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The Effect of Trawling on the Setline Fishery for Halibut

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

The catch and catch per unit effort (CPUE) of halibut in the Canadian and United States setline fishery declined sharply in the Bering Sea and the northeast Pacific during the 1960's and early 1970's. Part of the decline has been attributed to the incidental catch of halibut by the foreign and domestic trawl fisheries which expanded during this period, but only recently have estimates of the incidental catch been available to evaluate the effect of trawling on the setline fishery. The results show that trawling reduced the survival of juvenile halibut and, hence, recruitment to the setline fishery. Although yield loss was substantial, trawling accounts for only part of the decline in the setline catch and CPUE. CPUE began to decline when the yield loss from trawling was relatively low. The initial decline in CPUE was expected because the International Pacific Halibut Commission (IPHC) increased the setline catch in the 1950's to test estimates of maximum sustainable yield. However, CPUE continued to decline in the late 1960's and early 1970's, even though IPHC reduced the setline catch. Reduced recruitment apparently was responsible for part of the later decline in CPUE and probably was caused by adverse environmental conditions or reduced spawning stocks, as well as by trawling. To reduce the loss from trawling, IPHC proposed that foreign trawling be prohibited in areas and times when the incidental catch was high. Canada and the United States supported the proposal and, in subsequent negotiations, Japan and the U.S.S.R. agreed to trawl closures. These closures have reduced the mortality of juvenile halibut.

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INTRODUCTION

Domestic (Canadian and United States) fishermen harvest halibut *(Hippoglossus stenolepis)* with setline gear in the Bering Sea and the northeast Pacific, and the International Pacific Halibut Commission (IPHC) regulates the fishery. The catch and catch per unit effort (CPUE) of halibut declined sharply in the setline fishery during the 1960's and early 1970's. Bell (1970) attributed a large part of the decline to an expansion of foreign fishing (Japan and U.S.S.R.) in the northeast Pacific and the Bering Sea and to an increase in domestic trawling off British Columbia. Most foreign fishing is with trawls and Skud (1973) noted that halibut stocks began to decline when effort by trawlers was relatively low. Skud concluded that trawling accelerated the decline, but that the decline was initiated when IPHC increased the setline catch to test estimates of the maximum sustainable yield (MSY).

An assessment of the effect of trawling on the domestic setline fishery has been hampered by a lack of information on the magnitude of the halibut catch by trawls. The trawl fisheries are directed at other species of groundfish, and regulations prohibit the retention of trawl-caught halibut by domestic and Japanese fishermen. However, halibut are an incidental catch, and those that are released still represent a loss of biomass because many die from injuries received during capture (Hoag, 1975). The magnitude of this loss was unknown until recently because the incidental catch was not reported directly. Hoag (1971) and Hoag and French (1976) estimated the incidental catch by domestic and foreign trawlers from data collected by observers who sampled the groundfish catch. IPHC sampled the catch by domestic trawlers, and most of the data from foreign trawlers were collected in programs arranged through the International North Pacific Fisheries Commission (INPFC) or bilateral agreements and coordinated by the U.S. National Marine Fisheries Service (NMFS). These programs involved scientists from Canada, Japan, the United States, and IPHC. The results showed that the incidental catch increased sharply during the 1960's and early 1970's, varied with area and season, and consisted of halibut younger than those caught by setlines. To reduce the effect of trawling, IPHC proposed that certain critical areas be closed to trawling when the incidental catch of halibut was high and, through negotiations with Canada and the U.S., Japan and the U.S.S.R. agreed to most of the proposed closures (IPHC, 1976). The purpose of this report is to evaluate the effect of trawling on the domestic setline fishery and examine benefits that may accrue from the trawl closures. The effect of trawling was examined in several ways. The trend and magnitude of the incidental catch were compared with changes in the setline fishery and with changes in the abundance of juvenile halibut. The potential loss of yield to the setline fishery was estimated from a Ricker yield-per-recruit model.

THE HALIBUT CATCH

In evaluating the effect of trawling, it is important to recognize the limitations of the estimates of the incidental catch of halibut. The incidental catch was estimated by sampling the groundfish catch and extrapolating the observed incidence of halibut to the total groundfish catch by the fleet. Data on the incidence were meager or lacking in some instances, and several assumptions were required. Hoag and French (1976) discussed these limitations:

> "The estimates of the incidental catch do not account for the possibility that trawlers occasionally fish specifically for halibut. When halibut are concentrated they are a potential target species for trawls because their value is several times that of other groundfish. Halibut were not a target species when scientists were aboard, but the sampling may not have been representative of the entire fleet as Canadian and U.S. fishermen and enforcement officers occasionally have observed trawlers operating on productive halibut grounds and noted halibut catches of over a metric ton per haul. Further, Japanese vessels have been observed illegally retaining halibut and several have been apprehended. To the extent that foreign trawlers fish specifically for halibut, the estimates are less than the actual catch.
>
> Data on the incidence of halibut were meager or lacking in many months, areas, and years. Because of these limitations, several assumptions were required to estimate the halibut catch. First, data were available for only a few years, and it was necessary to assume that annual differences in the incidence were inconsequential and combine data from all years. Annual differences, however, occurred in the gear, the target species, and the abundance of halibut and other groundfish, and each of these factors could affect the incidence of halibut. In fact, the abundance of halibut generally declined during the 1960's and early 1970's (IPHC, 1976), and gear modifications (Takahashi, 1974) have increased the catch of the target species. As a result, we may have overestimated the halibut catch during the 1970's and underestimated the catch during the 1960's. The error, however, may be small as the abundance of other groundfish also declined during this period. A decline in the abundance of other groundfish would tend to compensate for the error caused by a decline in halibut abundance, i.e., the incidence of halibut was expressed as the number of halibut per metric ton of groundfish.
>
> Because data from Soviet trawlers were not sufficient to estimate their incidental catch, the incidence on Soviet trawlers was assumed to be the same as that observed on Japanese trawlers. This assumption may not be valid because observations suggest that Soviet trawls are fished off bottom more frequently than Japanese trawls. The problem of estimating the U.S.S.R. catch was further complicated in that the statistics of the total groundfish catch by U.S.S.R. trawlers are of questionable accuracy. R. C. Naab (NMFS, personal communication) reported major discrepancies in the magnitude and location of the U.S.S.R. catch when compared with the fishery activities documented by aerial surveillance reports. Also, the U.S.S.R. did not report their catch every year and reported it only for large areas in other years. For these reasons, estimates for the U.S.S.R. are less reliable than those for Japan."

Although individual estimates of the incidental catch are subject to error, the potential errors may be partly offsetting and, overall, I consider the estimates indicative of the general level of the catch. In any event, data are not available to improve the estimates.

The annual catch of halibut by trawls was compared with the catch by setlines in the Bering Sea (east and west of 175° W) and in IPHC regulatory areas in

the northeast Pacific: Area 2, waters south of Cape Spencer, Alaska, and Area 3, waters west of Cape Spencer (Table 1). *All catches are expressed as round weight.*

Table 1. Annual catch of halibut (m.t. round weight) by trawls and setlines in the Bering Sea and the northeast Pacific.

BERING SEA

Year	East of 175° W				West of 175° W			
	Foreign Trawl	Japanese Setline	Domestic Setline	Total	Foreign Trawl	Japanese Setline	Domestic Setline	Total
1954	52	0	0	52	0	0	0	0
1955	42	0	0	42	0	0	0	0
1956	102	0	158	260	0	0	0	0
1957	102	0	24	126	0	0	0	0
1958	168	0	1,316	1,484	0	1,271	0	1,271
1959	894	0	2,514	3,408	0	2,240	0	2,240
1960	2,166	0	3,416	5,582	0	6,931*	0	6,931
1961	3,229	0	2,398	5,627	0	11,141*	1	11,142
1962	2,257	0	4,343	6,600	112	9,898	86	10,096
1963	680	3,021	4,866	8,567	659	4,878	54	5,591
1964	867	243	1,392	2,502	1,299	466	17	1,782
1965	1,042	2	601	1,645	1,324	14	205	1,543
1966	1,284	1	672	1,957	2,542	214	52	2,808
1967	2,082	35	1,431	3,548	5,298	48	18	5,364
1968	2,696	0	797	3,493	3,243	168	2	3,413
1969	3,697	0	619	4,316	3,045	12	127	3,184
1970	3,982	0	524	4,506	5,411	5	161	5,577
1971	7,470	0	410	7,880	4,049	0	115	4,164
1972	6,364	0	199	6,563	2,751	0	325	3,076
1973	5,053	0	71	5,124	1,988	0	72	2,060
1974	4,547	0	110	4,657	1,299	0	154	1,453

NORTHEAST PACIFIC

Year	IPHC AREA 2				IPHC AREA 3		
	Foreign Trawl	Domestic Trawl	Domestic Setline	Total	Foreign Trawl	Domestic Setline	Total
1962	nil**	620	17,394	18,014	1,290	23,515	24,805
1963	nil**	567	15,879	16,446	2,976	22,364	25,340
1964	nil**	583	11,879	12,462	6,322	22,970	29,292
1965	nil**	756	14,727	15,483	9,103	22,788	31,891
1966	100	795	14,121	15,016	6,208	22,788	28,996
1967	347	691	11,939	12,977	4,475	20,061	24,536
1968	439	815	10,000	11,254	3,487	18,727	22,214
1969	377	961	13,576	14,914	2,236	21,030	23,266
1970	239	754	12,061	13,054	2,709	20,545	23,254
1971	231	894	10,182	11,307	1,839	17,576	19,415
1972	509	769	9,879	11,157	3,422	15,697	19,119
1973	519	629	7,939	9,087	2,976	11,175	14,151
1974	435	651	6,471	7,557	3,573	6,108	9,681

*Includes an unknown catch by Japanese trawlers.

**A small catch by U.S.S.R. trawlers may have occurred in this area.

The incidental catch by foreign trawls is from Hoag and French (1976), and the catch by domestic trawls is updated from Hoag (1971). (Data are not available on the incidence of halibut in the domestic shrimp and crab fisheries, and estimates of their incidental catch are not included.) Regulations prohibit the retention of halibut by domestic trawls and only 50% of their catch is shown in Table 1; this adjustment was based on the estimated survival of released halibut (Hoag, 1975). In the Japanese trawl fishery, the total groundfish catch is larger and the sorting process longer; as a result, the mortality of halibut released is near 100% and no adjustment was made. The location of the incidental catch was not always known for specific areas within the Bering Sea and the northeast Pacific, and in these cases, the catch was assigned an area based on aerial surveillance reports (R. C. Naab, NMFS, personal communication). Japan also has a setline fishery at times in the Bering Sea, and data on their halibut catch were obtained from unpublished documents by the Fisheries Agency of Japan (Far Seas Fisheries Research Laboratory, Shimizu, Japan) that were submitted to INPFC.

In the eastern Bering Sea, the halibut catch increased during two periods. During the first period, 1954 to 1963, the trawl and setline fisheries expanded and the total halibut catch increased from less than 300 m.t. to over 8,000 m.t. The incidental catch peaked at about 3,000 m.t. in 1961, and the setline catch increased sharply in 1963 to nearly 8,000 m.t. The sudden rise in the setline catch was caused by Japan's entry into the halibut fishery (Bell, 1970; Skud, 1973). Under the INPFC Convention, Japan agreed to abstain from fishing North American halibut stocks that are fully utilized. Although IPHC argued that stocks were being exploited at maximum levels, INPFC concluded that the evidence was not sufficient to support this position in the Bering Sea. In 1963, halibut were removed from the abstention list in the Bering Sea, and INPFC established the catch limit for the setline fleets of Canada, Japan, and the United States. The setline catch fell below 2,000 m.t. in 1964 and CPUE decreased sharply (Figure 1). Bell (1970) concluded that the setline catch in 1963 was excessive and that by 1964 "the stocks were decimated". After 1965, the total catch of halibut again increased and reached nearly 8,000 m.t. in 1971. This second increase was caused exclusively by the trawl fishery as the setline catch continued to decline. The CPUE by setlines did not increase during the late 1960's or 1970's, even though the catch and effort by the setline fishery has remained low since the mid-1960's.

In the western Bering Sea, the effect of trawling on the domestic setline fishery probably is small. The area has not been extensively fished by domestic setlines, and their annual catch usually was less than 200 m.t. The trawl fisheries may have indirectly affected the setline fishery in the eastern Bering Sea by reducing the number of halibut that emigrate from the western Bering Sea. This effect, however, apparently is small as IPHC estimated that only 1.2% of the halibut tagged in the western Bering Sea migrated to the eastern Bering Sea (unpublished document submitted to INPFC in 1973). On the other hand, trawling may have adversely affected the Japanese setline fishery in the western Bering Sea. Japanese setlines caught substantial quantities of halibut, exceeding 11,000 m.t. annually, in the late 1950's and early 1960's, but the catch declined sharply to less than 500 m.t. in 1964. Since 1970, halibut have not been reported by the Japanese setline fishery.

In the northeast Pacific, the estimated catch of halibut by trawls is much less than the halibut catch by setlines. Before 1962, there was no foreign trawl fishery

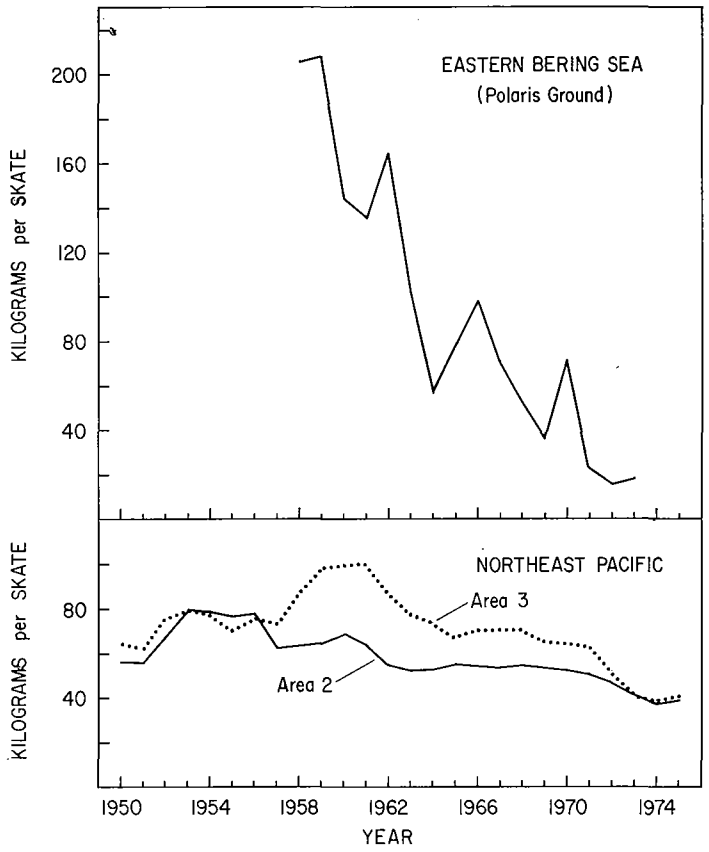

Figure 1. CPUE (round weight) in the domestic setline fishery, 1950-1975. Data are meager in the eastern Bering Sea since 1965.

and the incidental catch by domestic trawlers probably was less than 500 m.t. annually. In Area 2, the combined incidental catch by foreign and domestic trawlers was less than 800 m.t. annually before 1966 and has since fluctuated between 900 and 1,400 m.t. In contrast, the catch by setlines exceeded 22,000 m.t. in 1954 and then declined to about 6,000 m.t. in 1974. The incidental catch is considerably larger in Area 3 and increased from about 1,000 m.t. in 1962 to 9,000 m.t. in 1965 and then declined to about 3,000 m.t. in the early 1970's. The trawl catch of halibut, however, is still less than the setline catch which declined from over 23,000 m.t. in 1962 to about 6,000 m.t. in 1974. In both areas, the decline in the setline catch resulted from reduced catch limits imposed by IPHC following a sharp decline in the setline CPUE (Figure 1). Part of the decline in CPUE was expected as IPHC had allowed the setline catch to increase to test estimates of MSY (Bell, 1970; Skud, 1973). Setline CPUE, however, continued to decline in the late 1960's and early 1970's even though IPHC reduced the setline catch.

Several factors complicate the evaluation of the effect of trawling. First, trawl-caught halibut are younger than setline-caught halibut. Halibut caught by trawls are primarily juveniles (less than 65 cm long and usually less than 7 years old), whereas those caught by setlines usually are over 65 cm long. Trawling primarily reduces recruitment, the number of young halibut that enter the setline fishery, and

thus the full effect on the setline fishery occurs several years after the incidental catch. Also, the loss in yield to the setline fishery exceeds the incidental catch because the growth of juvenile halibut exceeds their natural mortality. Further, halibut migrate from the Bering Sea to the northeast Pacific and, therefore, trawling in the Bering Sea also affects the setline fishery in the northeast Pacific. These factors will be discussed later in the paper, but several conclusions can be drawn from trends in the incidental catch. In Area 2, the setline CPUE began to decline when the incidental catch was relatively low; this supports Skud's (1973) conclusion that the trawl fisheries were not responsible for the initial decline in the setline CPUE. The incidental catch in the eastern Bering Sea, however, was substantial from 1960 to 1962 and may have contributed to the initial decline in setline CPUE that occurred in Area 3 and the Bering Sea during the early 1960's. The incidental catch during the 1960's and 1970's undoubtedly contributed to the later decline in CPUE in all areas, but the effect varied with area. The magnitude of the incidental catch relative to the setline catch suggests that the effect of trawling probably was greatest in the Bering Sea and smallest in Area 2. The lack of information on the incidental catch hampered IPHC's management of the stocks. During the 1960's, data on the incidence of halibut were meager, and Bell (1970) estimated that the loss from foreign fishing was probably between 2,000 and 5,000 m.t. annually (all areas) and that this accounted for a large part of the initial decline in setline catch and CPUE. If IPHC had realized that the loss was greater than this and that the full effect would not occur until several years after the incidental catch, the setline fishery might have been curtailed more severely and sooner, thus preventing or reducing the decline in stocks.

LOSS OF RECRUITMENT

Reduced recruitment appears to be the primary cause of the low setline CPUE in the 1970's (IPHC, 1976). The decline in recruitment is evident in IPHC surveys of juvenile halibut in the Bering Sea and the northeast Pacific that show a decreasing catch rate since the mid-1960's. The cause of the reduced recruitment is not understood fully and environmental factors as well as the trawl and setline fisheries may have contributed to the decline. Most of the juveniles caught in IPHC surveys were 2 to 7 years old, whereas most of the halibut in the incidental catch were 4 to 7 years old (Hoag and French, 1976). To separate changes caused by trawling from those caused by factors affecting year class strength, i.e., environment and spawning stocks, trends in the abundance of 2- to 3-year-olds were compared with trends in the abundance of 4- to 7-year-olds. Only data from the Bering Sea survey were examined, and I used the CPUE at 34 index stations (Best, 1969a, 1969b, 1970, 1974, and unpublished data). Although the surveys began in 1963, only a few index stations were fished in 1963 and 1965 and none were fished in 1964.

The CPUE of halibut of both age groupings has declined since 1963 (Figure 2). The CPUE of 2- to 3-year-olds (not vulnerable to trawls) dropped sharply from 1963 to 1967, an indication that year class strength had declined. The cause of the decline is unknown, but may be related to adverse environmental conditions or to a reduction of spawners that followed the large removals of adult halibut by the setline fishery in the early 1960's. Caution is necessary, however, in interpreting the decline in the CPUE of 2- to 3-year-olds. Data were not available on the age composition of the incidental catch during the 1960's, and it was assumed to be

identical to that observed during the 1970's. The trawl fisheries, however, have changed or modified their gear, target species, and fishing locations since the 1960's, and these changes may have altered the age composition of the incidental catch. If there was a substantial catch of 2- and 3-year-olds, it may account for part of the apparent decline in year class strength. The incidental catch, however, does not account for the continued low CPUE of 2- to 3-year-olds during the 1970's.

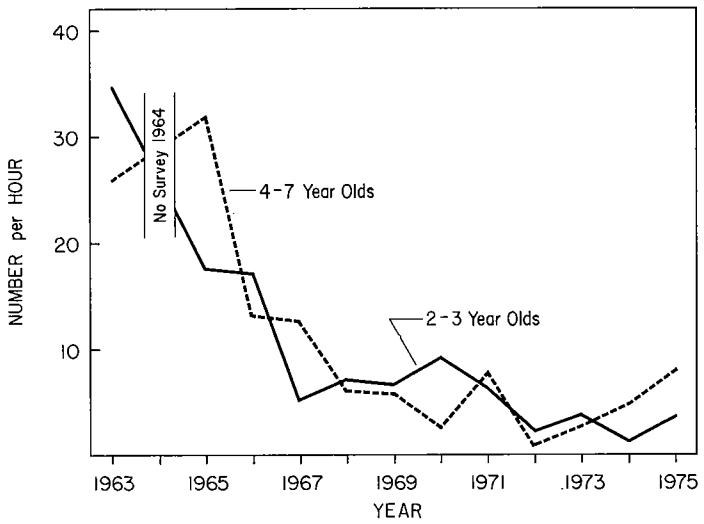

Figure 2. CPUE of juvenile halibut in IPHC surveys in the southeastern Bering Sea, 1963-1975.

The CPUE of 4- to 7-year-olds (vulnerable to trawls) also declined, but most of the decline occurred from 1965 to 1970 and followed the apparent reduction in year class strength. Trawling reduced the survival of juvenile halibut and became more important during the 1970's when the abundance of halibut was low and the trawl catch was large. During the 1970's, the CPUE of 2- to 3-year-olds continued to decline, but the CPUE of 4- to 7-year-olds increased after reaching a low in 1972. This increase coincides with a decline in the incidental catch from 1972 to 1974 (Table 1), and preliminary estimates indicate that the incidental catch continued to decline in 1975 as a result of trawl closures that are discussed in a later section. If the abundance of juvenile halibut increased because of a reduction in the incidental catch, the effect should be manifested as an increase in the survival. I estimated the annual survival of juvenile halibut by age in each year class:

$$\frac{\text{CPUE in year i + 1}}{\text{CPUE in year i}}$$

Survival varied considerably among ages and years, but the average survival for ages vulnerable to trawls declined from 0.5 in 1966-1967 to 0.2 in 1971-1972 and then increased to 0.7 in 1974-1975. These general trends indicate that the increase in the incidental catch during the late 1960's and early 1970's reduced the survival of juvenile halibut and that the subsequent decline in the incidental catch increased the survival. The CPUE of juveniles, however, is still much lower than during the early 1960's.

IPHC surveys of juvenile populations in the northeast Pacific also showed a decline in CPUE since the 1960's (IPHC, 1976). Sampling effort, however, has been small relative to the wide spatial distribution of halibut, and specific fishing locations have varied annually. IPHC presently is reexamining the data to standardize the results and establish an index of abundance, and therefore, I did not use data from the northeast Pacific to compare trends in CPUE of juveniles. The effect of trawling on recruitment in the northeast Pacific should be less than in the Bering Sea because the incidental catch is less relative to the setline catch and presumably to the population of juveniles. The effect of trawling is complicated, however, by the migration of halibut from the Bering Sea to the northeast Pacific. Dunlop et al (1964) estimated that 24% of the halibut tagged in the eastern Bering Sea migrated to the northeast Pacific over a 7-year period. I did not use Dunlop's estimate to predict the loss in the northeast Pacific because his estimate was based on only one year's tagging and may not be applicable to juvenile halibut; all of the tagged fish were over 80 cm long at release. Nevertheless, his estimate indicates that migration from the Bering Sea may be substantial, and hence, the incidental catch in the Bering Sea must be considered in evaluating the effect of trawling on the setline fishery in the northeast Pacific. Similarly, tagging experiments indicate that significant migrations occur within the northeast Pacific (Bell and Best, 1968; Skud, 1975). Most of the migrations have been eastward and apparently counteract the westward drift of eggs and larvae (Dunlop et al, 1964). This indicates that the incidental catch in Area 3 also affects the setline fishery in Area 2.

LOSS OF YIELD

If young halibut were not caught by foreign trawlers, some would die naturally and others would grow and eventually be caught by domestic setliners. The catch of halibut by trawls is analogous to a loss of recruitment to the setline fishery, and a Ricker (1958) yield-per-recruit model was used to estimate the resulting loss of yield to the setline fishery. The yield loss varies with the age of halibut in the trawl catch, and the expected loss from the capture of halibut of a given age was estimated from Ricker's Equation 10.3 (page 209) by assuming that "$W_{T\,(O)}$" (the initial biomass) is the weight of the fish at the time of trawl-capture. The yield loss is estimated by applying instantaneous rates of setline fishing mortality, natural mortality, and growth to this initial biomass over the projected life of the fish. This procedure is repeated for each age in each year's trawl catch, and the results are totaled by the year in which the loss took place.

Ricker's model provides a convenient method of estimating the yield loss, but the values of the parameters in the model are not known precisely and probably vary with time and area. The parameters have been estimated in previous studies (IPHC, 1960; Chapman, Myhre, and Southward, 1962; Myhre, 1967, 1969, and 1974; and Southward, 1967), and I used the following values: a fishing mortality by setlines of 0.2, an age of entry into the setline fishery of 7 years (i.e., fishing mortality was zero before 7 years), a natural mortality of 0.2, and the growth rates from Myhre (1974). The age distributions from Hoag (1971) and Hoag and French (1976) were used to estimate the trawl catch of halibut by age.

Because the parameters in the model are not known precisely, I varied the parameter values to test the effect of error on the estimates of yield loss. IPHC (1960) and Myhre (1967) reported estimates of fishing mortality that generally ranged from 0.1 to 0.3. Within this range, the estimates of yield loss varied about

25%. Also, the yield loss occurred sooner when fishing mortality was higher: about 75% of the yield loss occurred during the first 5 years (after a given incidental catch) when fishing mortality was 0.3 compared to 50% when fishing mortality was 0.1. Age of entry is known more precisely than fishing mortality and, within the range of likely values, is not critical to the estimates of yield loss: yield loss changed less than 10% when age of entry ranged from 6 to 8 years. Growth and natural mortality have the greatest effect on the estimates of yield loss. I accepted the growth rates reported by Myhre (1974) and did not examine the effect of errors in the estimates of growth. Growth, however, does differ among areas and increased substantially from the 1920's to the 1960's (Southward, 1967). Estimates of natural mortality are not precise and range from 0.1 to 0.3 (IPHC, 1960). Further, natural mortality has not been estimated for halibut below the age of entry in the setline fishery, and Hoag (1975) indicated that natural mortality is probably higher for halibut less than 80 cm long. The yield loss is about three times higher if natural mortality is 0.1 than if it is 0.3. Another source of error is that the parameters were estimated with data collected from the setline fishery which catches predominately females (Southward, 1967). The sex composition of the incidental catch is not well known, but limited data suggest that at least half of the catch are males (Hoag and French, 1976). Female halibut grow faster than males (Southward, 1967), and recent studies indicate that natural mortality may be higher for males (Myhre, unpublished). This suggests that the yield loss may be overestimated. For these reasons, the estimates of yield loss are subject to error but, nevertheless, are useful as an indication of the potential loss to the setline fishery.

Table 2 shows the potential yield loss from trawling in the eastern Bering Sea and the northeast Pacific. Estimates were not calculated for the western Bering Sea because, as previously mentioned, trawling in the western Bering Sea apparently has little effect on the domestic setline fishery. In the eastern Bering Sea, the yield loss increased to over 1,000 m.t. in the early 1960's, an indication that trawling contributed to the initial decline in CPUE of the setline fishery. The yield loss continued to increase and by 1974 was over 5,000 m.t., similar to the peak catch by domestic setlines in the early 1960's (Table 1). Dunlop et al (1964) estimated that MSY was about 3,000 m.t. (round weight) in the southeastern Bering Sea, the most productive area for the setline fishery. The estimates of yield loss exceeded the MSY and suggest that trawling essentially eliminated the yield available to the domestic setline fishery. These results show that trawling had a greater effect on the setline fishery than was indicated by changes in the abundance of juvenile halibut that were discussed in the previous section.

Conclusions regarding the yield loss in the northeast Pacific depend, in part, on the extent of the migration of halibut from the Bering Sea and between Areas 2 and 3. If migration was negligible, the estimates indicate that trawling had little effect on the setline fishery in Area 2. The yield loss was less than 500 m.t. before 1968 and less than 1,000 m.t. in 1974. The yield loss in 1974 was less than 15% of the total yield (setline catch plus yield loss) and about 5% of the MSY (19,400 m.t. round weight) estimated by Chapman, Myhre, and Southward (1962). Trawling had a greater effect in Area 3 where the yield loss increased to almost 4,000 m.t. in 1974, nearly 40% of the total yield. The yield loss, however, accounts for only part of the decline in the setline catch and CPUE. The yield loss was only 75 m.t. in 1962 when CPUE began to decline and, in 1974, was only

Table 2. Potential yield loss (m.t.) to the domestic setline fishery from foreign and domestic trawling.

Year	Eastern Bering Sea	Northeast Pacific			All Areas Total
		Area 2*	Area 3	Total	
1954	3				3
1955	8				8
1956	17				17
1957	33				33
1958	51				51
1959	112				112
1960	282				282
1961	602				602
1962	1,011	51	75	126	1,137
1963	1,364	150	327	477	1,841
1964	1,618	231	887	1,118	2,736
1965	1,705	311	1,901	2,212	3,917
1966	1,649	400	3,006	3,406	5,055
1967	1,658	487	3,974	4,461	6,119
1968	1,766	582	4,752	5,334	7,100
1969	2,029	699	4,972	5,671	7,700
1970	2,376	783	4,884	5,667	8,043
1971	2,981	870	4,269	5,139	8,120
1972	3,733	935	4,321	5,256	8,989
1973	4,449	969	3,970	4,939	9,388
1974	5,172	997	3,946	4,943	10,115

*Excludes the loss from domestic trawling before 1962.

18% of the MSY (21,800 m.t. round weight) estimated by Chapman, Myhre, and Southward (1962). Trawling did not initiate the decline in the setline catch and CPUE, but the lack of a quantitative measure of the yield loss may have led to overexploitation by the setline fishery. When CPUE fell during the 1960's, IPHC gradually reduced the catch limit in the setline fishery. Estimates of the yield loss were not available to IPHC and it now appears that the reductions in the setline catch were not sufficient to compensate for the increase in yield loss. The total yield exceeded MSY (21,800 m.t.) from 1962 to 1971 and peaked at 26,000 m.t. in 1969 (Figure 3). The equilibrium yield probably declined below MSY as the setline CPUE dropped by 60% from 1962 to 1974 and, hence, the degree of overexploitation was even greater than indicated by the comparison of MSY with total yield.

If Areas 2 and 3 are combined (assuming migration was substantial), the yield loss in 1974 accounts for nearly 30% of the 1974 total yield and about 12% of the estimated MSY. The effect of trawling would be greater in Area 2 and less in Area 3 than indicated in the previous paragraph. If areas of the northeast Pacific are combined with the eastern Bering Sea, the total yield loss in 1974 was about 10,000 m.t., 44% of the 1974 total yield and 23% of the combined estimates of MSY. Regardless of how the areas are combined, the yield loss from trawling accounts for only part of the total decline in setline catch and CPUE in the northeast Pacific. As previously stated, however, the lack of information on yield loss may have led to overexploitation by the setline fishery.

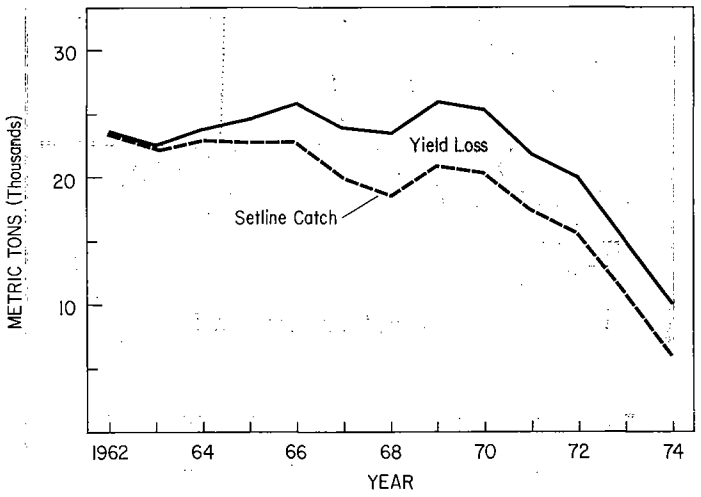

Figure 3. Setline catch and yield loss in Area 3, 1962-1974.

TRAWL CLOSURES

Realizing the importance of the trawl fisheries and recognizing that trawling will continue even if national fishing zones are extended, IPHC proposed a scheme that would reduce the incidental catch of halibut but allow the continuation of a profitable trawl fishery (IPHC, 1974, 1975, 1976; Hoag and Skud, 1975). In 1973, IPHC recommended that foreign trawling be prohibited in particular areas of the Bering Sea during the winter months when the incidence of halibut was high but trawl effort was low. Other areas would remain open to trawling year-round, and the closed areas would be open to fishing the remainder of the year, thereby allowing time and area to conduct a productive trawl fishery. At the annual meeting of INPFC (November 1973, Tokyo), the governments of Canada and the U.S. supported the proposal, but it was not accepted by Japan. In subsequent negotiations, Japan agreed to prohibit trawling in parts of the southeastern Bering Sea from December to March 1974. Analysis of additional data, however, showed that the incidence of halibut also was high during the spring and that additional closures were needed. In response to a second proposal by IPHC in 1974, trilateral negotiations continued, and Japan agreed to extend the duration and area of the Bering Sea closures for 1975. Further, closures were adopted in the northeast Pacific as a result of bilateral negotiations between Japan and the U.S. Closures also were discussed with the U.S.S.R. on several occasions and similar agreements finally were reached for 1976-1977 during U.S.-U.S.S.R. bilateral negotiations.

Figure 4 shows the area and duration of the closures that pertain to halibut in the Bering Sea and the northeast Pacific. Japan and the U.S.S.R. also agreed to refrain from fishing in certain areas for several days immediately before and after the opening of the halibut fishing season, and several areas (not depicted) are closed to protect crabs. These closures also reduce the incidental catch of halibut. In the Bering Sea, trawling is prohibited in most of the areas and months when the incidence of halibut is high, and the closures provide significant protection. In 1974, the first year that Japan instituted closures, the incidental catch by Japan declined by about 700 m.t. in the areas affected by the closure (Hoag and French, 1976). Data are not available to estimate the savings that resulted from the

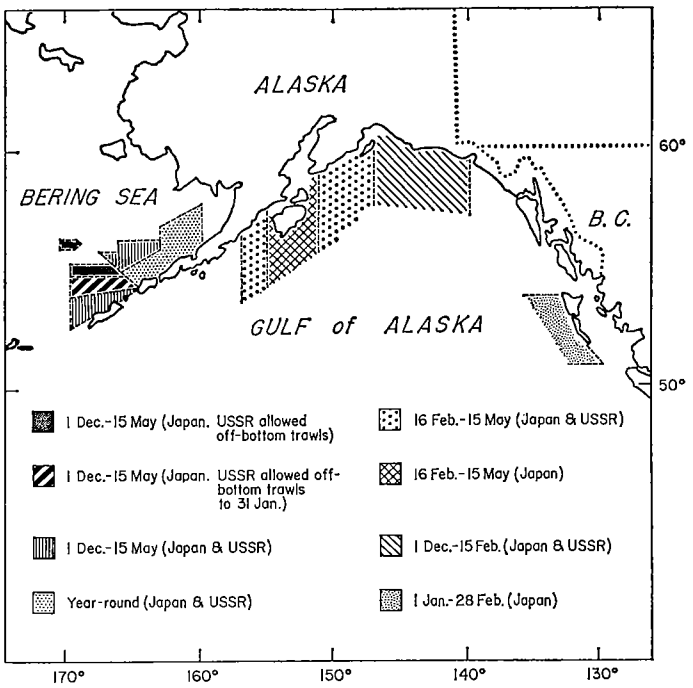

Figure 4. Japanese and Soviet trawl closures pertaining to halibut in the Bering Sea and the northeast Pacific.

expanded closures in 1975, but projections based on the past distribution of Japanese fishing effort indicate that the incidental catch declined an additional 400 m.t. in 1975. A further decline is predicted in 1976 when the U.S.S.R. institutes trawl closures. The Soviet closures are the same as the Japanese except that Soviet trawlers can fish with off-bottom trawls in some months and areas that are closed completely to the Japanese. If the U.S.S.R. adheres to the off-bottom provision, the agreements are essentially the same with regard to halibut and should result in savings of about 1,000 m.t. in 1976. In short, the closures for Japan and the U.S.S.R., coupled with the reduction in total Japanese groundfish catch that occurred during 1972-1974, should reduce the incidental catch in the eastern Bering Sea by nearly 4,500 m.t. or about 60% of the peak catch in 1971.

In the northeast Pacific, halibut are more widely distributed, and the closed areas do not provide the degree of protection that occurs in the Bering Sea. Closures were not in effect until 1975, and therefore, data are not available to directly estimate the savings. Based on the distribution of Japanese effort in recent years, the closures reduced the incidental catch by about 500 m.t. However, if fishing effort was not reduced, but rather shifted to open areas where the incidence of halibut is nearly as high as in the closed areas, then the effect of the closures may be minimal. The incidental catch in the northeast Pacific has generally been less than in the Bering Sea because of less fishing effort. The potential incidental catch, however, is actually much greater in the northeast Pacific because of the higher incidence of halibut in trawl catches. Consequently, steps should be taken to insure that the incidental catch does not increase. This could be accomplished with expanded time-area closures, effort restrictions, and gear modifications. IPHC has urged its national governments to develop effective means of reducing the

incidental catch of halibut and specifically proposed that an experiment be conducted to test the effects of off-bottom versus on-bottom trawls. In 1975, Canada, Japan, and the U.S. developed such a study under the auspices of INPFC, and it is presently in operation. Preliminary results indicate that the incidence of halibut in the experimental off-bottom trawl was less than half of that in the on-bottom trawl.

The immediate result of the closures should be an increase in the abundance of juveniles, and as previously mentioned, IPHC's surveys showed that the abundance increased in the Bering Sea in 1975, just one year after the closures were instituted. Eventually, the number of older halibut available to the setline fishery also will increase, but this will not occur for several years because of the age difference between trawl- and setline-caught halibut. However, because factors other than trawling are at least partially responsible for the decline in the abundance of juveniles and yield in the setline fishery, trawl closures alone will not restore stocks to former high levels.

IPHC has also examined means of reducing losses from incidental catches by domestic trawlers (Hoag, 1975; Hoag and Skud, 1975). The problem is similar to that encountered with the foreign trawl fisheries in that it involves a multi-species fishery and several management agencies. In 1975, IPHC recommended that Canada and the United States increase their research effort to reduce the incidental catch by the domestic trawl fishery and develop management regimes which permit the optimum catch of halibut and other groundfish. Although further study is needed, a reduction in the loss from domestic trawlers could be achieved by modifying the trawl fishery to reduce the incidental catch or allowing limited retention of halibut by domestic trawlers to convert part of the loss into production or by combining aspects of both methods. Several alternative schemes of management should be considered, some of which may be impractical because of social, economic, and enforcement problems. Individually, schemes could adversely affect either the trawl or setline fisheries, but a combination of schemes could improve the catch of halibut without reducing the catch of other groundfish.

SUMMARY

During the 1960's and early 1970's, foreign trawl fisheries expanded in the Bering Sea and the northeast Pacific, and the domestic trawl fishery expanded off British Columbia. The trawl fisheries were directed at other groundfish, but halibut were an incidental catch. The catch and CPUE in the domestic setline fishery also declined during the 1960's and 1970's, but the effect of trawling could not be evaluated until recently because the halibut catch by trawls was unknown. Hoag (1971) and Hoag and French (1976) estimated the halibut catch by extrapolating the incidence of halibut in samples of the groundfish catch to the entire fishery. They found that the halibut catch by trawls was substantial and consisted of fish younger than those caught by setlines. Using these estimates of the halibut catch, the effect of trawling on the setline fishery was evaluated in several ways. The trend and magnitude of the halibut catch by trawls was compared with changes in the setline fishery and with trends in the abundance of juvenile halibut. The potential loss of yield to the setline fishery was estimated from a Ricker yield-per-recruit model.

The results show that by the early 1970's trawling accounted for about 95% of the total halibut catch in the Bering Sea and 15% in the northeast Pacific. Trawling reduced the survival of juvenile halibut and, hence, recruitment to the

setline fishery. The estimated yield loss to the setline fishery was substantial, increasing to over 5,000 m.t. in 1974 in the eastern Bering Sea and averaging about 5,000 m.t. since 1967 in the northeast Pacific. The loss from trawling, however, explains only part of the decline in the setline catch and CPUE. In the northeast Pacific, the setline CPUE began to decline when the loss from trawling was relatively low, and the estimates of yield loss (Areas 2 and 3 combined) in 1974 account for only 12% of the estimated MSY. The initial CPUE decline occurred after IPHC allowed the setline catch to increase to test estimates of MSY (Skud, 1973). The lack of information on the magnitude of the yield loss may have led to overexploitation by the setline fishery as reductions in the setline catch were not sufficient to compensate for the increase in yield loss. Reduced recruitment probably is partly responsible for the present low stock size. Although trawling contributed to the reduced recruitment, the abundance of juvenile halibut in the Bering Sea declined at ages younger than those caught by trawls, an indication that adverse environmental conditions or reduced spawning stocks also affected recruitment.

Several sources of error should be recognized. Data on the incidence of halibut were meager or lacking in some instances, and the estimates of the incidental catch do not account for trawl fisheries that occasionally may fish specifically for halibut. Further, halibut migrate and the trawl fishery in one area may affect the setline fishery in another area. Also, the parameters in the yield model are not known precisely, and the estimates of the yield loss are subject to considerable error. Although data are not available to improve the results, the potential errors may be partly offsetting.

To reduce the effect of trawling on the setline fishery, IPHC proposed that foreign trawling be prohibited in areas of the Bering Sea and the northeast Pacific when the halibut catch by trawls was high. The governments of Canada and the United States supported the proposal and, in subsequent negotiations, Japan and the U.S.S.R. agreed to trawl closures. In the Bering Sea, juvenile halibut are concentrated with respect to time and area, and the closures provide significant protection. In the northeast Pacific, however, halibut are more widely distributed, and the closed areas do not provide the degree of protection that occurs in the Bering Sea. The closures reduced the mortality of juvenile halibut, and IPHC surveys show that the abundance of juveniles increased in the Bering Sea in 1975, just one year after the closures were instituted. In time, the closures will increase the abundance of older halibut available to the setline fishery.

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