Project Title: Developing maturity schedules to improve stock assessments for data-poor commercially important flatfishes in the Gulf of Alaska.

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Summary

The goal of this project was to update estimates of length and age at maturity for commercially important flatfish species in the Gulf of Alaska (GOA). Some of these estimates were generated from studies occurring over 15 years ago. In order to achieve our objectives, samples were collected at fishery processing plants in Kodiak, Alaska, in 2012 and 2013 through a partnership with the industry group, Alaska Groundfish Data Bank (AGDB), who played a major role by funding the collection of field samples necessary for successful completion of this project. Otolith (age structures) and ovary samples were collected from four commercially important flatfish species for the purposes of updating maturity estimates (arrowtooth flounder *Atheresthes stomias*, southern rock sole *Lepidopsetta bilineata*, northern rock sole *Lepidopsetta polyxystra*, flathead sole *Hippoglossoides elassodon*). The role of the Alaska Fisheries Science Center (AFSC) for this project was performing histological analysis, ageing of specimens, data analysis, and report preparation. New data on maturity-at-age can result in changes in the values of the fishing mortality reference points, acceptable biological catch (ABC) and overfishing level (OFL), and the estimate of spawning stock biomass (SSB). Spawning biomass is computed based on the time of peak spawning and the maturity and weight schedules available in each species'

stock assessment. Determination of maturity is crucial in determining the biological productivity of these stocks and the target fishing mortality rate necessary to maintain a healthy reservoir of SSB. These new data will directly enhance stock assessments and fisheries management. Updated maturity estimates are also important to the industry to maintain Marine Stewardship Council (MSC) certification of some commercially important flatfish species.

This proposed maturity project has been a cooperative effort with the fishing industry. It was borne out of annual MSC meetings where one of the conditions for re-certification was to enhance and update maturity estimates for most of the Bering Sea-Aleutian Islands (BSAI) and GOA flatfish stocks. The industry (Alaska Seafood Cooperative)agreed to take on the specimen collection part of the project (under our sampling guidance, technical expertise on the reproductive biology of the stocks, and provision of supplies) and we agreed to try and complete the sample processing, histology, and age determination work required. The BSAI work is now complete (funded through a grant from the North Pacific Research Board) due in part with industry cooperation through the hiring of an at-sea sampler in 2012 to assist in some of the required field sampling aboard a commercial vessel. For the GOA samples, industry hired a sampler for 2012 and 2013 to provide samples for our processing, analysis, and report documentation. Here we present results and briefly discuss the maturity and reproductive aspects based on our findings, and compare our maturity estimates with previously published estimates.

Methods

In 2012 and 2013, opportunistic sampling for the four flatfish species was conducted at Kodiak processing plants by AGDB personnel. Otoliths and ovaries were collected from female

specimens within a specified size range. A total of 709 samples were collected. Each ovary was placed inside a separate cloth specimen bag with a label and submerged in a 5-gallon buckethalf-filled with 10% formalin to be processed and analyzed later by AFSC personnel. Otoliths were stored dry in vials and placed in styrofoam boxes and shipped to AFSC for subsequent ageing.

After processing, samples were shipped to an outside histology services laboratory for final slide processing where ovarian cross sections were embedded in paraffin, thin-sectioned to 4 μm, mounted on slides, and stained with hematoxilyn and eosin. Individuals exhibiting yolk deposition (vitellogenesis) were defined as mature. Spawning individuals were defined by those with ovaries containing either hydrated oocytes or ova, with or without post-ovulatory follicles. Reproductive characteristics (notably atresia, or oocyte absorption) were recorded. Otoliths were hydrated with a glycerol thymol solution for a minimum period of 7 days prior to ageing. The break-and-burn method was used for ageing otoliths of each species. Standard quality control methods were used to age specimens, including precision statistics based on testing from a secondary age reader. Data was fitted to a logistic equation to estimate length and age at 50% maturity using generalized linear modeling based on binomial data under the statistical package R. Akaike's information criterion (AIC) was used as the goodness-of-fit index.

Results/Discussion

A total of 694 of the 709 samples collected were later analyzed for histological characteristics and estimates of maturity. There were a few samples from the collection that had to be discarded or were not available for analysis. Reasons for the discrepancy between number of samples collected and number of samples analyzed were collector error (i.e., no tissue in the bag during

laboratory processing, samples from small fish identified as males after histological examination) and otoliths from different fish discovered in vials when ageing.

There was no apparent difficulty in interpretation of otolith patterns and recording annuli (years of age) for any of the four species in this study. Precision statistics showed that ageing completed for this study was better than that of historical estimates during production ageing. For example, for arrowtooth flounder, perfect agreement between readers was 67.9% among tested samples, and the total CV and APE was 4.39 and 3.10, respectively. Historical estimates for this species show perfect agreement to be 50.1% of the tested arrowtooth flounder samples, with a total CV and APE of 8.37 and 5.92, respectively. Ageing error and low precision can be problematic in maturity-at-age estimates used in stock assessments due to the lack of information in estimates with wide variances, but our results show that this was minimized, leading to more reliable maturity estimates.

Southern rock sole collections were made during the months of April, October, and November (Table 1). Ovaries appeared to be maturing during the spring as evidenced by a relatively large number in later stages of vitellogenesis. In the fall, spawning was observed in a small percentage of females (hydrated oocytes observed). Of note, our estimate of southern rock sole mature proportion at age was lower than a previous estimate. Our estimate was 6.8 years at 50% maturity (Figure 1; Table 2), compared to an average age of 9.0 years at 50% maturity from a study conducted from 1996 to 1999 (Stark 2002). Our length at 50% maturity estimate of 35.7 cm was similar to Stark's (2002) estimate of 34.7 cm.

A total of 62 northern rock sole were collected in late winter and during the spring (Table 1). Observations of spawning females were recorded throughout the collection period with some individuals exhibiting a “spent” stage, as noted by the presence of post ovulatory follicles in April. Our estimates of length and age at 50% maturity for northern rock sole were 40.4 cm and 6.1 years, respectively (Table 2). This compares to Stark’s (2002) estimates of 32.8 cm and 7 years. These estimates may not be useful due to a relatively small sample size. For example, there was only a single observation from the sixth year that was between 0 and 100% proportion mature in the maturity-at-age ogive generated (Figure 1). The lack of observations resulted in an error in the statistical output (i.e. large variance, non-significance); therefore, no conclusions can be drawn from this estimate. Furthermore, the lack of samples also resulted in a skewed length estimate towards larger individuals.

Flathead sole females were collected during the months from February to April (Table 1). Collections were conducted during a near-spawning to spawning period for this species. During the months of February and March, ovaries from mature females exhibited advanced vitellogenesis. Spawning individuals were observed in April. Our estimates of length and age at 50% maturity were 36.7 cm and 9.2 years, respectively. These estimates are slightly larger than Stark’s (2004), whose estimates for 50% of the population were 33.3 cm and 8.7 years.

Arrowtooth flounder were collected over two seasonal periods, in July and during the fall (Table 1). Based on the histological characteristics, ovaries were primarily developing in July with many females exhibiting some vitellogenesis, and in the fall months, showing more advanced vitellogenesis with a few observed in spawning mode. The maturity estimates for arrowtooth

flounder were similar to previous estimates. The length and age at 50% maturity from our study were 48.3 cm and 7.7 years, respectively (Table 2). This is in close agreement to Stark's (2008) study based on GOA collections in 2002 and 2003 that resulted in estimates of length and age at 50% maturity of 46.3 cm and 7.0 years.

Conclusion

The main objective for this cooperative research project was to update estimates of length and age at maturity for four commercially important flatfish species in the GOA. These new estimates will provide updated and critical information for the formulation of reference fishing mortality rates and catch levels (ABCs and OFLs), substantially improving stock assessments for the respective species. The following conclusions can be made from this study:

- Collections and histology work for the three species in this study (southern rock sole, flathead sole, and arrowtooth flounder) were successful for updating estimates of age-and length-specific maturity schedules and providing the best estimates of SSB. This was due to such factors as seasonal timing in sampling, a broad size range of specimens representing both immature and mature fish, and confidence in ageing interpretation. These estimates are considered reliable. The maturity-at-age estimates calculated for these species are now available to update their respective 2015 GOA age-structured stock assessments.
- The fourth species, northern rock sole, was not successful due to a relatively low sample size resulting in maturity estimates that were inconclusive. More data needs to be collected for this species in the future for more reliable estimates.

References

Stark, J. W., and D. A. Somerton. 2002. Maturation, spawning and growth of rock soles off Kodiak Island in the Gulf of Alaska. Journal of Fish Biology 61:417-431.

Stark, J. W. 2004. A comparison of the maturation and growth of female flathead sole in the central Gulf of Alaska and south-eastern Bering Sea. Journal of Fish Biology 64:876-889.

Stark, J. W. 2008. Age- and length-at-maturity of female arrowtooth flounder (*Atheresthes stomias*) in the Gulf of Alaska. Fishery Bulletin 106:328-333.

Table 1. Number of samples by month by species collected in the Gulf of Alaska (GOA) in 2012 and 2013.

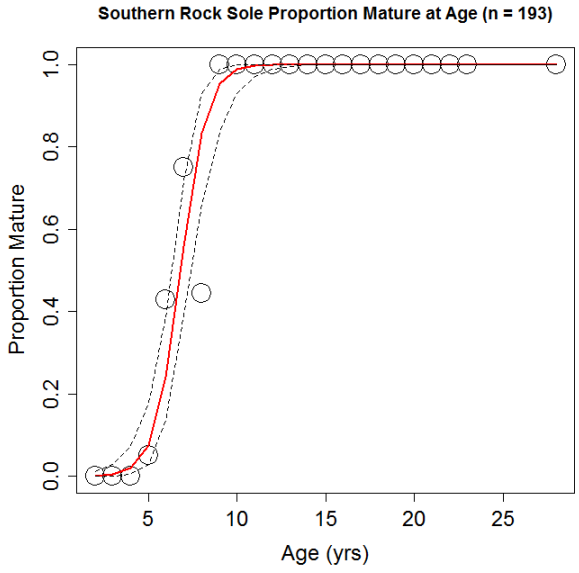
Species/Month	*n*	Length range (cm)	Mean size (cm)
Southern rock sole			
October 2012	78	23−50	38.7
November 2012	12	25−42	30.5
April 2013	84	19−60	41.2
May 2013	21	20−48	30.2
Northern rock sole			
February 2013	15	28−50	40.9
April 2013	26	24−56	42.4
May 2013	21	21−36	27.5
Flathead sole			
February 2013	74	23−49	38.8
March 2013	29	31−53	41.3
April 2013	69	21−49	35.1
Arrowtooth flounder			
July 2012	52	28−65	47.5
October 2012	124	21−66	42.7
November 2012	104	22−80	45.9

Table 2. Updated estimates of length and age at 50% maturity (L_{50} or A_{50}) for the flatfish species in this study. SE = standard error for either the length or age variable; *P*-value = statistical

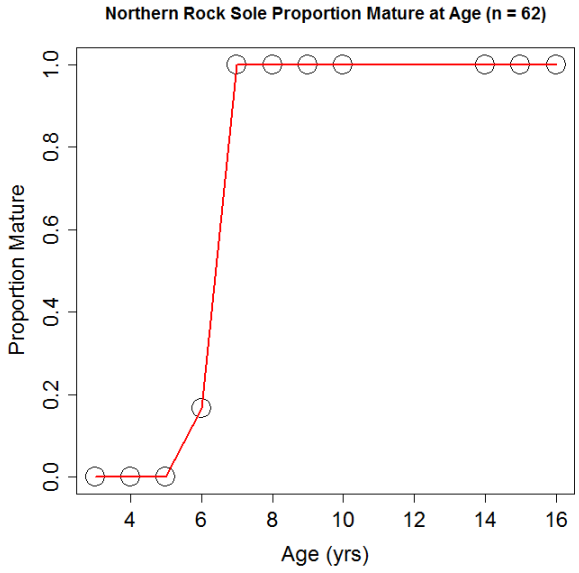
significance assigned to each variable, testing that they were significantly different from 0 using z-tests; AIC = Akaike's information criterion. SRS – southern rock sole; NRS – northern rock sole; FHS – flathead sole; ATF – arrowtooth flounder.

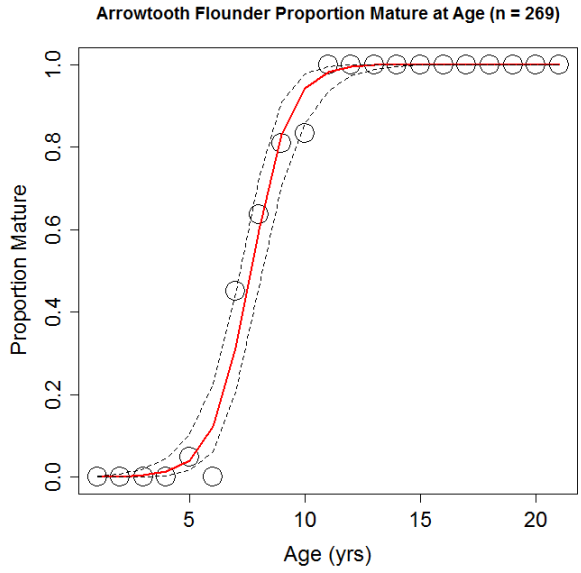
Species	Variable	Coefficients (α, β)		L_{50} or A_{50}	SE	*P*-value	AIC
SRS	Length	-26.165	0.732	35.73	0.146	<0.0001	31.08
	Age	-9.427	1.379	6.83	1.631	<0.0001	27.87
NRS	Length	-16.929	0.419	40.38	0.114	<0.0001	25.21
	Age	-146.33	24.120	6.07	110807	0.999	5.82
FHS	Length	-22.216	0.606	36.67	0.098	<0.0001	43.13
	Age	-7.539	0.822	9.18	0.127	<0.0001	34.79
ATF	Length	-34.574	0.716	48.32	0.128	<0.0001	27.14
	Age	-9.102	1.188	7.66	0.170	<0.0001	25.72

Figure 1. Maturity-at-age ogives for the four flatfish species in this study.


Southern Rock Sole Proportion Mature at Age (n = 193)
Proportion Mature
0.0
0.2
0.4
0.6
0.8
1.0
5
10
15
20
25
Age (yrs)

Flathead Sole Proportion Mature at Age (n = 170)
Proportion Mature
0.0
0.2
0.4
0.6
0.8
1.0
5
10
15
20
Age (yrs)


Northern Rock Sole Proportion Mature at Age (n = 62)
Proportion Mature
0.0
0.2
0.4
0.6
0.8
1.0
4
6
8
10
12
14
16
Age (yrs)


Arrowtooth Flounder Proportion Mature at Age (n = 269)
Proportion Mature
0.0
0.2
0.4
0.6
0.8
1.0
5
10
15
20
Age (yrs)