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Survival of Halibut Released After Capture By Trawls

by

Stephen H. Hoag

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P.O. BOX 5009, UNIVERSITY STATION
SEATTLE, WASHINGTON 98105, U.S.A.

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ABSTRACT

Foreign and domestic trawlers catch substantial quantities of halibut incidentally when fishing for other species. Regulations require the release of trawl-caught halibut, but the survival of the released halibut is unknown. The condition of halibut caught by Japanese trawlers indicates that survival is low. The survival of halibut released by domestic trawlers was estimated from the recovery rate of tags and from expected rates of natural mortality and other losses. Survival was positively correlated with length of fish and negatively correlated with time on deck and weight of total catch. The average survival from domestic trawlers was about 50%. Management implications of these findings are discussed.

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INTRODUCTION

In the northeast Pacific Ocean, halibut *(Hippoglossus stenolepis)* are fished commercially with setlines by Canadian and United States (domestic) fishermen but are also caught with bottom trawls. Domestic and foreign (primarily Japan and U.S.S.R.) trawling has increased substantially since the 1950's, and these fisheries frequently catch halibut incidentally while fishing for other groundfish. Domestic trawls caught about 3,000,000 pounds of halibut annually in the 1960's (Hoag, 1971), and observations on Japanese trawlers indicate that foreign trawls caught over 10,000,000 pounds annually in the early 1970's (Hoag, unpublished). The International Pacific Halibut Commission (IPHC) prohibits the retention of halibut caught by domestic trawlers, and the International North Pacific Fisheries Commission prohibits the retention of halibut caught by Japanese trawlers east of 175° W longitude. (Japanese domestic regulations also prohibit the retention of halibut between 175° W and 180° W.) The reason for the prohibition is that many of the halibut caught in trawls are under the size that produces maximum yield (Bell, 1956; Myhre, 1969).

Some of the trawl-caught halibut are dead when captured; others, that are alive when released, die later from injuries received during capture. The survival of the released halibut is critical in assessing the effect of trawling on halibut stocks. In this report, I review reports on the condition of halibut caught by Japanese trawlers and estimate the survival of halibut caught by domestic trawlers from the recovery rate of tags. Some factors which determine survival are examined. Also, management implications of these findings are discussed.

JAPANESE TRAWLING

Chitwood (1969) described the Japanese trawl fishery in the northeast Pacific and the Bering Sea. The fishery is directed primarily at Pacific ocean perch *(Sebastes alutus)* in the northeast Pacific and walleye pollock *(Theragra chalcogramma)* and yellowfin sole *(Limanda aspera)* in the Bering Sea. The fishery consists of two fleets: (1) the independent stern trawlers that process their own catch, and (2) the mothership operations that process the catch from several types of fishing vessels (pair trawlers, side trawlers, or Danish seiners).

In programs coordinated by the U.S. National Marine Fisheries Service (NMFS), observers from Canada and the United States collected data on the incidental halibut catch by Japanese trawls during 1963-1969 in the northeast Pacific and during 1972-1974 in the Bering Sea. Halibut were usually less than 3% of the catch and were generally in poor condition when released. Observations on the physical condition and mortality of halibut caught in the northeast Pacific were summarized by NMFS (unpublished). Observers subjectively judged the "viability" of halibut by the general appearance of the fish and the fish's reaction when a finger was placed under the gill cover. The percentage judged viable averaged about 50% at the time of release but varied considerably between vessels. The observers reported that most of the halibut were alive when landed on deck and that most of the deaths occurred during the time required to sort the catch. Larger catches required greater sorting time and, therefore, the mortality in large catches was generally higher than in small catches. (The catch of all species was usually between 10,000 and 30,000 pounds per haul but was as high as 80,000 pounds.) The subjective judgement of viability by the observers cannot be used to estimate the survival from trawl-capture as some of the halibut that are alive when released may die from undetected injuries. Also, observers reported that the halibut received better care by the fishermen when data were being collected. The estimates of viability did indicate, however, that survival was less than 50%.

Observers in the Bering Sea reported that nearly all the halibut caught by Japanese trawlers were dead when released. Most observers did not record the condition of individual halibut but rather gave a subjective opinion on the survival for all halibut observed during the sampling; this ranged from nil to 10%. Other observers recorded the condition of individual halibut; only 43 (4%) of 1,056 examined showed signs of life. The catches were larger and the sorting process longer in the Bering Sea fishery than in the northeast Pacific fishery; these factors apparently account for the lower survival of halibut. The catch of all species averaged over 40,000 pounds per haul, and some catches exceeded 100,000 pounds. Also, the catch from several hauls was usually combined, and the total catch on the deck of motherships would often exceed 400,000 pounds. The catch of independent stern trawlers was emptied into large bins which held about 80,000 pounds of fish, and the halibut were not released until the catch entered the factory below deck. Because of the time required to sort the catches, halibut generally were not released until several hours after capture. Several observers reported that sea lions killed most of the halibut that were alive at release.

DOMESTIC TRAWLING

Bell (1956) estimated that between 75% and 95% of the halibut were alive when released from domestic trawlers. This estimate was based on data collected by observers from the Fish Commission of Oregon, the Washington Department of Fisheries, the Fisheries Research Board of Canada, and IPHC. The estimates were subjective and varied considerably among observers. The percentage of live fish decreased markedly with the size of the groundfish catch even though the catch was usually less than 3,500 pounds — much less than in Japanese trawls. Some observers reported that only 40% of the halibut were alive in hauls with over 3,500 pounds of groundfish. Mortality in large catches was attributed to suffocation in the net and the length of time required to sort the catch. These observations, as those on Japanese trawlers, can be used only as a maximum estimate of survival as they do not include the deaths (from undetected injuries) that occur after the halibut are released. Wilimovsky (unpublished)* placed trawl-caught halibut in a live tank and found that only 20% survived after 16 hours. The live tank was small (8 x 3.5 x 4 feet), however, and crowded conditions may have contributed to the low survival.

The mortality that occurs during trawl-capture and immediately after release can be estimated from the recovery rate of tagged halibut. In 1970, over 2,000

* A preliminary report on viability of incidentally drag-caught halibut by Norman J. Wilimovsky, University of British Columbia.

halibut were tagged from trawlers fishing off British Columbia. These halibut were caught in 398 hauls with 3½- to 4½-inch mesh nets between May and September. About 75% of the halibut were caught in Hecate Strait and 25% in Queen Charlotte Sound (Figure 1). The trawlers were fishing commercially, and the fishermen were requested to handle the fish in their usual manner. Before the halibut were released, their physical condition was judged on external injuries and level of activity.

Condition of Halibut

Halibut were occasionally injured during trawling and handling on deck, but external injuries apparently were not an important cause of death. Only 10% of the halibut had external injuries, and most of these were superficial skin abrasions. Loss of scales was generally not extensive, but scars were frequent, an indication that halibut survive minor external injuries. Serious injuries do occur when fishermen use pews to sort the catch, but only 2% of the halibut sampled were injured with pews. Most of these injuries were in the body muscles, but occasionally a major blood vessel was punctured and bleeding was severe. Because of their large size, halibut are probably less susceptible to serious injury than other groundfish. Bagge (1970) showed that about 30% of the plaice *(Pleuronectes platessa)* were injured when caught with Danish seines. Most of the injuries were minor and tag recoveries showed that survival of injured plaice was only slightly less than that of uninjured ones.

Trawl-caught halibut may die from stress caused by extreme muscular activity during capture and prolonged periods out of water. Many of the halibut sampled

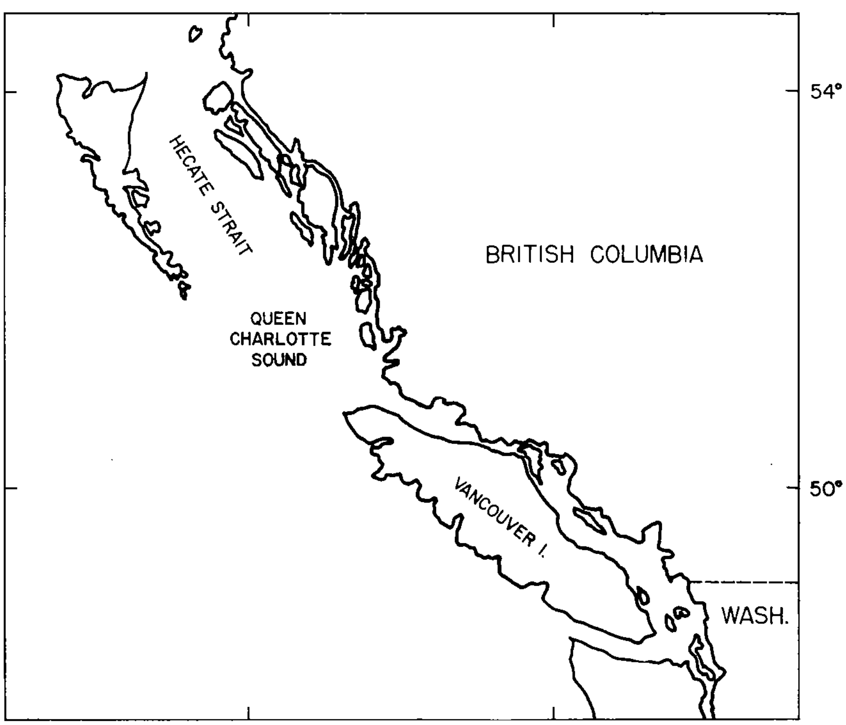

Figure 1. British Columbia sampling areas.

were inactive and had poor muscle tone, an indication of physical exhaustion or suffocation. Death following muscular activity has been correlated with the build-up of lactic acid in the blood, e.g. Parker, Black, and Larkin (1959) for Pacific salmon *(Oncorhynchus)*; Barrett and Connor (1962) for tuna *(Neothunus macropterus* and *Katsuwonus pelamis)*; and Beamish (1966) for haddock *(Melanogrammus aeglefinus)*. Other investigators have reported little or no mortality after extreme muscular activity, e.g. Gronlund et al (1968) for Pacific salmon and Bagge (1970) for plaice. Most of the reports of death after muscular activity have been for fish struggling during hook-capture. Studies by Peltonen (1969) indicate that muscular activity during hook-capture does not cause death in halibut. He placed hook-caught halibut in a submerged live tank (20 x 20 x 6 feet); none died before the sixth day of retention and only 3% died during a 14-day holding period.

To determine lactic acid levels that result from stress, halibut must be held in a live tank because a build-up of lactic acid continues for at least 8 hours after trawl-capture (Wilimovsky, unpublished). The time of peak concentration apparently varies with species: 3 to 7 hours for plaice (Bagge, 1970) and 1.5 to 4 hours for haddock (Beamish, 1966). Unless the live tank is large, holding the fish will probably cause additional stress and perhaps mortality. Adequate space was not available for a large live tank on domestic trawlers, and I did not use lactic acid as an indicator of stress for trawl-caught halibut. Instead, I assumed that stress could be measured from the degree of physical activity at the time of release, i.e. a fish that was still active had not suffered appreciably from stress. The physical activity of the fish was judged from body and opercular movements, and each fish was assigned to one of five categories of condition:

(1) Excellent — vigorous body movement before or after release; could close the operculum tightly; minor external injuries, if any.

(2) Good — feeble body movements; could close the operculum tightly; minor external injuries, if any.

(3) Fair — no body movement; could close the operculum tightly; minor external injuries, if any.

(4) Poor — no body movement; could move the operculum but not close it tightly; severe injuries (bleeding).

(5) Dead — no body or opercular movement.

The number and percentage of halibut in each condition were:

	Excellent	Good	Fair	Poor	Dead
Number	122	431	906	189	409
Percent	5.9	21.0	44.0	9.2	19.9

About 80% of the halibut were recorded as alive when released; this is within the range (75% to 95%) reported by Bell (1956).

Factors Affecting Condition

Bell (1956) found that mortality of trawl-caught halibut was high in trawl catches that contained dogfish *(Squalus acanthias)*. Presently dogfish are not fished commercially by most trawlers, and only small quantities were caught in this experiment. Most of the trawl catch consisted of flatfish: English sole *(Parophrys vetulus),* rock sole *(Lepidopsetta bilineata),* and dover sole *(Microstomus pacificus);* and roundfish: ling cod *(Ophiodon elongatus),* Pacific cod *(Gadus macrocephalus),* and rockfish *(Sebastes* spp.). To determine whether the condition of halibut differed with the target species, the hauls were separated according to the species group that was dominant in the catch. Most (62%) of the halibut were caught when flatfish dominated the catch, but the condition of the halibut was independent of the species group (chi-square = 5.7 with 4 degrees of freedom), indicating no significant effect on the condition of halibut.

Other factors that may influence condition include length of fish, time on deck before release, depth of haul, duration of the haul, and total groundfish catch of the haul. To test the importance of these factors, the condition of each fish was given a numerical code ranging from one (EXCELLENT) to five (DEAD). Correlation coefficients (r) were then calculated between condition and each factor. All factors except depth were significant, but the coefficients were less than 0.4 (2,055 d.f.). Condition was best correlated with time on deck (r = 0.38), total catch (r = 0.33), and length of fish (r = —0.24). The multiple correlation coefficient between condition and all factors was 0.51. To further examine the importance of these factors, I stratified the three factors which gave the highest correlations and calculated the average condition within each stratum (Table 1). Average condition generally was better with larger fish and poorer with longer time on deck and greater total catch.

Table 1. Average condition within each stratum of total catch, length of fish, and time on deck.

	Total Catch (pounds) <5000				Total Catch (pounds) ≥5000			
Time On Deck	Length (cm) <61	61-80	81-100	>100	Length (cm) <61	61-80	81-100	>100
(minutes)	Average Condition							
<11	2.7	2.5	2.3	2.1	2.8	3.0	2.5	2.4
11-20	3.2	2.9	2.7	2.7	3.2	3.1	3.3	3.4
21-30	3.7	3.2	3.1	3.2	3.8	3.7	3.2	3.7
31-40	4.4	4.1	3.9	3.5	4.4	4.1	3.9	4.0
>40	4.8	4.7	4.5	3.8	4.8	4.7	4.8	4.6

An analysis of variance showed that these factors had a significant effect on condition:

Source	Degrees of Freedom	Mean Square	F
Catch (total)	1	.73	36.5**
Length of Fish	3	.38	19.0**
Time on Deck	4	5.17	258.5**
Catch-Length	3	.11	5.5*
Catch-Time	4	.02	1.0
Length-Time	12	.04	2.0
Error	12	.02	

* Significant at p = .05 ** Significant at p = .01

Time on deck before release was the most important of the factors that affect condition. Over 75% of the halibut that were on deck less than 11 minutes were GOOD or FAIR, whereas over half of those on deck more than 30 minutes were DEAD (Table 2). About 35% of the halibut were released within 11 minutes and 60% within 20 minutes. Only 10% were on deck over 40 minutes. Length of halibut also was an important factor. A majority of the halibut were GOOD or FAIR in all length groups, but the percentage of EXCELLENT fish increased and the percentage of DEAD fish decreased with length (Table 2). The halibut ranged from 35 to 208 cm (fork length), but most were between 60 and 80 cm, similar to that described by Hoag (1971).

Table 2. Percentage of halibut in each condition by time on deck and length group.

Time on Deck (minutes)	Number of Fish	Percentage in Each Condition				
		EXCELLENT	GOOD	FAIR	POOR	DEAD
<11	719	11.5	40.6	36.2	7.7	4.0
11-20	555	5.2	19.4	57.5	9.4	8.5
21-30	378	1.9	7.1	61.1	13.0	16.9
31-40	201	1.0	1.5	35.8	10.9	50.8
>40	204	0.5	0.5	11.8	5.4	81.8
Length (cm)						
<61	394	3.3	14.2	43.7	9.1	29.7
61-80	1,204	5.1	22.3	45.5	8.2	19.9
81-100	339	8.8	22.1	43.1	11.5	14.5
>100	120	15.0	26.7	33.3	12.5	12.5

Total catch, although significant, had less effect on condition than the other two factors. The average condition of halibut was only slightly better in hauls with a small total catch (<5,000 pounds) than in hauls with a large total catch (≥5,000 pounds); the difference was slightly greater for large halibut than for small halibut (catch-length interaction was significant). Nevertheless, total catch indirectly affects condition because the time that the halibut are on deck increases with total catch. About 25% of the halibut were on deck over 40 minutes in large catches — much above the 5% in small catches. Total catch ranged from less than 500 pounds to about 10,000 pounds, and these catches were considerably smaller than those on Japanese trawlers. This difference probably accounts for the better condition of halibut in domestic trawl catches.

Test of Criteria

Criteria for judging condition were tested by comparing the recovery rate of tagged fish in each condition. All of the EXCELLENT to POOR fish and most of the DEAD fish were tagged with wire-spaghetti tags, described by Myhre (1966). Tags were recovered from 1970-1973 by trawl and setline vessels. Setlines recovered more tags than did trawls, and the proportion of the recoveries by setlines generally increased with the size of fish (Table 3). The increase in the proportion recovered by setlines can be ascribed to the selective properties of the two gears. Myhre (1969) estimated the selection curves with respect to halibut length for setlines and trawls fishing off British Columbia and showed that the selectivity of trawls declined sharply at lengths over 60 cm, whereas the selectivity of setlines increased up to 80 cm. The percentage of tags recovered generally declined with poorer condition and indicates that the criteria are meaningful. However, the criteria are subjective and not precise as some of the DEAD fish were recovered. Most of the DEAD fish were recovered by setlines several months after release, an indication that the fish had been actively feeding and apparently were healthy. The recoveries showed that survival was similar for EXCELLENT and GOOD fish and also for FAIR and POOR fish, suggesting that three categories would adequately define condition.

Table 3. Percentage of tagged fish recovered by length, gear, and condition.

	Condition				
	EXCELLENT	GOOD	FAIR	POOR	DEAD
Release Length: ≤80 cm					
Number Released	74	324	720	135	288
Percent Recovered:					
Setline	10.8	21.0	10.0	6.0	0.7
Trawl	14.9	6.7	4.9	8.1	1.0
Total	25.7	27.7	14.9	14.1	1.7
Release Length: >80 cm					
Number Released	48	107	186	54	51
Percent Recovered:					
Setline	33.3	27.1	17.2	13.0	7.8
Trawl	6.2	4.7	4.3	5.6	0.0
Total	39.5	31.8	21.5	18.6	7.8
All Sizes					
Number Released	122	431	906	189	339
Percent Recovered:					
Setline	19.7	22.5	11.5	8.5	1.8
Trawl	11.5	6.3	4.8	7.4	0.9
Total	31.2	28.8	16.3	15.9	2.7

Survival of Halibut

If mortality due to capture occurs shortly after release, then survival of fish in each condition category is proportional to the recovery rate of tags. Beverton, Gulland, and Margetts (1959) estimated the survival of tagged fish in various conditions by assuming that all EXCELLENT fish survive. The survival of fish in each of the other conditions (i) was then estimated from the ratio of the recovery rates: $\frac{(\%\ \text{recovered})_i}{(\%\ \text{recovered})_{\text{excellent}}}$. This assumption gives a maximum estimate because some of the EXCELLENT fish may die from undetected injuries. I used the same procedure, but estimated the survival of EXCELLENT fish from the observed tag recoveries and from expected rates of fishing mortality and other losses, i.e. natural mortality, tag loss, non-reporting of tags, and emigration of tagged fish.

The expected number of tags recovered (n_t) from the time of tagging to time T is:

$$n_t = \frac{\theta F S N_o}{(F + X)} \left[1 - e^{-(F + X) T}\right] \qquad (1)$$

Where θ = proportion of the recovered tags that are reported;
F = annual instantaneous fishing mortality;
X = annual instantaneous disappearance rate from all causes except fishing;
S = the survival of fish immediately after tagging;
N_o = number of tags released at T = 0.

The survival can be estimated by solving equation (1) for S:

$$S = \frac{(F + X)\, n_t}{\theta F N_o} \left[\frac{1}{1 - e^{-(F + X) T}} \right] \qquad (2)$$

Myhre (1966) estimated that only 84% of the tag recoveries were reported (θ). This is a maximum estimate because he calculated the reporting loss from double-tag experiments which exclude the loss when finders fail to report tagged fish regardless of the type or number of tags. The magnitude of this additional loss of tags is unknown but is probably small for setline recoveries. Tags on setline-caught halibut are usually noticed as each halibut is processed individually when captured and again when landed at port. In addition, IPHC regularly contacts the setline fleet for recovered tags. On the other hand, the reporting loss of tags on trawl-caught halibut may be substantial. Many tags are probably not noticed because trawl fishermen cannot legally retain halibut (except those that are tagged) and, therefore, do not carefully examine halibut. An unaccounted loss of trawl-caught tags would primarily bias the estimated survival of halibut ≤80 cm as fish of these sizes dominate the trawl catch; θ would be less than 0.84 and survival underestimated. I elaborate on the possibility that survival was underestimated later in this section.

The disappearance rate from all causes (F + X) was estimated by a regression of the logarithm of the annual number of tag recoveries per effort against time (Gulland, 1963). The slope of the regression line is the average disappearance rate. Only setline recoveries per effort were used because effort by trawls was directed at species other than halibut and the incidental catch of halibut varies with area, season, and target species (Hoag, 1971). Tag recoveries were used from all fish regardless of condition. (I assumed that condition affects survival immediately after tagging and does not affect the annual disappearance rate.) From 1971 to 1973, the annual disappearance rate was 0.98 for fish ≤80 cm and 0.76 for fish >80 cm. Similar rates were obtained when both setline and trawl recoveries were used.

Fishing mortality (F) was not known precisely. Myhre (1967) showed estimates that ranged from 0.1 to 0.6 for individual tagging experiments in Hecate Strait and Queen Charlotte Sound. F can be estimated, however, by subtracting the disappearance rate from other causes (X) from F + X. Myhre estimated that X was 0.34 for halibut that were tagged from setline vessels, but most of these fish were >80 cm. Estimates of X were not available for fish ≤80 cm so I assumed that X was 0.34 for fish of all sizes. This assumption results in an F of 0.64 for fish ≤80 cm and 0.42 for fish >80 cm and includes the mortality due to both setlines and trawls. (The F for fish ≤80 cm was higher than expected and suggests that X may be higher than 0.34. If F was overestimated, then survival was underestimated.) The number of tagged EXCELLENT fish (N_o) and the subsequent number of recoveries (n_t) are shown in Table 3. The recovery period from mid-1970 through 1973 (T) was 3.5 years.

Substituting the above values into equation (2), the estimated survival of EXCELLENT fish was 48% for those $\leqslant$80 cm and 92% for those $>$80 cm. The survival of halibut in the other conditions was then estimated from the recovery rate of tags:

$$(\text{survival})_{\text{condition } i} = \frac{(\%\ \text{recovered})_i}{(\%\ \text{recovered})_{\text{excellent}}} \times (\text{survival})_{\text{excellent}}$$

The estimated survival in each condition was:

Length	Excellent	Good	Fair	Poor	Dead
$\leqslant$80 cm	48%	52%	28%	26%	3%
$>$80 cm	92%	74%	50%	43%	18%

The average survival of fish in all conditions was estimated by weighting the survival in each condition by the number of fish in each condition. The average survival was 28% for those $\leqslant$80 cm and 55% for those $>$80 cm.

The estimates of survival probably were not biased for large fish ($>$80 cm) but were low for small fish ($\leqslant$80 cm). The estimates showed that the survival of small fish was about half that of large fish, an indication that small fish are more susceptible to injuries or stress. However, the survival of small fish in EXCELLENT condition also was low. This indicated that the survival of small fish was underestimated because EXCELLENT fish showed no signs of injury or stress and criteria for judging condition were the same for fish of all sizes. I suspect that the parameters used to estimate the survival of small fish were in error as the values were from previous tagging experiments that involved mostly large fish. As previously mentioned, non-reporting of tags and losses other than fishing (primarily natural mortality) are probably higher for small fish than for large fish. If so, the survival of small fish was underestimated. I recalculated the survival of small fish in EXCELLENT condition using values of θ and X that would produce a survival comparable to that of large fish. For example, if θ was 0.50 (rather than 0.84) and X was 0.40 (rather than 0.34), then the survival of small fish in EXCELLENT condition would be 90% — similar to that estimated for large fish (92%) and more in agreement with the assumption from Beverton, Gulland, and Margetts (1959) that all EXCELLENT fish survive. The average survival of all small fish would then be 52%. Though the correct values are unknown and may differ from those in the example, I concluded that the average survival of small fish was higher than 28% and was probably close to 50%.

MANAGEMENT IMPLICATIONS

Although the survival of small fish is not known precisely, I assumed an average survival of 50% for all sizes and calculated the annual loss of halibut due to capture by domestic trawlers. The annual catch of halibut by domestic trawlers averaged about 3,500,000 pounds during 1970-1972; this was estimated from the method and rate of incidence used by Hoag (1971) and the fishing effort by trawlers (Pacific Marine Fisheries Commission, 1970-1972). With a 50% survival, the annual loss in biomass was 1,750,000 pounds: 875,000 pounds of small fish and 875,000 pounds of large fish. (About 20% of trawl-caught halibut are large fish, but these represent about half of the catch of halibut by weight.) In addition, Hoag showed that the loss in yield to the setline fishery exceeded the loss in biomass because most of the halibut caught by trawls were of ages where growth exceeds natural mortality. Using Hoag's model and parameter values, I estimated that the yield loss was approximately 1.5 times the loss in biomass of small fish and 0.8 times the loss in biomass of large fish. Therefore, the annual loss in yield was about 2,000,000 pounds: (1.5) (875,000) + (0.8) (875,000). The accuracy of this estimate, of course, is dependent on the assumption of a 50% survival.

IPHC is responsible for maximizing the yield of halibut and, consequently, for examining means of reducing the yield loss from trawling. The problem of reducing the yield loss, however, concerns the multi-species trawl fishery and, therefore, any solution must involve other management agencies. In 1975, IPHC recommended that Canada and the United States increase their research effort to reduce the incidental catch and develop management regimes which permit the optimum catch of halibut and other groundfish. Though further study is required before a proposal can be made, the means of reducing the loss in yield fall into three general categories: (1) modification of the trawl fishery to increase the survival of released halibut, (2) modification of the trawl fishery to reduce the incidental catch, and (3) allowance of retention of halibut by trawlers to convert part of the loss in yield into production. There are several alternatives within each category, some of which may be impractical because of social, economic, and enforcement problems.

The survival of released fish could be increased by changing the system of fishing and processing the catch. This change would require a reduction in the size of the trawl catch and immediate release of the halibut. Even if such a change were feasible, the loss of halibut still would be substantial. For example, when halibut were released within 10 minutes, in hauls of less than 5,000 pounds, the estimated survival of large fish was still only 70%.

A reduction in trawl effort during the summer would reduce the incidental catch of halibut; Hoag (1971) showed that the rate of incidence is highest during May-August. The production of the trawl fisheries would also be affected, however, as the groundfish catch during the summer is substantial. Table 4 shows the average effort and the catch of halibut and groundfish by season and area in the domestic trawl fishery during 1970-1972. About 55% of the groundfish catch occurred during May-August compared to about 90% of the halibut catch. The groundfish catch per unit of effort during September-April is similar to that during May-August, an indication that at least some species of groundfish can be harvested successfully during September-April. Also, some of the fish that are not harvested during May-August would be available during September-April.

Some reduction in the incidental catch would occur if trawl effort were shifted from Hecate Strait to Queen Charlotte Sound or Vancouver Island as Hoag (1971) showed that the incidence of halibut was about 30% higher in Hecate Strait. The shift, however, would increase the incidental catch in the other areas, and the net reduction in the annual incidental catch would only be about 300,000 pounds even if all the effort were shifted from Hecate Strait. A larger reduction would occur with a shift in target species; Hoag (1971) showed that the incidence of halibut was much lower in the fishery for Pacific ocean perch than for other species. Recent studies show that the incidence is also low in the fishery for dover sole. Pacific ocean perch and dover sole are now about 30% of the catch during May-August. If trawlers targeted only on these species during the summer, the incidental catch of halibut would be reduced by about 2,500,000 pounds annually.

Table 4. **Average effort (hours) and catch (millions of pounds) of halibut and groundfish by area and season in the domestic trawl fishery, 1970-1972.**

	Vancouver Island	Queen Charlotte Sound	Hecate Strait	Total
May - Aug.				
Effort	7,069	11,929	4,260	23,258
Halibut Catch	0.8	1.4	0.9	3.1
Groundfish Catch	9.1	16.3	6.6	32.0
Sept. - April				
Effort	8,173	5,784	4,970	19,017
Halibut Catch	0.1	0.1	0.2	0.4
Groundfish Catch	10.2	10.3	6.7	27.2
Total				
Effort	15,242	17,803	9,230	42,275
Halibut Catch	0.9	1.5	1.1	3.5
Groundfish Catch	19.3	26.6	13.3	59.2

* Based on Pacific Marine Fisheries Commission statistical areas: Vancouver Island—3C, 3D; Queen Charlotte Sound—5A, 5B; Hecate Strait—5C, 5D.

The use of off-bottom trawls would also reduce the incidental catch of halibut. Recent studies by the U.S. National Marine Fisheries Service (Ellis, unpublished) show that the catch of halibut is reduced substantially if the groundline of the trawl is over 1 foot off bottom. The effect of this type of trawl on the catch of groundfish has not been adequately assessed, but the catch of species which are not directly on the bottom probably would not be reduced substantially.

The regulation that prohibits the retention of net-caught halibut is a source of controversy between trawl and setline fishermen. Trawl fishermen have argued that the regulation is wasteful in that all halibut must be released regardless of condition. On the other hand, setline fishermen argue that if retention by trawlers were allowed, then trawl fishermen would direct their fishing effort toward halibut and the catch and mortality of halibut below optimum harvesting size would increase.

My findings indicate that a reduction in the yield loss might be achieved by allowing limited retention of trawl-caught halibut. Retention by trawls would increase the yield loss to the setline fishery, but would convert some of this loss to production by the trawl fishery. The net yield loss that occurs with retention by trawls is the difference between the loss to the setline fishery and the production to the trawl fishery. If the present incidental catch by trawlers (3,500,000 pounds) were landed, the loss to the setline fishery would increase from 2,000,000 pounds (based on a 50% survival) to 4,000,000 pounds, but the net yield loss would be reduced from 2,000,000 pounds to 500,000 pounds (4,000,000 — 3,500,000).

About 50% of the halibut catch (weight) by trawls is below the minimum legal size (81 cm) in the setline fishery and would be released if the same minimum size were adopted for the trawl fishery. The net yield loss would be higher than would occur with no size restrictions because of the mortality on sublegal halibut; trawl landings would be 1,750,000 pounds, the setline loss would be 2,700,000 pounds, and the net yield loss would be 950,000 pounds. Therefore, if retention by trawls were allowed, the maximum yield would occur with no size restriction.

There are at least two factors, however, that might reduce the benefits of allowing retention. First, if retention were allowed, trawlers would probably direct some of their effort toward halibut as the price of halibut is about seven times that of most groundfish species. The shift of effort would increase the catch of halibut below optimum size and reduce the benefits from allowing retention. For example, if the trawl catch increased from 3,500,000 pounds to 5,000,000 pounds, the loss to the setline fishery would increase to 5,750,000 pounds, and the net loss would be 750,000 pounds. This net loss is still less than the present loss with no retention (2,000,000 pounds) but is higher than the loss with retention and no increase in catch (500,000 pounds). Second, the enforcement of regulations would be complicated if retention by trawlers were allowed during periods when fishing was closed to setliners, and would be further complicated if size restrictions were different in the two fisheries. Solutions to the enforcement problem would probably require either uniform halibut regulations for the two fisheries or additional costs which would reduce the benefits of allowing retention.

This examination suggests several alternative schemes of management that could reduce the loss from the incidental capture of halibut by domestic trawlers. Individually, some schemes could adversely affect either the trawl or setline fisheries, but a combination of schemes could reduce the incidental catch of halibut and also optimize the catch of halibut and other groundfish. Before such a scheme is proposed, further study of its impact on the trawl and setline fisheries is required.

SUMMARY

General observations on the condition of halibut caught and released by Japanese trawlers indicate that survival is low. The low survival was attributed primarily to the time required to sort the catch.

The physical condition of over 2,000 halibut caught and released by domestic trawlers was judged, and fish were placed into one of five categories based on their external injuries and physical activity. Condition was positively correlated with length of fish and negatively correlated with time on deck and the weight of the total catch. Most of the halibut were tagged, and the recovery rate declined with poorer condition. The criteria for judging condition are meaningful, although not entirely accurate as some of the fish that were considered dead were subsequently recovered.

The survival of fish was estimated from the recovery rate of tags and expected rates of fishing mortality and other losses. The average survival of halibut in all conditions was 28% for those $\leqslant$80 cm to 55% for those $>$80 cm. The survival, however, for fish $\leqslant$80 cm was probably underestimated, and I concluded that survival for all sizes was about 50%. The estimates of survival indicate that about 1,750,000 pounds of halibut died annually during 1970-1972 as a result of incidental capture by domestic trawlers. Several ways of reducing this loss were examined. They included modifications of the trawl fishery to reduce the incidental catch and allowance of halibut retention by trawls to convert some of the loss into production.

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