INTERNATIONAL PACIFIC HALIBUT COMMISSION

ESTABLISHED BY A CONVENTION BETWEEN
CANADA AND THE UNITED STATES OF AMERICA

Scientific Report No. 55

Minimum Size and Optimum Age of Entry for Pacific Halibut

by

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SEATTLE, WASHINGTON
1974

The International Pacific Halibut Commission has three publications: Annual Reports, Scientific Reports, and Technical Reports. Until 1969, only one series was published. The numbering of the original series has been continued with the Scientific Reports.

INTERNATIONAL PACIFIC HALIBUT COMMISSION
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ABSTRACT

In 1940 the Halibut Commission established a fork length of 26 inches as the minimum legal size for halibut. Recent estimates of mortality and growth in a Ricker yield model showed that the sustainable yield could be increased by raising the size limit, provided the mortality of undersized fish caught and released was not too high. The Commission adopted a 32-inch size limit in 1973 and expects the added protection of small halibut, coupled with their rapid growth, to increase yields. The new size limit will cause the fisherman to avoid certain grounds where small halibut are concentrated. Care in unhooking and releasing undersized fish will also increase their survival.

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by

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INTRODUCTION

Each species has an optimum size and age of harvesting, depending on its rate of growth and natural mortality. The youngest harvesting age, also known as the age of entry, must be adjusted to the fishing mortality to achieve the optimum harvesting age and the maximum harvest for the species. Older ages of entry are required when fishing mortality is high. Size limits are frequently established when it is necessary to control age of entry. In a trawl fishery the size (age) of entry also can be controlled by regulating the mesh size of the trawl nets.* In a setline fishery size selection is not readily controlled so the desired age of entry is achieved by establishing a minimum harvesting size. The mortality of undersized fish caught and released must be relatively low to attain the intended benefit from the regulation.

In its first report the International Pacific Halibut Commission (IPHC) expressed concern about the excessive capture of small halibut (Babcock et al. 1928), but the original Halibut Convention did not specifically authorize a minimum size regulation. The first regulations to protect young halibut were those prohibiting fishing on "nursery" grounds and reducing fishing mortality. In 1940 the Commission decided it had authority to set size limits and a minimum weight of 5 pounds (2.27 kg) was established for fish with head and entrails removed. The 5-pound limit was the division between the "baby" (less than 5 pounds) and "chicken" (5 to 10 pounds) trade categories. Since only a few vessels landed fish under 5 pounds and their catches usually comprised less than 5% baby halibut, the regulation had little effect. In 1944 a head-on length limit of 26 inches (66 cm), which was equivalent to the 5 pound weight limit, was added for the convenience of the fishermen. When the Convention was revised in 1953 the Commission was given specific authority to impose size limits and the uncertainty that had delayed adoption of the size limit was eliminated.

In previous studies (IPHC, 1960) age of entry and fishing mortality were used to determine what conditions would produce the maximum sustainable yield but control of age of entry was not discussed. Chapman, Myhre and Southward (1962) reported that changes in fishing mortality cause small changes in age of entry which affect the potential yield curve. Increases in fishing mortality reduce average age and age of entry as the abundance of old fish declines. The inverse relationship between fishing mortality and age of entry is inimical to attainment of maximum sustainable yield which requires that age of entry vary directly with fishing mortality.

This report indicates the size limit expected to provide the maximum sustainable yield under a range of conditions, including those prevailing at present. The model

* IPHC regulations prohibit retention of halibut by net gear, including trawls, because it will not permit the maximum sustainable yield.

follows a year class through its lifetime, estimating yield at each age and summing to obtain the total yield during the life of the class under each set of conditions. Under stable conditions the same yield would be produced by a sequence of year classes during a single year. To decide whether the theoretical benefits are realistic, the conditions which would produce the greatest yield in the model are compared with observations from the commercial fishery. The conclusion reached contributed to a Commission decision to raise the size limit to 32 inches (81 cm).

YIELD MODEL

Several methods of calculating the optimum size limit or age of entry have been reported (Ricker, 1945; Allen, 1953; Beverton and Holt, 1957.) Ricker's method is used in this report because growth and mortality are age-specific. The initial biomass is represented by N fish with average weight $\overline{W}$. The biomass at each successive age is determined from the biomass at the previous age:

$$N_{t+1}\overline{W}_{t+1} = N_t\overline{W}_t \left[\exp\left(-F_{\Delta t}S_{\Delta t}[1-K+KR]-M_{\Delta t}+g_{\Delta t}\right)\right] \quad (1)$$

where $F_{\Delta t}$ and $M_{\Delta t}$ are the instantaneous fishing and natural mortality rates during the interval $\triangle t$ between ages t and $t+1$, $g_{\Delta t}$ is the instantaneous growth rate during $\triangle t$ and $S_{\Delta t}$ is the gear selection ratio during $\triangle t$ and takes values $0 \leq S_{\Delta t} \leq 1$. R is the retention factor which is 0 if t is less than the age of entry (fish cannot be retained) and 1 otherwise. K is the survival rate of released fish (i.e. undersized fish caught and released) which takes values $0 \leq K \leq 1$. The yield, $Y_{\Delta t}$, obtained during $\triangle t$ from the population at age t is

$$Y_{\Delta t} = \tfrac{1}{2} N_t\overline{W}_t \left[1+\exp\left(-F_{\Delta t}S_{\Delta t}[1-K+KR]-M_{\Delta t}+g_{\Delta t}\right)\right] F_{\Delta t}S_{\Delta t}R. \quad (2)$$

The exponential term controls change in population biomass during $\triangle t$. Removals by the fishery are controlled by $F_{\Delta t}$, $S_{\Delta t}$, K and R.

The total yield expected from a year class is the sum of the annual yields during its life span. A yield surface shows the yield that can be obtained under different conditions and the set of conditions which will produce the maximum yield from a given recruitment.

Two characteristics of the model deserve special mention. First, all fish in a year class are the same age and size and, therefore, are subject to the same gear selection and retention factor at any given time. Second, in Equation (2) the average biomass during $\triangle t$ is placed at $t + \frac{1}{2}\triangle t$. Ricker (1958) said the arithmetic mean is usually better than the exponential alternative because growth in weight usually decreases throughout the life of a fish. He also advised making $\triangle t$ sufficiently small so that growth and mortality change little within that period. Yields obtained with halibut data using $\triangle t$ set at 1 year and at 3 months were not significantly different over the ranges of fishing mortality and ages of entry under consideration. Consequently, t of 1 year is used in this report. The values used for each parameter are described below.

Initial Biomass

A constant initial biomass was used in the model although recruitment is expected to fluctuate in response to environmental and fishery-induced conditions. Environmental conditions are expected to fluctuate around some average value. Annual changes in initial biomass could alter the level of the yield surface but not the shape or slope. High levels of fishing mortality would reduce egg production and recruitment and could change the shape and slope of the yield surface. Interactions of this type were not included in the model but are considered in drawing conclusions from the yield surfaces.

Age

The model population was divided into age groups from 4 to 21 years. The biomass at the end of the 21st year was relatively small and the yield produced by older fish was negligible. This choice is supported by the observation that the commercial fishery produces little yield from fish older than 21 years.

Growth

Known variations in the growth of halibut complicate the choice of a single representative growth curve. Growth rate has increased during the past few decades, primarily among young fish (Southward, 1967), and growth varies by sex and geographic area as well. Age-length data were obtained from over 10,000 fish ranging from 2 to 29 years old caught during fishing experiments in 1963-1966 in the western Gulf of Alaska and in British Columbia. Setline gear was used so the average size of the younger fish was overestimated because of gear selection (Myhre, 1969). To reduce this bias fish under 5 years old taken off British Columbia were omitted and 1- and 2-year old fish taken with trawl gear were added to the series. The average length at each age was calculated from the total sample and the average length-weight relationship was used to calculate the weight (heads-off and eviscerated) at each age. The instantaneous rate of growth was obtained from Ricker's (1958) Equation 1.31. The average length, weight and growth rate at each age under present conditions are given in Table 1.

Natural Mortality

Chapman, Myhre and Southward (1962) estimated an instantaneous natural mortality of 0.15 to 0.20 for adult halibut. They regarded any value within this range as reasonable and I adopted an intermediate value of 0.175. Reliable estimates of the natural mortality of young halibut are not available so the same natural mortality was used for all ages. Trawl fisheries cause mortality of halibut and these deaths might be classified as natural mortality since they do not contribute to yield by North American vessels. I assumed that trawl mortality is insignificant for ages above 4 and would only reduce initial biomass. Trawl mortality among older ages would reduce optimum age of entry as would increased natural mortality.

Fishing Mortality

Fishing mortality was varied from 0.05 to 0.70, a range which includes the fishing mortalities estimated for the setline fishery (Myhre, 1967). The overall fishing mortality on fully recruited fish in the setline fishery is in the 0.20 to 0.40 range at the present time. The fishing mortality of small fish is less because of gear selection; sizes below the selection range suffer no fishing mortality; within the selection range fishing mortality varies with the selection factor. Myhre (1969) found different selection properties in the Gulf of Alaska and British Columbia. This report uses an average of the two selection ratios of 0.084, 0.266, 0.526, and 0.830 for ages 4, 5, 6 and 7, respectively. The selection ratio for all ages above 7 was set at 1.000.

Table 1. Average length, weight and growth rate by age.

Age	Length (cm)	Weight (kg)	Growth rate
4	50.5	1.036	0.681
5	62.3	2.048	0.541
6	73.4	3.518	0.436
7	84.2	5.439	0.356
8	94.0	7.761	0.293
9	102.9	10.406	0.244
10	111.0	13.279	0.204
11	118.2	16.279	0.171
12	124.6	19.317	0.144
13	130.2	22.314	0.122
14	135.2	25.217	0.103
15	139.6	27.967	0.088
16	143.5	30.543	0.075
17	146.9	32.929	0.064
18	149.8	35.113	0.055
19	152.4	37.087	0.047
20	154.6	38.866	0.040
21	156.5	40.461	0.035
22	158.2	41.885	0.030

Mortality of Released Fish

In 1966 the setline vessel *Chelsea* caught 2,042 halibut of which 471 were considered dead at capture. All remaining fish were tagged; 233 were subjectively classified in "poor" condition and 1,338 as "good" or "excellent". During 1967-1969 the return from the poor-condition fish was approximately half that from the fish in good and excellent condition (12% compared to 25%). This mortality was not affected by fish length. Peltonen (1969) reported that when halibut in apparently good condition were tagged and held in live boxes, 4% died from injuries he associated with tagging. Applying this estimate to the *Chelsea* data, a total mortality of 32% was calculated as follows:

$$\frac{471 + 233(.54) + 1338(.04)}{2042} = .32$$

Even if the mortality of fish in good and excellent condition had been as high as 20%, the total mortality of the *Chelsea* fish would have been only 43%. Although release mortality is probably close to 32%, a range of values is considered in this report.

Age of Entry

In the model, age of entry is the age at which fish reach legal size under present growth conditions and can be retained if they are caught. Younger fish are below the legal size and must be released. Ages of entry from 4 to 14 were considered in the model to incorporate all reasonable minimum size and age limits.

SIMULATED YIELDS

Yields were calculated from Equation (2) for the various combinations of ages of entry and fishing mortality, and are compared in three-dimensional yield surfaces. The level of the yield surface indicates the relative yield in weight under given conditions; the highest point on the yield surface indicates the set of conditions expected to produce the greatest yield; and the slope of the yield surface indicates the change in yield resulting from changes in fishing mortality and age of entry. The optimum age of entry at each level of fishing mortality is indicated by the maximum yield line.

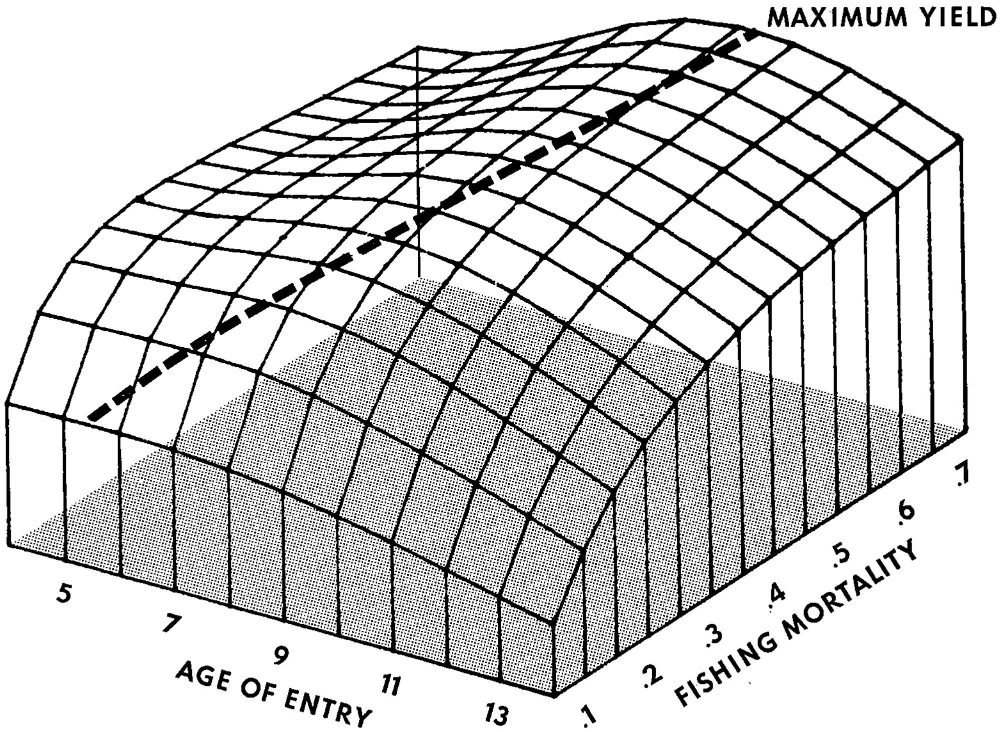

Figure 1. Relative yield of halibut when all undersized fish are released and survive.

The relative yields when all undersized fish survive after release are shown in Figure 1. The best ages of entry are between 6.7 years (81 cm) at a fishing mortality of 0.10 and 10.2 years (112 cm) at a fishing mortality of 0.60. A more realistic situation is one in which 25% of the fish below legal size die upon release (Figure 2). Under this assumption the best ages of entry are from 5.6 years (69 cm) at a fishing mortality of 0.10 up to 6.7 years (81 cm) at a fishing mortality of 0.60. If 50% of the undersized fish die upon release the best age of entry ranges from 4.6 years (58 cm) at a fishing mortality of 0.10 up to 4.8 years (60 cm) at a fishing mortality of 0.60 (Figure 3). At release mortalities this high the 66 cm size limit will reduce yields slightly.

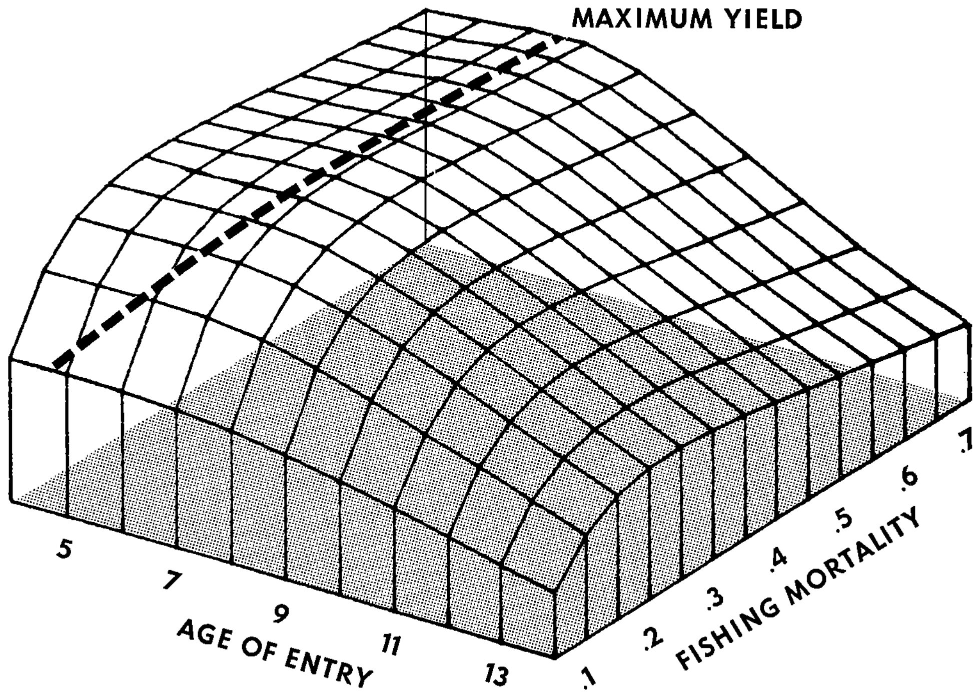

Figure 2. Relative yield of halibut when all undersized fish are released and 25% die soon thereafter.

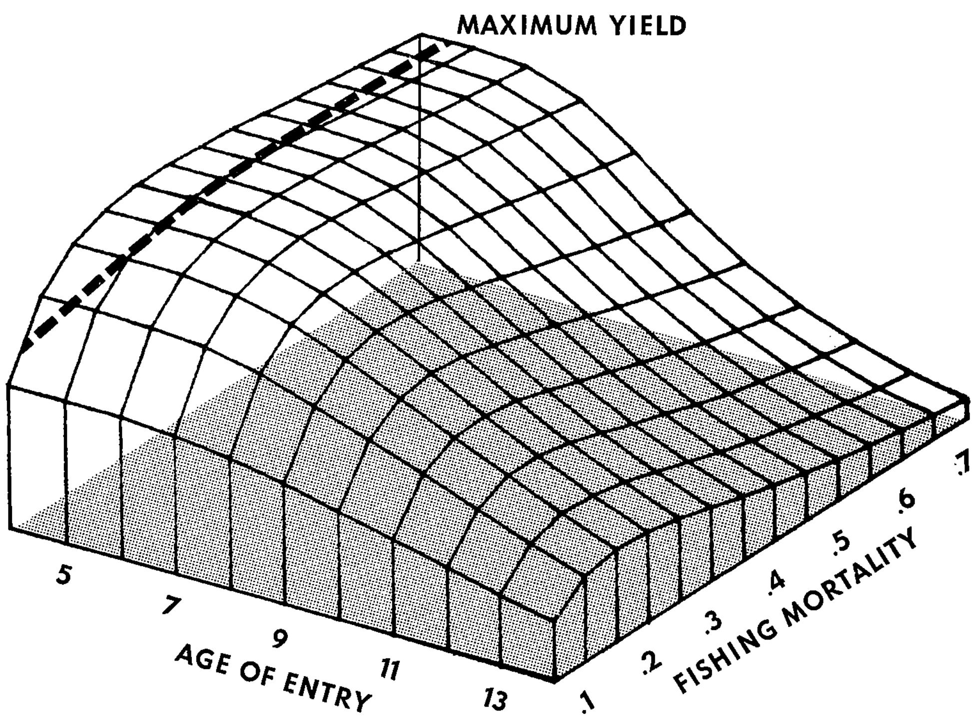

Figure 3. Relative yield of halibut when all undersized fish are released and 50% die soon thereafter.

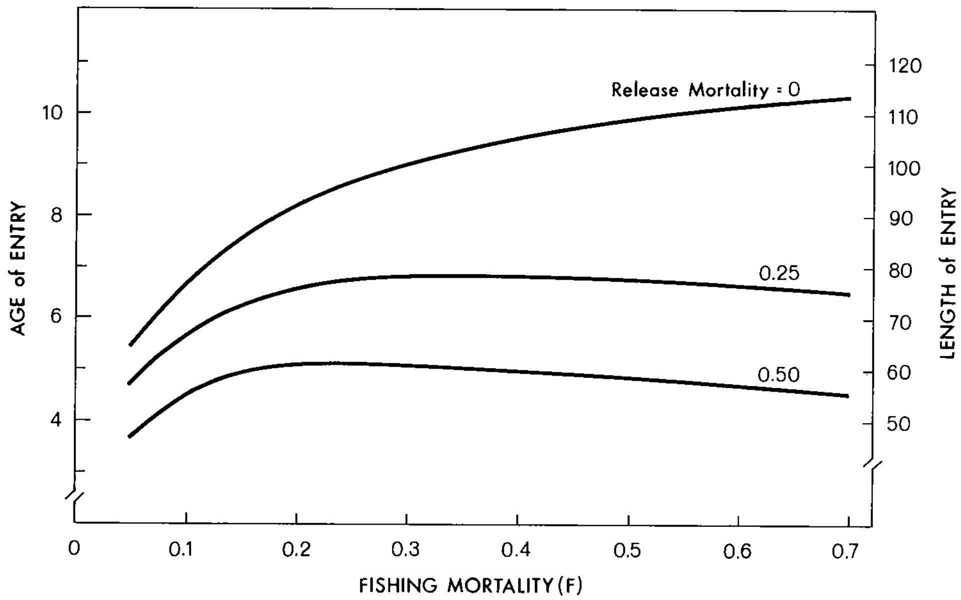

Figure 4. Relationship between age and length of entry and fishing mortality at three levels of release mortality.

The relationship between age (length) of entry and fishing mortality at the three levels of release mortality is shown in Figure 4. Assuming the overall fishing mortality is between 0.20 and 0.40 and the release mortality is 32%, the best size limit would be 75 cm which corresponds to an age of entry of 6.2 years. Clearly, the minimum size limit of 65 cm adopted in 1940 is too low under present conditions. A size limit greater than 75 cm is justified if release mortality of 25% or less can be achieved.

The above conclusions do not depend critically upon the specific values assigned to the parameters used in the model. If other values within a reasonable range were substituted for the ones used, the yield surface would change little. For example, changes in growth and mortality, especially at young ages, affect the level of the yield surface but not its shape. The shape of the selection curve has little effect on the yield surface, but shifting the curve to younger or older ages, respectively, lowers or raises yields at low ages of entry, particularly when fishing mortality is high.

Two key assumptions of the model do not hold in the halibut stocks. First, recruitment is constant in the model, but high fishing mortalities might reduce the number of spawners sufficiently to reduce the number of young. If so, yields may be overestimated at high fishing mortalities but this would not affect the choice of size limit. Second, a fixed selection curve is used in the model but if the size limit is increased halibut fishermen are expected to shift their fishing grounds to maximize their catch of legal-sized fish. This shift will reduce the catch of sublegal fish which is important, particularly when the mortality of released fish is high. Thus release mortality would be unimportant if few undersized fish are caught.

MANAGEMENT CONSIDERATIONS

The yield model shows that under present conditions a larger size limit can produce a greater yield and that a high release mortality can cancel the expected gain in yield. The model indicates which size limit is best for any level of release mortality. The purpose of this section is to discuss how a larger size limit can produce a greater yield for the halibut fishery and what other effects the change might have on the fishery.

At present setline and troll gear are used to catch halibut, but setline gear produces most of the catch. Setline-caught fish frequently sustain serious injury because they often swallow the hook and may remain on the hook for many hours before the gear is retrieved. Setline-caught fish that must be released because they are too small may suffer a relatively high mortality. Troll-caught halibut usually are hooked in the forward part of the mouth and hauled in as soon as they are hooked so the survival of the undersized fish is probably high. The survival of fish released from either gear can be improved if fishermen use care in unhooking them.

Although small halibut are widely distributed, they predominate on certain grounds, particularly where fishing mortality is high. If the size limit is raised, the salable catch on small-fish grounds will be reduced and fishermen will shift to grounds occupied by larger fish. Fewer undersized fish will be caught and more will survive. The same benefit could be achieved by closing the small fish grounds during all or part of the year but this would be more difficult to enforce. Fishermen will ultimately be rewarded by the greater average size of fish on the grounds, assuming stable growth and mortality.

After weighing these considerations, the Commission decided to raise the minimum size limit for the commercial fishery to a fork length of 32 inches (81 cm). Fish of this length weigh about 10 pounds with head and viscera removed. The new size limit will eliminate most of the landings of chicken halibut. The larger size limit will have less effect on the present fishery than it would have had several years ago because chicken halibut have declined steadily from 15 million pounds, or 30% of the total catch in 1929, to 3 million pounds or 5% of the catch in 1971 (Figure 5). The faster growth rate has surely contributed to the decline because halibut now pass

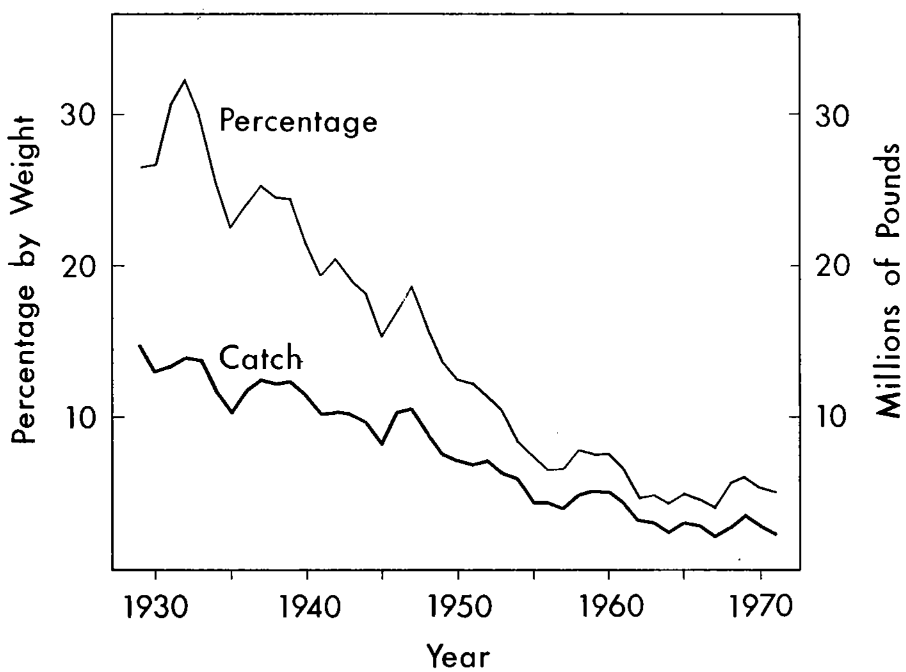

Figure 5. Catch of chickens and their percentage in the total catch from Areas 2 and 3, 1929-1971.

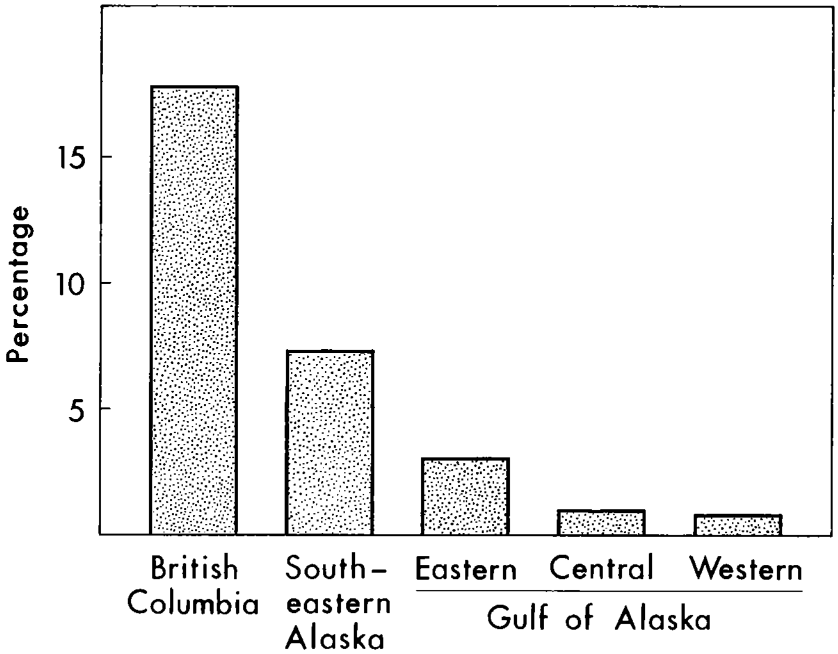

Figure 6. Catch of chicken halibut as a percentage of the total catch from each region, 1968-1970.

through the chicken category so much faster that there are fewer of them in the category at any time. The higher price for the larger sizes has probably contributed to the decline by making larger fish more valuable to fishermen.

The catch of chickens varies considerably by location. For example, during 1968-1970 chicken halibut contributed 18% in British Columbia but under 5% in the Gulf of Alaska (Figure 6). In fact 61% of the total chicken halibut caught in those years came from British Columbia.

SUMMARY

In 1940 the minimum size limit for Pacific halibut was set at 26 inches, a corresponding weight limit of 5 pounds with head and viscera removed was added in 1944. A biological benefit was expected in spite of some unavoidable mortality of small fish caught and released.

A yield model using current estimates of natural and fishing mortality, growth and setline selectivity was used to estimate relative yields at different ages (sizes) of entry, when 0, 25% and 50% of released fish die. The best size limit under present conditions ranged from a high of 112 cm when all released fish survive to a low of 58 cm when 50% of the released fish die. The release mortality of setline-caught halibut is estimated to be 32% and on this basis the size limit should be increased. Fishermen are expected to avoid concentrations of undersized fish, reducing the capture of small halibut and making the release mortality less critical.

In 1973 the Commission adopted a fork length of 32 inches (81 cm) as the minimum size of halibut taken by the commercial fishery in the Gulf of Alaska. This new size limit eliminates most of the catch of chicken halibut which are usually under 8 years old. These young fish will weigh more and be worth more if allowed to grow a few more years. The larger size limit is expected to increase the yield of halibut.

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