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Pacific Halibut Bycatch in the Groundfish Fisheries: Effects on and Management Implications for the Halibut Fishery

by

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Contents

ABSTRACT

The International Pacific Halibut Commission is responsible for the conservation of the Pacific halibut resource. Management practices implemented to meet this objective include monitoring stock levels and determining allowable quotas for the directed Pacific halibut fishery. Retention of Pacific halibut bycatch (removals by fisheries directed at other species) is prohibited. Not all halibut discarded as bycatch survive, so bycatch mortality is an important factor to consider when assessing the impact of removals on the stock. High levels of bycatch of halibut make the attainment of the conservation objective complex. Bycatch mortality impacts the halibut fishery by reducing the reproductive potential of the population and by reducing the fish biomass otherwise available to the fishery. A method to determine the compensation necessary to account for loss of reproductive potential is developed. The compensation accounts for the lifetime egg production of bycaught fish by replacing it with production of fish forfeited from the direct fishery. The results indicate that a one-pound reduction of the allowable direct catch for each pound of bycatch mortality should circumvent long term effects on stock production. Approximately 1.7 pounds are lost as yield to the fishery per pound of bycatch mortality. Further application of the methodology indicates that length distributions of bycatch determine the required level of the reproductive compensation and the magnitude of the yield losses. This is illustrated through the analysis of data from three Pacific cod fisheries with different gear-specific selectivities for halibut and through the analysis of data from the 1990-1991 groundfish fisheries.

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INTRODUCTION

Authority for management of the Pacific halibut (*Hippoglossus stenolepis*) fishery and responsibility for conservation of the resource is designated to the International Pacific Halibut Commission (IPHC) by the Pacific Halibut Convention, a treaty established between the United States and Canada in 1923. The treaty was most recently amended in 1979 (McCaughran and Hoag 1992). A major conservation goal of the IPHC under the Halibut Convention is to maintain the halibut resource at a level that supports optimum yield. To reach this goal, the Halibut Convention authorizes the IPHC to define management areas, establish seasons and quotas by management area, set size limits, and determine allowable gear. Each country may establish its own procedures for domestic allocation, provided they are not in conflict with IPHC regulations.

Identifying the source of fishing mortality was straight forward during the first 35 years of the IPHC stewardship when the only removals were the domestic longline catches by Canadian and U.S. fishermen. In the late 1950s, however, bycatch of halibut by fishing fleets targeting on other species obscured the level and origins of fishing mortality, causing a serious management and conservation problem in the North Pacific. Halibut bycatch is estimated from a bycatch rate, usually given as weight of halibut per unit weight of groundfish or weight of halibut per unit of fishing effort, and is multiplied by the total weight or effort of groundfish. Under domestic regulations, halibut bycatch must be discarded at sea, and depending on fishing and handling methods, the discard mortality rate can range from near zero to almost 100%. Thus, bycatch mortality is calculated as the product of bycatch and the discard mortality rate.

IPHC has established management areas for the halibut fishery (Figure 1). In U.S. waters the majority of the Pacific halibut bycatch occurs off Alaska. Bycatch in Alaskan waters is under the management of the North Pacific Fishery Management Council (NPFMC). The NPFMC requires mandatory observer coverage in the groundfish fisheries, and sets and allocates a bycatch mortality limit among the several fisheries that take place in the region. The National Marine Fisheries Service (NMFS) administers the observer program and estimates bycatch and bycatch mortality. Premature closure has occurred for groundfish fisheries that exceed halibut bycatch limits. Bycatch mortality limits currently in effect for Alaska, 12.3 million pounds net weight[1] in 1993, are higher than bycatch levels of about 7-9 million pounds achieved in the mid 1980s. Canada recently began a bycatch reduction program that includes observers and a bycatch mortality reduction schedule. The Canadian Department of Fisheries and Oceans provides data on bycatch and bycatch mortality. The Pacific Fishery Management Council (which manages fisheries off Washington, Oregon, and California) does not actively manage or monitor bycatch. Bycatch and bycatch mortality

[1]Accounting for Pacific halibut landing has traditionally been in pounds net weight (head off, guts out, and ice and slime removed). Net weight is 0.75 of round weight. Groundfish harvest is commonly measured in metric tons round weight, and will be so designated in this report. Because bycatch impacts presented later are ratios, the mixing of pounds net weight for halibut and mt round weight for groundfish should not cause confusion.

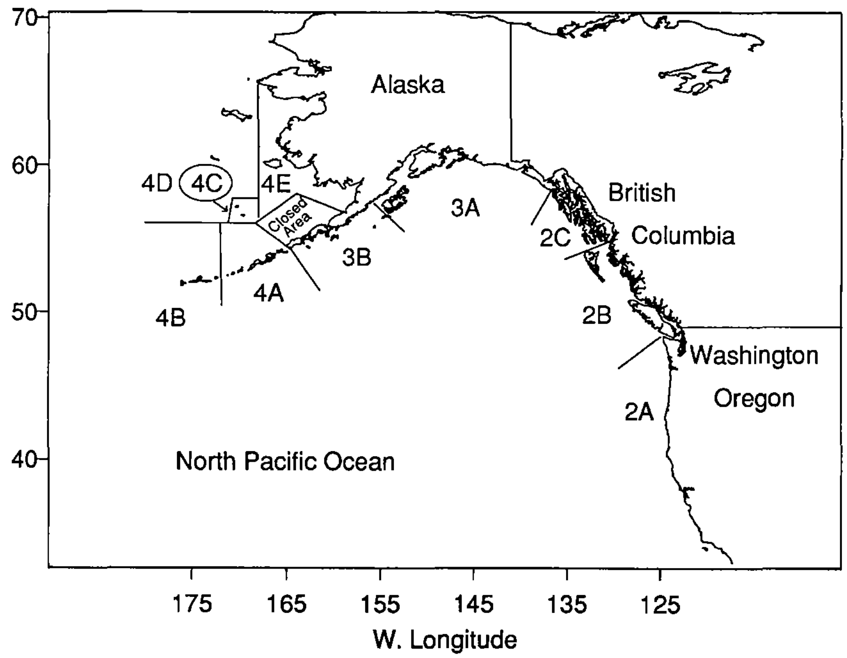

Figure 1. IPHC regulatory areas, 1993.

estimates are made indirectly from survey data. Estimated coast-wide halibut bycatch mortality totaled 15.0 million pounds in 1993.

To compensate the halibut stock for the loss in production caused by bycatch mortality in other fisheries, the IPHC reduces the directed commercial halibut catch quota. The intent of quota reductions is to allow adult halibut to remain at large to reproduce, so that stock reproduction would be the same as if bycatch had not occurred. However, the bycatch reproductive compensation occurs several years earlier than the reproduction that would have occurred if the bycaught halibut had remained at large. Estimating the appropriate level of quota reduction, determining the loss to the directed halibut fleet resulting from this reduction, and factoring in the additional yield loss due to bycatch mortality requires an understanding of how and where directed commercial catch and bycatch occur and how these different sources of removal interact with the growth, mortality, and migration of the halibut population. The reproductive potential of halibut in the bycatch must be contrasted with that of adult halibut that occur in the commercial catch to determine the level of quota reduction needed to offset the reproductive loss due to bycatch.

The directed commercial halibut harvest takes place in the coastal waters of the North Pacific and has a minimum size limit of 32 in (81.3 cm) fork length. The greater portion of this catch is taken in the central Gulf of Alaska and in waters off British Columbia (IPHC 1993). In contrast, most halibut bycatch occurs in groundfish fisheries conducted in the Bering Sea (Williams et al. 1989), killing smaller, younger halibut that would likely undergo extensive migrations.

The purpose of this report is to document the effects of Pacific halibut mortality that results from non-direct removals and to develop management actions that ameliorate the effects of this mortality on the long-term reproductive potential of the Pacific halibut stock. The issue of bycatch could also be addressed from a number of economic and social perspectives (Queirolo et al. 1989, Thompson, In press) that will not be dealt with here.

This report addresses the issue of bycatch, its effect on the halibut fishery, and its implications for management in three ways. First, the history of Pacific halibut bycatch is reviewed to provide a perspective on the magnitude, location, timing, and source of this mortality. Second are developed the procedures to assess the impact of bycatch on the stock and on the fishery, to account for the impact on the stock, and to examine consequences of these procedures to yield in the directed halibut fishery. Third is broadening the approach to address changes in size composition of individuals in the bycatch and changes in organization of the groundfish fleet.

HISTORICAL PERSPECTIVE OF HALIBUT BYCATCH

Halibut bycatch mortality was relatively insignificant until the late 1950s and early 1960s when it increased rapidly due to the sudden influx of foreign fishing vessels off the North American Pacific coast (Williams et al. 1989). Bycatch in the foreign fleets was originally unrestricted and unmonitored. Negotiations with the corresponding governments resulted in agreements that imposed time and area closures designed to limit bycatch, required bycatch reporting, and required monitoring by U.S. observers (Fredin 1987, Trumble 1992).

The Magnuson Fishery Conservation and Management Act gives priority in allocating groundfish first to fully domestic operations, second to domestic fishermen who sold to foreign processors (joint ventures), and last to foreign fishermen. Closed areas previously negotiated with fishing countries were imposed on the foreign and joint venture fisheries. Subsequently, the NPFMC developed Groundfish Fishery Management Plans for the Bering Sea-Aleutian Islands and the Gulf of Alaska, and mandated a series of bycatch controls on foreign and joint venture fishing fleets. These included time-area closures such as a Bristol Bay Pot Sanctuary, a Bering Sea Winter Halibut Savings Area, and a longline Sanctuary in the Gulf of Alaska. These controls required observer coverage of all foreign and joint venture fishing operations. Also, in 1982 the NPFMC established a halibut bycatch reduction policy for the foreign fisheries which required foreign fisheries to reduce bycatch rates by 50% by 1987.

Initially, domestic fishing operations had less severe restrictions than those required for foreign operations, and joint venture operations were not bound to the 50% bycatch reduction schedule. Bycatch savings from foreign rate reductions dissipated as joint venture and fully domestic operations replaced foreign fishing. The NPFMC allowed year-round groundfish trawling for domestic fishermen in the Bering Sea Pot Sanctuary and in the Winter Halibut Savings Area. In 1985, the NPFMC imposed a bycatch limit for all bottom trawl fisheries in the Gulf of Alaska. In 1987, the NPFMC closed a portion of the eastern Bering Sea year-round to trawling, and placed a limit on the amount of halibut bycatch by yellowfin sole and other flatfish fisheries in a portion of the Bering Sea. In 1989, the NPFMC extended bycatch limits to all Bering Sea groundfish bottom trawl fisheries, specified zones to be closed when part or all of the bycatch quota was reached, and allocated the bycatch quota among specific fisheries. The bycatch limit was extended to fixed gear in Gulf of Alaska in 1990, and to the Bering Sea in 1992. A mandatory observer program for fully domestic fisheries began in 1990 for all Alaskan waters.

The total estimated bycatch mortality[2] (Figure 2) peaked in 1962 at about 25 million pounds net weight, although the actual amount may have been higher. After 1962, bycatch generally decreased with sporadic surges to around 20 million pounds in 1971, 1980 and 1990. A slight decline in bycatch mortality occurred through 1993. Before the 1980s bycatch mortality from all sources (Table 1) was generally greatest in the Gulf of Alaska (Areas 2C and 3). Bycatch mortality in the Gulf of Alaska peaked in the early 1980s at around 7 million pounds, fell to a low of about 1 million pounds in the mid 1980s, and increased again to over

[2]The Japanese conducted directed fishing for halibut from 1960-1964 under the authority of the International North Pacific Fisheries Commission. The IPHC opposed Japanese directed fishing on the grounds that halibut was fully utilized (Bell 1981). For accounting purposes, these landings are included with the bycatch.

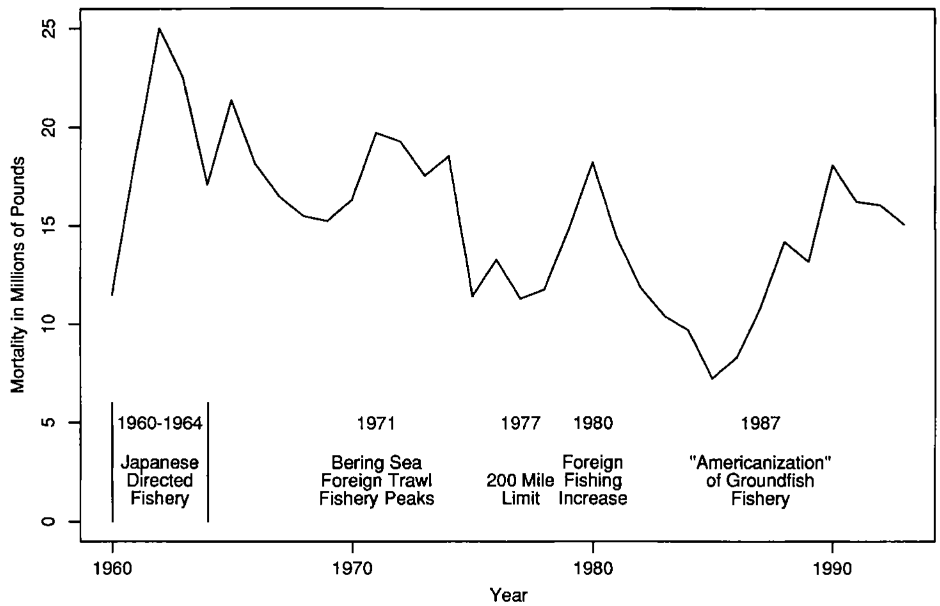

Figure 2. Pacific halibut bycatch mortality from 1960-1993.

Table 1. Pacific halibut bycatch mortality by IPHC regulatory area (thousands of pounds).

Year	Area 2B	Area 2C	Area 3	Area 4	Total
1978	1,471	377	4,895	5,023	11,765
1979	1,852	821	6,715	5,419	14,806
1980	1,372	520	7,099	9,257	18,248
1981	1,188	507	6,282	6,508	14,484
1982	867	302	5,972	4,776	11,918
1983	943	304	4,892	4,269	10,407
1984	1,074	302	3,647	4,984	10,007
1985	1,139	301	1,578	4,207	7,225
1986	1,161	303	1,246	5,576	8,286
1987 *	1,649	303	3,113	5,738	11,348
1988 *	1,609	303	3,415	8,858	14,730
1989 *	1,498	303	4,086	7,282	13,715
1990 *	1,679	875	6,437	8,520	18,058
1991 *	1,992	715	5,367	7,567	16,186
1992 *	1,745	616	4,969	8,148	16,023
1993 *	1,579	722	5,340	6,826	15,012

*Bycatch mortality estimates of 545,000 pounds for Area 2A are included in the total.

6 million pounds in 1990. In the mid 1980s, the relative importance of the bycatch in the Bering Sea (Area 4) began to increase as joint venture operations, processing domestically-caught groundfish, started to displace the foreign fishing fleets. Bycatch mortality has not fallen below 4 million pounds in the Bering Sea since 1978, and peaked at 9.2 million pounds in 1980. Bycatch mortality in British Columbia (Area 2B) remained fairly constant at about 1.0 to 1.5 million pounds from the early 1960s to the mid 1980s, then increased to about 1.5 to 2.0 million pounds. A single estimate of 545,000 pounds of bycatch mortality from Washington-Oregon-California waters (Area 2A) was made in 1993 from 1987 data (G. H. Williams, IPHC, Seattle, personal communication) and applied to subsequent years pending updated values.

Coast-wide bycatch mortality during the early 1990s reached levels comparable to the peak values of the early 1980s. The recent increase in incidental mortality, especially off Alaska, occurred despite a reduction in foreign and joint venture fishing, and seems to be due to higher bycatch rates experienced by the fully domestic groundfish fisheries. For example, over the past several years bycatch mortality has fluctuated with the mixed contributions of foreign, joint venture and fully domestic fishing (Figure 3). However, total groundfish harvest and relative species composition has not changed significantly. In the Bering Sea, for

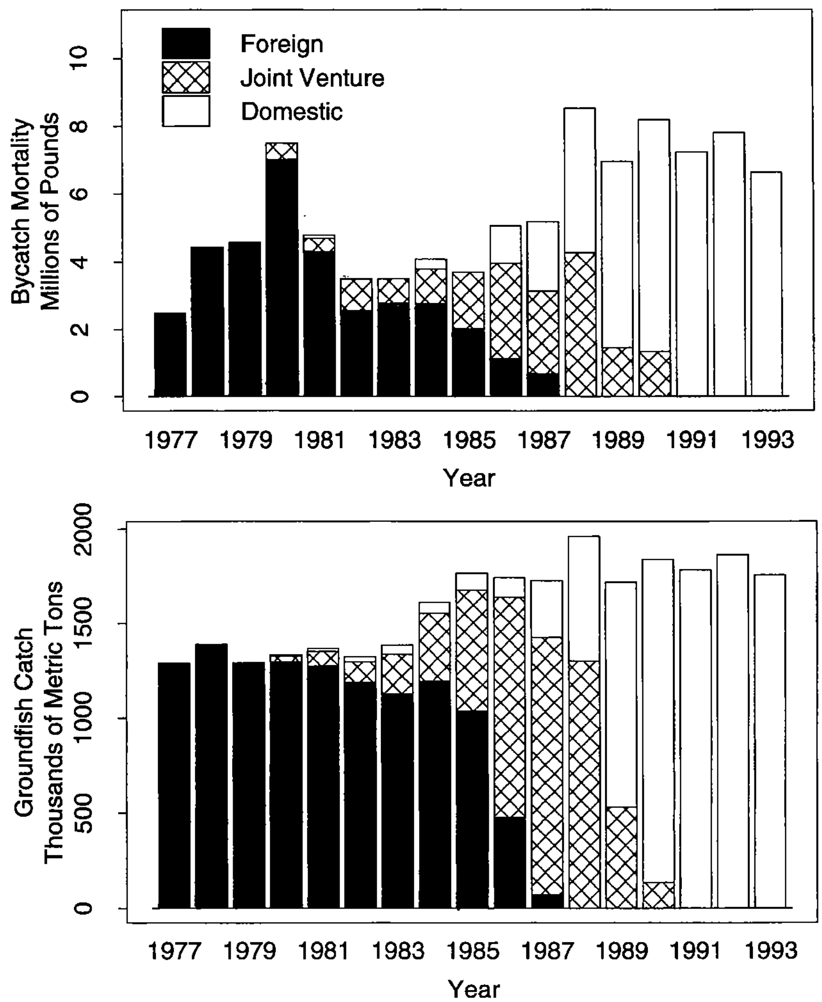

Figure 3. Pacific halibut bycatch mortality from ground fisheries and groundfish harvest in the Bering Sea-Aleutian Islands during the transition from foreign to domestic fishing.

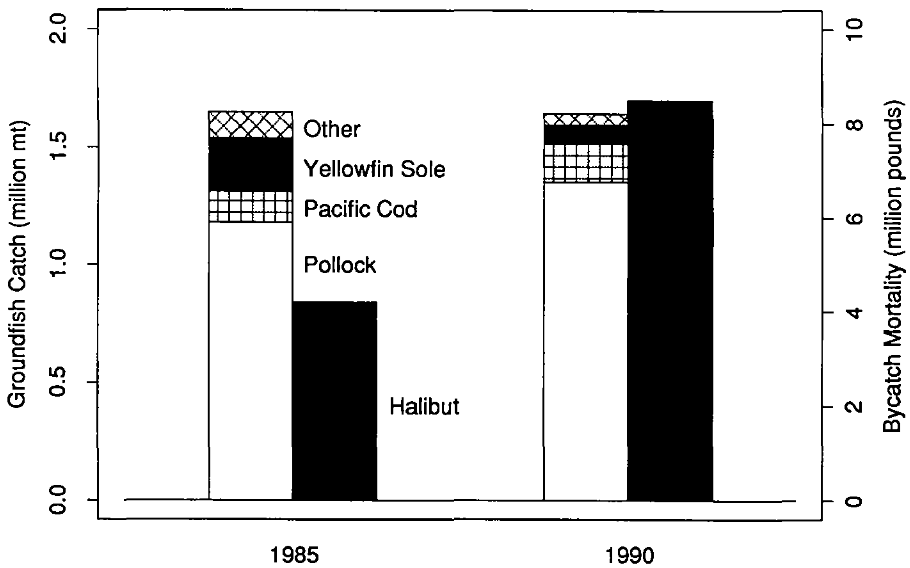

Figure 4. Groundfish harvest and halibut bycatch mortality in the Bering Sea-Aleutian Islands, 1985 and 1990.

example, groundfish harvest reached about 1.8 million mt in 1985 and in 1990 (Figure 4). In both years, groundfish catch was made up primarily of pollock, and secondarily of Pacific cod and yellowfin sole, yet incidental halibut mortality more than doubled in 1990.

As groundfish harvest remained relatively stable during this period, the observed increase in bycatch must be attributable to an increase in bycatch rates. Bycatch rates can increase as a result of changes in groundfish abundance relative to halibut (i.e. less groundfish or more halibut) or as a result of changes in fishing practices. However, groundfish abundance remained fairly constant from 1985 through 1990, with a reduction by 10-20% in the biomass of pollock, Pacific cod, and yellowfin sole which dominated the catches[3]. And while the number of Pacific halibut has doubled in the Bering Sea since 1987, the total biomass of halibut (which includes the strong 1987 year class) showed little change through 1992[4]. The transition of the groundfish fishery from a foreign fishery, to a joint venture fishery, to fully domestic fishery in the late 1980s and early 1990s is perhaps the most notable change. The fully domestic fishery had none of the bycatch restrictions that were imposed on the foreign and joint venture fisheries. While there is some indication that the increase in bycatch may be related to changes in relative abundance between groundfish and halibut, it seems more likely that higher bycatch rates have resulted from changes in fishing practices.

Management based primarily on bycatch limits does not provide sufficient incentive for individual groundfish fishermen to reduce bycatch rates under an overcapitalized, open-access fishery. The competitive, open-access system for groundfish in the North Pacific tends to cause fishing practices that maximize groundfish catch rates for individual vessels, even at the cost of higher bycatch rates. Hughes (1992) demonstrated that for fisheries with small numbers of like-minded participants, voluntary compliance with bycatch reduction measures can succeed; but when the number grows to include participants not willing to comply with voluntary restrictions, the participants are no longer willing to reduce competitiveness necessary to reduce bycatch rates. Peer pressure has provided an incentive to reduce bycatch

[3]NPFMC. 1993. Stock assessment and fishery evaluation report for the groundfish resources of Bering Sea/Aleutian Islands regions as projected for 1994. North Pacific Fishery Management Council. Anchorage, Ak.

[4]Clark, W. G. and G. E. Walters. 1994. Results of the 1993 NMFS Bering Sea trawl survey. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 1993: 341-345.

in some Alaskan coastal communities (Blackburn and Davis 1992).

The NPFMC developed a series of bycatch management actions for Alaskan waters since 1991 that included a limited individual incentive program, authority to close regions with high bycatch rates, modified definitions of pelagic trawling, and enhanced reporting requirements for the groundfish fleets. Bycatch management planning continues under the NPFMC. In 1991, the IPHC established a Halibut Bycatch Working Group which reviews and recommends bycatch management actions and plans in each country (Salveson et al. 1992).

Bycatch also occurs in the directed halibut fishery, as the fishery became more compressed and competitive. The number of participants in the directed halibut fishery grew substantially during the 1980s as crab fisheries declined, salmon fisheries experienced limited entry, and the halibut stocks rebuilt. The total season length in the Gulf of Alaska dropped from over 40 days required to harvest about 20 million pounds in the late 1970s to one full day and one restricted day in 1993 to harvest about 37 million pounds. The number of vessels increased from several hundred to several thousand. Halibut below the legal size were often released in poor condition which caused high mortality. Fishermen who could not retrieve all the gear set before the end of the 24 hr fishing period abandoned the excess, and gear tangles caused by fishermen setting on top of each other caused lost gear. Halibut mortality caused by lost and abandoned gear and discard of sublegal fish reached 3.6 million pounds in 1991 before declining to 2.3 million pounds in 1993[5].

IMPACT OF BYCATCH ON THE HALIBUT FISHERY: CURRENT EVALUATIONS

The impacts of incidental halibut catch differ in important ways from those imposed by the directed halibut fishery. Both sources of fish removal reduce the standing stock biomass, thus modifying stock productivity and affecting long-term and short-term yields. Currently, with the present makeup of the domestic groundfish fleet, the size composition of the fish in the bycatch differs from that of the directed catch. In the bycatch, halibut average between 3-5 years in age (about 40-60 cm in length), while in the directed fishery halibut average between 11-12 years in age (about 100-120 cm in length). Variation in size composition in the bycatch, determined by the magnitude, timing, and geographic location of groundfish fishing, affects the impact on the halibut stock and on the directed halibut fishery.

The IPHC has adopted a policy of harvest management based on constant harvest rates, which tends to assure a more stable harvest for species with fluctuating abundance compared to the unstable alternative of yield-maximizing policies (Quinn et al. 1985, Parma 1990). Determining the effect of bycatch on the spawning potential of the population and attempting to compensate for that effect are actions directed towards having removals be controlled and consistent with the Commission harvest management policy of a constant exploitation rate. The constant exploitation rate is established by examining spawning stock trajectories that result under various proposed harvest rates applied to the exploitable stock[6]. The exploitation rate is applied annually to the estimated exploitable biomass to determine a constant exploitation yield (CEY). The CEY is adjusted for removals that occur outside the directed setline harvest to determine the directed setline quota.

In an idealized situation, with strictly single species fisheries, there would be no bycatch, the harvest in the directed halibut fishery could be maximized, and the viability of the stock could be more directly controlled by halibut managers. However, such idealized situations

[5]Wade, M. F. 1994. Wastage in the Pacific halibut commercial fishery. Int. Pac. Halibut Comm. Report of Assessment and Research Activities. 1993: 27-29.

[6]Parma, A. M. 1993. Evaluation of alternative harvest rates for Pacific halibut. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 1992: 121-132.

rarely exist, bycatch does occur, and all removals must be accounted for to prevent undo stress to the stock's reproductive potential. If the age and size composition of the bycatch were similar to that of the commercial halibut catch, then that catch could be directly incorporated into the stock assessment and the removals dealt with in a manner analogous to the commercial fishery. Alternatively, if the bycatch were constant, or made up a constant proportion of the spawning stock biomass, then the Commission's harvest rate and the CEY could be adjusted directly to account for the reduction in spawning potential. Given that bycatch mortality is not insignificant, that it is not similar to the commercial fish catch, and that it is not constant, the best action available is to reduce the directed removals to a level that is consistent with the Commission's constant harvest rate policy.

Bycatch mortality also reduces the yield from the halibut stock by taking away fish that otherwise would be available for harvest in the directed fishery. This impact cannot currently be compensated for by management regulations, and is a direct loss to the fishery.

The magnitude of the effect of halibut bycatch to the directed halibut fishery is determined by the size composition of the bycaught fish and by the biological processes of growth, mortality, reproduction, and species spatial dynamics. Because bycaught halibut are generally younger and smaller than those harvested by the directed fishery, a net gain in stock biomass would have occurred had they remained at large instead of being removed, due to the greater cumulative gain in individual weight relative to the losses incurred from mortality. For example, if all fish in the bycatch were 5 years old, by the time they were 8 years old their abundance would be reduced by half due to natural mortality while their aggregate biomass would have increased by 30% due to individual growth over the three year period. This gain in yield with the postponement of harvest is consistent with previous studies of minimum size limits (Myhre 1974) and yield per recruit (IPHC 1960).

Sexual maturity is also a factor. In terms of reproductive capacity, most of the fish in the bycatch are not sexually mature. Consequently they are precluded from contributing to the production of future generations. Harvesting small immature halibut results in reduced yield and the loss of a lifetime of reproductive contributions to the stock.

Evaluating the effect of the bycatch in space and time and allocating quota reductions to maintain the reproductive potential requires an understanding of the population's spatial dynamics. Pacific halibut is considered as a single population. Spawning occurs primarily during winter, from central British Columbia through the Gulf of Alaska and into the Bering Sea, at depths of 100 to 250 fathoms (St-Pierre 1984). Eggs and larvae drift passively with the ocean currents and gradually rise toward the surface. Prevailing currents at spawning depth and near the surface tend to flow counterclockwise, paralleling the British Columbia and Alaska coastline. Skud (1977) summarized available information on egg and larval drift and on juvenile and adult migrations. Eggs and larvae can drift for hundreds or thousands of miles before reaching shallow water where the larvae can settle to the bottom (Skud 1977). It is hypothesized that the progeny move back to the east and south at some stage in the life history to counter the drift of eggs and larvae. Under this hypothesis, virtually all halibut off the coast of British Columbia, Washington, Oregon, and California have migrated through Alaskan waters. The counter migration occurs primarily during the juvenile stage, 2 to 6 years of age (Skud 1977). Most migration takes place at sizes smaller than 65 cm, although migration at larger sizes does occur. Subsequent tagging studies also indicate a southern movement of tagged juvenile Pacific halibut (Hilborn et al. In press). Because most of the bycatch is made up of juvenile fish in areas of transit, the effect of the bycatch on the direct fishery is often felt in areas other than where bycatch took place.

Yield Loss to the Halibut Fishery Due to the Absence of Bycaught Fish

The yield loss to the commercial halibut fishery due to the absence of bycaught fish, or adult equivalent loss (AE_{Loss}), is an estimate of how much the bycaught fish would yield if left at large to become available to the setline fishery as adults. This loss currently cannot be compensated for by management regulations. Loss in yield is estimated by modelling bycatch as a separate portion of the halibut population. This portion corresponds to observed bycatch length compositions. A length-based population model is used to project the numbers of fish at length from the bycatch in a given year through a 20 year time horizon. The numbers of fish at length in the bycatch change according to the processes of natural mortality, fishing mortality, and individual growth. If $N_{l,t}$ represents the numbers of bycaught fish in length class l at time t, then the number of fish surviving from that year to the next and growing from length class l to length class $l + k$ is estimated as

$$N_{l+k,t+1} = N_{l,t} e^{-(F_{l,t}+m)} \qquad (1)$$

where k is the growth increment in centimeters per year, and m and F are the instantaneous rates of natural and fishing mortality, respectively. Growth is assumed to be linear with a constant annual change in length (k) of 7 cm (Myhre 1974). Information for estimating age-specific m of juvenile halibut is unavailable, so the 0.2 value generally estimated for adult halibut (IPHC 1960, Chapman et al. 1962, Myhre 1967, Deriso et al. 1985) was applied. This value is consistent with natural mortality estimates of other flatfish in Alaskan waters of a size similar to juvenile halibut[3].

The fishing mortality rate $F_{l,t}$ is estimated as

$$F_{l,t} = f_t s_l \qquad (2)$$

where f_t is the full-recruitment fishing mortality at time t, and s_l is the length-specific selectivity of the setline gear. Full recruitment fishing mortality used in the model is 0.22, corresponding to the average fishing mortality rate in the halibut fishery from 1988 to 1991. Annual fishing mortalities are estimated using catch-at-age analysis (Deriso et al. 1985), applied to the halibut catch observed for all fishing areas combined. Selectivity at length (Table 2) is determined by combining an age-based selectivity (Quinn et al. 1985), and an age-length relationship (Myhre 1974).

Table 2. Selectivity of halibut in the setline directed fishery by age and length.

Age	Length	Selectivity
8*	94.0	0.16
9	102.9	0.30
10	111.0	0.46
11	118.2	0.58
12	124.6	0.75
13	130.3	0.80
14	135.2	0.92
15	139.6	1.00
16	143.5	1.00
17	146.9	1.00

* Selectivity under 8 years old is assumed to be 0

Bycatch length frequency data used in the analysis are from joint venture and foreign fisheries taking place in the Bering Sea and Gulf of Alaska, from the US domestic trawl fishery, and from crab and shrimp fisheries over the years 1977-1986 (Figure 5). Data are from the Observer Program of the NMFS, and provided by the Alaska Fisheries Science Center, Seattle. Length frequency data are combined over fisheries by year. Length data are divided in intervals of 7 cm starting at 32 cm. Numbers in each length class are projected over a 20 year lifetime horizon using the equations presented above. Individuals of length greater than 165 cm are cumulated in the last length class interval.

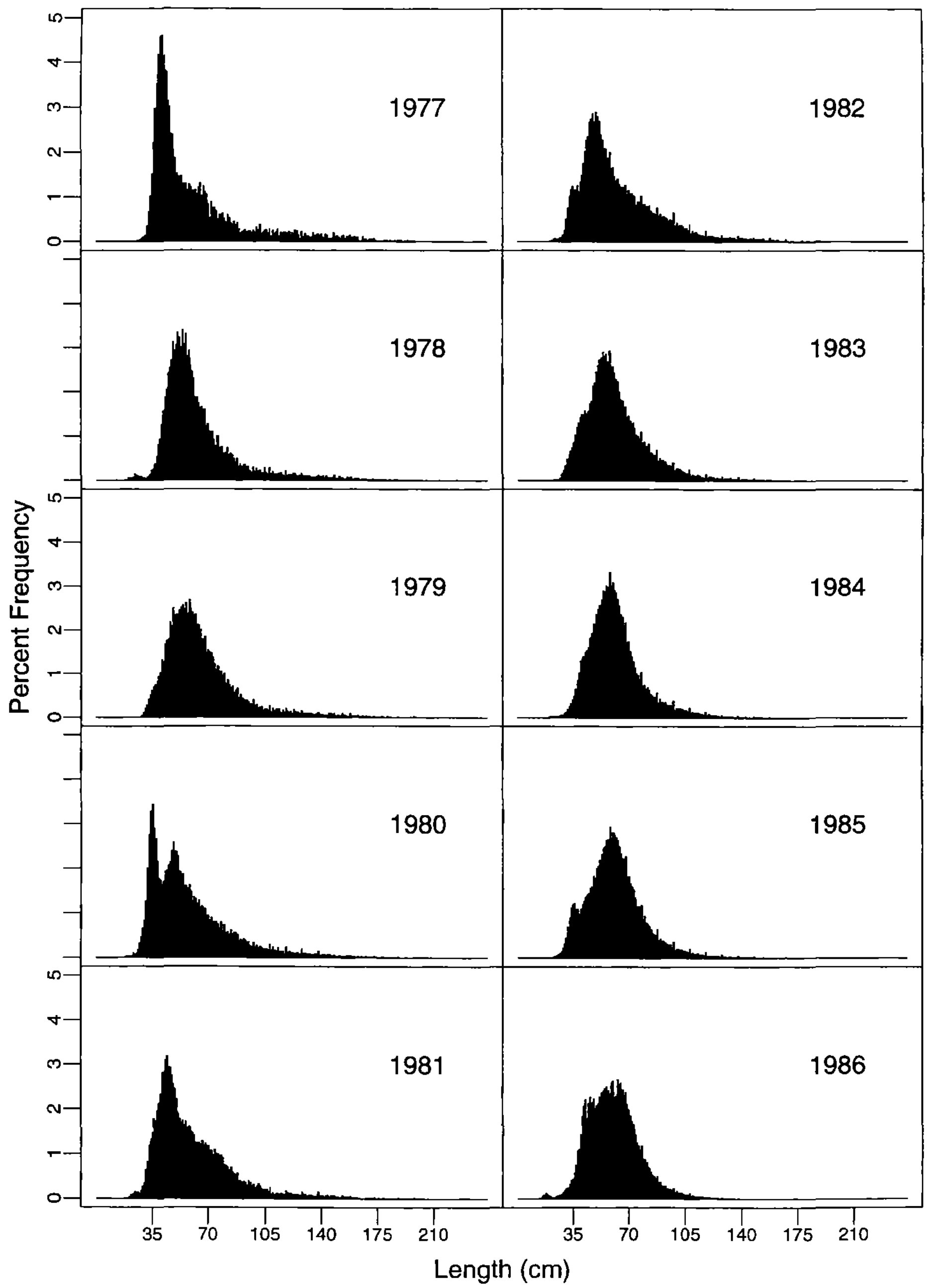

Figure 5. Length frequencies of halibut bycatch in 1977-1986 groundfish fisheries.

From the projected numbers at each length class l, the corresponding yield $Y_{l,t}$ that would have been obtained from the bycaught fish is calculated using a length-based Baranov catch equation:

$$Y_{l,t} = N_{l,t} \frac{F_{l,t}}{F_{l,t}+m} (1 - e^{-(F_{l,t}+m)}) W_l \quad (3)$$

where W_l is the average weight of the midpoint of the length class. This weight in pounds net weight is calculated from the relationship proposed by Quinn et al. (1983): $W = 0.00000692 L^{3.24}$. The total yield loss Y_{Loss} is the sum of the losses over all length classes. Adult equivalent loss (AE_{Loss}), the yield loss inflicted by one pound of bycatch, is calculated as the ratio of yield loss to the bycaught biomass B_o

$$AE_{Loss} = \frac{Y_{Loss}}{B_o} \quad (4)$$

where B_o is the sum of the product of the numbers of halibut at length in the bycatch at the time that bycatch occurs (t_o) and their corresponding weights. Adult equivalent losses caused by bycatch from 1977 to 1986 in the fisheries mentioned above are shown below:

Year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
AE_{Loss}	1.15	1.20	1.18	1.24	1.24	1.22	1.30	1.34	1.36	1.44

Variation in AE_{Loss} results from changes in the length frequency distribution of the bycatch. The average yield loss per pound of bycatch in the above table is 1.3 pounds. This average is currently used to determine the yield loss inflicted to the halibut fishery by bycatch in a given year due to the subsequent absence of the bycaught fish. In other words, yield loss is estimated by multiplying total bycatch mortality in a given year by 1.3.

Loss of Reproductive Potential

Bycatch not only results in yield loss as discussed in the previous section, but also in eventual reduction of the spawning biomass, which could affect stock viability and long-term yield. Reductions to the recommended halibut fishery catch limits are designed to compensate the spawning stock for losses in reproductive potential caused by bycatch, although it may not completely mitigate for loss in spawning potential. To calculate the catch limit reduction, an adult reproductive compensation (ARC) factor is estimated. This factor, when multiplied by bycatch mortality, indicates the amount that the allowable catch in biomass should be reduced to maintain the reproductive potential of the stock at the levels similar to those attained had no bycatch occurred.

The ARC estimate is derived in two steps. First, the loss in recruitment per pound of bycatch is calculated using a length-based model. Next, the reproductive potential per pound of recruits is estimated using an age-based model. Loss in recruitment biomass is calculated using the model presented in the previous section. Halibut numbers at length estimated in the bycatch mortality are projected only up to the length interval between 81 to 87 cm. Fish in this length interval are assumed to be 8 years old. The loss of recruits per pound of bycatch is calculated as the ratio between the loss in recruitment and the bycatch biomass B_o. To determine total yield loss rates, the analysis is performed using length frequency data from the Bering Sea and Gulf of Alaska joint venture and foreign groundfish fisheries, domestic trawl groundfish, crab and shrimp fisheries. The resulting losses in pounds of recruits per pound of bycatch lag over several years from the time when bycatch occurs (Table 3). A weighted average of recruitment loss over all fisheries is obtained by weighting fishery-specific rates given in Table 3 by the 1981-1988 average bycatch mortality estimates (Bering Sea: 3,775 mt; Gulf of Alaska: 935 mt; Crab: 1,617 mt; Shrimp: 17 mt; Domestic trawl: 1,206 mt). The estimated weighted average is 1.2 pounds of recruits loss per pound of bycatch.

Table 3. Recruitment loss by fishery for Bering Sea and Gulf of Alaska joint venture and foreign groundfish fisheries, domestic trawl groundfish, crab and shrimp fisheries, 1981-1988.

Lag (years)	Bering Sea JV and foreign	Gulf JV and foreign	Crab	Shrimp	Domestic trawl
0	0.42	0.51	0.83	0	0.25
1	0.11	0.10	0.08	0	0.20
2	0.16	0.14	0.06	0	0.24
3	0.19	0.16	0.04	0	0.26
4	0.18	0.15	0.02	0.94	0.22
5	0.11	0.09	0.01	0.82	0.07
6	0.07	0.05	0	0	0.01
7	0.03	0.01	0	0	0
Total	**1.26**	**1.21**	**1.04**	**1.76**	**1.24**

The reproductive potential of a fish cohort over time is calculated as the sum of the number of eggs that it could have produced from age 8 up to age 20 as

$$E_R = N_R F_R \sum_{t=8}^{20} S_{8,t} M_t E_t \tag{5}$$

where N_R is the number of recruits (eight-year-old halibut) that would have entered the adult population had bycatch not taken place, F_R represents the fraction of these that are females, $S_{8,t}$ represents the survivorship at age, M_t the percent of mature females at age, and E_t the female fecundity. The age range of 8 to 20 was chosen to bound the problem to age classes with significant abundance in the fishery and to be consistent with assumptions and data used in the analysis of long term harvest management policies. Data to calculate the female percentage in the population are from setline surveys conducted by IPHC from 1983 through 1986. Age-specific survival rates are determined using the exponential survivorship model discussed earlier except for the fact that length is replaced by age. Natural mortality and fishing mortality are the age-specific analogues to those used in the earlier population model. Maturity at age is determined from data presented by St-Pierre (1984), and fecundity at age follows the relationship specified by Schmitt and Skud (1978).

The reproductive contribution of the fish in the directed setline catch is estimated using a modification of equation 5:

$$E_c = N_c \sum_{a=8}^{20} D_a F_a \sum_{t=a}^{20} S_{a,t} M_t E_t \qquad \textbf{(6)}$$

were N_C is the number of halibut in the catch, and D_a is the fraction of the catch in numbers in each age class. The fraction of the catch at age is calculated from the average length frequency of the 1974 to 1988 halibut fishery. The estimates E_R and E_C are used to estimate the per capita ratio for reproductive potential of recruits to adults in the catch as 0.4. Thus, on the average for the size composition observed in the bycatch, 40 adults from the catch produce the same number of eggs as 100 recruits over their respective spawning lifetimes. The corresponding per pound ratio of the reproductive potentials is estimated to be 0.83, based on the average weight at age in the catch over the years 1974 through 1988 and the average weight of eight year old recruits (19.26 pounds). Thus, it takes 83 pounds of adults, as they would show up in the catch, to produce the same number of eggs as 100 pounds of recruits over their respective spawning lifetimes. To arrive at the global ARC estimate the recruitment loss factor and the reproductive potential per pound of bycatch are multiplied (1.2*0.83=1.0). The results indicate that to compensate for reproductive loss, the allowable catch must be reduced by an amount equal to the bycatch mortality.

Total Yield Loss

The yield loss to the directed halibut fishery consists of losses that result from bycatch-induced catch limit reductions and losses from the absence of the bycaught fish in the population. The catch limit reductions immediately deprive the directed fishery of one pound of yield for each pound of bycatch taken the previous year. Because these fish are left in the stock, some of them will eventually be caught. Analysis using the catch-length distribution data and the models and assumptions described earlier indicate that about 60% of each pound forfeited to reproductive compensation is eventually caught. Thus, the loss to the halibut fishery due to reproductive compensation is 0.4 pounds per pound of bycatch. The loss due to absence of bycaught fish from the population (the AE factor) was estimated to be 1.3 pounds for every pound of bycatch. Thus, the total yield loss caused by a pound of bycatch is estimated to be the 1.7 pounds, the sum of both losses.

Compensation Versus Timing of Impact

Bycaught halibut are generally smaller and younger than the directly harvested halibut. This means that the effect of bycatch on the reproduction and yield from the exploitable stock will be delayed several years. The delay between the time of bycatch and the time of recruitment to the directed fishery leads to a fundamental question: should compensation be made at the time of bycatch, or should it be structured to better reflect the timing of the impact on the directed fishery? More biological realism would accrue from lagging compensation, such that the replaced eggs, and therefore the reproductive contribution, would coincide with the time when bycaught halibut would have produced their eggs. However, such a procedure would entail annual recalculation of the compensation factors based on fishing mortality and exploitable biomass estimates that are annually revised. Lagged compensation would, perhaps more problematically, also require annual projections of harvest and population levels for both the existing stock and the bycaught portion had it remained in the stock under a similar harvest regime. Simplifying assumptions employed regarding future harvest and future stock levels would be similar to those made in the development of the simpler approach of compensation at the time of bycatch. The added complexity of a more elaborate approach seems unwarranted.

Area-Specific Catch Limit Reduction

Determining appropriate area-specific catch limit reductions requires consideration of the movement of spawners, the mixing of eggs and larvae, and the mixing of juveniles. Analysis of these factors leads to a conclusion that reproductive losses resulting from bycatch mortality affect the reproductive potential of the entire stock, that is, a pooled concept of reproductive potential. The procedure for allocating the catch limit reduction currently applied by the IPHC, based on pooled reproductive potential, reduces catch limits for regulatory areas in proportion to the estimated exploitable halibut biomass present in each area. If individuals throughout the range contribute equally to the reproductive potential, then a reduction to catch limits applied proportionally to the stock biomass in each area should provide a stock-wide adjustment (Table 4). Individual bycatch data in areas 3A and 3B are not available, so a combined estimate is presented.

Table 4. Catch limit reduction (millions of pounds) to compensate for bycatch mortality, by IPHC regulatory area, 1993. Bycatch mortality, multiplied by 1.0 (ARC) is distributed across areas in proportion to the estimated exploitable biomass in each area. Totals for each area are the column sums of the relative impact contributed by each area.

Area	Exploitable Biomass	Bycatch Mortality	2A	2B	2C	3A	3B	4	Total
2A	2.59	0.5	0.00	0.08	0.10	0.23	0.04	0.05	0.50
2B	49.30	1.6	0.01	0.26	0.33	0.73	0.11	0.15	1.60
2C	61.84	0.7	0.01	0.11	0.14	0.32	0.05	0.07	0.70
3A	136.68	5.3	0.05	0.87	1.09	2.41	0.37	0.51	5.30
3B	21.12								
4	28.83	6.8	0.06	1.12	1.40	3.09	0.48	0.65	6.80
Total	**300.36**	**14.9**	**0.13**	**2.45**	**3.07**	**6.78**	**1.05**	**1.43**	**14.90**

Area-Specific Yield Loss

The yield loss caused by bycatch mortality, which cannot be compensated for by management actions, affects all halibut fishery areas. The estimation of the spatial distribution of the total yield loss under the current allocation scenario can be separated into two components: 1) estimation of loss due to the absence of bycaught fish in the fishery, and 2) estimation of loss due to quota reduction. Although no management actions are currently based on yield loss distributions, the calculations show where losses occur to the directed halibut fishery.

The first component is estimated using a migration-based concept: bycaught halibut are generally smaller and younger than those harvested by the directed fishery and likely to migrate prior to entering the fishery, so bycatch in one area reduces the potential yield in that area and in other areas downstream. Migration, survivorship, and growth determine location and magnitude of the impact. The distribution of exploitable biomass is used as a proxy for these factors, on the basis that areas with greater or lesser exploitable biomass will receive a greater or lesser share of the migrating halibut. Accordingly, distribution of yield losses resulting from the absence of fish in the population ($AE_{Loss}= 1.3$) was estimated assuming that the loss in each area would affect that particular area and the areas to the south in proportion to exploitable biomass.

The second component, the loss from quota reductions, is calculated in proportion to the coast wide distribution of exploitable biomass, because harvest lost from catch limit reduction occurs in the area of the reduction. Yield loss distribution by areas derived from the quota reduction can be estimated by multiplying the quota reduction in each area by 0.4. Yield loss estimates by regulatory area (Table 5) are calculated by combining both components.

Table 5. Total yield loss (millions of pounds) resulting from bycatch mortality, by IPHC regulatory area, 1993. Bycatch mortality is multiplied by 1.3 (AE_{Loss}), distributed across all areas east and south in proportion to exploitable biomass, and by 0.4 (catch reduction loss), distributed across all areas in proportion to exploitable biomass. Totals for each area are the column sums of the relative impact contributed by each area.

Area	Exploitable Biomass	Bycatch Mortality	2A	2B	2C	3A	3B	4	Total
2A	2.59	0.5	0.65	0.03	0.04	0.09	0.01	0.02	0.85
2B	49.30	1.6	0.11	2.08	0.13	0.29	0.05	0.06	2.72
2C	61.84	0.7	0.02	0.44	0.55	0.13	0.02	0.03	1.19
3A	136.68	5.3	0.09	1.70	2.14	4.73	0.15	0.20	9.01
3B	21.12								
4	28.83	6.8	0.10	1.90	2.38	5.26	0.81	1.11	11.56
Total	**300.36**	**14.9**	**0.97**	**6.16**	**5.24**	**10.50**	**1.04**	**1.42**	**25.33**

FUTURE DIRECTIONS

The methodology and concepts used in calculating ARC and yield loss in halibut management can be used to explore numerous aspects of the relationships between bycatch removals and stock dynamics. For example, size and age of halibut in the bycatch varies by fishery and area, and combined with mortality and size-specific growth, suggest that ARC and yield loss will vary with changes in the size composition of halibut in different fisheries and areas. The improved quality and quantity of information available on bycatch in the last three years, due to mandatory observer coverage of the domestic groundfish fisheries, provide data to explore these relationships. Additionally, information generated from recent research performed by IPHC staff provides the opportunity for continued refinements of the methodology. Some of these areas of research and development are presented.

Model Refinements

A fully length-based model is now used in place of the more restrictive age-based model discussed earlier. New information required for a length-based model has become available, since the development and implementation of the previous model, on several aspects of halibut length-based stock dynamics (i.e. selectivity at length, maturity at length, and sex ratio at length). The yield loss is estimated as before by modelling the bycaught fractions of the halibut population as if they remained at large. These population fractions correspond to the numbers of fish at length in the bycatch, and the numbers at length are subjected to natural and fishing mortality, and to individual growth. The yield is calculated as the cumulative catch that would have resulted from these population fractions.

Growth is still assumed to be linear (Figure 6), but halibut up to 81 cm in length are assumed to grow 10 cm per year (Best 1977), while fish larger than 81 cm are assumed to grow 7 cm per year as before. Based on this growth model, trawl and longline bycatch length frequency distributions are divided into 20 length classes. The upper limit of the first class is 20 cm, corresponding to individuals of age 1. The next 6 classes (ages) are in 10 cm increments, the following 12 classes are in 7 cm increments and the last class, corresponding to age 20 or more, contains individuals $\geq$ 165 cm.

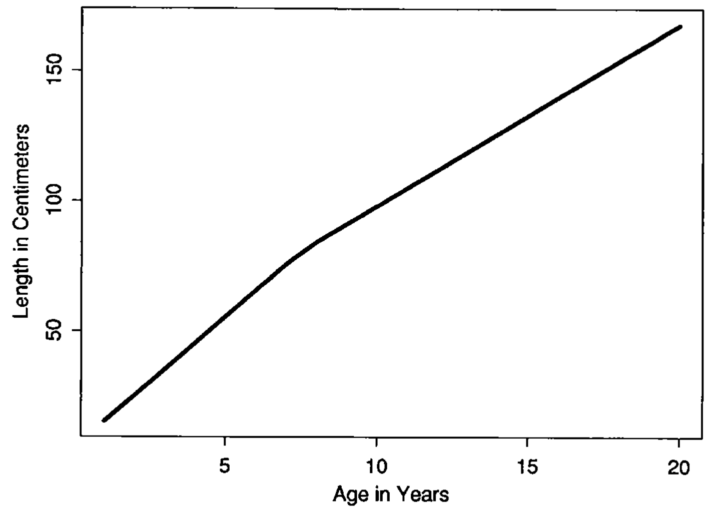

Figure 6. Halibut length at age used to determine k in the length-based model.

Population survival from one period to the next uses an *F* calculated from the length-specific selectivity (Figure 7) of the halibut setline gear[7]. Selectivity of halibut under the 81 cm minimum size is set at 0. Growth occurs annually from length class l to $l + k$, with k equaling either 10 or 7 cm.

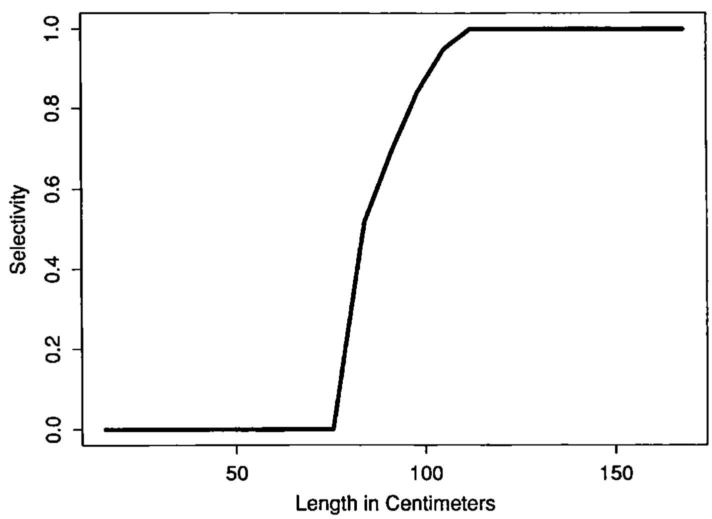

Figure 7. Length-based selectivity of halibut in the setline directed fishery.

[7]Clark, W. G. 1993. Estimation of halibut growth and selectivity parameters. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 1992: 95-112.

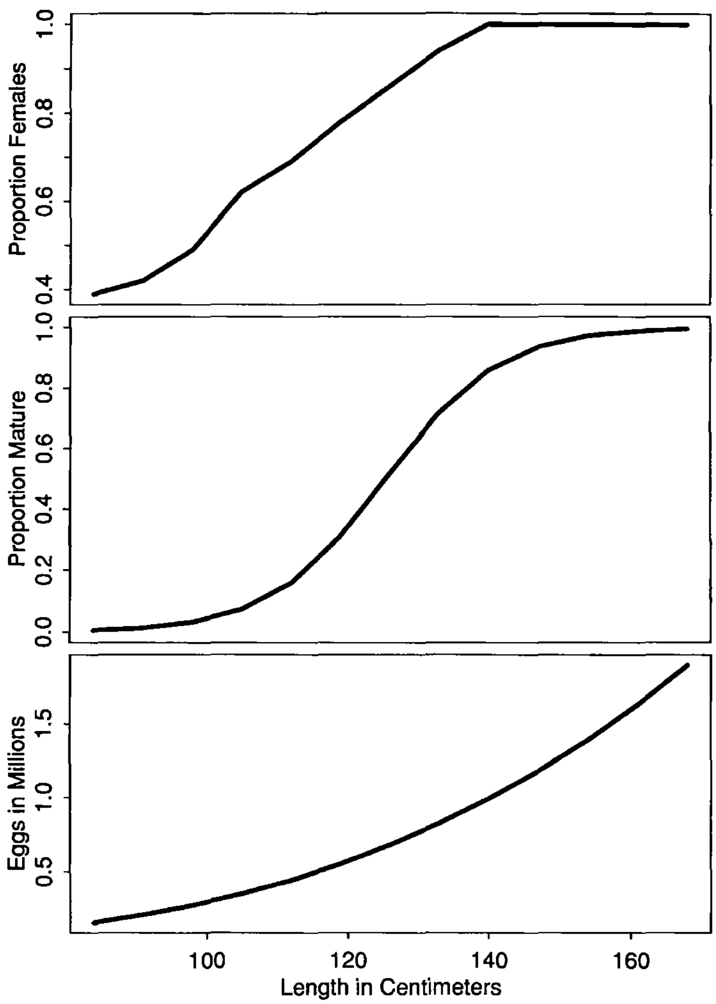

Figure 8. Relationships used in the length-based model to calculate reproductive potential.

As in the original procedure, the yield that the bycaught fish could have produced is calculated using a Baranov catch equation. The yield loss to the fishery is calculated as the cumulative loss from each length category. The loss per pound of bycatch is calculated as the ratio between the yield loss and the actual bycatch weight. The bycatch weight is calculated as the sum of the products between the bycatch proportions at length and their corresponding weights at length.

The reproductive output foregone from bycaught fish on a per pound basis is calculated in the length-based model with no intermediate step of calculating lost recruits. Thus, eggs produced by each length cohort in the bycatch are calculated directly from the numbers of fish calculated previously using a length-based version of Equation 5. Female percentage in each length class is from Clark[7], proportion of mature females in each length class is from Parma[8], and the egg production of a female in each length class (Figure 8) is from Schmitt and Skud (1978). Length data used to calculate the reproductive potential per pound of halibut stock (Figure 9) was obtained from market samples of the 1991 halibut commercial

[8]Parma, A. M. 1993. Estimation of halibut maturity as a function of length. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 1992: 113-120.

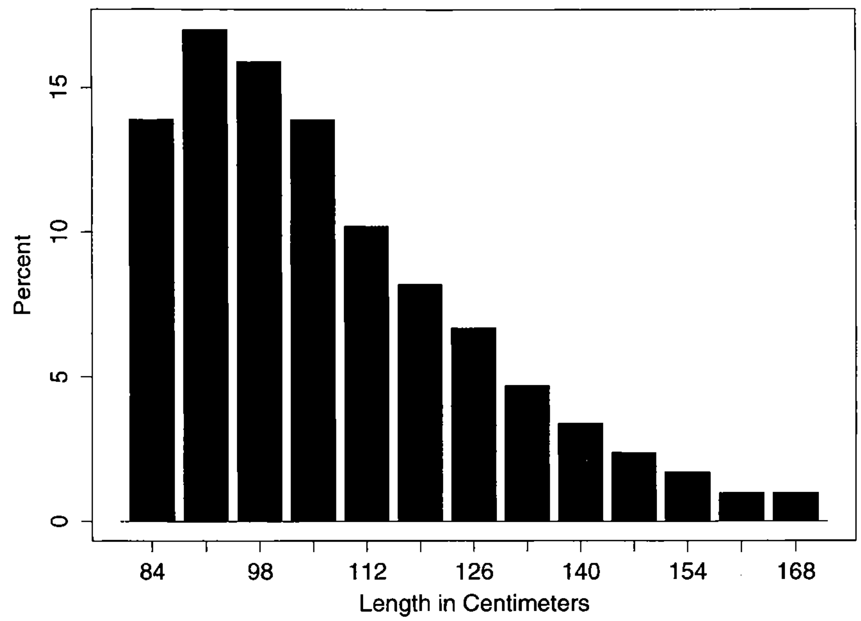

Figure 9. Length composition data from the 1991 market sample of halibut commercial catch

catch (A. Parma, IPHC, Seattle, personal communication).

The stock biomass required to replace the reproductive output of one pound of bycatch is calculated from the length-based model as the ratio of the reproductive potential of the catch to the reproductive potential of the bycatch. The loss due to forfeiting one pound of catch is calculated by incorporating the length frequency of the catch into the population model and the Baranov catch equation as before.

Effect of Halibut Size in the Bycatch

Halibut bycatch in the groundfish fisheries of the Bering Sea is made up primarily of fish 35 to 55 cm in length, while 55 to 75 cm halibut are common in the bycatch in Canadian waters. In the Bering Sea Pacific cod fisheries, the trawl bycatch is dominated by halibut 40 cm, while the bycatch in the longline fishery is dominated by fish larger than 60 cm. Annual variations in the size structure of the halibut population from strong and weak year classes can also cause differences in the proportion of fish at length in the bycatch from various fisheries.

To explore the consequences of extreme variation of the size structure of bycatch the length-based model is applied to bycatch made up of a single cohort with average size ranging from 35 to 168 cm (mid points of the length intervals used in previous analyses). The results indicate that if all fish in the bycatch are in the 30 to 40 cm interval, the ARC is 3.5 pounds per pound of bycatch. The ARC decreases to 0.5 in the 81 to 87 cm range, increases to about 1.3 between 130 and 143 cm, and decreases to 0.5 in the 165 to 171 cm interval (Figure 10). These results show that the impact of a pound of bycatch can vary with changes in its size distribution.

The nonlinear behavior of the relationship between size range and ARC is determined by the trade-off between growth, mortality, and reproductive potential. The number of halibut decreases exponentially with length, while weight increases exponentially. Thus, cohort biomass increases until the fish reach 81-87 cm of length, after which it decreases. On the other hand, the reproductive potential of a cohort increases exponentially with length

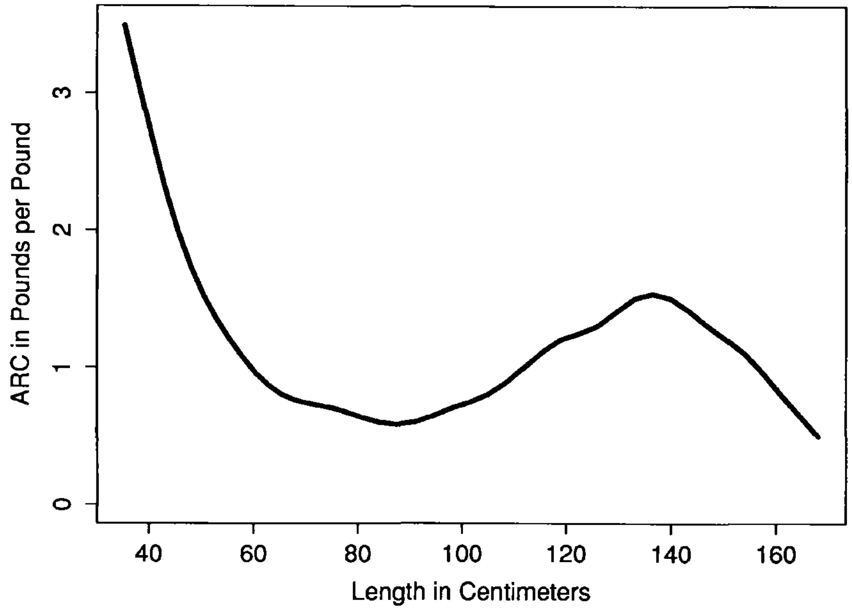

Figure 10. Adult reproductive compensation (ARC) factor as a function of halibut length.

reaching a maximum when females attain 133-140 cm. The value of ARC can vary considerably depending on the predominant sizes in the bycatch. However, the broad range of sizes typically present in the bycatch should dampen year-to-year variation in the ARC.

Domestic Groundfish Fisheries: 1990 and 1991

Using the fully length-based model and length frequency data from 1990 and 1991 groundfish fisheries in the Bering Sea and the Gulf of Alaska, the reproductive compensation factor and partial and total yield losses are calculated by year (Table 6). Length data are provided by NMFS Alaska Fisheries Science Center, Seattle, from the NORPAC data base. Length frequencies are combined within each year across target fisheries and gear type for the Bering Sea and Gulf of Alaska to calculate ARC and yield loss.

Table 6. Adult equivalent, adult reproduction compensation (ARC), and yield loss factors calculated for groundfish fisheries in Alaskan waters from 1990 and 1991 observer data.

Year	Factor	Gulf of Alaska	Bering Sea
1990	Adult equivalent	0.96	1.29
	ARC	0.91	1.03
	ARC loss	0.30	0.34
	Total yield loss	1.26	1.63
1991	Adult equivalent	1.05	1.66
	ARC	0.95	1.25
	ARC loss	0.31	0.41
	Total yield loss	1.36	2.07

The composite estimate across regions in 1990-1991 is 1.4 for the adult equivalent and is 1.1 for the ARC. These composite estimates are slightly higher than the current 1.3 and 1.0 values estimated from data from the 1977 to 1986 fisheries.

Results using the 1990-1991 data show higher variability in the estimates of ARC for the Bering Sea than for the Gulf of Alaska. This is the result of the latitudinal distribution of the halibut population by length. The size structure of the population fraction in the Bering Sea fluctuates as weak or strong year classes enter and grow. The size structure of the bycatch, made up mainly by young halibut, varies accordingly. A lower proportion of the youngest halibut is found in the Gulf of Alaska, and the size structure of the bycatch is more stable.

Impact of Specific Fisheries: Pacific Cod

The extreme effects of variation in average size of halibut in the bycatch on ARC and yield loss suggests that it would be informative to examine the impact of bycatch from specific fisheries. For example the Bering Sea Pacific cod fishery exhibits diverse size distributions by gear, and also causes well over 1,000 mt bycatch mortality per year. The length-based model and length frequency data from 1990 and 1991 cod fisheries in the Bering Sea are used to calculate the overall yield and reproductive loss factors by trawl, longline and pot gear.

Halibut bycatch length frequency data (Figure 11) from data collected in 1990 for trawl and longline vessels and in 1991 for pot vessels from Pacific cod fisheries is used in calculating halibut survival and growth. Data were provided by the NMFS Alaska Fisheries Science Center, Seattle from the NORPAC data base.

The bycatch length structure from the Pacific cod fisheries corresponds to 1.04 pounds of direct loss yield per pound of longline bycatch, 1.97 pounds loss per pound of trawl bycatch, and 0.99 pounds loss per pound of pot bycatch.

Because of size differences of halibut bycatch in the three Pacific cod fisheries, the analysis indicates that replacing the reproductive potential requires 1.03 pounds of catch reduction for each pound of trawl bycatch mortality, 0.75 pounds of catch reduction for each pound of longline bycatch mortality, and 0.70 pounds of catch reduction for each pound of pot bycatch mortality. Further, results indicate that when 1.00 pound of catch is forfeited, 0.67 pounds are eventually harvested, leaving the direct fishery with a loss of 33% of the forfeited catch. To maintain the reproductive potential of the halibut stock, the longline bycatch imposes a yield loss of 0.25 pounds per pound of bycatch, pot bycatch 0.23 pounds, and the trawl bycatch 0.34 pounds.

The estimated total yield loss is 1.29 pounds from 1.00 pound of longline bycatch mortality, 1.22 pounds from 1.00 pound of pot bycatch mortality, and 2.31 pounds 1.00 pound of trawl bycatch mortality. Bycatch mortality from the Pacific cod trawl fishery produced 1.80 and 1.90 times, respectively, the yield loss to the direct halibut fishery as from the longline and pot fisheries. This difference is determined by the characteristics of the bycatch size distribution from the three gears. The trawl gear captures a large proportion of small size halibut. Those fish, if left in the population, would increase in biomass at a faster rate than the larger fish captured by the longline or pot gear.

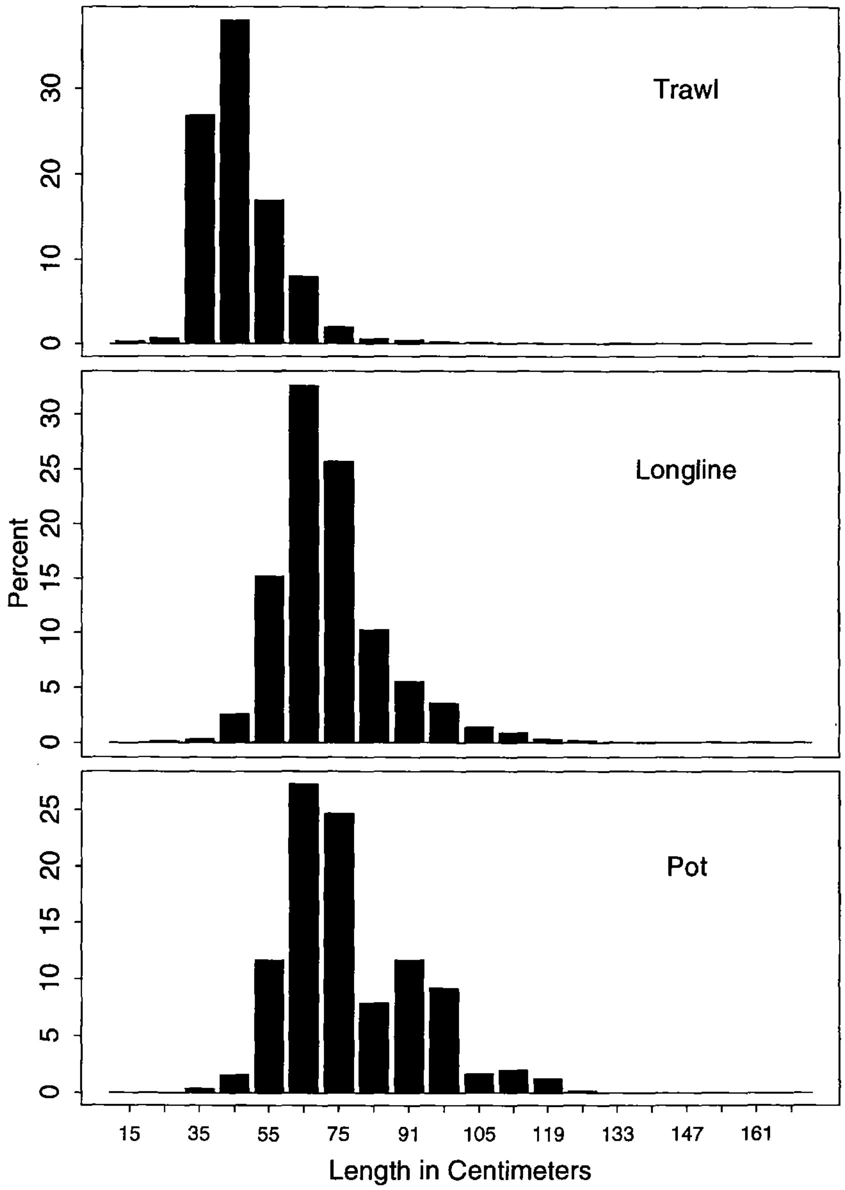

Figure 11. Length distribution of halibut in the 1990 Pacific cod longline and trawl fisheries and in the 1991 Pacific cod pot fishery.

SUMMARY

Halibut mortality caused by bycatch reduces the amount of halibut available to the directed halibut fishery by 1.3 times the bycatch mortality. Bycatch also reduces the reproductive potential of the population. Thus, to compensate for loss of reproductive potential the IPHC reduces annual halibut catch limits by an amount equal to bycatch mortality (one pound per pound of bycatch). Reducing the catch results in an additional yield loss to the halibut fishery of 0.4 pounds per pound forgone. Thus, the total yield loss to the halibut fishery is estimated to be 1.7 pounds per pound of bycatch mortality. Results show that these figures vary with size distribution of the bycatch.

Quota reduction to compensate for reproduction loss is allocated among regulatory fishery areas in proportion to the exploitable biomass in each area. Eggs and larvae drift from offshore spawning grounds and mix over long distances with the north- and west-flowing currents. On the assumption that reproductive losses from bycatch affect the reproductive potential of the entire population, the bycatch is treated as a pool, and making catch limits proportional to the exploitable biomass provides a stock-wide adjustment.

Bycatch produces yield losses in all halibut fishery areas. Young halibut, those typically caught as bycatch, migrate to the south and east as they grow older. Thus, bycatch in one year and area is likely to affect yields both in that area and in areas located to the south and east. Accordingly, this yield loss is estimated in proportion to exploitable biomass in the area where the bycatch occurred and the areas downstream. Although catch limit reduction to compensate for lost reproductive potential is distributed to all areas in proportion to exploitable biomass, the yield loss resulting from the reduction is thought to affect only the yield of the area where the quota reduction occurred, given that the fish forgone there are adults. Thus, the second yield loss impacts only the area of quota reduction. The two losses are combined to give the area-specific total losses. The IPHC adjusts catch limits for reproductive compensation the year after bycatch occurs rather than according to the time lag required for bycatch to recruit to the commercial fishery. Although incorporating a lag would have greater biological justification, the uncertainty of forecasting recruitment made the simpler approach preferable.

A fully length-based model, with results consistent with the age-based model, has been developed to evaluate the impact of bycatch for application in future research. The application of the model indicates that the impact of bycatch hinges on its size composition. Thus, the impact varies with differential gear selectivity, as exemplified by the results of an analysis of Pacific cod harvested with different gears, and as is shown by the results of analysis of total groundfish data in different years.

The analysis presented in this report provides a mechanism for evaluating the effects of bycatch on the halibut fishery and protecting the halibut resource from reproductive loss, but it does not offer a means for determining the amount of bycatch mortality that should be allowed. Determining this quantity requires evaluation of social, economic, management, and biological factors. As fishery managers address the trade-off between the use of halibut as catch or bycatch, the IPHC will compensate the halibut population for bycatch mortality through reducing directed harvest in its continuing effort to maintain the resource at levels that support optimum yield while minimizing the risk to the stock.

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