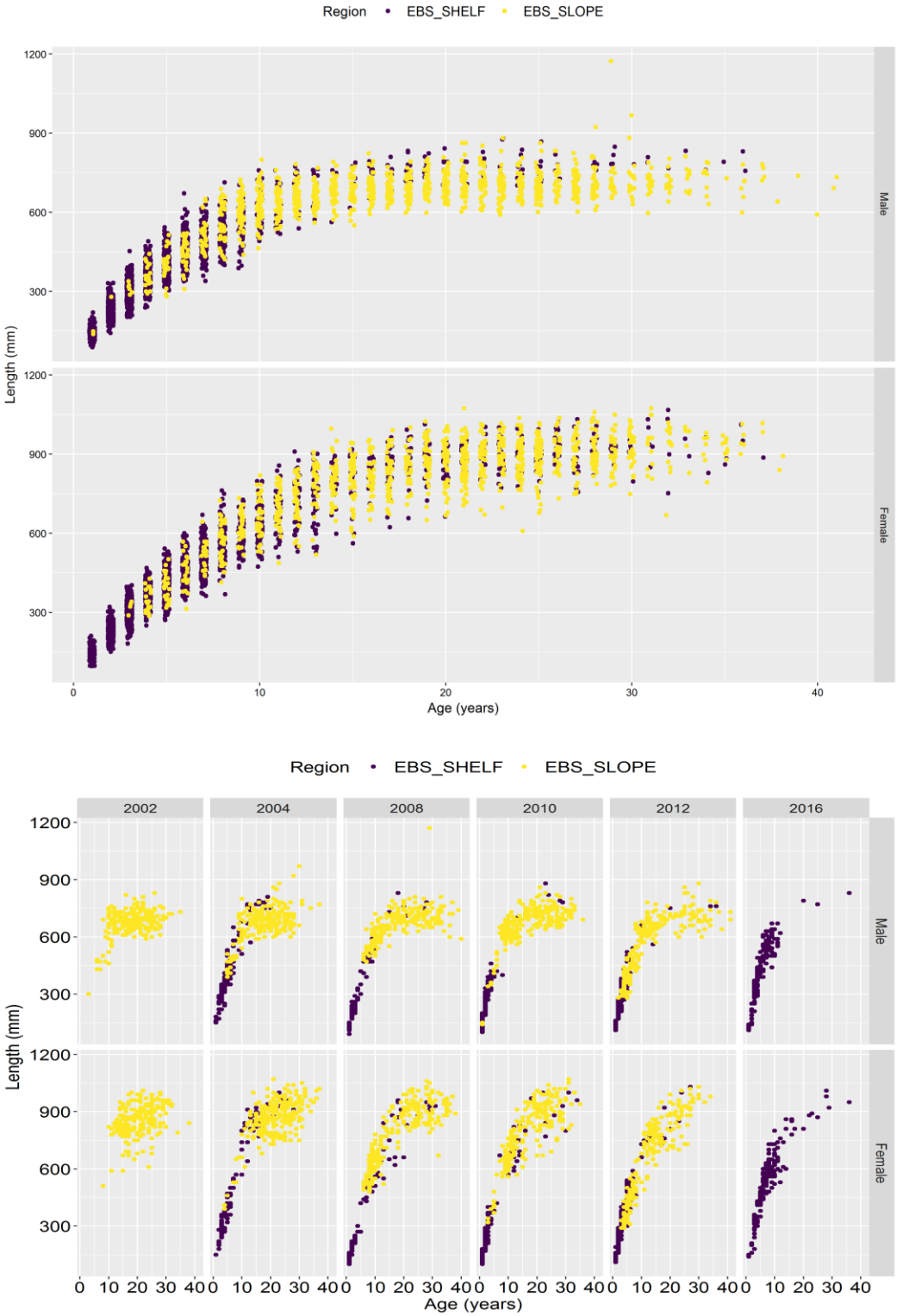
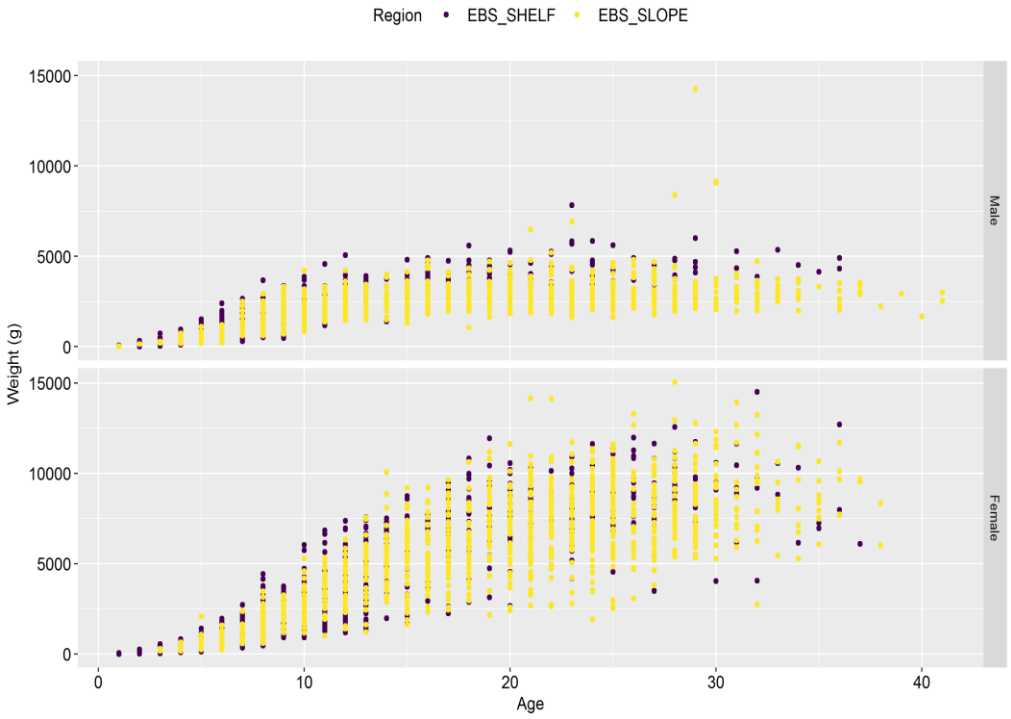


Figure 3. Length-at-age a) overall and b) by year and sex. The years shown are when the EBS slope survey has been conducted.

a)



b)

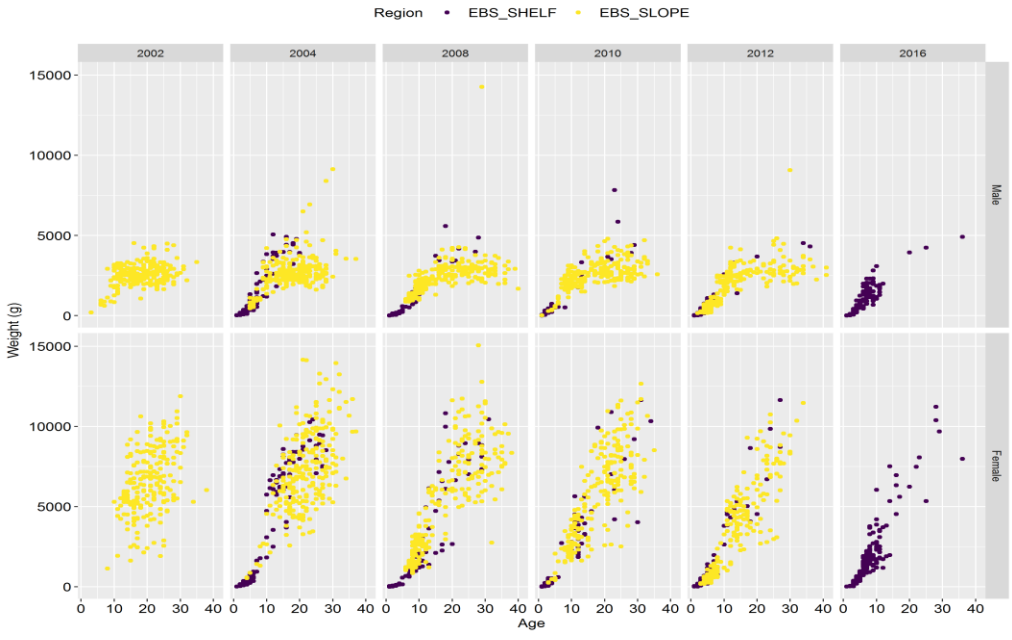
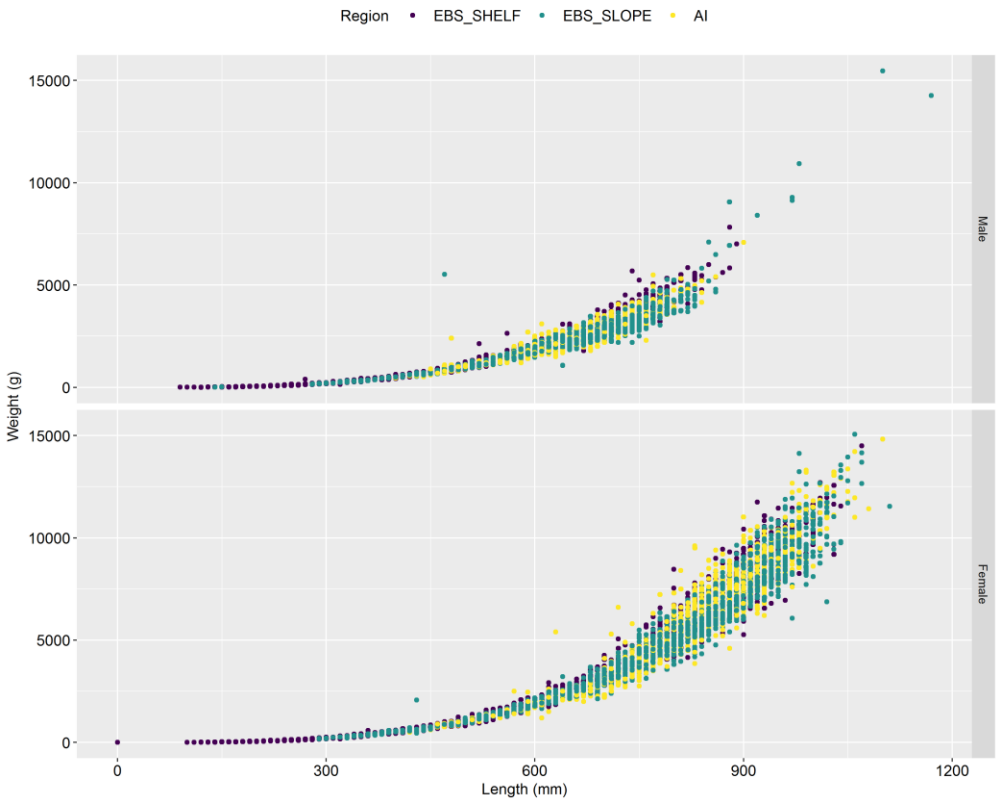


Figure 4. Weight-at-age a) overall and b) by year and sex. The years shown are when the EBS slope survey has been conducted.

a)



b)

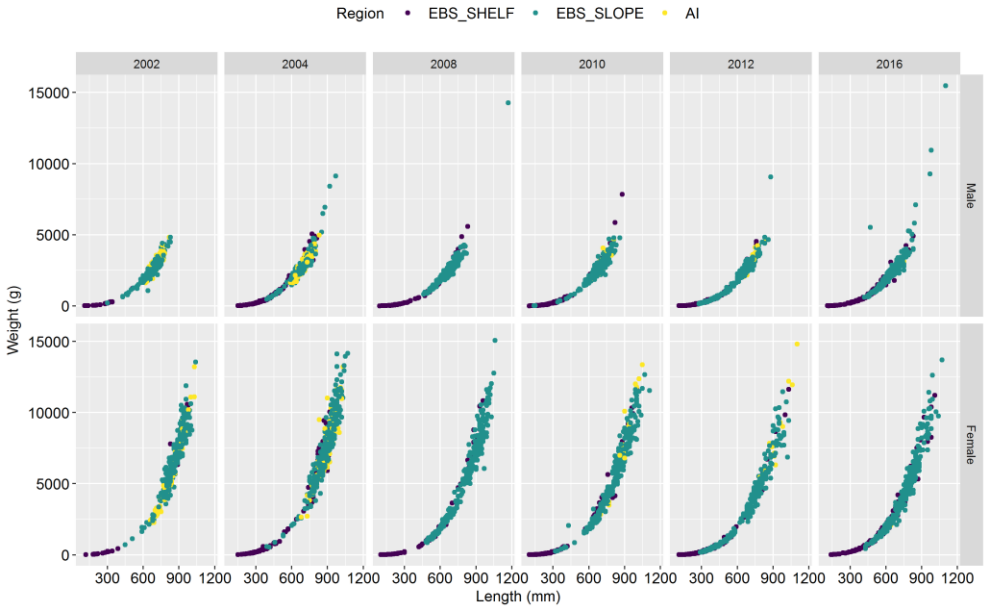


Figure 5. Length-weight relationship a) overall and b) by year and sex. The years shown are when the EBS slope survey has been conducted.

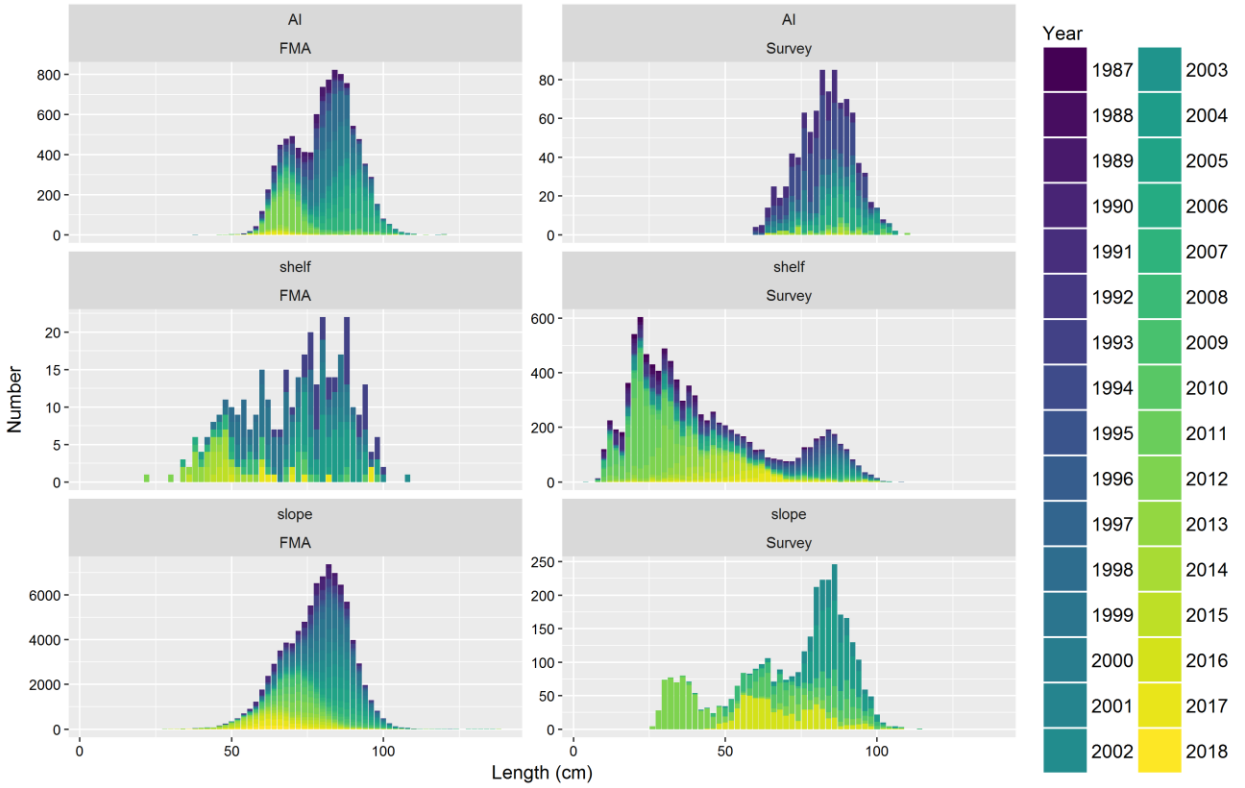


Figure 6. Female Greenland turbot length distributions by year, data source (Fisheries Monitoring and Analysis (FMA) or survey), and area (AI, EBS shelf (shelf), and EBS slope (slope)).

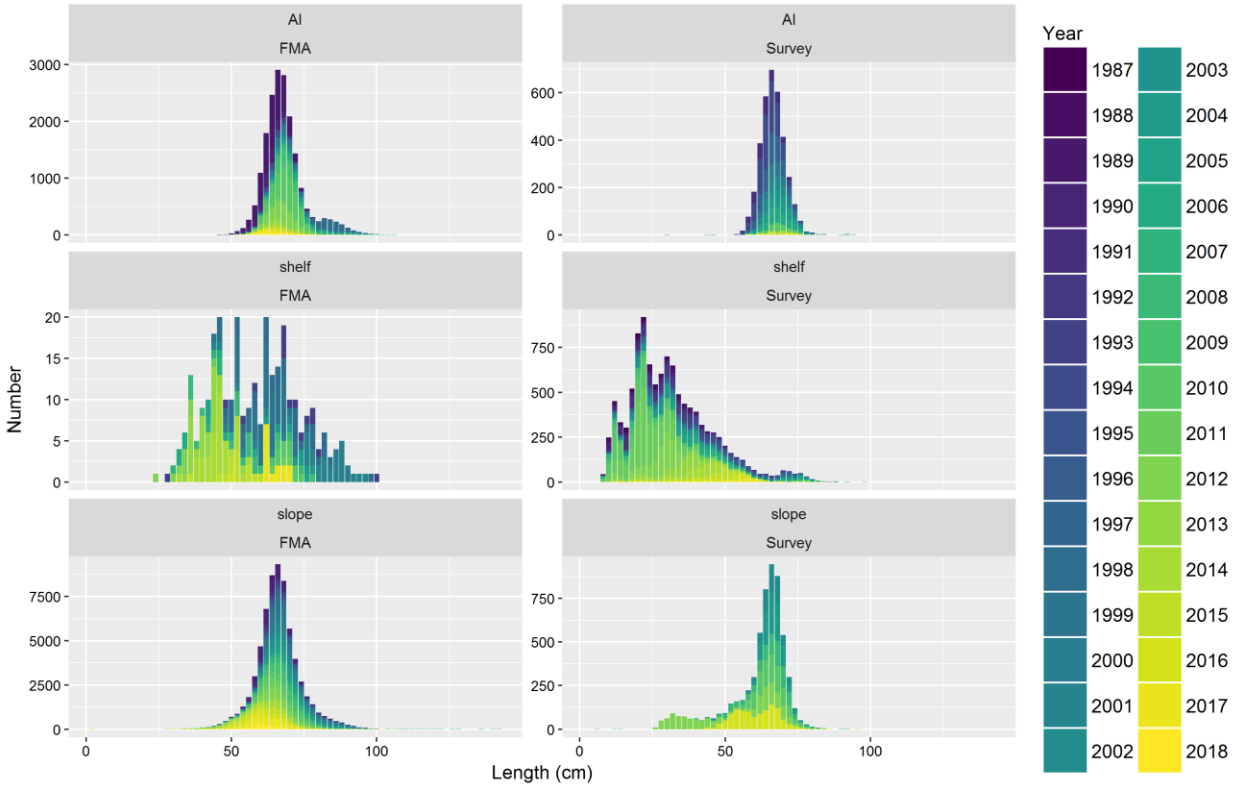


Figure 7. Male Greenland turbot length distributions by year, data source (FMA or survey), and area (AI, EBS shelf (shelf), and EBS slope (slope)).