Sex ratio, Spawning Period, and Size and Age at Maturity of Sablefish *Anoplopoma fimbria* Off Northern California

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(Received January 7, 1988)

Size, sex, state of maturity and age were determined for sablefish captured by commercial otter trawl vessels at depths from 100 m to 900 m off northern California from January through August 1984. Sex ratios appeared to be 1:1 among immature fish at all depths, but significantly departed from a 1:1 ratio among mature fish during many months and at many depths, without any clear pattern. Plots of percent spent fish against month suggested that spawning took place from late January through March with a probable peak during early February. Estimated fork lengths at 50% maturity showed a shift to a smaller size with increasing depth. A greater fraction of males and females was mature at smaller sizes and younger ages in deeper waters (>600 m) than in shallow waters (<600 m). Maturation of both sexes occurred over a wide range of ages and sizes (from 3 to 8 years of age and from 40 to 65 cm in fork length), although females generally matured at a larger size and older age than males. Two alternative hypotheses could explain collected data. Sablefish may move to deeper waters at the onset of sexual maturity (for which size and age may vary considerably among individuals), or distinct deep water and shallow water stocks may exist off northern California. Tagging experiments are necessary for distinguishing between these alternative explanations.

Sablefish *Anoplopoma fimbria* is one of the more important species captured in the northern California bottom trawl fishery. Depth distribution of adult sablefish ranges from the continental shelf to at least 1,500 m. Sigmund et al. reported that sablefish otoliths from deeper waters were more difficult to age than those from shallower waters. Maeda and Hankin found that aging discrepancies between surface and sectioned sablefish otoliths were substantial (from 0 to 24 years) but highly variable, particularly among males. They speculated that these inconsistent aging discrepancies might reflect: 1) the existence of multiple stocks; or 2) highly variable growth pattern within a stock of sablefish that were harvested in the northern California fishery. They, however, provided no data regarding depth of capture for their specimens.

The research described in this report was, in part, designed to provide further data regarding the possible dependence of aging difficulties and discrepancies on sex, month and depth of capture for sablefish landed in northern California fishery. Size, sex, gonad maturation state and age (from sectioned otoliths) were obtained from sablefish collected at monthly intervals from January through August of 1984, at depths from 100 to 900 m. Analyses of these data provided indirect evidence for movement of sablefish to deeper waters at the onset of maturity.

Materials and Methods

Sablefish were collected on board of commercial otter trawl vessels fishing out of the port of Eureka, California, from January through August of 1984 (Fig. 1). Mean depth and location were recorded for each tow made on a given trip. Trips were from 1 to 4 days in duration. Tows were stratified by depth into three independent categories: zone 1 (<300 m), zone 2 (301 to 600 m), and zone 3 (>600 m). Systematic samples of sablefish were collected from each tow made, with systematic sampling intervals varying among tows according

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to volume of catch and time constraints for measurements of fish. At least ten percent of sablefish captured were examined from each tow.

Fork lengths of sampled sablefish were measured to the nearest cm, and all fish were also sexed and state of maturation was determined (following Mason et al.4). Pairs of otoliths (sagittae) were removed from most sampled fish for later age determinations. The broken and burnt section aging method5 was used for aging of samples collected from April through August of 1984.

Proportions of female among samples, by month and zone of capture, for mature and immature fish, were tested against a null hypothesis of a proportion of one half using a log-likelihood ratio test.6 Logistic models relating percent maturity to size of fish7 were fit separately to males and females collected in different depth zones, using a logit transformation.8 Percent maturity was also plotted as a function of fish age for males and females separately for each depth zone to allow qualitative examination of possible differences in age/maturity relations between sexes and/or depth zones.

Results

A total of 2781 sablefish was sampled from within a total of 7155 sablefish that were captured by 12 different commercial otter trawl vessels from January through August of 1984. Otoliths were removed from a total of 1345 fish, and successful age assignments were made for 780 out of

<table>
<thead>
<tr>
<th>Sex</th>
<th>Depth (m)</th>
<th>Total sampled</th>
<th>Otoliths removed</th>
<th>Otoliths aged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>≤ 300</td>
<td>77</td>
<td>77</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>301–600</td>
<td>425</td>
<td>329</td>
<td>182</td>
</tr>
<tr>
<td></td>
<td>601&lt;</td>
<td>1046</td>
<td>251</td>
<td>172</td>
</tr>
<tr>
<td></td>
<td>Male Total</td>
<td>1548</td>
<td>657</td>
<td>418</td>
</tr>
<tr>
<td>Female</td>
<td>≤ 300</td>
<td>117</td>
<td>117</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>301–600</td>
<td>582</td>
<td>389</td>
<td>144</td>
</tr>
<tr>
<td></td>
<td>601&lt;</td>
<td>534</td>
<td>182</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td>Female Total</td>
<td>1233</td>
<td>688</td>
<td>362</td>
</tr>
</tbody>
</table>
801 individuals collected from April through August (Table 1). Otoliths were not aged from January through March collections. Sex ratios among mature fish showed no clear seasonal trends with depth of capture, but likelihood ratio tests suggested significant departures from an equal proportion of males and females in many month/depth strata. Average percentage
of females among mature fish was 37% and decreased from an average of about 70% in zone 1 to 31% in zone 3. However, few samples were obtained from zone 1. At depths from 601 to 900 m, males were dominant among mature fish on all trips and in all months (Table 2).

Among immature fish, likelihood ratio tests failed to detect a significant departure from an assumed 50% female proportion in 12 of 15 cases. There was no indication of any dependence of sex composition on month or depth of capture among immature fish (Table 3).

Percentage females strongly depended on size of fish captured. Among fish below 56 cm fork length, male fish were predominant, whereas above 60 cm fork length female fish were predominant. Almost all fish exceeding 70 cm in fork length were female (Fig. 2).

Assessments of state of maturity of sampled fish suggested that peak sablefish spawning activity occurred from late January through late February. The percentage of spent females increased from less than 5% during January to more than 95% in February samples (Fig. 3).

Estimated parameters for fitted logistic size/maturity relations are presented for males and females by depth zones in Table 4. For males, maturity curves were shifted to the left with increasing depth, indicating that a larger fraction of males was mature at a given size in deeper waters than in shallow waters. For example, no males were mature at fork lengths of less than 50 cm in zone 1 (≤300 m), whereas more than 80% were mature at a fork length of 50 cm in zone 3 (>600 m) (Fig. 4, top). Trends in maturation curves for females were less clear than for males, although the greatest fraction mature at a given size was

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**Table 4.** Estimated logistic parameters* (A and B) for maturation curves, and predicted size at 50% maturity for male and female sablefish collected from three depth zones in northern California from January through August 1984

<table>
<thead>
<tr>
<th>Sex</th>
<th>Depth Zone</th>
<th>A</th>
<th>B</th>
<th>Size at 50% (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>1</td>
<td>-13.22</td>
<td>0.24</td>
<td>55.6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-12.02</td>
<td>0.23</td>
<td>53.1</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-5.30</td>
<td>0.12</td>
<td>44.8</td>
</tr>
<tr>
<td></td>
<td>1, 2, 3</td>
<td>-8.51</td>
<td>0.17</td>
<td>49.0</td>
</tr>
<tr>
<td>Female</td>
<td>1</td>
<td>-6.90</td>
<td>0.12</td>
<td>55.7</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-10.95</td>
<td>0.19</td>
<td>58.6</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-5.62</td>
<td>0.11</td>
<td>52.2</td>
</tr>
<tr>
<td></td>
<td>1, 2, 3</td>
<td>-7.32</td>
<td>0.13</td>
<td>56.4</td>
</tr>
</tbody>
</table>

* Parameters A and B were estimated for the logistic model relating percent maturity (\(P(X)\)) to fish length (\(X\)) as: \(P(X) = \frac{1}{1+\exp(-AX+BX)}\).
almost always obtained in the deepest zone (zone 3) (Fig. 4, bottom).

Fig. 5. Proportion mature versus section age of male (above) and female (below) sablefish from three different depth zones, using samples collected by commercial otter trawl vessels from April to August, 1984 in northern California. Number in parentheses indicates sample size.

Maturation curves were gradual for both males and females at all depth zones, indicating that sablefish maturation must take place over a wide range of possible sizes. Females matured at a larger average size than males, however. Based on calculated logistic maturation curve parameters, sizes at 50% maturity were 55.6 cm, 53.1 cm, and 44.8 cm in fork length for males in depth zones 1, 2, and 3, respectively, whereas they were 55.7 cm, 58.6 cm, and 52.2 cm in fork length for females. For all depth zones combined, sizes at maturity for males and females were 49.0 cm and 56.4 cm in fork length respectively.

Discussion

Minimum sizes at maturity were 44 cm fork length for males and 46 cm fork length for females in this study. These lengths agree well with other reports. Estimated size of females at 50% maturity (56.4 cm in fork length in this study) agrees with that in Parks and Shaw, but not with that found by Phillips and Imamura or Mason et al. Estimated size of males at 50% maturity was smaller than has been found in the previous studies. If depth of capture is ignored, average age for 50% maturity was 4 or 5 years for both males and females and was in agreement with Mason et al. However, in this study age at 50% maturity decreased substantially with increasing depth, especially among males. Differences in estimated sizes or ages at maturity among existing studies may reflect differences in depths of sampling or in aging methods, or they may reflect real variation in size at maturity between areas or stocks.

The trends of increased percent mature at a smaller size and younger age in deeper waters as compared to shallower waters (Figs. 4, 5), particularly among males, appear to exist multiple stocks of sablefish off northern California as Maeda and Hankin postulated. There may be a slow-growing, early-maturing type in deeper waters (>600 m), and a fast-growing, late-maturing type in shallower waters (≤600 m). Pacific ocean perch are believed to exhibit such a multiple stock distribution by depth.

Alternatively, the differences between depth zones in maturity curves suggest that sablefish may move a deep water movement triggered by maturation. This possibility is further supported by a general increase of percent mature fish among samples taken from January through August, 1984. Percentage mature fish shifted from 21% to 34% to 81% from depth zone 1 through 3. The previous reports showed sablefish off shore movement in Canadian waters and the Bering Sea. Although we believe that this alternative explanation for our collected maturity data is more
plausible than multiple stocks between different depths, only tagging of immature sablefish found in shallow waters can confidently establish the relative merits of these alternative explanations. If the percentage of mature recoveries among fish tagged as immature fish in shallow waters were highly correlated with subsequent depth of recovery, then the second hypothesis of a deep water movement would be strongly supported.

Acknowledgments

We thank Dr. Yoshiharu Matsumiya, Ocean Research Institute, University of Tokyo and Dr. Syoiti Tanaka, Tokyo University of Fisheries, for reviewing the manuscript and offering helpful suggestions. We are grateful to Doris Chilton, the head of the laboratory at Pacific Biological Station, Department of Fisheries and Ocean, Nanaimo, British Columbia, Canada, for her generous training in the broken and burnt aging method. I would like to thank Pete Leipzig, president of the Fishermen’s Marketing Association, Eureka, California, and local members of this Association for providing us to the opportunity to sample on board Association vessels.

References