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NOTE

Updated Maturity Estimates for Flatfishes (Pleuronectidae) in the Eastern Bering Sea, with Implications for Fisheries Management

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Abstract

Female Yellowfin Sole *Limanda aspera*, Alaska Plaice *Pleuronectes quadrituberculatus*, and Flathead Sole *Hippoglossoides elassodon* were collected from the eastern Bering Sea during known prespawning, spawning, and postspawning periods in 2012 and 2013, and their ovaries and otoliths were sampled for use in histological analysis to update historical maturity estimates. For fisheries management, new information on maturity at age can lead to possible changes in estimated reproduction potential (measured as female spawning stock biomass [SSB]) and values of fishing mortality reference points. Our analysis indicated that Yellowfin Sole currently mature at an age similar to that estimated in a study conducted 20 years ago. An evaluation of impacts on the stock assessment indicated that updated estimates of Yellowfin Sole SSB were over 7% higher, but the reference points only changed slightly. The first histologically derived maturity estimates for Alaska Plaice were close to the anatomically derived estimates (visual assessments from 1987), resulting in a marginal decrease (5%) in SSB, but changes in reference points were near 10%. Based on the new maturity estimates for Flathead Sole, SSB estimates increased by 7% compared with estimates currently used in the stock assessment, which relied on maturity data collected in 1999 and 2000. The change in Flathead Sole SSB was concomitant with changes of 16–18% in fishing mortality reference points. Our results indicated minimal differences from historical maturity estimates after re-examination, but in some cases those differences led to relatively large changes in the respective reference points, underscoring the reference points' sensitivity to changes in maturity. Incorporation of these new maturity estimates into the stock assessment process provides valuable updated information for fisheries managers. However, a more comprehensive sampling program is needed to investigate the spatial and temporal aspects of reproduction for each species.

New data on maturity at age can lead to changes in the values of fishing mortality reference points and estimates of female spawning stock biomass (SSB; Brooks 2013). Female SSB is computed based on the time of peak spawning and the maturity and weight schedules available in each species' stock assessment (Wilderbuer et al. 2013). Determination of maturity is crucial in evaluating the biological productivity of these stocks and the fishing mortality rate necessary to maintain a healthy SSB. Confidence in stock assessment procedures can be increased with periodic updates to maturity. An examination of newly estimated maturity schedules for species relative to their stock assessment model estimates of fishery selectivity is informative for fisheries management (Clark 1991). Although quantitative assessment of reproductive biology parameters is essential for stock assessment calculations, qualitative information on spawning dynamics is also important, especially as fisheries managers have begun taking an ecosystem approach to management (Link 2002). Maturity and other life history traits, such as fecundity and growth, can be used as indices for population viability and biological productivity (Rochet 2000). Many stock assessments involve the assumption that maturity is temporally and spatially constant (Lowe et al. 2008); however, maturity estimates are subject to variability. Commercial exploitation in combination with environmental changes leads to potential shifts in growth, maturity, and other life history factors such that time series or periodic updates to maturity estimates are necessary to deal with this

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variability. A re-examination of maturity parameters—sometimes decades after the most recent estimates—is therefore necessary for contemporary fisheries management.

Fisheries for Alaskan groundfishes are managed by the North Pacific Fishery Management Council (NPFMC 2014). Separate fishery management plans are in place for the Bering Sea–Aleutian Islands (BSAI) and Gulf of Alaska (GOA) management areas. Groundfish species that are exploited commercially in Alaskan waters are managed according to six tiers based on the quality and amount of data that are available for stock assessment and fishery management. Stocks with the most available data belong to Tier 1 and are assessed with complex age-structured population models to support assessment and fishery management. In contrast, stocks in Tier 6 lack reliable estimates of biomass and life history parameters, so their harvest recommendations are assessed based on historical catches because no other reliable data are available. Estimates of maturity are required for age-structured models of species in tiers 1–3 and for calculating fishing mortality reference points for species in Tier 4. Alaskan fishery management policies aim to conserve SSB; thus, inaccurate maturity estimates based on limited information can lead directly to misspecified harvest rates and can have consequences for the long-term sustainability of a stock (Lambert 2013).

Within the BSAI management area, there are several commercially important flatfish stocks for which management would be improved by an enhanced knowledge of reproductive biology. Three shallow-water flatfish species that are commonly found in the eastern Bering Sea and that represent a substantial portion of the flatfish biomass in this region are the Yellowfin Sole *Limanda aspera*, Alaska Plaice *Pleuronectes quadrituberculatus*, and Flathead Sole *Hippoglossoides elassodon* (Lauth and Nichol 2013). The Yellowfin Sole and Alaska Plaice are considered single stocks; Yellowfin Sole are managed as a Tier 1 stock, and Alaska Plaice are managed as a Tier 3 stock. The Flathead Sole is managed under Tier 3 as part of a two-species complex with its morphologically similar congener, the Bering Flounder *H. robustus*.

There is a lack of recent maturity data for Yellowfin Sole and Flathead Sole, and no maturity estimates exist for Alaska Plaice based on the histological examination of ovaries. Visual assessments without the use of microscopic analysis often rely on subjective measures, such as morphological features of the gonad, and are considered a less reliable approach to determining maturity status (e.g., Vitale et al. 2006; Williams 2007; Costa 2009; Ferreri et al. 2009; Midway et al. 2013). Historical maturity estimates are currently used in the stock assessments for each of the three flatfish species. For Yellowfin Sole, Nichol (1995) estimated the age and length at 50% maturity using histological examination of specimens collected during eastern Bering Sea trawl surveys conducted by the Alaska Fisheries Science Center (AFSC) in 1992 and 1993. Maturity estimates for Flathead Sole were derived using histological examination of specimens collected in 1999 and 2000 (Stark

2004). Finally, the Alaska Plaice stock assessments rely on maturity estimates from fish that were collected in 1987 and visually assessed by fisheries observers using certain anatomical criteria (Zhang et al. 1998). Therefore, the two main objectives of this study were to (1) update the maturity schedules for these three flatfish species based on histological analyses of ovaries and compare the resulting maturity schedules with the historical maturity estimates; and (2) incorporate the updated maturity information into current age-structured stock assessment models to examine concomitant changes in reference points and fishery selectivity.

METHODS

Field collections.—Fish were collected from both fishery-independent and fishery-dependent sources along the eastern Bering Sea continental shelf (Figure 1). For this study, we collected samples that covered the prespawning, spawning, and postspawning periods. Nichol (1995) indicated that Yellowfin Sole displayed a protracted spawning season that began as early as May and extended into August. For Alaska Plaice, Zhang et al. (1998) reported that the spawning season occurred from April through June. According to Stark (2004), the spawning of Flathead Sole began in April, and the post-spawn period began in June. In our study, Yellowfin Sole samples were collected during commercial fishing operations in March 2012; Yellowfin Sole and Alaska Plaice were collected in June and July 2012 aboard the vessel conducting the AFSC's annual groundfish trawl survey of the eastern Bering Sea continental shelf (Table 1). Alaska Plaice and Flathead Sole were obtained during commercial fishing operations in late winter and early spring of 2012 and 2013; these two species were also sampled aboard an AFSC-chartered vessel during a research cruise in June 2013 (Table 1).

Fish in this study were collected by using a length-stratified sampling scheme with a goal of collecting at least three female specimens per 1-cm length-group per species within a specific size range (FL). We targeted a wide size range to ensure that both immature and mature fish were collected. For each fish, the FL and total weight (g) were recorded. The blind-side lobe of the ovary (located on the ventral side of the fish) and both sagittal otoliths were collected from each specimen. Otoliths either were stored dry in plastic vials or were stored in a glycerol–thymol solution at the time of collection. The ovary was excised and placed inside a cloth specimen bag with a label and was preserved in 10% buffered formalin until laboratory processing.

Age determination.—The ages of Yellowfin Sole, Alaska Plaice, and Flathead Sole are routinely determined by the AFSC's Age and Growth Program via the standard aging procedures outlined by Matta and Kimura (2012). Consistent with the quality control used in that program, precision statistics were applied to otolith aging between two age readers (Kimura and Anderl 2005; Matta and Kimura 2012). Before final release of each collection, disagreements between the reader

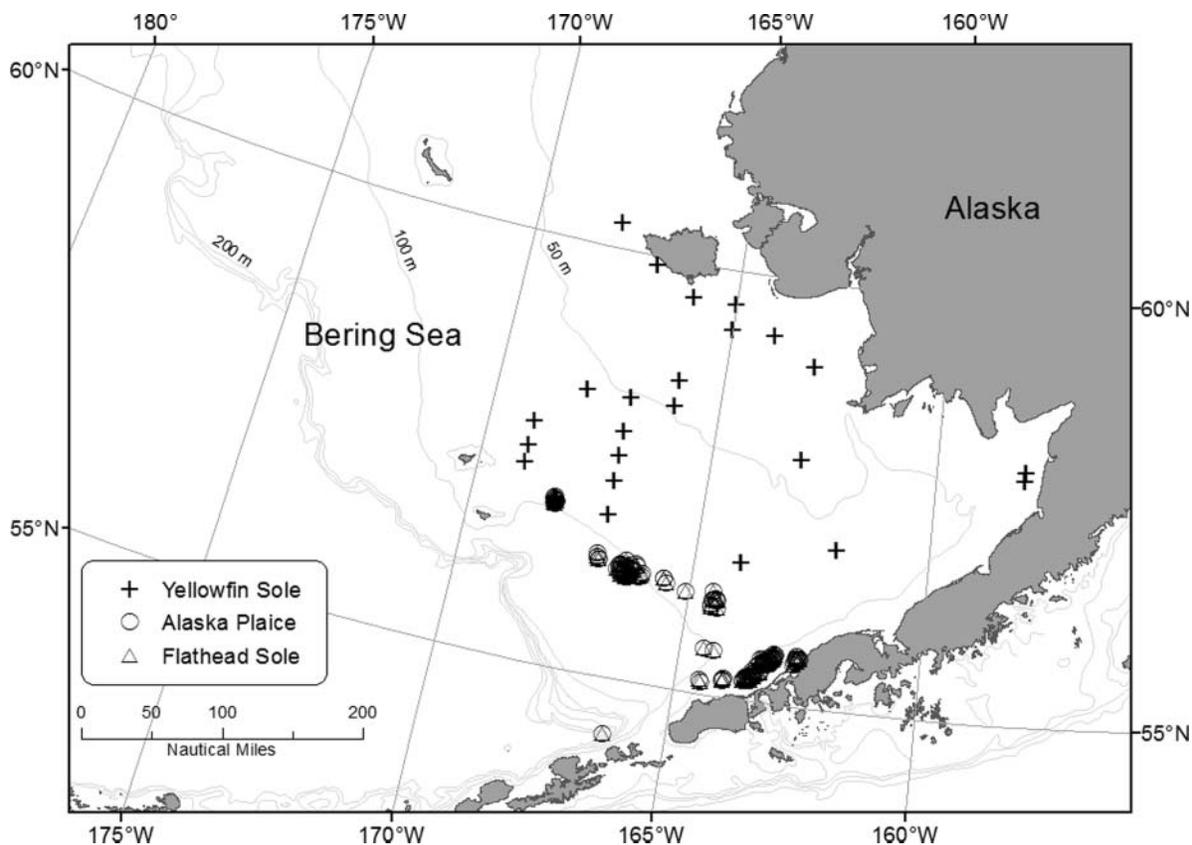


FIGURE 1. Collection locations for Yellowfin Sole (plus symbols), Alaska Plaice (open circles), and Flathead Sole (open triangles) along the eastern Bering Sea continental shelf.

and tester were resolved, and those otoliths were subsequently assigned updated ages. Each sample collection was aged and tested separately, and their respective precision statistics were calculated. Overall precision statistics were applied to each species.

TABLE 1. Number of female flatfish collected from the eastern Bering Sea during each sampling month in 2012 and 2013.

Month and year	<i>n</i>	FL range (cm)	Age range (years)
Yellowfin Sole			
Mar 2012	77	27–43	8–28
Jun 2012	214	9–43	3–34
Jul 2012	8	32–42	10–30
Alaska Plaice			
Mar 2012	99	34–59	10–28
Jun 2012	32	19–53	23–24
Apr 2013	210	26–49	6–27
Jun 2013	36	36–53	
Jul 2013	5	34–43	
Flathead Sole			
Mar 2012	87	31–52	6–26
Apr 2013	203	22–56	4–26
Jun 2013	41	33–50	

Maturity.—An approximately 1–2-g cross section was removed from the middle portion of the ovary prior to histological sectioning. Stark (2004) demonstrated that in Flathead Sole, histological sections taken from any area of either ovary were representative of oocyte development for the entire ovary and did not introduce sampling bias. We also applied this result to Yellowfin Sole and Alaska Plaice. Ovarian cross sections were embedded in paraffin, thin-sectioned to 4 μm , mounted on slides, and stained with hematoxylin and eosin. Histological slides were viewed under 100 \times magnification with transmitted light and were assigned maturity stages based on the classifications described by Stark (2004). The histological indicator for mature fish was defined as (1) any presence of yolk deposition (vitellogenesis) regardless of number (West 1990); or (2) a more advanced stage of development, such as evidence of recent spawning (i.e., postovulatory follicles [POFs]) often accompanied by other histological characteristics (e.g., a high frequency of atresia, general disorganization of ovarian structure, and/or an absence of vitellogenic oocytes). We were able to histologically distinguish between immature and mature fish during each month of sampling, although in some cases this can be difficult during spawning periods (Hunter et al. 1992). Our histological indicator for distinguishing an immature fish from a mature individual was the same as that used previously for Yellowfin Sole (Nichol 1995)

and Flathead Sole (Stark 2004). The consistent interpretation of maturity between our study and the Stark (2004) and Nichol (1995) studies allowed for more meaningful and reliable comparisons, especially since maturity information is important in the calculation of critical fishing mortality reference points, and these past maturity estimates have been used to estimate SSB. Atresia or oocyte resorption was recorded. Postovulatory follicles and atresia were recorded to demarcate active spawning and the cessation of spawning, respectively. The presence of POFs and atretic oocytes was based on histological characteristics of oocyte resorption and degeneration as detailed by Hunter and Macewicz (1985).

Estimates of length and age at 50% maturity and their 95% confidence intervals (CIs) were based on binomial data (0 = immature; 1 = mature) fitted to a logistic equation using the generalized linear model function in R version 2.13:

$$P_x = \frac{1}{1 + e^{-(\alpha + \beta x)}},$$

where P_x is the proportion of mature fish in the sampling population, α and β are the parameters to be estimated, and x is the FL or age of the fish.

Fishery management implications.—All three flatfish species are subject to stock assessments, which are fully documented by Wilderbuer et al. (2013) for Yellowfin Sole, Wilderbuer et al. (2011, 2012) for Alaska Plaice, and Stockhausen et al. (2012) for Flathead Sole. These statistical models calculated the female SSB and the spawning biomass per recruit, which are used to determine the following fishing mortality reference points: the annual allowable fishery catch (i.e., acceptable biological catch [ABC]); the fishery catch defining the overfishing limit (OFL); and the fishing mortality rates at the ABC (F_{ABC}) and OFL (F_{OFL}). In summary, the abundance, mortality, recruitment, and selectivity were modeled by simulating the dynamics of the population and comparing the expected values for population characteristics to the values observed from surveys and fishery sampling programs (Fournier and Archibald 1982). This was accomplished by simultaneous estimation of the parameters in the model using the maximum likelihood estimation procedure. The fit of the simulated values to the observable characteristics was optimized by maximizing a log-likelihood function given some distributional assumptions about the observed data.

The species-specific maturity estimates derived here were assumed to be representative of the entire Bering Sea population. These updated maturity estimates were used as inputs to the stock assessment for each species. The F_{ABC} , F_{OFL} , ABC, OFL, and SSB estimated from the historical maturity estimates were then compared with those derived from our updated maturity estimates. In addition, fishery selectivity at age as determined from the stock assessments was compared with the updated maturity estimates to determine whether females of

the three flatfish species are vulnerable to capture before they have an opportunity to spawn.

RESULTS

Age Determination

Aging precision statistics in this study were similar to historical aging precision for each species, ensuring comparable age estimates for Yellowfin Sole (coefficient of variation [CV] = 2.45%; average percent error [APE] = 1.74%), Alaska Plaice (CV = 1.88%; APE = 1.33%), and Flathead Sole (CV = 7.46%; APE = 5.27%). The age of females examined in this study ranged from 3 to 34 years for Yellowfin Sole; from 6 to 28 years for Alaska Plaice; and from 4 to 26 years for Flathead Sole (Table 1).

Maturity

For each species, histological analysis was conducted on females that were collected during each month of sampling (Table 2). Oocytes from Yellowfin Sole collected during March were observed to be vitellogenic; some specimens exhibited spawning, as evidenced by hydrated oocytes. Spawning in Yellowfin Sole was also observed during summer collections. Alaska Plaice spawning occurred during the collection months of March and April. Postspawn Alaska Plaice females were observed in the summer based on (1) the presence of POFs and (2) a regeneration phase that was marked largely by early vitellogenesis. Spawning female Flathead Sole were observed in March and April, and ovaries in a post-spawn condition were collected during June.

Updated maturity estimates were calculated for Yellowfin Sole, Alaska Plaice, and Flathead Sole (Figure 2; Table 3). For Yellowfin Sole, age at 50% maturity was estimated at 10.14 years (95% CI = 9.78–10.50 years), and length at 50% maturity was estimated at 29.57 cm FL (95% CI = 29.38–29.76 cm). The youngest mature Yellowfin Sole was 9 years old, and the smallest mature fish was 22 cm FL. Based on histological examination of Alaska Plaice, the estimated age at 50% maturity was 9.50 years (95% CI = 9.21–9.79 years), and the estimated length at 50% maturity was 31.93 cm FL (95% CI = 31.70–32.17 cm). The youngest mature Alaska Plaice was 8 years old, while the smallest mature fish was 29 cm FL. The age at 50% maturity estimate for Flathead Sole was 8.88 years (95% CI = 8.71–9.05 years); the length at 50% maturity estimate was 34.26 cm FL (95% CI = 34.07–34.46 cm). The youngest mature Flathead Sole was 5 years old, and the smallest mature individual was 28 cm FL.

Fishery Management Implications

The maturity ogives calculated for Yellowfin Sole, Alaska Plaice, and Flathead Sole were used to update their respective

TABLE 2. Results of histological analyses, showing the number of female flatfish in the most advanced stage of oocyte development: primary growth (PG) or previtellogenic; cortical alveolus (CA); early vitellogenesis (EV); advanced vitellogenesis (AV), including the migratory nucleus stage; hydrated oocyte (HY); and postovulatory follicle (POF). Presence of atresia (AT; any stage [alpha, beta, or delta]) is given as the number (percentage in parentheses) of mature females with atretic oocytes. Note that in many cases, spawning fish had several oocyte stages present.

Month	<i>n</i>	Oocyte stages in immature females		Oocyte stages in mature females				
		PG	CA	EV	AV	HY	POF	AT (%)
Yellowfin Sole								
Mar	35	3	1	4	20	7		29 (94)
Jun	207	88	17	10	63	1	28	65 (64)
Jul	8			1	5		2	3 (38)
Alaska Plaice								
Mar	69		1	5	29	34		64 (94)
Apr	205	13	58	43	48		43	116 (87)
June	19		5				14	11 (79)
July	5						5	5 (100)
Flathead Sole								
Mar	44		2	1	18	11	12	42 (95)
Apr	205	43	71	37	37	1	16	67 (74)
Jun	41						41	37 (90)

fishing mortality reference points (Table 4). Based on the maturity-at-age estimates for Yellowfin Sole, a run of the stock assessment model (updated through the 2014 stock assessment) resulted in an approximate 7% increase in estimated SSB relative to the previous maturity schedule but only a small (<1%) change in ABC. For Alaska Plaice, the new, histologically determined maturity estimates yielded results that were close to those of the anatomically derived estimates; the updated stock assessment model produced a 5.1% decrease in SSB relative to the prior estimates, whereas ABC decreased by 9.8%. The stock assessment model estimates for Flathead Sole (updated through 2013) generated (1) a 7.3% increase in the estimated SSB relative to the previous maturity schedule and (2) a 16.2% increase in ABC.

Based on a comparison of fishery selectivity at age and the age at 50% maturity for female Yellowfin Sole, the age at first capture in the fishery was approximately 1 year younger than the age of first spawning (Figure 3). For female Alaska Plaice, the age at first spawning and the age at first capture in the fishery were nearly the same. In the case of female Flathead Sole, model estimates of fishery selectivity indicated that first capture occurred at an age much older than the age at 50% maturity.

DISCUSSION

The maturity estimates used to calculate SSB for each species are assumed to represent a single stock whose population exhibits little or no spatial or temporal variation. Given the lack of maturity estimates and the reliance on a single study or a few years of data for many species, periodically updating estimates or creating a time series of data seems appropriate

for achieving effective decision making and management of commercially important species. The eastern Bering Sea continental shelf is a vast area, with major oceanographic influences along its depth domains. Predator-prey interactions, species distributions, fisheries exploitation, and cyclical climate variability are just a few of the possible conditions that could influence life history parameters such as maturity or other aspects of reproduction. For example, size- or age-at-maturity estimates might change, spawning schedules might shift, or both might occur as a result of environmental conditions. For Walleye Pollock *Gadus chalcogrammus* in the GOA, variation in maturity has been documented on an annual basis since 1983 (Dorn et al. 2013). Maturity at age or size may be subject to annual variability given the response of species to short-term environmental conditions through some adaptation in their life history traits (Stearns 1993). For example, Walleye Pollock could exhibit at least some within-species variation along the broad eastern Bering Sea shelf, which is subject to larger climatic shifts than the GOA. Estimates of SSB are typically used as a proxy for reproductive potential in stock assessments. Although a species may experience annual variation in maturity, stock assessments will not necessarily be improved by the use of such a time series, as was noted by Spencer and Dorn (2013); their work with GOA Walleye Pollock demonstrated that annual updates to maturity did not improve the fit to an index of SSB, suggesting that some of the interannual variation was statistical noise or unexplained variation. An understanding of the functional relationship between maturity and environmental conditions is needed in order to deal with this variation. Therefore, updating maturity information on a periodic basis should be viewed as a minimum step.

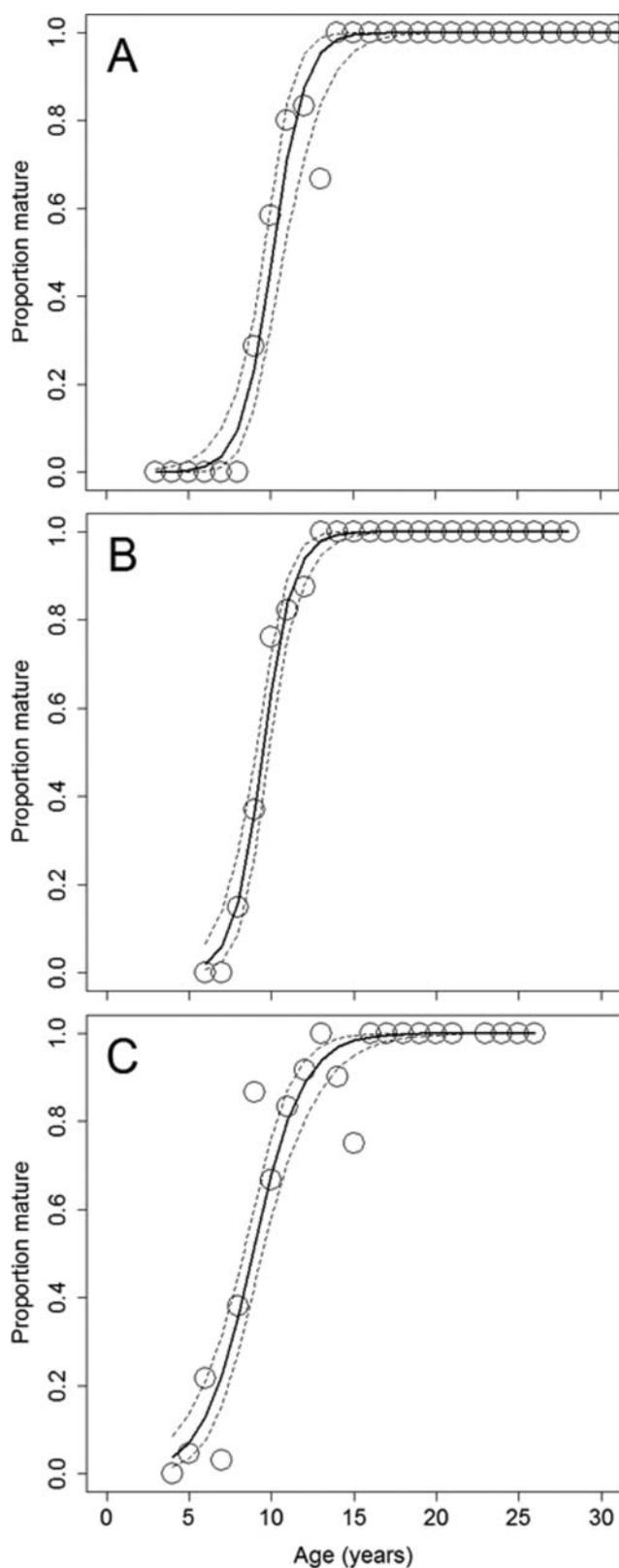


FIGURE 2. Maturity-at-age estimates for female (A) Yellowfin Sole ($n = 232$), (B) Alaska Plaice ($n = 275$), and (C) Flathead Sole ($n = 237$) collected along the eastern Bering Sea continental shelf.

TABLE 3. Maturity estimates (length at 50% maturity [L_{50}], cm FL; age at 50% maturity [A_{50}], years) and summary statistics from binary logistic regression models (α , β = estimated parameters; CI = confidence interval) for female flatfish collected from the eastern Bering Sea.

Variable	Coefficient		L_{50} or A_{50}	SE	95% CI
	α	β			
Yellowfin Sole					
Length	-19.1635	0.6482	29.57	0.0953	29.38–29.76
Age	-10.6213	1.0470	10.14	0.1841	9.78–10.50
Alaska Plaice					
Length	-27.7895	0.8704	31.93	0.1197	31.70–32.17
Age	-10.4850	1.1037	9.50	0.1485	9.21–9.79
Flathead Sole					
Length	-26.1240	0.7625	34.26	0.0997	34.07–34.46
Age	-5.8924	0.6631	8.88	0.0864	8.71–9.05

Our objective of updating maturity estimates does not replace the need for a more comprehensive examination in understanding the reproductive biology of these flatfish species. For example, we did not address spatial and temporal

TABLE 4. Fishing mortality reference points estimated from the current stock assessment model using historical maturity estimates (see Methods) in comparison with the updated maturity estimates from this study (ABC = acceptable biological catch, metric tons; OFL = overfishing limit, metric tons; F_{ABC} = fishing mortality rate at the ABC; F_{OFL} = fishing mortality rate at the OFL). The percent difference column highlights the change in spawning stock biomass (SSB; metric tons), which is based on maturity-at-age estimates.

Reference point	Maturity at age		Percent difference
	Historical estimates	Present estimates	
Yellowfin Sole			
F_{ABC}	0.104	0.102	
F_{OFL}	0.110	0.110	
ABC	219,600	219,150	<1.0
OFL	233,200	235,800	+1.1
SSB	662,900	711,800	+7.4
Alaska Plaice			
F_{ABC}	0.150	0.135	
F_{OFL}	0.184	0.163	
ABC	46,900	42,300	-9.8
OFL	56,700	50,600	-10.7
SSB	229,200	217,500	-5.1
Flathead Sole			
F_{ABC}	0.285	0.337	
F_{OFL}	0.348	0.420	
ABC	68,000	79,000	+16.2
OFL	82,000	97,000	+18.3
SSB	245,000	263,000	+7.3

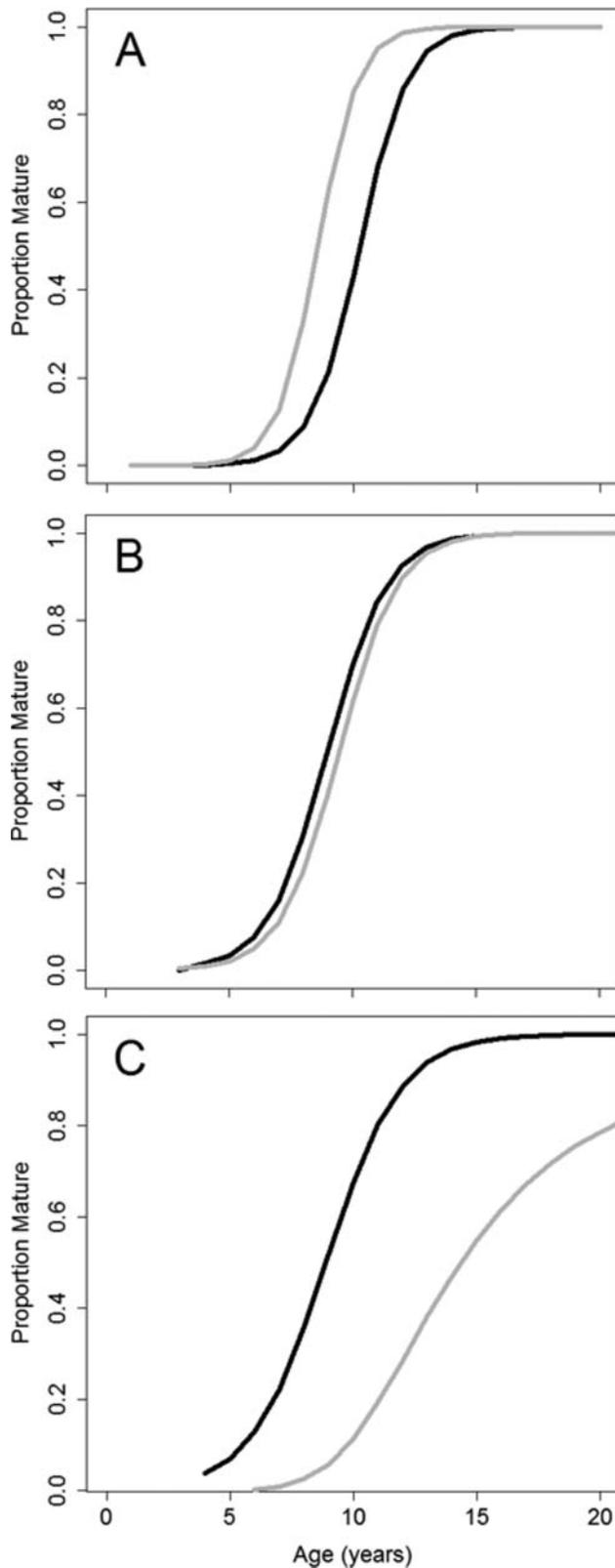


FIGURE 3. Fishery selectivity curves (gray lines) and maturity curves (black lines) for female (A) Yellowfin Sole, (B) Alaska Plaice, and (C) Flathead Sole based on the most current stock assessment model for each species.

differences through year-round sampling, which might have revealed or confirmed patterns in characteristics such as spawning season, style of gonadal development, distribution and extent of spawning populations, spawning behaviors, and rates of atresia. Our study placed an emphasis on ovarian histology from samples collected prior to spawning so as to avoid possible biases when classifying maturity status (Hunter et al. 1992). Information on spawning dynamics is important, especially since an ecosystem approach to fisheries management is becoming more common (Link 2002). Reproductive strategy and the factors affecting population dynamics are closely linked. Each aspect of reproductive biology informs scientists of a stock's vulnerability to fishing and informs the selection of sustainable management strategies. There are still some basic research gaps in reproductive biology that must be addressed. For Yellowfin Sole, we found spawning females in March, 2 months prior to the first spawning females identified in Nichol's (1995) investigation. Has there been an actual temporal shift in spawning, or was Nichol's (1995) summer study simply limited in scope? Future research should target a more comprehensive monthly sampling plan to investigate maturity and the duration of the spawning season for Yellowfin Sole. Our histological examination of Alaska Plaice confirms Fadeev's (1965) observations based on a visual examination of spawning ovaries—namely, that Alaska Plaice spawn intermittently in batches. Further investigation is needed to determine whether Alaska Plaice produce more than one series of batches within a spawning season, as has been observed for Yellowfin Sole (Nichol and Acuna 2001). For Flathead Sole, limitations in sampling effort were noted for our study as well as Stark's (2004) study, in which only 2–3 months of collections were obtained.

In the present study, Yellowfin Sole sampling was distributed along a large area of the shelf, whereas Alaska Plaice and Flathead Sole collections were more localized. When sampling Yellowfin Sole in 1992 and 1993, Nichol (1995) concentrated more in the shallower spawning areas, primarily at depths less than 50 m. We generated maturity estimates similar to those from 20 years ago (Nichol 1995), and our estimates were derived from samples collected over a broader area throughout the eastern Bering Sea continental shelf. We were unable to discern whether spatial and temporal differences in sampling were important factors in maturity determination for Yellowfin Sole since the maturity estimates from the two studies have remained stable. Despite the small difference between the updated estimate of age at 50% maturity (10.14 years) and the historical estimate (10.5 years) that was used in past Yellowfin Sole stock assessments, maturity has likely fluctuated over the last two decades, particularly given the potential variability in the proportion mature at age.

We sampled Alaska Plaice from only a fraction of the eastern Bering Sea shelf, and based on our data, it was not possible to deduce whether there were spawning aggregations or to identify spawning grounds. Our collections of Flathead Sole were made in an area across the middle and outer depth

domains of the southeastern Bering Sea continental shelf—similar to the area sampled by Stark (2004), who noted that his collections were obtained in subareas that had over 60% of the total biomass of Flathead Sole, which might be representative for this species. However, Flathead Sole also inhabit areas to the north of our survey area along the middle and outer shelf, where the species co-occurs with its congener, the Bering Flounder (Lauth and Conner 2014). The overlap in distribution may result in interspecific competition for available spawning grounds (Stark 2011), potentially leading to differences in maturation rates between Flathead Sole in the northern and southern areas. Our mean estimate of age at 50% maturity for Flathead Sole (8.88 years) was 10% lower than Stark's (2004) estimate of 9.7 years (95% CI = 8.9–10.5 years).

An important aspect in fisheries science is determining the sizes and ages of fish that are targeted by the fisheries. For Yellowfin Sole, fishery selectivity has historically indicated that females are selected by the fishery at about age 9 (at 50% maturity) and are nearly fully selected by age 13, with annual variability (Wilderbuer et al. 2013). The current model runs indicated that 50% selection to the fishery occurs between age 8 and age 9. The fishery begins to catch Yellowfin Sole before the age of first spawning; therefore, to ensure that the population has a reservoir of spawning fish, managers would recommend a lower fishing mortality rate relative to a case in which maturity and fishery selectivity schedules are the same (Clark 1991). Conversely, the management recommendation for the Flathead Sole fishery would be a higher fishing mortality rate (to preserve the SSB at 40% of the unfished biomass) since these fish can spawn up to five or six times before they are available for capture in the fishery. With the new maturity estimates for Flathead Sole, the SSB estimate has increased, resulting in a higher ABC (16.2%) and OFL (18.3%). According to Stockhausen et al. (2012), the fishery for Flathead Sole is not suspected of affecting the population's size structure, as fishing mortality is relatively light. The fishery's effects on Flathead Sole maturity at age are unknown, although they are expected to be small (Stockhausen et al. 2012). For Alaska Plaice, the modeled estimate of 50% fishery selectivity was about 10 years for females (Wilderbuer et al. 2012). The reference fishing mortality rate for Alaska Plaice is determined by the available amount of reliable population data, including SSB. Here, we demonstrated that both the ABC and the OFL for Alaska Plaice have decreased by around 10%; however, due to the historical low fishing mortality rates, these decreases are not expected to have significant impacts on Alaska Plaice stock size structure or maturity at age.

Collections of Yellowfin Sole, Alaska Plaice, and Flathead Sole were successful for updating estimates of age- and length-specific maturity schedules and for providing current estimates of SSB. Seasonal timing of collections, a broad size range of specimens representing both immature and mature fish, and confidence in otolith age interpretation were contributing factors. The maturity-at-age estimates calculated for the three flatfish species are now available

for use in updating their respective future BSAI age-structured stock assessments. In summary, our age-at-maturity estimate for Yellowfin Sole was very close to the 1992–1993 estimate (10.5 years; Nichol 1995) that is currently used in the stock assessment model (Wilderbuer et al. 2013). For Alaska Plaice, the updated maturity estimates using histological methods were more reliable than estimates based on visual examinations in the field, which were conducted by fishery observers during the 1980s (Zhang et al. 1998); thus, we can place greater confidence in the present estimates since spawner-per-recruit calculations are sensitive to estimates of maturity (Brooks 2013). Finally, our maturity estimates for Flathead Sole represent an update to estimates derived from samples that were collected 15 years ago by Stark (2004), although our upper 95% CI for age at 50% maturity narrowly falls within the lower 95% CI for Stark's (2004) estimate. In this particular case, it may be necessary to further investigate Flathead Sole maturity on a more frequent temporal scale to determine whether there is a possible shift to earlier maturation. Our results exhibited minimal differences from historical maturity estimates, but in some cases those differences led to relatively large changes in the respective reference points, underscoring the reference points' sensitivity to changes in maturity.

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REFERENCES

- Brooks, E. N. 2013. Effects of variable reproductive potential on reference points for fisheries management. *Fisheries Research* 138:152–158.
- Clark, W. G. 1991. Groundfish exploitation rates based on life history parameters. *Canadian Journal of Fisheries and Aquatic Sciences* 48:734–750.

- Costa, A. M. 2009. Macroscopic and microscopic identification of the maturity stages of female Horse Mackerel. *ICES Journal of Marine Science* 66:509–516.
- Dorn, M., K. Aydin, D. Jones, W. Palsson, and K. Spalinger. 2013. Assessment of the Walleye Pollock stock in the Gulf of Alaska. Pages 53–158 in Stock assessment and fishery evaluation document for groundfish resources in the Gulf of Alaska region as projected for 2014. North Pacific Fishery Management Council, Anchorage, Alaska.
- Fadeev, N. S. 1965. Comparative outline of the biology of flatfishes in the southeastern part of the Bering Sea and condition of their resources. Pages 112–129 in P. A. Moiseev, editor. *Soviet Fisheries Investigations in the Northeastern Pacific, Part 4*. Translated from the Russian by the National Technical Information Service, TT 67-51206, Springfield, Virginia.
- Ferreri, R., G. Basilone, M. D'Elia, A. Traina, F. Saborido-Rey, and S. Mazzola. 2009. Validation of macroscopic maturity stages according to microscopic histological examination for European Anchovy. *Marine Ecology* 30:181–187.
- Fournier, D. A., and C. P. Archibald. 1982. A general theory for analyzing catch-at-age data. *Canadian Journal of Fisheries and Aquatic Sciences* 39:1195–1207.
- Hunter, J. R., and B. J. Macewicz. 1985. Rates of atresia in the ovary of captive and wild Northern Anchovy, *Engraulis mordax*. U.S. National Marine Fisheries Service Fishery Bulletin 83:119–136.
- Hunter, J. R., B. J. Macewicz, N. C. H. Lo, and C. A. Kimbrell. 1992. Fecundity, spawning, and maturity of Dover Sole *Microstomus pacificus*, with an evaluation of assumptions and precision. U.S. National Marine Fisheries Service Fishery Bulletin 90:101–128.
- Kimura, D. K., and D. M. Anderl. 2005. Quality control of age data at the Alaska Fisheries Science Center. *Marine and Freshwater Research* 56:783–789.
- Lambert, Y. 2013. Long-term changes in life history characteristics and reproductive potential of northern Gulf of St. Lawrence Cod (*Gadus morhua*) and consequences for the stock productivity. *Fisheries Research* 138:5–13.
- Lauth, R. R., and J. Conner. 2014. Results of the 2011 eastern Bering Sea continental shelf bottom trawl survey of groundfish and invertebrate fauna. NOAA Technical Memorandum NMFS-AFSC-266.
- Lauth, R. R., and D. G. Nichol. 2013. Results of the 2012 eastern Bering Sea continental shelf bottom trawl survey of groundfish and invertebrate resources. NOAA Technical Memorandum NMFS-AFSC-256.
- Link, J. S. 2002. What does ecosystem-based fisheries management mean? *Fisheries* 27(4):18–21.
- Lowe, S., J. Ianelli, M. Wilkins, K. Aydin, R. Lauth, and I. Spies. 2008. Stock assessment of Bering Sea/Aleutian Islands Atka Mackerel. Pages 1119–1198 in Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage, Alaska.
- Matta, M. E., and D. K. Kimura. 2012. Age determination manual of the Alaska Fisheries Science Center Age and Growth Program. NOAA Professional Paper NMFS-13.
- Midway, S. R., J. W. White, W. Roumillat, C. Batsavage, and F. S. Scharf. 2013. Improving macroscopic maturity determination in a pre-spawning flatfish through predictive modeling and whole mount methods. *Fisheries Research* 4:359–369.
- Nichol, D. R. 1995. Spawning and maturation of female Yellowfin Sole in the eastern Bering Sea. Pages 35–50 in Proceedings of the international flatfish symposium. University of Alaska, Alaska Sea Grant Report 95-04, Anchorage.
- Nichol, D. R., and E. I. Acuna. 2001. Annual and batch fecundities of Yellowfin Sole, *Limanda aspera*, in the eastern Bering Sea. U.S. National Marine Fisheries Service Fishery Bulletin 99:108–122.
- NPFMC (North Pacific Fishery Management Council). 2014. Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. NPFMC, Anchorage, Alaska.
- Rochet, M.-J. 2000. May life history traits be used as indices of population viability? *Journal of Sea Research* 44:145–157.
- Spencer, P. D., and M. W. Dorn. 2013. Incorporation of weight-specific relative fecundity and maternal effects in larval survival into stock assessments. *Fisheries Research* 138:159–167.
- Stark, J. W. 2004. A comparison of the maturation and growth of female Flathead Sole in the central Gulf of Alaska and southeastern Bering Sea. *Journal of Fish Biology* 64:876–889.
- Stark, J. W. 2011. Contrasting the maturation, growth, spatial distribution and vulnerability to environmental warming of *Hippoglossoides robustus* (Bering Flounder) with *H. elassodon* (Flathead Sole) in the eastern Bering Sea. *Marine Biology Research* 78:778–785.
- Stearns, S. C. 1993. The evolution of life histories. Oxford University Press, Oxford, UK.
- Stockhausen, W. T., D. Nichol, and W. Palsson. 2012. Assessment of the Flathead Sole stock in the Bering Sea and Aleutian Islands. Pages 1099–1224 in Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 2013. North Pacific Fishery Management Council, Anchorage, Alaska.
- Vitale, F., H. Svedang, and M. Cardinale. 2006. Histological analysis invalidates macroscopically determined ovoids of the Kattegat Cod (*Gadus morhua*) and suggests new proxies for estimating maturity status of individual fish. *ICES Journal of Marine Science* 63:485–492.
- West, G. 1990. Methods of assessing ovarian development in fishes: a review. *Australian Journal of Marine and Freshwater Research* 41:199–222.
- Wilderbuer, T. K., D. G. Nichol, and J. Ianelli. 2013. Yellowfin Sole. Pages 619–708 in Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 2014. North Pacific Fishery Management Council, Anchorage, Alaska.
- Wilderbuer, T. K., D. G. Nichol, and P. D. Spencer. 2011. Assessment of the Alaska Plaice stock in the Bering Sea and Aleutian Islands. Pages 993–1046 in Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 2012. North Pacific Fishery Management Council, Anchorage, Alaska.
- Wilderbuer, T. K., D. G. Nichol, and P. D. Spencer. 2012. Alaska Plaice. Pages 1225–1227 in Stock assessment and fishery evaluation document for groundfish resources in the Bering Sea/Aleutian Islands region as projected for 2013. North Pacific Fishery Management Council, Anchorage, Alaska.
- Williams, K. 2007. Evaluation of the macroscopic staging method for determining maturity of female Walleye Pollock *Theragra chalcogramma* in Shelikof Strait, Alaska. *Alaska Fishery Research Bulletin* 12:252–263.
- Zhang, C. I., T. K. Wilderbuer, and G. E. Walters. 1998. Biological characteristics and fishery assessment of Alaska Plaice, *Pleuronectes quadrituberculatus*, in the eastern Bering Sea. *Marine Fisheries Review* 60:16–27.