Bering Sea, Aleutian Islands, and Gulf of Alaska arrowtooth flounder stock structure

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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 2013 meeting of the joint Groundfish Plan Team, the Team recommended application of the template to the Gulf of Alaska and BSAI arrowtooth flounder stocks to evaluate the appropriateness of existing stock categorizations and management boundaries. Very little research has been done pertaining to stock structure in arrowtooth flounder. The SSWG template (Table 1) has a few categories relevant to GOA arrowtooth flounder: exploitation rates, spatial concentration of fishery relative to abundance, and pairwise genetic differences/isolation by distance. Those aspects are considered in detail here.

Spatial concentration of fishery relative to abundance

Gulf of Alaska

In the Gulf of Alaska, the highest concentration of arrowtooth flounder is found in the central region (Table 2). This pattern is stable across time, from 2007-2013 (Table 2). Acceptable biological catch (ABC) is estimated by calculating the fraction of the survey biomass in each area and applying that fraction to the ABC. Therefore, ABC reflects the area-specific biomass (Table 3). Catch is proportional to the biomass in the western, central, and eastern Gulf of Alaska (Table 4), although it is significantly less than the ABC (Table 3).

BSAI

Arrowtooth flounder biomass is highest on the Bering Sea shelf and similar between the Bering Sea slope and Aleutian Islands (Figure 1; Table 5). The highest biomass of arrowtooth flounder in the Aleutian Islands is found in the eastern region, and the lowest is in the western region (Figure 2; Table 6). Catch of arrowtooth flounder was generally higher in the Eastern Bering Sea than in the Aleutian Islands, except in 2010, due to a high catch of 23,645 t in the Eastern Aleutian Islands (Table 7). Catch in the Aleutian Islands is generally highest in the eastern region and lowest in the west, reflecting the proportions of biomass in each region (Tables 6, 7).

Fishing mortality (Area-specific exploitation rates)

Gulf of Alaska

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 an order of magnitude lower on average than the F_{ABC} specified by the Gulf of Alaska arrowtooth assessments (Table 8). There is no evidence that disproportionately high fishing effort is present in any of the three spatial areas examined (western, central, and eastern Gulf of Alaska).

BSAI

Exploitation rates are generally low relative to the target fishing mortality rates, with the exception of fishing in the eastern AI in 2010 (Table 9). In that year, exploitation rates were estimated to be 0.55 due to a high catch of 23,325 t and an estimated biomass of 43,325 t (Tables 6, 7). The 95% confidence interval on the estimate of biomass in that region was (8,039 – 78,611).

Pairwise genetic differences/Isolation by distance

No research has been performed on arrowtooth flounder population structure, but a review of population structure of flatfish in general is pertinent to this document. Population structure and dispersal have been found in a range of scales in flatfish, but there is currently a need for studies on population structure of flatfish, particularly in Alaska and along the Pacific west coast (Bailey 1997). Such information is fundamental to management of these species. Significant genetic population structure has been found between Pacific halibut (*Hippoglossus stenolepus*) from the Aleutian Islands, Bering Sea, and Gulf of Alaska (Nielsen et al. 2009).

Other information on flatfish population structure comes from European species of flatfish. Significant genetic differentiation was found among samples of turbot (*Scophthalmus maximus* L.) in the NE Atlantic, with a maximum pairwise F_{ST} of 0.032 (Nielsen et al. 2004). A sharp cline was found in genetic differentiation from the Baltic Sea to the North Sea but little differentiation was found among samples from the Atlantic/North Sea area and within the Baltic Sea (Nielsen et al. 2004). Temporally stable and highly significant genetic differentiation was detected among samples of European flounder (*Platichthys flesus*) across the northeast Atlantic and Baltic Seas (global F_{ST}=0.024, p<0.0001; Hemmer-Hansen et al. 2007), as well as among the Baltic, Kattegat, and Skagerrak seas (Florin and Hoglünd 2008). Oceanographic and bathymetric barriers were likely mechanisms for isolation and structuring within the northeast Atlantic. Life history differences, benthic vs. pelagic spawning, were responsible for genetic differentiation in the Baltic Sea (Hemmer-Hansen et al. 2007; Florin and Hoglünd 2008). In addition to genetic differentiation, significant isolation by distance was detected in the pelagic spawning fish from the Baltic (Florin and Hoglünd 2008).

Conclusions

Biomass of arrowtooth flounder in the Gulf of Alaska is spatially concentrated in the central region. Catch is higher in this region, but exploitation rates are low relative to the target levels by approximately an order of magnitude. Exploitation rates are typically low relative to target levels in all regions from 2007-2013.

Biomass of arrowtooth flounder in the Bering Sea and Aleutian is spatially concentrated on the Bering Sea shelf. Biomass estimates are lower in the Aleutian Islands and lowest on the Bering Sea slope. Catch is highest in the Bering Sea, with the exception of 2010 in which catch was particularly high in the Eastern AI. Exploitation rates are typically lower than the target fishing mortality rate, but the high catch in the Eastern AI in 2010 resulted in exploitation rates of 0.55, higher than the target fishing mortality rate of 0.235 in that year. This appears to be an anomaly; catch in the Eastern AI in 2010 were twice as large as the second highest recorded catch (Table 7).

Fishing fleets began to target Kamchatka flounder in the Eastern Aleutian Islands in 2008, but at that time, and through 2011, Kamchatka flounder were managed in a complex with arrowtooth flounder. The fleet targeting Kamchatka flounder grew from 2 catcher/processors in 2008 to 5 in 2010 and 8 in 2011.The high exploitation rate in 2010 was a result of effort on Kamchatka flounder.

No studies on genetic population structure of arrowtooth flounder have been undertaken to date. Genetic population structure has been identified in other flatfish species, but this information does not imply that stock structure exists in arrowtooth flounder. Genetic population structure studies of Alaskan flatfish species would be beneficial to management.

References

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

HARVEST AND TRENDS	
Factor and criterion	Justification
Fishing mortality (5-year average percent of F_{abc} or F_{ofl})	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
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. Relative arrowtooth survey biomass by INPFC area for the past four National Marine Fisheries Service Gulf of Alaska surveys (2007, 2009, 2011, 2013).

Year	Western	Central	West Yakutat	East Yakutat/SE	Total
2007	13.61%	74.15%	6.73%	5.51%	100
2009	16.11%	67.82%	10.58%	5.50%	100
2011	12.92%	67.25%	9.94%	9.90%	100
2013	15.94%	59.18%	19.06%	5.82%	100

Table 3. Acceptable biological catch (ABC) in tons (t) by INPFC area from 2008-2015. The ABC by management area using $F_{40\%}$ was estimated by calculating the fraction of the survey biomass in each area and applying that fraction to the ABC.

Year	Western	Central	West Yakutat	East Yakutat/SE	Total
2008	30,817	167,936	15,245	12,472	226,470
2009	31,080	169,371	15,375	12,579	228,405
2010	34,773	146,407	22,835	11,867	215,882
2011	34,263	144,262	22,501	11,693	212,719
2012	27,495	143,162	21,159	21,066	212,882
2013	27,386	142,591	21,074	20,982	212,033
2014	31,142	115,612	37,232	11,372	195,358
2015	30,217	112,178	36,126	11,035	189,556

Table 4. Catch (t) by area from 2005-2014 (as of September 12, 2014). Source: NMFS AKRO BLEND/Catch Accounting System. Eastern Gulf is West Yakutat and East Yakutat/SE combined.

Year	Western	Central	Eastern	Total
2005	2,545	17,379	66	19,989
2006	2,043	25,580	116	27,740
2007	3,149	22,210	162	25,521
2008	3,172	26,043	67	29,283
2009	1,498	23,334	80	24,913
2010	2,387	21,540	166	24,094
2011	1,678	29,084	188	30,949
2012	1,229	19,282	64	20,575
2013	806	20,732	86	21,625
2014	1,309	24,492	54	25,856

Table 5. Arrowtooth survey biomass by area: Bering Sea (BS) shelf, BS slope, and Aleutian Islands. Data based on National Marine Fisheries Service survey biomass estimates.

Year	BS shelf	BS slope	Aleutian Islands
1982	69,690	24,700	
1983	127,942		24,465
1984	181,091		
1985	163,668	74,400	
1986	229,865		110,476
1987	297,095		
1988	308,562	30,600	
1989	374,893		
1990	435,125		
1991	329,218	28,400	21,897
1992	420,598		
1993	538,805		
1994	570,604		58,191
1995	480,842		
1996	556,416		
1997	478,667		73,893
1998	368,604		
1999	263,115		
2000	340,365		65,028
2001	409,227		
2002	356,558	61,153	88,750
2003	546,672		
2004	550,984	68,568	94,998
2005	763,887		
2006	670,131		183,836
2007	546,483		
2008	583,918	96,248	
2009	453,559		
2010	528,667	74,065	80,060
2011	563,233		
2012	443,593	73,676	49,969

Table 6. Arrowtooth survey biomass by area within the Aleutian Islands (AI); Western, Central, and Eastern, corresponding to National Marine Fisheries Service (NMFS) areas 543, 542, and 541 respectively. Data is based on the NMFS Aleutian Island survey results.

Year	**Western AI**	**Central AI**	**Eastern AI**	**AI total**
1980	1,266	4,063	7,206	12,535
1983	2,361	4,041	9,872	16,273
1986	12,250	6,732	86,656	105,638
1991	4,710	7,216	6,873	18,799
1994	8,455	12,011	28,737	49,203
1997	12,530	21,885	27,988	62,403
2000	13,090	10,633	32,471	56,194
2002	14,398	12,352	49,105	75,855
2004	17,400	16,909	42,263	76,572
2006	10,516	35,257	126,923	172,696
2010	18,053	9,445	43,325	70,823
2012	17,342	3,739	28,888	49,969

Table 7. Catch (t) by area from 2004-2014 (as of September 12, 2014). The Western Aleutian Islands (AI) corresponds to the National Marine Fisheries Service (NMFS) area 543, Central AI is 542, and Eastern AI is 541. The Eastern Bering Sea (EBS) and the total catch from the AI are also shown. Source: NMFS AKRO BLEND/Catch Accounting System.

Year	Western AI	Central AI	Eastern AI	AI Total	EBS	Total
2004	128	266	424	818	17,367	18,185
2005	183	202	450	834	13,409	14,243
2006	172	837	466	1,476	11,966	13,442
2007	119	247	494	860	11,082	11,942
2008	192	214	2,066	2,471	18,897	21,368
2009	89	212	10,387	10,688	19,212	29,900
2010	179	276	23,643	24,098	14,784	38,881
2011	77	179	3,012	3,269	16,927	20,195
2012	104	165	3,131	3,400	18,979	22,379
2013	63	180	6,325	6,479	14,023	20,502
2014	45	100	3,920	4,066	12,736	16,802

Table 8. Exploitation rates by area for the past four years in which National Marine Fisheries Service Gulf of Alaska surveys were conducted (2007, 2009, 2011, 2013), and F_{ABC}, the fishing mortality rate that would provide the acceptable biological catch.

Year	Western	Central	Eastern	F_{ABC}
2007	0.01073	0.01396	0.00062	0.186
2009	0.00457	0.01690	0.00024	0.183
2011	0.00613	0.02042	0.00089	0.219
2013	0.00246	0.01704	0.00017	0.174

Table 9. Exploitation rates from the Aleutian Islands: western, central, and eastern regions, and the Eastern Bering Sea (EBS), and the target fishing mortality rate, F_{ABC}.

Year	Western AI	Central AI	Eastern AI	EBS	F_{ABC}
2004	0.0074	0.0157	0.0100	0.0280	0.26
2008				0.0278	0.24
2010	0.0099	0.0292	0.5457	0.0245	0.235
2012	0.0060	0.0441	0.1084	0.0367	0.22