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Anne McBride
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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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Southwest Fisheries Science Center

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Abstract

Validation studies have shown that sablefish (Anoplopoma fimbria) otoliths contain several false annuli along with the true annual marks. Distinguishing between the two is difficult and agreement among readers is much lower for sablefish than for most other species. Because of this low precision, we used linear and nonlinear regression analysis to develop models for predicting fish age from otolith characteristics (weight, length, thickness, and width) and fork length. Correlation analysis indicated a strong relationship between several otolith characteristics and fish age, with highest correlations observed for otolith thickness. Multiple regression models based on otolith characteristics accounted for a relatively high fraction (75%) of the variability in age. However, agreement between model-predicted age and age determined by readers was much lower than agreement between the two readers. Model and reader age distributions were significantly different (Prob. = 0.05 for females, 0.06 for males), whereas no differences were detected between age distributions from two readers. Model estimates of relative abundance for broader age categories were generally in good agreement with estimates from the two readers. Further research is needed to determine whether model predictions for pooled age categories provide adequate information for stock assessment.

Introduction

Several structures have been used to estimate sablefish (*Anoplopoma fimbria*) age, including scales, fin rays and otoliths. Of these, broken and burnt otoliths are believed to provide the most accurate ages (Beamish and Chilton 1982; Chilton and Beamish 1982; Lai 1985; Beamish and McFarlane 1987). That conclusion is based in part on validation studies using oxytetracycline-injected fish, which have shown that the bands or marks observed on broken and burnt otoliths were in most cases formed annually (Beamish and Chilton 1982, Beamish et al. 1983). Those studies also suggested that the material deposited to form new annuli may not be evenly distributed on the otolith surface (Beamish et al. 1983); therefore, otolith surface ages may be underestimates of true age. Comparative studies have shown that ages obtained from scales and otolith surfaces tend to be lower than ages obtained from broken and burnt otoliths (Chilton and Beamish 1982, Maeda and Hankin 1983, Lai 1985, Fujiwara and Hankin 1988). Sablefish fin ray sections proved unsatisfactory because of the difficulty in identifying growth zones (Beamish and Chilton 1982) or because of irregular patterns or oily tissue that made sections unclear and difficult to read (Lai 1985). Based on the above studies, the agencies involved in sablefish management have spent considerable effort obtaining age data from broken and burnt otoliths. The value of those data is uncertain, however, because of low levels of agreement among readers. Lai (1985) reported 29% agreement for broken and burnt readings; we have observed similar results (unpublished data). Percent agreement among readers is generally higher for other West Coast species, such as *Sebastes alutus* (41%, Kimura and Lyons 1991).

The low precision observed for sablefish may be due to the presence of false annuli (checks) during the first few years of life. The first few annual rings can appear quite broad with several thin lines that sometimes converge on the otolith edge (Beamish and Chilton 1982; Chilton and Beamish 1982). Those annuli are more readily located on the otolith surface, so the current approach for interpreting otolith growth is to use the surface as a guide to determine the position of the first several annuli on the broken and burnt section.

Because information on age composition is used in managing the sablefish fishery, the subjectivity associated with ageing could undermine the reliability of management decisions. For that reason, it would be preferable if reliable objective methods for determining sablefish ages could be developed. One possible approach would be to develop a model to predict fish age using fish length and otolith characteristics such as length, weight, or thickness. Sablefish grow slowly beyond age 10-15 (McFarlane and Beamish 1983), consequently, an age-length key would be a poor predictor of age for older fish. A predictive model incorporating otolith size and fish size may be a better predictor of age (Reznick et al. 1989, Secor and Dean 1989, Pawson 1990). Boehlert (1985) developed predictive models for canary (S. pinniger) and splitnose rockfish (S. diploproa) and found that 70-86% of the variability in otolith section age could be accounted for by curvilinear functions of fish length and otolith length, weight, thickness and width. Advantages of this approach include a consistent interpretation of otoliths and a substantial reduction in the amount of training required. The objective of this study was to develop models for predicting sablefish age from a set of easily measured otolith characteristics. The results also provide useful insights regarding the morphological changes that sablefish otoliths undergo with increasing age.

Methods and Materials

Otoliths used in this study were collected in port samples from the Washington-Oregon-California sablefish fishery (Hightower 1986). Following Boehlert (1985), we measured otolith length, width, thickness and weight for a sample of 499 fish caught in 1988. Otolith length was defined as the maximum anterior-posterior distance through the focus, and width was defined as the maximum dorsal-ventral distance. Thickness was determined by turning the otolith on its ventral side, anchoring it in black clay and measuring the maximum thickness. Length, thickness, and width were measured using a dissecting microscope with 10x eyepieces and a 6x objective. The 10x eyepieces were used instead of a higher power because all three measurements could be made at the same magnification. This allowed for simpler and faster data collection and, presumably, fewer recording errors. Otolith weight was measured using a digital scale with an accuracy of ± 0.001 g. Boehlert (1985) obtained otolith weights after drying to a constant weight at 58°C. We chose not to dry otoliths because we felt the extra handling time could make the method impractical for production ageing. Because sablefish otoliths break easily during collection and handling, measurements were made using either whole otolith. As noted for canary and splitnose rockfish (Boehlert 1985), we observed no apparent differences between right and left otoliths. Fork length (mm) was measured by port samplers.

Two readers independently examined both whole otoliths and broken and burnt sections to estimate fish ages. Sex and fish length were not used as supplemental information in estimating ages. Otolith measurements for each sex were obtained from a stratified random sample of 10 fish per age class, based on the first author's age determination. If fewer than 10 fish were available, then all fish of that age were measured. The data used to develop the model and calculate percent agreement between reader 1 and model predictions were final ages for reader 1 which included some difficult otoliths examined jointly by the two readers. The data used to calculate percent agreement between readers were the original ages for each reader (i.e., all ages obtained independently).

Fish to be aged were drawn randomly from port samples. Ages were determined by using production ageing techniques recommended by Chilton and Beamish (1982). The two readers also participated with National Marine Fisheries Service, Seattle age readers in otolith exchanges and a sablefish ageing workshop in order to minimize differences in interpretation among laboratories.

We used forward stepwise regression analysis (SAS Institute Inc. 1987) as an exploratory technique for obtaining the linear predictive models. For a simple linear model, potential independent variables were fish length and otolith length, weight, thickness and width, as well as squared, cubic and interaction terms derived from these variables. Separate models were developed for each sex because male and female sablefish have different growth patterns (McFarlane and Beamish 1983; Beamish and McFarlane 1987). Only those variables significant at a 0.05 probability level were retained in the model.

We used cross-validation (Efron and Gong 1983; Dolman 1990) to obtain unbiased estimates of the error rate, which was defined as the probability that the age assigned by the model was incorrect. The estimated error rate obtained by examining model residuals could be low because the same data were used to construct and test the model. The cross-validated estimate of the error rate was:

$$1/n \sum_{i=1}^{n} Q[a_i, f(\underline{a}, X)_i]$$

where n was the total number of fish used to fit the regression model, a_i was the observed age for the ith fish, $f(\underline{a},X)_i$ was the predicted age for the ith fish (rounded to the nearest year) from the regression model obtained by omitting the ith fish and fitting the vector of age data ($\underline{a}$) to the matrix of fish and otolith measurements (X), and Q was the error indicator. Q was 1 if the predicted and observed ages differed for fish i and 0 if the ages agreed. Thus, the error rate was the probability that a fish's age was not predicted correctly when that fish was not used to construct the model.

Results and Discussion

Correlation analysis demonstrated a strong relationship among most of the measures of otolith size and fish size (Table 1). The highest correlation for females was between otolith weight and otolith length, while for males the highest correlation was between otolith weight and otolith thickness.

For both sexes, fish age was most highly correlated with otolith thickness followed by otolith weight (Table 1, Figure 1). Fork length and otolith length appeared to be correlated with age through about age 10 but essentially independent thereafter. The lowest correlation for both sexes was between fish age and otolith width. Beamish (1979) measured otoliths from Pacific whiting for the same characteristics that we used and found high correlation ($r = 0.78$) between otolith thickness and fish age.

The growth patterns that we observed for fish length and otolith characteristics were consistent with patterns observed in earlier studies. Beamish et al. (1983) suggested that sablefish otolith growth occurs on the medial (interior) surface; consequently, otolith weight and thickness would continue to increase after growth in otolith length slowed. Evidence supporting that growth pattern was obtained from sablefish age validation studies using oxytetracycline (OTC); OTC marks seen on the medial (interior) surface of the broken section edge (before burning) were not always visible on the whole otolith surface (Beamish et al. 1983). Fujiwara and Hankin (1988) found that thickness of sablefish otoliths increased linearly with otolith section age, whereas fork length and otolith radius reached asymptotes at about age 10.

Similar growth patterns have been observed for other species as well. Beamish (1979) reported increasing thickness and weight for otoliths of Pacific whiting (*Merluccius productus*), along with reduced growth in otolith length and width as the fish grew older. Fargo and Chilton (1987) reported that for rock sole (*Lepidopsetta bilineata*), new material was deposited near the sulcus but did not always extend out to the surface edges of the otolith. Boehlert (1985) found that for canary and splitnose rockfish, otolith weight continued to increase with age after otolith length and fork length reached asymptotes. Finally, Bennett et al. (1982) reported that otolith weight increased continuously with age for two splitnose rockfish shown to be about 80 years old. The rate of growth was rapid for the first 10-15 years, then decreased to a constant rate about 30% of the rate at young ages.

The linear models that we developed performed well, resulting in a linear relationship between reader age and model-estimated age (Figure 2). The models accounted for 75% of the variability in age for both males and females (Table 2). Boehlert (1985) obtained similar results, accounting for 85-86% of the variability in otolith section age for *S. diploproa* and 70-85% for *S. pinniger*. As in Boehlert's (1985) study, our linear models included several derived variables. The model for males included otolith thickness x otolith length and otolith width x otolith weight. The model for females included otolith length^3 and otolith width^3. These derived variables accounted for nonlinearities in the relationship between age and otolith characteristics.

Despite the relatively high R^2 values obtained from the regression models, the level of agreement between the models and the reader was low (13.6% for females, 14.3% for males, Figure 3). Agreement between readers was considerably higher in this study (29.1% for females, 25.1% for males, Figure 3) and in an earlier study (29%, Lai 1985). Our results indicate that when used to estimate the strength of individual year classes, even models with relatively high R^2 values may not be adequate. The low levels of agreement for predicted ages are consistent with the observation of Beamish and Chilton (1982) that although otoliths from older sablefish are obviously thicker, fish size and otolith thickness do not precisely indicate reader-determined age. Of course, some of the differences between predicted and reader-determined ages could be due to reader errors (i.e., the age predicted from otolith characteristics could sometimes be more accurate). Unfortunately, the reliability of reader versus model ages cannot be evaluated conclusively unless a sufficient sample of known-age fish can be obtained.

Because sample sizes were large, we obtained essentially equivalent estimates of percent agreement from the cross-validation runs and the run with all observations included. For that reason, we estimated percent agreement for the nonlinear and polynomial models (discussed below) using single runs with all observations.

The cross-validation analysis was useful for illustrating the sensitivity of the stepwise regression model to the particular observations included. In the cross-validation runs for male sablefish, the model contained the same variables in all 279 trials. For female sablefish, 94% of the trials resulted in a model containing the same variables given in Table 2; however, the remaining 14 trials resulted in models with seven different suites of variables.

Because different suites of variables were sometimes obtained when only 1 of 220 observations was omitted, we also evaluated simpler linear and nonlinear models that might be less sensitive to the particular observations used to fit the model. We used otolith thickness as the independent variable because of the high correlation between otolith thickness and age. Among the models we considered were a power curve ($y = b_0x^{b_1}$) and a polynomial equation ($y = b_0+b_1x+b_2x^2+b_3x^3$), where y = age and x = otolith thickness. The power curve performed reasonably well, although the distribution of residuals was negatively skewed and percent agreement (9.5% for males, 10.2% for females) was lower than that obtained from the full multiple regression model. The distribution of residuals also was skewed for the polynomial model; however, agreement (11.5% for males, 13.6% for females) was only slightly less than that obtained from the full model.

We also examined using otolith thickness to predict age for younger sablefish for which age and otolith thickness appeared to be linearly related (otolith thickness $\leq$1.2 mm; Figure 1). Percent agreement for females (17.3%) and males (16.4%) was higher than for the full data set, but still substantially lower than between-reader agreement (females:40.0%, males:36.1%).

The primary objective of our port sampling and ageing program is to determine the age composition of the commercial landings. For that reason, we compared the predicted age distribution of the full model to the observed age distribution for the two readers (for those fish with measured otolith characteristics), using the same age groups (15-19, 20-24, 25+) used in the most recent stock assessment (Methot and Hightower 1990). The age distribution for reader 1 was relatively uniform because we used an equal sample size whenever possible from each age class (Figure 4). The distribution of the model-predicted ages differed significantly from that of reader 1 (χ^2-test, prob. = 0.05 for females, 0.06 for males), whereas distributions for readers 1 and 2 were not different (prob. = 0.99 for females, 0.90 for males; Figure 4).

Model predictions for broad age categories were in relatively good agreement with estimates for the two readers (Table 3). The categories for older fish (15-19, 20-24, 25+) were used in the stock assessment to reduce the effect of ageing error. The relative abundance of older fish was an important factor in determining historical levels of fishing mortality (Methot and Hightower 1990). Younger fish were not pooled in the stock assessment, although percent agreement was relatively low beyond about age 3 (Methot and Hightower 1990). Presumably because of ageing error, strong or weak year classes were not apparent in the age composition data. If the relative abundance of individual cohorts cannot be determined reliably, it may be sufficient to use in the assessment several pooled age bins, and to obtain age composition data from a predictive model. If so, use of a predictive model could (1) eliminate the subjectivity present in the current approach, (2) eliminate the need for time consuming studies of reader agreement within and between agencies, and (3) enable agencies to increase the sample size upon which the estimate of the age distribution is based.

Conclusion

It is unclear whether improvements in methodology can enhance the quality of the age data obtained from sablefish otoliths. Precision can probably be increased through experience coupled with workshops and exchanges of reference collections, although those approaches may not improve the accuracy of the data. Given sufficient funding, validation studies can be used to increase our understanding of otolith formation and to aid in interpreting sablefish otoliths. Nevertheless, determining sablefish ages from visual examination of otoliths is likely to remain a subjective process.

Predictive models based on otolith characteristics account for a relatively high fraction of the variability in age, but percent agreement between model and reader was much lower than between two readers. Model estimates of relative abundance for broader age categories were generally in good agreement with reader estimates. Further research is needed to determine whether model prediction for pooled age categories provide adequate information for assessment.

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Literature Cited

Beamish, R. J. 1979. Differences in the age of Pacific hake (Merluccius productus) using whole otoliths and sections of otoliths. J. Fish. Res. Board Can. 36:141-151.

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 others methods to validate a method of age determination for sablefish. Proceedings of the International Sablefish Symposium. Alaska Sea Grant Report. 83:95-116.

Beamish, R. J. and G. A. McFarlane. 1987. Current trends in age determination methodology. In Summerfelt, R. C., and G. E. Hall (eds), Age and growth of fish, p. 15-42. Iowa State University Press.

Bennett, J. T., G. W. Boehlert, and K. K. Turekian. 1982. Confirmation of longevity in Sebastes diploproa (Pisces: Scorpenidae) from Pb^{210}/Ra^{226} measurements in otoliths. Marine Biology 71:209-215.

Boehlert, G. W. 1985. Using objective criteria and multiple regression models for age determination of fishes. Fish. Bull., U. S. 83(2):103-117.

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. Pub. Fish. Aquat. Sci. 60:102p.

Dolman, W. B. 1990. Classification of Texas reservoirs in relation to limnology and fish community associations. Trans. Am. Fish Soc. 119:511-520.

Efron, B., and G. Gong. 1983. A leisurely look at the bootstrap, the jackknife, and cross-validation. The American Statistician 37(1):36-48.

Fargo, J., and D. E. Chilton. 1987. Age validation for rock sole in Hecate Strait, British Columbia. Trans. Am. Fish. Soc. 116:77-778.

Fujiwara, S., and D. G. Hankin. 1988. Aging discrepancy related to asymmetrical otolith growth for sablefish Anoplopoma fimbria in northern California. Nippon Suisan Gakkaishi 54(1):27-31.

Hightower, J. E. 1986. Sampling strategies for the Washington-Oregon-California sablefish fishery. U. S. Dep. Commer., NOAA-TM-NMFS-SWFC-63, 43p.

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

Lai, H. 1985. Evaluation and validation of age determination for sablefish, pollock, Pacific cod and yellowfin sole; Optimum sampling design using age-length key; And implications of ageing variability in pollock. Doctoral Dissertation. University of Washington.

Maeda, R., and D. Hankin. 1983. Age and growth of sablefish landed in Eureka, California: A comparison of conventional surface age assignments with sectioned otolith assignments. Proceedings of the International Sablefish Symposium. Alaska Sea Grant Report. 83:81-93.

McFarlane, G. A. and R. J. Beamish. 1983. Biology of adult sablefish (Anoplopoma fimbria) in waters off western Canada. Proceedings of the International Sablefish Symposium. Alaska Sea Grant Report 83:59-79.

Methot, R., and J. Hightower. 1990. Assessment of the west coast sablefish stock in 1990 and recommendations to management in 1991, Appendix B In Status of the Pacific coast groundfish fishery through 1990 and recommended acceptable biological catches in 1991. Pacific Fishery Management Council, Portland, Oregon.

Pawson, M. G. 1990. Using otolith weight to age fish. J. Fish Biol. 36:521-531.

Reznick, D., E. Lindbeck, and H. Bryga. 1989. Slower growth results in larger otoliths: An experimental test with guppies (Poecilia reticulata). Can. J. Fish. Aquat. Sci. 46:108-112.

SAS Institute, Inc. 1987. SAS/STAT Guide for personal computers. Version 6 edition. SAS Institute, Inc., Cary, NC 1028p.

Secor, D. H. and J. M. Dean. 1989. Somatic growth effects on the otolith-fish size relationship in young pond-reared striped bass (Morone saxitalis). Can. J. Fish. Aquat. Sci. 46:113-121.

Table 1. Correlation coefficients for sablefish otolith characteristics, fish length, and observed fish age.

	Fork length	Otolith weight	Otolith length	Otolith width	Otolith thickness
Males N=279					
Age	0.414	0.747	0.397	0.339	0.847
Otolith thickness	0.523	0.842	0.530	0.409	
Otolith width	0.417	0.587	0.374		
Otolith length	0.726	0.739			
Otolith weight	0.696				
Females N=220					
Age	0.432	0.695	0.545	0.366	0.847
Otolith thickness	0.646	0.846	0.727	0.505	
Otolith width	0.689	0.722	0.623		
Otolith length	0.859	0.907			
Otolith weight	0.844				

Table 2. Parameter estimates and associated statistics for the regression models used to predict sablefish age. Significance level refers to the probability that the true value of the parameter is 0.

Parameter	Parameter estimate	SE	Significance level
Females N=220	R^2= 0.75		
Intercept	-17.2871	1.6711	0.0001
Otolith thickness	24.0271	2.3215	0.0001
Otolith length^3	-0.0079	0.0018	0.0001
Otolith width^3	-0.0989	0.0373	0.0086
Otolith weight	361.3479	101.3812	0.0004
Males N=279	R^2= 0.75		
Intercept	-24.8120	1.6320	0.0001
Otolith thickness	38.8480	3.1521	0.0001
Otolith weight	750.0738	147.9165	0.0001
Otolith thick*length	-1.9420	0.3402	0.0001
Otolith width*weight	-86.5062	28.4399	0.0026

Table 3. Pooled age distributions (%) for model predictions and the two readers. Age categories 15-19, 20-24, 25+ are used in the current stock assessment.

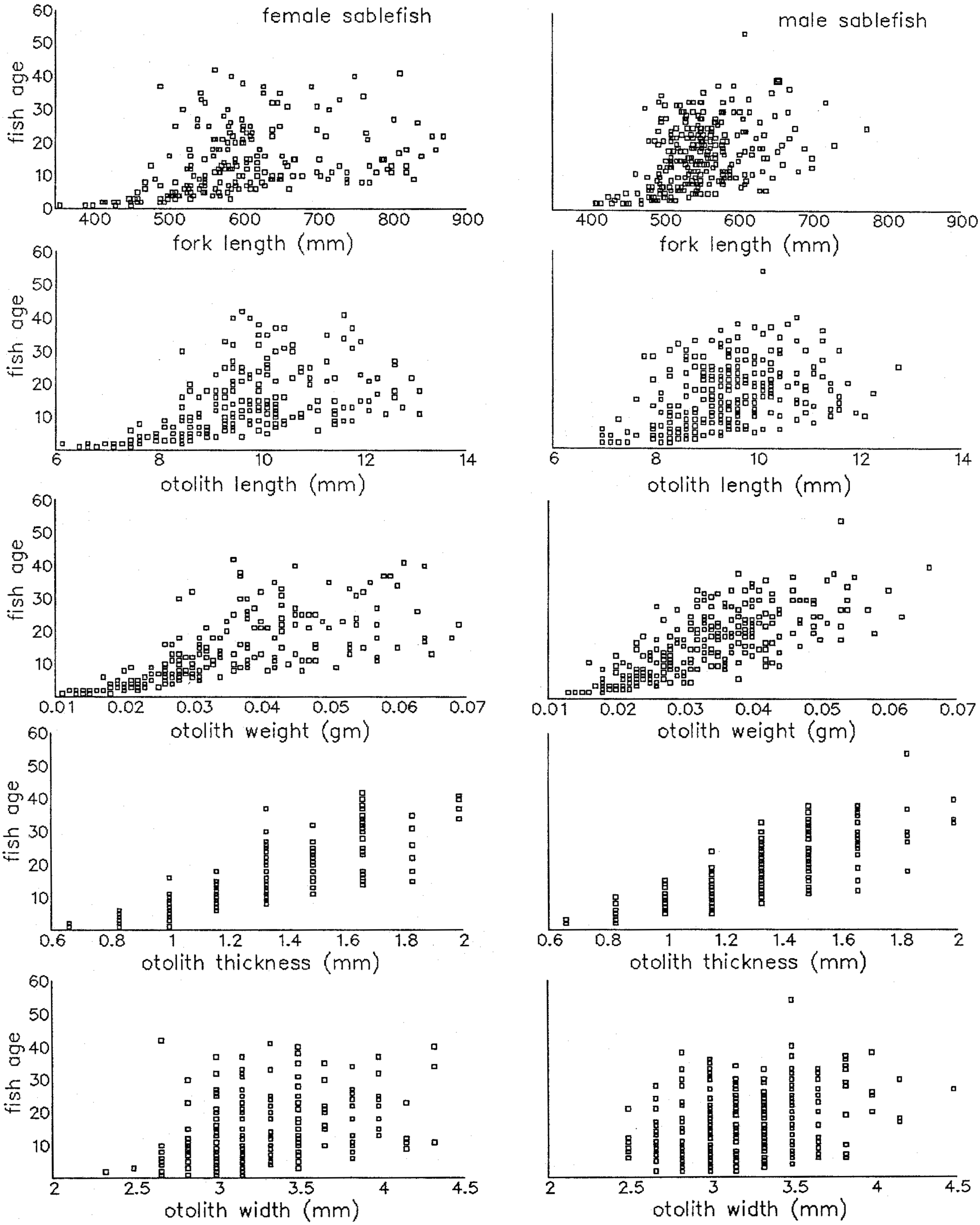
	Female			Male		
Age group	Model	Reader 1	Reader 2	Model	Reader 1	Reader 2
1-14	53.6	60.9	63.6	41.6	46.2	44.4
15-19	21.4	12.3	8.2	21.9	16.1	17.6
20-24	10.0	10.4	13.6	19.7	16.5	19.4
25+	15.0	16.4	14.6	16.8	21.2	18.6

Figure 1. Sablefish age versus fork length and otolith length, weight, thickness, and width for males (n=279) and females (n=220).

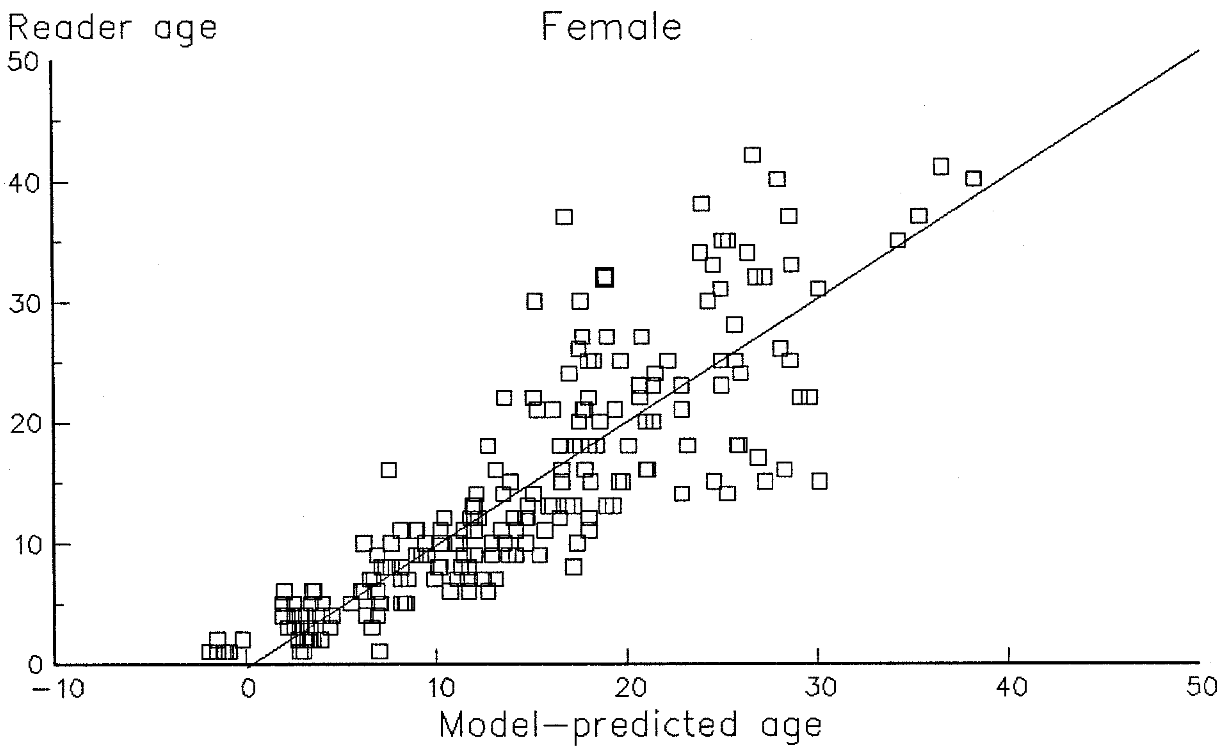
Figure 2. Reader-determined age (reader 1) versus model-predicted age. The line on each plot represents a 1:1 relationship between model-predicted and reader age.

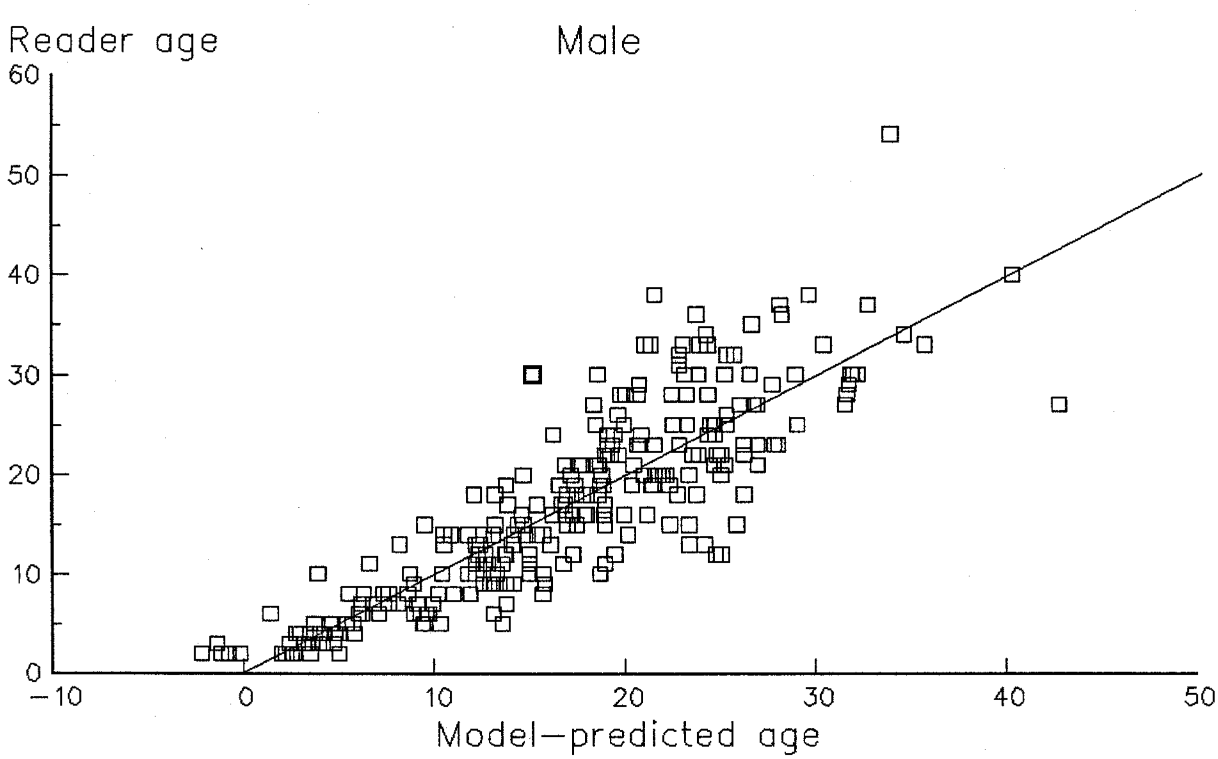
Figure 3. Percent agreement between model-predicted ages obtained from cross-validation and ages determined by reader 1 (upper panel). Percent agreement between reader 2 and reader 1 (lower panel).

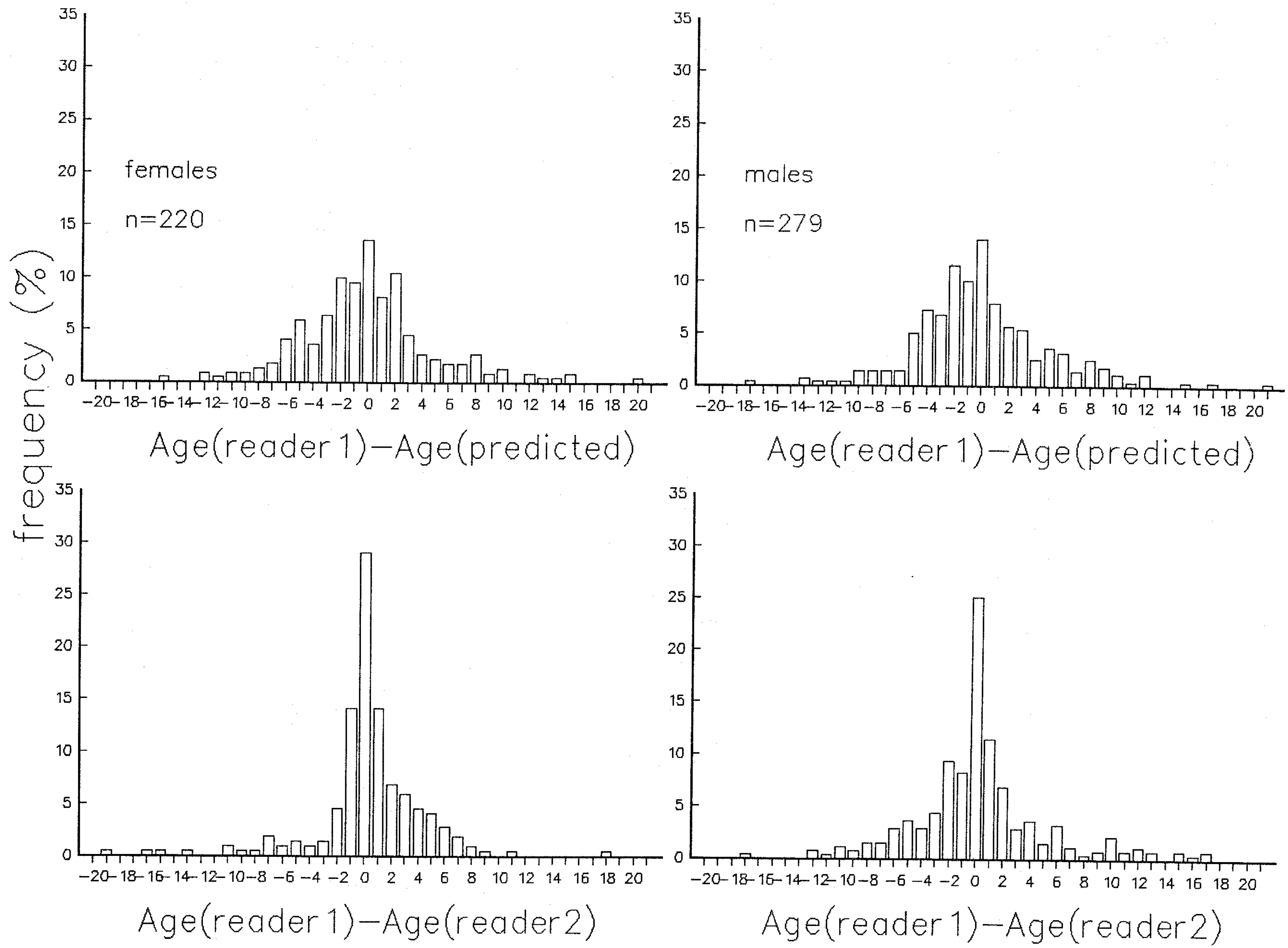
Figure 4. Age distributions for model predictions, reader 1 and reader 2. The age groups for older sablefish (ages 15-19, 20-24, and 25+) were the same categories used in the current stock assessment (Methot and Hightower 1990).

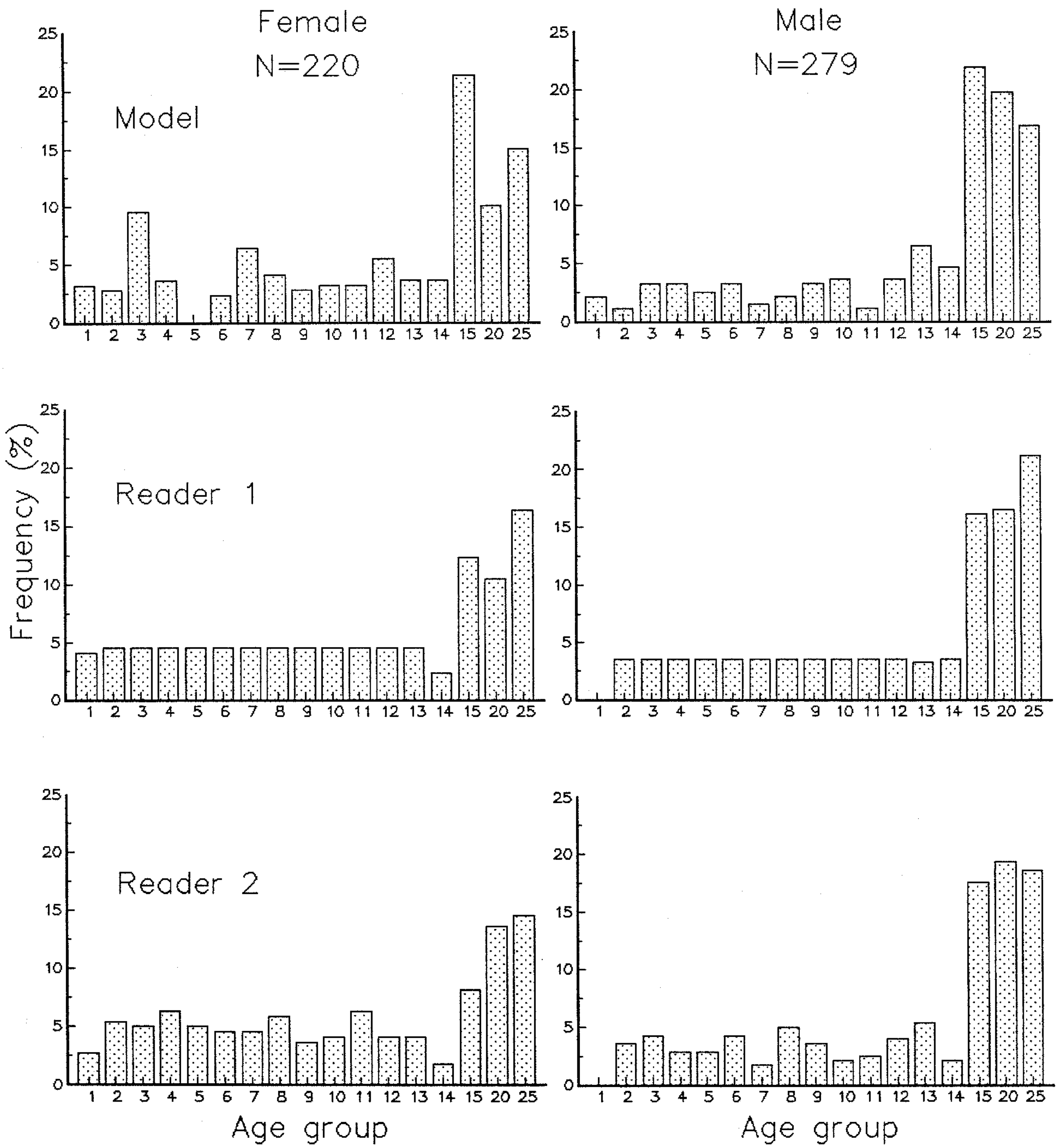


female sablefish
male sablefish
fish age
fork length (mm)
otolith length (mm)
otolith weight (gm)
otolith thickness (mm)
otolith width (mm)


Reader age
Female
50
40
30
20
10
0
−10
0
10
20
30
40
50
Model−predicted age


Reader age
Male
60
50
40
30
20
10
0
−10
0
10
20
30
40
50
Model−predicted age


frequency (%)
females
n=220
Age(reader 1)−Age(predicted)
males
n=279
Age(reader 1)−Age(predicted)
Age(reader 1)−Age(reader2)
Age(reader 1)−Age(reader2)



Female
N=220
Male
N=279
Model
Reader 1
Reader 2
Frequency (%)
Age group
Age group
0
5
10
15
20
25
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 20 25

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