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Bycatches in Fisheries and their Impact on the Ecosystem

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DIRECTOR'S FOREWORD

Academic fishery researchers, fisheries graduate students, government fishery scientists, fisheries consultants and a commercial fishermen gathered at the Fisheries Centre at UBC on October 13th and 14th 1994 in order to discuss the problems of by-catch. 51 participants came from British Columbia, Washington, Alaska, California, Mexico and Australia. This comprises the 3rd report in the UBC Fisheries Centre's Research Report Series.

There is little doubt that, for conventional fisheries and the existing spectrum of species, the sustainable marine world fish catch has reached its limits of around 80 million tonnes per annum. It is not surprising therefore that we hear growing public concern at the amount of discarded by-catch in world fisheries, currently estimated at around 30%. That one tonne of fish in every three caught is tipped back into the sea is perceived as a waste of fish and of fishing activity in a world short of protein for human nutrition and rife with demands for economic development. Conservation groups focus on such iniquities as evidence of irresponsible fishing driven by greed, multinational corporations and evil fisher folk. To make matters worse, mortality of marine mammals and turtles as by-catch in commercial fisheries enrages conservation groups and large sectors of the general public. This workshop was held to establish some of the facts about by-catch, discuss how its adverse effects might be mitigated, and try to determine whether the different perspectives of the fishing industry, fish ecologists, conservationists and policy makers on this issue might be reconciled.

Discards are large and widespread in tropical fisheries for high value species like prawns, where in the worst examples in South East Asia as much as ten tonnes of small fish are discarded for every tonne of prawns landed. Fish that are caught below legal size limits of target species are commonly discarded, for example in purse seine fisheries for mackerel in Europe, a practice known as 'high- grading' (Figure 1). It is a surprise and a paradox that large by-catch

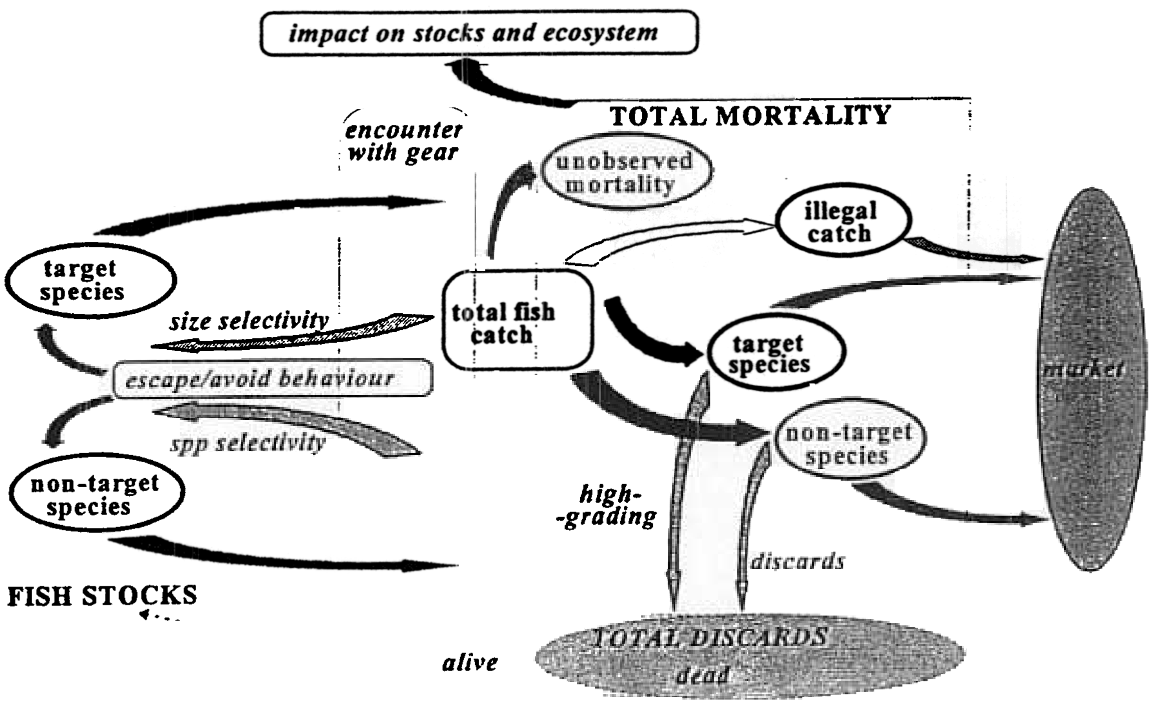

Figure By-catch: by Hook and by Crook

discards are endemic in many intensively researched and managed fisheries in North America, and that these discards occur as a direct consequence of complex and well-considered regulations supporting policies devised to avoid depletion.

Operational reduction of bycatch through more careful fishing practice, in tandem with incentives to vessel skippers and crew, is one development presented here that has significantly reduced bycatch in tuna fisheries. Technical solutions may be found lie in the improvement of gear design to allow target species to escape the gear and survive but this simple objective often turns out to be not as simple as might be thought. Figure 1 illustrates schematically what happens when fish encounter fishing gear. Fish make a series of behavioural decisions that result in evasion, escape or capture. Most fishing gears have traditionally been designed to maximise capture, and so the technical challenge in reducing bycatch is to identify key behavioural components of this system that may selectively release or allow the escape of fish that are too small or of the wrong species. Several solutions of this kind were presented at the workshop. Nevertheless, even with technical advances in the design of fishing gear, some bycatch is inevitable, and at the workshop there was discussion of the idea that we have to learn to accept that trade-offs have to be made, even with marine mammal deaths, if fisheries are to be managed optimally and sustainably.

An analysis of bycatch may distinguish ecological, technological, economic and policy determinants, with consequences and candidate remedies that may be associated with each of these categories. This report commences with a section devoted to a review of ecological and economic factors, followed by reports on two important North Pacific fisheries. Subsequent sections then discuss bycatch in three different types of fishing gear: trawls, purse seines and passive gear such as long-lines. Technical development of selective trawl and purse seine gears is evaluated and case studies presented from Australia, British Columbia, Alaska and Mexico. There is also a review of by-catch problems affecting world shark populations. Section 5 presents progress towards a general classification and strategies for solving bycatch problems, while the final section comprises summaries of the discussions on ecological and economic impacts, technological solutions and policy and attitudes to bycatch that were presented following discussions among three working groups at the workshop.

In contrast to the atmosphere of gloom and foreboding that seems obligatory at many workshops on fisheries problems these days, most of the participants were generally more optimistic at the end of the workshop than at the beginning. Hopefully, this was not just on account of the convivial atmosphere that is associated with Fisheries Centre workshops, and is a portent of reasonable solutions may soon be devised to the bycatch problem.

Tony J. Pitcher
Director, Fisheries Centre UBC, Vancouver

WORKSHOP AGENDA

13 October 1994

8:15 - 8:45	Registration & Continental Breakfast
8:45 - 9:00	Welcoming and Opening Address Bycatch in Fisheries: By Hook and By Crook *Tony Pitcher, UBC Fisheries Centre*

Session 1: Ecological and Economic Impact of Bycatches on Fisheries

9:00 - 9:10	General Introduction *Peter Larkin, UBC, North Pacific Universities Marine Mammal Research Consortium*
9:10 - 9:30	The bycatch problem from an economic perspective *Joe Terry, NMFS, Washington*
9:30 - 9:50	Bycatch mortality impacts and control for Pacific halibut *Bruce Leaman, PBS, Nanaimo*
9:50 - 10:10	Three proposed solutions to bycatch and discard in the North Pacific: focus on the U.S rocksole fishery *John Gauvin and Joe Blum, American Factory Trawler Association*
10:10-10:30	Coffee Break

Session 2: Bycatches and Trawl Fisheries

10:30-10:40	General Introduction *Dayton L. Alverson, Natural Resources Consultants, Inc., Washington*
10:40-11:00	The Pacific groundfish trawl fisheries: bycatch problem and potential solutions *Barry Ackerman, DFO*
11:00-11:20	Research and development efforts in bycatch elimination in trawl fisheries of British Columbia *Douglas March, Deep Sea Trawlers Association of B.C.*
11:20-11:40	Development of by-catch reducing trawl gears in NSW's prawn trawl fisheries *Steven Kennelly, NSW Fisheries, Australia*
11:40-12:00	Use of a semi-pelagic trawl in a tropical demersal trawl fishery *David Ramm, Dept. of Primary Industry and Fisheries, Darwin, Australia*
12:00 - 1:00	Sandwich lunch *(in Ralf Yorque Room)*

Session 3: Bycatches and Passive Gear Fisheries

1:00 - 1:10	General Introduction *Andrew Trites, UBC, North Pacific Universities Marine Mammal Research Consortium*
1:10 - 1:30	World bycatches of sharks in high-seas fisheries: appraising the waste of a resource *Ramon Bonfil, UBC Fisheries Centre*
1:30 - 1:50	Management of bycatch in hook-and-line groundfish fisheries off Alaska *Janet Smoker, Fisheries Info. Service*
1:50 - 2:10	Bycatch of steelhead (*Oncorhynchus mykiss*) and coho (*O. kisutch*)in the Skeena river sockeye (*O. nerka*) fishery *Joel Sawada and Art Tautz, B.C. Provincial Fisheries Branch*

Session 4: Bycatches and Purse-seine Fisheries

2:10 - 2:20	General Introduction *Martin Hall, Inter-American Tropical Tuna Commission*
2:20 - 2:40	Bycatches in purse-seine fisheries *Martin Hall, Inter-American Tropical Tuna Commission*
2:40 - 3:00	Bycatch in B.C. purse-seine fisheries: recent experiences in south coast chum salmon fisheries *Paul Ryall, DFO*
3:00 - 3:20	Coffee Break
3:20 - 3:40	Reducing bycatch through gear modifications: the experience of the tuna-dolphin fishery *Harold Medina, California*
3:40 - 4:00	Bycatch strategies: some success stories and promising approaches *Brad Warren, National Fisherman, Washington*
4:00 - 4:20	A classification of bycatch problems and some approaches to their solutions *Martin Hall, Inter-American Tropical Tuna Commission*
4:20 - 5:30	Summary of Day One (*identification of major issues to be addressed on Day Two*)

14 October 1994

9:00 - 12:00	Parallel sessions of working groups, addressing major issues identified on Day One.
12:00 - 1:00	Sandwich lunch *(in Ralf Yorque Room)*
1:00 - 2:00	Chair of each working groups report to the full meeting
2:00 - 4:00	Full meeting discussion and summary / Discussion of possible publication.
4:00	Adjourn

SECTION

ECOLOGICAL AND ECONOMIC IMPACT OF BYCATCHES ON FISHERIES

SESSION SUMMARY:

ECOLOGICAL AND ECONOMIC IMPACT OF BYCATCHES ON FISHERIES

Peter Larkin, North Pacific Universities Marine Mammal Research Consortium, Room 18, Hut B-3, 6248 Biological Sciences Road, Vancouver, B.C. V6T 1Z4, Canada.

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Because fisheries management has focused on statistics of landings the effect of bycatches on marine ecosystems and on the economics of fisheries operations has not been given sufficient attention. It has been estimated by Alverson et al (1994) that the world marine fisheries catch of 83 million tonnes may be 30% less than actual catch.

The ecological effects include mortality of discards of undersize, wrong sex or otherwise unwanted individuals of target species, incidental mortality to desired but non-target species, ready availability of food to scavenging species, and differential effects on the interactions between species in fish communities with possible reverberations through community structure.

Economic issues include the loss of time in sorting the catch, the costs of selective gear or restrictions on time and area of fishing, the costs of retaining the bycatch and its value if landed.

The economic perspective on bycatch was succinctly presented by Joseph Terry of the Alaska Fisheries Science Centre. Bycatch is an economic problem "if it precludes other higher valued uses" and "if there are costs associated with actions to reduce bycatch". His analysis related the marginal costs and benefits to the level of bycatch mortality from the perspectives of the individual fisher and of society. The ecological impacts are not readily quantified in economic terms.

Bruce Leaman described the bycatch problem of the trawl fisheries of Alaska and British Columbia with particular reference to the bycatch of halibut. The market for the bycatch of many species and sizes is limited. For valued species such as halibut, quotas or trip limits pose problems of monitoring and enforcement. Ecological impacts are not readily assessed because there is no routine monitoring of abundance of non-target species. The relative abundance of target and non-target species is important in determining the severity of the bycatch problem.

John Gauvin and Joe Blum presented solutions to the rock sole bycatch problem in the Gulf of Alaska: increasing mesh size, increasing retention rates, establishment of individual transferable quotas (ITQs) with tradeable rights to bycatch. The measures would reduce the bycatch from a fishery that targets on females with roe.

Discussion was combined with that of session two and underlined the uncertain nature of ecological impacts. Except for historical data on fisheries recently developed there is little information on pristine relative abundance of species. Changes in abundance of non-target species may be available from research cruises but the selectivity of gear makes even these data unreliable indices.

The view was unanimous that greater attention should be given to bycatch issues if management is to take better account of the ecological and economic issues involved.

THE BYCATCH PROBLEM FROM AN ECONOMIC PERSPECTIVE

Joseph M. Terry, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA F/AK C2, 7600 Sand Point Way NE, Seattle, WA 98115, USA

ABSTRACT

Bycatch occurs whenever fishing gear is not perfectly selective. Bycatch is a problem if it precludes higher valued uses of fish and other living marine resources and if there are costs associated with actions to reduce bycatch. If the former condition is not met, there is not a problem. If the latter condition is not met, the solution to the problem is trivial. There are two related issues that should be considered in determining how to control bycatch. They can be stated in terms of the following two-part question. What are the appropriate levels of bycatch and why are those levels being exceeded? Both the benefits and costs of decreasing bycatch are important in determining the answer to each part of this question, in comparing the extent of the bycatch problem among fisheries, and in evaluating fishery management alternatives intended to address the bycatch problem. This paper is based on a three part series of discussion papers on proposals currently under consideration by the North Pacific Fishery Management Council to address the problems of bycatch, discard, and the utilization of catch in the groundfish fisheries off Alaska.

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The objective for fishery management is to increase the contribution of fishery resources to the well-being of the Nation. This can be done by increasing the total net benefit resulting from the use of fishery resources and by improving its intra-temporal and inter-temporal distributions. The uses of these resources are not limited to direct consumptive uses by man. In the case of a stock of fish, the uses include being taken as catch and bycatch in a variety of fisheries and for a variety of purposes, providing prey for other living marine resources, acting as predators, and contributing to the future size of that stock of fish.

The net benefit to the Nation is equal to the difference between the total benefit (value) of the outputs and the total cost (value) of the inputs associated with the uses of fishery resources. Costs and benefits should be defined broadly from the Nation's perspective to include those that accrue to direct and indirect participants in the fishery as well as to other members of society.

The inputs used in a commercial fishery include fish taken as target catch and bycatch; other living marine resources; the fishing vessels, gear, and bait used in harvesting; the plants or vessels, equipment, and materials used for processing; and the fuel and labor used throughout the production process. The cost of each input should be measured in terms of its opportunity cost which is the net benefit foregone in its highest valued alternative use. Because each use of a fishery resource is associated with a different combination of inputs and outputs, alternative uses cannot be ranked in terms of net benefits without considering the values to the Nation of all the inputs and all the outputs of each use.

The net benefit of the use of fish in a commercial fishery and its distribution are determined jointly by the answers to the following four questions:

1. How much fish is removed each year by the fishery?
2. How is it removed?
3. By whom is it removed?
4. For what purposes is it removed?

The answers to these questions are determined by the decisions made by individual fishermen and processors in response to a variety of incentives and constraints that reflect the economic, social, regulatory, biological, and physical environments in which they operate.

Each of these four questions is intended to encompass a range of questions. The first question addresses not only total removals but also the size, age, sex, temporal, and spacial distributions of the removals. The second question addresses the cost of all the inputs associated with a particular method of harvesting fish. The third question is intended principally to address a range of distribution questions. The fourth question addresses both the cost of all the inputs associated with the use of catch and the benefits of those uses.

The amount of fish removed (used) by fishermen is total fishing mortality. In addition to fishing mortality accounted for by retained catch, it includes the fishing mortality resulting from the following: discarded catch; lost gear; and other direct interactions of fish with fishermen, fishing vessels, or their gear. Often it is difficult to obtain good estimates for the removals accounted for by retained catch and even more difficult to do so for the other components of fishing mortality.

The at-sea and on-shore observer program and product weight monitoring program for the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) groundfish fisheries in the US EEZ provide better estimates of catch, bycatch, discards, and the use of retained catch and bycatch for these two fisheries than are available for most other fisheries. Although the bycatch rates vary significantly among individual components of these two fisheries, the overall bycatch rates in these two fisheries are not high compared to those in many fisheries. However, these rates result in levels of bycatch that are high compared to those in many fisheries due to the sheer magnitude of the BSAI and GOA groundfish fisheries. In 1993, estimated total groundfish catch in the BSAI and GOA groundfish fisheries was about 2,148,000 metric tons (t) and estimated groundfish discards were 348,000 t for an average discard rate of 16.2% (Table 1). For the BSAI fisheries, the 1993 discard rates ranged from 4.5% in the pelagic pollock trawl fishery (Table 2) to 69% in the rock sole trawl fishery (Table 3).

In response to concerns about the levels of bycatch in the BSAI and GOA fisheries, the North Pacific Fishery Management Council (Council) has recommended and the Secretary of Commerce has approved and implemented a variety of management actions that were intended principally to control the bycatch of halibut, crab, herring, and salmon in the groundfish fisheries. Recently, the bycatch of groundfish and the utilization of the catch and bycatch of groundfish have received increased attention as has the bycatch of crab in the BSAI crab fisheries.

There are two related issues that should be considered in determining how to control bycatch. They can be stated in terms of the following questions:

What is the appropriate level of bycatch?

2 Why are there currently excessive levels of bycatch?

Each question is answered below.

What is the appropriate level of bycatch? A common response to this question is that no bycatch is the appropriate level. Some modify this response to say that the lowest level of bycatch practicable is appropriate. This modification recognizes that it may not be technologically possible to eliminate all bycatch without eliminating some very important fisheries. This modification is a step in the right direction. However, unless the definition of "practicable" is extended to consider the costs, as well as the benefits, of decreasing bycatch, that response is also incorrect in terms of increasing the net benefit to the Nation from using fishery resources. Basically, it makes sense to reduce bycatch in a cost effective manner to the level at which further changes would increase costs more than they would increase benefits. If cost effective methods are not used to decrease bycatch, the point at which the additional costs exceed the additional benefits will be reached at a higher level of bycatch.

The marginal benefit and marginal cost curves in Figure 1 present graphically the concept of the optimum level of bycatch. The marginal benefit curve depicts the marginal (or additional) benefit of reducing bycatch mortality by one more unit. Similarly, the marginal cost curve depicts the marginal (or additional) cost of reducing bycatch mortality by one more unit. When there are high levels of bycatch and little has been done to control bycatch, there are probably some simple and low cost actions that can be taken to reduce bycatch. However, at some point, the simple and low cost methods of reducing bycatch will be exhausted and more difficult and costly actions would be necessary and extreme measures may be necessary to eliminate the last few units of bycatch. Therefore, the marginal cost curve is expected to slope down to the right. The marginal benefit curve is expected to slope up to the right for the following reasons. At very low levels of bycatch, most of the fishing mortality of the species taken as bycatch is accounted for by other fisheries and the net benefit of some of the uses of that species in those other fisheries probably is quite low. However, at very high levels of bycatch, much of the fishing mortality of that species is accounted for by the bycatch and the lower valued uses in other fisheries would have been eliminated. As a result, the opportunity cost of a unit of bycatch which is the marginal benefit of reducing bycatch would be high.

If the marginal benefit and cost curves capture all benefits and costs to the Nation, the appropriate level of bycatch is that at which the marginal cost and marginal benefit are equal. In this example, marginal cost and marginal benefit both equal $10 when bycatch equals 10,000. At lower levels of bycatch, the marginal cost of reducing bycatch is greater than $10 and the marginal benefit is less than $10; therefore, reducing bycatch below 10,000 units would decrease net benefit. However, at higher levels of bycatch, the marginal cost is less than $10 and the marginal benefit is greater than $10; therefore, net benefit would be increased by decreasing bycatch.

The implications of not using cost effective methods of controlling bycatch are depicted in Figure 2. MC1 and MC2, respectively, are the marginal cost curves when cost effective methods are uses and when they are not used. The appropriate level of bycatch is 10,000 units when the cost effective methods are used, but it is 15,000 units when MC2 is the marginal cost curve because cost effective methods are not used.

Why are there currently excessive levels of bycatch? A common response to this question is that the greed or lack of concern by the fishermen who make decisions on when and how to fish results in excessive bycatch. Perhaps a more thoughtful and productive response is that excessive bycatch is but one of the symptoms of a major flaw in the way many fisheries are managed. Experience and economic theory demonstrate that, in an open access fishery, each fisherman has incentives to make decisions that result in the wrong answers to the four questions that jointly determine the level and distribution of the net benefit generated by a commercial fishery. Generally, too much fish will be removed and, due to the answers to the last three questions, the cost of inputs will be unnecessarily high and the value of outputs (benefit) will be unnecessarily low for each given level of removals.

The source of the problem principally is that in making decisions each fisherman is motivated by his expectations concerning the benefit he will receive and the cost he will bear but his decisions can result in benefits and costs for others. These externalities (i.e., benefits and costs that are to some extent external to the fisherman and his decision making process) result in individual fishermen making decisions that collectively decrease the net benefit generated from the use of fishery resources.

The source of the problem is depicted in Figure 3 in which MBF and MBS, respectively, are the marginal benefits curves for a fisherman and for society at large including the fisherman. From the fisherman's perspective, it makes sense for him to control bycatch up to the point at which his marginal benefit and marginal cost of reducing bycatch are equal. In this example, MBF and MC are equal when bycatch is 200. Because the marginal benefit curve for society (MBS) includes the marginal benefit to the fisherman and to the rest of society and because the rest of society also benefits from a reduction in bycatch, MBS is above MBF and the optimum level of bycatch for that fisherman from society's perspective is only 150. The external benefit results in the fisherman taking too much bycatch.

The concept of the optimum level of bycatch as presented above is quite simple. Applying the concept can be very difficult due to the difficulty in determining all of the benefits and costs of decreasing bycatch. As noted above, the direct benefit of decreasing bycatch is the decrease in the total opportunity cost of using fish as bycatch and the opportunity cost of a use of fish equals the net benefit foregone in its highest valued alternative use. The alternative uses include: (1) catch in another commercial fishery; (2) consumptive uses in subsistence and recreational fisheries; (3) contributions to the stock and other sectors of the ecosystem, some of which are non-consumptive uses; and (4) other non-consumptive uses. The value of the fourth includes existence and option values.

Fortunately, many of the species that are the focus of concern are taken as target catch in commercial fisheries. If it is determined that the use of a specific species as retained catch with adequate utilization is an appropriate use of fish of that species, there is an implicit determination that the value of that use is at least as high as the value of any use other than in a commercial fishery. If this were not the case, that use would not be appropriate and it should be eliminated. Therefore, the opportunity cost of using such a species as bycatch is at most the foregone net value of the use that was determined to be appropriate. If the use of a species for bycatch does not result in foregone catch for that acceptable use, the per unit opportunity cost may be less than the net benefit per unit of acceptable use.

For the living marine resources that are not used commercial but that are inputs for a fishery, opportunity costs would have to be estimated based on their expected values in other uses such as their contribution to the value of the ecosystem. Such valuations are difficult. The marginal contribution can be positive or negative and we may not know which it is without a substantially increased understanding of the ecosystem. Information on the magnitude of bycatch relative to the biomass of such species may indicate whether bycatch is expected to have a significant effect on the contribution of such species to the value of the ecosystem. The valuation of the opportunity cost of these non-commercial species is important when different management policies are expected to result in significantly different levels of use of these resources (inputs).

The cost of decreasing bycatch can be equally difficult to predict accurately. The range, effectiveness, and cost of changes in fishing strategies that would decrease bycatch are not known by the fishery managers. Part of the uncertainty concerning the cost of reducing the bycatch of one species occurs because bycatch is a multi-species problem in which actions to reduce the bycatch of one species often increase the bycatch of other species.

The problems of predicting the costs and benefits of regulatory actions to control bycatch make it difficult to evaluate either the net National benefits of proposed regulatory changes or the distributions of the changes in net benefits. However, these problems do not eliminate the rational for attempting to consider both the benefits and costs of actions to decrease bycatch and to use cost effective methods. The conceptual framework for determining the optimum level of bycatch and for understanding why regulatory intervention is necessary are useful in evaluating bycatch management alternatives even when accurate estimates and projections of all costs and benefits are not feasible.

Bycatch is a problem when it results in a lower valued use of a fishery resource. Eliminating that use is one solution and increasing the value of that use is another. The appropriate mix of these two solutions will depend on the marginal benefits and costs of decreasing bycatch and of increasing the value of bycatch.

The benefits and costs of decreasing bycatch also are important in comparing the extent of the bycatch problem among fisheries. Although bycatch is typically measured in terms of physical units, such as weight or numbers of animals, aggregate physical measures of bycatch often are of limited use and frequently are misleading. The problem is that the importance or value of bycatch per physical unit can vary significantly by species, size, sex, season, and area. Because an aggregate physical measure of bycatch does not account for such differences, it is not useful in comparing bycatch among fisheries for which there are differences in either the ecological or economic value per unit of bycatch within or among fisheries. A value based measure of bycatch, such as the opportunity cost of using fishery resources as bycatch, would provide a substantially more useful measure if both ecological and economic relationships are reflected adequately in the estimates of the opportunity cost of bycatch. With respect to proving meaningful comparisons among fisheries, even limited attempts to account for differences in the opportunity cost per physical unit of bycatch could result in a substantial improvement compared to strictly physical aggregate measures of bycatch. Such measures would provide estimates of the benefits of decreasing bycatch. To compare the potential net benefits among fisheries of reducing bycatch, the cost of reducing bycatch also has to be considered by fishery.

Table 1 Estimated groundfish catch and discards (1,000 metric tons) in the BSAI and GOA groundfish fisheries, 1991-1994.

BSAI	1991	1992	1993	1994
Catch	2,127	1,996	1,887	1,140
Discards	285	316	296	187
% Discarded	13.4	15.8	15.7	16.4
GOA	1991	1992	1993	1994
Catch	260	284	261	181
Discards	36	61	52	24
% Discarded	13.8	21.4	19.9	13.0
BSAI and GOA	1991	1992	1993	1994
Catch	2,387	2,280	2,148	1,321
Discards	321	377	348	211
% Discarded	13.4	16.5	16.2	16.0

Note: The discard rate estimates that were calculated using unrounded estimates of catch and discards cannot all be reproduced exactly using the data provided in this table.

Source: NMFS Alaska Region blend estimates through July 16, 1994.

Table 2 Groundfish catch and discards in the BSAI pelagic pollock trawl fishery, 1991-1994*

	Total catch		Discarded catch		
	Metric tons	Species composition	Metric tons	Species composition	Discard rate
1991					
Pollock	680,902	99.2%	50,216	92.4%	7.4%
Pacific cod	3,019	.4%	1,806	3.3%	59.8%
Sablefish	2	.0%	2	.0%	96.8%
Turbot	63	.0%	59	.1%	93.8%
Rock sole	207	.0%	184	.3%	88.7%
Yellowfin	39	.0%	31	.1%	79.6%
Arrowtooth	456	.1%	398	.7%	87.2%
Flat other	856	.1%	754	1.4%	88.1%
Rockfish	68	.0%	52	.1%	76.9%
Atka mack	0	.0%	0	.0%	95.8%
Other	878	.1%	827	1.5%	94.2%
Total	686,490	100.0%	54,330	100.0%	7.9%
1992					
Pollock	1,295,707	97.7%	80,653	77.2%	6.2%
Pacific cod	13,492	1.0%	8,658	8.3%	64.2%
Sablefish	8	.0%	4	.0%	54.8%
Turbot	251	.0%	187	.2%	74.4%
Rock sole	3,268	.2%	3,061	2.9%	93.7%
Yellowfin	186	.0%	176	.2%	94.7%
Arrowtooth	2,798	.2%	2,635	2.5%	94.2%
Flat other	5,629	.4%	5,068	4.8%	90.0%
Rockfish	205	.0%	180	.2%	87.6%
Atka mack	242	.0%	219	.2%	90.5%
Other	4,159	.3%	3,695	3.5%	88.8%
Total	1,325,944	100.0%	104,536	100.0%	7.9%
1993					
Pollock	1,227,495	98.6%	41,359	73.0%	3.4%
Pacific cod	8,648	.7%	7,052	12.5%	81.5%
Sablefish	0	.0%	0	.0%	15.9%
Turbot	67	.0%	66	.1%	99.6%
Rock sole	2,089	.2%	2,068	3.7%	99.0%
Yellowfin	579	.0%	556	1.0%	96.0%
Arrowtooth	557	.0%	497	.9%	89.2%
Flat other	2,659	.2%	2,508	4.4%	94.3%
Rockfish	234	.0%	227	.4%	96.9%
Atka mack	35	.0%	34	.1%	98.0%
Other	2,346	.2%	2,252	4.0%	96.0%
Total	1,244,710	100.0%	56,619	100.0%	4.5%
1994*					
Pollock	1,185,024	99.0%	20,774	72.7%	1.8%
Pacific cod	8,230	.7%	4,906	17.2%	59.6%
Sablefish	2	.0%	1	.0%	37.6%
Turbot	65	.0%	64	.2%	99.6%
Rock sole	333	.0%	293	1.0%	88.2%
Yellowfin	147	.0%	126	.4%	85.6%
Arrowtooth	956	.1%	834	2.9%	87.3%
Flat other	1,457	.1%	878	3.1%	60.3%
Rockfish	91	.0%	61	.2%	66.8%
Atka mack	61	.0%	58	.2%	94.2%
Other	713	.1%	563	2.0%	78.9%
Total	1,197,078	100.0%	28,558	100.0%	2.4%

Source: NMFS Alaska Region blend estimates through Oct 29, 1994.

Table 3 Groundfish catch and discards in the BSAI rock sole trawl fishery, 1991-1994*

	Total catch		Discarded catch		
	Metric tons	Species composition	Metric tons	Species composition	Discard rate
1991					
Pollock	9,699	22.7%	8,735	32.4%	90.1%
Pacific cod	4,258	10.0%	1,652	6.1%	38.8%
Sablefish	9	.0%	9	.0%	100.0%
Turbot	1	.0%	1	.0%	100.0%
Rock sole	22,038	51.7%	11,120	41.2%	50.5%
Yellowfin	2,040	4.8%	1,495	5.5%	73.3%
Arrowtooth	254	.6%	254	.9%	100.0%
Flat other	2,606	6.1%	2,076	7.7%	79.7%
Rockfish	46	.1%	1	.0%	1.9%
Atka mack	3	.0%	3	.0%	100.0%
Other	1,692	4.0%	1,651	6.1%	97.6%
Total	42,646	100.0%	26,998	100.0%	63.3%
1992					
Pollock	10,339	19.4%	9,491	27.8%	91.8%
Pacific cod	4,805	9.0%	2,108	6.2%	43.9%
Sablefish	0	.0%	-	-	-
Turbot	3	.0%	-	-	-
Rock sole	24,866	46.6%	12,194	35.7%	49.0%
Yellowfin	4,848	9.1%	2,977	8.7%	61.4%
Arrowtooth	630	1.2%	628	1.8%	99.7%
Flat other	4,727	8.9%	3,620	10.6%	76.6%
Rockfish	22	.0%	22	.1%	97.7%
Atka mack	10	.0%	3	.0%	32.3%
Other	3,133	5.9%	3,107	9.1%	99.2%
Total	53,384	100.0%	34,150	100.0%	64.0%
1993					
Pollock	18,573	22.0%	17,321	29.7%	93.3%
Pacific cod	8,160	9.7%	5,632	9.7%	69.0%
Sablefish	4	.0%	3	.0%	68.2%
Turbot	28	.0%	26	.0%	92.9%
Rock sole	39,857	47.2%	23,283	39.9%	58.4%
Yellowfin	6,277	7.4%	3,799	6.5%	60.5%
Arrowtooth	1,144	1.4%	1,143	2.0%	100.0%
Flat other	7,270	8.6%	4,031	6.9%	55.4%
Rockfish	21	.0%	18	.0%	89.8%
Atka mack	15	.0%	8	.0%	53.7%
Other	3,091	3.7%	3,030	5.2%	98.0%
Total	84,439	100.0%	58,295	100.0%	69.0%
1994*					
Pollock	16,077	20.6%	15,139	27.8%	94.2%
Pacific cod	6,271	8.0%	3,882	7.1%	61.9%
Sablefish	16	.0%	2	.0%	12.8%
Turbot	50	.1%	39	.1%	78.3%
Rock sole	40,418	51.7%	23,664	43.5%	58.5%
Yellowfin	4,809	6.2%	3,546	6.5%	73.7%
Arrowtooth	1,744	2.2%	1,744	3.2%	100.0%
Flat other	5,488	7.0%	3,125	5.7%	57.0%
Rockfish	125	.2%	116	.2%	92.8%
Atka mack	0	.0%	-	-	-
Other	3,162	4.0%	3,119	5.7%	98.6%
Total	78,161	100.0%	54,377	100.0%	69.6%

Source NMFS Alaska Region blend estimates through Oct 29 1994

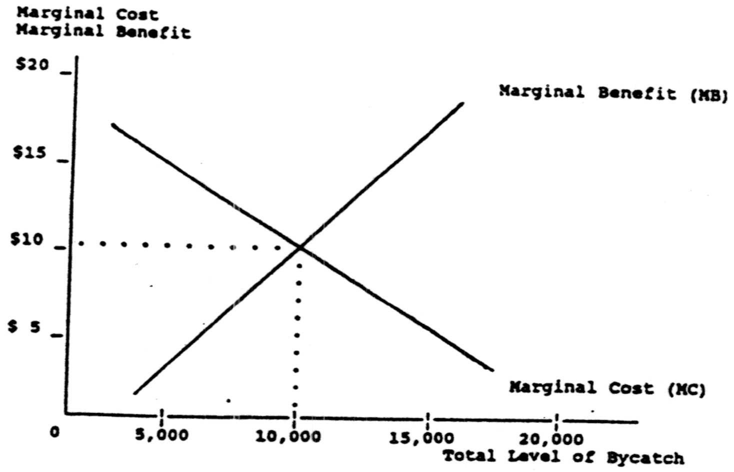

Figure 1 The marginal benefit and marginal cost of reducing bycatch and the optimum level of bycatch.

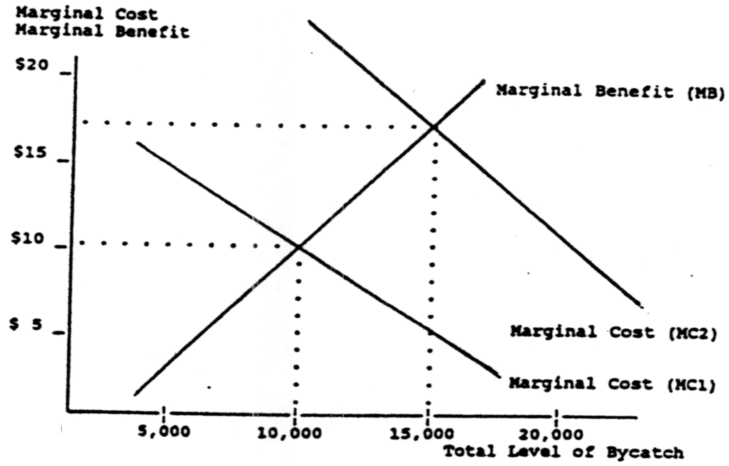

Figure 2 The marginal benefit, marginal cost of reducing bycatch with cost effective methods (MC1), marginal cost of reducing bycatch without cost effective methods (MC2), and the optimum levels of bycatch with and without cost effective methods of reducing bycatch.

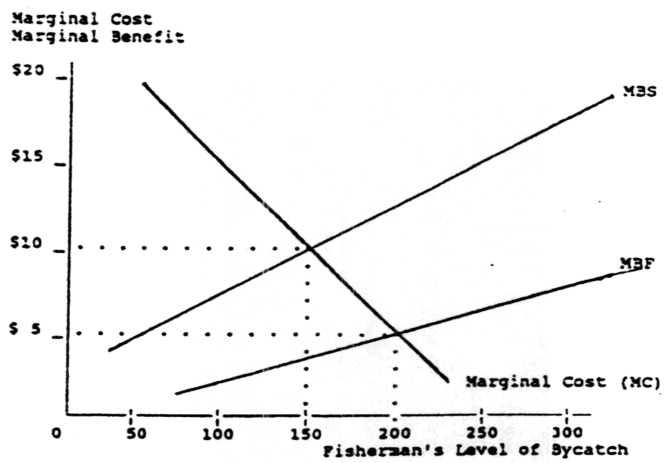

Figure 3 The marginal benefit to the fisherman (MBF), marginal benefit to society including the fisherman (MBS), marginal cost (MC) of reducing bycatch, and the optimum levels of bycatch, respectively, for the fisherman and for society.

BYCATCH MORTALITY IMPACTS AND CONTROL FOR PACIFIC HALIBUT

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ABSTRACT

The groundfish trawl fishery off British Columbia is characterized by multispecies landings which arise through both biological associations and the fishery management regime. Catches of many species may be discarded at sea due to lack of markets, size constraints of existing markets, catch prohibition, or quota/trip limit restrictions. Mortality of the discarded species varies with the fishing method and the biology of the species. The fishing gear characteristics, as well as the exploitation histories and underlying productivities of the target species which are caught together limit the opportunities for joint yield optimization of these target species. In addition, incidental mortality on species which are not targets for the trawl fishery decreases yield in fisheries for which these species are the targets. This paper examines some of the economic impacts of bycatch in British Columbia trawl fisheries from the perspectives of lost yield, management costs, and the impact on knowledge of the population dynamics of non-target species arising from bycatch mortality. The primary focus of this paper is on the impacts of bycatch mortality of Pacific halibut arising from capture in trawl fisheries.

The management program for Pacific halibut is one of the few management regimes in the world that incorporates explicit recognition and accounting for bycatch mortality. The International Pacific Halibut Commission reduces the catch quota for the directed halibut fishery to account for bycatch mortality occurring in trawl fisheries from Alaska to B.C. For 1994, this reduction totalled over 1100 t and resulted in a catch quota of approximately 4500 t for B.C. waters. Coastwide, the reduction for bycatch was approximately 27% of the final halibut quotas for Canada and the United States. In 1991, Canada and the United States began a cooperative program of bycatch monitoring and control to reduce the impact of bycatch on the Pacific halibut resource. Control of bycatch has been difficult and has not been achieved without significant costs in other fisheries. The paper reviews some of the lessons that have emerged from this process.

Coastwide bycatch mortality has been reduced from approximately 7900 t in 1990 to approximately 6900 t in 1993. Canada will be implementing direct bycatch control measures in 1995 and has established a target mortality of approximately 490 t in 1997, a reduction of 50% from 1991 levels. Data collected from observer programs and directed research studies are producing the information necessary to design and monitor programs to achieve this result. The paper examines some of the economic trade-offs which must be considered in the design of bycatch control measures. Finally, the paper explores the impacts of discard mortality on our understanding of the population dynamics of non-target species.

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INTRODUCTION

The British Columbia groundfish trawl fishery shares features with most trawl fisheries in the world. It is prosecuted with fishing gears that have limited selectivity and yields multispecies catches with relatively high proportions of discards at sea. In addition to the voluntary discard of fish arising through market forces, discarding can also be mandated by management prohibition, or arise through the interaction between biological associations and the management framework used to enforce quotas for species or species groups. While the quantity of fish discarded can often be 50% or higher of that actually landed, few species management programs in the world provide adequate recognition and accommodation for this mortality. In this paper, I examine the magnitude of the discard problem in the British Columbia trawl fishery, as determined through by on-board observations in one the major fishing areas, the myriad causes for discarding, and the impacts of discarding Pacific halibut (*Hippoglossus stenolepis*) in a non-target fishery on the yield available to a target fishery for this species. I also present the measures that have been taken on an international level to control and reduce bycatch mortality of Pacific halibut and illustrate the tradeoffs associated with some of these control measures.

Causes of Bycatch and Bycatch Mortality

The operational definition of *bycatch* used in this paper is that portion of the catch by a given gear that is, for any reason, unwanted by the harvester. *Bycatch mortality* is the mortality generated through this catching process and the subsequent treatment of the catch. *Bycatch* is then fundamentally an issue of the selective properties of the fishing gear. If the fishing gear were perfectly selective for the species and sizes desired in the market, there would be no bycatch. Such selectivity is exceedingly uncommon and is usually restricted to harvesting methods involving visual identification of targets prior to harvest. More commonly, fishing gear shows imperfect selectivity, ranging from highly selective for species or sizes to non-selective. The selectivity may be entirely a function of the gear itself, e.g. mesh or hook sizes, or may be related to associations of species in the habitat in which the gear is deployed.

Bycatch itself is therefore largely a passive function of fishing gear and deployment in conjunction with the distribution and biology of the species involved in fishing. Conversely, *bycatch mortality* is a much more complex and active process. The major contributors to bycatch mortality can be segregated into direct and indirect factors. A listing of the major factors under these categories (Table 1) finds both those which are under the control of the individual harvester and those driven by economic forces quite removed from actions aboard an individual vessel.

Table Factors affecting bycatch mortality in fisheries.

DIRECT FACTORS
- Depth of capture
- Duration of fishing
- Species mixture and quantity in catch (e.g., smooth-bodied vs. spiny)
- Anatomy and Physiology of the species concerned
- Size and age of the individual
- Temperature and exposure to desiccation
- Handling practice and time prior to discarding

INDIRECT FACTORS
- Market acceptability limits on species and sizes of fish
- Vessels' capability to process catches to meet market specifications (e.g., freezing)
- Management prohibition on retention by specific gears
- Management measures which are do not account for the multispecies nature of catches within fisheries (e.g., individual species trip limits in multispecies fisheries)

Impacts of Bycatch Mortality

Assessing the impacts of bycatch mortality requires attention to both obvious and obscure processes (Table 2). The most direct impact that fishery biologists should consider regularly is the impact on population dynamics and yield of target species for which there is bycatch mortality of juveniles. However, this mortality component is seldom considered, even though it is arguably the most obvious impact of bycatch. Stock assessment biologists seldom have information on the levels of discards for target species in even the most well documented fisheries. For example, the British Columbia groundfish trawl fishery is subject to compulsory logbook reporting of catch and effort, on a tow-by-tow basis. Although the logbooks contain provision for discard reporting, harvesters seldom provide such data. Assessment biologists therefore know little about the quantities and species composition of the discarded catch. Research survey data are sometimes used to estimate the probability of discarding for given size or age groups but this information is generally insufficient for estimation of specific time and area impacts.

Table 2. Impacts of bycatch mortality and bycatch control measures

DIRECT IMPACTS
- Loss of recruits to fished population through juvenile discards
- Ecological impacts related to predator-prey and competitive interactions
- Economic impacts through lost or enhanced yields of target species
- Costs of enforcement for bycatch control
- Costs of monitoring and management

INDIRECT IMPACTS
- Loss of future yields for species targeted by other fisheries (e.g. halibut, crab)
- Extended economic costs concerning undeveloped processing and marketing potential
- Ecological effects through long-term dynamics of communities
- Effects on dynamics of individual species subject to bycatch mortality
- Effects on the information basis for stock assessment of both target and non-target species

The magnitude of the bycatch problem in the B.C. trawl fishery is beginning to be documented through observer placement aboard fishing vessels. Observer data gathered in the shallow water fisheries of Hecate Strait during 1991-1992 illustrates the general nature of discarding (Table 3). Discards in this fishery during the period averaged 56% of the landed

Table 3. Summary of observed catch and discards for the trawl fishery in Hecate Strait, 1991-1992.

SPECIES	SUMMER CATCH (kg)	SUMMER DISCARD (kg)	SUMMER PROP.	WINTER CATCH (kg)	WINTER DISCARD (kg)	WINTER PROP.	COMBINED CATCH (kg)	COMBINED DISCARD (kg)	PROP.
Arrowtooth flounder	76695	76695	1.00	32305	32011	0.99	109000	108706	1.00
Big skate	16130	14020	0.87	4395	4395	1.00	20525	18415	0.90
Black rockfish	18	0	0.00	227	0	0.00	245	0	0.00
Blue rockfish	0	0	0.00	40	0	0.00	40	0	0.00
Bocaccio	191	65	0.34	2134	0	0.00	2325	65	0.03
Butter sole	14461	7310	0.51	209	209	1.00	14670	7519	0.51
C-O sole	124	124	1.00	96	96	1.00	220	220	1.00
Canary rockfish	1638	47	0.03	417	145	0.35	2055	192	0.09
China rockfish	trace	trace	0.00	0	0	0.00	0	0	0.00
Copper rockfish	110	0	0.00	90	0	0.00	200	0	0.00
Curlfin sole	20	20	1.00	59	59	1.00	79	79	1.00
Darkblotched rockfish	363	209	0.58	408	0	0.00	771	209	0.27
Deepsea sole	0	0	0.00	131	131	1.00	131	131	1.00
Dover sole	36311	9672	0.27	13237	4650	0.35	49548	14322	0.29
English sole	87198	56701	0.65	121945	64805	0.53	209143	121506	0.58
Flathead sole	1635	1036	0.63	1654	1654	1.00	3289	2690	0.82
Greenlings	trace	trace	0.00	55	55	1.00	55	55	1.00
Greenstriped rockfish	0	0	0.00	trace	trace	0.00	0	0	0.00
Kelp greenling	trace	trace	0.00	trace	trace	0.00	0	0	0.00
Lingcod	9623	145	0.02	21872	115	0.01	31495	260	0.01
Longnose skate	1190	1140	0.96	16819	16819	1.00	18009	17959	1.00
Pacific cod	135268	10577	0.08	185022	4850	0.03	320288	15427	0.05
Pacific hake	0	0	0.00	15	15	1.00	15	15	1.00
Pacific halibut	36995	36995	1.00	10710	10710	1.00	47705	47705	1.00
Pacific herring	77	77	1.00	545	545	1.00	622	622	1.00
Pacific ocean perch	498	310	0.62	1402	0	0.00	1900	310	0.16
Pacific sanddab	1122	1122	1.00	148	148	1.00	1270	1270	1.00
Pacific tomcod	0	0	0.00	78	78	1.00	78	78	1.00
Petrale sole	1477	695	0.47	7903	1703	0.22	9380	2398	0.26
Poachers	0	0	0.00	236	236	1.00	236	236	1.00
Prowfish	0	0	0.00	3	3	1.00	3	3	1.00
Quillback rockfish	439	0	0.00	508	55	0.11	947	55	0.06
Redbanded rockfish	417	0	0.00	491	0	0.00	908	0	0.00
Redstripe rockfish	151	109	0.72	3695	543	0.15	3846	652	0.17
Rex sole	12556	11196	0.89	19722	15535	0.79	32278	26731	0.83
Rock sole	193057	92920	0.48	57194	21428	0.37	250251	114348	0.46
Rosethorn rockfish	97	0	0.00	0	0	0.00	97	0	0.00
Rougheye rockfish	64	0	0.00	0	0	0.00	64	0	0.00
Sablefish	9661	9163	0.95	9681	9681	1.00	19342	18844	0.97
Salmon	trace	trace	0.00	64	62	0.97	64	62	0.97
Sand sole	12022	5921	0.49	15812	14189	0.90	27834	20110	0.72
Sandpaper skate	10	10	1.00	237	237	1.00	247	247	1.00
Sculpins	0	0	0.00	111	111	1.00	111	111	1.00
Shad	trace	trace	0.00	91	91	1.00	91	91	1.00
Shiner perch	0	0	0.00	153	153	1.00	153	153	1.00
Shortspine thornyhead	1242	302	0.24	136	136	1.00	1378	438	0.32
Silvergray rockfish	373	0	0.00	9124	388	0.04	9497	388	0.04
Skates	31133	31133	1.00	41257	40986	0.99	72390	72119	1.00
Slender sole	0	0	0.00	7	7	1.00	7	7	1.00
Speckled sanddab	0	0	0.00	277	227	0.82	277	227	0.82
Spiny dogfish	87734	87734	1.00	43672	43672	1.00	131406	131406	1.00
Spotted ratfish	19820	19820	1.00	24910	24910	1.00	44730	44730	1.00
Starry flounder	8618	8558	0.99	3987	3987	1.00	12605	12545	1.00
Starry skate	0	0	0.00	30	30	1.00	30	30	1.00
Sturgeon poacher	0	0	0.00	29	29	1.00	29	29	1.00
Tiger rockfish	0	0	0.00	trace	trace	0.00	0	0	0.00
Vermilion rockfish	0	0	0.00	5	0	0.00	5	0	0.00
Walleye pollock	7639	4256	0.56	24269	17612	0.73	31908	21868	0.69
Widow rockfish	trace	trace	0.00	215	10	0.05	215	10	0.05
Wolfeel	70	70	1.00	35	35	1.00	105	105	1.00
Yelloweye rockfish	50	0	0.00	279	0	0.00	329	0	0.00
Yellowmouth rockfish	0	0	0.00	150	0	0.00	150	0	0.00
Yellowtail rockfish	1253	967	0.77	598	50	0.08	1851	1017	0.55
TOTAL / AVERAGE	807548	489119	0.37	678894	337595.88	0.58	1486442	826715	0.56

catch, i.e., for every 1000 t of fish landed, over 500 t was discarded. The proportion discarded is higher during summer months, when averaged across all species, although the proportion of the total catch discarded during the winter months was higher. Of the species with significant discard ratios (Fig. 1), only Pacific halibut must be discarded by regulation. All other discards result primarily from a lack of markets for the sizes or species obtained. In several instances (e.g. some flatfish spp.) discards could be reduced through gear modifications, such as larger mesh sizes.

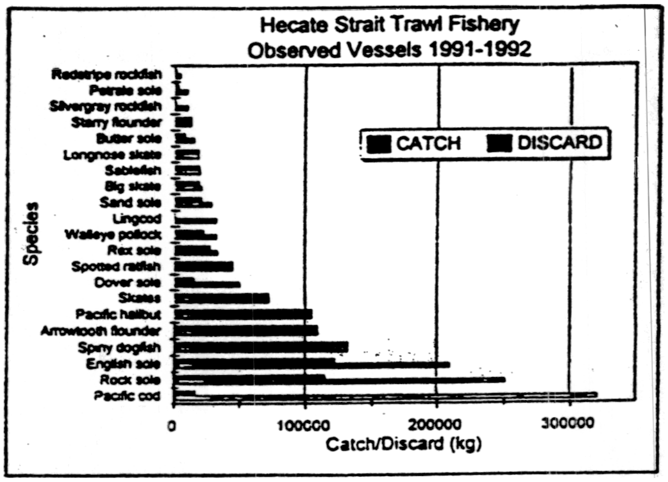

Figure 1. Catches and discards of groundfish species observed on Canadian trawlers operating in Hecate Strait during 1991-1992.

Perhaps the most insidious effect of bycatch mortality for target species is generated through discarding and misreporting of target species to accommodate or circumvent management measures for individual species, in mixed-species fisheries. For example, there are approximately 24 stocks of nine species of rockfishes (genus *Sebastes*) assessed in British Columbia. These stock units, which have considerably different exploitation histories and current productivity levels, are presently compressed into three coastwide aggregates for management. This compression is a direct consequence of industry practices of misreporting and discarding of species to overcome constraints imposed through a previous management regime, which attempted to manage these stocks individually. The aggregation of individual stock yields into coastwide aggregates has led to significant imbalances in removals relative to available yield for some of these stock units (Leaman 1990). The costs of this approach to the long-term yield from these stock units is not yet fully understood but may be substantial. A further cost of aggregation is a comprehensive dockside monitoring program for all landings from the fishery. This program imposes a shared cost on both industry and government of approximately $700,000/y, solely to provide accurate landing statistics for this management program. The level of discarding at sea to used to circumvent annual quotas and individual trip limits on these aggregates remains unknown.

The discussion of bycatch mortality impacts on non-target species seldom passes beyond the speculative, due to the paucity of information on either the quantities of discards or the parent stock from which they were derived. Unless these non-target species are themselves the objects of directed fisheries, insufficient knowledge exists to estimate the degree of fishing mortality imposed through bycatch. A notable exception is the Pacific halibut (*Hippoglossus stenolepis*), which will be treated in the second portion of this paper.

Where bycatch reduction and control programs are in place, two major impacts of such programs dominate consideration: the cost of monitoring, managing, and enforcing them; and, the economic losses associated with either adherence to restrictions in target fisheries, or continued bycatch mortality on non-target species when restrictions are not adhered to. These aspects will also be discussed with respect to the interactions of groundfish trawl fisheries and the directed setline fishery for Pacific halibut.

Finally, an impact of bycatch mortality that is less visible but of significant consequence is the impact on our knowledge base for stock assessment. The most benign form of this impact occurs where there is chronic but stable discarding of either target or non-target species. Here, the additional fishing mortality from discarding will be transparent to most stock assessments and be generally subsumed within the estimated natural mortality rate. More destructive to assessment data sets are instances where bycatch is highly variable within years or in response to incremental management measures. For example, under previous management regimes for the B.C. trawl fishery the early subscription of trip limits for some species would often result in higher reported landings of species with normally low levels of incidental occurrence. This scenario suggests high levels of discarding for species with fully-subscribed quotas, in order to accrue sufficient landings of these alternative species. The alternative of misreported landings of these alternative species to avoid prosecution for illegal landings of the primary species creates equally problematic data. Unreported discards of minor species also has the impact of removing any opportunity to observe unfished stock characteristics. Productivity of such resources will generally tend to be overestimated if observed characteristics are mistakenly assumed to represent the unexploited condition.

PACIFIC HALIBUT BYCATCH

Historical Perspective

The Pacific halibut is the object of a major directed fishery off the west coast of North America, extending from the Bering Sea to Oregon. This lucrative fishery yielded over 59 Mlb in 1994, worth over $200M (U.S.) to harvesters (IPHC 1994). Pacific halibut have a complex reproductive biology involving spawning migration of adults and consequent counter-migration of juveniles. Although smaller amounts of spawning occur throughout the coast, the majority of halibut spawners migrate toward the central Gulf of Alaska (Fig. 2, Areas 3A/B) in the winter months. Eggs and larvae drift with prevailing westerly currents to the western Gulf and eastern Bering Sea. Juveniles begin migrating back in an easterly and southerly direction beginning at about age 2 y and are intercepted by target fisheries for other species between ages 2-7 y. The primary fisheries of interception are trawl (both groundfish and shrimp) and hook and line fisheries in the Bering Sea (Area 4), Gulf of Alaska (Areas 2C-3A), trawl fisheries off British Columbia (Area 2B), and trawl fisheries off Washington and Oregon (Area 2A).

Historically, bycatch mortality of Pacific halibut occurred primarily in fisheries conducted by foreign distant-water trawlers operating in Alaskan waters. Bycatch mortality rose to over 20 Mlb in the mid-1960s but was reduced to approximately 7 Mlb following the promulgation of extended fisheries jurisdiction by North American states in 1977 (Fig. 3). Coastwide

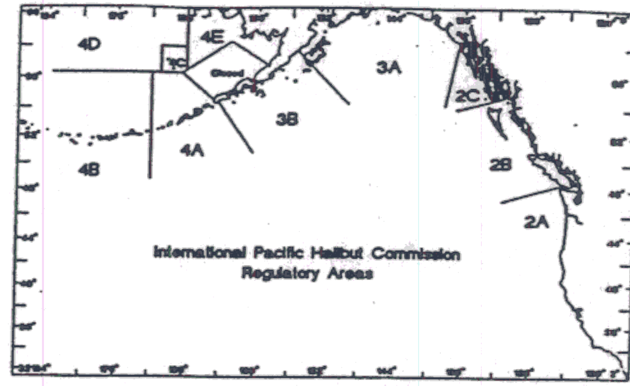

Figure 2. Regulatory areas of the International Pacific Halibut Commission for the west coast of North America.

bycatch increased after 1985 as the U.S. "Americanized" the fisheries of the Bering Sea and Gulf of Alaska. U.S. factory trawlers fishing for pollock, flatfish and Pacific cod were the source of most of this increase. Estimated bycatch mortality in Area 2B (B.C.) during the same period was relatively stable (Fig. 3), and was generally below 2 Mlb. The bycatch of halibut in B.C. is highest in Hecate Strait, followed by Vancouver Is. and Queen Charlotte Sound, with fisheries for shallow water soles and Pacific cod accounting for the majority of bycatch mortality.

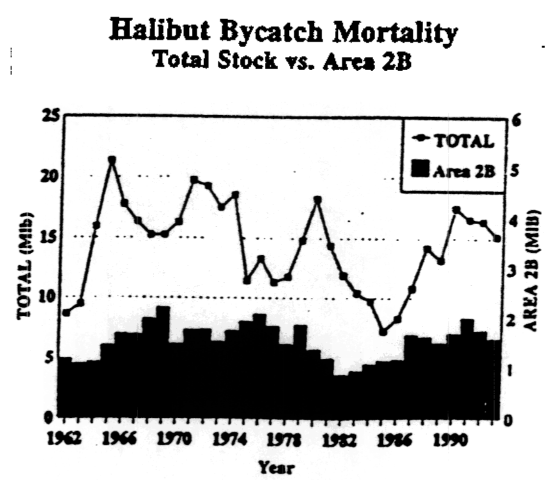

Figure 3. Bycatch mortality of Pacific halibut for British Columbia waters (Area 2B) and the entire west coast of North America, 1962-1993.

Bycatch is a joint function of fishing effort, the abundance of the target species, and the abundance of the non-target or bycaught species. The influence of halibut juvenile abundance on bycatch can be inferred from data relating abundance of juvenile halibut in the Bering Sea, estimated through systematic research trawl surveys, to bycatch of halibut in groundfish fisheries (Fig. 4). The declining bycatch of halibut following extended jurisdiction, although clearly related to a number of area closures and bycatch restrictions imposed on foreign vessels, also occurred during a period of declining abundance of juvenile halibut. Conversely, the increasing bycatch after the Americanization of the Alaskan fisheries was coincident with increasing abundance of halibut juveniles in the Bering Sea.

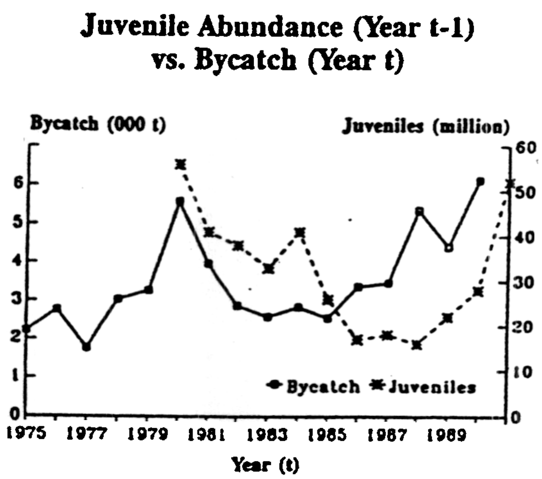

Figure 4. Relationship of the bycatch of halibut juveniles in the Bering Sea and the abundance of halibut juveniles estimated by trawl surveys in the previous year, 1975-1991.

Compensation Measures

The Pacific halibut resource is managed jointly by the U.S. and Canada through the International Pacific Halibut Commission (IPHC). The IPHC is one of the few management agencies in the world that attempts to deal explicitly with the effects of bycatch mortality on the exploitable stock. The IPHC has developed estimates of losses to the halibut stock due to lost recruitment, lost reproductive potential, and total lost yield (Table 4). At present, the Commission attempts to compensate the stock for bycatch mortality through reductions in directed fishery quotas to replace the potential egg production lost through bycatch. Compensation is calculated on a coastwide pool basis because of the observed spawning behaviour but assigned to each management area in proportion to the distribution of adult biomass. Compensation thus accounts for the movement of juveniles out of the areas of bycatch occurrence. However, this has the novel effect of dissociating some of the areas where bycatch originates (primarily the Bering Sea) from the penalties in lost yield that are paid (Gulf of Alaska and further south). Table 5 shows the relation of bycatch source and these yield reduction penalties among management areas.

Table 4. Losses due to bycatch mortality of Pacific halibut.

RECRUITMENT LOSS

No adjustment to compensate for
Average loss in adult equivalent weight is 1.2 times weight of bycatch

LOST REPRODUCTIVE POTENTIAL

IPHC adjusts setline yield to attempt to compensate the stock
Lost recruitment (1.2) times the ratio of adult equivalent biomass to recruitment biomass (0.83) is used to replace egg production lost through bycatch
The resulting 1.0 is the adult equivalent biomass subtracted from the setline quota for each lb of bycatch (adult reproductive compensation)

TOTAL LOST YIELD

Adult reproductive compensation (1.0), of which 0.6 will eventually be caught in subsequent years in the fishery -> 0.4
+ Lost recruitment biomass = 1.2 times bycatch
Results in a total yield loss of 1.6 lb/ lb of bycatch

The measures adopted by the IPHC for bycatch compensation result in substantial penalties paid by B.C. halibut fishers for bycatch mortality occurring in Alaska. For example, in 1995 the total quota reduction of halibut extracted to compensate the stock for bycatch mortality will be approximately 16.0 Mlb, to which bycatch mortality in B.C. contributed 1.3 Mlb. However, B.C. fishers will pay a total of 3.05 Mlb in quota reduction penalties, of which 2.8 Mlb accrues to B.C. solely due to bycatch in U.S. waters. While the system used by the IPHC also results in direct penalties to U.S. halibut fishers for Canadian bycatch, the balance is strongly against Çanada. This imbalance, coupled with the increasing trend in U.S. bycatch in the late

1980s, triggered a landmark agreement to control and reduce bycatch mortality between the two countries in 1991.

Table 5. Example of apportionment of catch limit reductions by the IPHC (reproductive compensation) by regulatory area for effects of bycatch mortality in 1992.

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

The 1991 IPHC Bycatch Reduction Agreement

Canada and the United States, through the IPHC, agreed in 1991 to embark on a process of halibut bycatch mortality control and reduction. A Halibut Bycatch Work Group (HBWG) was created by resolution of the Commission and produced a series of recommendations, that were adopted by the Commission in July 1991 (Salveson et al. 1992). The HBWG conducted an extensive investigation of the bycatch issue, reviewed existing measures for bycatch control, and detailed a number of mechanisms that could be implemented to reduce bycatch mortality. The group identified the low levels of bycatch mortality achieved in the mid-1980s as a desirable goal for reduction. Notably, the group also identified that increasing the survival of those fish which were caught and discarded would likely be as, or more, effective than decreasing the number of fish actually caught in non-target fisheries. This recognition provided support for alternative measures of bycatch mortality reduction to traditional measures involving only time and area prohibitions. .

The 1991 agreement identified a process, a timetable and a target. In particular, the United States agreed to bring all fisheries under bycatch limits for 1992 and to implement a program to reduce bycatch limits by a minimum of 10%/y beginning in 1993. Canada has subsequently committed to bring its bycatch mortality down to 1.0 Mlb by 1997.

Measures Used to Monitor and Control Halibut Bycatch

The most significant feature of bycatch reduction programs is the development of a process to estimate bycatch and monitor changes resulting from various reduction measures implemented. The U.S. began a comprehensive program of monitoring in the early 1990s which is now funded directly by harvesters. This program involves 100% observer coverage for vessels > 125' in length and graduated observer coverage for smaller vessels. The program cost is variable but is generally in the $15-20 M range. This program is designed to estimate bycatch through direct observation. Canada has also implemented an observer program, although it is not user-funded. It is designed to estimate accurately the ratios of halibut bycatch to target species catches for the purpose of extrapolation to total bycatch.

A variety of measures to control and reduce bycatch mortality in the two countries have been implemented since the 1991 agreement. These include: bycatch caps or limits for areas and fisheries; time/area closures; bycatch performance standards for specific fishing gears; seasonal apportionment programs for bycatch caps to prolong fishing seasons; fishing gear modifications to reduce encounters of halibut; careful release programs involving grid sorting and manipulation of fish on hook gear; and, vessel incentive programs designed to reward fishing to lower bycatch levels, through access to additional target species' quotas.

The implementation of these measures has not been without controversy. They involve direct control of valuable groundfish fisheries and, particularly during the initial years of implementation, direct penalties in terms of forgone groundfish yield due to fishery closures as bycatch caps were reached. For example, in 1992 fishery closures associated with bycatch control resulted in forgone groundfish harvests of over 174,000 t in Alaskan waters. This economic cost to the groundfish industry represents a substantial proportion of the total worth of the halibut fishery. This comparison has fuelled intense debate on the merits of protecting a halibut fishery within the U.S. management system. It is some tribute to the resolve of both countries that adherence to the principles of the 1991 agreement has been maintained. The recognition that groundfish catches similar to those at present were harvest by foreign fleets in the mid-1980s with much lower halibut bycatch, has helped to support this resolve. Canada has explored similar approaches to fishery closures and the flavour of the economic tradeoffs involved can be seen in Table 6.

Table 6. Economic tradeoffs associated with potential closures of trawl fisheries off the west coast of Vancouver Island.

VANCOUVER ISLAND TRAWL FISHERY
(Based on 1976-1990 monthly averages)

	May	June	July	Area annual	Coast annual
Groundfish catch (t)	1195.0	1067.6	865.6	8188.3	26016.3
Halibut mortality (000 lb)	112.1	101.9	82.4	384.2	1208.5
% of AREA groundfish annual total	14.7	13.2	10.7	38.5	12.0
% of AREA halibut annual total	29.1	26.5	21.4	77.1	24.5
% of COAST groundfish annual total	4.6	4.1	3.3		
% of COAST halibut annual total	9.3	8.4	6.8		
Value of groundfish ($0.34/lb)	$0.896M	$0.800M	$0.649M		
Value of halibut ($2.50/lb)	$0.280M	$0.255M	$0.206M		

There have also been significant costs to the implementation of bycatch reduction that were not recognized explicitly at the beginning of the program. Aside from observer programs costing millions of dollars, catch monitoring programs, enforcement and prosecution, and the research required to evaluate reduction measures (e.g. physiology research and tagging programs to estimate viability of discarded fish) have resulted in substantial costs in the program of bycatch reduction.

Progress on Bycatch Reduction

Coastwide halibut bycatch mortality declined from a high of 18.101 Mlb in 1990 to 15.189 Mlb in 1993. Some of this decline resulted from changes to our estimates of discard mortality rates for bycaught fish, and the remainder from lower actual catches of halibut. Discard mortality was reduced through modified fishing practices and improved estimation of halibut condition resulting from observer data. However, in 1994 coastwide bycatch mortality again rose, to 15.996 Mlb, in spite of a reduction in Canadian bycatch mortality from 1.661 to 1.305 Mlb over the same period. The lack of adherence to U.S. mortality caps resulted largely from difficulties in projecting closure dates for trawl fisheries due to large variability in fleet composition, and higher than estimated incidence rates in rock sole and turbot fisheries.

Future progress on bycatch reduction is somewhat uncertain, although both countries have reaffirmed their commitment to the 1991 agreement. There are presently no measures to reduce bycatch mortality caps in Alaskan waters before U.S. management agencies. Canada remains committed to achieving a 1.0 Mlb bycatch mortality limit by 1997 and has implemented a mortality cap in Hecate Strait for 1995. This will be followed by additional caps for the west coast of Vancouver Island and Queen Charlotte Sound as required in 1996 and 1997.

Lessons from the Halibut Bycatch Reduction Program

A number of important lessons have emerged from the joint efforts of the United States and Canada to reduce halibut bycatch mortality. Perhaps the single most important lesson is that a recognition of the need for change must be established in the minds of regulators. If management agencies do not share user groups' perceptions of the need to reduce bycatch, implementation of programs will be delayed or frustrated at every potential occasion.

Another important lesson is that we cannot have everything. That is, achievement of the goal of bycatch reduction requires recognition that bycatch mortality cannot be reduced to zero without elimination of some other fisheries. It will clearly be unacceptable to eliminate groundfish fisheries solely to eliminate bycatch mortality for halibut. Participants in all fisheries must be willing to accommodate the needs of other sectors if progress is to be made. However, participants must also acknowledge that halibut bycatch is presently higher than it needs to be in order to harvest the full groundfish quotas. Decisions on bycatch control measures involve millions of dollars worth of halibut and groundfish harvests, and proponents of particular measures can be expected to be well-funded and persistent in supporting measures they favour.

This persistence will translate into prolonged lobbying of management agencies for desired results. Efforts to effect change will therefore be most effective if they are pursued within a joint optimization framework for target and non-target species.

The information that is necessary to evaluate alternative measures is highly detailed and analyses may be complex. Collection and analyses of these data will be correspondingly expensive and user groups can expect to bear some or all of the costs for these programs. These "hidden" costs to implementation of bycatch control, and the need to generate the regulatory authority to recover these costs, have been a significant component of the difficulty in reducing bycatch mortality.

Finally, the efforts to reduce bycatch mortality have been extremely slow in large measure because it has been difficult to implement reduction measures that incorporate individual responsibility for bycatches. Most of the measures that have been implemented have been applied at the level of entire fleets or gear sectors. Many of these measures have foundered on the reality that fleets do not act in the best interests of individuals. The absence of mechanisms to effect control and reduction measures, and more importantly to provide incentives, at the individual vessel level was an important element in the slow progress achieved in the initial stages of the halibut bycatch control program. Regulators have now recognized that embedding individual responsibility in such programs is often the most important prerequisite to success.

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THE IMPLICATIONS OF VOLUNTARY AND REGULATORY SOLUTIONS TO BYCATCH AND DISCARD IN THE ROCK SOLE FISHERY

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ABSTRACT

Approximately 65% of the catch by weight in the Bering Sea and Aleutian Islands (BSAI) rocksole fishery was discarded last year. Rocksole is targeted for its roe although the flesh of large rocksole is utilized. Discard is motivated by the fact that small rocksole lack roe and command very low prices. Production costs for small rocksole would exceed revenues even for the most efficient trawlers.

The rocksole stock and stocks of bycatch species are all believed to be healthy according to stock assessments. The allowable biological catch (ABC) for rocksole was 313,000 mt in 1993, but the total allowable catch (TAC) was set at 75,000 because of a two million mt ecosystem removal cap. Only 60% of the rocksole TAC was taken in 1993 because the bycatch allowance for Pacific halibut was taken before the TAC was met. Thus the bycatch/discard problem in this fishery is not overfishing of rocksole or bycatch species, but a perceived resource waste issue.

This presentation will discuss resource waste and mandated full utilization which would reduce efficiency and bring about economic losses. Three proposed bycatch/discard solutions will be outlined as they relate to the rocksole fishery. The first is an industry proposal to increase mesh size. The second proposal, called "Harvest Priority", is billed as a reward program. It would take away fishing time from vessels whose bycatch rates exceed an industry-proposed standard by gear and area. Fishing would still be conducted in a common property race for fish. The final proposed solution is an individual transferable quota system (ITQ) with tradable rights to bycatch species. The bycatch/discard reduction mechanism of the ITQ is expected to result from elimination of the common property race and the potential for rights to flow to harvesters who fish with the lowest bycatch. In addition, the ITQ proposes gradual reductions in ITQs for bycatch species when ITQ shares are transferred.

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Bycatch and discard will likely be the primary focus for fisheries management for the remainder of this decade. Of great concern, from the perspective of the fishing industry, is that the issue of bycatch and discard is being oversimplified and the facts are being misrepresented in a wholesale manner. For one, due to erroneous statements and the lack of a thorough and unbiased treatment of the issue, bycatch and discard are generally construed to be related to or associated with overfishing. As a consequence, for the average person who follows environmental concerns, a thematic link exists between bycatch, discard, and overfishing. There are, however, significant departures from this convenient rule of thumb of "they're wiping it out and they're wasting it all" that certain environmental groups contend.

One very large departure to this rule of thumb is in the largest fisheries in the United States, the fisheries of the North Pacific: the Gulf of Alaska and the Eastern Bering Sea. Biological assessments of the fishery resources in the North Pacific confirm that overfishing is not occurring for most species. Yet in Bering Sea and Gulf of Alaska fisheries, bycatch and discard in terms of tonnage are relatively high, by virtue of the magnitude of the fisheries in the region. To complicate matters, data from an independent fishery observer program in the North Pacific show that bycatch rates per ton produced are generally low compared to other United States fisheries or fisheries around the world (NRC, 1994). This serves to muddy what some environmentalists want the public to believe. In fact, the more the public learns about the fisheries of the North Pacific, the more complicated the issues and tradeoffs are likely become.

Why focus on the Rock Sole Fishery?

As attention has been focussed on what advocacy groups are calling "waste" in the North Pacific, the fishery for rock sole (*Pleuronectes* *bilineatus*) in the Bering Sea/Aleutian Islands (BS/AI) has received a great deal of scrutiny. One reason is that in 1993, approximately 65% of the groundfish brought on board in the fishery was discarded. This is the highest discard rate for a trawl fishery in the North Pacific. In fact, it is four times higher than the average discard rate for trawl fisheries in the Bering Sea in 1993 (Pacific Associates, 1994).

This paper focuses on rock sole because it is a North Pacific fishery where bycatch is large in absolute terms as well as in terms of a rate per ton. The rock sole fishery is exceptional for the North Pacific because, in some ways, it does fit the mold of what environmentalists contend is occurring in the North Pacific. On the other hand, the link between overfishing and bycatch espoused by the environmental group does not fit the rock sole fishery and really fits none of the North Pacific fisheries at all. Through this discussion of the rock sole fishery, it is hoped that the reader's appreciation for the complexity of the bycatch/discard issue, its causes, and the tradeoffs involved with potential "solutions" will be enriched.

The Rock Sole Fishery

Although rock sole is a relatively insignificant fishery in the BS/AI management area in terms of tonnage, comprising only 5% of the overall BS/AI trawl catch in 1993, the 65% discard rate in the fishery does bring the fishery to the forefront in terms of potential regulatory fixes to the bycatch/discard issue. In contrast, the midwater pollock (Theragra chalgogramma) trawl fishery in the Eastern Bering Sea accounted for 1.3 million metric tons in 1993 (67% of overall BS/AI landings), and only 49,000 metric tons of this have been discarded (a discard rate of four percent).

The rock sole fishery produced approximately 22,400 metric tons of retained landings of rock sole in 1993, worth approximately $34 million dollars at the first wholesale level. Roe rock sole was the principle component of revenue from the fishery. Roe rock sole are typically frozen whole or headed and eviscerated with the roe left in the body cavity. Roe is removed from fish when secondary processing occurs. Most roe rock sole is exported to Japan. The flesh of the rock sole is consumed separately after the roe is removed.

Approximately 25 vessels targeted roe rock sole in 1994. All of these vessels were trawl catcher/processors and most of these boats were at-sea processors that head, eviscerate, and freeze product on board. Vessel lengths typically range from 140 to 250 feet, which is considerably smaller than catcher/processors with more sophisticated processing capability.

To understand the fishery, it must first be recognized that rock sole are targeted principally during a four to six week period from January 20 to the beginning of March. During that time, the fishery is an Olympic style fishery wherein fishermen compete for rock sole before the prohibited species bycatch caps (PSCs) for halibut or red king crab are exhausted or the prime roe period is over, the former being more likely to occur before the latter. The total allowable catch limit for rock sole does not drive the race for fish in the fishery because prohibited species caps and other management regulations generally mean that the rock sole fishery is closed long before the total allowable catch limit is met.

Female rock sole with the highest recovery rate of roe receive the highest prices and females without roe and male rock sole command relatively low prices. Even during the peak of the roe rock sole period, catches include rock sole without roe, Pacific cod, pollock, and flatfish other than rock sole (flathead sole, rex sole, yellowfin sole, Alaska plaice etc.). In addition, considerable quantities of other species that are generally considered to have no or very low commercial value such as skates, rays, demersal sharks, and arrowtooth flounder are taken.

With the race for rock sole before the king crab or halibut prohibited species catch limits are met, fishermen generally process only the highest-valued species which can mean only roe rock sole or roe rock sole and Pacific cod and some large flatfish other than rock sole. Although distasteful to some, this is economically rational behavior because to fill freezer space with species other than roe rock sole could mean that the vessel would have to offload processed product earlier and might not be able to return to the fishing grounds before the season was over. Even if freezer space were not critical in terms of having to offload and thus forfeiting a second roe rock sole trip, retaining these other species would result in lost fishing time during the window of time when the fishery is open and rock sole roe recovery and quality is high.

Another mitigating factor in the decision to retain or discard Pacific cod and other round fish species with commercial value is that round fish are frequently in less-than-optimal condition when captured in conjunction with flatfish. This is due to the abusiveness of flatfish skin.

What drives the impetus to discard non-roe rock sole and other species in the rock sole fishery is the derby nature of the fishery and the sheer magnitude of price differentials for the species in the flatfish complex that are taken while targeting rock sole (Table 1). Prices for non-roe rock sole can be as little as one-third to one-fourth that of roe rock sole and Pacific cod is generally less than half the price of roe rock sole.

Rock Sole Industry Initiatives to Decrease Discard in the Fishery

Table 1: Wholesale prices for species landed in the rock sole fishery, FOB Dutch harbor

Species	Price
roe rock sole	1.05
rock sole (S-L)	0.40
Pacific cod (H+G)	0.55
pollock (H+G #2)	0.25
Alaska plaice	0.25
flathead sole	0.45
yellowfin sole	0.25

(average wholesale prices from industry data)

Mesh Size

A potential means of increasing the retention percentage in the fishery is to increase codend mesh size so that at least more of the small rock sole and other groundfish escape through the net webbing. Some of these fish would presumably survive. If increased net mesh works to allow unwanted fish to escape, this would make the percentage of roe rock sole in the catch greater.

In July of 1994, industry requested that the North Pacific Fishery Management Council (NPFMC) develop regulations to require a six inch square mesh panel in the top portion of net codends. According to an industry survey, most rock sole fishing currently occurs with codend mesh openings of four to five inches and codends are mostly double-walled. Double-walled codends further restrict the size of net mesh openings.

If larger mesh serves to avoid catches that will later be discarded, then it is logical to ask why the fishing industry would not have already increased the size of the mesh voluntarily. The answer is that an unfortunate side effect of existing regulations designed to control bycatch under the Vessel Incentive Program (VIP) set standards of prohibited species (PSCs) catch rates in terms of percentages of total weight caught. This means, for instance, that the halibut VIP rate which could trigger a violation is based on the number of halibut per ton of total catch, not retained catch. Assuming the same number of halibut per tow, a fishing operation that excluded catches of small fish by using larger mesh could be in violation because the actual halibut rate might exceed the VIP standard rate. Had the larger mesh codend not been used, the same tow might not have been in violation. Under this regulatory regime, small rock sole and other fish thus serve as ballast and any change in mesh would have to be accompanied by a change in VIP standard rate.

In December of 1994, the North Pacific Fishery Management Council approved the increase in mesh size for the rock sole fishery but this change, assuming prompt consideration and approval by the Secretary of Commerce, cannot be in place for the upcoming fishery in the winter/spring of 1995. In spite of this, many members of the rock sole fishery appear willing to increase mesh size to six inches throughout their codends without a regulation in place and lacking a change in the VIP standard rate. This could result is a dramatic increase in VIP violations if cases are prosecuted. Some in the industry see the move to larger mesh nets as the one of the few available avenues for the fishery to reduce its discards and therefore improve its public image given the current regulatory regime.

Proposed Industry Initiative to Increase Retention

Another means of increasing retention in the fishery is to retain more of the catch that is currently being discarded. This could be done on a voluntary basis to respond to public criticism of "waste" in the rock sole fishery. In September of 1994, rock sole fishermen agreed upon an industry-wide rock sole initiative to increase retention in the fishery by thirty percent in 1995. Several rock sole participants have stated that thirty percent is probably the maximum increase in retention that is possible in the short run given the economic conditions facing the industry and the expectation of continued open-access management.

Lack of defined individual allocations under open access continues the race for fish which creates the incentives to fish as fast as possible. This means that fish of lesser value cannot be processed economically because the fishery is driven to process as much of the high-value product before one of the PSC caps is met and the fishery closes. Some of the economic effects of this proposal to increase retention under the Olympic fishery are evaluated below.

Seen on a per trip basis, increasing retention by thirty percent would have large effects on the exvessel trip revenue and possibly make the fishing unprofitable for marginal participants. Assuming that a typical vessel has a freezer capacity of 300,000 pounds of processed product, the goal of increasing retention by 30% would mean that a vessel would, on average, have to increase its retention percentage from 35% to 46%, an net increase in retention of 11%. If a vessel retained only roe rock sole before, on a 300,000 trip approximately 33,000 pounds of non-roe rock sole would have to be processed and retained.

On a first wholesale basis ("freight on board" (FOB) Dutch Harbor), if a firm decided to retain Pacific cod, a logical choice given its price relative to other candidates, then the gross revenue loss of approximately $0.50 per pound would occur for every pound of processed cod retained . This is based on an average first wholesale (headed and gutted) cod price of $0.55 and an average roe rock sole price of $1.05 for frozen (round, ungraded) product. Under these assumptions, gross revenue would decrease by $16,500 per trip. Assuming there are 25 vessels fishing next year and that each vessel make two or three trips during the roe season, the loss of gross revenue that can be expected from the industry initiative is approximately $825,000 to $1.23 million for the rock sole roe season.

Proportionally larger decreases in gross revenue could be expected for every unit increase in percentage retention beyond 46% that the industry has proposed. This is because fishing operations will first select the fish that have the value closest to that of roe rock sole. If cod are the most likely to be retained, then the cod with the highest value will be retained first. Next cod damaged by contact with flatfish would be a candidate, or other flatfish species that command relatively high prices to minimize the loss of revenue to the vessel. If the retention percentage were significantly increased, then small rock sole without roe will have to be retained and effects this would have on revenue losses would be very significant.

The impacts of increasing retention would have on the rock sole fleet should not be viewed in a vacuum because many vessels are at or just above the break even point at this time. To appreciate the effects of such a decrease in gross revenue, one has to understand that catcher/processors typically fish in high volume, low profit margin fisheries. Vessels work on tight profit margins because fishing in the Bering Sea involves high fishing costs due to the remoteness of operations, large travel distances to offload points, fishing conditions that are harsh and expensive, and what can be described as high variable cost structures of at-sea processing operations in general.

The Potential Benefits of Increased Retention in the Rock Sole Fishery

The potential benefits of decreasing bycatch and discard can be evaluated in terms of resource conservation, ecosystem effects, consumer benefits, and improvement in public perception. In theory, these benefits could be realized if the percent retained in the fishery is increased or fishing methods are better able to target roe rock sole so that bycatches do not occur.

Although expectations for these types of benefits are reasonable, in the particular case of the rock sole fishery, and other North Pacific fisheries where exploitation rates are very low, whether there are biological benefits from decreasing bycatch and discard is debatable. There may be ecosystem effects but whether these would be positive or negative depends on how criteria are defined and whether exploitation rates that currently occur from the rock sole fishery significantly impact fish stocks at all.
Overall, the main benefit of increased retention or improved targeting of roe rock sole is likely to be improved public image for the rock sole fishery. This is because fishing mortalities overall on rock sole and the other species bycaught in the fishery are extremely low and there are probably no tangible stock conservation benefits to improving the ability to target female rock sole from male rock sole or other members of the flatfish and roundfish species complex.
The effective annual exploitation rate on the rock sole population is less than four percent and the population has been growing steadily over the last decade (Figures 1+2). The same is true for other flatfish that comprise most of the bycatch in the fishery such as flathead sole, yellowfin sole, rex sole, and Alaska plaice according to stock assessments (USDOC, 1994). The biomass increase in recent years for rock sole is slightly more dramatic than has occurred for yellowfin sole and other flatfish species that are commonly bycaught in the rock sole fishery, but overall, the biomass of flatfish is thought to be increasing to historically high levels (USDOC, 1994). Exploitation rates for other flatfish are generally similar or lower than that for rock sole (USDOC, 1994).

Decreasing catches of prohibited species such as red king crab and halibut affect the amount of target catch that can be produced in the rock sole fishery but probably have no tangible effect on crab and halibut stocks. This is because halibut and crab PSC caps are very low in terms of the percentage of the biomass that the cap comprises. For red king crab, for instance, the red king crab PSC limit for the rock sole fishery represents less than one-fourth of one percent of the red king crab population (population size as of 1994). Fluctuation in crab stocks affects this percentage but caps are designed to be a small fraction of the biomass, and in essence, and percentage that is a fraction of the measurement error in the assessment of stock biomass (see NPFMC, 1992).

Pollock and cod are the principle round fish bycaught in the rock sole fishery. A large increase in biomass has occurred for Pacific cod in recent years and the status of the pollock stock is thought to be excellent (USDOC, 1994). Fishing mortality on cod and pollock that results from the rock sole fishery is only a small percentage of overall mortality on these species. As is the case for all fishery management in the North Pacific, the mortality from the rock sole fishery is accounted for when allowable biological catch (ABC) and total allowable catch (TAC) limits are set for these species. So there is little in the way of a biological evidence that fish stocks bycaught in the rock sole fishery would be in better health if bycatch were reduced or eliminated in the rock sole fishery.

One could argue that consumers forfeit the available source of edible protein when bycatch is discarded and hence not brought to the consumer. This argument, however, must first recognize that only a portion of these bycatches are on adult fish of market size, i.e. of a size that consumers would be willing to eat. Where bycatch is of juveniles of commercially important species, the impact on consumers, the fishing industry, and value from the nation's natural resources as a whole must be evaluated as the discounted future revenues from those fish, and after the effects of natural mortality are accounted for. This is particularly true when the resource is healthy, as is the case for the bycatch species in the rock sole fishery because future stock conditions are not jeopardized by removals as bycatch or as directed fishing. In the North Pacific, allowable fishing levels take into account both directed fishing and bycatch.
Another consideration in assessing the value of fish taken as bycatch versus taken by directed fishing is that, just like mandating high levels of retention, avoiding bycatch is not without costs to the efficiency of fishing operations. Analytically, the cost of avoiding bycatch must be compared to the net future benefits (i.e. discounted at some relevant discount rate) from juvenile fish to understand the tradeoffs fully. This cost benefit comparison would also involve the effects of natural mortality on the future

benefit of juvenile fish over the interim period. When overall fishing mortality is low and stocks are increasing, removals of juvenile fish bycaught in the rock sole fishery may have little measurable effect on stock conditions. Yet avoiding capturing those juvenile fish is expensive. If this were not the case, then the fishing operation would have done so in the first place. When unwanted catches occur, fishing operations incur the cost of sorting and discarding which involves time and labor costs.

When evaluating the effects of regulations or initiatives that require increased utilization of the catch, another consideration is that in many cases, it would cost more to the fishing operation to produce something out of these catches than the catches themselves could be sold for. This would likely be the case for skates, rays, sharks, or cod and pollock that are damaged because they are brought up in the codend with flatfish. In this case, operating losses from mandating utilization of non-economic species and damaged fish would have to be passed on to the products that are produced, i.e. higher prices and potential losses of consumer benefit.

For adult cod and pollock that are not damaged, and for the flatfish species for which markets exist but price differentials tend to motivate discard rather than retention in the rock sole fishery, fishing operations may be able to process and retain these catches without incurring deadweight losses. The loss in this case is the opportunity cost of sacrificed rock sole with roe earnings compared to lower earnings through retention and processing of lower-valued species. Devoting limited hold space to other species when the roe season lasts approximately six weeks could impose large profit losses for some operations. From the perspective of economics, regulations that require increased retention are mandate reduced profits are difficult to justify where measurable biological benefits are not created, or those biological benefits created are negligible.

One could argue that consumer benefits and tax basis would be created if these species are produced for the domestic market. On the other hand, consumer benefits and tax basis are created from export earnings when companies that produce roe rock sole are allowed to maximize profits. Profits are taxable and export earnings are recirculated through the domestic economy.

Concluding Thoughts

Fishing companies that participate in the rock sole fishery have volunteered to increase retention by 30% for the coming season. This may not satisfy public perceptions but, according to the industry, this is a considerable first step considering the inherent tradeoffs and the economic health of the industry. An important consideration is that lack a concrete model to systematically compare economic losses to benefits of increased retention in the fishery. A defined objective that clarifies why bycatch and discard are a consideration when fishing exploitation rates are so low is also lacking. A careful, stepwise approach is probably warranted under these circumstances, rather than an emotional approach that seeks to "solve" the problem in a very short period of time. For instance, a measured approach might evaluate available evidence of economic performance in the fishery as retention standards or bycatch restrictions are gradually increased.
A reasonable schedule of increases in retention known to industry participants in advance could facilitate this transition by allowing the gradual development of markets for lower-value species or allowing participants with a less ability to process and market low margin species to find other fishing or business opportunities. Such a measured approach would at least minimize economic disruptions should policy makers conclude that retention is a more important objective than economic performance, employment, export earnings, and other economic factors.

A potential long run solution that would increase the ability to utilize low-valued species under an increased retention standard is to slow the race for fish that currently occurs in the roe rock sole fishery. Some critics contend that mandating retention will already slow the fishery down, but that approach does so at a maximum cost to economic efficiency. A more reasonable approach would be to break the incentives to race for fish by allocating individual fishing allotments of prohibited species catches for halibut and crab species. This would allow individual fishing operations to fish at a pace that is better able to avoid prohibited species catches. This approach provides a means of avoiding the impetus to fish as fast as possible before the total prohibited species cap is met and the fishery closes, as currently occurs.

With individual allotments of bycatch of PSCs, operations may be able to slow down there fishing pace and not incur the costs created by the externality of being affected by other fishery participants' bycatch behavior in the face of a total overall cap for the fishery. Loss of revenue from a premature closure of the rock sole fishery by other fishing operations would no longer be a possibility because the costs of fishing indiscriminately would be internalized by fishing operations that cannot fish cleanly, rather than externalized to the whole fleet. With individual bycatch allotments, firms may be able to adjust to a higher retention standard with far less economic cost to the industry and the nation than if the retention standard alone was required. Individual bycatch quotas have been attempted in the high seas purse seine fishery for yellowfin and skipjack tuna with some success. That program has accomplished some individual accountability and allowed fishermen to make adjustments in fishing practices without facing externalities of a fleet-wide closure as a total cap is attained. That approach has also effectively removed the worst offenders in terms of bycatch from the fishery.

A controversial but potentially promising means of making individual bycatch quotas effective for rock sole would be to make quotas tradable. Such a system could allow more target catch per unit of bycatch or perhaps the same directed catch with far less bycatch. Both of these are economically efficient outcomes. The mechanism that allows achievement of improved utilization efficiently is a market for bycatch shares. Such a market would tend to allocate rights to those who fish with lower bycatch rates because those individuals would be able to catch more directed catch per unit of bycatch. Thus trading bycatch shares would allow bycatch units to flow to those who make best economic use of the bycatch.

Some environmental groups oppose this approach as a potential solution because they believe rights would flow to entities with high bycatch rates and a greater ability to pay for bycatch rights. This argument ignores the fact that, in the long run, firms that catch lower amounts of target catch per unit of bycatch will be unprofitable and exit the fishery. The willingness to pay for bycatch rights by firms that fish cleanly will represent a huge opportunity cost for rights held initially by firms that cannot fish with low bycatch rates.

Markets to efficiently allocate effluent rights are currently being used in regulation of pollution in the manufacturing industry. Experience with that approach may some day convince environmental groups of the merits of market-based approaches to environmental and resource management.

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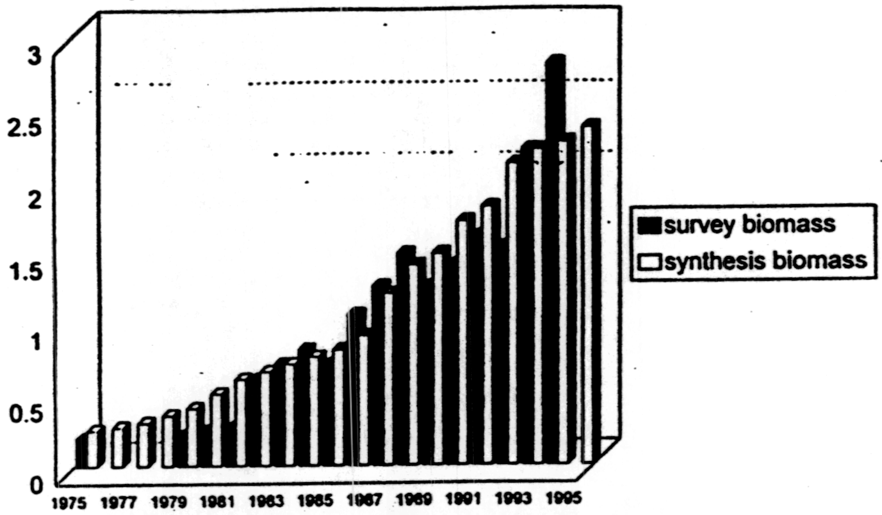
FIGURE 1: Eastern Bering Sea Rock Sole

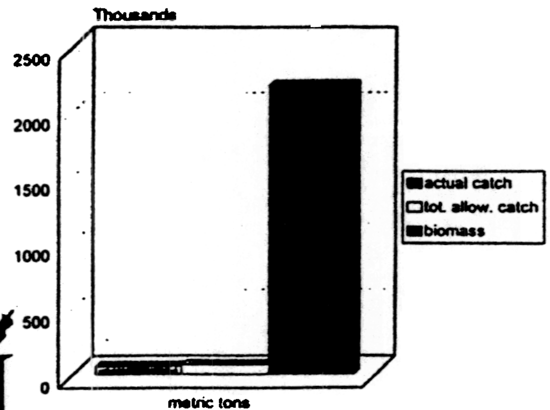
biomass trends 1975-1994



source:N.M.F.S. 1995 "Stock Assessment and Fishery Evaluation" (SAFE) Report

Figure 2. EXPLOITATION RATE FOR ROCK SOLE IN THE EASTERN BERING SEA

note. actual catch of rock sole is less than 3% of the estimated biomass in 1994. Rock sole TAC is set at a low level because of the 2 million metric ton(ecosystem) cap on BS/AI removals and the industry's preference for pollock



source NMFS SAFE Report, NMFS Final Specifications for the Groundfish Fisheries of the Bering Sea Aleutian Islands (1994)