MEASURING THE ECONOMIC IMPLICATIONS OF PROHIBITED SPECIES BY-CATCH MORTALITY, INCLUDING LOSS OF REPRODUCTIVE POTENTIAL, IN NONSELECTIVE MULTISPECIES COMMERCIAL FISHERIES

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ABSTRACT

The objective of this analysis is the development of a methodological approach that would permit a more complete evaluation of the physical and economic consequences of prohibited species by-catch (PSC) losses, such as occur in the harvest of groundfish.

To achieve efficient management of the several marine species involved in the groundfish and associated PSC controversy, U.S. regulatory authorities sought to obtain estimates of the probable economic and physical impacts attributable to these harvesting activities. Early efforts were based upon the assumption that all PSC losses were attributed to directed fisheries in the year subsequent to that in which the by-caught specimen would have been legally harvestable.

The present analysis hypothesizes that substantial latent economic costs, associated with losses in reproductive potential, are also attributable to PSCs and incorrectly ignored by previous assessment methodologies. To test this assertion an alternative methodology was developed and empirically applied to the case of Pacific salmon (*Oncorhynchus* ssp.) PSCs in the Gulf of Alaska groundfish fisheries.

The empirical results demonstrate the presence of substantial latent losses associated with salmon PSC reproductive potential foregone. Although preliminary, these results confirm the presence of the hypothesized long-run adverse economic impacts on directed salmon fisheries associated with a single season's PSC interception. Similar results would be expected in the case of Pacific halibut (*Hippoglossus stenolepis*), king crab (*Paralithodes* ssp.), and Tanner (snow) crab (*Chionoecetes* ssp.), although substantial research on the biological impacts of PSC losses on these species remains to be done.

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INTRODUCTION

With respect to fishery management, the Gulf of Alaska encompasses a region of the eastern North Pacific Ocean extending on the east and south from the Alexander Archipelago of the panhandle of southeast Alaska to the Andreanof Islands on the west. The islands of the Aleutian chain serve as a northern boundary between the gulf and the Bering Sea (Fig. 1).

The gulf supports a rich and diverse complex of living marine resources within its more than 61,500 mi^2 continental shelf area. Serving both as rearing habitat for highly migratory species, such as the salmonids, and permanent home for a myriad of demersal and semimigratory pelagic species, the Gulf of Alaska represents one of the most Economically and ecologically valuable and multifarious environments in the world.

Historical Development of Gulf of Alaska Resources

The living marine resources of this region have historically attracted the interest of those determined to exploit this wealth. While the earliest "commercial" exploitation of this resource base was conducted by the coastal native populations to enhance trading opportunities with inland tribal populations and, subsequently, early non-native explorers, the first large-scale commercial ventures probably involved the Russian trading companies attracted by the abundance of commercially valuable sea otter (Enhydra lutris) and fur seal (Callorhinus ursinus) pelts (Alaska Geographic Society 1982).

With the decline in marine mammal populations and the sale of Alaska to the United States, commercial attention shifted toward the rich fishery resources of the area. Early commercial fisheries developed principally for Pacific cod (Gadus macrocephalus) and Pacific halibut (liippoglossus stenolepis), employing hook and line technology, but subsequently expanded to include a wide variety of other groundfish species (NPFMC 1984).

These early gulf fisheries were developed and sustained by both U.S. and Canadian fishermen. It wasn't until the decade of the 1960s that substantial fishing pressure from the technologically efficient distant water fleets, principally of the Soviet Union and Japan, began to appear in the gulf (Chitwood 1969). In succeeding years the Soviets and Japanese were joined in these fisheries by, among others, the Republic of Korea (ROK), Republic of China (Taiwan), and the Polish People's Republic (PPR).

All of these distant water fleets employ relatively large, well-equipped, well-supplied, and well-coordinated vessels. By utilizing highly efficient trawl technology, supported by on-site factory ship processing, these operations capture and process enormous volumes of fish for transshipment to foreign markets (Chitwood 1969). However, it is precisely this characteristic efficiency which presents such a potentially severe management problem in this complex multispecies-multiple habitat region of the North Pacific.

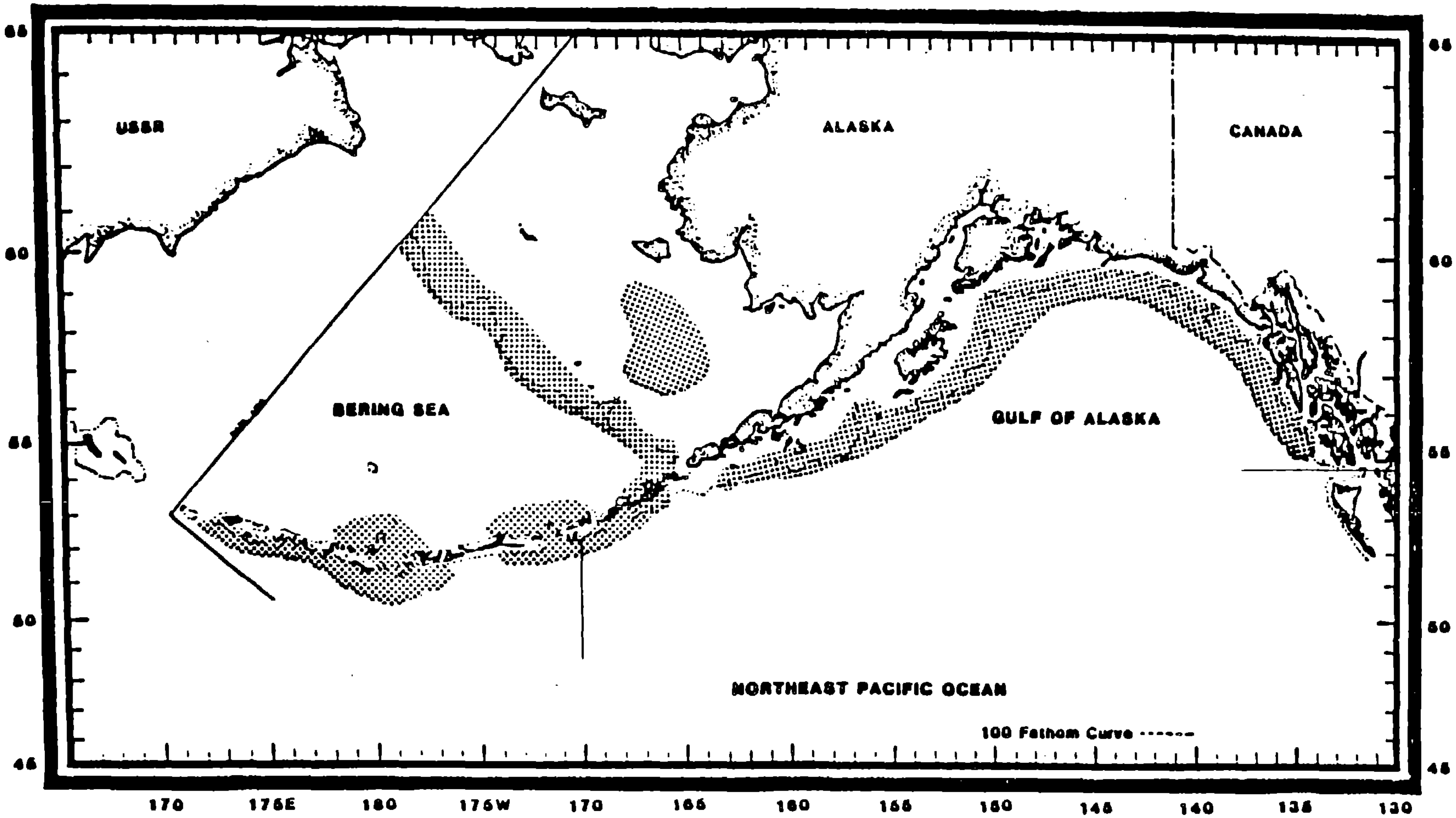

Figure 1. General areas of foreign and joint venture fishing (shaded) off Alaskan coast of United States. U.S. Gulf of Alaska management area bounded on the west by 170" W longitude; on the southeast by 54° 30'N latitude.

Trawl gear, whether fished on-bottom or pelagically, is essentially a nonselective harvesting technology, sweeping up everything in its path. As a result, a considerable potential for diversity in species composition exists with each trawl catch. Longline gear, also employed in the harvest of groundfish from the gulf, is somewhat more species selective. Nonetheless, both gear types produce significant, and to some extent, unavoidable by-catches of nongroundfish species in pursuit of the target complex.

Some of this by-catch is composed of high valued species such as Pacific halibut, king crab (Paralithodes spp.), Tanner (snow) crab (Chionoecetes spp.), and Pacific salmon (Oncorhynchus spp.), each of which supports a large domestic directed fishery. Because of their economic importance to U.S.-directed fisheries, halibut, king crab, Tanner crab, and Pacific salmon have been designated as "prohibited" for both foreign and domestic groundfish fishermen under authority of the Magnuson Fisheries Conservation and Management Act (MFCMA). Prohibited species status, which, according to one source, is drawn from the regulations of the International Pacific Halibut Commission (Skud 1977), requires that by-catches of these species be minimized and that all interceptions be returned to the sea, no matter what their condition. The intent of this prohibition is to remove any incentive a groundfish fisherman might have for clandestinely targeting on one or more of these fully utilized species. Marasco and Terry (1981) point out that:

> This prohibition does not provide an incentive to avoid incidental catch; and the stress associated with capture, holding, and release is sufficient to assure that most of the incidental catch does not survive to enter directed domestic halibut, salmon, or crab fisheries.

It is within this historical context, and in response to an environment of growing political and economic conflict between groundfish fishermen and those dependent upon the harvest of species that comprise the prohibited species by-catch, that the present research is initiated.

The principal objectives of this analysis are:

1. To review and evaluate the methodologies employed in the assessment of economic costs and benefits associated with the harvesting of the groundfish resource and the accompanying incidental interception of high valued "prohibited species";

1/Some small proportion of the total groundfish harvest in the Gulf of Alaska is taken on longline gear. While an important component of the fishery for some species, e.g., sablefish (Anoplopoma fimbria), longline gear will not be explicitly treated in the empirical portion of this analysis.

2. To develop an alternative methodology for the evaluation of by-catch loss and empirically compare the results obtained by application of the traditional approach with those from the alternative methodology for salmon prohibited species by-catches;

3. To conduct a sensitivity analysis with the proposed model to evaluate the robustness of empirical estimates obtained.

A REVIEW OF THE PROHIBITED SPECIES BY-CATCH ISSUE

The concept of prohibited species status reflects a recognition by resource managers that limitation of access to some subset of the fishery complex is desirable from a biological, political, or economic standpoint. Biologically, prohibited species status has been invoked to protect potentially vulnerable species or stocks from overexploitation, particularly in mixed stock fisheries employing nonselective gear types. Many of the earliest applications of this regulatory approach centered upon a perceived biological imperative to protect populations and avoid harvest of immature fish.

Major (1981) reports that the prohibited species concept had its origins in the Pacific salmon abstention provisions of the International Convention for the High Seas Fisheries of the North Pacific Ocean and in the old bilateral fisheries arrangements between the United States and Japan. Another of the early applications of prohibited species regulation as noted above was associated with the Pacific halibut fishery. Bernard Skud (1977) indicates that the International Pacific Halibut Commission (IPHC) created by Canada and the United States through a 1923 convention included, among its original articles, provisions for prohibited species status for halibut by-catch. The specific article provided that:

> Any halibut that may be taken incidentally when fishing for other fish during the season when fishing for halibut is prohibited under the provisions of this Article may be retained and used for food for the crew of the vessel by which they are taken. Any portion thereof not so used shall be landed and immediately turned over to the duly authorized officers of the Department of Marine and Fisheries of the Dominion of Canada or of the Department of Commerce of the United States.

While this early prohibition provision, which accompanied a season closure provision, was subsequently considered to have had relatively little effect on stock conservation (Babcock et al. 1931), it did establish a regulatory precedent. In 1944, the provision was extended under IPHC authority to preclude the taking of halibut by nets for fishery conservation purposes. By this time the IPHC had obtained scientific evidence that halibut caught by net, particularly trawl nets, were predominantly immature fish below the optimal harvest size (Skud 1977). Because of the very high handling mortality associated with trawl by-catch, these interceptions were perceived to be a biological threat to the stability of the halibut biomass.

With the advent of the MFCMA in 1976, the extension of prohibited species by-catch (PSC) protection to other fully utilized species living in or migrating through the new ZOO-mile fishery conservation zone became possible (P.L. 94-265, as amended, 90 STAT 351). In the North Pacific, prohibited status was extended under the MFCMA to include not only halibut, but among others, salmon, Tanner crab, and king crab (Queirolo 1981). Shrimp, clams, coral, and several less important crabs are also afforded protection under PSC provisions, although they are, at present, not of serious concern as by-catch to fishery managers (Balsiger 1981). Very recently sablefish has become a species of concern and has been incorporated into the PSC framework (Wilson and Larson 1985).

According to Bevan, 2/ the IPHC prohibited species regulatory framework serves as the model by which the Pacific and North Pacific Fishery Management Councils (NPFMC), established under the MFCMA, have applied this PSC tool to the management of the foreign, joint venture, and ultimately, domestic groundfish by-catch problem. Explicit PSC provisions have now been adopted in the Bering Sea/Aleutian Island Groundfish Plan and its incorporated amendments 1 through 8 (NPFMC 1983) and in the Gulf of Alaska Groundfish Plan and its incorporated amendments 1 through 11 and 13 (NPFMC 1984).

Several independent studies have been undertaken to examine particular characteristics of the by-catch problem. In research into the handling mortality losses associated with halibut by-catches in the trawl fishery, Hoag (1975) established for the first time a baseline estimate of the physical loss attributable to PSCs for this species. Hoag concluded that at a minimum 50 percent of the halibut intercepted and subsequently returned to the sea fail to survive the experience, and in the foreign trawl fisheries, virtually 100 percent mortality occurs.

In a subsequent report on the effects of halibut by-catch Hoag (1981) suggests that the incidental interception of halibut, predominantly in the groundfish trawl fisheries, constitutes a management problem because the magnitude of the catch is unspecified and therefore imprecisely estimated. In combination with the directed catch, by-catches may result in overfishing. In order to maintain stocks, directed catches may have to be restricted, resulting in substantial economic losses. Hoag concludes that:

> The incidental catch of halibut in the groundfish fishery is primarily an economic problem although biological considerations are present. Because most

2/Donald Bevan, Associate Dean, College of Ocean and Fishery Sciences, Univ. of Washington, Seattle, 98195: Pers. commun., May 1985.

of the incidental catch occurs in foreign fisheries, it is also a question of domestic versus foreign interests.

Wespestad et al. (1982) investigated means of obtaining reductions in the incidental catches of prohibited species in the Bering Sea groundfish fisheries. These researchers were specifically interested in the effects of gear restrictions on directed catch and by-catch in the harvesting of the groundfish complex. They concluded that substantial reductions in PSCs could be obtained by altering the trawl gear employed by groundfish fishermen from on-bottom to off-bottom configurations. If only off-bottom gear were permitted there would be some reduction in the groundfish catch, primarily associated with flounders, yellowfin sole, and turbots (Order pleuronectiformes). However, the researchers conclude that with carefully regulated, area-specific use of on- bottom gear the harvest of soles, flounders, and turbots could be permitted, so long as the remainder of the groundfish catch was harvested with off-bottom trawl technology. Because it is not possible to harvest flatfish without simultaneously capturing some halibut and crab, the authors suggest that an alternative to an on-bottom prohibition would be to reduce the allowable catch of turbot, sole, and flounders to assure PSC savings.

Examining PSC interceptions in pot fisheries, Williams et al. (1982) sought to compare the rates of intercept of halibut in Tanner crab pots between top-loading pots and side-loading pots, and side-loading pots with and without Tanner boards.3/ The researchers concluded that top-loading pots tended to reduce the by-catch of halibut without significantly altering the effective catch rates for the target Tanner crab.

Meacham (1980, 1981) examined the effects of trawl by-catches on chinook salmon (Oncorhynchus tshawytscha) of western Alaskan origin. He concluded that biological effects may include increased mortality of female chinook salmon because of their tendency to spend a greater number of years in the ocean maturing than the males. Biological impacts of the trawl fishery alone may not pose an immediate conservation threat to western Alaska chinook stocks, he concludes, but in combination with other high seas exploitation of these stocks by-catches do have the potential to damage individual populations and increase the management risks associated with directed inshore salmon fisheries. This, in turn, contributes to economic and social instability within the rural communities dependent upon the harvest of these salmon populations.

Another focus of PSC research has been on stock identification of the highly migratory Pacific salmon which comprise an important part of the by-

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3/ Tanner boards are devices which are fitted to king crab pots to restrict the size of the openings to the interior. Boards restrict the capture of the larger king crab while allowing for the harvest of Tanner crabs. The restriction of the entrance tunnel size would simultaneously limit capture of larger halibut.

catch in the Gulf of Alaska groundfish fisheries. Dahlberg (1980, 1982) has been chiefly responsible for the compilation and analysis of coded-wire tag data from salmonids captured in foreign high seas fisheries along the west coast of North America. Because the MFCMA has only relatively recently enabled on-board observer coverage of foreign fishing activities along the North American coast, the analysis of coded-wire tag recoveries has been limited. A series of three reports spanning the period 1980 through 1984 has been issued by the National Marine Fisheries Service (NMFS), documenting the numbers, species, release site, brood year, and capture site of coded-wire tagged salmonids from this region. To date, insufficient data are available to draw indisputable conclusions concerning the source of origin of the salmon captured as trawl by-catches, but preliminary estimates of stock identification can be made based upon these data.

Another means of stock identification of salmonids is by linear discriminant analysis of scale pattern data. Rogers et al. (1982, 1984) examined scales taken from chinook salmon intercepted by the Japanese high-seas mothership fishery in an effort to determine the relative contribution of North American chinook salmon stocks to the reported high seas catches of the Japanese. Samples were categorized into groups including Asian, western Alaskan, central Alaskan, and southeast Alaska-British Columbian stocks. While the study's conclusions indicated that a reduction in the interception of North American origin chinook salmon might benefit coastal chinook fisheries in western Alaska, a change in fishing activity, either geographically or temporally, which reduced the by-catch of chinook salmon could result in substantially greater interceptions of Bristol Bay sockeye salmon. Rogers and his associates concluded that additional data on age composition and abundance were badly needed in order to reliably identify the source of origin of these intercepted salmon.

Myers and Rogers (1985) examined scales from chinook salmon collected by U.S. fishery observers aboard foreign trawlers operating in the U.S. fishery conservation zone. While the researchers were able to develop some preliminary results for Bering Sea by-catches, they concluded that the results provided very little information on origins of chinook salmon caught by the foreign groundfish fishery in the Gulf of Alaska. They also recommended a considerable amount of additional research in this area.

It was the perception of significant interceptions of North American Pacific salmon in the Japanese high-seas mothership fishery, and the accompanying economic loss to domestic salmon fisheries, which prompted the investigations of Bering Sea interceptions. Perhaps as the economic impact of by-catch losses is better appreciated, the necessary support for further scale analysis research leading to accurate stock identification will be forthcoming.

To date, there has been relatively little analysis done on the economic implications of PSCs in the groundfish fisheries. Most of the early treatment of the economics of PSCs was done as an aside by the biologist or policy analyst examining the physical and biological parameters of the problem.

Skud (1977) mentions only in passing that much of the objection of trawlers to halibut PSC regulations centers on the economic loss the individual groundfish fisherman perceives he or she suffers by discarding by-caught halibut. Skud notes that the loss of production is a waste that rankles trawl fishermen, particularly when the price of halibut exceeds $1 per pound, while the value of other groundfish is only $0.10 to $0.40 per pound.

Perhaps a more typical treatment of the economic loss associated with PSCs is presented by Hoag (1981). In his discussion of the effects of groundfish trawl interceptions of halibut, Hoag notes that incidental catches reduce the potential yield available to the directed fisheries. In an effort to estimate this loss in economic terms Hoag applies a “1979 price of about $4,OOO/mt (ex-vessel) and $lO,OOO/mt (retail) to the incidental halibut catch in the groundfish fishery," thus deriving estimates of the economic loss to directed halibut fisheries of $21,912,000 at ex-vessel, $54,780,000 at retail.

Meacham (1981) similarly evaluated the economic impact of chinook salmon interceptions "by application of estimated mortality schedules, average age composition, average weight at return, and average price per pound statistics to the incidental catch." Meacham concluded that the loss from the 1979 groundfish by-catch is "estimated to be 1 to 2 million dollars to western Alaska fishermen."

These two studies are cited not as unique or isolated cases and are not singled out for criticism, but rather as examples of the general treatment historically afforded economic impacts associated with fishery management analyses of by-catch losses.

Recently some economists have turned their attention to the PSC problem in response to growing management concern. Queirolo (1982) examined the economic implications for U.S. and Canadian salmon fisheries of a proposed revocation by the U.S. governmentof the tri-lateral International Convention of the High Seas Fisheries of the North Pacific Ocean with Annex and Protocol, May 9, 1952. The protocol, signed by Japan, Canada, and the United' States in 1953 required the signatories to refrain from entering fisheries in which stocks were fully utilized under a maximum sustainable yield management system. The convention was intended to prevent further eastward expansion by the Japanese distant water salmon fleets nearer the North American mainland.

The Japanese mothership fleets operating in the North Pacific and Bering Sea had the potential to intercept large numbers of North American salmon on the high seas which were bound for near-shore and in-shore fisheries (Fredin et al. 1977). The convention agreement reduced, this risk as long as its provisions were in place.

Utilizing recent historical Japanese catch rates, stock composition and age data, in combination with three possible operational scenarios which Japan might undertake in the absence of the convention's constraints, the analyst concluded that Japanese interceptions of North American salmon could increase to as many as 26.8 million fish annually. Employing a data series on local ex-vessel prices for regional domestic salmon fisheries, exploitation rates, and assumptions concerning real price behavior, interception figures were analyzed and real discounted losses estimated. The use of a simple sensitivity analysis allowed for the comparison of several potential outcomes. The conclusions drawn from the study indicate that in a worst case scenario, Japanese interceptions of North American salmon could impose an annual real discounted ex-vessel loss of more than $128.2 million on U.S. and Canadian fisheries.

Marasco and Terry (1981) proposed an alternative approach to the economic analysis of by-catch losses. They noted that,

> With the possible exception of halibut, resource abundance objectives can be met by limiting the directed harvests of prohibited species. Therefore, at present levels, the incidental catch of prohibited species by groundfish fleets poses an allocation rather than a conservation problem; and the problem is that the harvests of the halibut, salmon, and crab fleets are less than they might otherwise be.

These authors suggested that the potential loss in gross earnings by domestic fishermen is one measure of the magnitude of the by-catch problem. Using a mathematical algorithm, Marasco and Terry evaluated the ex-vessel discounted present value loss attributable to the 1979 Bering Sea/Aleutian Islands Area prohibited by-catch, for halibut, chinook, and chum salmon (*O. keta*), king crab (blue and red), and Tanner crab (*bairdi* and *opillio*). With empirical estimates of the discounted ex-vessel loss attributable to groundfish by-catch, Marasco and Terry developed arguments for the use of economic disincentives in the form of incidental catch fees to induce a more nearly optimal by-catch level. The authors noted that since there are costs associated with reducing incidental catch, the optimal level of PSCs is not zero. Furthermore, maximization of net benefits from the fishery by equating the marginal benefit of by-catch controls with the marginal cost of controls would involve the maximization of the joint net benefit of the United States and the foreign nations harvesting groundfish in this region.

Subsequent to Marasco and Terry (1981), a series of analyses have been conducted employing the same methodological framework but utilizing Gulf of Alaska by-catch data.

Anderson (1983) examined the economic loss attributable to crab by-catches in the Gulf of Alaska groundfish fishery. He found that estimated losses of real ex-vessel gross revenue in domestic directed crab fisheries ranged from a high of $747,000 in 1978 to a low of $109,000 in 1981 (in 1982 real dollars) for all species of crab.

Terry and Hoag (1983) evaluated Gulf of Alaska halibut by-catch losses in the groundfish fishery. They concluded that over the period 1977 through 1982 the annual impact on discounted real ex-vessel gross earnings in the domestic halibut fishery ranged from $1,499,000 to $4,202,000 for both foreign and joint venture interceptions, depending on the real discount rate employed.

In neither of these studies were impacts beyond the harvesting level considered.

A more troublesome limitation associated with these by-catch studies is their failure to explicitly recognize and account for longer term economic losses resulting from annual Gulf of Alaska groundfish prohibited species interceptions. As in the original Marasco and Terry analysis, these later studies recognized the need to incorporate rates of natural mortality and handling mortality, as well as exploitation rates, and discount rates, in evaluating the economic implications of intercepting fish which would not have otherwise entered a directed fishery for a number of additional years. That is, observer data clearly demonstrate that groundfish trawl PSC by-catches are composed almost exclusively of immature individual specimens. This suggests that, had these fish not been captured as by-catch, they would have spent additional years maturing in the North Pacific before recruiting into year classes susceptible to directed fisheries.

Therefore, it is appropriate that these changes be explicitly reflected in the models used to evaluate directed fishery losses from PSCs. The studies cited above accomplish this to the extent that total gross estimated by-catches are reduced in the models by an annual natural mortality rate applied for the appropriate number of years the PSCs would have spent achieving sufficient size and age to be harvested by directed fishermen. At this point, however, these analyses make an explicit assumption that all remaining PSCs would have been taken in a directed fishery. The treatment of these fish as losses only at this point in time fails to adequately account for the physical and, therefore, economic losses attributable to subsequent harvest opportunities. Most significantly, these students, predicated as they are on the basic Marasco-Terry approach, tend to neglect the cost to society of the lost reproductive potential associated with PSC mortality. Because these losses accrue to future fisheries, their omission from the estimated measurement of PSC losses is potentially a serious understatement of the true social cost of groundfish harvesting activities in the Gulf of Alaska.

It has been suggested that, because the Marasco-Terry methodology explicitly assumes that all PSCs (which would have survived to harvestable size except for their interception in the groundfish fishery) are harvested in the directed commercial fishery in the year of recruitment into the legal population, at least some partial accounting of reproductive loss is made. That is, by assuming 100 percent commercial exploitation of these fish, while in reality recognizing that some unknown number would have avoided capture and contributed' to the spawning population, the Marasco-Terry methodology overstates the immediate impact of PSCs on domestic directed fisheries. At the same time, however, the methodology understates the future adverse effect on directed fisheries attributable to this by-catch loss. In effect then, the Marasco-Terry approach contains inherent upward and downward biases. The ability to predict, with any certainty, the net effect these biases will have on the resulting estimated impacts has not heretofore been possible.

In another study of the by-catch problem Terry (1985) argued for use of market-oriented solutions to arrive at optimal incidental by-catch levels. In the absence of reliable historic baseline interception data it is virtually impossible for fishery managers to identify the "correct" by-catch levels, he argues. However, to the extent that the market is permitted to operate, the marginal cost and marginal benefit of by-catch control will define the optimal interception level of prohibited species in the groundfish fishery, and managers will not find it necessary to estimate these levels of catch through trial and error.[4/]

This approach requires careful, accurate measurement of the benefits and costs attributable to alteration of PSCs. The present analysis attempts to refine and extend the methodology developed by Marasco-Terry as a first step in an effort to provide a more comprehensive measurement of the benefits to U.S. and Canadian directed fisheries from reductions in PSCs in the Gulf of Alaska.

PACIFIC SALMON PROHIBITED SPECIES BY-CATCH

The Problem

The scope of the present empirical analysis is confined to the problem of Pacific salmon by-catch in the Gulf of Alaska groundfish fishery. The purpose of focusing exclusively upon salmon is several-fold, but should not be interpreted as implying that halibut and crab interceptions are less a problem. Rather, the highly migratory life cycle of Pacific salmon, growing in the gulf but originating from as far north as the Arctic-Yukon-Kuskokwim region in the Bering Sea, and south to the spawning streams of northern California, result in temporally, geographically, and politically diverse economic and fishery management implications. Furthermore, the life histories of these five anadromous species have been subject to study for many years and can be described in some detail. Of significant biological importance is the fact that all Pacific salmon spawn once and then die, a semelparous reproductive strategy.

In the case of Pacific salmon, incidental by-catch mortality associated with either the groundfish longline or trawl fishery is virtually 100 percent. Thus every salmon intercepted represents a potential pure biological and economic loss to the directed salmon fisheries of the United States and Canada. Alternatively, had that salmon survived to spawn, it would have contributed future wealth in the form of a benefit stream from successive generations of its off-spring, a portion of which in their turn would have entered directed salmon fisheries or contributed to spawning escapement. In addition, because the salmon by-catch must be sorted from the target catch and discarded into the sea, the by-caught fish impose additional

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[4/] Darrell Hueth, Dep. Agricultural and Resource Economics, University of Maryland, College Park, MD 20742. Pers. commun., Dec. 1984.

operating costs upon the groundfish fisherman, therein increasing the average cost per unit of the primary catch. Finally, by-caught and discarded salmon represent a protein loss to mankind, except as they may re-enter the food chain of the oceanic biosphere to be harvested in another form.

From a fishery management perspective, by-catch losses pose, at the very least, the threat of further complication of an already difficult and unstable allocation system, whether among competing U.S. fishermen or between U.S. and Canadian salmon fisheries. In the worst case, prohibited species losses may actually result in the subversion of salmon enhancement and rehabilitation programs involving substantial public and private capital investments and operation and maintenance expenditures in the two nations.

As a prime example, with congressional ratification in March 1985 of the "Treaty Between the Government of the United States of America and Government of Canada Concerning Pacific Salmon, signed at Ottawa, January 28, 1985" (__ UST _____ T.I.A.S.), (the treaty) the United States and Canada concluded nearly 15 years of intensive negotiations over access to and control over their respective Pacific salmon resources and directed salmon fisheries. Acquisition of the treaty agreement and adherence to its provisions have been linked by both countries to proposed aggressive expansion of large scale capital investment in facilities for enhancement of depleted or endangered salmon runs. Such capital expenditures depend explicitly on the ability of both the United States and Canada to control the interceptions of their respective salmon production, and so guarantee that a significant portion of the benefit created by these capital and operating expenditures accrue to nationals of the country making the investment. The treaty is predicated on a formula, as yet not fully articulated, wherein historic patterns of interceptions of one nation's salmon by the other will be systematically reduced by catch quota limitations, time or area closures, etc., and/or mitigated, perhaps by construction of additional hatchery capacity paid for by the intercepting country. Clearly, the treaty's allocation program will involve complicated and finely delineated estimates of production capacity, directed harvest, and interceptions by each nation. Diversion of even a relatively few fish from either nation's resource base will have potentially significant economic and political implications.

Yet, according to sources associated with the scientific and technical staff which support U.S. negotiations, prohibited species by-catch losses of salmon to trawl fisheries have been, to date, treated as "natural mortality" losses for purposes of the treaty formula, principally because insufficient information exists as the magnitude and distribution of the economic costs associated with such interceptions. As such information can be made available, and particularly as the Gulf of Alaska groundfish fisheries evolve toward wholly domestic operations, continued high annual

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5/Aven Andersen, NMFS Alaska Region Office, P.O. Box 1668, Juneau, AK 99802. Pers. commun., June 1985; and Kenneth Henry, Northwest and Alaska Fisheries Center, 7600 Sand Point Way N.E., Seattle, WA 98115. Pers. commun., June 1985.

by-catch interceptions of salmon are expected to be examined within the context of the treaty's bi-lateral allocation-mitigation scheme.

This suggests that, for example, salmon of Canadian origin which are intercepted by U.S. trawl fisheries in the gulf, could be assessed against U.S. allocations in directed salmon fisheries, reducing these catches, and further, that these salmon may be included under compensation-mitigation provisions of the treaty, requiring U.S. capital expenditures on mitigation and enhancement facilities to supplement Canadian salmon stocks.

Another potential conflict between U.S. trawler by-catch and Pacific salmon mitigation exists with regard to the Columbia-Snake River system. Passage by Congress of the Pacific Northwest Electric Power Planning and Conservation Act in 1980 created the Northwest Power Planning Council. The council has responsibility, under the provisions of the act, for the development of a program to restore the fish and wildlife resources of the Columbia Basin, principal among which are the anadromous salmon runs. In an effort to further these objectives the council adopted the Columbia Basin Fish and Wildlife Program in late 1982, which included plans for three major hatchery facilities for the enhancement of upriver salmon stocks. Subsequently, the council has taken the public position that funding for construction of at least two of these production facilities is contingent upon assurances that the benefits associated with these capital expenditures will accrue to the citizens of the Pacific Northwest states (Lewis and Clark Law School 1983). Without such assurances in the form of "adequate ocean harvest controls" over Columbia River produced salmon, the council proposes no further investment in enhancement facilities. To the extent then that Gulf of Alaska by-catches include Columbia system salmon, as evidence indicates they indeed do, high groundfish fishery by-catch losses may result in further delays, or complete elimination, of much needed salmon enhancement investment in this region (Dahlberg et al. 1986).

The Groundfish Fishery in the Gulf of Alaska

The present analysis will examine the post-MFCMA period in the gulf groundfish fishery. Over this period, 1977-84, six foreign nations operated in the Gulf of Alaska directed groundfish fishery. These included Japan, U.S.S.R., ROK, PPR, Federal Republic of German (FRG), and Mexico. In addition, seven joint venture operations were conducted in this fishery during roughly the same period..6/ Each joint venture employed U.S. catcher boats delivering trawl catches to foreign processing vessels in the fishery conservation zone (FCZ). The foreign nations participating in these joint ventures were Japan, ROK, PPR, U.S.S.R., FRG, Spain, and Taiwan (Table 1). Total groundfish landings as well as prohibited species by-catches in these fisheries varied significantly over this period by nation, area, gear type, and season (Tables 2a-2e and Appendix B).

6/ Joint ventures involve U.S. fishing vessels harvesting the groundfish but landing them aboard a foreign factory ship for processing into final products. Joint venture operations in the Gulf of Alaska commenced in 1978.

Table 1. -- Foreign nations participating in the Gulf of Alaska groundfish harvest under the MFCMA 1977-84.

Type of fishery	1977	1978	1979	1980	1981	1982	1983	1984
Foreign	Japan	Japan	Japan	Japan	Japan	ROK	Japan	Japan
	ROK c/	ROK	ROK	ROK	ROK	Japan	ROK	ROK
	USSR	USSR	USSR	USSR	PPR			PPR
	PPR d/	PPR	PPR	PPR				FRG e/
			Mexico					
Joint Venture	None	ROK	USSR	USSR	Japan	ROK	Japan	Japan
			ROK	ROK	ROK	Japan	ROK	ROK
						PPR	USSR	USSR
						FRG	Taiwan	PPR
								FRG
								Spain
								Taiwan

a/ Magnuson Fishery Conservation and Management Act of 1976.

b/ Source: Personal communication with Mike Brown, National Marine Fisheries Service, U.S. Foreign Fisheries Observer Program, 7600 Sand Point Way NE, Seattle, WA 98115.

c/ Republic of Korea.

d/ Polish People's Republic.

e/ Federal Republic of Germany (West Germany).

Table 2a. -- Estimated foreign and joint venture catches by species group in the Gulf of Alaska, 1977-84.[a/]

	1977	1978	1979	1980	1981	1982	1983	1984
Foreign Directed Catches (t)								
Total	199,617	165,100	163,348	208,038	232,542	153,734	147,470	123,705
Squid	NA	322	426	841	1,135	277	267	120
Flounders	16,044	14,314	13,474	15,496	14,442	8,986	9,531	3,033
Pollock	117,839	96,328	103,187	112,996	130,323	92,612	81,358	99,259
Pacific cod	1,992	11,369	13,174	34,243	34,968	26,937	29,777	15,897
Sablefish	15,965	7,127	6,884	6,139	7,976	5,646	4,966	1,107
Atka mackerel	19,455	19,586	10,948	13,162	18,727	6,760	11,471	536
All rockfish[b/]	23,590	10,067	12,286	16,647	17,859	10,467	7,846	3,178
Other fish[c/]	4,732	5,987	2,969	8,514	7,112	2,049	2,256	576
Joint Venture Catches (t)								
Total	d/	48	1,522	1,911	16,966	74,450	142,984	219,625
Squid		0	<1	0	<1	16	4	5
Flounders		5	77	209	18	18	2,691	3,448
Pollock		34	583	1,136	16,856	73,918	134,131	207,104
Pacific cod		7	711	466	58	193	3,426	4,650
Sablefish		0	19	20	<1	1	275	528
Atka mackerel		<1	1	3	0	0	790	585
All rockfish[b/]		1	97	28	1	3	2,276	2,036
Other fish[c/]		1	34	49	33	301	391	1,268

a/ Estimates for years 1977-83 are from Berger et al. 1984.

b/ As rockfish reporting requirements have changed over the years, all rockfish are combined into a single group for comparison purposes.

c/ Reporting requirements of rattails, Coryohaenoides spp., have changed. In 1978, rattails were included in the "other fish" category. In 1980, rattails were reported in a separate category, and in this table, rattails make up 2,960 t of the 1980 foreign catches of "other fish." (No rattails were estimated to have been taken in the 1980 joint venture fishery.) In the other years, foreign nations were not required to report them unless they were utilized.

d/ Joint venture activity did not begin until 1978.

Source: National Marine Fisheries Service, U.S. Foreign Fisheries Observer Program, 7600 Sand Point Way NE, Seattle, WA 98115.

Table 2b. -- The estimated incidental catch (numbers and metric tons) of Pacific salmon in the foreign and joint venture groundfish fisheries in the Gulf of Alaska, 1977-84.

	Foreign Vessel Catch		Joint Venture Catch		Total	
Year	No.	t	No.	t	No.	t
1977	5,272	19.30	NF	NF	5,272	19.30
1978	45,603	131.27	b/	b/	45,603	131.27
1979	20,410	68.69	1,050	2.31	21,460	71.00
1980	35,901	106.90	168	1.07	36,069	107.97
1981	30,860	95.89	0	0	30,860	95.89
1982	5,556	18.89	1,411	2.77	6,967	21.66
1983	9,621	31.76	4,263	11.98	13,874	43.74
1984	12,001	36.13	63,845	168.97	75,846 c/	205.10

a/ Estimates for years 1977-83 are from Berger et al. 1984. Estimate for 1984 from the U.S. Foreign Fisheries Observer Program.

b/ No estimates of incidental catch were made of the limited joint venture fishery in 1978.

c/ Final estimate for 1984, issued December 1985.

NF -No fishing.

Source: National Marine Fisheries Service, U.S. Foreign Fisheries Observer Program, 7600 Sand Point Way NE, Seattle, WA 98115.

Table 2c. -- Estimated incidental catch (numbers and metric tons) of Pacific halibut in the foreign and joint venture groundfish fisheries in the Gulf of Alaska, 1977-84. a/

	Foreign Vessel Catch		Joint Venture Catch		Total	
Year	No.	t	No.	t	No.	t
1977	413,009	2,200	NF	NF	413,009	2,200
1978	293,374	11,259	b/	b/	293,374	1,259
1979	249,641	2,576	5,127	21.49	254,768	2,597
1980	511,521	13,205	19,318	48.50	530,839	3,254
1981	417,311	2,499	274	4.81	417,585	2,504
1982	562,196	2,690	2,371	3.60	564,567	2,694
1983	689,688	3,235	98,571	356.49	788,259	3,592
1984	361,913	1,506	165,721	589.66	527,634	2,096

a/ Estimates for years 1977-83 are from Berger et al. 1984. Estimate for 1984 from the U.S. Foreign Fisheries Observer Program.

b/ No estimates of incidental catch were made of the limited joint venture fishery in 1978.

NF - No fishing.

Source: National, Marine Fisheries Service, U.S. Foreign Fisheries Observer Program, 7600 Sand Point Way NE, Seattle, WA 98115.

Table 2d. -- Estimated incidental catch (numbers and metric tons) of king crab in the foreign and joint venture groundfish fisheries in the Gulf of Alaska, 1978-84.[a/]

	Foreign Vessel Catch		Joint Venture Catch		Total	
Year	No.	t	No.	t	No.	t
1978	93,875	135.31	b/	b/	93,875	135.31
1979	24,094	40.30	466	0.83	24,560	41.13
1980	6,395	8.95	6,285	13.03	12,680	21.98
1981	6,619	8.01	0	0	6,619	8.01
1982	3,464	5.60	11	0.03	3,475	5.63
1983	2,124	3.00	4,454	15.01	6,578	18.01
1984	1,465	4.89	5,482	20.15	6,947	25.04

a/ Estimates for years 1978-84 are from Berger et al. 1984. Estimate for 1984 from the U.S. Foreign Fisheries Observer Program.

b/ No estimates of incidental catch were made of the limited joint venture fishery in 1978.

Source: National Marine Fisheries Service Foreign Fisheries Observer Program, 7600 Sand Point Way NE, Seattle, WA 98115

Table 2e. -- Estimated incidental catch (numbers and metric tons) of Tanner crab in the foreign and joint venture groundfish fisheries in the Gulf of Alaska, 1978-84.

	Foreign Vessel Catch		Joint Venture Catch		Total	
Year	No.	t	No.	t	No.	t
1978	23,969	14.16	b/	b/	23,969	14.16
1979	16,992	11.30	626	0.25	17,618	11.55
1980	27,844	16.62	58,022	41.43	85,866	31.05
1981	96,662	70.19	0	0	96,662	70.19
1982	63,293	35.33	364	0.17	63,657	35.50
1983	30,609	22.42	102,840	54.87	133,449	77.29
1984	8,885	5.69	41,668	27.36	50,548	33.05

a/ Estimates for years 1978-84 are from Berger et al. 1984. Estimate for 1984 from the U.S. Foreign Fisheries Observer Program.

b/ No estimates of incidental catch were made of the limited joint venture fishery in 1978.

Source: National Marine Fisheries Service, U.S. Foreign Fisheries Observer Program, 7600 Sand Point Way NE, Seattle, WA 98115.

Pacific salmon by-catch is associated predominantly with mid-water trawl gear, although the large surimi trawlers of Japan use on-bottom gear and also take salmon incidentally. Nelson 7/ reported that high incidental catches of salmon tend to occur in western and central management areas of the gulf during the winter season (October through February). These interceptions were primarily associated with nations and vessels targeting on Walleye pollock (*Theragra chalcogramma*).

Walleye pollock represents the single most important species, by weight, targeted by groundfish trawlers in the gulf. In 1983, for example, foreign vessels harvested an estimated 147,500 metric tons of groundfish, 55.2 percent of which was pollock. Joint venture operations took approximately 143,000 metric tons of groundfish in that year, 94 percent of which was pollock (Berger et al. 1984).

This fishery has evolved rapidly since the advent of the MFCMA from an exclusively foreign fishery to what had become by 1984 a joint venture dominated fishery (see Table 3). This evolution is expected to continue, ultimately resulting in wholly domestic operations displacing the U.S.-foreign joint ventures.

Throughout this transitional period prohibited species by-catch has been a serious problem economically, biologically, and managerially. At present, U.S. management agencies have the authority to insist that foreign and joint venture groundfish operators submit to on-board observer coverage to monitor and assure compliance with prohibited species regulation. As the groundfish fisheries become predominantly domestic operations, without special provisions imposing similar on-board observer requirements on U.S. vessels, monitoring of by-catch losses will cease, and the means to evaluate the tradeoff between groundfish catches and foregone 8/ salmon, halibut, and crab landings will be lost.

The purpose of the present study is in part to develop a methodology to fully account for external costs imposed on directed salmon fisheries by trawl fisheries in the course of harvesting the groundfish resource. A further purpose is to define a basis for interpreting the probable benefits and costs associated with the ability to monitor and enforce prohibited by-catch regulations.

Within this framework the analysis of the physical and economic impacts of Gulf of Alaska PSCs pose several interesting challenges and simultaneously offer the potential of providing important insights into the tradeoffs being made between the harvest of groundfish and the directed fisheries for halibut, crabs, and salmon from this region.

7/ Russell Nelson, Northwest and Alaska Fisheries Center, 7600 Sand Point Way N.E., Seattle, WA 98116. Pers. commun., July 1985.

8/ The term "foregone" is used throughout this paper in the sense of "unrealized" or "sacrificed," as in benefits foregone due to a loss of reproductive potential.

Table 3. -- Estimated foreign and joint venture catches of Walleye pollock in the Gulf of Alaska, 1977-84.

Year	Foreign catch (t)	Joint venture catch (t)	Total
1977	117,839	None	117,839
1978	96,328	34	96,362
1979	103,187	583	103,770
1980	112,996	1,136	114,132
1981	130,323	16,856	147,179
1982	92,632	73,918	166,550
1983	81,357	134,132	215,489
1984	99,212	202,400	301,612

Sources: Russell Nelson, Northwest and Alaska Fish. Cent., 7600 Sand Point Way NE, Seattle, WA 98115; Janet Smoker, NMFS Alaska Regional Office, P.O. Box 1668, Juneau, AK 99802.

AN EXTENDED METHODOLOGY TO EXAMINE PSC LOSSES

The analytical approach delineated below is fundamentally an extension of the Marasco-Terry (1981) methodology designed to explicitly incorporate and account for a significant component of the PSC loss which the original procedure neglects. In particular, the proposed extension adds to the original model an iterative arithmetic algorithm which permits the inclusion of an estimate of the physical and economic costs of losses in reproductive potential, directly attributable to PSC mortality.

While the theoretical model presented in the following pages may be generalized to reflect the specific biological and economic characteristics of any prohibited species and its associated directed fisheries, complications arise when attempting to empirically apply the extended model to some of the prohibited species intercepted in the gulf. This is principally because insufficient data, and a lack of predictive biological models, presently exist for the Gulf of Alaska which would permit an adequate description of the life history and reproductive potential of long-lived, iteroparous species such as Pacific halibut, Tanner and king crabs. At such time as these data become available it should be relatively easy to employ the proposed methodology to more fully evaluate the by-catch costs associated with loss of reproductive potential for these remaining species.

The Model

The compound model is configured to allow empirically derived by-catch data (e.g., U.S. Foreign Fisheries Observer Program interception estimates), to be employed in conjunction with parametric estimates of prevailing physical, economic, and management policy constraints, to derive theoretically consistent estimates of benefits foregone as a result of PSC mortality. The model begins with the raw by-catch estimate of physical loss, in numbers of fish, by species, in the groundfish fishery. NMFS observers, as well as other independent researchers, examining by-catch composition from Gulf of Alaska trawl catch samples, have established profiles of PSC characteristics.

The model is formulated to incorporate these characteristics to the fullest extent possible, although some simplifications have been necessary. In the algorithm, the gross by-catch estimate, in numbers of fish, is potentially reduced by the initial application of a handling mortality factor. Based upon biological research, handling mortality (or conversely by-catch survival) rates have been hypothesized for the various species represented in the PSC. These rates vary by species, capture technology, and care with which the catch is handled. They represent one parameter within the model which can be adjusted to reflect, for example, advances in trawling technology, handling methods, sorting of catch, and rapidity with which PSCs are returned to the sea. At the present time most intercepted species are assumed to incur 100 percent handling mortality, although exceptions do exist. For example, Hoag's estimates of handling mortality for halibut ranged from approximately 50 percent when fish are taken by longline or smaller draggers, to 100 percent in the foreign groundfish fisheries.

Thus, the model initially applies to the gross by-catch estimate an assumed rate of handling mortality, by species, and gear type, to arrive at an "initial gross PSC loss" estimate in numbers of fish (see Equation 1).

$$(\text{Raw by-catch est.})_{tjs} \times (\text{Handling mortality})_{js} = (\text{Initial Gross PSC Loss})_{tjs} \quad (1)$$

where,

t = year of interception in the groundfish fishery
j = intercepting gear-type
s = species of PSC.

The model next incorporates information on the age composition of the PSC. While there are exceptions which will be noted below, the PSC profiles indicate that virtually all crab, halibut, and salmonids captured in these fisheries are sublegal juveniles. That is, by-catches essentially involve the capture of prohibited species which, absent their interception in the groundfish fishery, would not have entered a directed fishery for some significant period of time.

For example, according to observer data, the chinook salmon captured as PSCs in the gulf groundfish fishery, average 61.3 cm in length and are approximately 3 years of age. This suggests that these individual fish would typically be 1 1/2 to 3 years, away from physical maturity, depending on area of origin, and thus an equivalent period away from directed terminal fisheries, hatcheries, or spawning grounds. During the remainder of their natural rearing cycle each individual would have continued to grow and be susceptible to the same rate of natural mortality as the general population of that species. Therefore, in assessing by-catch impacts it would be inappropriate to debit the entire "initial gross PSC loss" against the groundfish fishery. The model explicitly accounts for this phenomenon by applying to the initial gross PSC loss estimate a species-specific annual natural mortality rate. This rate is compounded over the average number of years away from maturity the by-catch was at the time of interception. This reduces the initial gross loss to a potential realized physical loss, measured in numbers of fish foregone (see Equation 2).

$$\sum_{i=1}^{j} [(\text{Initial Gross PSC Loss})_{tjs} \times (1 - \text{Annual Natural Mortal. Rate}_s)^{(n)}] = \text{Potential Realized Loss}_{(t+n)s} \quad (2)$$

where in addition,

n = average number of years away from maturity the by-catch was at capture.

Each of the species of principal concern to fishery managers, with regard to prohibited species interception in the gulf, is fully utilized and supports an intensive directed fishery. Each fishery has developed under one or more administrative jurisdictions which, through management regulations, have established exploitation rates for their respective directed fisheries. By applying these fishery-specific exploitation rates to the "potential realized physical loss," by species, by area, the model is capable of yielding an estimate of the "actual physical loss" in numbers of fish accruing to area-specific directed fisheries in the next most recent period following the PSC loss. That is, to the extent that the original by-catch of immature prohibited species can be identified by stock of origin (e.g., Columbia River chinook salmon), it becomes possible within the model's framework to anticipate the future impact on a specific directed salmon fishery by utilizing the prevailing exploitation rate within that jurisdiction (see Equation 3).

$$(\text{Potential Realized Loss}_{ms}) \times (\text{Directed Exploitation Rate}_{sk}) = (\text{Actual Physical Loss}_{smk}) \qquad (3)$$

where m = (t+n) for notational convenience and k = geographic region of directed fishery.

Because the by-caught fish is typically immature at interception, the loss to the directed fishery is assumed to accrue only after a sufficient period of time has passed to have permitted the juvenile fish to mature and be recruited into the directed fishery. In the case of halibut this average period between by-catch loss and potential recruitment has been estimated at 5 years; for chinook salmon 3 to 5 years, depending upon origin of stock; for some crab species perhaps as little as 6 months.

At this stage of the analysis the model has generated an estimate of the actual physical loss, in numbers of fish, which will accrue to the directed fishery or fisheries as a result of the prohibited species interception. It is then a relatively simple task to convert the physical loss from numbers of fish to pounds of fish by multiplying the former by the average weight per fish in the directed fishery. By then multiplying the pounds of fish foregone by the prevailing ex-vessel price (real or nominal) one obtains an estimate of the gross (nondiscounted) ex-vessel value loss to the directed fishery, in that year, attributable to the earlier annual by-catch in the groundfish fishery (see Equation 4).

$$[\text{Actual Physical Loss}_{smk}(\text{numbers of fish})] \times [\text{Average Weight}_{sk}] \times [\text{Prevailing Ex-Vessel Price}_{msk}] = [\text{Gross Ex-Vessel Loss}_{msk}] \qquad (4)$$

Unless the by-catch loss occurs in the same year as the directed fishery loss (i.e., the PSC is composed of mature fish which would have entered the directed fishery in the year of their capture by groundfish gear), it is necessary to discount the estimated gross ex-vessel loss to directed fisheries in order to place all attributable costs and benefits within a comparable context. That is, as Baumol (1977, p. 60) points out, discounting "permits us to convert amounts payable or receivable at different dates into similar terms--they are all made comparable by being translated into their equivalent current (or present) value" (see Equation 5).

$$[\text{Gross Ex-Vessel Loss}_{msk}] \times \left[\frac{1}{(1+i)^m}\right] = [\text{Discounted Present Value Ex-Vessel Loss}_{sk}] \qquad (5)$$

where, in addition, i = social discount rate.

Of course, the ability to directly compare costs and benefits which accrue at different points in time is essential to a comprehensive assessment of the impacts of PSCs within the broader context of the Gulf of Alaska groundfish harvest.

Among the most contentious aspects of the discounting of future costs and benefits is the issue of the appropriate discount rate. The discount rate itself, whether private or social, can be thought of as a measure of the opportunity cost of not having immediate access to a resource. Baumol (1977) suggests that the determination of an appropriate discount rate is crucial, although somewhat subjective. The choice depends upon such factors as risk preference and the degree to which capital markets operate efficiently. As a result no consensus presently exists within the economics profession with respect to a formula for deriving the "correct" discount rate. As Just et al. (1982) note, real rates of between zero and eight percent appear with regularity in the literature. At present, a U.S. Office of Management and Budget "advisory" requires the use of a ten percent real discount rate for all public investment and policy analysis, unless some other rate can be justified on a case-by-case basis.

With respect to exploitation of natural resources, the issue becomes one of defining a discount rate which reflects society's collective preference regarding the rate at which its resources are to be exploited. Just et al. (1982), in discussing social discount rates, state that, "the choice of discount rate may have overriding importance in any cost-benefit analysis of government policy."

In general, the higher the discount rate the more rapid the desired rate of resource use and the less valued is future exploitation. Just et al. (1982) note:

> The prevailing market rate of interest should reflect consumers' preferences toward financing current consumption through consumer debt as opposed to deferred consumption. The market rate of interest,

> however, may not reflect the value of using resources . . . which exceed the life of the present generation or . . . (for) goods for which perfect markets do not exist (for example public goods). In particular: the market rate of interest will not reflect society s regard for consumption by future generations. (Because) future generations are not involved in current markets (they) cannot represent their interest.

Therefore, governments must assume this obligation, through social discounting. They conclude that, "the social rate of discount that is appropriate for public policies may differ from the prevailing market rate of interest."

This is the context within which a social discount rate is applied in the present analysis. The problem of PSC losses is one of long term resource wealth distribution, with potential intergenerational implications. Because the resources under consideration are public their management and utilization influences society's collective welfare, despite the fact that private firms may exploit some share of them. The use of a present value gross ex-vessel estimate of social benefits foregone is 'admittedly imperfect, but it is a reflection of data limitations and not an indication that the losses are fundamentally private in nature.

Clearly, the process of defining an "appropriate" social discount rate for public policy analysis involves a complex of economic objectives and political agendum. The model treats the discount rate as an exogenously introduced parameter in the evaluative matrix thus permitting assessment of the sensitivity of the predicted results to changes in apparent "social time preferences."

Accounting for Reproductive Potential

Insofar as the exploitation rates in the directed fisheries are less than 100 percent of the allowable biological catch, some proportion of the PSC loss goes uncounted by evaluating the foregone harvest only in terms of an estimated actual physical loss to directed fisheries in the next most recent harvestable period. Specifically, to the extent that some proportion of the intercepted by-catch would have survived to maturity, passed through the directed fisheries and contributed to the spawning population, failure to account for the future benefit stream associated with this reproductive contribution has the potential to severely understate the impact of prohibited species interceptions. The model addresses this potential shortcoming by explicitly allocating the balance of the potential physical loss, in numbers of fish, to spawning escapement, by area. For example, if 1,000 chinook salmon of central Alaskan origin represented the potential physical loss to that region's directed salmon fisheries, the model would calculate the product of the area-specific exploitation rate, i.e., 0.45, and the "potential physical loss," in numbers of fish, or 450 fish. The remaining 550 chinook salmon would accrue to spawning escapement in the central Alaska subroutine of the model (see Equation 6).

$$(\text{Potential Realized Loss}_{ms}) \times (1 - \text{Directed Exploitation Rate}_{sk}) = (\text{Contribution to Spawning Escapement}_{msk}). \quad (6)$$

Because reproductive potential is typically measured in terms of females on the grounds or in the hatchery the 550 spawners are weighted by an estimate of the proportion of spawners which are female, by region. For the central Alaska example, chinook salmon escapement is composed of 55 percent males, 45 percent females. Therefore approximately 248 of the 550 salmon escapement would be comprised of reproductively mature females in this region (see Equation 7).

$$(\text{Contribution to Spawning Escapement}_{msk}) \times (\%\ \text{Females}_{sk}) = (\text{"Spawners"}_{msk}). \quad (7)$$

Salmonid biologists have estimated that the adult-to-spawner ratio for chinook salmon spawning in the wild in central Alaska is approximately 4:1. That is, for each reproductively mature female on the spawning grounds four mature adults will recruit into the directed fishery at the end of the next cycle. While this figure varies by geographic area, a four-to-one ratio is reportedly a generally accepted estimate of spawner to recruitment for chinook salmon. Recruitment rates for hatchery spawned salmon are somewhat higher, primarily due to the controlled hatchery environment. As a result, the model weights the adult-to-spawner ratio by region in accordance with the relative representation of hatchery to wild spawning production assumed to occur therein (see Equation 8).

$$(\text{"Spawners"}_{msk}) \times (\text{Adult to Spawner Ratio}_{sk}) = (\text{Physical Reproductive Potential Foregone}_{msk}). \quad (8)$$

Having established the loss to escapement represented within the PSC, and the physical reproductive potential those foregone spawners represent to future directed salmon fisheries in the area, the model can track, compound, and discount the physical and economic costs over any number of successive generations by simply reintroducing successive generations into the iterative calculus. Specifically, the loss of a spawning salmon will have repercussions through successive generations as a portion of its potential offspring are lost to directed fisheries and, more significantly, as a portion is lost to future reproductive potential for the stock itself.

By utilizing an algorithm which accounts for spawner success, growth and natural mortality of the offspring, exploitation by directed fisheries, and reproductive potential of successive generations, the model is capable of comprehensively portraying the long-term implications of PSC losses in both physical and economic terms. As each generation passes through this cycle, the model diverts those fish which would have been harvested by directed fisheries into a subroutine. There the fish are converted to pounds landed and valued at assumed prevailing ex-vessel prices; this value is discounted back to the year of analysis to provide a present value representation of earnings foregone for each spawning cycle.

For species other than the semelparous Pacific salmon the model must account for continued potential spawning by the original generation as well as that of its offspring. This will be reduced to the extent that the original generation will continue to be susceptible to natural and directed fishery mortality until finally succumbing to one or the other.

The model may thus be employed to evaluate the long run aggregate loss directly attributable to annual prohibited species by-catches through successive generations. Furthermore, by permitting modification of parametric components of the algorithm, the model provides the analyst with the flexibility to assess potential responsiveness of the biologic and economic systems to variations in physical, political, or economic conditions within the fishery management framework. The model may also be employed to assess the geographic distribution of losses imposed by PSCs, which should aid in evaluating the relative merits of capital investments in enhancement or mitigation projects, as well as long-term expenditures on infrastructure in support of fishery development.

Finally, the model should enable the fishery analyst or manager to more accurately and comprehensively evaluate the costs associated with promotion and development of the groundfish fishery in the gulf by U.S. fishermen. These costs will, in large measure, be borne by future fisheries targeting on Pacific halibut, Tanner crab, king crab, and the several Pacific salmon species which make up the PSC in the gulf. An explicit recognition of this fact is necessary if society is to make an informed judgment as to the optimal use of its fishery resources in this region.

AN EMPIRICAL APPLICATION

As previously indicated, an empirical application of the extended PSC model has been made with reference to the groundfish by-catch of Pacific salmon in the Gulf of Alaska. The process of evaluating the physical and economic loss to directed Pacific salmon fisheries is relatively complex. This is principally true because, as earlier suggested, the Gulf of Alaska serves as a rearing habitat for salmon originating from river systems throughout Alaska, British Columbia, Washington, Oregon, and northern California. Therefore, losses of salmon in the gulf necessarily accrue to different directed fisheries, and at different times, in proportion to the contribution each region makes to the pool of immature salmon found in the Gulf of Alaska.

Several limiting assumptions were required, owing to gaps in the data, in order to permit the quantitative estimation of the magnitude and distribution of these impacts. The empirical results of the analysis are dependent upon the reasonableness of the assumptions made. In an effort to accommodate any concerns about limitations on some aspects of the empirical data utilized within the model, alternative specifications have been considered and compared for purposes of testing the sensitivity of the empirical results to variations in assumptions.

Similarly, sensitivity analyses have been conducted with regard to several of the exogenously determined parametric components of the model. These results are also reported below and contribute insights into the robustness of the empirical results derived from application of the model.

Because the proposed model is an extension of the earlier Marasco-Terry methodology, the empirical results obtained from the hybrid model are compared with the results of the Marasco-Terry approach to judge the relative performance of the two techniques.

The absence of reliable data pertaining to several key aspects of the PSC salmon problem make the empirical results very preliminary. However, the results indicate that the economic costs of prohibited species interceptions are substantial, and further, that principal among these impacts is the loss to future salmon fisheries associated with foregone reproductive potential.

The Empirical Setting

All five Pacific salmon species are taken incidentally in the groundfish fisheries of the gulf. However, by far the most numerous are chinook and chum salmon accounting for roughly 89 percent and 9.8 percent of the incidental salmon by-catch, by number of fish, respectively. The remaining three species account for so few fish, relatively, that they will not be explicitly treated within the current empirical analysis.

Over the period 1977 through 1984, the actual size of the Pacific salmon by-catch in the Gulf of Alaska foreign and domestic groundfish fisheries varied substantially (see Table 4). From an estimated low by-catch of 5,272 fish in 1977, the salmon PSC jumped to 45,603 fish the following year. In 1979, 1980, and 1981, the incidental catches of salmon in the gulf remained at relatively high levels, numbering 21,460; 36,069; and 30,860 fish, respectively. In 1982 the incidence of salmon by-catch took a dramatic downturn to an estimated 6,976 fish interception despite relatively constant total groundfish harvest and an actual increase in total landings of Walleye pollock. In 1983 salmon by-catches rose sharply to 13,874 fish, although remaining well below the previous historic average interception level. In 1984 by-catch of salmon in the gulf soared to the largest interception observed since MFCMA coverage began in 1977. Initially, estimated at over 71,200 fish, this PSC represents a potentially substantial loss to future U.S. and Canadian salmon fisheries.

Table 4. -- Prohibited species by-catch of Pacific salmon given as numbers of fish, 1977-84.

Year[a/]	Foreign fisheries	Joint ventures	Total by-catch
1977	5,272	0	5,272
1978	45,603	0	45,603
1979	20,410	1,050	21,460
1980	35,901	168	36,069
1981	30,860	0	30,860
1982	5,556	1,411	6,976
1983	9,621	4,253	13,874
1984	12,163	59,045	71,208[b/]

a/ Preliminary estimate, U.S. Foreign Fisheries Observer Program.

b/ Early season preliminary estimate issued in spring of 1985. Subsequent revision in December 1985 produced somewhat higher estimate, reflected reflected in Table 2b, p. 16.

Because annual variability of salmon by-catch has been so erratic and extreme over the period of observation, the empirical analysis below has been undertaken as a dichotomous worst case-best case investigation intended to bound or bracket the empirically observed extremes in this fishery.

NMFS observer data, compiled for both foreign and joint venture operations, indicate that by-caught chum salmon tend, for the most part, to be mature fish (averaging 64 cm in length) in their last year of ocean life (Nelson 1983). Had these fish not been intercepted they would have entered directed salmon fisheries or contributed to spawning escapement in the same year as their capture. This is in marked contrast to most observed by-catch and particularly that of chinook salmon intercepted in the gulf.

Chinook PSCs are, on average, 1 1/2 to 3 years away from maturity, depending upon stock, and therefore a similar period away from recruitment into either directed fisheries or the spawning biomass. Samples taken by U.S. observers place chinook salmon in the by-catch at roughly 3 years of age and on average 61.3 cm in length (Nelson 1983).

Owing to the absence of reliable scientific information on stock identification of by-caught salmon from the gulf it has been necessary to derive estimates of this parameter for purposes of the empirical application of the model. These estimates, while preliminary, are based upon historic coded-wire tag recovery data for the gulf and the informed opinions of several scientists experienced in salmonid biology and management in the North Pacific (Dahlberg et al. 1986). It must be emphasized, however, that until appropriate research has been done with which to verify stock identification for gulf by-caught salmon, even the most informed speculation is still only a guess as to source of origin for these fish. Therefore, in an effort to assess the relative sensitivity of the output of the model to assumptions about stock origin, several slightly different allocation schemes have been evaluated and their individual results presented below for comparison.

Stocks were divided, by origin, into four major geographic regions: western Alaska, central Alaska, southeastern Alaska/northern British Columbia, and southern British Columbia/Washington/Oregon/northern California. Proportional representation in the by-catch, by source of origin, for each run of the model is summarized below (see Table 5). Each revised contribution estimate reflects a different set of assumptions regarding natural regional salmon productivity, enhancement contributions, and migratory range and patterns of local chinook stocks.

Mean age at maturity (rounded to the nearest whole year in the empirical algorithm) has been derived from coastwide harvest statistics, by directed fishery, as have the regional exploitation rates. Estimated average weight at harvest, by origin of stock and species, was obtained from the Alaska Department of Fish and Game, (ADF&G) fish ticket files for Alaska fisheries. Washington Department of Fisheries (WDF) data were consulted for mean harvest weight statistics for non-Alaska fisheries. The percent of escapement comprised of females, by region, enters the model as an exogenously determined parameter, and was obtained from the sources cited above.

Table 5. -- Alternative empirical specifications.

Contribution to by-catch (%)	Source of origin: Western Alaska	Central Alaska	SE Alaska/ northern BC[a]	Southern BC/WA/OR/ CA
I	10	40	30	20
II	5	25	30	40
III	2	18	50	30
Mean age at maturity (years)	5.75	5.60	5.00	4.40
Mean weight at harvest (lbs.)[b]	20.7	25.5	19.8	17.6
Escapement comparison of females (%)	50	45	40	40

[a] British Columbia, Canada.

[b] Average weight in directed fishery measured in round equivalents.

Chum salmon captured incidentally in the groundfish fishery were all assumed to be of central Alaska origin. This assumption is based upon chum salmon production capacity in the adjacent regions. As "final ocean year" fish a ten percent natural mortality rate was uniformly applied to the gross estimated by-catch for this species. That is, 90 percent of the chum salmon taken in the groundfish fishery in year (t), would have survived to enter directed fisheries (or contribute to reproduction) in the same year as intercepted.

Survival to harvest or escapement for chinook salmon was determined for each geographic region of origin by applying a declining mortality schedule to a maturity schedule developed for chinook stocks in each area on the assumption that natural mortality rates decrease with increasing age and size of the fish. The maturity schedules, as well as estimates for exploitation rates in each area, were drawn from ADF&G and WDF sources.

The principal hypothesis of this analysis is that there are substantial and quantitatively measurable latent costs associated with by-catch destruction of salmon which would have matured and successfully passed through the directed fisheries to contribute to stock reproductive potential. In the present empirical analysis, the numbers of these fish have been derived by estimating the "survival to harvest," in numbers of fish, for each geographic region. This number is then reduced by the prevailing exploitation rate in that same area. The remaining fish, with an assumed sex ratio, represent that portion of the by-catch which would have contributed to spawning escapement.

Spawners may then be divided among natural runs and hatchery stocks. To the extent that there does not exist substantial surplus production, either in the wild or hatchery environments, the value of an additional spawner (in this case a mature female) is appropriately measured by the future production of adult salmon resulting from successive reproductive cycles, discounted to the present:[9/]

According to salmonid biologists and aquaculturalists, reproductive potentials of hatchery and wild spawners differ substantially. Empirical evidence indicates that wild spawning stocks of chinook salmon yield to the

[9/] With only isolated exceptions, both wild and hatchery North American chinook salmon stocks, which contribute to the gulf biomass, appear to be in depressed condition. While some have very recently shown improvement in escapement/returns over historic low levels, virtually none, either wild or hatchery, can be characterized as having surplus production. Mike Stratton, Oregon Department of Fish and Wildlife, P.O. Box 59, Portland, OR 97207; Bob Garrison, Oregon Department of Fish and Wildlife, 303 Ballard Extension Hall, Oregon State University, Corvallis, OR 97331; Mel Siebel, Alaska Department of Fish and Game, P.O. Box 3-2000, Juneau, AK 99802; and Aven Andersen, National Marine Fisheries Service, P.O. Box 21668, Juneau, AK 99802. Pers. commun., February 1986.

target fishery and to escapement on the order of four adults per spawner, while hatchery stocks may produce 30 to 70 adults per spawner, over observed output ranges.10/ Clearly, at these rates, at some point there would be a diminishing return to additional units of hatchery production, but perhaps only after wild stocks were substantially displaced.

Loss of wild runs of Pacific salmon through displacement by hatchery stocks would impose other, and some suggest greater, costs on directed fisheries, society, and ultimately the ocean environment, than are associated with PSC losses. The present analysis is confined to ranges of wild and hatchery production which presently exist or can be anticipated in the future? for example, based upon projected output levels from planned mitigation and enhancement programs.

When artificially produced species comprise a majority or even a substantial minority of the total production of these species, the findings and implications of this analysis will have to be re-examined in light of these new conditions. However, there is no indication that such artificial production levels are likely to be achieved in the foreseeable future.

At this writing, it is believed that hatchery-produced chinook salmon account for a relatively small number of fish intercepted in the gulf. .11/ Of these, the majority are assumed to originate in the southern British Columbia/Washington/Oregon/California region. For modeling purposes the assumption of 4:l natural and 3O:l hatchery adult-to-spawner ratios has been employed. An assumed wild-to-hatchery stock composition in the southern most geographic region results in a weighted adult to spawner ratio of 6.6:1 for this area..

So few hatchery-produced chinook originate from the other three regions, relative to natural production, at the present time, that the adult-to-spawner ratio for each is assumed to equal the wild ratio (i.e., 4:1), for iterations I and II of the model. As additional chinook salmon hatcheries come into production, in both the United States and Canada, greater numerical losses, through foregone reproductive potential, and thus greater economic costs, will be associated with chinook PSCs.

In its present configuration the empirical model tends to weight the present value loss of a hatchery-produced chinook more heavily than the loss of a wild chinook. This is so because, based on relative reproductive potential, hatchery chinook produce greater numbers of offspring which survive to contribute to subsequent directed fisheries and spawning populations. Therefore, the value, as approximated by the discounted stream of future ex-vessel revenues to directed fisheries, from a hatchery-produced chinook appears greater than an equivalently measured value from a wild fish.

10/Al Didier, Alaska Department of Fish and Game, Juneau, AK 99802. Pers. commun., June 1982

11/Michael Dahlberg, Northwest and Alaska Fisheries Center, Auke Bay Lab, Auke Bay, AK 99802. Pers. commun., July 1982.

This is appropriate only over the range of hatchery-to-wild production believed to prevail at present or which can be reasonably anticipated in the future. At some point, nonpecuniary values attributable to retention of wild spawning populations (e.g., genetic diversity, disease resistance, unique recreational or aesthetic characteristics, etc.), may reverse the relative value of hatchery-to-wild stocks presented in this analysis. Furthermore, the higher cost of producing a hatchery fish may net out some of this apparent value advantage.

To the extent that substantial artificial propagation capacity expands beyond the southernmost region, the geographic distribution of salmon PSC economic losses will broaden. In an effort to evaluate this eventuality, run III of the empirical analysis incorporates an adult to spawner ratio for northern British Columbia/SE Alaska of 6.6:l (the same as that of the southern zone) to reflect the planned increase in hatchery output of chinook proposed for this geographic region.

Within the present analytical framework a zero ex-vessel price effect has been assumed. Specifically, it is assumed that the presence or absence of the intercepted salmon in the regionally specific directed fisheries will not measurably influence prevailing prices. This assumption appears to be reasonable in light of the relatively small total numbers of salmon PSCs as compared to the size of the aggregate directed salmon harvest in Alaska, British Columbia, Washington, Oregon, and California.

By employing gross ex-vessel value of the foregone harvest as the measure of loss, the analysis implicitly assumes that the marginal cost to directed fisheries of harvesting these salmon, had their interception not occurred, would have been essentially zero. To the extent that these salmon would have been fished in mixed stock fisheries, the assumption is probably appropriate, at least as a reasonable approximation of the marginal cost of harvest. Stock densities would not be altered substantially by inclusion of these fish; thus marginal catch rates per unit effort would likely vary imperceptibly. For example, a power troller would still be expected to apply essentially the same number of hours, lines, and hooks of effort over the course of the harvest season, with or without the inclusion of these fish. The assumption may be somewhat less appropriate for single stock terminal area fisheries. In such circumstances, gross ex-vessel value would tend to overstate benefits foregone by an amount equal to the marginal cost of harvest in that fishery.

Tending to understate unrealized benefits within the model is the simplifying assumption that all foregone exploitation would have occurred in the commercial harvesting sector. This is perhaps a more severe shortcoming of the present analysis than the potential failure to account for marginal harvest costs. Estimated exploitation rates, cited above, reflect aggregate utilization of each region's salmon resource, including the commercial harvest, recreational, subsistence, and treaty Indian use. However, all extractive use has been valued as if harvest occurred in the terminal area commercial fisheries, owing to data limitations on subsistence, ceremonial, and tribal cultural values of this resource. By accounting for harvesting losses only at a commercial ex-vessel equivalent value, and by ignoring secondary impacts imposed upon processors, wholesalers, retailers, and consumers by the loss of these fish, the total impact of incidental salmon interceptions in the gulf is very probably substantially understated in this analysis. Because data limitations prevent a comprehensive treatment of these impacts, the estimated losses developed below should be interpreted as a minimum cost estimation.

A final simplification has been made regarding the distribution of unrealized catches. In particular, Pacific salmon were assumed to have been destined for directed fisheries in the geographical region of their origin The catch foregone was therefore measured in mature round weights and valued in constant real dollars, at prevailing 1984 ex-vessel prices, by area, weighted by gear-type.[12/] This simplification was assumed to be appropriate despite the fact that some fish, particularly chinook salmon from the southernmost region, are intercepted by salmon fishermen as relatively immature fish in areas other than that of their origin. These fish may be substantially smaller in size and weight than they would have been as fully mature salmon in a terminal fishery. Nonetheless, due to the discounting procedure employed, this assumption tends to underestimate the economic benefit foregone to some slight but undefined extent. It, also results in some shift in the distribution of impacts between geographic regions, but to an unknown degree.

Empirical Results

Three different configurations of the model were evaluated empirically and are reported in the following pages'. In the first two specifications the prevailing composition of the aggregate. biomass between hatchery and natural production, by geographic region, was assumed. That is, the southernmost region was assumed to enjoy a 6.6:1 weighted "adult-to-spawner" ratio, reflecting relatively substantial hatchery production, while the three other regions were assumed to produce at the natural adult-to-spawner rate of 4:l.

In addition, the relative contribution of each region to the observed aggregate by-catch was varied to assess the sensitivity of total and regional estimated losses to such variation. Otherwise the three empirical runs were identically specified.

Two by-catch levels were analyzed, each reflecting an empirically observed extreme recorded between 1977 and 1984. These were 5,272 salmon for the low by-catch, and 71,200 fish for the higher interception. The resulting impacts of each by-catch level, presented below, reflect the aggregate gross ex-vessel loss to directed salmon fishermen attributable to a single year's incidental interception of salmon in the Gulf of Alaska groundfish fisheries.

12/ The analysis assumes approximately constant real ex-vessel prices over the interval of observation, utilizing 1984 prices as a base.

As previously noted, approximately 90 percent of the salmon by-catch in the Gulf of Alaska is composed of chinook salmon. The remaining ten percent is assumed to be chum salmon for purposes of the empirical analysis. At the present time, virtually no data are available with which to evaluate the reproductive potential of the chum salmon lost to by-catch. The Alaska Department of Fish and Game is in the very early stages of development of a program to acquire spawning escapement information for the major chum producing river systems, but these data are perhaps a decade or more in the future. 13/ Therefore, all chum salmon taken as groundfish by-catch, minus a ten percent natural mortality loss, have been valued at their commercial ex-vessel equivalence, as if taken in the central Alaska directed salmon fishery in the same year as their by-catch interception.

The aggregate gross ex-vessel loss attributable to the Gulf of Alaska groundfish fishery interception of chum-salmon in the base year was $30,313 and $2,244 for the high by-catch and low by-catch levels, respectively.

To account for chinook salmon losses, including loss of reproductive potential, it was necessary that the analysis be carried out over several successive spawning cycles. Because some chinook salmon stocks under consideration mature, on average, in 5 years while other stocks mature as 6-year-old fish, losses accrue at different rates and in different years for each group. That is, in the case of 5-year-old chinook salmon stocks, losses to directed fisheries and spawning populations occur at 5-year intervals; 6-year maturing stocks accrue losses every sixth year. Arithmetically then, on a 30-year cycle losses attributable to both 5- and 6-year maturing stocks accrue in the same year. In the present analysis the first occurrence of this "grand" cycle takes place in the year 2012, or 28 years after the base year observed interception.

This arithmetic cycle continues in 30-year increments ad infinitum. However, the contribution of each successive year to the aggregate ex-vessel value foregone becomes increasingly less significant and the limiting assumptions used in the model less tenable. Also, depending upon the social rate of discount employed, a large portion of the total unrealized benefit stream can be accounted for at the conclusion of the first grand cycle. For purposes of comparison then, the economic costs associated with each of the several specifications of the model will be summarized at the conclusion of the first grand cycle, recognizing that these represent the majority of, but not the total, present value of the benefits foregone as a result of a single year's trawl interception of North American salmon.

Based upon the preceding assumptions and parameters the coastwide aggregate gross ex-vessel impacts for model specifications I, II, and III were derived (Table 6).

13/ Scott Marshall, Alaska Department of Fish and Game, P.O. Box 3-2000, Juneau, AK 99802. Pers. commun., September 1985.

Table 6. -- Coastwide aggregate real present value ($) loss to directed salmon fisheries

Model specification	Real social discount rate					
	0%		5%		10%	
	High	Low	High	Low	High	Low
Number I	2,867,844.20	212,325.45	1,807,481.70	133,019.80	1,307,741.30	96,820.62
Number II	3,089,306.20	228,721.79	1,989,637.20	147,306.00	1,458,560.90	107,986.95
Number III	4,418,481.90	327,129.58	2,713,949.70	200,931.76	1,916,355.90	141,880.56

Specification I

Specification I assumes that ten percent of the annual Gulf of Alaska groundfish by-catch of chinook salmon is comprised of fish from western Alaska sources. This assumption is based on the following circumstantial evidence. Chinook salmon are an exceptionally wide ranging species. Scale pattern analyses conducted on chinook salmon captured in the Bering Sea have demonstrated that fish from the southern three regions, defined in the present study, migrate to and rear in the Bering Sea. These stocks are presumed to be present in the central and western North Pacific as well.

Given this propensity for distant migration and stock mixing, it is conceivable that some number of western Alaska chinook salmon move southward into the gulf during periods of their life cycle, thus becoming vulnerable to gulf groundfish fishing effort.

Ten percent is believed to represent an upper limit on the proportion of total by-catch interceptions in the gulf composed of western Alaska stocks. It serves as an initial point of departure for the empirical model. In a similar manner, contributions from the central Alaska region were hypothesized to be forty percent, on average; northern British Columbia/ southeast Alaska 30 percent; and southern British Columbia/Washington/ Oregon/California 20 percent.

Based upon these assumptions, the gross ex-vessel equivalent loss to coastal directed salmon fisheries at the conclusion of the first complete cycle can be summarized as. follows. Utilizing a zero real social discount rate (SDR) the cumulative loss exceeds $2.86 million. Employing the conservative assumption of a ten percent SDR results in an estimated coastwide cumulative loss of approximately $1.31 million. At an assumed five percent SDR the aggregate loss is estimated to be just under $1.81 million. These figures account for 69 percent, 91 percent, and 98 percent of the total cumulative value of the loss as measured over the first two 30-year cycles at zero, five, and ten percent SDRs, respectively.

The low by-catch results in aggregate ex-vessel losses of $189,448; $133,820; and $96,821, at zero, five, and ten percent SDRs, respectively.

It should be emphasized that these estimated losses, as well as those derived from the other specifications of the empirical model, reflect the cumulative present value losses to directed salmon fisheries in Alaska, British Columbia, and the Pacific Northwest over one grand cycle (as defined above) attributable to a single season's salmon PSC in the Gulf of Alaska groundfish fisheries. Therefore, each groundfish fishing season which produces a salmon by-catch results in losses to directed salmon fisheries which extend well into the future and compound one upon another.

Specification II

Specification II of the empirical model reflects the first of a series of modifications in the assumed proportional contribution of the four geographic regions to the aggregate composition of the by-catch. As before, only the southernmost region (i.e. southern British Columbia/Washington/ Oregon/California), was assumed to have substantial hatchery production of chinook salmon. In combination with the region's large natural production potential, this results in an assumed by-catch contribution from the southern British Columbia/Washington/Oregon/California region of 40 percent. The northern British Columbia/southeast Alaska region is also noted for high natural productivity of chinook salmon, and in this specification is assumed to account for 30 percent of the by-catch loss, on average.

Subsequent examination of International North Pacific Fisheries Commission (INPFC) documents on chinook salmon populations of the North Pacific suggests that the productive potential of the central Alaska region with respect to chinook is smaller than that of the other three regions (INPFC 1967). Utilizing information, compiled on the basis central Alaska drainage systems, the contribution to by-catch loss from this region was assumed to be approximately 25 percent in this iteration.

The remaining five percent of the by-catch was assumed to be from the western Alaska region. This reduction from Specification I reflects the absence of empirical evidence on migratory patterns of these stocks and concern that over-representation in the model of western Alaska chinook could result in an underestimate of the commercial impact of salmon by-catch. This risk exists principally because the exploitation of the chinook salmon resource in the western Alaska region is not predominantly commercial but. includes a very large and important subsistence harvest. As a result, the commercial value of chinook in this region is low relative to the other regions and volume of the commercial harvest is similarly relatively small.

Given the above allocation of physical loss the aggregate present value estimate of ex-vessel gross benefit foregone is $3.06 million, $1.96 million, and $1.43 million; for zero, five, and ten percent SDRs, respectively, at the high by-catch level. This reflects the compound loss after one grand cycle and accounts for 75 percent, 93.5 percent, and 98.5 percent of the estimated benefits foregone over two full cycles, for zero, five, and ten percent SDRs, respectively, for chinook losses.

At the low by-catch level, through one grand cycle, the aggregate present value losses from chinook by-catches are $226,478; $145,062; and $105,743; for zero, five, and ten percent SDRs, respectively.

To these losses must be added the single season chum salmon losses estimated to be $30,313 for the high by-catch level and $2,244 for the low interception level.

The change in regional contribution to by-catch, as between iteration I and II of the model, has resulted in an increase in the present value aggregate economic loss of 7.7 percent; 10.7 percent; and 11.53 percent for the zero, five, and ten percent SDRs, respectively. This is the result of the higher ex-vessel value placed on each chinook salmon lost to the directed harvest in the more southerly regions. As will be apparent below, the distributional implications of by-catch composition for the various regions can be important, quite apart from the aggregate costs.

Specification III

A third, alternative specification of the model was evaluated in an effort to assess the probable economic costs of by-catch losses under conditions reflecting increased artificial enhancement, particularly in the northern British Columbia/southeast Alaska region. Both the British Columbian and Alaskan fishery management agencies have indicated strong interest in expanded hatchery or other enhancement measures for chinook salmon in this region. In fact, the recently concluded U.S.-Canada salmon treaty envisions substantial expenditures by both nations on enhancement and rehabilitation programs, with a strong emphasis on expanded chinook production in southeast Alaska.

As an example, the Alaska Department of Fish and Game projects an increase in chinook production from southeast facilities of approximately 232,400 adult fish by 1994 (see Table 7).

Within this context then, the third iteration of the model was defined to include wholly natural rates of adult-to-spawner productivity for the northern two regions. The higher "enhancement augmented" adult-to-spawner ratio was assumed for both the northern British Columbia/southeast Alaska and the southern British Columbia/Washington/Oregon/California regions, in order to reflect productivity from expanded hatchery and stream enhancement.

In combination with these modified productivity rates the relative contribution of each region to the intercepted biomass was altered. In this iteration, on average, two percent of the by-catch was assumed to be of western Alaska origin, while approximately 18 percent were presumed to originate in central Alaska systems. With the projected expansion of northern British Columbia/southeast Alaska production capabilities for this species, the proportion of by-catch loss attributable to this region was assumed to increase substantially. In this iteration of the model northern British Columbia/southeast Alaska region was assumed to account for fully 50 percent of the by-catch loss in numbers of chinook. The remaining 30 percent were attributable to southern British Columbia/Washington/Oregon/California sources.

The assumption concerning the magnitude of the total by-catch loss was unchanged; only the relative contribution by region has been altered to. evaluate the probable impact of proportional variation in attributable production potential. As chinook salmon output in the aggregate is expanded through capital expenditures on enhancement facilities and stream rehabilitation projects the risk of substantially greater aggregate by-catch losses to groundfish trawls exists. To sustain interception levels within the range under consideration in the face of greatly expanded total juvenile chinook salmon output will necessitate an actual reduction in the rate of salmon intercepted per unit of groundfish harvested.

Table 7. -- Projected adult chinook salmon production from southeast Alaska hatcheries, 1985-94

Facility	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Projected chinook returns from state facilities at current capacity										
Crystal Lake	5,100	7,000	11,800	13,100	27,100	40,100	45,100	48,100	48,100	48,100
Deer Mountain	1,900	2,700	4,400	5,700	6,700	7,000	7,000	7,000	7,000	7,000
Hidden Falls	0	1,300	2,000	2,400	2,900	3,200	5,600	8,000	8,200	8,200
Snettisham	2,200	3,700	9,700	15,700	24,700	48,700	68,700	68,700	68,700	68,700
FRED[a] TOTAL	9,200	14,700	27,900	36,900	61,400	99,000	126,400	131,800	132,000	132,000
Projected chinook returns from PNP[b] facilities at permitted capacity										
Medvejie	80	500	650	850	1,450	1,850	1,850	1,850	1,850	1,850
Neets Bay	5,800	8,200	11,100	19,500	31,100	35,400	36,200	36,200	36,200	36,200
Port Armstrong	0	0	100	500	850	850	850	850	850	850
Sheldon Jackson	0	0	100	500	850	850	850	850	850	850
Whitman Lake	1,000	500	1,400	6,500	8,700	8,800	9,000	9,100	9,100	9,100
PNP TOTAL	6,880	9,200	13,350	27,850	42,950	47,750	48,750	48,850	48,850	48,850
Projected chinook returns from other facilities										
Little Port Walter	1,350	2,550	3,850	4,350	4,350	4,350	4,350	4,350	4,350	4,350
Tongass	800	2,000	4,000	5,100	10,600	12,100	13,900	30,500	38,800	47,200
OTHER TOTAL	2,150	4,550	7,850	9,450	14,950	16,450	18,250	34,850	43,150	51,550
SOUTHEAST TOTAL	18,230	28,450	49,100	74,200	119,300	163,200	193,400	215,500	224,000	232,400

[a] Fishery Rehabilitation and Enhancement Division of Alaska Department of Fish and Game.

[b] Private Non Profit.

Source: Alaska Department of Fish and Game, P.0; Box 3-2000, Juneau, AK 99802.

Specification III produced the following results. For the high by-catch rate the aggregate ex-vessel present value loss to directed fisheries was estimated to be $4.42 million through the first grand cycle at a zero SDR. At five percent, the loss was approximately $2.71 million, while utilization of a ten percent SDR results in an estimated gross ex-vessel present value loss of $1.92 million.

At the low by-catch level the estimated coastwide gross ex-vessel loss was estimated to be $327,130; $200,932; and $141,881, respectively, for zero, five, and ten percent SDRs over the first grand cycle.

The marked increase in present value loss attributable to a single season's by-catch interception associated with this latter configuration is, in part, due to the higher value per pound of salmon harvested in the directed fisheries in the more southerly regions.

More importantly, however, is the assumed presence of substantially greater numbers of artificially produced chinook in the by-catch, especially originating from the northern British Columbia/southeast Alaska region. Their influence on the weighted regional adult-per-spawner ratio results in a substantially greater latent loss being associated with the PSC interceptions than would have been the case in the absence of artificial enhancement of regional runs. Significantly, this latent loss becomes apparent only when a comprehensive accounting of the by-catch loss is made.

A Comparison of Predicted Results From Two Methodologies

From the inception of the present analysis an implicit hypothesis has been that substantial latent losses associated with PSC interceptions have gone unaccounted for utilizing existing assessment approaches. Now the merits of this supposition can be empirically evaluated.

Utilizing precisely the same set of parametric assumptions as delineated above, the Marasco-Terry (1981) methodology was applied to the high and low by-catch levels observed between 1977 and 1984. Marasco-Terry make the explicit assumption that, except for losses to natural mortality, all salmon intercepted as PSC would have been harvested in the directed fishery at maturity in the absence of their interception. For example, immature chinook salmon sacrificed to groundfish by-catch in 1984 are assumed to be fully accounted for as losses to gross ex-vessel earnings in directed fisheries in 1986 or 1987, depending upon whether the stocks mature as 5- or 6-year-old fish. The economic losses are then discounted, as in the extended model, to the present at the appropriate SDR.

The results of the comparison demonstrate the magnitude of the latent present value loss associated with reproductive potential foregone, through one grand cycle, attributable to a single season's by-catch loss (Table 8). These data indicate that, for Specifications I and II, approximately 67 percent, 53 percent, and 41 percent of attributable present value ex-vessel

Table 8. -- Comparative results from Marasco-Terry and extended models using social discount rates of 0, 5, and 10 percent

	High By-Catch			Low By-Catch		
	0%	5%	10%	0%	5%	10%
			Specification I			
Extended model	$2,867,844	$1,807,481	$1,307,741	$212,325	$133,820	$96,821
Marasco-Terry	954,176	857,002	774,212	70,644	63,450	57,320
Latent reproductive present value loss	$1,913,668	$ 950,479	$ 533,529	$141,681	$ 70,370	$39,501
			Specification II			
Extended model	$3,089,306	$1,989,637	$1,458,561	$228,722	$147,306	$107,987
Marasco-Terry	1,046,637	945,364	858,449	77,490	69,992	63,557
Latent reproductive present value loss	$2,042,669	$1,044,273	$ 600,112	$151,232	$ 77,314	$ 44,430
			Specification III			
Extended model	$4,418,482	$2,713,950	$1,916,356	$327,130	$200,932	$141,881
Marasco-Terry	1,207,156	1,093,204	995,011	89,374	80,937	73,667
Latent reproductive present value loss	$3,211,326	$1,620,746	$ 921,345	$237,756	$119,995	$ 68,214

loss, through one grand cycle, goes unaccounted for utilizing the earlier methodology, for zero, five, and ten percent SDRs, respectively.

When additional hatchery and enhancement production is represented in the by-catch, as in Specification III, the degree to which the loss is understated by use of the unmodified Marasco-Terry approach rises to 73 percent, 60 percent, and 48 percent, respectively, for zero, five, and ten percent SDRs. The implications of such an underestimate of cost for resource managers and enhancement program planners should be obvious. Failure to account for losses of these relative magnitudes may lead to misallocation of fishery resources as, for example, between groundfish and salmon catch quotas, wastage of productive inputs in the respective directed harvesting sectors, and inappropriate public or private capital investment in facilities intended to augment natural production.

It is apparent from the results presented above that the addition to the Marasco-Terry model of a methodologic strategy, which includes an assessment of lost reproductive potential as a direct result of by-catch losses, can contribute importantly to a comprehensive cost accounting.

An Empirical Postscript

Data on salmon PSCs in the Gulf of Alaska groundfish fishery were obtained from the U.S. Foreign Fisheries Observer Program, Northwest and Alaska Fisheries Center, Seattle, Washington. The 1984 by-catch estimate was identified as "preliminary," although NMFS sources expressed the opinion that these PSC estimates would not change substantially. 14/ The empirical analysis of salmon PSCs for the high by-catch was predicated on this preliminary data.

Subsequent to evaluation of the models, final estimates of the 1984 Gulf of Alaska salmon PSCs were released. These data indicate that approximately 75,846 salmon were intercepted in these fisheries, an increase of 4,636 fish over the preliminary estimate.

This increase reflects a change of sufficient magnitude to result in substantially higher estimated economic losses than are delineated in the empirical analysis for the high by-catch. However, the purpose for the empirical application was to demonstrate the kinds of results that potentially can be obtained by employing the extended model, as contrasted with those of an alternative methodology, for some given by-catch. The increase in estimated by-catch will not result in a change in any of the basic conclusions drawn from the empirical analysis. Therefore, no effort has been made to re-evaluate the empirical portion of this study utilizing the final estimated 1984 PSC data.

14/ Janet Wall, Northwest and Alaska Fisheries Center, 7600 Sand Point Way N.E., Seattle, WA 98115. Pers. commun., May 1985.

CONCLUSIONS

The proposed extended methodology owes its development to the pioneering efforts in by-catch valuation assessment made by Marasco and Terry (1981). The present model is an "extension" of their basic approach intended to address a perceived shortcoming of the original model when applied to regulatory and economic regimes such as presently prevail in the gulf groundfish fishery.

The methodology developed above had as its basic premise the supposition that significant latent losses, in the form of reproductive potential foregone, are associated with PSC interceptions. Heretofore, these losses have neither been recognized nor fully accounted 'for in assessing the impacts of prohibited species by-catches on directed fisheries.

It must be pointed out that at a sufficiently high discount rate the results of the two methodologies converge. This is so because at relatively high discount rates society is assumed to place no value on delayed consumption. Therefore, the foregone benefits attributed to lost reproductive potential of the by-caught species have no present value. In this case, the appropriate measure of loss is, as Marasco and Terry correctly point out, the ex-vessel equivalent earnings foregone in the next most recent directed fishery, following interception.

This is simultaneously the solution which would be obtained under assumptions of perfect open access in the fishery, as well. In this theoretical state, the value of the marginal loss to PSCs would appropriately be measured as the ex-vessel equivalent loss to directed fisheries. This is so because, as in the "commons" dilemma articulated by Hardin (1968), each fisherman would always find it in their individual best interest to capture every available fish in the present period. That is, under this set of assumptions, it would never be rational for a salmon fisherman to voluntarily forego the harvest of an available fish, with the expectation that they could obtain future benefits from its progeny. By foregoing the capture of the marginal fish, a fisherman can be relatively assured that someone else will harvest that fish in the present fishery, thus preventing its contribution to future runs. Thus, the fisherman who refrains from capturing the marginal fish not only incurs the ex-vessel loss associated with that fish in the present catch, but sees all prospects of acquiring future benefits from his or her decision not to harvest eliminated by a fellow competitor.

Therefore, in a purely open access unregulated fishery the marginal loss to PSC would be equal to the ex-vessel equivalent value in the next most recent directed fishery following loss, and have no attributable costs to the directed fishermen in terms of future catch.

This does not imply that society does not suffer costs in the form of inefficiencies and suboptimal rates of resource exploitation under these circumstances.

With either regulatory constraints on directed catch (e.g., management provisions for escapement), or social discount rates within the range typically encountered in the literature, the two methodologies under examination produce empirical results which diverge by an amount approximately equal to the present value of the foregone reproductive potential attributable to PSC interceptions.

This discussion suggests that "context" is an important and legitimate consideration for the economist in the prosecution of an empirical analysis. This issue deserves further illumination.

Consider the following argument. From an abstract perspective, the apparent least-cost solution for mitigating losses attributable to PSC interception would involve reducing the directed fishery (on the species designated as "prohibited") proportionally and then compensating directed fishermen for their ex-vessel losses. Under this proposition, losses of reproductive potential would not be attributable to PSC by-catches if an equivalent number of other fish are not harvested, but permitted to replace those potential spawners lost in PSCs. In essence, salmon lost to PSCs and salmon harvested in directed fisheries are assumed to be relatively perfect substitutes.

Because no decline in the spawning population is necessary, if only directed fisheries are adequately reduced in subsequent seasons, the "appropriate" (and incidentally lowest) estimated measure of attributable loss to PSCs under this argument is confined to the ex-vessel revenue foregone by directed fisheries. This is precisely equivalent to the value calculated using the original Marasco-Terry technique. (This of course ignores the problems connected with identifying the directed fishery into which each by-caught fish would have recruited in order to appropriately distribute the catch reductions, etc.)

The ex-vessel value in the directed fishery would be an approximate measure of the minimum willingness to accept compensation by directed fishermen for their reduced catches from groundfish, fishermen responsible for PSCS. No actual compensation need be paid, as the Kaldor-Hicks compensation criteria demonstrate (Just et al. 1982), for this solution to be judged socially superior in theory. It would require only a finding that groundfish fishermen gain sufficiently by being permitted to take PSCs in the course of their harvesting activity to enable them to potentially compensate directed fishermen and still be better off themselves.

The most serious problem with this theoreticalsupposition in practice is that despite its apparent efficiency in minimizing the potential estimated cost of mitigating PSC losses, this solution requires actions by groundfish fishermen, directed fishermen, regulators and policy makers, and' the American public which are unlikely given the existing political and economic situation. Therefore, this purported solution does not constitute a viable alternative to resolve this problem. In this respect, the estimated loss to society attributable to PSCs is understated because the context within which the estimate is derived is irrelevant.

Alternatively, it might be hypothesized that the most efficient means of addressing the loss, for example, of Pacific salmon PSCs, would be to invest in sufficient artificial salmon production capacity to yield outputs which would fully offset such losses to groundfish by-catch. Specifically, if sufficient numbers of additional immature salmon could be introduced into the ocean, adequate total levels of survival should theoretically be attainable so as to fully compensate for all losses sustained in the original interception.

If that level of artificial production could be achieved, given limitations on natural carrying capacity and aquacultural technology, then the appropriate aggregate measure of PSC loss would be equivalent to the total cost of production, including the amortized capital costs, operation and maintenance expenditures, etc., for the required hatchery capacity and output.

This argument suggests that groundfish fishermen could be required to provide sufficient enhancement capacity to fully compensate directed fishermen for all PSC losses, thus negating the need to consider foregone reproductive potential associated with by-catch.

This conceptualization implicitly assumes that fish lost to PSCs can be perfectly substituted for by fish of the same species produced in hatchery facilities. This proposition is not supported empirically. For example, one chinook salmon is not necessarily a perfect or even adequate substitute for all other chinook salmon. Compare the characteristics and value of a Columbia River spring chinook with those of a Tule chinook salmon produced at the Oregon Department of Fish and Wildlife Columbia River Bonneville Dam salmon hatchery. These fish are not equivalent organisms. Therefore, in order to actually artificially propagate close substitutes for PSC interceptions a myriad of small facilities would be required. One result would certainly be to drive the per unit costs up dramatically as economies of scale are sacrificed.

Likewise, to the degree that hatcheries tend, over time, to reduce the genetic diversity of the species and thus increase the risk of catastrophic disaster due, for example, to the lack of resistance to a virulent disease, this result contradicts the suggestion that perfect or even satisfactory widespread substitution of one stock for another is possible.

While ultimately an empirical question, the probable costs of employing this means of ameliorating PSC losses appears excessive even in the case where maricultural technology exists. Furthermore, with the extreme variability in annual PSC interceptions, as documented above, and the lag between the loss and potential recruitment into directed fisheries, the hatchery production scheduling dilemma associated with this solution would be so complex and costly as to preclude successful implementation.

The conclusion, then, regarding the "appropriate" measure of value attributable to PSC losses to directed fisheries centers on the issue of mitigation. To the extent that an acceptable substitution cannot be made between PSCs and directed fisheries harvests, within the biological and political-economic contexts which prevail, a full accounting of the impact of PSC losses must appropriately include the long-run costs associated with foregone reproductive potential, as articulated in the extended model.

A tangential implication may be drawn from this analysis as well. Specifically, to the extent that the discounted present value of-a Pacific salmon as a "spawner" exceeds its value in the directed commercial fishery, one must conclude that something is wrong with the escapement goal setting process. Too many fish are being harvested, too few are escaping to spawn. These conclusions follow directly from the prevailing biological parameters, e.g., mortality rates, recruit/spawner ratios, exploitation rates, etc., utilized in the management of this resource. They suggest a critical evaluation of the management process may be in order.

In summary, the empirical analysis supports the proposition that substantial physical and economic costs are imposed on domestic directed fisheries, and thereby upon society, as a result of the interception of economically important and fully utilized prohibited species in the Gulf of Alaska groundfish fishery. In the case of Pacific salmon, depending upon specific assumptions regarding source of origin, the discounted present value loss through one "grand" cycle as approximated at the ex-vessel level, ranges from $1.46 million to $3.1 million (for the high by-catch) at ten percent and zero percent SDRs, respectively. When the same estimate was made under assumptions of significant additional salmon hatchery production, the equivalent estimated loss increased to $1.92 million in the former case and $4.42 million in the latter. These losses represent the present value cumulative impact on directed salmon fisheries from a single year's salmon PSC in the gulf groundfish fishery.

Salmon exploitation rates employed in the empirical analysis reflect the estimated aggregate utilization of each region's chinook salmon resource, including commercial, recreational, subsistence, and Native American treaty use. However, all extractive use was valued as if harvest had occurred in a terminal area commercial fishery. By accounting for harvesting losses only in terms of a commercial ex-vessel equivalent value, and by ignoring secondary impacts imposed on processors, wholesalers, retailers, and consumers by the loss of these fish, the total impact of incidental salmon interceptions in the gulf groundfish fisheries is very probably understated by these estimates. Because data or analytical limitations preclude a comprehensive treatment of these diverse impacts, the estimated losses derived from application of the proposed methodology should be interpreted as minimum cost estimates. Further research, particularly into theoretically sound methodologies for assessing the economic impacts on subsistence and native cultural resource users, would contribute tremendously to a more accurate understanding of this problem.

The absolute size and distribution of by-catch impacts appear to be relatively sensitive to the proportional contribution each region makes to the aggregate biomass of immature salmon. While this is not particularly surprising, it does suggest the presence of some very clear implications for development and siting of future salmon enhancement facilities. Salmon by-catch losses could conceivably have an important influence on the viability of such enhancement facilities, depending in large part on the location and species/stock composition selected for each project. At the very least, a recognition of the potential adverse impacts of PSC losses should be taken into account in hatchery or enhancement planning and siting.

The PSC controversy could become a double edged sword for U.S. fisheries development. Given the strong and widening commitment to full "Americanization" of the EEZ by 1990, PSCs may become the most contentious issue in the management and allocation of marine fishery resources. That is, as all foreign and joint venture activity is eliminated from the U.S.. management zone, tradeoffs between attainment of landing levels equivalent to the available harvestable surpluses of groundfish stocks and conservation of fully utilized prohibited species intercepted in these fisheries will no longer pit foreign against domestic interests. Rather, gains in this context by one U.S. fishery will come at the direct expense of some other U.S. fishery. The potential for conflict under these circumstances is very great. Fishermen and resource managers alike have begun to recognize the potential scope of this problem and its implications for development of the U.S. fishing industry.

There exists a critical need for acquisition of primary data, analytical research, and methodological development in this area. The present analysis reflects a small step in the direction of a comprehensive response to this need.

Comparing the empirical results of the extended methodology with estimates obtained from an earlier assessment approach suggests that a significant portion of the aggregate PSC loss is directly attributable to foregone reproductive potential, as hypothesized. For example, in the case of the observed high by-catch of salmon in the 1984 gulf groundfish fishery, the failure of the earlier model to account for reproductive potential foregone resulted in an underestimation of the present value discounted loss to domestic directed salmon fisheries of between 41 percent and 67 percent, for ten percent and zero percent SDRs, respectively. The relative performance of the two models was virtually unchanged for Specifications I and II, as defined on page 31. That is, despite changes in the assumed proportional contribution of the PSC losses, by geographic region of origin, the extended model consistently accounted for losses which the earlier assessment technique failed to capture.

When expanded artificial production was included in the model, as under the assumptions of Specification III, the relative difference in performance of the two methodologies appears to be even more pronounced. That is, with the assumed increased presence of hatchery fish in the by-catch, failure to fully and explicitly account for lost reproductive potential by the earlier methodology underestimated the attributable present value salmon PSC loss by 73 percent, at a zero SDR. Utilizing a five percent SDR the difference was 60 percent, while at a ten percent SDR the model understated the loss by 48 percent, in present value terms.

A cursory examination of equivalent PSC data for Pacific halibut, king crab, and Tanner crab suggests that significant latent losses of reproductive potential are very likely associated with by-catch mortality for these species as well. Very recently, allegations to this effect have been made concerning king crab by-catches in the Bering Sea yellowfin sole joint venture fishery.. Some individuals concerned with the continued depressed condition of the king crab stocks have suggested that the handling and on-bottom mortality inflicted by trawl gear on king crab, particularly female crab, have significantly reduced the reproductive potential of these stocks and adversely affected the natural cyclical rebuilding of king crab populations. Critical evaluation of this claim awaits acquisition of hard data.

It should be emphasized that, in the case of species like Pacific salmon, where present aquaculture technology may permit substitute organisms to be produced as replacement for PSC losses, the application of the methodology developed above may be called into question. That is, in the event that perfect, or even acceptably close, substitutes for the PSC loss can be replicated at a relatively low cost, efforts to account for losses in reproductive potential may be unnecessary. To the extent that no acceptably close substitute exists for the by-caught organism or the cost of producing such a substitute in the necessary volume and at the location and point in time required is prohibitive, then a full accounting of the cost to society attributable to PSCs must include the unrealized future benefit stream reflected in the present value discounted loss of reproductive potential, as demonstrated above.

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APPENDIX A

SALMON PROHIBITED SPECIES BY-CATCHES

As previously noted, salmon by-catches have historically varied over time by gear type, nation, area, and season. Prior to the enactment of the Magnuson Fisheries Conservation and Management Act (MFCMA) in 1976, no reliable data on incidental by-catch were compiled. Since 1977, by-catch information has been acquired through the National Marine Fisheries Service (NMFS) on-board observer program. The levels of observer coverage of the foreign and joint venture fleets and, therefore, the reliability of the by-catch estimates, have increased during the period 1977-1984. As Berger et al. (1984) report:

> During the year (1983), 134 observers sampled aboard 93 different vessels in the Gulf of Alaska fishery. The 134 observers sampled about 93 of the 99 foreign vessels (nearly 94 percent) which participated in the groundfish fisheries. Percent observer coverage (100 x observer days/vessel days) of total vessel days varied from 27.0 percent on the Korean small stern trawlers to 85.3 percent of the U.S.-Japan joint ventures. Observers sampled a total of 4,046 of the 7,998 vessel days, making an overall percent coverage of 50.6 percent.

Citing an earlier report by Nelson (1983) they go on to say that, "this is an increase of 54 percent over the 1982 coverage of 32.8 percent and is more than five times the 1981 coverage of 9.6 percent." In 1984 U.S. observer coverage in the gulf rose to 86.3 percent or 4,415 observer days for 5,117 foreign vessel days. Of the 136 foreign vessels participating in the 1984 foreign and joint venture groundfish harvest in the gulf, NMFS observers sampled aboard 127 (or 93.4 percent). 1/

From data compiled by NMFS on-board observers the following characterization of salmon interceptions can be made.

During the period 1977 through 1984 incidental salmon interceptions in the gulf groundfish fisheries ranged from a low of approximately 5,272 fish (in 1977) to a peak by-catch of more than 71,200 salmon (in 1984). 2/ Over this time interval both total landings of all groundfish species combined and total landings of Walleye pollock demonstrated steadily upward trends (Fig. Al).

1/ Russell Nelson, Northwest and Alaska Fisheries Center, 7600 Sand Point Way NE, Seattle, WA 98115. Pers. commun., July 1985.

2/ Preliminary estimates of PSC loss provided by U.S. Foreign Fisheries Observer program, mid-year 1985.

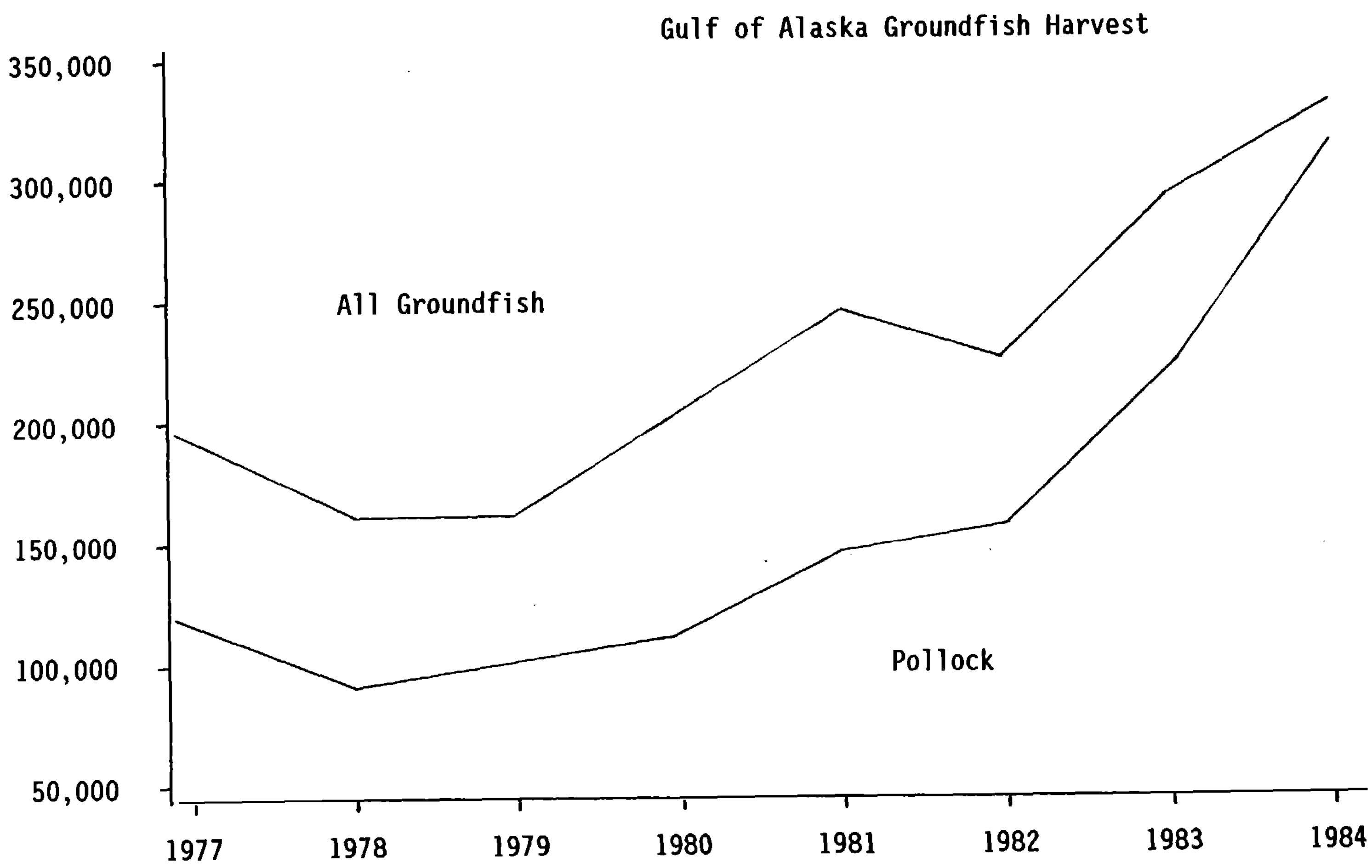

Figure Al. -- Total landings of pollock and all groundfish, 1977-84.

Source: National Marine Fisheries Service, U.S. Foreign Fisheries Observer Data.

However, an initial examination of the salmon by-catch data for this period failed to demonstrate a clearly discernible pattern (Figs. A2 and A3). In response, two hypotheses concerning the relationship between Pacific salmon by-catch and total catch of groundfish, and total pollock landings were proposed. Specifically, it was hypothesized that as total landings of groundfish increased, salmon by-catches would be expected to increase. Furthermore, because salmon by-catch appears to be very closely associated with the harvesting of pollock in the gulf, one might hypothesize an even greater positive correlation between metric tons of pollock harvested and the numbers of salmon intercepted.

In an effort to test the validity of these two hypothesized relationships a simple bivariate linear regression was performed with numbers of salmon by-caught as the dependent variable, total metric tons of groundfish harvested in case one, total metric tons of pollock harvested in case two, as the independent variable. The statistical results appear in Tables Al and A2 below.

After consideration of the fundamental characteristics of the by-catch relationship a decision was made, a priori, to fit the least squares equation to the annual data without inclusion of a constant term. 3/ This decision reflects the basic fact that when there is no groundfish fishery there can be no prohibited species loss attributable to such activity. While no observations in the range of a zero groundfish harvest were among those under statistical examination, the assumption is consistent with the expected value of the dependent variable when the independent variable takes on a value of zero.

When observed annual salmon by-catch data for the Gulf of Alaska were regressed against total foreign and joint venture groundfish landings data for the gulf in the same year, the coefficient on the latter, independent variable entered the equation with the hypothesized positive sign (Table Al). Further, the coefficient was determined to be statistically different from zero at a .995 probability level, based on Student's t test. The R statistic for the regression suggests that approximately 71 percent of the observed variation in the dependent variable, salmon PSCs, is accounted for by the annual level of catch for all groundfish combined, in the Gulf of Alaska target fisheries, over the period 1977-84.

3/ Some concern has been expressed in the statistical literature about the effects of fitting ordinary least squares (OLS) equations without inclusion of a constant term when no actual data are observed in the vicinity of the origin. After reviewing pertinent articles on the subject, including "Leverage and Regression Through the Origin" by George Casella, <u>The American Statistician</u>, May 1983, and "Errors in Computer Packages Least Squares Regression Through the Origin," by H. A. Gordon, in <u>The Statistician</u>, Vol. 30, 1981, and consulting with Dr. J. L. Hintze, Number Cruncher Statistical Systems Co., Kaysville, Utah, and Dr. W. G. Brown, Oregon State University, Corvallis, Oregon, a determination was made that sufficient information regarding the relationship between PSCs and directed groundfish harvest exists to support the decision to omit the constant term.

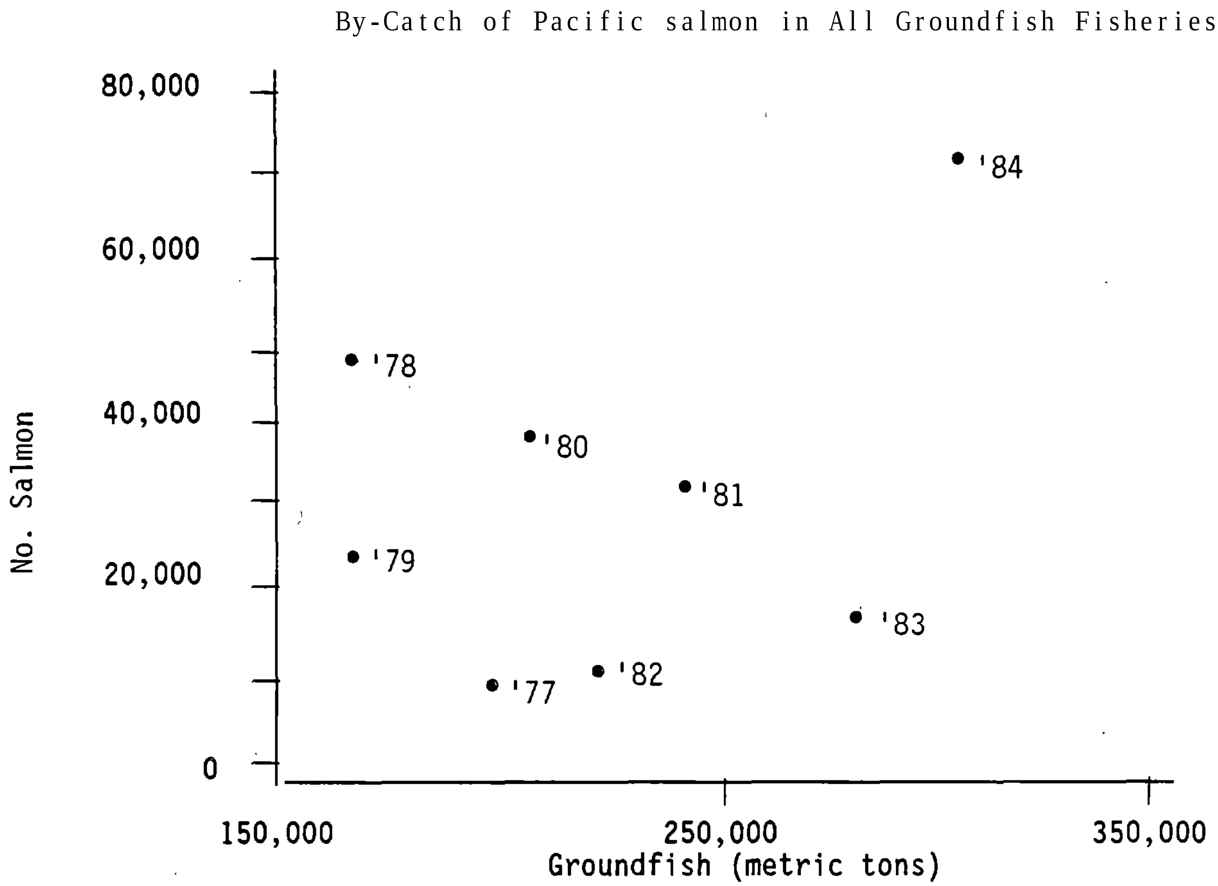

Figure A2. Annual observed salmon by-catch and total groundfish harvest in the Gulf of Alaska, 1977-84.

By-Catch of Pacific salmon in Pollock Fisheries

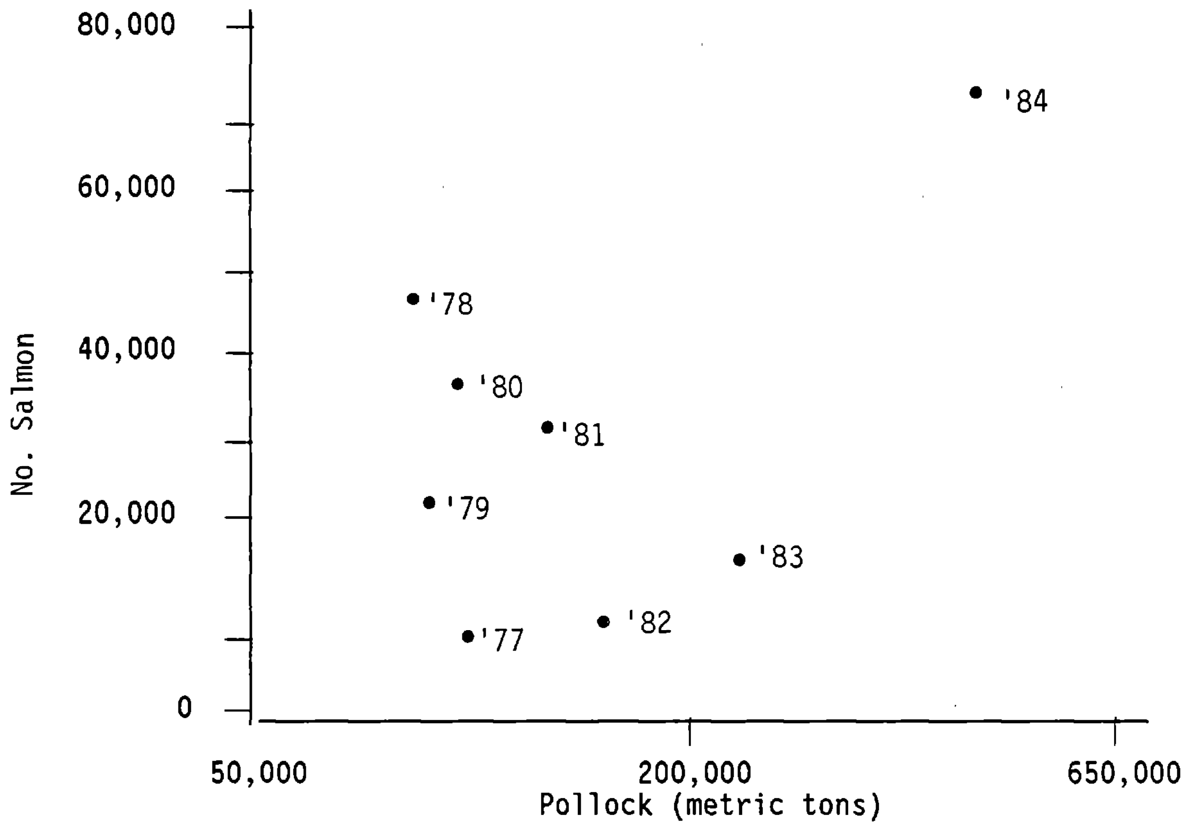

Figure A3. Annual observed salmon by-catch and total pollock harvest in the Gulf of Alaska, 1977-84.

Table Al. -- Bivariate regression of salmon prohibited species by-catch on total annual groundfish harvest, 1977-84.*

[Salmon PSC] = .1298 [Total Groundfish Harvest]
.0314
(4.13)

adjusted R^2 = .7088

prob. b = 0 .004

Durbin-Watson 1.987

where standard error appears below the coefficient and Student's-t is in parentheses.

* Based on U.S. Foreign Fisheries Observer Program, NMFS, data for the Gulf of Alaska.

Table A2. -- Bivariate regression of salmon prohibited species by-catch on annual pollock harvest, 1977-84.*

[Salmon PSC] = .1849 [Pollock Harvest)
.0238
(7.76)

adjusted R^2 = .7320

prob. b = 0 .003

Durbin-Watson 2.08

where standard error appears below the coefficient and Student's-t is in parentheses.

Based on U.S. Foreign Fisheries Observer Program, NMFS, data for the Gulf of Alaska.

As hypothesized, when salmon PSCs are regressed against annual pollock landings, the results suggest an even stronger statistical relationship exists. That is, the coefficient on the explanatory variable (i.e., annual pollock harvest) enters the regression with the hypothesized positive sign and at a significance level of 0.995, based upon the Student's t statistic (Table A2). In addition, the R^2 for this regression, i.e., $R^2 = .732$, suggests that more than 73 percent of the annual observed variation in salmon by-catch is accounted for by the variation in pollock harvest in the Gulf, during the period 1977 through 1984.

For both regressions the Durbin-Watson statistic for autoregressive tendencies indicates an absence of serial correlation within the respective independent variables.

The Relationship Between Total Salmon Run Size and Salmon PSCs

An alternative hypothesis concerning the observed annual variation in Pacific salmon PSCs in the gulf centers upon the influence of total salmon abundance as reflected in run size. From U.S. foreign fisheries observer reports it has been established that salmon by-catches in the gulf groundfish fishery are composed predominantly of immature chinook salmon. Therefore, it is hypothesized that in those years when greater than average numbers of chinook salmon are present in the Gulf of Alaska the observed salmon by-catch should increase. Conversely, in years of relatively low chinook abundance the region's groundfish fisheries should record reduced salmon interceptions, ceteris paribus.

There are no reliable estimates of annual chinook salmon abundance in the gulf. Neither are there data on annual chinook salmon production, nor even total run size, by major geographic area in this region. However, one proxy for chinook salmon abundance, albeit an imperfect one, is the size of the annual directed commercial harvest. These data have been compiled in a relatively consistent manner over the period of interest.

Catch data employed in the evaluation of this particular hypothesis were limited to those from western, central, and southeast Alaska. The reason for excluding British Columbia, Washington, and Oregon catches was that substantial, but not well-defined, portions of the harvest from these areas are composed of chinook salmon stocks which do not migrate into the regions of the North Pacific and Gulf of Alaska where the foreign and joint venture salmon by-catches under examination occur. 4/ Therefore, inclusion of these directed catches in this portion of the analysis might produce erroneous statistical conclusions.

4/Pat Pattillo, Washington Department of Fisheries, Harvest Management Division, General Administration Bldg., Olympia, WA 98504. Pers. commun., August 1985.

One obvious difficulty with using catch as an approximation of ocean abundance in this context is that the chinook salmon intercepted in the groundfish fisheries of the gulf are immature fish. This suggests that they would, absent their loss to by-catch, have spent perhaps several more years in the ocean before recruiting into a directed fishery. As a result, it is necessary to account for this period between age at by-catch and recruitment in the model. This was accomplished by lagging the explanatory variable or variables.

A simple linear model, with annual salmon by-catch as the dependent variable, was fitted using ordinary least squares. The explanatory variables included various combinations of lagged area specific directed chinook catch. Whether utilizing a 1, 2, or 3-year lag in multiple or bivariate regressions, in only a single case was a statistically significant relationship indicated, on the basis of R^2, F, or Student's t statistics. The one exception was in the case of the bivariate regression of by-catch against western Alaska chinook harvest, lagged 3 years. In this case the coefficient of the explanatory variable was positive, and the coefficient was statistically different from zero at the .995 confidence level, based on the Student's t statistic. The R^2 for the regression was .343, indicating that just over 34 percent of the observed variation in the dependent variable was being accounted for in this specification. An examination of the plot of the residuals did not reveal any apparent systematic pattern (i.e., no indication of autocorrelation), although the small sample size makes the use of more rigorous tests impossible.

Interpretation of this result is difficult given the sample size, the lack of correlation between by-catch and other regional landings, and several apparently contradictory "facts" about western Alaska stocks. Specifically, several important western Alaska chinook stocks are not believed to be heavily exploited by commercial users. The region's chinook salmon represent an important cash resource but tend to be an equally important subsistence resource. This use would not be reflected in the catch data employed in the regression. Therefore, of all of the regions for which catch data are compiled, it is the western Alaska region commercial landings data which are probably least reflective of chinook salmon abundance.

In addition, the generally accepted rule regarding western Alaska chinook salmon stocks has been that they do not represent a significant part of the biomass of immature chinook which are found in the Gulf of Alaska and which are therefore vulnerable to groundfish fishery interception there. (Certainly no more than ten percent, although more on this issue will be discussed in subsequent pages.) Yet the regression results seem to imply that these stocks have a disproportionate influence on by-catch variation.

At this point the results do not permit a conclusive statement as to the merits of the hypothesis under examination. There is certainly reason to continue to speculate about the role of run size in determining by-catch. Further serious empirical examinations of this hypothesis must await additional run size and by-catch data.

Another hypothesis regarding the variation in salmon by-catch was also proposed. Specifically, it was hypothesized that oceanographic conditions in the gulf significantly influenced the observed annual variation in salmon interceptions. Such phenomena as freshwater runoff from snow melt, temperature anomalies, or salinity changes might result in immature salmon becoming increasingly or decreasingly vulnerable to trawler's nets.

In an effort to test this hypothesized relationship, data on salmon by-catch rates per metric ton of groundfish harvested, by International North Pacific Fishery Commission (INPFC) management area, by month for the period 1980-84, were statistically fitted to physical oceanographic and hydrologic data for the gulf and surrounding drainages, compiled by researchers at the Institute of Marine Science, University of Alaska-Fairbanks (T. C. Royer 1985).

These data include monthly observations of sea surface temperature and salinity anomolies at 27 sites, on a 5° grid, spanning the gulf (Fig. A4). Snow melt, runoff, and surface water storage data for adjacent regions were obtained from the same source.

A series of least squares multiple regressions were performed. INPFC area specific by-catch rates were hypothesized to be the dependent variable in each regression model, while various combinations of physical phenomena were serially employed as explanatory variables. For example, the rate of salmon by-catch recorded in the Chirikof INPFC area was first regressed against sea temperature and salinity observations within the Chirikof area. Then snow melt runoff, and storage data were added to the equation and the regression was re-evaluated. Finally, the dependent variable was regressed against oceanographic observations from immediately adjacent sites outside the Chirikof area.

This process was repeated for each of the INPFC reporting areas in the gulf within which foreign and/or joint venture groundfish fishing activity was recorded.

The results of the regressions do not suggest the presence of a statistically significant relationship between salmon by-catch rates and oceanographic-hydrologic conditions in the gulf. None of the regressions produced adjusted-R^2 statistics greater than 0.046 and in no case were the F-statistics for the regression statistically significant at the 90 percent confidence level. Therefore, one must conclude that the null hypothesis cannot be rejected, at least over the range of observations in the sample.

This is an important caveat because as Xiong and Royer (1984) point out in their analyses of the oceanic environment of the gulf', "Sea surface <temperature data... indicate that the upper layer water temperatures in the Northeast Pacific have experienced long period fluctuations...." Furthermore, they state that "The long period temperature fluctuations are not evident in the other quadrants of the North Pacific, so the effect does not extend over the entire ocean basin." Their research seems to imply that physical environmental changes in this region are unique and move through detectable cycles. It may be that these physical conditions affect the

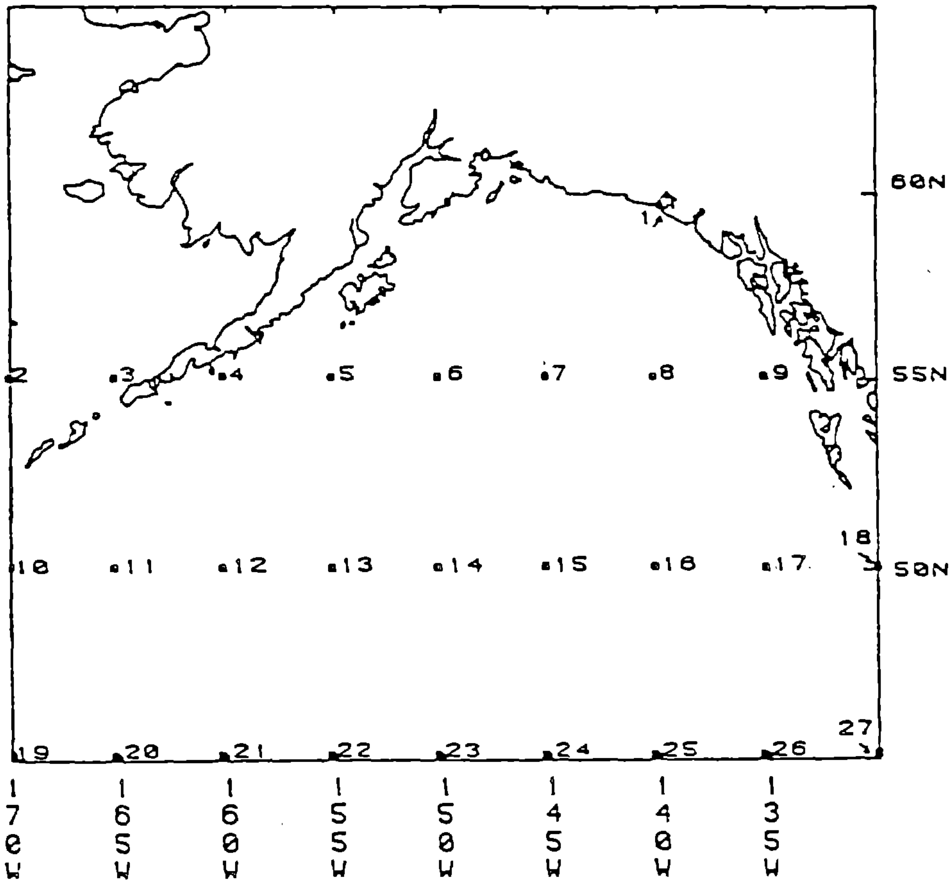

Figure A4. Oceanographic observation sites for sampling temperature and salinity.

incidence of salmon interceptions, but owing to the relative cycle length of oceanographic events as compared to the PSCs sampled in this analysis the relationship is not being revealed. As additional PSC data become available, further analysis of this hypothesis may be warranted.

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APPENDIX B

Prohibited Species By-Catch Attributable to Vessel Classes by Area by Nation, 1977-84

(Source for the following tables is U.S. Foreign Fisheries Observer Program, NWAFC, Seattle)

Table B1. -- Estimated incidental catch of Pacific halibut in the foreign and joint venture groundfish fisheries in the Gulf of Alaska, 1977-84.[a]

Nation/vessel class	Total all areas							
	1977	1978	1979	1980	1981	1982	1983	1984
Japan								
Small stern trawler	27,406	25,871	23,396	46,201	17,342	20,038	19,474	9,464
Large freezer trawler[a]	164,825	56,475	35,935	59,804	47,607	30,275	40,210	6,032
Large surimi trawler[a]	---	---	5,390	8,016	10,688	5,102	4,163	12,839
Longliner[b]	---	18,320	59,779	323,845	309,151	426,920	590,490	300,882
Republic of Korea								
Small stern trawler	---	---	---	---	4,366	13,128	2,498	1,934
Large freezer trawler	37,921	124,693	95,580	22,288	21,847	59,118	32,667	30,183
Longliner[b]	---	419	1,465	7,146	6,028	2,116	186	---
U.S.S.R.								
Large freezer trawler	182,074	67,311	22,746	44,221	---	---	---	---
Polish People's Republic								
Large freezer trawler	783	234	699	0	282	---	---	579
Mexico								
Small stern trawler	---	---	4,651	---	---	---	---	---
Total foreign catch	413,009	293,323	249,641	511,521	417,311	556,697	689,697	361,913
Joint venture	---	92	5,127	19,318	274	2,280	98,571	165,721

Table Bl. -- Continued.

Nation/vessel class	Shumagin area							
	1977	1978	1979	1980	1981	1982	1983	1984
Japan								
Small stern trawler	5,093	6,866	930	930	121	3,090	2,246	4,007
Large freezer trawler[a]	73,543	23,446	8,051	948	1,500	6,958	8,858	868
Large surimi trawler[a]	---	---	517	0	1,042	1,731	689	5,151
Longliner[b]	---	5,683	19,911	79,465	105,010	65,140	131,316	182,989
Republic of Korea								
Small stern trawler	---	---	---	---	1,609	9,770	273	833
large freezer trawler	34,534	122,480	34,243	21,015	13,282	32,675	12,985	6,167
Longliner[b]	---	280	568	7,005	1,106	24	0	---
U.S.S.R.								
Large freezer trawler	3,247	21,405	243	5,935	---	---	---	---
Polish People's Republic								
Large freezer trawler	---	---	278	0	0	---	---	---
Mexico								
Small stern trawler	---	---	151	---	---	---	---	---
Total foreign catch	116,417	180,160	64,892	115,298	123,670	119,367	156,367	200,015
Joint venture	---	92	113	2,175	0	2,199	15,497	25,700

Table B1. -- Continued.

Nation/vessel class	Chirikof area							
	1977	1978	1979	1980	1981	1982	1983	1984
Japan								
Small stern trawler	1,250	996	2,315	1,738	2,620	4,743	6,560	1,723
Large freezer trawler[a]	48,609	14,090	0	887	6,006	10,280	12,946	2,958
Large surimi trawler[a]	---	---	64	142	3,131	1,591	3,394	4,351
Longliner[b]	---	10,379	23,223	159,328	164,504	219,221	281,787	117,893
Republic of Korea								
Small stern trawler	---	---	---	---	1,864	3,231	2,225	1,101
Large freezer trawler	3,387	2,210	---	---	8,478	24,874	19,682	24,016
Longliner[b]	---	139	---	---	524	13	1	---
U.S.S.R.								
Large freezer trawler	27,375	45,075	4,630	2,411	---	---	---	---
Polish People's Republic								
Large freezer trawler	---	---	0	0	153	---	---	0
Mexico								
Small stern trawler	---	---	503	---	---	---	---	---
Total foreign catch	80,621	72,889	30,735	164,506	187,280	263,953	326,595	152,042
Joint venture	---	---	0	11,629	274	68	2,275	13,528

Table Bl. -- Continued.

Nation/vessel class	Kodiak area							
	1977	1978	1979	1980	1981	1982	1983	1984
<u>Japan</u>								
Small stern trawler	11,027	5,141	12,845	27,612	4,745	12,205	10,659	3,734
Large freezer trawler[a]	73,543	23,446	13,316	31,258	8,869	13,037	18,406	2,206
Large surimi trawler[a]	---	---	4,809	7,367	6,213	1,780	80	3,337
Longliner[b]	---	1,667	12,535	83,791	24,900	85,002	136,687	---
<u>Republic of Korea</u>								
Small stern trawler	---	---	---	---	893	127	---	---
Large freezer trawler	---	---	---	---	87	1,569	---	---
Longliner[b]	---	---	---	---	3,566	814	5	---
<u>U.S.S.R.</u>								
Large freezer trawler	147,914	803	17,569	35,875	---	---	---	---
<u>Polish People's Republic</u>								
Large freezer trawler	783	234	421	---	---	---	---	579
<u>Mexico</u>								
Small stern trawler	---	---	3,918	---	---	---	---	---
Total foreign catch	178,071	16,207	65,413	185,903	49,273	114,534	165,837	9,856
Joint venture	---	---	4,962	5,514	---	13	80,799	126,493

Table Bl. -- Continued.

Nation/vessel class	Yakutat area							
	1977	1978	1979	1980	1981	1982	1983	1984
<u>Japan</u>								
Small stern trawler	9,396	12,811	4,565	15,533	9,538	0	9	---
Large freezer trawler[a]	73,543	23,446	3,535	15,810	20,647	---	0	---
Large surimi trawler[a]	---	---	0	497	302	---	---	---
Longliner[b]	---	591	4,110	1,261	14,737	57,557	40,700	---
<u>Republic of Korea</u>								
Small stern trawler	---	---	---	---	0	---	---	---
Large freezer trawler	---	---	54,059	1,273	0	---	---	---
Longliner[b]	---	0	862	141	832	1,265	180	---
<u>U.S.S.R.</u>								
Large freezer trawler	3,507	20	304	---	---	---	---	---
<u>Polish People's Republic</u>								
Large freezer trawler	---	---	---	---	129	---	---	---
<u>Mexico</u>								
Small stern trawler	---	---	79	---	---	---	---	---
Total foreign catch	23,068	18,902	67,514	34,515	46,185	58,822	40,889	---
Joint venture	---	---	47	---	---	---	---	---

Table B1. -- Continued.

Nation/vessel class	Southeastern area 1977	1978	1979	1980	1981	1982	1983	1984
Japan								
Small stern trawler	640	57	2,741	388	318	---	---	---
Large freezer trawler[a]	14,161	5,097	11,033	10,901	10,585	---	---	---
Large surimi trawler[a]	---	---	0	10	---	---	---	---
Longliner[b]	---	---	---	---	---	---	---	---
Republic of Korea								
Small stern trawler	---	3	7,287	---	---	---	---	---
Large freezer trawler	---	---	35	---	---	---	---	---
Longliner[b]	---	---	---	---	---	---	---	---
U.S.S.R.								
Large freezer trawler	31	8	---	---	---	---	---	---
Polish People's Republic								
Large freezer trawler	---	---	---	---	---	---	---	---
Mexico								
Small stern trawler	---	---	---	---	---	---	---	---
Total foreign catch	14,832	5,165	21,087	11,299	10,903	---	---	---
Joint venture	---	---	5	---	---	---	---	---

a/ For Japan in 1977-78, large freezer trawlers and large surimi trawlers are combined under large freezer trawler.

b/ No estimate made of longline catch in 1977.

Table B2. -- Estimated incidental catch of king crab in the foreign joint venture groundfish fisheries in the Gulf of Alaska, given as a number of crab by INPFC regulatory areas 1977-84.[a]

Nation/vessel class	Total all areas							
	1977	1978	1979	1980	1981	1982	1983	1984
Japan								
Small stern trawler	---	769	182	298	873	120	127	305
Large freezer trawler[a]	---	579	13	877	239	741	296	174
Large surimi trawler[a]	---	---	12	0	35	0	9	726
Longliner[b]	---	3,228	4,643	4,112	5,007	1,163	1,582	200
Republic of Korea								
Small stern trawler	---	---	---	---	0	0	0	0
Large freezer trawler	---	89,193	19,077	905	85	685	32	60
Longliner[b]	---	106	165	180	379	443	78	---
U.S.S.R.								
Large freezer trawler	---	0	0	23	---	---	---	---
Polish People's Republic								
Large freezer trawler	---	---	0	0	1	---	---	---
Mexico								
Small stern trawler	---	---	2	---	---	---	---	---
Total foreign catch	---	93,875	24,094	6,395	6,619	3,152	2,124	1,465
Joint venture	---	0	466	6,285	0	0	4,454	5,482

Table B2. -- Continued.

Nation/vessel class	Shumagin area							
	1977	1978	1979	1980	1981	1982	1983	1984
Japan								
Small stern trawler	---	36	0	0	0	63	11	14
Large freezer trawler[a/]	---	463	0	786	129	14	0	3
Large surimi trawler[a/]	---	---	0	0	0	0	0	0
Longliner[b/]	---	1,518	2,345	2,324	736	808	23	185
Republic of Korea								
Small stern trawler	---	---	---	---	0	0	0	0
Large freezer trawler	---	89,193	19,077	905	85	3	0	21
Longliner[b/]	---	34	79	180	35	391	6	---
U.S.S.R.								
Large freezer trawler	---	0	0	0	---	---	---	---
Polish People's Republic								
Large freezer trawler	---	---	0	0	0	---	---	---
Mexico								
Small stern trawler	---	---	0	---	---	---	---	---
Total foreign catch	---	91,244	21,501	4,195	985	1,279	40	223
Joint venture	---	0	0	3	0	0	167	38

Table 82. -- Continued.

Nation/vessel class	Chirikof area							
	1977	1978	1979	1980	1981	1982	1983	1984
Japan								
Small stern trawler	---	0	9	0	76	7	30	265
Large freezer trawler[a/]	---	0	0	0	0	657	202	143
Large surimi trawler[a/]	---	---	0	0	0	0	3	256
Longliner[b/]	---	139	1,139	307	3,090	238	1,008	15
Republic of Korea								
Small stern trawler	---	---	---	---	0	0	0	0
Large freezer trawler	---	0	---	---	0	6	32	39
Longliner[b/]	---	2	---	---	13	0	9	---
U.S.S.R.								
Large freezer trawler	---	0	0	0	---	---	---	---
Polish People's Republic								
Large freezer trawler	---	---	0	0	0	---	---	---
Mexico								
Small stern trawler	---	---	0	---	---	---	---	---
Total foreign catch	---	141	1,148	307	3,179	908	1,284	718
Joint venture	---	---	0	41	0	0	44	987

Table B2. -- Continued.

Nation/vessel class	Kodiak area							
	1977	1978	1979	1980	1981	1982	1983	1984
<u>Japan</u>								
Small stern trawler	---	55	42	56	114	50	86	26
Large freezer trawler[a]	---	44	0	0	39	70	94	28
Large surimi trawler[a]	---	---	12	0	30	0	6	470
Longliner[b]	---	648	856	1,481	1,181	103	512	---
<u>Republic of Korea</u>								
Small stern trawler	---	---	---	---	0	0	---	---
Large freezer trawler	---	---	---	---	0	676	---	---
Longliner[b]	---	69	---	---	331	52	60	---
<u>U.S.S.R.</u>								
Large freezer trawler	---	0	0	23	---	---	---	---
<u>Polish People's Republic</u>								
Large freezer trawler	---	0	0	---	0	---	---	0
<u>Mexico</u>								
Small stern trawler	---	---	0	---	---	---	---	---
Total foreign catch	---	816	910	1,560	1,695	951	758	524
Joint venture	---	---	466	6,241	---	0	4,243	4,457

Table B2. -- Continued

Nation/vessel class	Yakutat area							
	1977	1978	1979	1980	1981	1982	1983[c]	1984[c]
Japan								
Small stern trawler	---	678	119	235	683	0	---	---
Large freezer trawler[a]	---	73	6	77	71	---	---	---
Large surimi trawler[a]	---	---	0	0	5	---	---	---
Longliner[b]	---	923	303	0	0	14	39	---
Republic of Korea								
Small stern trawler	---	---	---	---	0	---	---	---
Large freezer trawler	---	---	0	0	0	---	---	---
Longliner[b]	---	1	83	---	0	0	0	3
U.S.S.R.								
Large freezer trawler	---	0	0	---	---	---	---	---
Polish People's Republic								
Large freezer trawler	---	---	---	---	1	---	---	---
Mexico								
Small stern trawler	---	---	2	---	---	---	---	---
Total foreign catch	---	1,674	513	312	760	14	42	
Joint venture	---	---	0	---	---	---	---	---

Table B2. -- Continued

Nation/vessel class	Southeastern area							
	1977	1978	1979	1980	1981	1982	1983 c/	1984 c/
Japan								
Small stern trawler	---	0	12	7	0	---	---	---
Large freezer trawler a/	---	0	7	14	0	---	---	---
Large surimi trawler a/	---		0	0	---	---	---	---
Longliner b/	--	0	---	---	---	---	---	---
Republic of Korea								
Small stern trawler	---	---	---	---	---	---	---	---
Large freezer trawler	---	0	0	---	---	---	---	---
Longliner b/	---	---	3	---	---	---	---	---
U.S.S.R.								
Large freezer trawler	---	0	---	---	---	---	---	---
Polish People's Republic								
Large freezer trawler	---	---	---	---	---	---	---	---
Mexico								
Small stern trawler	---	---	---	---	---	---	---	---
Total foreign catch	---	0	22	21	0	---	---	---
Joint venture	---	---	0	---	---	---	---	---

a/ No estimates made of the 1977 catch.

b/ For Japan in 1978, large freezer trawlers and large surimi trawlers are combined under large freezer trawler.

c/ Amendment 10 to the Gulf of Alaska groundfish management plan prohibited foreign and joint venture trawling in the eastern gulf, including Southeastern and Yakutat areas, after 1982.

Table B3. -- Estimated incidental catch of Pacific salmon in the foreign and joint venture groundfish fisheries in the Gulf of Alaska, given as number of fish by INPFC regulatory area 1977-84. [a/]

	Total all areas							
Nation/vessel class	1977	1978	1979	1980	1981	1982	1983[c/]	1984[c/]
<u>Japan</u>								
Small stern trawler	518	1,116	268	2,128	727	1,114	1,598	839
Large freezer trawler[a/]	1,532	3,104	670	1,384	1,286	2,030	2,371	185
Large surimi trawler[a/]	---	---	1,109	1,467	4,718	740	2,820	3,820
Longliner[b/]	---	249	682	134	295	16	27	---
<u>Republic of Korea</u>								
Small stern trawler	---	---	---	---	169	132	197	81
Large freezer trawler	216	33,144	13,674	7,075	944	1,385	2,601	892
Longliner[b/]	---	5	3	0	17	0	7	---
<u>U.S.S.R.</u>								
Large freezer trawler	2,943	7,732	2,294	19,052	---	---	---	---
<u>Polish People's Republic</u>								
Large freezer trawler	63	253	1,635	4,668	22,704	---	---	6,181
<u>Mexico</u>								
Small stern trawler	---	---	75	---	---	---	---	---
Total foreign catch[d/]	5,272	45,603	20,410	35,901	30,860	5,417	9,621	12,001
Joint venture[d/]	---	3	1,050	168	0	1,259	4,253	63,845

Table B3. -- Continued.

Nation/vessel class	Shumagin area 1977	1978	1979	1980	1981	1982	1983	1984
Japan								
Small stern trawler	107	319	113	0	303	266	710	451
Large freezer trawler[a]	740	955	93	247	42	190	462	28
Large surimi trawler[a]	---	---	36	0	579	204	684	2,047
Longliner[b]	---	4	0	0	0	16	6	0
Republic of Korea								
Small stern trawler	---	---	---	---	13	21	80	81
Large freezer trawler	209	33,139	13,674	7,069	471	351	1,832	208
Longliner[b]	---	1	0	0	0	0	7	---
U.S.S.R.								
Large freezer trawler	15	325	0	9,500	---	---	---	---
Polish People's Republic								
Large freezer trawler	---	---	0	2,363	8,191	---	---	---
Mexico								
Small stern trawler	---	---	0	---	---	---	---	---
Total foreign catch	1,071	34,743	13,916	19,179	9,599	1,048	3,781	2,815
Joint venture	---	3	0	165	0	0	123	513

Table B3. -- Continued.

Nation/vessel class	Chirikof area							
	1977	1978	1979	1980	1981	1982	1983	1984
<u>Japan</u>								
Small stern trawler	1	30	20	568	296	334	661	244
Large freezer trawler[a/]	14	1,291	80	631	768	1,326	1,351	38
Large surimi trawler[a/]	---	---	47	0	4,903	479	2,038	1,497
Longliner[b/]	---	225	661	21	247	0	21	3
<u>Republic of Korea</u>								
Small stern trawler	---	---	---	---	156	105	117	0
Large freezer trawler	7	5	---	---	451	1,014	769	684
Longliner[b/]	---	4	---	---	0	0	0	---
<u>U.S.S.R.</u>								
Large freezer trawler	144	6,538	1,267	5,242	---	---	---	---
<u>Polish People's Republic</u>								
Large freezer trawler	---	---	1,606	2,305	14,509	---	---	313
<u>Mexico</u>								
Small stern trawler	---	---	64	---	---	---	---	---
Total foreign catch	166	8,093	3,745	8,767	20,520	3,257	4,957	2,779
Joint venture	---	---	0	3	0	1,170	1,519	8,828

Table B3. -- Continued.

Nation/vessel class	Kodiak area							
	1977	1978	1979	1980	1981	1982	1983	1984
Japan								
Small stern trawler	123	471	87	1,405	128	508	227	144
Large freezer trawler[a]	250	725	262	195	94	515	558	119
Large surimi trawler[a]	---	---	1,019	1,467	35	57	98	276
Longliner[b]	---	---	7	113	48	0	0	---
Republic of Korea								
Small stern trawler	---	---	---	---	0	6	---	---
Large freezer trawler	---	---	---	---	22	20	---	---
Longliner[b]	---	0	---	---	17	0	0	---
U.S.S.R.								
Large freezer trawler	2,748	869	1,027	4,310	---	---	---	---
Polish People's Republic								
Large freezer trawler	63	253	29	---	---	---	---	5,868
Mexico								
Small stern trawler	---	---	10	---	---	---	---	---
Total foreign catch	3,184	2,318	2,441	7,490	344	1,106	833	6,407
Joint venture	---	---	1,049	0	---	89	2,611	54,504

Table B3. -- Continued.

Nation/vessel class	Yakutat area							
	1977	1978	1979	1980	1981	1982	1983	1984
Japan								
Small stern trawler	277	295	48	137	0	6	---	---
Large freezer trawler[a/]	294	6	25	261	205	---	---	---
Large surimi trawler[a/]	---	---	5	0	11	---	---	---
Longliner[b/]	---	20	14	0	0	0	---	---
Republic of Korea								
Small stern trawler	---	---	---	---	0	---	---	---
Large freezer trawler	---	---	0	6	0	---	---	---
Longliner[b/]	---	0	3	0	0	0	---	---
U.S.S.R.								
Large freezer trawler	36	0	0	---	---	---	---	---
Polish People's Republic								
Large freezer trawler	---	---	---	---	4	---	---	---
Mexico								
Small stern trawler	---	---	1	---	---	---	---	---
Total foreign catch	607	321	96	404	220	6	---	---
Joint venture	---	---	1	---	---	---	---	---

Table B3. -- Continued.

Nation/vessel class	Southeastern area							
	1977	1978	1979	1980	1981	1982	1983	1984
Japan								
Small stern trawler	10	1	0	1	0	---	---	---
Large freezer trawler a/	234	127	210	50	177	---	---	---
Large surimi trawler a/	---	---	2	0	---	---	---	---
Longliner b/	---	---	---	---	---	---	---	---
Republic of Korea								
Small stern trawler	---	---	---	---	---	---	---	---
Large freezer trawler	---	0	0	---	---	---	---	---
Longliner b/	---	---	0	---	---	---	---	---
U.S.S.R.								
Large freezer trawler	---	0	---	---	---	---	---	---
Polish Peopel's Republic								
Large freezer trawler	---	---	---	---	---	---	---	---
Mexico								
Small stern trawler	---	---	---	---	---	---	---	---
Total foreign catch	244	128	212	61	177	---	---	---
Joint venture	---	---	0	---	---	---	---	---

a/ For Japan in 1977-78, large freezer trawlers and large surimi trawlers am combined under large freezer trawler.

b/ No estimate made of longline catch in 1977.

c/ Amendment 10 to the Gulf of Alaska groundfish management plan prohibited foreign and joint venture trawling in the eastern gulf, including Southeastern and Yakutat areas, after 1982.

d/ Final 1984 data received October 1985.

Table B4. -- Estimated incidental catch of tanner (snow) crab in the foreign and joint venture groundfish fisheries in the Gulf of Alaska given as number of crab by INPFC regulatory area 1977-84.[a]

Nation/vessel class	Total all areas							
	1977	1978	1979	1980	1981	1982	1983	1984
<u>Japan</u>								
Small stern trawler [a]	---	7,814	1,237	2,550	3,469	1,421	433	96
Large freezer trawler [a]	---	58	576	33	4,806	6,281	3,147	236
Large surimi trawler [a]	---	---	388	21	914	362	128	3,440
Longliner [b]	---	9,241	6,743	15,651	84,054	34,129	20,615	3,750
<u>Republic of Korea</u>								
Small stern trawler	---	---	---	---	1,825	280	219	6
Large freezer trawler	---	6,757	217	127	315	14,505	1,303	1,354
Longliner [b]	---	99	1,466	767	1,273	7,555	4,764	---
<u>U.S.S.R.</u>								
Large freezer trawler	---	0	166	8,695	---	---	---	---
<u>Polish People's Republic</u>								
Large freezer trawler	---	---	1	0	6	---	---	3
<u>Mexico</u>								
Small stern trawler	---	---	6,198	---	---	---	---	---
Total foreign catch	---	23,969	16,992	27,844	96,662	64,533	30,609	8,885
Joint venture	---	28	629	58,022	0	364	102,840	41,633

Table B4. -- Continued.

Nation/vessel class	Shumagin area							
	1977	1978	1979	1980	1981	1982	1983	1984
Japan								
Small stern trawler	---	0	0	0	0	744	192	12
Large freezer trawler[a]	---	0	23	0	219	140	1,907	9
Large surimi trawler[a]	---	---	0	0	44	174	31	314
Longliner[b]	---	767	277	4,312	5,156	10,799	5,598	2,745
Republic of Korea								
Small stern trawler	---	---	---	---	170	0	0	6
Large freezer trawler	---	6,757	217	115	35	507	249	397
Longliner[b]	---	12	22	406	341	6,511	4,209	---
U.S.S.R.								
Large freezer trawler	---	0	0	2,996	---	---	---	---
Polish People's Republic								
Large freezer trawler	---	---	0	0	0	---	---	---
Mexico								
Small stern trawler	---	---	0	---	---	---	---	---
Total foreign catch	---	7,536	539	7,829	5,965	18,875	12,186	3,483
Joint venture	---	28	0	4,117	0	364	73	475

Table B4. -- Continued.

Nation/vessel class	Chirikof area 1977	1978	1979	1980	1981	1982	1983	1984
Japan								
Small stern trawler	---	0	58	0	150	517	204	42
Large freezer trawler[a]	---	14	0	0	367	153	691	217
Large surimi trawler[a]	---	---	3	0	75	188	31	1,089
Longliner[b]	---	238	754	7,423	74,924	18,789	11,757	1,005
Republic of Korea								
Small stern trawler	---	0	---	---	1,655	264	219	0
Large freezer trawler	---	4	---	---	280	13,048	1,054	951
Longliner[b]	---	---	---	---	379	336	27	---
U.S.S.R.								
Large freezer trawler	---	---	141	0	---	---	---	---
Polish People's Republic								
Large freezer trawler	---	---	0	0	0	---	---	---
Mexico								
Small stern trawler	---	---	0	---	---	---	---	---
Total foreign catch	---	256	961	7,423	77,830	33,295	13,983	3,310
Joint venture	---	---	---	49,140	0	0	339	3,006

Table B4. -- Continued.

Nation/vessel class	Kodiak area 1977	1978	1979	1980	1981	1982	1983	1984
Japan								
Small stern trawler	---	308	267	0	0	160	37	42
Large freezer trawler[a]	---	29	174	0	889	5,988	549	10
Large surimi trawler[a]	---	---	385	21	795	0	66	2,037
Longliner[b]	---	580	1,291	524	1,390	1,939	765	---
Republic of Korea								
Small stern trawler	---	---	---	---	0	16	---	---
Large freezer trawler	---	---	---	---	0	950	---	---
Longliner[b]	---	73	---	---	407	0	150	---
U.S.S.R.								
Large freezer trawler	---	0	25	5,699	---	---	---	---
Polish People's Republic								
Large freezer trawler	---	0	1	---	---	---	---	3
Mexico								
Small stern trawler	---	---	6,181	---	---	---	---	---
Total foreign catch	---	990	8,324	6,244	3,481	9,053	1,567	2,092
Joint venture	---	---	618	4,765	---	0	102,428	38,152

Table B4. -- Continued.

Nation/vessel class	Yakutat area							
	1977	1978	1979	1980	1981	1982	1983[c]	1984[c]
Japan								
Small stern trawler	---	7,506	912	2,543	3,319	0	---	---
Large freezer trawler[a]	---	15	379	33	3,331	---	---	---
Large surimi trawler[a]	---	---	0	0	0	---	---	---
Longliner[b]	---	7,656	4,416	3,392	2,584	2,602	2,495	---
Republic of Korea								
Small stern trawler	---	---	---	---	0	---	---	---
Large freezer trawler	---	---	0	12	0	---	---	---
Longliner[b]	---	10	1,387	361	146	708	378	---
U.S.S.R.								
Large freezer trawler	---	0	0	---	---	---	---	---
Polish People's Republic								
Large freezer trawler	---	---	---	---	6	---	---	---
Mexico								
Small stern trawler	---	---	17	---	---	---	---	---
Total foreign catch	---	15,187	7,111	6,341	9,386	3,310	2,873	---
Joint venture	---	---	8	---	---	---	---	---

Table B4. -- Continued.

Nation/vessel class	Southeastern area 1977	1978	1979	1980	1981	1982	1983[c/]	1984[c/]
Japan								
Small stern trawler	---	0	0	7	0	---	---	---
Large freezer trawler[a/]	---	0	0	0	0	---	---	---
Large surimi trawler[a/]	---		0	0	---	---	---	---
Longliner[b/]	---	---	---	---	---	---	---	---
Republic of Korea								
Small stern trawler	---	---	---	---	---	---	---	---
Large freezer trawler	---	0	0	---	---	---	---	---
Longliner[b/]	---	---	57	---	---	---	---	---
U.S.S.R.								
Large freezer trawler	---	0	---	---	---	---	---	---
Polish People's Republic								
Large freezer trawler	---	---	---	---	---	---	---	---
Mexico								
Small stern trawler	---	---	---	---	---	---	---	---
Total foreign catch	---	0	57	7	0	---	---	---
Joint venture	---	---	---	---	---	---	---	---

a/ For Japan in 1977-78, large freezer trawlers and large surimi trawlers are combined under large freezer trawler.

b/ No estimate made of longline catch in 1977.

c/ Amendment 10 to the Gulf of Alaska groundfish management plan prohibited foreign and joint venture trawling in the eastern gulf, including Southeastern and Yakutat areas, after 1982.