Age validation and analysis of ageing error from marked and recaptured sablefish, *Anoplopoma fimbria*

Jonathan Heifetz
Auke Bay Laboratory, Alaska Fisheries Science Center
National Marine Fisheries Service, NOAA
11305 Glacier Highway, Juneau, Alaska 99801-8626
E-mail address: jon.heifetz@noaa.gov

Delsa Anderl
Resource Ecology and Fisheries Management, Alaska Fisheries Science Center
National Marine Fisheries Service, NOAA,
7600 Sand Point Way NE, Seattle, Washington 98115-0070

Nancy E. Maloney
Thomas L. Rutecki
Auke Bay Laboratory, Alaska Fisheries Science Center
National Marine Fisheries Service, NOAA
11305 Glacier Highway, Juneau, Alaska 99801-8626

Abstract.–Sablefish, *Anoplopoma fimbria*, are especially difficult to age. Ages are typically determined by counting growth zones that are assumed to be annuli on the burnt cross section of an otolith. We evaluated the accuracy of ageing methods by comparing the ages obtained from two experienced age readers with those ages that were known. A mark-recapture experiment on sablefish provided a relatively large sample (n=49) of 2–9 year old sablefish. This sample of known-age fish provided a unique opportunity to evaluate the accuracy of ageing methods for young sablefish. Our study generally confirmed the criteria used to age young sablefish. According to the assignment of ages from two experienced age readers, about two-thirds of the fish were misaged. Of these, most fish (81% and 71% for the two readers) were misaged by only one year. After reexamination of the otoliths, most of the discrepancies between reader age and known age could be resolved. Ageing-error matrices that define the probability of assigning an age to a fish of a given true age were estimated from among-reader variability and from comparison of known ages to reader ages. Estimates of ageing errors, based on comparison of known ages to reader ages, were considerably higher than estimates obtained from among-reader variability. We recommend that ageing-error corrections applied in stock assessment models be based on the ageing-error matrix derived from known and reader ages.

Manuscript accepted 5 May 1998.
Fish. Bull. 97:256–263 (1998).

Errors in fish ageing may result in biases in stock assessments and possible mismanagement of fisheries. Estimates of natural mortality, age composition, growth parameters, and maturity schedules of a fish population all depend on accurate ageing for their reliability. Thus, valid ageing is a key to understanding the biology and dynamics of fish populations.

Ageing error in stock assessment models can lead to errors in modeling results (Kimura, 1990). Ageing errors tend to smooth differences in year-class strengths and may confound attempts to estimate stock recruitment relationships and to relate year-class strength to environmental factors (Fournier and Archibald, 1982; Richards et al., 1992). Estimation of ageing errors enables such errors to be accounted for by allowing observed ages to be converted back to correct ages (Richards et al., 1992). If misspecified or unaccounted for, ageing error can lead to erroneous yield projections and overfishing (Lai and Gunderson, 1987; Tyler et al., 1989).

Sablefish, aged as old as 63 years in Alaska (Sigler et al., 1997), is an especially difficult species to age (Kimura and Lyons, 1991). Beamish and Chilton (1982) first suggested that sablefish was a much longer-lived species than previously thought and proposed an ageing method using broken and burnt otoliths that would result in more accurate ages. Preliminary data from their tagging studies, otoliths marked with oxytetracycline (OTC), and a small sample (n=6) of known-age fish appeared to validate this new method. Results from subsequent studies with recaptured OTC-marked fish (Beamish et al., 1983; McFarlane and Beamish, 1995), a small sample of pen-reared fish (Lai, 1985), and radiometric ageing (Kastelle et al., 1994) have further substantiated the reliability of this method. This break-and-burn method is now widely accepted by sablefish age readers. Sablefish is still a very difficult species to age, and age determination is highly subject to an age reader's interpretation.

For this paper, sablefish tagged and released as young juveniles (Rutecki and Varosi, 1997a) provided a relatively large sample (n=49) of known-age fish, 2–9 years old when recaptured. This sample provided a unique opportunity to evaluate the accuracy of production ageing methods for young sablefish. "Production ageing" is the routine ageing of large samples of fish, usually to obtain age and growth information or age composition. We conducted a statistical analysis of ageing errors and compared ageing errors based on among-reader agreement with ageing errors based on reader and known-age agreement.

Materials and methods

Known-age fish

From 1985 to 1991 about 23,000 age 0–2 sablefish were tagged with individually numbered Floy anchor tags (Rutecki and Varosi, 1997a, 1997b). By 31 December 1993, 1160 of these fish had been recaptured, mostly from commercial fishing operations; otoliths were taken from 49. In Rutecki and Varosi's studies, cohorts of young (aged 0–2) sablefish were periodically sampled in interior bays of southeastern Alaska from spring through early fall. Depending on the time of year, usually only one or two age classes were present at the sampling locations, and these age classes could be distinguished easily from one another on the basis of nonoverlapping length frequencies (see Figs. 5 and 7 in Rutecki and Varosi [1997b]). Rutecki and Varosi (1997b) confirmed assignment of ages by ageing otoliths from a subsample of the fish measured for length. Of the 49 known-age sablefish, one was tagged at age 0, 41 at age 1, and seven at age 2. Known age of a fish was calculated by subtracting the year of release from the year of recapture and then adding the age at release. For example, the known age of a fish tagged in 1986 at age 1 and recaptured in 1992 would be 7 years.

Ageing methods

Extracted otoliths were stored in a 50% ethyl alcohol solution. A sample of otoliths from 140 fish, including the 49 known-age fish, were aged by two experienced readers in the Age and Growth Laboratory at the Alaska Fisheries Science Center (AFSC) in Seattle, Washington. Using normal production ageing procedures, the readers were told the fork length of each fish and the month and day of sampling. The year of sampling was withheld. Age readers were aware that known-age otoliths were in the sample but did not know what percentage of the sample were known-age specimens nor the age range of the known-age fish.

The primary age reader (hereafter referred to as "primary reader") prepared all the otoliths and was first to examine the sample. The ageing methods generally followed Beamish and Chilton (1982). The ageing routine began with placing each otolith in a water-filled petri dish with a black background and examining it through a light microscope with fiber-optic light. This gave the primary reader a general idea of an age range to expect before the otolith was broken and burned. Next, the otolith was broken dorsoventrally along the focus, and the broken surface was passed over a flame. The burnt half was then mounted into clay for support, and the burnt surface was coated with cedar oil for clarification. The burnt surface consisting of light and dark zones was then examined by using a light microscope and fiber-optic light. The light areas are known as opaque zones and the dark areas as translucent zones. Notes kept by the reader included the reasons for ageing decisions when uncertainties occurred. Typically in production ageing, an age reader may opt not to assign an age to an otolith if the otolith pattern or condition is considered so poor that the reader's confidence at reproducing roughly the same age again is questionable; this policy was followed in our study.

In production ageing at the AFSC, after the primary reader completes the age determinations, another reader (hereafter referred to as the "tester") typically rereads a 20% random sample of the otoliths without knowledge of the primary reader's ages. This is done mainly to control quality (Kimura and Lyons, 1991). Because the known-age specimens were not known to the readers, the randomly chosen 20% sample included only 10 of the known-age otoliths. To compare agreement on all known-age otoliths, a second subsample was drawn, which included all the remaining known-age otoliths interspersed with some unknown-age otoliths. The tester did not know the percent composition of known- to unknown-age otoliths in either subsample.

In addition to the ageing methods of Beamish and Chilton (1982), in production ageing at the AFSC, readers use the marginal increment component for ageing, i.e. they decide whether the most recent year's annulus was formed along the margin of an otolith. Many experienced sablefish age readers have concluded that the annulus usually forms in spring, but some annuli may form in summer. However, an age reader must decide whether an annulus was deposited before the date of otolith collection by considering the date of the otolith collection and the amount of otolith growth between the last annulus and the otolith margin. If the otolith was collected in the spring or summer and there is a relatively large area of growth along the otolith margin, an age reader would probably decide that the annulus had not yet been deposited and would therefore add 1 to the number of annuli observed on the otolith. However, if a relatively small area of growth is seen, then the reader would probably assume that the annulus had been deposited and assign an age equal to the number of annuli observed. By fall and winter, the current year's annulus is expected to have been deposited, and the fish age would, therefore, equal the number of annuli observed on the otolith.

Analysis of ageing errors

Present stock assessment of sablefish and many other groundfish species in Alaska is based on an age-structured model that attempts to estimate the true age composition of the population (Sigler et al.[1]). Ageing errors in catch-age models can be accounted for by supplying an ageing-error matrix (Fournier and Archibald, 1982; Methot, 1990; Richards et al., 1992). This matrix defines the probability of assigning a particular age to a fish with a given true age. The results of multiple age determinations from independent age readings can be used to estimate the ageing-error matrix (Richards et al., 1992). In practice, a normal distribution of observed age for each true age is assumed and because ageing error tends to increase with age, an increase in the standard deviation with increasing age is used (Lai and Gunderson, 1987; Methot, 1990). Use of multiple readings to assess ageing errors cannot detect a systematic difference (i.e. bias) between observed and true ages (Richards et al., 1992).

We constructed two ageing-error matrices to illustrate the possible difference in perceived ageing error based on agreement between primary reader and tester and between reader and known age. The first matrix was based on primary-reader and tester ages and the second was based on reader (both primary reader and tester) and known ages.

Richards et al. (1992) presented a statistical model for estimating ageing error. We used the "normal model" of Richards et al. (1992). For a given true age b, the standard deviation $\sigma(b)$ of the observed age is defined by three parameters σ_1, σ_A, and α such that

$$\sigma(b) = \begin{cases} \sigma_1 + (\sigma_A - \sigma_1)\,\dfrac{1 - e^{-\alpha(b-1)}}{1 - e^{-\alpha(A-1)}}; & \alpha \neq 0 \\[2ex] \sigma_1 + (\sigma_A - \sigma_1)\,\dfrac{b-1}{A-1}; & \alpha = 0 \end{cases} . \quad (1)$$

The σ_1 and σ_A are standard deviations for the minimum and maximum ages, respectively. The parameter α determines the nonlinearity of the function, where $\sigma(b)$ becomes linear in b as α tends to 0. Given the parameter vector $\mathbf{\Phi} = (\sigma_1, \sigma_A, \alpha)$ and observed age classes a, the age-error matrix $q(a \mid b, \mathbf{\Phi})$ is defined by

$$q(a \mid b, \mathbf{\Phi}) = \frac{x_{ab}(\mathbf{\Phi})}{\sum_{a=1}^{A} x_{ab}(\mathbf{\Phi})}, \quad (2)$$

where $x_{ab}(\mathbf{\Phi})$ is the discrete normal density function such that

$$x_{ab}(\mathbf{\Phi}) = \frac{e^{-\frac{1}{2}\left[\frac{a-b}{\sigma(b)}\right]^2}}{\sqrt{2\pi\sigma(b)}} . \quad (3)$$

In Richards et al. (1992), the assumed "true age" for a fish aged by multiple readers is the modal age among multiple readers. We used the mean age rounded to the nearest integer because the mode is not defined for two readings when the ages differ. For the reader and known-age data, the true age is the known age. A value for the maximum age A is required. For the reader and known-age data set, we set A equal to the maximum known age. For the primary reader and tester data set, we set A equal to the maximum assigned age.

The model of Richards et al. (1992) does not include estimation of bias. The use of known ages allows bias to be estimated and incorporated in the ageing-error matrix. By including three additional parameters, Ericksen (1997) generalized the methods of Richards et al. (1992) to include estimation of bias for tag recapture and known-age data. As with Equation 1, for a given true age b, the bias $\beta(b)$ of the observed age is defined by three parameters, β_1, β_A, and λ, such that $\mathbf{\Phi} = (\sigma_1, \sigma_A, \alpha, \beta_1, \beta_A, \lambda)$ and

$$\beta(b) = \begin{cases} \beta_1 + (\beta_A - \beta_1)\dfrac{1 - e^{-\lambda(b-1)}}{1 - e^{-\lambda(A-1)}}; & \lambda \neq 0 \\[2ex] \beta_1 + (\beta_A - \beta_1)\dfrac{b-1}{A-1}; & \lambda = 0 \end{cases} . \quad (4)$$

Equation 3 is modified to obtain

[1] Sigler, M. F., J. T. Fujioka, and S. A. Lowe. 1997. Sablefish. *In* Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fish. Manage. Council, 605 W 4th Ave., Suite 306, Anchorage, AK 99501.

$$x_{ab}(\mathbf{\Phi}) = \frac{e^{-\frac{1}{2}\left[\frac{a-(b+\beta(b))}{\sigma(b)}\right]^2}}{\sqrt{2\pi\sigma(b)}}. \qquad (5)$$

To estimate the classification matrix defined by Equation 2, maximum likelihood was used to estimate the parameters of the model. The likelihood (L) of the observed ages **A** given the true ages **B** is

$$L(\mathbf{A}|\mathbf{B}) = \prod_{i=1}^{I}\prod_{j=1}^{J} q(a_{ij}|b_i, \mathbf{\Phi}), \qquad (6)$$

where a_{ij} = the age assigned to fish i by reader j; and
b_i = the true age of fish i.

In practice, the inference function –2 log $L(\mathbf{A} | \mathbf{B})$ is minimized to obtain parameter estimates. Given the number of parameters N, the Akaike information criteria (AIC) (Akaike, 1974; Richards et al., 1992),

$$AIC = -2\log L(\mathbf{A}|\mathbf{B}) + 2N, \qquad (7)$$

was used in the model identification process. A model with a low AIC value in relation to other models is considered the best-fit model with the fewest parameters.

Six alternative representations (cases) of ageing error were considered in the analysis. The different cases represented the two different data sets, full models, and models reduced by parameter constraints (Table 1). Although not within the scope of our study, we recognize other alternative model specifications may be appropriate for these data sets. For example, a classification matrix with skewed distributions of the probability of assigning an age to a fish of a given true age may be appropriate.

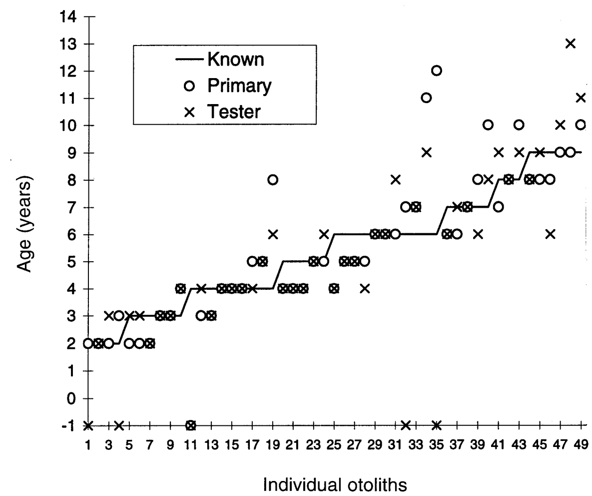

Figure 1

Comparison of known age with ages obtained by two age readers for 49 sablefish. A value of –1 for a age denotes the reader chose not to age the given sample. The x-axis has been sorted by known age from youngest to oldest.

Table 1

Alternative cases for analysis of ageing error based on primary reader and tester data (data set 1) and reader and known-age data (data set 2).

Case	Data set	Parameters	Constraints
1	1	σ_1, σ_A, α	—
2	1	σ_1, σ_A	$\alpha = 0$
3	2	σ_1, σ_A, α, β_1, β_A, λ	—
4	2	σ_1, σ_A, α, β_1, β_A	$\lambda = 0$
5	2	σ_1, σ_A, β_1, β_A, λ	$\alpha = 0$
6	2	σ_1, σ_A, β_1, β_A	$\lambda = 0$; $\alpha = 0$

Results and discussion

Comparison of reader ages to known ages

The primary reader ages agreed with the known ages in 35.4% of the cases (Fig. 1). Of the 49 known-age sablefish otoliths, the primary reader chose not to age one specimen because of the poor condition of its otoliths. Of the 31 misaged fish, the primary reader misaged most (80.6%) by 1 year: 17 of the 18 underaged fish and 8 of the 13 overaged fish. In three cases (known ages=4, 6, and 6 years), the primary-reader ages differed substantially at 8, 11, and 12 years.

Results for the tester were generally similar to those of the primary reader. The tester age agreed with the known age in 38.6% of the 44 total otoliths that the tester aged (Fig. 1), and 5 otoliths were considered unreadable. Of the testers's misaged fish, most (70.1%) were misaged by 1 year: 10 of the 13 underaged fish and 9 of the 14 overaged fish. The largest discrepancy was 4 years: known age was 9 years and tester age was 13 years.

Agreement between primary reader and tester ages was much greater than between the known and primary-reader ages or the known and tester ages (Fig. 1). Primary reader and tester matched ages in 24 of the 44 (54.5%) specimens compared, indicating that they interpreted annuli similarly. Most discrepancies (n=12; 60.0%) were discrepancies of one year. The primary reader tended to age the fish younger than the tester: 12 less than tester ages and 8 greater. Only once did their ages differ by more than two years (known age=9; primary reader=9; tester=13).

Table 2

Comparison of parameter estimates for alternative models of ageing error for sablefish based on primary reader and tester data (data set 1) and reader and known-age data (data set 2). Number of observations (n), maximum age (A), number of parameters (N), minimum values of the inference function (l), and Akaike information criterion (AIC) are also given.

Case	Data set	n	A	N	σ_1	σ_A	α	β_1	β_A	λ	l	AIC
1	1	88	13	3	0.399	2.464	−0.358	—	—	—	139.3	145.3
2	1	88	13	2	0.270	1.094	set to 0	—	—	—	143.1	147.1
3	2	92	9	6	0.253	1.792	0.341	−0.284	0.289	0.116	308.8	320.8
4	2	92	9	5	0.213	1.796	0.346	−0.191	0.307	set to 0	308.9	318.9
5	2	92	9	5	0.911	1.948	set to 0	−1.731	0.276	0.604	310.0	320.0
6	2	92	9	4	0.699	2.089	set to 0	−0.340	0.433	set to 0	310.4	318.4

This study generally confirmed the criteria used for ageing young sablefish. Even though a high proportion of fish were misaged, most fish were misaged by only one year. In addition, after reexamining the otoliths after the known ages had been revealed, the primary reader could reconcile the differences between the known and assigned ages in most cases (25 of 31). Anderl and Heifetz[2] have described three types of misinterpretation of otolith patterns that resulted in most misages: 1) misinterpretation of an ambiguous check (i.e. false annulus) immediately following the first annulus; 2) misinterpretation in assessing whether the most recent year's annulus had been formed; and 3) misinterpretation of multiple checks on parts of the otolith (a check is a mark, growth zone, or part of a growth zone on an otolith that does not form annually but reflects various environmental or physiological changes [Chilton and Beamish, 1982]).

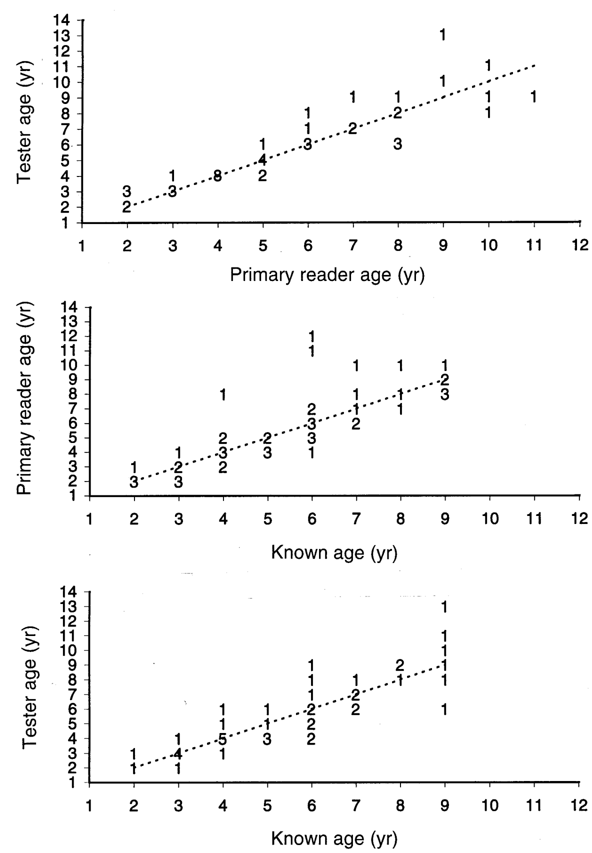

Figure 2

Observed relation for sablefish between primary reader age and tester age, known age and primary reader age, and known age and tester age. Points are represented by the frequency distribution of observations. A dotted line of slope 1 is included for reference in each panel.

Analysis of ageing errors

Table 2 summarizes the parameter estimates for various model specifications from the data in Figure 2. The estimates based on between-reader variability include only data where both primary reader and tester readings were available. The data consisted of I = 44 fish and J = 2 readings per fish resulting in n = 88 observations. The estimates based on reader and known ages were derived from data where at least one reader determined an age. The data consisted of I = 44 fish with J = 2 readings per fish and I = 4 fish with J = 1 reading per fish resulting in n = 92 observations.

For the estimates that included only between-reader variability, a model with all three parameters estimated (case 1) provided the best fit with the fewest parameters (i.e. lowest AIC values). The AIC value for a model with α constrained to 0 (case 2) was nearly

[2] Anderl, D., and J. Heifetz. 1999. An evaluation of ageing criteria for sablefish based on known age specimens. In prep.

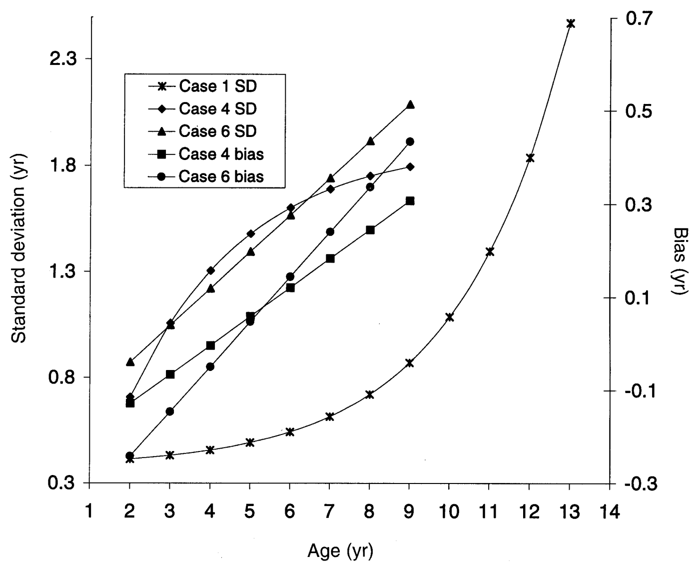

Figure 3

Estimated standard deviation (SD) and bias of observed age of sablefish for each true age based on primary-reader and tester ages (case 1) and reader and known ages (case 4 and case 6). Case refers to model specifications listed in Table 1.

2 units above the AIC value for case 1. For the reader and known-age data set, a model with α and λ constrained to 0 (case 6) provided the best fit with the fewest parameters. The AIC value for a model with only λ constrained to 0 (case 4) was only 0.5 units above the minimum. The closeness of the AIC values for these two cases indicates that case 6 provides only a slightly better model fit than case 4. The difference between case 4 and case 6 is best understood by comparing estimated standard deviation and bias at age (Fig. 3). Case 4 results in a nonlinear relationship between standard deviation and age, and the standard deviation approaches an asymptote near age 9; whereas for case 6, the standard deviation increases linearly with age. Bias is linear for both cases, and case 6 has higher absolute bias than case 4 for most ages.

Estimates of ageing errors based on comparison of known ages to reader ages were considerably higher than estimates obtained from between-reader variability (Fig. 4). For example, for age 2–9 fish, according to primary reader and tester ages, the estimates of the probability of assigning the true age was 0.95–0.46. In contrast, according to the estimates from reader and known ages, the probability was only 0.71–0.19. This discrepancy was expected because agreement between readers was considerably greater than between reader and known ages. Thus, use of between-reader agreement to assess ageing error may lead to a false sense of the true error.

In conclusion, use of ageing errors based on known-age samples may help improve stock assessment of sablefish. Future analysis of ageing errors for sablefish may require consideration of the time of year otoliths are taken because, as Anderl and Heifetz[2] have shown, ageing error may depend on the season when an age sample is taken. Precaution should be taken in extending our results to fish older than age 9. Results should be compared between stock assessments that use parameter estimates for the ageing-error matrix based on case 4 and case 6. If a sample is obtained that includes older known-age fish, the ageing-error matrix can be estimated for older fish. We expect such a sample to be available in the future as the fish tagged as juveniles by Rutecki and Varosi (1997a) continue to be recovered. For many species other than sablefish, known-age specimens are not available. For such species, variability between readers may be the only data available to assess ageing error. Such data are valuable for evaluating the precision and consistency of ageing criteria applied by different readers. Estimates derived solely from between-reader variability should be viewed as minimum estimates of ageing error.

Acknowledgments

Critical reviews by Dave Clausen, Jerome Pella, Mike Sigler, Jeff Fujioka, and two anonymous referees

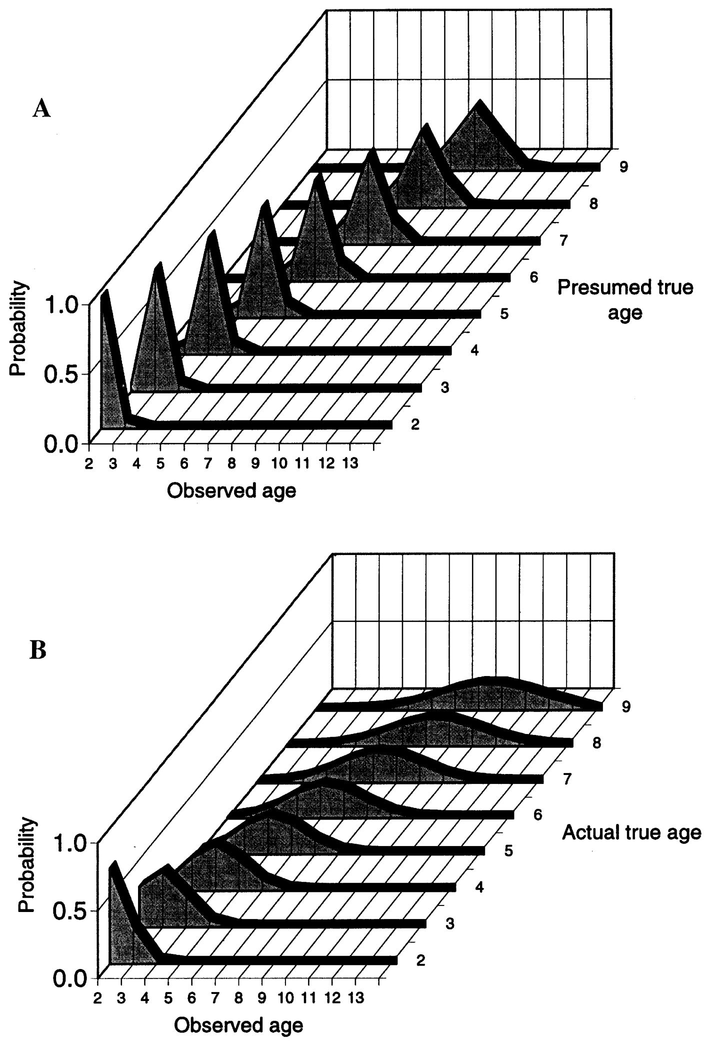

Figure 4

Estimated probability of observing a given age for a particular true age of sablefish estimated from primary-reader and tester ages (**A**, case 1) and from reader and known ages (**B**, case 6). Case refers to model specifications listed in Table 1.

helped improve this manuscript. We thank Julie Lyons for serving as the tester for this study and our co-workers that tagged numerous juvenile sablefish throughout southeastern Alaska. Our appreciation is also extended to the many observers and scientists who provided otoliths of recaptured sablefish. We also thank James Ianelli for helping implement estimation of the ageing-error matrix.

Literature cited

Akaike, H.
1974. A new look at the statistical identification model. Institute of Electrical and Electronic Engineers (IEEE) Trans. Auto. Control 19:716–723. [Referred to in Richards et al. (1992).]

Beamish, R. J., and D. E. Chilton.
1982. Preliminary evaluation of a method to determine the age of sablefish (*Anoplopoma fimbria*). Can. J. Fish. Aquat. Sci. 39:277–287.

Beamish, R. J., G. A. McFarlane, and D. E. Chilton.
1983. Use of oxytetracycline and other methods to validate a method of age determination for sablefish. *In* Proceedings of the second international sablefish symposium, p. 95–116. Alaska Sea Grant Rep. 83-8, Univ. Alaska, Fairbanks, AK.

Chilton, D. E., and R. J. Beamish.
1982. Age determination methods for fishes studied by the groundfish program at the Pacific Biological Station. Can. Spec. Publ. Fish. Aquat. Sci. 60, 102 p.

Ericksen, R. P.
1997. Estimation of aging accuracy and precision, growth,

and sustained yield of coastal cutthroat trout in Southeast Alaska. M.S. thesis, Univ. Alaska Fairbanks, Juneau, AK, 126 p.

Fournier, D., and C. P. Archibald.
1982. A general theory for analyzing catch at age data. Can. J. Fish. Aquat. Sci. 39:1195–1207.

Kastelle, C. R., D. K. Kimura, A. E. Nevissi, and D. R. Gunderson.
1994. Using Pb-210/Ra-226 disequilibria for sablefish, *Anoplopoma fimbria*, age validation. Fish. Bull. 92:292–301.

Kimura, D. K.
1990. Approaches to age-structured separable sequential population analysis. Can. J. Fish. Aquat. Sci. 47:2364–2374.

Kimura, D. K., and J. J. Lyons.
1991. Between-reader bias and variability in the age-determination process. Fish. Bull. 89:53–60.

Lai, H.-L.
1985. Evaluation and validation of age determination for sablefish, pollock, Pacific cod and yellow fin sole; optimum sampling design using age-length key; and implications of aging variability in pollock. Ph.D. diss., Univ. Washington, Seattle, 426 p.

Lai, H. L., and D. R. Gunderson.
1987. Effects of ageing errors on estimates of growth, mortality and yield per recruit for walleye pollock (*Theragra chalcogramma*). Fish. Res. 5:287–302.

McFarlane, G. A., and R. J. Beamish.
1995. Validation of the otolith cross-section method of age determination for sablefish (*Anoplopoma fimbria*) using oxytetracycline. *In* D. H. Secor, J. M. Dean, S. E. Campana (eds.), Recent developments in fish otolith research, p. 319–329. Univ. South Carolina Press, Columbia, SC.

Methot, R. D.
1990. Synthesis model: an adaptable framework for analysis of diverse stock assessment data. *In* L.-L. Low (ed.), Proceedings of the symposium on application of stock assessment techniques to gadids, p. 259–277. International North Pacific Fisheries Commission (INPFC) Bull. 50.

Richards, L. J., J. T. Schnute, A. R. Kronlund, and R. J. Beamish.
1992. Statistical models for the analysis of ageing error. Can. J. Fish. Aquat. Sci. 49:1801–1815.

Rutecki, T. L., and E. R. Varosi.
1997a. Migrations of juvenile sablefish, *Anoplopoma fimbria*, in southeast Alaska. *In* M. E. Wilkins and M. W. Saunders (eds.), Biology and management of sablefish, *Anoplopoma fimbria*, p. 123–130. U.S. Dep. Commer. NOAA Tech. Rep. NMFS 130.
1997b. Distribution, age, and growth of juvenile sablefish, *Anoplopoma fimbria*, in southeast Alaska. *In* M. E. Wilkins and M. W. Saunders (eds.), Biology and management of sablefish, *Anoplopoma fimbria*, p. 45–54. U.S. Dep. Commer. NOAA Tech. Rep. NMFS 130.

Sigler, M. F., S. A. Lowe, and C. R. Kastelle.
1997. Area and depth differences in the age-length relationship of sablefish, *Anoplopoma fimbria*, in the Gulf of Alaska. *In* M. E. Wilkins and M. W. Saunders (eds.), Biology and management of sablefish, *Anoplopoma fimbria*, p. 55–63. U.S. Dep. Commer. NOAA Tech. Rep. NMFS 130.

Tyler, A. V., R. J. Beamish, and G. A. McFarlane.
1989. Implications of age determination errors to yield estimates. *In* R. J. Beamish and G. A. McFarlane (eds.), Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models, p. 27–35. Can. Spec. Publ. Fish. Aquat. Sci. 108.