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ARTICLE

Age Determination of the Yellow Irish Lord: Management Implications as a Result of New Estimates of Maximum Age

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Abstract
The yellow Irish lord *Hemilepidotus jordani* is an abundant, large sculpin found in the eastern Bering Sea and Aleutian Islands, where it is one of the most commonly caught sculpins. Interest in ecosystem-based fisheries management has increased, prompting the need to collect life history information from nontarget or incidental bycatch species. Sagittal otoliths were used to age 776 yellow Irish lords sampled during 2005 and 2006 in summer bottom trawl surveys conducted by the Alaska Fisheries Science Center in the eastern Bering Sea and Aleutian Islands regions. Annuli viewed on otolith surfaces and thin sections were enumerated to arrive at estimates of age. Specimens ranged from age 1 to a maximum of age 28, more than doubling the previously published estimate of longevity for this species. Age estimates from both regions were used to calculate separate sex-specific total mortality rates for yellow Irish lords based on catch-curve analysis. These new age estimates have resulted in potential changes in yellow Irish lord harvest recommendations, demonstrating the importance of age and growth information to fisheries managers.

Fisheries management has shifted toward knowledge of the entire ecosystem, including the assessment and monitoring of those species that are not commercially targeted. Life history information on nontargeted fish stocks incidentally caught in commercial fisheries is a key scientific component required for ecosystem-based fishery management (Botsford et al. 1997; Kaiser et al. 2004). Life history characteristics such as longevity, growth rate, and age at maturity represent critical components of stock assessments and determine a population's dynamics and harvestable surplus.

The North Pacific Fishery Management Council, responsible for U.S. federal fisheries management in Alaskan waters, has adopted a tier level system approach, based principally on the quantity and quality of available data, to manage commercial groundfish species or species complexes. One of these complexes, sculpins (Cottidae), is considered data poor and requires reliable estimates of stock biomass based on fishery-independent survey data and instantaneous natural mortality (M) rates under this system. Sculpins are an abundant group of fishes, and the largest species are commonly landed in fishery catches. In the eastern Bering Sea and Aleutian Islands, annual sculpin biomass estimates have exceeded 225,000 metric tons (Ormseth and TenBrink 2010), 90% of which is composed of five large species: the yellow Irish lord *Hemilepidotus jordani*, plain sculpin *Myoxocephalus jaok*, great sculpin *Myoxocephalus polyacanthocephalus*, warty sculpin *Myoxocephalus verrucosus*, and bigmouth sculpin *Hemitripterus bolini*.

Until recently, one of the difficulties in managing sculpins has been the lack of any region-specific life history information needed to estimate M. Although M is one of the most difficult model parameters to directly estimate and is often derived from other sources of data (Beverton and Holt 1957), its influence is not trivial because it exerts a large effect on fishing mortality rate (F) estimates used in setting management controls of acceptable biological catch (ABC) and threshold overfishing limits (OFLs). Before 2007, a proxy M-value of 0.19 was adopted for all sculpin stocks because it was assumed to represent a conservative value selected from among a range of values available

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(Reuter and TenBrink 2008). In this instance, M was derived using the indirect method based on reproductive potential (Rikhter and Efanov 1976) from a maturation value in a study from Russian waters (Tokranov 1988). New life history information has recently been collected on large sculpins, thus providing an opportunity for managers to calculate region-specific M-values for these abundant bycatch species.

Our study focuses on recent age estimates of yellow Irish lords. Along the eastern Bering Sea continental shelf, the yellow Irish lord is the fourth most abundant sculpin species, with biomass estimates approaching 30,000 metric tons (Ormseth and TenBrink 2010). Approximately 50% of the sculpin biomass in the Aleutian Islands is composed of yellow Irish lords (Ormseth and TenBrink 2010). Ecologically, the yellow Irish lord is both key predator and prey. Commercially important crab species (Tanner crab *Chionoecetes bairdi* and snow crab *C. opilio*) form a significant portion of the diet of maturing yellow Irish lords (T. Buckley, National Marine Fisheries Service, Alaska Fisheries Science Center [AFSC], personal communication). The yellow Irish lord is a primary diet component of the endangered western stock of Steller sea lions *Eumetopias jubatus* in the Aleutian Islands, occurring in greater than 15% of all analyzed scats during the winter (Sinclair and Zeppelin 2002). Before our study, the only known publication on the age determination of yellow Irish lords was conducted by Tokranov (1988), who estimated a maximum age of 13 years from samples collected in waters off Kamchatka, Russia. Consequently, the objectives of this study were to (1) report on the age determination criteria and longevity of the yellow Irish lord in eastern Bering Sea and Aleutian Islands, (2) re-estimate M based on new age estimates by using catch-curve analysis, and (3) review the management consequences of these new age estimates, specifically by addressing potential harvest changes within the yellow Irish lord stock.

METHODS

Sampling.—Sagittal otoliths used for age determination were collected during AFSC bottom trawl surveys in the eastern Bering Sea (June–July 2005 and 2006; Lauth and Acuna 2007) and along the Aleutian Islands (June–August 2006; Rooper 2008). All yellow Irish lords captured were sexed, weighed (g), and measured (fork length; cm). Fish were subsampled for otoliths by using a length-stratified sampling scheme of three specimens per sex per 1-cm length-bin. Otolith pairs were removed from each specimen and stored in vials containing a solution of 70% ethanol before aging.

Otolith preparation.—Otolith pairs were placed in a water-filled Petri dish against with a black background. The otoliths were placed distal side up and examined through a dissecting microscope illuminated by a fiber optic light source at 6.3 × magnification. Age was estimated by counting annuli on otoliths with clear growth zones. An annulus was defined as one opaque (light-colored) and one translucent (dark-colored) growth zone. If an age could not be generated from the surface, the thin-section method was used (Hutchinson 2004). This method consisted of embedding otoliths in Artificial Water polyester resin, thin sectioning the otolith to 300-μm-thick strips, and mounting them onto slides. The slides were viewed with a dissecting microscope at 32 × to 60 × magnification. Mineral oil was applied to the surfaces of the thin sections to enhance the growth zone patterns. The slides were illuminated with reflected light to view and enumerate opaque and translucent growth zones.

Establishing aging criteria and age estimation.—Initially, 15 otoliths were examined independently by two age readers (readers 1 and 2) to evaluate the difficulty of determining yellow Irish lord growth patterns. Both age readers in this study were experienced in aging commercial groundfish species in Alaska but had no prior experience with aging yellow Irish lords. The otoliths were then examined together by the age readers to establish aging criteria, such as locations of the first three annuli, what constituted an annulus, and whether to count marginal edge growth for both surface and thin-sectioned otoliths. Annuli were identified by the strength, completeness, and regularity of the translucent growth zones along various counting axes of the otolith. Yellow Irish lords did not present any unusual or difficult growth patterns, except in their early years, which were often not well defined. Despite this problem, some otolith surfaces and thin sections displayed clear early growth zones. Measurements were taken to the nearest 0.1 mm from 18 otoliths to determine average transverse widths of the first, second, and third translucent growth zones, which were used as a guide to determine age from specimens with vague early annuli. Whether edge growth was counted in estimating age depended upon the amount of fast growth (opaque zone). Growth that was deemed less than a full year's growth was not counted.

After the aging criteria were established, 129 otoliths were aged independently by both readers. Subsequent samples were aged entirely by reader 1 (primary reader), and reader 2 (tester) aged a random subsample of 20% of the total number of specimens. Discrepancies in age estimates between readers were resolved to an agreed age.

Natural mortality.—To estimate M for yellow Irish lords, we used catch-curve analysis to describe sex-specific and region-specific total mortality (Z). Age–length keys were used to assign ages to all sampled fish based on the known ages of the subsampled fish. The catch curves assume a constant recruitment and gear selectivity of all age groups in the calculations. Following Ricker (1975), the slope of a linear line fitted to the descending limb of the age composition ($\log_e$ [number of fish at age]) of an unexploited or lightly exploited stock can be used to estimate Z. Separate catch curves were calculated by using age estimates from samples collected during the 2006 Aleutian Islands trawl survey ($n = 398$) and from samples collected during the 2005 ($n = 220$) and 2006 ($n = 166$) eastern Bering Sea surveys. Catch-curve analysis for each data set was truncated at the first age-class with less than five observations (Murphy 1997).

Management benchmark measures.—We evaluated the effects of applying sex-specific estimates of M to generate yellow

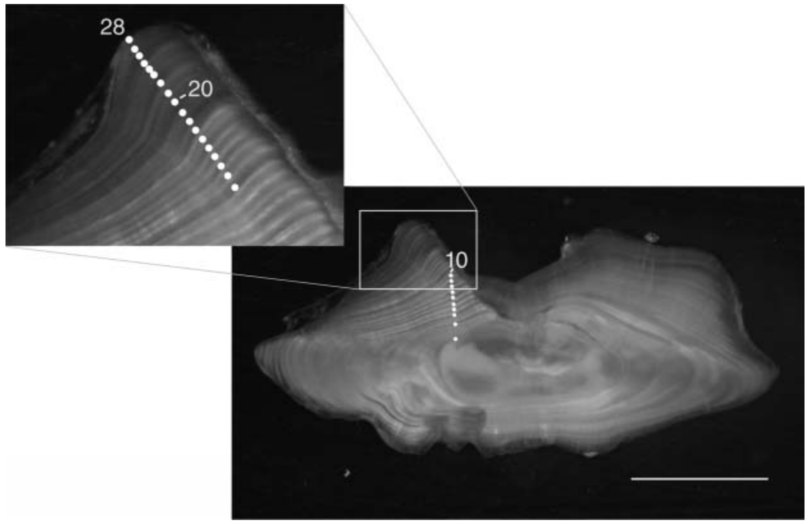

FIGURE 1. Otolith of a female yellow Irish lord from the Bering Sea; age was estimated at 28 years, the greatest age observed in the present study. Annuli are represented by white dots; every 10th annual mark and the last year are numbered. Otolith was viewed with reflected light (scale bar = 1 mm).

Irish lord harvest recommendations. Values of M from our study were compared with the previously used status quo estimate of M (0.19) from sculpin stock assessments conducted before 2007. These values were used to estimate F via the current tier-5 control rules: (1) F at the OFL (F_{OFL}) was equal to M; and (2) F at the ABC (F_{ABC}, where $F_{ABC} = 75\%$ of F_{OFL}) was less than or equal to $0.75M$.

Harvest reference points were defined by these control rules, where the ABC was equal to $F_{ABC} \times$ biomass and the OFL was equal to $F_{OFL} \times$ biomass. Yellow Irish lord biomass was a 3-year (2007–2009) average of estimates from Bering Sea and Aleutian Islands bottom trawl surveys. Because sculpins were not assessed with a stock assessment model, multiyear projections were not possible.

RESULTS

Age Determination

Upon examination of the initial 15 prepared otoliths, we determined that yellow Irish lords had similar growth patterns to other groundfish aged by both of the experienced age readers. Opaque and translucent growth zones generally appeared clearer in otolith thin sections than on surfaces. In total, 41 otoliths were aged solely from the surface, while the remaining 730 otoliths were aged using the thin-section method. Annuli on the surface generally became difficult to interpret beyond year 4.

The first and second annuli were sometimes difficult to interpret and marginal growth zones were sometimes compressed in older specimens. Averaged measurements of clear translucent growth zones from 18 specimens were as follows: (1) the first translucent growth zone averaged 1.39 mm (SD = 0.16; range = 1.15–1.76 mm), (2) the second translucent growth zone averaged 2.00 mm (SD = 0.22; range = 1.59–2.36 mm), and (3) the third translucent growth zone averaged 2.41 mm (SD = 0.32; range = 1.83–3.06 mm). On older aged specimens for which the opaque growth zone at the edge appeared to be equivalent to the previous year's opaque growth zone, in the majority of cases we added one annulus to the number of annuli counted (Hyndes et al. 1992). Some specimens were starting to form a translucent zone along the otolith margin, suggesting that yellow Irish lords may lay down their annual marks in approximately June or July.

Estimated ages of 20 years or greater were observed in both regions. The oldest yellow Irish lords in both regions were females, and the greatest age estimate was 28 years for a specimen from the Bering Sea (Figure 1). In the Bering Sea region, 15 females were age 20 or older; in the Aleutian Islands region, 18 females were age 20 or older. Only a single male from each region attained an estimated age of 20 or greater: the Bering Sea male was age 24, and the Aleutian Islands male was age 20.

Precision

Of the 776 otoliths that were aged for this study, 285 otoliths (37%) were assigned an age by both readers and were used to generate precision values, including percent agreement, coefficient of variation (CV; Chang 1982), average percent error (Beamish and Fournier 1981), and age bias plots. The overall percent agreement between age readers was 34.7% (i.e., no difference in age); the CV was 10.31%, and the average percent error was 7.29%. Between the two readers, overall agreement within 1 year was 75.4% and within 2 years was 87.7%. The highest CV and average percent error values between age readers generally occurred for ages 2–10, which may reflect how early growth zones were interpreted. Plots measuring aging bias between readers were generated from the initial set of readings for all samples tested (Figure 2). For ages greater than 7 years, there was a tendency for reader 2 to assign younger ages than reader 1.

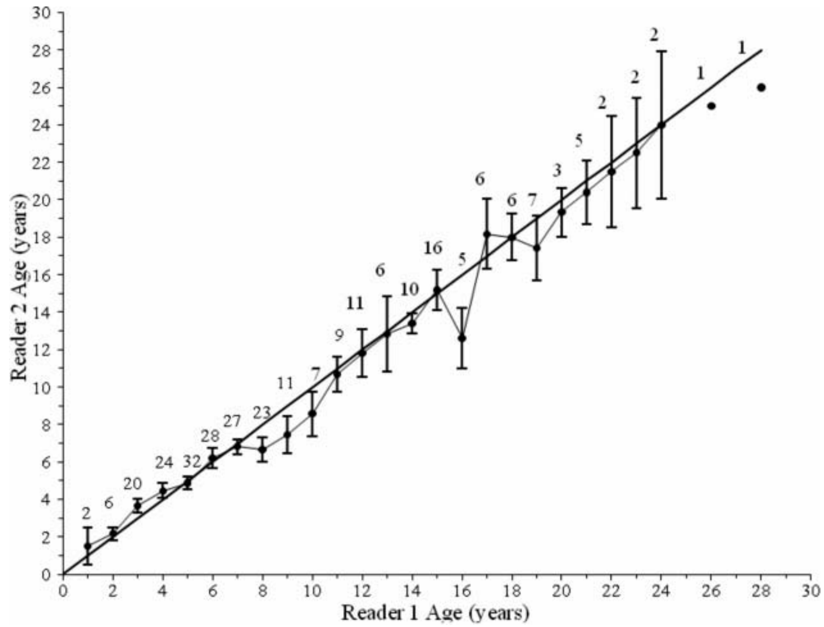

FIGURE 2. Yellow Irish lord age bias plot, depicting otolith ages estimated by reader 1 (primary reader) versus those estimated by reader 2 (tester), for combined collections in the eastern Bering Sea and Aleutian Islands. Each error bar represents the 95% confidence interval of the mean age assigned by reader 2 to all specimens assigned a given age by reader 1. The 1:1 line represents perfect agreement between estimates. Sample sizes are listed above each error bar.

Natural Mortality and Implications for Harvest Specifications

The estimated catch at age derived from constructed age–length keys for both regions produced an M range of 0.14–0.22 (Figure 3). The new sex-specific estimates of M were comparable to or lower than the previously used status quo M of 0.19 (Reuter and TenBrink 2008), which is believed to be a conservative estimate. Given the higher maximum age of females in each data set (with the exception of the 2006 Bering Sea samples), M-values were consistently lower for females than for males. The female population from the 2006 Aleutian Island data set, as calculated through catch-curve analysis, had a low M of 0.14, whereas males from the 2005 Bering Sea population had an M-value of 0.19.

The new estimates of M based on the new age estimates altered the harvest specifications for yellow Irish lords (Table 1).

TABLE 1. Yield projections by method, area, and year for Bering Sea (BS) and Aleutian Islands (AI) yellow Irish lords under two management scenarios: (1) fishing mortality (F) at the overfishing limit (OFL; F_{OFL}) was equal to natural mortality (M); and (2) F at the acceptable biological catch (ABC; F_{ABC}, where $F_{\mathrm{ABC}} = 75\%$ of F_{OFL}) was less than or equal to $0.75M$. Biomass (26,403 metric tons) and fishery catch (916 metric tons) estimates are 3-year averages (2007–2009) from Ormseth and TenBrink (2010).

Method	Scenario	Region	Year	Sex	M	Yield (metric tons)
Status quo	1				0.19	5,017
	2				0.19	3,763
Catch curve at age 20	1	AI	2006	Male	0.22	5,809
	2					4,356
Catch curve at age 26	1	AI	2006	Female	0.14	3,696
	2					2,722
Catch curve at age 19	1	BS	2005	Male	0.19	5,017
	2					3,763
Catch curve at age 28	1	BS	2005	Female	0.16	4,224
	2					3,168
Catch curve at age 24	1	BS	2006	Male	0.20	5,280
	2					3,960
Catch curve at age 24	1	BS	2006	Female	0.16	4,224
	2					3,168

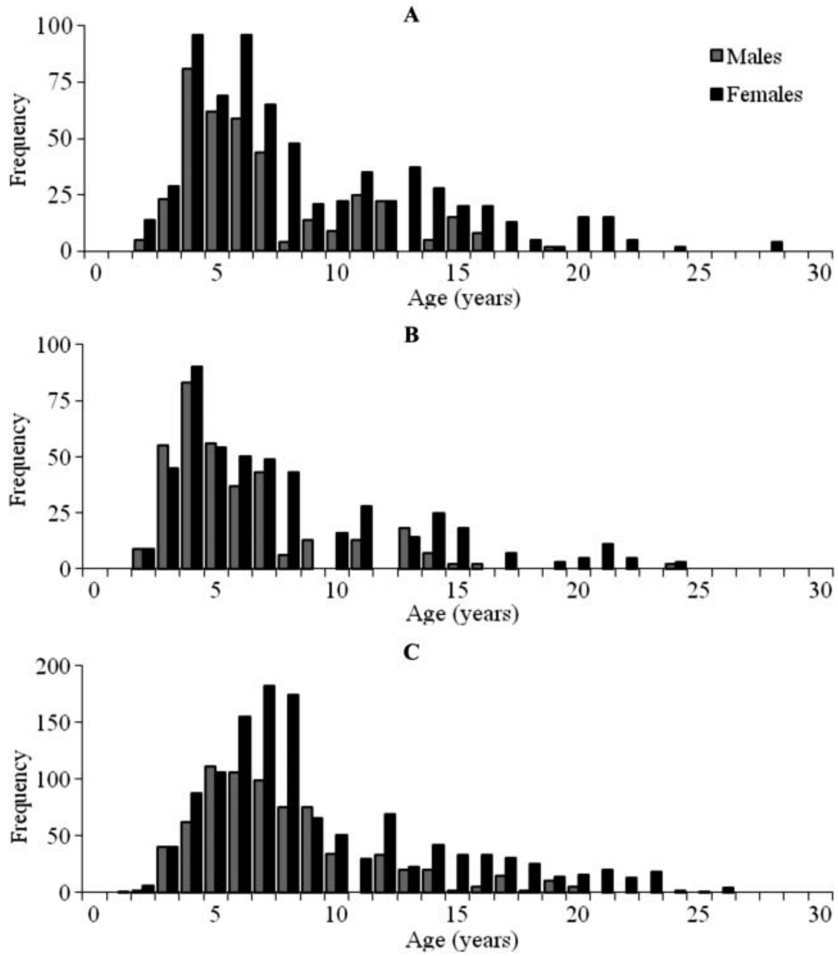

FIGURE 3. Estimated catch at age for male and female yellow Irish lords in **(A)** the eastern Bering Sea during 2005, **(B)** the eastern Bering Sea during 2006, and **(C)** the Aleutian Islands during 2006 (note that the *y*-axis scale differs for panel C).

For example, changing M from the status quo value of 0.19 to the new value of 0.14 resulted in a 26% reduction in OFL and ABC for females from the 2006 Aleutian Islands data set. Reductions in the OFLs and ABCs were also observed for females from the other data sets.

DISCUSSION

The maximum age reported in this study was more than twice that previously reported for yellow Irish lords. Thin sectioning was the method of choice for yellow Irish lord otoliths because individual growth marks appeared clearer than in whole otoliths. The previous maximum age estimate of 13 years was based on break-and-burn methodology (Tokranov 1988). Our new age estimates, however, will have to be validated in the future. Agreement between age readers was 34.7%, but this statistic is cited as a poor measure of precision (Campana 2001); in many cases, the CV and average percent error are better tools for gauging precision. The reported CV values in our study are comparable with precision values for routinely aged species, such as the rougheye rockfish *Sebastes aleutianus*, sablefish *Anoplopoma fimbria*, and Dover sole *Microstomus pacificus* (Kimura and Anderl 2005); thus, we consider the precision in the current study to be acceptable.

Whether our estimate of observed maximum age is close to the true maximum life span of the yellow Irish lord is unknown. The yellow Irish lord is an incidentally caught species, and its fisheries mortality is limited. Based on data from 2008, the first year in which sculpin catches were reported to the species level, the estimated fishery catch rate is 1–3% of the total biomass (Reuter and TenBrink 2008). Due to the narrow temporal sampling in our study, however, it would be reasonable to assume that individuals may approach 30 years of age or greater. The yellow Irish lord is a new species for our aging unit, and as more aging is performed we will gather more knowledge on the longevity of this species. Our estimated ages indicate that females live longer than males. The estimates of maximum age for the yellow Irish lords in our study currently indicate that this species is the longest-lived sculpin in Alaskan waters (Ormseth and TenBrink 2010), and to our knowledge these are the highest published estimates of maximum age for any cottid sculpin.

The yellow Irish lord is one of the more common sculpins within the Bering Sea and Aleutian Islands; therefore, based on these new age estimates, we examined some possible fishing effects on the population. Species-specific life history information can be used to determine more meaningful harvest limits—a goal of the Magnuson–Stevens Fishery Conservation and Management Act. Our study demonstrates the potential change in harvest limits when new information is used. Furthermore, the use of proxy values should be viewed with a high degree of skepticism, especially when applied indiscriminately across taxa. For exploited stocks, population dynamics models are highly sensitive to changes in M, but with regard to data-poor stocks, for which OFLs and ABCs are derived as a simple fraction of M, changes to M can be just as influential. Although there are no plans to formally assess and manage sculpin stocks at the species level for Alaskan waters in the near future, new biological information, such as updated age and growth estimates, allows for a review of the fishing effects on species for which sufficient information is available. Species-level identification of the larger sculpins in fishery catches makes this evaluation easier than in years past; before 2008, catch was at best only reported to the genus level for the larger sculpins.

Life history studies on Alaska groundfish have had some impact on setting new biological reference points for management. Lunsford's (1999) study on maturity of Pacific ocean perch *Sebastes alutus* resulted in a shift in the $F_{40\%}$ harvest management strategy (i.e., the target annual F that maintains the female spawning biomass at 40% of the unfished equilibrium biomass) for this species in the Gulf of Alaska, as the estimated 50% maturity value increased from 7.5 to 10.0 years. Recent work by Stark (2007, 2008) on the maturation of Pacific cod *Gadus macrocephalus* and arrowtooth flounder *Atheresthes stomias* resulted in changes in spawning biomass estimates that subsequently led to revisions in stock assessments.

Management of data-poor species can be difficult, but supplemental measures involving the use of known biological information can be employed to determine stock status. These semiqualitative data help managers evaluate risk or vulnerability (e.g., Musick 1999; Patrick et al. 2010). Ormseth and Spencer (in press) applied a vulnerability analysis to Alaska groundfish stocks, including nontarget or data-poor species. Their analysis involved comparing a stock's productivity to its susceptibility to fisheries. Productivity is determined largely by a consideration of numerous life history variables, including maximum age. A data quality score is assigned to describe the strength of information used to determine vulnerability. Therefore, the overall power of the analysis is strengthened by life history values determined for stocks in the Bering Sea and Aleutian Islands.

Knowledge of life history variables such as age and growth of fishes also aids in the understanding of fish responses to ecosystem change. The maximum age generated from this study, the known life history information about the yellow Irish lord, and general life history pattern of this species suggest that the yellow Irish lord follows an intermediate strategy (Winemiller 1989; King and McFarlane 2003), having characteristics that are generally mid-range between "r-selected" and "K-selected" attributes. Based on historical AFSC trawl survey data, estimates of yellow Irish lord biomass in the eastern Bering Sea have been relatively stable since 2004, although over the last 25 years the population has had dramatic fluctuations. Our results on yellow Irish lord longevity suggest that their recruitment may be able to respond more favorably under highly variable environmental conditions than shorter-lived species, such as the Pacific herring *Clupea pallasii* (as noted by King and McFarlane 2003). Pacific herring populations tend to fluctuate according to climate regimes but may not exhibit the long-term stability seen in fishes with so-called steady-state populations (Spencer and Collie 1997).

Our findings indicate that yellow Irish lords can attain a maximum age well beyond the previously estimated maximum age for this species. Although the age readers in this study had not previously aged this species and the new aging criteria should be corroborated with age validation techniques, we believe that thin sectioning is the most suitable method now available for aging yellow Irish lords. Furthermore, our age determinations also showed reasonable repeatability based on results from age precision statistics. Although there is some uncertainty in estimating M (e.g., Vetter 1988), obtaining region-specific aging information provides more reliable estimates of M than adopting a general status quo assumption. The age-based catch-curve analysis, which uses a direct solution to estimate M, is a more favorable method than indirect analyses and should be used, whenever possible, for evaluating sculpin stocks in Alaskan waters when aged samples are available (Ormseth and TenBrink 2010). This study represents an improvement in the stock assessment and management of a data-poor species. Our work demonstrates the need for further research on understudied species and shows that some sculpins could possibly be long-lived species, which may affect harvest specifications.

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