ESTIMATES OF FISHING MORTALITY FOR HALIBUT IN EASTERN BERING SEA--
prepared by the
INTERNATIONAL PACIFIC HALIBUT COMMISSION
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Separate estimates of instantaneous fishing mortality within
Bering Sea are available from (1) catch statistics, (2) tagging experi­
ments, and (3) age composition data. Catchability coefficients derived
from each of the several types of data are converted to estimates of
fishing mortality in the summary.

(1) Catch Statistics

Detailed fishing records for the United States and Canadian
setline fishery on the edge (Polaris and Clipper grounds) provide daily
catch and effort data from which the daily catch per unit effort can be
computed. Catch statistics for the first ten days' fishing on the edge
grounds in each year from 1960 to 1963 were used to estimate the
coefficient of catchability per unit of fishing effort, by the method of
Leslie and Davis (1939).

The period used was restricted to the first ten days to minimize
the effects of movements of both fish and vessels upon catchability.
The 1960 to 1963 data were selected because the fishery during the first
ten days of those seasons was more intensive and more consistent from
day to day than in 1958 and 1959, thus providing more reliable estimates.
Bad weather in 1959 and widely variable dates of arrival of the vessels
on the grounds in 1958 reduced the utility of the data for this purpose.

One example of the calculation of the catchability estimates is as
follows: The daily catch per unit effort and the cumulative catch in
1960 is given in Table 1 and Figure 1. From these data a least squares
line of best fit was obtained having a slope of 0.045 which is an estimate
of the catchability coefficient per 1000 units of effort (skates) in 1960.
Data from the edge fishery in the years 1961 through 1963 provided com­
parable estimates of 0.040, 0.042, and 0.033, respectively, per 1000
skates.

The general agreement between the several estimates of the catch­
ability coefficient from 1960 to 1963 shows that they are reproducible
and suggests that some statistical confidence is warranted. Separate
estimates for the Polaris and Clipper sections of the edge during the
first ten days of the 1960 season closely corresponded with the estimates
given above although the Clipper ground sample was small and exhibited
considerable day-to-day variability.
(2) Tagging Experiments

The June and August tagging experiments conducted on the edge in 1956 have produced sufficient numbers of recoveries over an adequate number of years to be used for computing fishing mortalities. The two experiments were similar with respect to sizes of fish tagged and to tagging location but some differences were observed with respect to the distribution of recoveries and the percentage return. However, the two experiments were combined because the two samples probably represent the edge population more nearly than either one alone and because the returns from the individual experiments were too few to justify separate analysis.

Since tagging vessels tend to return to past tagging locations they usually recover more tagged halibut per unit of fishing effort than do commercial vessels. For this reason, 12 tags recovered by the tagging vessel were omitted from the calculations. Also, there is a period of approximately two months after tagging during which tagged halibut are relatively unavailable due to the effects of capture and handling. This condition usually requires that zero-year recoveries be omitted when estimating fishing mortalities. Fortunately, 1956 recoveries could be used in these experiments since the latest tagging was done in August and the commercial vessels did not fish the area until late September, by which time the tagged fish appeared to have recovered from the effects of tagging. None of the sixty-three fish less than 80 cm. in length at tagging were recovered so these smaller fish are not involved in the following analyses. Tags recovered other than on the Bering Sea edge were also omitted. Recoveries in 1962 and 1963 were not used as the numbers involved were too few.

Year-to-year changes in the intensity of fishing preclude the use of actual recoveries in estimating the disappearance rate. An alternative is to use the decline in the number of recoveries per unit of fishing effort. The table below gives the data used, namely, the fishing intensity and the number of tag recoveries on the edge, 1956 through 1961.

<table>
<thead>
<tr>
<th>Recovery Year</th>
<th>Number of Recoveries</th>
<th>Fishing Intensity (1000's of Skates)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1956</td>
<td>23</td>
<td>0.4</td>
</tr>
<tr>
<td>1957</td>
<td>6</td>
<td>0.2</td>
</tr>
<tr>
<td>1958</td>
<td>107</td>
<td>7.4</td>
</tr>
<tr>
<td>1959</td>
<td>40</td>
<td>12.5</td>
</tr>
<tr>
<td>1960</td>
<td>8</td>
<td>19.8</td>
</tr>
<tr>
<td>1961</td>
<td>9</td>
<td>14.0</td>
</tr>
</tbody>
</table>

Figure 2 shows the yearly catch per unit effort of tagged fish plotted in logarithms. Two rates of disappearance are apparent: 0.69 for the period between 1956 and 1958 and 1.16 for the period between 1958 and 1961. The difference of 0.47 in slope can be attributed to a change in intensity of the Canadian and United States setline fishery, if the combined removal of tagged individuals from the edge due to natural mortality, emigration, tag loss and foreign fishing has been virtually
constant between 1956 and 1961. Although foreign fishing increased con-
tinuously since 1954, only two tags were returned by foreign vessels from
the 1956 experiments by the end of 1961 which suggests that foreign fish-
ing made a negligible contribution to the total disappearance rate of the
tagged members.

In view of the very low level of fishing during the earlier
period, the value of 0.47 may be taken as a minimum estimate of the
average fishing mortality coefficient in the 1958 to 1961 period. The
catchability coefficient is estimated to be 0.035 per 1000 skates,
obtained by dividing the fishing mortality estimate of 0.47 by the
associated average annual fishing effort, 13.4 thousand skates.

Another estimate of the catchability coefficient was obtained by
a method described by Gulland (in press). This method uses the regres-
sion of the logarithm of the number of recoveries per unit effort in
successive recapture periods to estimate the average relative abundance
of tagged members at the time of tagging. Applying this method to the
data in the foregoing table provided an estimate of 75.4 fish per 1000
skates. This value is then divided by 2354, the number of tagged fish
released to give an estimate of 0.032 for the catchability coefficient.
Only the recoveries taken before the end of 1958 were used in obtaining
this estimate and, hence, it is virtually independent of any influence
of foreign fishing which did not reach significant proportions in south-
eastern Bering Sea until after 1958. However, since the method requires
the use of the number originally tagged, it is subject to some error from
any non-reporting of recaptured tags and from tagging mortality.

Ricker (1948, 1958) and Beverton and Holt (1957) point out that
the recovery of tags in successive years is not independent when fishing
mortality varies appreciably from year to year. A linear method which
overcomes this difficulty is described by Beverton (1954) and by Beverton
and Holt (1957). The parameters estimated by this method are the
catchability coefficient of a unit of fishing intensity and the
coefficient of "other loss" which includes the rates of emigration, tag
loss and natural mortality. Variable fishing intensity and a minimum of
three recapture periods are required for this method.

Recently, Paloheimo (1961) introduced modifications that simplify
the above calculations and produce estimates having smaller variances.
The latter method provides estimates of the catchability coefficient of
0.027 and of the other-loss coefficient of 0.70. The data and the
regression line are shown in Figure 3. Little reliability can be at-
tached to these estimates because of the great variability in the data.
The linear method depends critically upon the accuracy of the fishing
intensity estimates (Beverton and Holt, 1957), and its extreme sensitivity
may offset its advantages where fishing intensity estimates are subject
to significant error.

Return from the 1959 experiment are now sufficient to permit
preliminary estimates of fishing mortality. In this case 0-year returns;
namely, those from 1959 could not be included in the analysis because
most of the fishing for that year had taken place before the tagging had
been completed. Also excluded were two recoveries by the tagging ves-
sel both of which were taken in 1959 and 13 recoveries taken by foreign
vessels. All fish less than 80 cm. long at tagging were also omitted from the analysis.

The method described by Gulland (in press) was used to calculate total mortality and the catchability coefficient from the data given in the following table:

<table>
<thead>
<tr>
<th>Mean Recapture Period (years)</th>
<th>No. of Recoveries</th>
<th>Percentage Recovered</th>
<th>Skates fished (1000's)</th>
<th>% Recovery per 100,000 Skates</th>
<th>In(%/u)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.26</td>
<td>26</td>
<td>1.94</td>
<td>19.8</td>
<td>.098</td>
<td>2.2824</td>
</tr>
<tr>
<td>2.29</td>
<td>8</td>
<td>.60</td>
<td>14.0</td>
<td>.043</td>
<td>1.4586</td>
</tr>
<tr>
<td>3.24</td>
<td>10</td>
<td>.75</td>
<td>25.0</td>
<td>.029</td>
<td>1.0647</td>
</tr>
<tr>
<td>4.23</td>
<td>4</td>
<td>.30</td>
<td>30.3</td>
<td>.010</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

The total mortality rate of 0.74 is estimated in the usual manner from the year to year decline in the abundance of tagged fish in the population. This slope is represented in Figure 4 by the straight line fitted to the natural logarithms of the percentage recovery per unit effort. The catchability coefficient is estimated from the value of the intercept of the fitted line with a perpendicular erected from the abscissa at a point corresponding to the mean time of tagging, 0.41 in this particular experiment. A catchability coefficient of 0.029 was obtained in this calculation.

It is difficult to assess the amount of statistical confidence that can be attached to these estimates. Some information can be obtained by comparing these estimates with those obtained from the 1956 experiments. For example, the total mortality rate of 0.74 is considerably below the estimate of 1.16 which was estimated in the 1958 to 1961 period from the 1956 experiment. On the other hand, the catchability coefficient of .029 is only slightly less than the 0.31 which was estimated as an average of three estimates obtained from the 1956 experiments. Since there has been a generally upward trend in the amount of gear fished on the edge since 1958 and the catchability coefficient has changed very little, it would appear that the difference in total mortality rate observed in the 1959 experiment must be due to a reduction in the "other loss" term which consists of natural mortality and emigration.

(3) Age Composition

The relationship between the instantaneous total mortality of the halibut on the Polaris ground estimated from age composition and fishing effort on the edge are shown in Figure 5. Data used in the calculation of the least squares fit are given in the following table:
Fishing effort is the average annual number of standardized units of effort of gear fished by the United States and Canadian setline fishery on the Polaris and Clipper grounds each two years. The instantaneous total mortality is derived from the average decline in abundance of fully-recruited year classes (at ages 12 to 25) in the early season, from one year to the next, weighted according to their contribution to the catch per unit effort as given in Tables 6 of INFFC Documents 596 and 660. Because of known seasonal variations in availability it is necessary to restrict such an examination, as nearly as possible, to the same period each year.

The increase in mortality with increase in fishing effort is obvious. The slope of the calculated regression (0.027) is a measure of the catchability per unit effort.

Summary

A summary of the foregoing catchability coefficients and the instantaneous fishing mortalities computed from the product of the fishing effort and the catchability coefficients is given below:

<table>
<thead>
<tr>
<th>Source of Data</th>
<th>Average Catchability Coefficient</th>
<th>Instantaneous Fishing Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catch Statistics</td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>Tagging</td>
<td>0.031</td>
<td>0.23</td>
</tr>
<tr>
<td>Age Composition</td>
<td>0.027</td>
<td>0.20</td>
</tr>
</tbody>
</table>

A Catchability estimates made annually for the years 1960-1963 as follows: 0.045, 0.045, 0.042, 0.033, respectively.

Based on 1956 experiments only. A preliminary catchability estimate of 0.029 was obtained for first four years' returns from the 1959 experiment.
The values indicated above for the years 1960 to 1963, inclusive are higher than the estimates reported (IFHC 1960) for grounds south and west of Cape Spencer which were as follows:

<table>
<thead>
<tr>
<th></th>
<th>South of Cape Spencer</th>
<th>West of Cape Spencer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age Composition</td>
<td>.30</td>
<td>.25</td>
</tr>
<tr>
<td>Tagging</td>
<td>.30</td>
<td>.10</td>
</tr>
</tbody>
</table>

REFERENCES


TABLE 1. Catch per unit effort and cumulative catch in pounds on the Polaris and Clipper grounds during the first ten days of the 1960 season.

<table>
<thead>
<tr>
<th>Day</th>
<th>Catch per Unit Effort</th>
<th>Cumulative Catch</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>354.6</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>297.9</td>
<td>161,200</td>
</tr>
<tr>
<td>3</td>
<td>334.3</td>
<td>481,600</td>
</tr>
<tr>
<td>4</td>
<td>305.6</td>
<td>937,400</td>
</tr>
<tr>
<td>5</td>
<td>298.1</td>
<td>1,342,300</td>
</tr>
<tr>
<td>6</td>
<td>292.6</td>
<td>1,784,800</td>
</tr>
<tr>
<td>7</td>
<td>236.9</td>
<td>2,252,000</td>
</tr>
<tr>
<td>8</td>
<td>239.1</td>
<td>2,648,600</td>
</tr>
<tr>
<td>9</td>
<td>217.4</td>
<td>2,984,700</td>
</tr>
<tr>
<td>10</td>
<td>194.8</td>
<td>3,308,900</td>
</tr>
</tbody>
</table>
FIGURE 1. Relationship between daily catch per unit effort and cumulative catch on the Polaris and Clipper grounds during the first ten days of the 1960 season.
FIGURE 3. Linear relationship between total mortality and fishing effort from tagging on the Bering Sea edge in 1956.
FIGURE 4. Decline in abundance of halibut tagged on the Bering Sea edge grounds in 1959 and recovered through late 1963.
FIGURE 5. Relationship between instantaneous total mortality on the Polaris ground calculated from age composition and the average number of standardized skates of gear fished in consecutive years by the United States and Canadian setline fishery on the edge.