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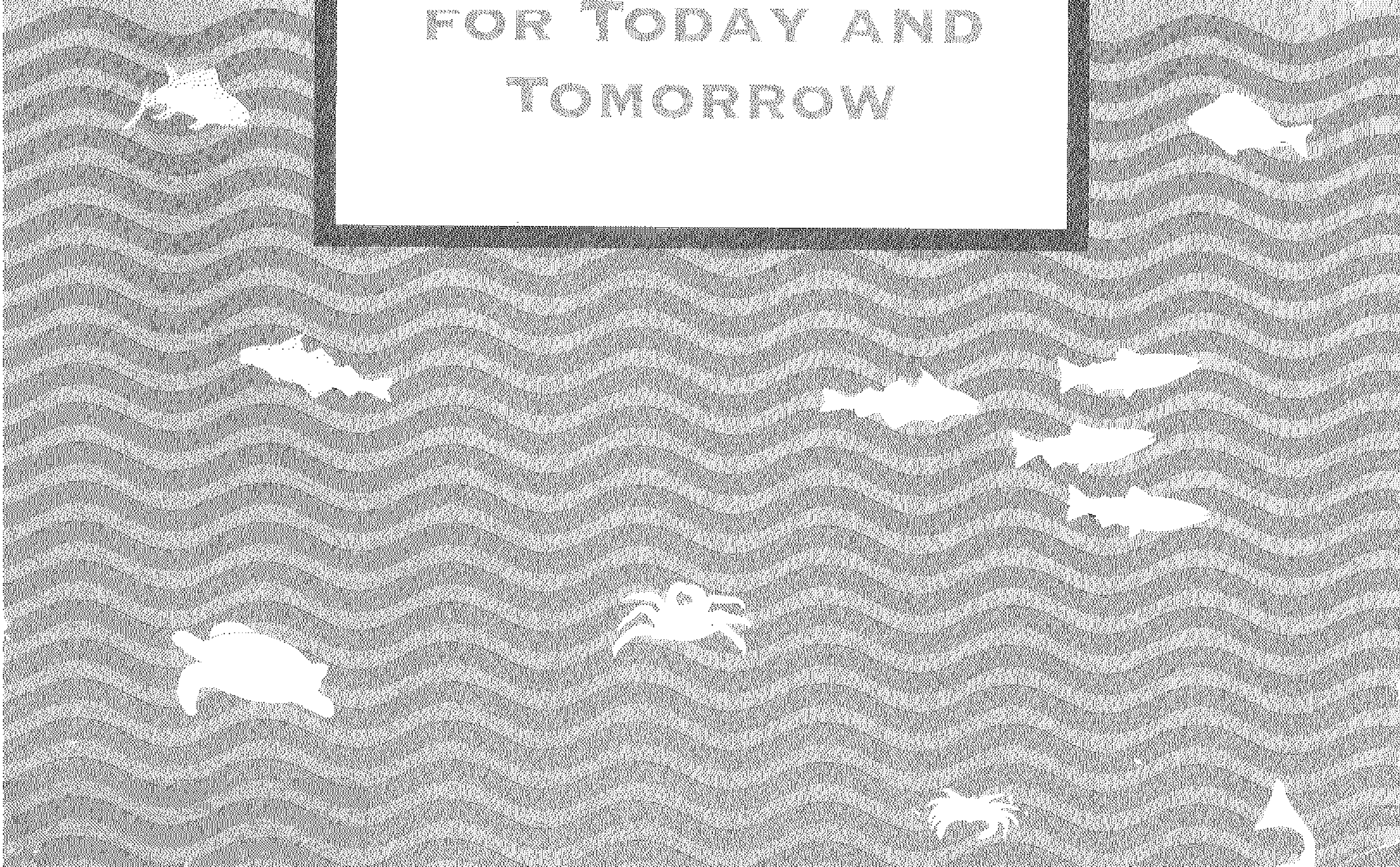
Solving Bycatch

Considerations for Today and Tomorrow



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SOLVING BYCATCH

CONSIDERATIONS FOR TODAY AND TOMORROW

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Alaska Sea Grant College Program
University of Alaska Fairbanks
Fairbanks, AK 99775-5040

Fax (907) 474-6285
E-mail FYPUBS@aurora.alaska.edu

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Acknowledgments

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Robert Alverson, West Coast Co-chairman, Fishing Vessel Owners Association, Inc., Seattle, WA
Steven A. Murawski, East Coast Co-chairman, National Marine Fisheries Service, Woods Hole, MA
Dayton L. Alverson, Natural Resources Consultants, Inc., Seattle, WA
James Cook, Pacific Ocean Producers, Honolulu, HI
Steve Davis, LGL Alaska Research Associates, Anchorage, AK
Paul Dayton, Scripps Institution of Oceanography, La Jolla, CA
Martin A. Hall, Inter-American Tropical Tuna Commission, La Jolla, CA
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WorkBoat
World Wildlife Fund

Preface

The Solving Bycatch Workshop: Considerations for Today and Tomorrow, started as a vision for the future and has become a reality today. Likewise, the visions we create today will become our tomorrow.

As we began to organize the workshop, we set goals for the workshop to work toward and eventually achieve. These goals can only be met by all of us working together as a united force. This is the first bycatch workshop where all of the individual fisheries are creating solutions for their own fishery, and working as a whole with other interested groups to reach our goals.

On behalf of the Steering Committee, I thank everyone who participated in making this workshop a success.

Workshop Goals

- To provide a workshop where fishermen can obtain world-class knowledge on reducing bycatch by using fishing techniques and gear devices resulting from the research of domestic and international industry, government, and academic organizations.
- To stimulate world-class research and development designed to bring about bycatch reduction.
- To create an arena for development of public/private partnerships for expansion and transfer of environmental technology.
- To create an arena for building and implementing new information technology and networks.
- To promote global environmental stewardship for the conservation and wise management of U.S. marine and coastal resources in order to ensure and enhance sustainable economic opportunities.
- To require and incorporate innovation, cooperation, and partnerships.
- To orient the program toward results that will be of significant short and long term benefit to the industry and the public.
- To promote research needed to realize technical solutions.

Mary Sue Lonnevik
Workshop Coordinator
Universal Plans, Inc.

Summary

Tom Wray
Technical Editor, Fishing News International, 12 Beech Road, Elloughton, Brough, East Yorkshire, HU15 1JX, United Kingdom

The Solving Bycatch: Considerations for Today and Tomorrow workshop held over three days in September, 1995 in Seattle, Washington, USA, was remarkable for a number of reasons.

Not only did it bring together over 260 participants from a wide variety of backgrounds, but it was sponsored by many private organizations as well as by government bodies: U.S. National Marine Fisheries Service, the Packard Foundation, fishing gear and marine electronics manufacturers, fishery management foundations, fishing companies and seafood processors, the tuna and halibut commissions, research associates, universities, banks, fisheries development associations, the fishing media, and more.

The workshop had two important objectives: (1) to review recent developments in bycatch reduction, and (2) promote dialogue on research and policy goals for the future.

Participants in the workshop included fishermen, fish processors, gear technologists, manufacturers of fishing gear, researchers, administrators, attorneys, engineers, environmentalists, consultants, fisheries managers and enforcement personnel.

Fishermen will have to lead the way in the development of improved or alternative ways of fishing, and it was good to see several owners and operators of fishing vessels make presentations at the workshop. These included excellent talks on achieving new objectives by innovative trawl footrope and net configurations, a management perspective of midwater trawls and Alaska pollock, and a fisherman's perspective of bycatch and the Individual Fishing Quota (IFQ) system in the Alaskan long-line fisheries.

All the main gear types were discussed at the workshop, and while its primary focus was on meeting the challenge of bycatch in U.S. fisheries, there were useful contributions from Australia, Canada, Japan, Norway, and the United Kingdom.

In her presentation on ecological impacts, Ms. Traci Romine of Greenpeace International talked on the perception and image of bycatch, by the public and by fishermen.

Bycatch considerations have become critical constraints on the prosecution and development of marine fisheries in the nation and the world, pointed out Dr. Steven A. Murawski of the Northeast Fisheries Science Center, NMFS, Woods Hole, Massachusetts, in the workshop's opening session.

He pointed out that since the first National Industry Bycatch Workshop, held in Newport, Oregon, in 1992, there has been considerable gear-based research in the USA, supported by industry, associations, and government partnerships.

However, much remains to be done. Regulatory schemes that encourage innovation and responsibility through incentives for bycatch reduction, and discourage those who jeopardize personal and collective fishing opportunities through disincentives, must be implemented.

Dr. Dayton L. Alverson of Natural Resources Consultants Inc., Seattle, Washington, said that avoiding bycatch has undoubtedly been practiced by conscientious fishermen since long before the institutionalization of fisheries management.

There has also been formal national and international recognition that bycatch in many world fisheries constitutes an important waste and there are various conservation, ecological, and economic issues requiring the priority attention of managers. As with many fisheries management issues, generic discarding solutions that can be broadly applied geographically and to the general gear types, are unlikely.

In addition, the philosophical base for management may differ by region and nation. The easiest solution to discard problems resolving severe over-exploited species may be the reduction of fishing effort. Understanding the biological, economic, or other impacts of current fishing practices, and the implied consequences of change will be essential.

Dr. Martin A. Hall of the Inter-American Tropical Tuna Commission, La Jolla, California, said that experience of the eastern Pacific tuna fishery shows that bycatch problems can be tackled successfully, but that some conditions have to be met to reach a solution.

Dr. Hall emphasized the importance of including environmentalists in the interactions, and went on to discuss challenges for them. Dr. Hall said that environmental groups have played a "very significant role" in bringing issues to the attention of the public, issues which have proved decisive in generating laws and regulations that have been valuable in some cases in solving or mitigating ecological problems.

The proliferation of ecological problems, coupled with reduced government budgets, has resulted in a growing number of unresolved crises. "Environmental groups should become part of the solution to the problems rather than just denouncing them," said Dr. Hall. He believes this role could be fulfilled in many different ways, from funding research work to volunteer work. One of the more critical needs in solving bycatch problems is to bring the technical issues that need to be addressed to the attention of the general public and to solicit input toward solutions.

Hall said, "the role of involving the public in the challenge of finding solutions that can allow the continuous use of the resources, while at the same time mitigating or eliminating the bycatch problems, is one where environmental groups can be more effective than any other group involved."

Introduction

Robert Alverson
Fishing Vessel Owners Association, Inc., Fisherman's Terminal, Seattle, WA 98199

On behalf of Steve Murawski, the east coast co-chairman, and myself, the west coast co-chairman, I am privileged to welcome you to the Solving Bycatch Workshop: Considerations for Today and Tomorrow.

Our first bycatch workshop was held in Newport, Oregon in 1992 and had a mission of identifying, defining, and acknowledging the problems of bycatch. Since the Newport bycatch workshop, headlines in the domestic and international papers have carried feature stories on the problems and causes of bycatch. Just last week, the chairman of the House Resource Committee in Washington, D.C., Congressman Young, addressed his concerns, which were printed in the Congressional Register. His statement was as follows:

> In the North Pacific Groundfish Fishery alone, more than 740 million pounds of fish were discarded in 1993. This represents 16% of the total catch of the fishery. We hope that fishermen will respond with innovative methods of reducing bycatch. Professor Gunderson, from the University of Washington, has suggested that the rapid decline in groundfish stocks of Washington, Oregon, and California may be the result of unaccounted bycatch. A senior National Marine Fisheries Service representative indicated, at the Sitka Bycatch Workshop, that the New England Groundfish collapse was significantly the result of unaccounted juvenile bycatch. Bycatch can have both economic and environmental costs associated with it. Clearly, the fishing industries can benefit economically from the use of fishing methods that enable greater utilization of the target resources. When you look at the unprecedented number of fishing industry sponsorships of this workshop, it is clear that the industry recognizes the problem of bycatch and the need to resolve it. It is similarly clear that the managers must properly account for bycatch as part of any overall harvesting strategy, whether it is commercially induced or sports generated.

The first objective and mission of this workshop is to disseminate information on new management systems and gear technologies now being used and developed to reduce bycatch. National and international attention to bycatch has stimulated a growth industry within the gear manufacturing community to address significant areas of bycatch. In debating the type of presentations for this workshop, the steering committee wanted to achieve the objective of this workshop with an emphasis on show and tell—to tell about what the fisheries agencies are doing in the area of management to address bycatch, and to showcase the new gear designs and research that are helping to address bycatch concerns. As a result, we hope that additional research and development in designs of fishing gear, as well as management systems that bring about a reduction in bycatch, maximize the utilization of what is caught, and the minimization of ecological impacts will result. This workshop will feature a variety of national and international specialists in gear design and research from the academic community as well as from the harvesting and gear manufacturing industries. We have 50 speakers, 12 of whom represent the seven foreign countries of Australia, Brazil, Canada, Italy, Japan, Norway, and Scotland.

Thank you all for being here. Steve and I are pleased to have you join us in looking forward to the interesting and informative presentations and discussions planned for the next three days.

Meeting the Challenges of Bycatch: New Rules and New Tools

Steven A. Murawski
National Marine Fisheries Service, Northeast Fisheries Science Center, Woods Hole, MA 02543

Bycatch considerations have become critical constraints on the prosecution and development of marine fisheries in the nation and the world. Unless species and size selectivity of fishing techniques are improved, tough new rules will place additional requirements on existing fisheries or fisheries may be closed all together. In these circumstances, the industry will likely be unable to develop fisheries for the nation's few remaining underutilized resources. This workshop has two important objectives: (1) review recent developments in bycatch reduction, and (2) promote dialogue on research and policy goals for the future.

Since the first National Industry Bycatch Workshop, held in Newport, Oregon, there has been considerable gear-based research, supported by industry, associations, and government partnerships. Technical standards for evaluating bycatch reduction have been developed and applied in some situations. Bycatch monitoring programs have been expanded to include a widening array of fisheries and the nature and extent of the bycatch problem subjected to quantitative evaluation. This information has exonerated some fisheries, and excoriated others. Recently, more sophisticated real-time bycatch monitoring systems have been developed, with capabilities for information dissemination. However, much remains to be done. Although often assumed, specific goals for bycatch management have rarely been articulated. Development of goals is a necessary step if we are to measure our success in solving bycatch. New approaches to information sharing, and personal accountability to operate "cleanly" are challenges which must be faced. As well, the scientific community needs to define "how clean is clean-enough?" and to evaluate the consequences of bycatch reduction alternatives on species and ecosystems. Regulatory schemes that encourage innovation and responsibility through incentives for bycatch reduction and discourage those who jeopardize personal and collective fishing opportunities through disincentives, must be implemented.

Bycatch and discarding have captured the attention and scrutiny of interest groups and the public, unlike any single fisheries issue in recent memory. The perceived *waste* of potentially valuable fish, killing and harassment of protected species, and inefficient use of available resources have brought the issue of bycatch to the fore in all regions of the country and internationally. New rules to limit fisheries with significant bycatches have been enacted in several of the nation's fisheries, and more regulations will doubtlessly come. Reacting to the increased interest on the part of the media, regulators, and legislators, the U.S. fishing industry organized its first national bycatch workshop in February 1992 (Schoning et al. 1992). Since that time there have been a number of significant developments including regional workshops, primarily sponsored by the industry. In addition, increased funding and emphasis has resulted in the initiation of numerous research, monitoring, and bycatch mitigation efforts. The purpose of this workshop is twofold: (1) to update progress in research, policy development, and management of bycatches, and (2) further the dialogue on goals, strategies, and expectations for bycatch reduction.

Progress in Bycatch Management

Progress, in the intervening four years since the Newport bycatch workshop, has occurred on several critical fronts. Attention focused on the bycatch issue in the general, environmental, and trade media has promoted better understanding of what bycatch is, and why it occurs. Unfortunately, this exposure has not always been completely factual, and there have been instances where extreme, unusual, or incorrect data on the rates and magnitude of bycatches have been used to excoriate specific fisheries. Nevertheless, results from a variety of newly created at-sea observer programs have increased the amount of data available on the subject, and allowed managers and policy makers to proceed from a factual rather than anecdotal basis (e.g., U.S. Dept. Of Commerce 1995). Aggressive industry involvement in the documentation and search for workable mitigation measures for bycatch has occurred as a result of increased grants via federal and state programs for observer coverage and experimental gear development. In particular, funding through the Saltonstall-Kennedy Act, the MARFIN, and other mandated programs in the southeast, and the Fishing Industry Grants (FIG) program in the northeast, have provided significant research dollars spent on technology-based solutions to bycatch. The industry has self-funded observer programs, analysis of time/space variation in bycatch rates, and development of new types of gears to meet rigid performance criteria for bycatch reduction. New private and public services to apprise industry of bycatch rates occurring in some fisheries are now available.

Initiatives coordinated through various nonprofit foundations have brought together a critical mass of fishermen and their representative groups, environmentalists, and researchers. Funding provided by private foundations has been used to support conferences such as this, and a variety of research and education programs. Education initiatives have been developed to assure that technical know-how is provided along with workable gear-based solutions. Likewise, education efforts have been undertaken to apprise the public, legislators, and managers of the significance of bycatch and efforts currently under way to reduce it.

Legislative interest concerning bycatch issues has followed that of the media and the public (Stroud 1993). Various draft revisions to the Magnuson Fishery Conservation and Management Act (MFCMA) call for an eighth national standard ensuring that bycatch is explicitly considered in the fishery management process, and that all prudent measures are taken to minimize it. Likewise, recent amendments to the Marine Mammal Protection Act (MMPA) have stiffened measures to reduce bycatch mortalities of whales, dolphins, and pinnipeds in the nation's fisheries. Because of this legislative interest, elected officials have become more sensitive to the bycatch issues. The United States has restricted imports of fishery products from nations failing to incorporate bycatch reduction in several fisheries, so as not to penalize American fishermen for their conservation efforts.

Research on bycatch has become much more prominent. The "Alverson report" (Alverson et al. 1994) estimated, to the extent feasible, the worldwide magnitude of bycatch discards, and their fishery and regional variation. As much as anything, the report highlighted the lack of consistent information on the amounts of catch discarded, and the need for better fundamental understanding of the biological, economic, and technological antecedents of bycatch. The academic community has become more involved with bycatch research, and federal research on the issue has expanded. This report details the progress to date. Following is my assessment of goals for bycatch management and strategies for their attainment.

Goals for Bycatch Management

As the nature of the bycatch problem has come into sharper focus in recent years, it is increasingly apparent that we need to develop specific goals for bycatch management. For most fisheries, it is unlikely that we could ensure *zero* bycatch without full closures. Therefore, management strategies will necessarily involve trade-offs between mortalities on bycatch populations and the increased costs/reduced revenues incurred by specific fisheries. What should be the guiding principles of bycatch management? Some guidance is provided in the various statutes (e.g., MMPA, MFCMA, and ESA). However, the evaluation of management approaches relative to (often conflicting) multiple objectives has suffered from the lack of consensus on strategic goals for such a process (Pikitch 1988, Murawski 1991). Based on the extensive discussions and technical presentations made at this and similar industry and scientific meetings, a consensus list of goals for bycatch management is, however, beginning to emerge.

Approach Full Utilization of Our Resources

Regulatory-induced discards of otherwise marketable animals represents a loss of potential revenue to producers, and supply for consumers. These discards can occur because trip or cumulative bycatch quotas for a target species are exceeded, animals are too small to be sold or retained, or because possession of the species is banned all together. Often this problem is manifested in the bycatch discard of animals from one fishery which are the targets for others. In the extreme, competitive fisheries may lead to sub-optimal utilization due to excessive mortality on small individuals that haven't reached their growth potential, or quota that is left on the table (non-harvested allocation), due to exceeding bycatch caps on nontarget species. In order for us to optimize the production of our fishery resources, there must be renewed efforts to ensure that, to the extent practicable, resources are harvested efficiently, and in a sustainable manner. Minimizing bycatch discards will result in the ability to harvest nearer the maximum harvest rates for full utilization, while at the same time maximizing yields. The increasing diversity of fisheries and products has rendered many traditional single-product fisheries obsolete. Regulators are increasingly asking for management measures which result in segregation of targets from their bycatches, in order to reconcile the diverse fishing strategies occurring in particular areas. In many cases such alternatives are not feasible and tough choices among sectors must be faced.

Eliminate Over-Exploitation

Alverson et al. (1993) conclude that one of the major contributing factors to the significance of the bycatch problem is systemic overfishing. High rates of harvest result in reduced numbers of ages contributing to the catch. In the extreme, only one or two young ages may comprise the bulk of the catch and landings. In cases such as these, the dearth of optional species, or older fish, results in the fishery targeting young animals that generally have not optimized their growth potential (e.g., growth overfishing), often with considerable economic waste. Even more damaging is the instance where recruitment fisheries *target* year classes that are only partially legal size (resulting in a high proportion of discarded catch), and the catch of animals that are not mature. When recruitment is differentially targeted, a downward spiral in the stocks and landings occurs because of the lack of viable alternatives for the fishery. Clearly, by reducing overall harvest rates and rebuilding the populations, the effects of discards on the viability of fishery populations is diminished. When harvest rates are reduced, even if some bycatch persists, it is likely to have less impact on the populations and fisheries, and mitigating their effects may not have quite the political and social imperative as when stocks are grossly overfished.

Reduce Conflicts

One of the most difficult manifestations of the bycatch problem occurs in cases where one segment of the fishery is pitted against another in competition for the bycatch species. Clearly, reducing bycatch rates to zero eliminates such conflicts (or at least changes their basis). However, such solutions have proved frustratingly unfeasible. A more realistic goal of management may be to minimize bycatch rates to the extent technically feasible, and then assess the resultant impact of the fishery in a biological and economic context, including all caught species and interacting fisheries. If we can define minimum acceptable bycatch magnitudes, then one potential arena for reducing inter-group conflict is direct negotiation among valid stakeholders. When coupled with the expectations that conservation sacrifices ultimately will translate into personal benefits, the case for mutual cooperation becomes more attractive. In the past, allocation of bycatches among sectors has been done by the regulators, with the sectors vying to occupy the "high ground" in such deliberations. The race for fish in fisheries regulated by total TAC and/or effort quotas has rendered bycatch mitigation as a secondary personal objective to maximizing catch. Allocative mechanisms that reward clean fishing practices have not generally been considered, although some punitive schemes for dirty fishing have been tried or proposed. Cooperation on gear design, sharing of knowledge of bycatch hot spots, and minimizing gear conflicts are but three potential benefits of approaches that reduce competition and conflict among sectors and individuals.

Separate Fact from Fiction

Resolution of bycatch issues is thwarted by unsupported claims of excessive discards, or by denials. In the absence of credible data—available to all parties and the public—media and interest groups tend to engage in hyperbole. Such tactics are troubling because they trivialize or sensationalize the issue, and they may create momentum for a single, often extreme, policy option as the only "viable" solution to the problem. Resolution lies partly in the collection, analysis, and timely distribution of credible information to all groups. Great strides have been made in recent years to develop databases from impartial at-sea observations of catches. In general, these programs have great visibility, are viewed with some degree of trust by fishermen, and have collected information with standard measurement protocols on trips selected according to some design scheme. Except for a few instances, observer programs sample only a small fraction of the total effort in a fishery, and may involve significant expense to either the vessel or the government, depending on the source of funds. Thus, the question of how representative the sampled trips are of all fishing trips undertaken by the fleet often arises. Furthermore, given the expense of such programs, they are not routine for the diversity of the nation's fisheries. The majority of fisheries still have little or no observer coverage, particularly if they are unlikely to encounter threatened or endangered mammals or turtles.

Apart from the issue of the collection of bycatch data, industry, in particular, has identified the need for aggressive responses to bycatch characterizations that are not supported by the facts. Who should perform such a function? Clearly, there is the perception that an industry under criticism for its practices may not be the best source of unbiased information. Is it a valid function of government to monitor the media, correcting factual errors, or should universities, private foundations, or other groups fill this role? The issue is not resolved.

Minimize the Cumulative Regulatory Burden

Most regulations enacted to minimize bycatch have either specified modifications to existing fishing gear, regulated where and when fishing could or could not occur, or some combination of the two. These regulations have usually been in addition to those intended to prevent overfishing on the target resource. To the extent feasible, integrated regulatory packages should be designed that accomplish biological goals for target and bycatch, while minimizing the cumulative nature of specific requirements. For example, if area closures are designed to minimize bycatch of protected species, it may create problems if the effect is to displace effort to areas of higher catch rates for the target species, particularly if regulated by a single TAC. In such cases, regulations might include measures such as a larger closed area, or complete cessation of fishing, in order to conserve the target species.

Define Milestones

How much bycatch reduction is enough? Some would say that any discard is too much, but this position is generally too restrictive, given the kinds of conservation goals we are attempting to achieve (ethical considerations not withstanding). With the exception of all but the most endangered species, fishing deaths of a few percent (in the case of whales) to roughly one-third of the population (for most finfish) are compatible with stock maintenance or rebuilding. Uncertainty regarding the tolerable exploitation rate for a species, and the measurement of actual population rates may lead to risk prone, risk neutral, or risk averse decisions, depending on how regulators account for this uncertainty when devising regulations. Better estimation and monitoring of these vital rates allows managers to more closely approach them, without mistakenly exceeding critical thresholds. Accounting for bycatch discards in assessment calculations allows for an evaluation of biological and economic impacts of various management alternatives. In particular, the economic impact of ameliorating bycatch in one fishery on linked fisheries that target the saved fish, could be the basis for designing transfer payment schemes among fisheries to offset the financial costs of bycatch reduction. Such schemes have not been tried, and would doubtlessly be controversial. Clearly, the evaluation of bycatch rates on populations and fisheries is critical to the design of effective and fair management policies, and represents a significant challenge to the research community. Likewise, the ecosystem impacts of altering the flow of discarded animals has only recently received consideration.

Achieving Our Goals for Bycatch Management

Once articulated, achieving our bycatch goals may indeed require that some fisheries as we know them will cease to exist. This does not, however, necessarily imply that target species be unexploited. What may be required are changes in the technology, operations, and expectations from existing fisheries.

Traditional responses to bycatch and discarding have been regulatory; little attention has focused on appealing to the self-interests of harvesters to take personal responsibility for ensuring clean fisheries (Fig. 1). Incentives for responsible operations have been few, and in many instances, regulators have often unwittingly created policies that result in disincentives to minimize discards. It is now clear that individual behaviors—those of captains, crews, dealers, and buyers—are a key to achieving the bycatch goals we established (Fig. 1). These behaviors can be supported by appealing to the pragmatic interests of the individuals, particularly through education, technical support, and demonstration of the economic advantages of responsible operation, and the consequences of the alternative. Likewise, developing positive incentive schemes must involve regulators, various sectors of the industry, and advocacy groups interested in the broader issues involved in bycatch mitigation. Should responsible fishing practices be rewarded, and if so, how can incentives (i.e., increased fishing time, quota, access to grounds, and direct cash payments) be made to work?

Key to the development of policies that will allow us to attain our bycatch goals is information describing the performance of fisheries and evaluation of the merits of various technological solutions. On the technology side, evaluating the performance of existing gear over the range of conditions experienced in the fishery, is a necessary first step as a benchmark by which alternatives can be measured (Fig. 2). Modifications to existing technologies need to be objectively as-

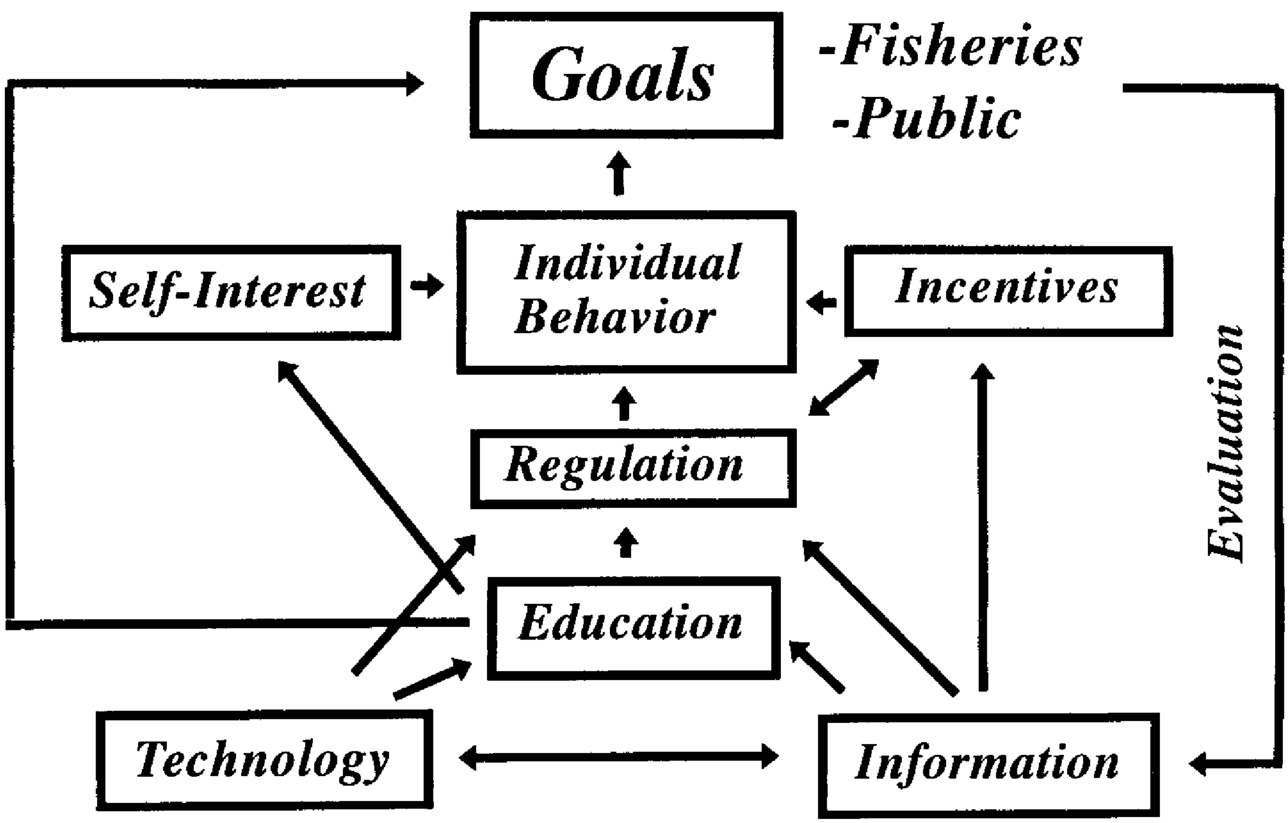

Figure 1. Schematic of factors important to achieving goals for bycatch management. Goals involve performance standards for the fisheries, and increasing public awareness and involvement. Technology and information are key elements supporting education and regulation initiatives. Evaluation is necessary to measure progress in attaining long-term goals.

TECHNOLOGY	INFORMATION
-Performance of Existing	-Collective Performance
-Modification of Existing	-Individual Performance
-Development	-Avoidance
-Involvement	-Consequences of Alternatives
-Real or Apparent Selection	-Impacts (Ecological/Economic)
	-Is Better 'Good Enough'?

Figure 2. Considerations in developing technology-based solutions for bycatch management, and for collecting information necessary to support bycatch management programs.

sessed relative to the benchmark. New technology alternatives must be widely sought. Innovation by those currently involved in the fishery must be a critical part of the development process, since it stands to reason that these participants would best understand the operational constraints on the gear, and may have sophisticated empirical bases for developing solutions. All valid stakeholders need to be actively involved at this stage, if the final policy options are to be successfully implemented. The evaluation of the net benefits of technology must consider the fate of animals encountering gear, but not retained. If technology still results in animals dying as a direct or indirect result of the encounters, these effects must be considered in evaluations of the impacts of the gear on the target and bycatch populations. It is not enough that the gear *appears* to reduce bycatch, based on what is hauled aboard the vessel.

Information needed to ensure attainment of bycatch management goals includes data on the collective and individual performance in the fisheries. Data are needed on a collective basis to evaluate population-level effects, and to assess the balance of yields among interrelated fisheries. Individual performance data are required to measure individual success relative to the norm, and to identify those operations most at odds with group performance. Accurate and timely information is the key to real-time avoidance of bycatch hot spots. Exciting new developments in this area are described in this volume.

Achieving bycatch goals is likely to progress by modest steps. Measurement of the direction and magnitude of bycatch rates is necessary if progress is to continue. Thus, at-sea observer programs should be considered integral long-term investments in the process of bycatch reduction, and not simply used to take "snap shots" of particular fisheries, or to conduct gear experimentation.

Questions to Ponder

Results from the workshop, documented in the subsequent chapters of this volume, provide new and useful information on gear, time/area closures, and other potential solutions to various bycatch issues. But devising a plan of action and appropriate measures is only the first step to achieving our goals. Fundamentally, the success of bycatch reduction efforts will depend on the commitment of fishermen, gear designers, regulators, and others to make these tools work in practice. Information contained within this report represents cutting-edge science, bold policy initiatives, and renewed commitments on the part of those responsible for allocating resources. The workshop will be considered successful if the information presented here sparks new developments, increases awareness, and invigorates the readers to put into practice some of the tools reviewed herein. As you read the various results contained in this report, the workshop organizers ask that you consider the following questions:

- Can I use this idea now?
- Can I make it better?
- How can I encourage others to use it?
- What needs more work?
- What's in it for me?
- What's the next step?

Answering these questions on a personal basis may be our best hope for achieving real progress in bycatch reduction.

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Bycatch: From Emotion to Effective Natural Resource Management

Dayton L. Alverson and Steven E. Hughes
Natural Resources Consultants, Inc. 4055 21st Ave. W, #200, Seattle, WA 98199

Bycatch of discards, as noted by many authors (Alverson et al. 1994, Hall 1994, Murawski 1992, Saila 1983) is not a new fisheries management issue or problem. Bycatch has been with us as an integral component of fishing since humans began to use the world seas, lakes, rivers, and streams as sources of food. Programs and techniques designed to reduce catches of non-target species or undersized target species are not just the product of recent fishery managers' attempts to deal with problems spawned by the use of non-discriminating fishing gears. Regulations to reduce the catch of undersized target species and to limit catch of non-target species constitutes a long accepted fisheries management technique introduced early in this century. Avoiding bycatch was also undoubtedly practiced by conscientious fishermen long before institutionalized fishery management.

What is new, however, is the explosive growth of bycatch as a major management issue over the past decade and the formal national and international recognition that bycatch in many world fisheries constitutes important waste and raises conservation, ecological, and economic issues requiring the priority attention of managers. This paper provides: (1) a cursory review of the recent development of bycatch policy, (2) presentation of bycatch as a problem in world fisheries, (3) discussion of bycatch as a component of fishing-induced mortalities with examples of graphics and tabular presentations of information on fishery-induced mortalities, and (4) reflections on issues of a philosophical nature.

The emergence of bycatch as a major management issue of this decade can, to a considerable degree, be traced to the phenomenal growth of the world's conservation and environmental groups and to their dedicated and focused efforts to protect populations of marine mammals, birds, or turtles impacted by commercial fisheries (Alverson et al. 1994, Alverson 1992, Bricklemyer 1989, Murray et al. 1992, and Northridge 1991).

The escalation of bycatch to a significant national policy issue in the United States, and other countries, followed a series of bycatch confrontations between conservation related groups and selected commercial fisheries over the past several decades. Perhaps the best known U.S. and international bycatch issue involves purposeful setting on dolphins using large purse seines in the eastern tropical Pacific (ETP) to harvest associated tunas. During the early 1970s dolphin deaths in the fishery were reported to have reached levels exceeding 300,000 animals (Marine Mammal Commission 1991). The dolphin mortality and threat to dolphin populations served as a powerful rallying cause to ocean oriented conservation groups, which quickly captured the interest of the U.S. Congress, who passed legislative acts to reduce the levels of dolphin kills in the ETP.

After almost 35 years this problem seems to have been largely resolved as the result of the development of new technology, operational net handling modes, skipper and crew training in the handling of captured dolphins, and extensive education of the fishermen within the international fleet exploiting tropical tunas. Unfortunately, the U.S. fleet became a casualty of the remedied actions of the policy of a major U.S. processor and changing economics within the fishery.

Further molding of U.S. and international bycatch policy and its growth as a priority management issue followed a series of conservation-fisheries conflicts involving, among others, bycatch of marine mammals and birds in the North Pacific salmon fisheries, turtles in the shrimp and other commercial fisheries in the Gulf of Mexico and elsewhere, Steller sea lions in the Northeast Pacific trawl fisheries, and marine mammals, birds, turtles, and various fishes in the high seas squid driftnet fisheries conducted in the North Pacific. The latter issue served to catapult bycatch policy to the highest level of collective world governments—the United Nations (UN).

Driftnet fisheries were characterized by such terms as "walls of death, indiscriminant killers, dirty and ecologically destructive." The public reacted in an emotional tidal wave to an issue that was clouded by a stream of descriptive adjectives that frequently could not be quantitatively supported. Nevertheless, the perceived threat of high seas gillnet fisheries rapidly transcended national boundaries and became an international conservation issue. The U.S. Congress, responding to environmental advocacy groups and growing leverage of the U.S. public, moved to establish a moratorium (1990) on high seas driftnet fisheries and shortly thereafter to join Canada, Australia, and New Zealand in fostering the UN termination of such fisheries (1991).

It is now evident that the momentum for action on the high seas driftnet fishery preceded serious analysis of the information regarding the quantitative nature of discards in these fisheries. To date, no comprehensive technical review of observed or other information has ever been published that provides answers to the pivotal biological and ecological consequences of these fisheries. Nevertheless, the fisheries have been terminated and the bycatch debate extended to new species and areas of concern. Regardless, even had the issue been considered in light of more recent information, it seems doubtful the outcome in the U.S. Congress and UN would have been different. Although the salmon, marine mammal, and bird interception rates in the Korean and Taiwanese squid fishery were low, the fishery constituted a staging area for illegal salmon operations to the north (Miles 1989, Burke et al. 1994). Further, the incidental albacore catch was impacting a stock apparently already overfished (Fox 1992), and some marine mammal populations may have been threatened, over time, by the Japanese squid fishery (Mangel 1993). These concerns, plus the lack of transparency in the high seas driftnet squid fisheries and the presumed need for timely action provided the basis for congressional actions. Perhaps of greater importance, the issue was emotionally charged and vigorously pursued by the world press, who were being fed information by government sources, advocacy groups, and scientists unfamiliar with the available scientific data. Finally, the numbers of marine mammals, seabirds, and other sea life killed in the driftnet fisheries were perceived to be ethically unacceptable to the U.S. public (Alverson et al. 1994).

As world fisheries began to approach the forecasted theoretical limits of ocean productivity in the late 1980s and early 1990s, and competition within and between fishing gears for limited resources became increasingly acute, various fisheries groups joined the bycatch debate. Driven by increased criticism of waste in world fisheries, concern for target and non-target stocks, and economic implications of bycatch in competing fisheries, numbers, and weights of suspected or observed bycatch losses frequently surfaced at national and international fisheries conferences. These factors helped to energize a press feeding frenzy which painted a dismal picture of waste in world fisheries.

It would be easy to argue that bycatch, a term having several technical definitions, has in many circles become a buzz word to describe a wide variety of sins including biological waste, non-selective fishing practices that threaten non-targeted sea life, and fishing in a manner inconsistent with the UN principles of responsible fishing.

By the early 1990s, the U.S. fishing industry had begun to examine and take stock of the bycatch storm which, in a matter of a decade, had suddenly become a global cyclone. An issue largely catalyzed by concerns over bycatch of marine mammals, birds, and turtles had become pervasive in all aspects of fishery management. Few fisheries escaped the scrutiny of their inherent bycatch levels.

A Contemporary View

In February 1992, elements of U.S. commercial fisheries sponsored and carried out a national industry bycatch workshop designed to help the industry better understand the scope and magnitude of the bycatch problem in its domestic fisheries (Schoning et al. 1992). The media characterization of waste and indiscriminatory killing in the North Pacific high seas driftnet fisheries had perhaps unintentionally helped to create the image of fishing in general as a "dirty" industry. Robin Alden (1992), publisher of *Commercial Fishing News*, stated at the 1992 workshop,

> tide of public opinion has turned against commercial fishing. Whereas before the industry was either invisible and ignored or seen as something desirable, it is now being seen as an extractive industry. We have become "industry"' instead of a proud, renewable and thus sound way of making a living. The barrage of negative publicity focuses the choice before us. Are we going to be an extractive industry paying for the power in Washington and State capitals to continue to operate unfettered? Or, are we going to grapple with the "dirty" side of our business, clean up our act, and then be able to defend, with pride, our right to exist at whatever scale is appropriate for a given fishery.

In response to Alden's challenge, industry, government, and conservation groups have begun to constructively grapple with the dirty side of fishing.

1. Significant technological advances have been made in a number of fisheries including ETP tuna seining, northern shrimp fishing, selected bottom trawl fisheries, and east coast set net fisheries.

2. Many of the technological and operational changes have resulted in significant reductions in bycatch levels or increased survival of discards.

3. Since the 1992 workshop, industry, in association with government and environmental groups, has sponsored or is in the process of conducting a number of regional workshops to focus on better definitions of bycatch issues and to describe efforts to solve local problems. Among others, these include the Seattle win-win bycatch solution conference, the Rhode Island East Coast bycatch conference, the Sitka and Kodiak Alaska bycatch workshops, Gulf and South Atlantic bycatch workshops, and this meeting, Solving Bycatch Workshop: Considerations for Today and Tomorrow.

Nevertheless, considerable confusion prevails in the minds of many resource managers, conservationists, fishermen, and the lay public as to the impacts of bycatch on target and non-target species, which fisheries are considered to be conducted in a responsible manner, and over how much progress is being made in resolving perceived problems. Most often we cannot effectively respond to these concerns. Contemporary bycatch conferences and workshops frequently highlight discards as a resource management issue on par with habitat degradation, sustainable fishing, and resource allocations. Bycatch is quantified in terms of rates of discards versus retained or total catch or in numbers or weights of animals discarded. It is important to remember that the ratio of discards to retained or total catch, as well as raw numbers and weights of discards, are not in themselves indicators of biological or ecological impacts. Such impacts must be evaluated on a case-by-case basis in terms of the discard mortality on target and non-target species populations. Low bycatch rates may generate severe impacts on non-target species populations. Conversely large numbers or weights of discards may not constitute serious biological or ecological problems at all.

Accurate impacts of bycatch and discards at the population level must take into account numbers and weight discarded and the survival of the discards, and equate the discard mortality in numbers or weight to the subject population. In this regard, the terms "dirty" or "clean" based on observed rates, are meaningless, except as they may relate to the issues of biological waste. Bycatch and discard problems represent too complex an issue to classify neatly as "good and bad" or "clean and dirty," based on ratios of discards to retained catch or on numbers, weights, or other absolute indices. Such classification, combined with the spin placed on reported numbers or weights of discards by advocacy groups, the press, and politicians, often serve to generate condemnation of a particular fishery or gear without regard to biological/environmental, economic, and cultural impacts of a specific fishery. Further, this process is too often blemished by inaccuracies and misrepresentations of facts (Alverson et al. 1994).

Although, in the author's view, while progress toward responsible fishing and lowered rates of bycatch is being made, the issue is not generally perceived in the context of more generic fishery management issues; that is, discerning mortalities resulting from resource harvesting, evaluating their consequence to impacted populations, and controlling the rate of fishing mortality in relationship to specific management goals. In many instances bycatch constitutes a topical discussion set apart from the basic question of population dynamics and the relative role which discard mortalities may play versus the mortalities generated by other aspects of fishing or natural processes.

Response to bycatch concerns has often been shaped by policy evolution which has been politically driven by strong emotions in very short time periods to top levels of many governments' legislative bodies. Early this decade little was known regarding bycatch rates and numbers and weights taken in many world fisheries. The first and most logical step to confront the growing concern over bycatch was the documentation of discards in terms of the levels of weights and numbers involved. We have made progress in moving toward this goal and we are attempting to extend our bycatch statistical database while trying to formulate solutions.

What we have not done in most cases is to systematically evaluate impacts on the population level and assess these impacts relative to other sources of mortality. Until we encompass and quantify discards as a part of a much larger management issue, the bycatch role in fishery management is very likely to be driven by the political expedience of competing user groups, managers, and environmental groups seeking to shape the management regimes reflecting their special interests.

Bycatch as a Component of Fishing Mortality

Discards have historically constituted a problem for managers because they represent an unaccounted mortality in fisheries. Although some fisheries scientists and management entities have attempted to estimate levels of discards of undersized target species, the overall consequences of discards resulting from the complex of fisheries of a region on specific stocks have largely been speculative. In recent studies, several authors have noted that the mortalities imposed as the result of fishing activities may be much greater than that suggested by landing reports (Alverson et al. 1994, ICES 1995). As a result of recent catch studies, we know that in some instances discard mortalities alone may at times approach or exceed catch mortality (Alverson et al. 1994). The sum of all fishery-induced mortalities occurring as a result of catch, or indirectly as a result of contact with or avoidance of the fishing gear, involves a number of factors in addition to catch and discards.

A recent report of the ICES study group on unaccounted mortality in fisheries has characterized fishing mortality (F) as the aggregate of all catch mortalities including discards, illegal fishing, and misreported mortalities. These mortalities include deaths of fish that escape after being captured and subsequently die, fish which avoid fishing gear yet die due to stress and injuries, deaths due to drop-out from nets, or from hooks. This also includes deaths of fish caught in ghost fishing gear and losses due to predation of fish that escape gears but would have otherwise survived. Finally, the authors note that over longer time periods losses may occur as the consequence of gear-induced changes to the habitat (ICES 1995).

This rather comprehensive list of potential sources of fishing mortality has been quantified by the formula,

$$F = (F_{CL} + F_{RL} + F_{SL}) + F_B + F_D + F_O + F_A + F_E + F_G + F_P + F_H$$

where:

F Sum of all direct and indirect fishing

F_{CL} Commercial landing mortalities

F_{RL} Recreational landing mortalities

F_{SL} Subsistence fishing landing mortalities

F_B Illegal and misreported landing mortalities

F_D Discard mortality

F_O Drop-out mortality

F_A The mortality resulting from fish that avoid gear but die from stress or incurred injuries

F_E The mortality resulting from fish contacting but escaping gear which subsequently die

F_G The mortality resulting from fish that are caught and die in ghost fishing gears

F_P The mortality resulting from predation of fish escaping from or stressed by fishing gear that would otherwise live

F_H The mortality of fish that die or are lost as a result of gear habitat modifications

Considering that we are just beginning to get a grasp on discard mortalities, the formula and task of identifying the unknown mortalities appears formidable.

Management for the better part of this century has operated largely in ignorance of many of the mortality coefficients. This may in part explain why many world fisheries are in trouble, and why there is growing support for risk aversion management. It must also be recognized that catch, bycatch, illegal fishing, and death resulting from contact with fishing gear are likely to constitute the major mortalities imposed by most fisheries. Many of the other identified mortality coefficients may be insignificant in terms of the summed F value. The authors of the ICES working group suggest that, of the various unknown fishing mortalities in the northeast Atlantic, illegal fishing and misreporting is frequently considered to be the largest source of unknown fishing mortality.

Graphic and Tabular Presentation of Fishing Related Mortalities

Sangster and Lehaman (1995), two European investigators, provide an excellent example of the fate of a haddock population entering a codend. The resultant data from their haddock survival experiment constitute results obtained where codend escapees were held in cages on the sea bed over a period of 60 days. These data were applied to selectivity information collected from the same fishery at the same time. The selectivity and survival data provided information on haddock which: (1) passed through the trawl but escaped and survived, (2) passed through the net and subsequently died, (3) were caught and discarded (<30 cm), and (4) were caught and landed.

This experiment is perhaps the first attempt to provide a visual image of the fate of a population of fish passing through a trawl. In this experiment the portion of the fish which enter the net and subsequently escape obviously dwarfs the portion (in numbers) caught and retained or discarded (Fig. 1). Likewise the portion of mortality imposed as a result of death due to contact with the gear but not captured constitutes a very significant portion of the total deaths resulting from the fishing activity. Nevertheless the impacts on the exploitable population are not clearly apparent as the calculation of the sub-components of F must be determined taking into account specific age classes impacted.

Ideally it would be desirable that fishery managers have estimates of all unaccounted fishing mortalities, but that is unlikely to occur over most of our life spans. Managers are likely to settle on filling in those elements of the equation for which data can be acquired at realistic cost and hopefully accounting for the remainder through the application of a conservation management regime.

Data available in many parts of the Northern Hemisphere make it possible to incorporate the discard mortality into our population assessment equations and begin to apply an ecological perspective regarding fishing mortalities imposed by a set or subset of regional fisheries. Although quantities, rates, and other elements of bycatch are frequently identified for various species and regions, they are most often not marshaled in a manner that allows fisheries managers to visualize the multiple fisheries impacts at the stock and/or ecological complex level.

This process might begin by summing major mortality coefficients imposed by a complex of regional fisheries (bottom fisheries and pelagic fisheries) in terms of their impacts on all of the major stocks of the region. In an attempt to evaluate the utility of presenting data in this manner, the authors have developed a matrix analysis of landings, bycatch of major groundfisheries of the eastern Bering Sea versus their impacts on the major fishery stocks of the region as well as the ecological complex targeted. The results are shown in the six tables.

Table 1 is organized with major fisheries listed in the left hand column and target stocks impact across the top horizontal row. Retained and discarded catch and unaccounted losses for each species by fishery are provided in the matrix cells while summed total bycatch and catch for each species across all fisheries is provided at the bottom of the table along with a Stock Use Efficiency index (SUE). The latter is defined as the retained catch of a specific species divided by the retained and discarded catch of that species taken in all fisheries. Summed discards and landings for each fishery across all species are provided in the last two columns along with the associated Ecological Use Efficiency (EUE), defined as the aggregate retained catch of all species of a fishery divided by the discards and retained catch of all species combined.

The species stock mortality rates resulting from retained or discarded catch, and other noted fishing impacts are then generated by dividing the retained and discarded catch along with other estimated mortality weights killed in each cell by the estimated stock biomass for each species (Table 2). Summed mortality rates by columns for retained and discarded species and other unobserved fishing mortalities are provided in the bottom row along with an indication of the species population trends. Further, the implicit ecological complex use rates of a fishery can be calculated by dividing the retained and discarded catches noted in Table 1 by the summed biomass of the impacted species (Table 3). The overall ecological mortality factors resulting from fishing the complex of stocks are the summed rates across each row. An indicator of the biomass trends of the respective species complex as provided in the final column. Similar information for fisheries impacting the crab stocks of the region are shown in Tables 4,5, and 6.

The data presented in tabular form should assist managers in relating retained catch and discards for the fisheries of the region, the relative impacts of retained catch versus discards and other impacts of fisheries related mortalities as well as stock and complex biomass trends. It is readily apparent from the tables that:

1. SUE is lowest for trawl flounder (general), turbot, rock sole, and rockfish fisheries while the bottom trawl rock sole and cod fisheries make poorest use of the ecological complex impacted (Table 1).

2. The overall fishing mortalities (discard and retained catch) for Bering Sea bottomfish species was generally low for 1993 ranging from 3 to 25% of the stock biomass fished with discard mortality accounting for 0.5 to 5.5% of the species impacted (Table 2).

3. Although the SUE for rock sole, turbot, flounder, and rockfish is poor, the overall fishing mortality for these stocks is low. Discards and retained catch removals are far below established Allowable Biological Catch (ABC) for these species/stocks (Tables 1 and 2).

4. The complex of fisheries targeting Bering Sea bottom stocks in 1993 killed about 11% of the ecological complex targeted. Of this total, discard constitutes 1% of the reported biomass complex (Table 3).[1]

5. For the complex of bottom fish stocks fished by the trawl, line, and pot fisheries in the Bering Sea, halibut alone appears to have sustained a relatively high discard impact level, about 0.24, in 1993, a mortality rate that constitutes about 0.68 of the regional fishing mortality.

6. Significant discards of undersized and female crabs also occur in the directed crab pot fisheries of the region; however, the bycatch mortalities imposed by these and other fisheries are still largely speculative. The pot fisheries for king and *C. bairdi* crabs have very low SUE indices while the pot fishery for *C. opilio* has a very high SUE.

In relation to the world Food and Agriculture Organization (FAO) statistical regions, the northeast Pacific groundfish discard rate (about 14%) is less than half the global reported discard rate (about 35%), and the northeast Pacific region is one of the few areas of the world where discards are added to landings in establishing Total Allowable Catch (TAC) annual harvest levels. Maintenance of relatively low overall harvest rates for most of the northeast Pacific groundfish species is probably a significant factor in the reported generally good condition of most of the fished stocks (Alverson et al. 1994).

Sorting Among Many Options

The matrix data format should assist managers in accessing the relative importance of the various fishing induced mortalities and the potential impact at a population or population complex level. Professional managers must weigh such impacts in terms of specific management criteria. Unfortunately, the criteria for managing discard levels in relation to those involving management goals for target species are at times confusing and ill-defined.

Hall (1994) suggested that discards might be classified according to the level and type of impact. In this regard he has suggested the following categories:

- Critical bycatch: bycatch of populations or species that are in danger of extinction.
- Non-sustainable bycatches: populations not at risk, but which should decline under current levels of bycatch.
- Sustainable bycatch: bycatch that does not result in declines in the population.

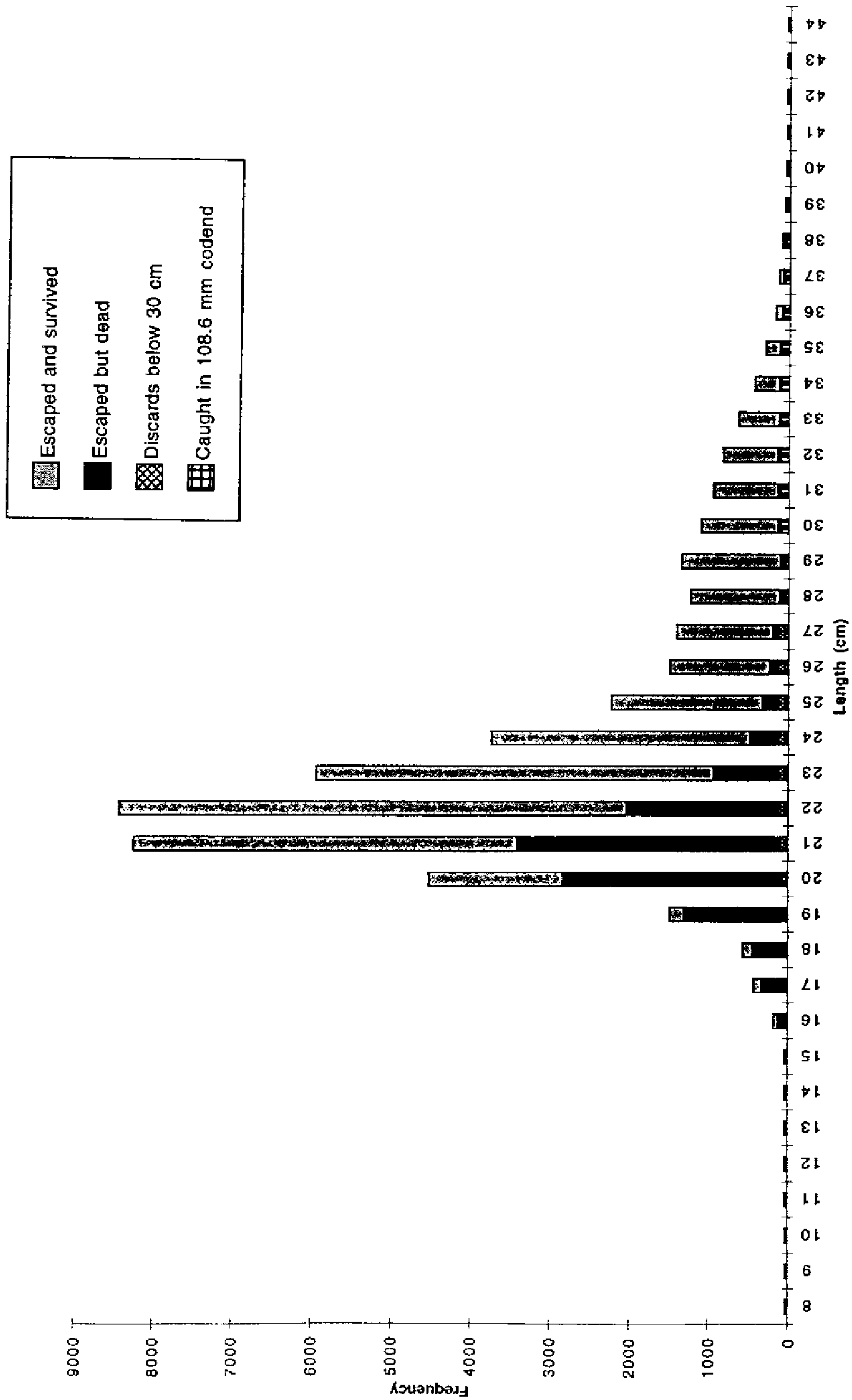

Figure 1. Fate of haddock population entering codend.

Table 1. Target and bycatch species catches (mt) retained, discarded, and unaccounted for by fishery in the Bering Sea/Aleutian Islands. Data based on NMFS and IPHC stock assessments, 1993.

FISHERY (mt)	Biomass (mmt)	Rock Sole 1.6	Atka Mackerel 1.2	Flounders 1.25	Turbot[1] 0.77	Pacific cod 0.66	Pollock 6.7	Pacific Ocean Perch 0.3	Rockfish 0.5	Sablefish 0.037	Yellowfin Sole 2.5	Halibut 0.0015	Total Catch[2]	Ecological Use Efficiency
BT-Atka Mackerel	Retained	10	47,824	1	2	2,111	37	321	23	4	0	0	50,333	0.771
	Discarded	90	11,704	4	284	2,001	104	527	48	0	0	207	14,969	
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
BT-Pollock	Retained	1,217	0	481	173	7,607	81,045	10	0	1	113	0	90,647	0.810
	Discarded	6,660	5	1,031	585	4,697	7,254	89	1	1	409	468	21,200	
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
BT-Pacific cod	Retained	265	378	161	103	47,769	2,440	294	2	3	4	0	51,419	0.522
	Discarded	5,141	2,764	2,401	172	6,925	26,947	741	22	0	814	1,081	47,008	
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
MWT-Pollock	Retained	22	0	155	64	1,592	1,178,743	7	0	0	23	0	1,180,606	0.957
	Discarded	2,018	41	2,411	558	6,863	40,556	178	3	0	516	521	53,665	
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
BT-Rock sole	Retained	16,527	7	3,239	2	2,527	1,252	1	0	1	2,478	0	26,034	0.321
	Discarded	23,013	8	4,010	1,168	5,581	17,251	14	4	3	3,793	121	54,966	
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
BT-Pacific Ocean perch	Retained	4	1,701	112	706	714	144	13,635	70	50	0	0	17,136	0.737
	Discarded	59	1,215	140	1,200	260	1,377	1,673	60	5	0	121	6,110	
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
LL-Sablefish	Retained	0	0	0	235	16	0	0	248	1,958	3	0	2,460	0.617
	Discarded	0	0	1	1,035	15	0	2	316	23	88	49	1,529	
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
BT-Yellowfin sole	Retained	3,042	0	2,629	0	3,477	1,351	0	0	0	70,294	0	80,793	0.603
	Discarded	4,505	0	7,057	5	5,290	14,079	5	1	0	21,610	603	53,155	
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
LL-Pacific cod	Retained	0	4	10	224	61,290	253	2	17	61	0	0	61,861	0.894
	Discarded	18	17	196	715	4,127	1,798	5	34	12	11	392	7,325	
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
LL-Halibut	Retained	0	0	0	0	0	0	0	0	0	0	1,724	1,724	#N/A
	Discarded	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	51	#N/A	
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	51	#N/A	
	Retained Catch (mmt)[3]	**0.021**	**0.050**	**0.007**	**0.002**	**0.127**	**1.265**	**0.014**	**0.000**	**0.002**	**0.073**	**0.002**		
	Discarded Catch (mmt)[3]	**0.042**	**0.016**	**0.017**	**0.006**	**0.036**	**0.109**	**0.003**	**0.000**	**0.000**	**0.027**	**0.004**		
	Stock Use	**0.337**	**0.760**	**0.282**	**0.209**	**0.780**	**0.920**	**0.815**	**0.424**	**0.979**	**0.728**	**0.326**		

NOTE: BT=Bottom Trawl; MWT= Midwater Trawl; LL=Longline; POT=Pot

[1]Turbot includes Greenland Turbot and Arrowtooth Flounder
[2]Total Catch equals the sum of landings across all stocks for each fishery
[3]Retained and Discarded Catch is summed across all fisheries for each stock.
[4]Halibut unaccounted for mortality is due to ghost fishing.

$$\text{Stock Use} = \frac{\sum RetainedCatch(stock)}{\sum RetainedCatch(stock) + \sum DiscardedCatch(stock)}$$

$$\text{Ecological Use Efficiency} = \frac{\sum RetainedCatch(fishery)}{\sum RetainedCatch(fishery) + \sum DiscardedCatch(fishery)}$$

Table 2. Fishery and direct and indirect impacts at the stock level of the Bering Sea/Aleutian Islands. Data based on NMFS catch stock assessments, 1993.

FISHERY	Biomass (mmt)	Rock Sole	Atka Mackerel	Flounders	Turbot	Pacific cod	Pollock	Pacific Ocean Perch	Rockfish	Sablefish	Yellowfin Sole	Halibut
		1.6	1.2	1.25	0.77	0.66	6.7	0.3	0.5	0.037	2.5	0.015
BT-Atka Mackerel	Retained	0.0000	0.0399	0.0000	0.0000	0.0032	0.0000	0.0011	0.0000	0.0001	0.0000	0.0000
	Discarded	0.0001	0.0098	0.0000	0.0004	0.0030	0.0000	0.0018	0.0001	0.0000	0.0000	0.0138
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
BT-Pollock	Retained	0.0008	0.0000	0.0004	0.0002	0.0115	0.0121	0.0000	0.0000	0.0000	0.0000	0.0000
	Discarded	0.0042	0.0000	0.0008	0.0008	0.0071	0.0011	0.0003	0.0000	0.0000	0.0002	0.0312
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
BT- Pacific cod	Retained	0.0002	0.0003	0.0001	0.0001	0.0724	0.0004	0.0010	0.0000	0.0001	0.0000	0.0000
	Discarded	0.0032	0.0023	0.0019	0.0002	0.0105	0.0040	0.0025	0.0000	0.0000	0.0003	0.0721
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
MWT-Pollock	Retained	0.0000	0.0000	0.0001	0.0001	0.0024	0.1759	0.0000	0.0000	0.0000	0.0000	0.0000
	Discarded	0.0013	0.0000	0.0019	0.0007	0.0104	0.0061	0.0006	0.0000	0.0000	0.0002	0.0347
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
BT-Rock sole	Retained	0.0103	0.0000	0.0026	0.0000	0.0038	0.0002	0.0000	0.0000	0.0000	0.0010	0.0000
	Discarded	0.0144	0.0000	0.0032	0.0015	0.0085	0.0026	0.0000	0.0000	0.0001	0.0015	0.0081
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
BT-Pacific Ocean perch	Retained	0.0000	0.0014	0.0001	0.0009	0.0011	0.0000	0.0455	0.0001	0.0014	0.0000	0.0000
	Discarded	0.0000	0.0010	0.0001	0.0016	0.0004	0.0002	0.0056	0.0001	0.0001	0.0000	0.0081
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
LL-Sablefish	Retained	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000	0.0000	0.0005	0.0529	0.0000	0.0000
	Discarded	0.0000	0.0000	0.0000	0.0013	0.0000	0.0000	0.0000	0.0006	0.0006	0.0000	0.0033
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
BT-Yellowfin sole	Retained	0.0019	0.0000	0.0021	0.0000	0.0053	0.0002	0.0000	0.0000	0.0000	0.0281	0.0000
	Discarded	0.0028	0.0000	0.0056	0.0000	0.0080	0.0021	0.0000	0.0000	0.0000	0.0086	0.0402
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
LL-Pacific cod	Retained	0.0000	0.0000	0.0000	0.0003	0.0929	0.0000	0.0000	0.0000	0.0016	0.0000	0.0000
	Discarded	0.0000	0.0000	0.0002	0.0009	0.0063	0.0003	0.0000	0.0001	0.0003	0.0000	0.0261
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
LL-Halibut	Retained	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1149
	Discarded	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.0034
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.0034
	Total Stock Impact	0.0391	0.0547	0.0192	0.0094	0.2468	0.2052	0.0583	0.0017	0.0574	0.0401	0.3593
	Stock Condition	high	high	high	low	high	moderate	moderate	moderate	low	high	moderate
	Stock Trend	↗	→	↗	↘	↗	→	→	→	↘	↗	↘

NOTE: BT=Bottom Trawl; MWT= Midwater Trawl; LL=Longline; POT=Pot

$$\text{Retained Stock Impact} = \frac{\text{RetainedCatch}}{\text{StockBiomass}}$$

$$\text{Discarded Stock Impact} = \frac{\text{DiscardedCatch}}{\text{StockBiomass}}$$

Table 3. Ecological impacts at the ecosystem level of the Bering Sea/Aleutian Islands. Data based on NMFS stock assessments and IPHC, 1993.

FISHERY	Biomass (mmt)	Rock Sole 1.6	Atka Mackerel 1.2	Flounders 1.25	Turbot 0.77	Pacific cod 0.66	Pollock 6.7	Pacific Ocean Perch 0.3	Rockfish 0.5	Sablefish 0.037	Yellowfin Sole 2.5	Halibut 0.0015	Aggregate Ecological Impact 15.9
BT-Atka Mackerel	Retained	0.000001	0.003008	0.000000	0.000000	0.000133	0.000002	0.000020	0.000001	0.000000	0.000000	0.000000	0.003166
	Discarded	0.000006	0.000736	0.000000	0.000018	0.000126	0.000007	0.000033	0.000003	0.000000	0.000000	0.000013	0.000941
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
BT-Pollock	Retained	0.000077	0.000000	0.000030	0.000011	0.000478	0.005097	0.000001	0.000000	0.000000	0.000007	0.000000	0.005701
	Discarded	0.000419	0.000000	0.000065	0.000037	0.000295	0.000456	0.000006	0.000000	0.000000	0.000026	0.000029	0.001333
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
BT-Pacific cod	Retained	0.000017	0.000024	0.000010	0.000006	0.003004	0.000153	0.000018	0.000000	0.000000	0.000000	0.000000	0.003234
	Discarded	0.000323	0.000174	0.000151	0.000011	0.000436	0.001695	0.000047	0.000001	0.000000	0.000051	0.000068	0.002956
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
MWT-Pollock	Retained	0.000001	0.000000	0.000010	0.000004	0.000100	0.074135	0.000000	0.000000	0.000000	0.000001	0.000000	0.074252
	Discarded	0.000127	0.000003	0.000152	0.000035	0.000432	0.002551	0.000011	0.000000	0.000000	0.000032	0.000033	0.003375
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
BT-Rock sole	Retained	0.001039	0.000000	0.000204	0.000000	0.000159	0.000079	0.000000	0.000000	0.000000	0.000156	0.000000	0.001637
	Discarded	0.001447	0.000001	0.000252	0.000073	0.000351	0.001085	0.000001	0.000000	0.000000	0.000239	0.000008	0.003457
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
BT-Pacific Ocean perc	Retained	0.000000	0.000107	0.000007	0.000044	0.000045	0.000009	0.000858	0.000004	0.000003	0.000000	0.000000	0.001078
	Discarded	0.000004	0.000076	0.000009	0.000075	0.000016	0.000087	0.000105	0.000004	0.000000	0.000000	0.000008	0.000384
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
LL-Sablefish	Retained	0.000000	0.000000	0.000000	0.000015	0.000001	0.000000	0.000000	0.000016	0.000123	0.000000	0.000000	0.000155
	Discarded	0.000000	0.000000	0.000000	0.000065	0.000001	0.000000	0.000000	0.000020	0.000001	0.000006	0.000003	0.000096
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
BT-Yellowfin sole	Retained	0.000191	0.000000	0.000165	0.000000	0.000219	0.000085	0.000000	0.000000	0.000000	0.004421	0.000000	0.005081
	Discarded	0.000283	0.000000	0.000444	0.000000	0.000333	0.000885	0.000000	0.000000	0.000000	0.001359	0.000038	0.003343
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
LL-Pacific cod	Retained	0.000000	0.000000	0.000001	0.000014	0.003855	0.000016	0.000000	0.000001	0.000004	0.000000	0.000000	0.003891
	Discarded	0.000001	0.000001	0.000012	0.000045	0.000260	0.000113	0.000000	0.000002	0.000001	0.000001	0.000025	0.000461
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
LL-Halibut	Retained	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000108	0.000108
	Discarded	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000003	#N/A
	Unaccounted	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	0.000003	#N/A

NOTE: BT=Bottom Trawl; MWT= Midwater Trawl; LL=Longline; POT=Pot

$$\text{Retained Ecological Impact} = \frac{RetainedCatch}{TotalBiomass}$$

$$\text{Discarded Ecological Impact} = \frac{DiscardedCatch}{TotalBiomass}$$

Total Biomass = 15.9 mmt

Table 4. Target and bycatch crab species catches (numbers) retained and discarded by fishery in the Bering Sea/Aleutian Islands. Data based on NMFS and ADF&G stock assessments, 1993.

Fishery (millions of crab)	Population (millions of crab)	King crab 47.50	Bairdi Tanner 249.90	Opilio Tanner 11,704.00	Other #N/A	Total Catch	Ecological Use Efficiency
POT-King crab	Retained	2.020	0.000	0.000	0.000	2.020	Prohibited
	Discarded	5.700	4.000	0.002	0.000	9.702	0.17
POT-Bairdi Tanner	Retained	0.000	5.000	0.000	0.000	5.000	Prohibited
	Discarded	0.162	12.213	0.210	0.116	12.701	0.287
POT-Opilio Tanner	Retained	0.000	0.000	229.457	0.000	229.457	Prohibited
	Discarded	0.002	6.700	4.560	9.600	20.862	0.95
BT-Atka Mackerel	Retained	0.000	0.000	0.000	0.000	0.000	Prohibited
	Discarded	0.005	0.001	0.001	0.001	0.008	Prohibited
BT-Pollock	Retained	0.000	0.000	0.000	0.000	0.000	Prohibited
	Discarded	0.515	1.290	#N/A	0.014	#N/A	Prohibited
BT-Pacific cod	Retained	0.000	0.000	0.000	0.000	0.000	Prohibited
	Discarded	0.001	0.165	#N/A	0.001	#N/A	Prohibited
MWT-Pollock	Retained	0.000	0.000	0.000	0.000	0.000	Prohibited
	Discarded	0.007	0.367	#N/A	0.200	#N/A	Prohibited
BT-Rock sole	Retained	0.000	0.000	0.000	0.000	0.000	Prohibited
	Discarded	0.164	0.440	#N/A	0.242	#N/A	Prohibited
BT-POP	Retained	0.000	0.000	0.000	0.000	0.000	Prohibited
	Discarded	0.001	0.001	#N/A	0.005	#N/A	Prohibited
LL-Sablefish	Retained	0.000	0.000	0.000	0.000	0.000	Prohibited
	Discarded	0.001	0.001	#N/A	0.002	#N/A	Prohibited
BT-Yellowfin sole	Retained	0.000	0.000	0.000	0.000	0.000	Prohibited
	Discarded	0.018	0.989	#N/A	9.470	#N/A	Prohibited
LL-Pacific cod	Retained	0.000	0.000	0.000	0.000	0.000	Prohibited
	Discarded	0.001	0.008	#N/A	0.120	#N/A	Prohibited
LL-Halibut	Retained	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Discarded	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Total Retained	**2.020**	**5.000**	**229.457**	**0.000**		
	Total Discarded	**6.577**	**26.175**	**4.772**[1]	**19.771**		
	Stock Use	**0.235**	**0.160**	**0.980**	**0.000**		

[1] **Total Discarded species and Stock Use for Opilio crab is summed for the pot crab fisheries only.**

NOTE: BT=Bottom Trawl; MWT= Midwater Trawl; LL=Longline; POT=Pot

Table 5. Fishery direct and indiret impacts at the crab stock level of the Bering Sea/Aleutian Islands. Data based on NMFS and ADF&G stock assessments, 1993.

Fishery	Population (millions)	King crab 47.50	Bairdi Tanner 249.90	Opilio Tanner 11,704.00
POT-King crab	Retained	0.043	0.000	0.000
	Discarded	0.120	0.016	0.000
POT-Bairdi Tanner	Retained	0.000	0.020	0.000
	Discarded	0.003	0.049	0.000
POT-Opilio Tanner	Retained	0.000	0.000	0.020
	Discarded	0.000	0.027	0.000
BT-Atka Mackerel	Retained	0.000	0.000	0.000
	Discarded	0.000	0.000	0.000
BT-Pollock	Retained	0.000	0.000	0.000
	Discarded	0.011	0.005	#N/A
BT-Pacific cod	Retained	0.000	0.000	0.000
	Discarded	0.000	0.001	#N/A
MWT-Pollock	Retained	0.000	0.000	0.000
	Discarded	0.000	0.001	#N/A
BT-Rock sole	Retained	0.000	0.000	0.000
	Discarded	0.003	0.002	#N/A
BT-POP	Retained	0.000	0.000	0.000
	Discarded	0.000	0.000	#N/A
LL-Sablefish	Retained	0.000	0.000	0.000
	Discarded	0.000	0.000	#N/A
BT-Yellowfin sole	Retained	0.000	0.000	0.000
	Discarded	0.000	0.004	#N/A
LL-Pacific cod	Retained	0.000	0.000	0.000
	Discarded	0.000	0.000	#N/A
LL-Halibut	Retained	#N/A	#N/A	#N/A
	Discarded	#N/A	#N/A	#N/A
	Total Stock Impact	0.1810	0.1247	#N/A
	Stock Condition	**Low**	**Low**	**Low**
	Stock Impact	↘	↘	↘

NOTE: BT=Bottom Trawl; MWT= Midwater Trawl; LL=Longline; POT=Pot

$$\text{Retained Stock Impact} = \frac{RetainedCatch}{StockNumbers}$$

$$\text{Discarded Stock Impact} = \frac{DiscardedCatch}{StockNumbers}$$

Table 6. Ecological impacts of crab species stocks on fisheries at the ecosystem level of the Bering Sea/Aleutian Islands. Data based on NMFS and ADF&G stock assessments, 1993.

Fishery	Population (millions)	King crab	Bairdi Tanner	Opilio Tanner	Other	Aggregate Ecological Impact 12,001.40
POT-King crab	Retained	0.000168	0.000000	0.000000	0.000000	0.000168
	Discarded	0.000475	0.000333	0.000000	0.000000	0.000808
POT-Bairdi Tanner	Retained	0.000000	0.000417	0.000000	0.000000	0.000417
	Discarded	0.000013	0.001018	0.000017	0.000010	0.001058
POT-Opilio Tanner	Retained	0.000000	0.000000	0.019119	0.000000	0.019119
	Discarded	0.000000	0.000558	0.000380	0.000800	0.001738
BT-Atka Mackerel	Retained	0.000000	0.000000	0.000000	0.000000	0.000000
	Discarded	0.000000	0.000000	0.000000	0.000000	0.000001
BT-Pollock	Retained	0.000000	0.000000	0.000000	0.000000	0.000000
	Discarded	0.000043	0.000107	#N/A	0.000001	#N/A
BT-Pacific cod	Retained	0.000000	0.000000	0.000000	0.000000	0.000000
	Discarded	0.000000	0.000014	#N/A	0.000000	#N/A
MWT-Pollock	Retained	0.000000	0.000000	0.000000	0.000000	0.000000
	Discarded	0.000001	0.000031	#N/A	0.000017	#N/A
BT-Rock sole	Retained	0.000000	0.000000	0.000000	0.000000	0.000000
	Discarded	0.000014	0.000037	#N/A	0.000020	#N/A
BT-POP	Retained	0.000000	0.000000	0.000000	0.000000	0.000000
	Discarded	0.000000	0.000000	0.000000	0.000000	0.000000
LL-Sablefish	Retained	0.000000	0.000000	0.000000	0.000000	0.000000
	Discarded	0.000000	0.000000	0.000000	0.000000	0.000000
BT-Yellowfin sole	Retained	0.000000	0.000000	0.000000	0.000000	0.000000
	Discarded	0.000000	0.000000	0.000000	0.000000	0.000000
LL-Pacific cod	Retained	0.000000	0.000000	0.000000	0.000000	0.000000
	Discarded	0.000000	0.000000	0.000000	0.000000	0.000000
LL-Halibut	Retained	#N/A	#N/A	#N/A	#N/A	
	Discarded	#N/A	#N/A	#N/A	#N/A	

NOTE: BT=Bottom Trawl; MWT= Midwater Trawl; LL=Longline; POT=Pot

$$\text{Retained Ecological Impact} = \frac{RetainedCatch}{TotalNumbers}$$

$$\text{Discarded Ecological Impact} = \frac{DiscardedCatch}{TotalNumbers}$$

- Non-biologically significant bycatch: bycatch so low as to be considered negligible from the point of view of the populations involved.

- Bycatch of unknown levels: lack of basic data on abundance and mortality to determine if it is sustainable or critical.

- Ecosystem-level impacts: the main focus of the problem is a complex of species that is being removed.

- Charismatic bycatch: reflection of different societies valuing species differently, with some perceived to have a special emotional value that may be independent of the level of the impact exacted on the species or on the conservation status of the species.

This list, although not exhaustive, constitutes a starting point from which the importance of discards versus other sources of mortality can be evaluated and whether they constitute a problem requiring the serious attention of a management agency. Although we might tinker with the operational definitions of the defined impacts, our main concern is that the list does not address economic impacts of discards. There is an array of underlying economic implications associated with discarding (Alverson et al. 1994), which may be exclusive or co-exist with biological and ecological impacts. Major categories of apparent economic classification include:

- Discards involving fisheries that negatively impact catch opportunities in competing fisheries but constitute fisheries that add significantly to the total available food supply and overall economic health of a region's fisheries.

- Discards involving fisheries that negatively impact catch opportunities in competing fisheries and constitute fisheries that by the nature of their discards practices diminish the overall potential food supply and economic health of a region's fishery.

Various studies on fishery bycatch have made it clear that discarding is pervasive in world fisheries, and depending on target species, time of the year, and location of the fishing activities, almost all gear types can generate high discard levels. Managers of fishery resources and their habitat must first decide whether discarding among other imposed fishing related mortality constitutes a priority issue needing their attention. Then with limited fiscal resources available, they decide which discards issue should be addressed. As discarding has become a high profile and priority marine resource management issue, request for bycatch funding will far exceed the available dollars. The successful managers will need to select from among a myriad of proposed programs that address important management concerns and not waste time and money attempting to put out fires that are non-existent. On the other hand, some bycatch programs will be mandated as the result of public concerns regardless of the biological/ecological impacts.

Philosophical Issue

There are many issues of a philosophical nature regarding appropriate solutions to discarding and the relative merits of addressing identifiable impacts or perceived impacts.

In this regard there is the issue of the appropriateness of discarding as a practice versus required retention and/or full use of discarded species. Required retention of all discard/undersized species, wrong sex, etc. could in many species management regimes run contrary to size and prohibited species regulations. If a normally discarded portion of the catch survives, retention could lead to higher mortality rates and aggravate the condition of species already suffering from intense exploitation or recruitment overfishing. There is also the possibility that requiring full retention may promote greater usage of fish or invertebrates of sizes and ages below the critical age or size, further aggravating recruitment overfishing (lowering yield per recruit). On the other hand, in some instances increased use of smaller size groups might lead to an overall increase in the economic value of the fishery. Those promoting full use see it as a means and incentive to foster fishing technology to reduce discards (because of handling costs) or to eliminate wastage.

The development of increased marketing opportunities for non-target discarded species or target species that are underutilized would seem an alternative to technological solutions designed to reduce discard levels of non-target species. This approach appears to have been frequently stressed in developing areas of the world and has been particularly important in attempts to reduce high discard levels in the tropical shrimp fisheries.

The issue of requiring full retention of the catch is also questioned by some conservationists who ask isn't it better use strategy to return unwanted catch to the sea where discards are recycled in the food web than requiring or allowing it to be retained and converted to low value meal products? Finally, in those fisheries were an extensive observer program exists, use of discards for meal may result in catch profiles with less detail in biodiversity and quantities of individual species caught.

In many world fisheries where reported high discard levels occur, impacts may not include overfishing, notable ecological shifts, or levels of deaths for marine mammals, birds, turtles, etc. which negatively impact these species groups. Such fisheries nevertheless are seen as wasteful of the resource complex that they harvest. They have, according to our usage classification, poor SUE and perhaps EUE rates. They are frequently accused of destroying food in a world where critical food shortages are anticipated or of concern. That discards constitute wasted potential food is a fact. However, it is food for which society is currently unwilling to pay the price to remove and process. In cases were overfishing is not a problem, the loss to society is of a temporary nature as the resource sustainability is not threatened.

Interestingly, in almost all fisheries conducted in the Pacific Northwest and Alaska, discards have constituted a significant component of the catch during some period of their development. In the early salmon fisheries, several species were unacceptable for canning and, thus, discarded or fed to animals. As few as 20 years ago, Alaskan crab fishing was almost exclusively directed toward the harvest of king crab. Later fisheries for Tannner crab, first *C. bairdi* and later *C. opilio* developed. Prior to the development of suitable markets for the complex of salmon and crabs, some species were discarded, and by contemporary standards, wasted.

The authors, conservation groups, and most fishermen do not condone wastage. Fisheries having low SUE should consider means to improve their SUE of animals captured. Managers should, however differentiate between wastage that contributes to undesirable biological and ecological problems requiring the immediate attention of managers, and those which have little or no consequence to the complex of species impacted. Hopefully, mangers will be more patient in the resolution of discard problems of the later category.

Conclusion

Although bycatch is a long-standing problem in global fisheries management, it has been escalated to the highest levels of many national governments and the UN. The pressure to document and make public levels of discards has resulted in fisheries being labeled as "inefficient" or using "dirty harvesting methods". In the past decade considerable progress has been made in reducing discards in several major world fisheries and discarding practices are increasingly better documented. This has perhaps been facilitated by a variety of discard workshops and meetings.

Nevertheless, the merging of discard impacts into the gamut of fishing related mortalities will require the dedicated attention of fishery scientists and managers. As with many fisheries management issues, generic discard solutions which can be broadly applied geographically and to general gear types is unlikely. In addition, the philosophical bases for management may differ by regions and nations. The easiest solution to discard problems involving overexploited species may be a reduction in fishing effort. Understanding the biological, ecological or other impacts of current fishing practices and the implied consequences of a proposed change is essential. This could be facilitated by matrix analysis of the fishery related mortalities imposed by different fisheries on the multiple stocks of a region.

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Endnote

[1] A number of non-commercial species are also taken in these fisheries and discarded. The weight of these discards constitutes a small fraction (about 10-12 %) of the overall discards. Because of the small size of many species, their capture is not indicative of actual abundance levels.

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Strategic Issues in Managing Fishery Bycatches

Martin A. Hall
Inter-American Tropical Tuna Commission, 8604 La Jolla Shores Dr., La Jolla, CA 92037

A brief analysis is made of the strategies that can be used to reduce bycatches in fisheries. They fall under two basic types: reduction of the level of effort, and reduction of the average bycatch per unit of effort (BPUE). The former frequently results in lower catches of the target species. Reduction in the BPUE, on the other hand, may offer a way to mitigate the problems with fewer negative impacts on the fisheries. Identifying the environmental, biological, and technological reasons why bycatches happen is the key point of those strategies that attempt to deal with the problems while at the same time maintaining the use of the resources involved. Five "lines of defense" are identified to try to mitigate or solve bycatch problems. The Tuna-Dolphin Program of the Inter-American Tropical Tuna Commission, is used as a case study to illustrate different issues. Finally, some of the conditions that have helped solve this problem are presented. Even though it is clear that each fishery will have to develop its own set of solutions, there are some common traits that may help in the search for solutions.

In two recent papers, some strategies were identified to address bycatch problems (Hall 1995a, 1995b). This paper presents a sequence of steps and decisions that need to be made during the process of successfully dealing with a bycatch problem. This analysis will draw in large part from the experiences acquired during the past 12 years working with the tuna fishermen from the eastern Pacific to reduce dolphin mortality and, in part, from observations on other fisheries.

Recently, a classification of bycatches was developed based on the level and type of impact (Hall 1995a). For convenience it is reproduced here in a shortened form.

1. Critical bycatches: bycatches of populations or species that are in danger of extinction.

2. Not sustainable bycatches: in this case, the populations are not at risk, but they are predicted to decline under the current levels of bycatch.

3. Sustainable bycatches: bycatches that do not result in population declines.

4. Not biologically significant bycatches: bycatches that are so low as to be considered negligible from the point of view of the dynamics of the population involved. These bycatches are also sustainable.

   The difference between 3. and 4. is arbitrary, but it is an attempt to separate one that requires some control and monitoring, from the other that is so low that it may not be worth the effort. The definition of biological insignificance is arbitrary; a mortality level of 0.5% of a conservative estimate of population abundance has been proposed for cetaceans, and one of 1% of that abundance for pinnipeds.

5. Bycatches of unknown level: when we lack the basic data on abundance or total mortality to determine if it is sustainable or critical.

6. Ecosystem-level impacts: in this case the main focus of the problem is a complex of species that is being removed, or large biomasses that may cause major alterations of the system.

7. Charismatic bycatches (taboos): this category is added to reflect the fact that different societies value species differently, and that value may be independent of the level of the impact exerted on the species, or of the conservation status of the species.

The categories listed above are not mutually exclusive. For example, a fishery may cause a critical bycatch at the same time as it causes an ecosystem-level impact. The distinction focuses on what is perceived as the main impact and what are the objectives of the bycatch-reduction program.

Critical and unsustainable bycatches require actions to reduce them to sustainable levels or to eliminate them. The actions can be specifically targeted toward individual species, or very broadly applied toward the ecosystem, when a suite of species or a habitat is being affected. Bycatches of unknown level can be the most difficult to handle; the response to them may have to be based on the *belief* by the decision-makers that they fit under some of the other categories. Bycatches of charismatic species, even when sustainable or biologically insignificant, may require action to mitigate the bycatches because society may highly value some species.

Bycatches that are biologically insignificant or sustainable will likely be ignored, given the needs of other more urgent problems competing for limited resources. For these cases the best alternative seems to be the development of markets or processing techniques that allow the complete utilization of all the captured species.

Bycatch Management Objectives

Management goals, even important ones, are not always explicitly stated (e.g., preventing the extinction of species or minimizing voter irritation in an election year). Following is a list of biological objectives that management agencies should attempt to achieve.

- Avoid extinction of species—This is the most basic and widely accepted objective. Achieving this goal requires that all bycatches are at least sustainable. Critical bycatches will require more immediate and more drastic approaches. In order to maintain widespread public support for this objective, it is necessary that both the inclusion and exclusion of species, on the lists of endangered or threatened species, be done judiciously and expeditiously based on solid scientific grounds. Otherwise, public support can be undermined.

- Retain the basic structure and functioning of the ecosystems—This objective is more difficult to define and to monitor. Our lack of knowledge of most ecosystems is such that we have no clear idea of the effects of changes in the abundance and distribution of one species on those of others. Only clear cases such as habitat destruction and massive removal of species will usually be considered as having an impact on the ecosystem.

  Other crucial ecological questions whose answers are not known include: What are the optimum levels of the different components of an ecosystem that would allow its continued sustainable use, while at the same time maintaining a new equilibrium which includes the harvest? When bycatch species are predators, competition, or prey of the target species, do we want to eliminate those takes or, from the point of view of ecosystem stability, is it better that the impacts be spread along and across the food web? The answers to these and other questions are needed to manage bycatches from the ecosystem point of view, but we don't have them yet.

- Rebuilding depleted populations—When a population has been subject to unsustainable bycatches or harvest for a prolonged period of time, it may be considered appropriate to rebuild it to some higher level. In some cases, it has been stated that the objective of rebuilding is to return a population to its pre-exploitation level. This may be problematic if other changes in the ecosystem have taken place and its characteristics (species composition, proportions, biomass, etc.) are different from those existing in the pre-exploitation period. For example, competitors may have expanded into the niche of the depleted population. A new equilibrium state may prevent the population from recovering fully to pre-exploitation levels. In addition, if other species are also depleted, or their biomasses are reduced because of harvest, allowing the recovery of one species without consideration of the effect on the others in the ecosystem may prove destabilizing. Given the increase in human activities affecting oceanic ecosystems (fisheries, pollution, urbanization, etc.), it is quite unlikely that changes have not occurred. If the pre-exploitation level is not the target, the question of what is a reasonable target remains unanswered. Somewhere between the current depleted condition and the original carrying capacity there is a level that is probably the most adequate for the current equilibrium condition of the system. The determination of this level requires in-depth knowledge of the ecosystem.

- Controlling increasing populations—When a population increases because of total protection, or because of changes generated by human activities that benefit it (e.g., because its predators or competitors have been reduced, or because fishery discards provide a new source of food), there may be a need to control its growth or it may affect the equilibrium of the system. For example, populations of seabirds that feed on fishery discards may have expanded at the expense of other species. In some areas the culling of seals has been proposed to reduce their impact on the threatened fish populations or to reduce perceived competition with fishers. Again, unless these actions are based on very solid scientific studies, they may end up being counterproductive. These attempts at "environmental engineering" may be made with little knowledge of the outcome before these measures are taken. The outcomes of inaction, however, are often similarly unknown.

Components of Bycatches

The total bycatch in a fishery is the product of two variables: the *effort*, and the average bycatch per unit of effort (BPUE). *Effort* is emphasized to point out that the definition of effort relevant to the bycatch problem may be quite different from the definition used in a traditional fisheries context. For instance, in some fisheries the effort measure is search time, yet search time does not cause bycatches. The proper units for bycatch estimation are all associated with the deployment of the gear.

To reduce bycatches, either effort or BPUE or both have to be reduced. As the reductions of effort are very easy to understand, we'll focus on ways to modify the BPUE.

1. Is the bycatch frequent enough that patterns can be described and the interactions between fishers, gear, and species caught be roughly understood? If not, it is not possible to develop plans, other than major technological changes that could eliminate the problem.

2. Is the bycatch controllable? If the fishers can control the bycatch through skillful deployment, maneuvers, etc., then it is possible to work on increasing the level of the necessary skills. Educational programs, spreading information to all the fleet concerning the factors that cause bycatches, identifying and implementing solutions to all perceived problems, determining the optimum operational conditions and equipment, and coupling them with programs that demand higher standards of performance with time from the fishers can be used in this case. The reductions in mortality of dolphins in the eastern Pacific tuna fishery were achieved in this way (Lennert and Hall 1995).

3. Is the bycatch concentrated in space or seasonal in time? Is this season/area of concentration consistent over the years? If so, the costs and benefits of time/area closures can be considered as one possible solution.

Incentives

Many of the solutions proposed are based on regulations, but incentives to the fishers may, in some cases, provide a better alternative. These may work as a Darwinian system, selecting for the operators with the lowest incidental takes. Some possible incentives follow.

- Individual vessel bycatch limits—The best operators can continue fishing for the whole year, or the full season, while the less skilled or motivated have to stop fishing earlier. The limits also promote the development of improved technology and procedures, training of crews, etc.

- Selective licenses—Licenses to fish in the best areas, or for longer seasons could be granted only to fishers with low bycatch:catch ratios, or some other measure of good performance. Alternatively, the cost of the licenses could be lower for the best operators.

- Economic advantages—Other advantages could be conferred on those with the best performances. Lower taxes, subsidies, lower fees, free services, etc., could be used as privileges granted to those who prove to be the best fishers.

- Individual awards or honors—These could accompany the more material benefits of the other options.

- Full retention of captured biomass—This acts as an incentive to technological development, by making it economically not viable to fish with large bycatches. This system is currently in use in some European countries.

Incentives are also needed in the area of gear development. The international community should offer substantial economic rewards to anyone creating a new type of gear, superior to the pre-existing ones by some standards, or proposing modifications to the current gear, that improve their performance by a fixed amount (e.g. that reduce some bycatch by x percent). Global initiatives should be undertaken to bring the problem to the attention of all who can make some contribution to the solution. Our approach to this problem should be two-pronged. On one hand we need to continue and step-up our efforts to quantify the bycatches in fisheries, identify their causes, and assess their ecological impacts on the marine ecosystems. On the other hand we need to develop the technological and managerial solutions that can be applied to eliminate or mitigate those impacts.

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Marine Debris Entanglement and Ghost Fishing: A Cryptic and Significant Type of Bycatch?

David W. Laist
Marine Mammal Commission, 1825 Connecticut Ave., Washington, DC 20009

Lost fishing gear and gear scraps are the most hazardous types of marine debris pollution for marine life. Lost gillnets and traps can remain intact and catch marine life for well over a decade. The amount of gear lost annually probably increases with increased fishing effort and, in some areas, derelict gear may outnumber active gear units. Most entangled seals, seabirds, and turtles are reported caught in small fragments of trawl net, gillnet, and monofilament line. However, some of the highest mortality levels may involve commercial fish and shellfish caught in lost gear while it is still relatively intact. Ghost fishing of some commercial stocks has been estimated to catch amounts equal to 5%-30% of the annual landing levels. These estimates only consider ghost fishing by gear lost in the associated fishery (e.g. mortality of lobster in lost lobster pots). If ghost fishing by all types of lost gear is considered, impacts on some fishery resources, especially crabs and lobsters, could be much greater than levels estimated to date. Highest priority needs are for designing and verifying the effectiveness of time-sensitive gear disabling mechanisms (e.g., escape panels for traps), providing services for the disposal of old fishing gear, developing technology and approaches to minimize gear loss, and research on the rates and causes of gear loss, and the catch by different types of derelict gear over the long term.

Lost fishing gear and gear scraps are the most hazardous type of marine debris, with relatively intact gear a source of ghost fishing, and small pieces of net and line the principal source of entanglement. Although ghost fishing and entanglement are not usually considered part of the bycatch issue, they catch many of the same species taken as bycatch. The only real difference is that one involves derelict fishing gear and the other involves active gear. In this sense, ghost fishing and entanglement are related parts of the same basic problem—namely, preventing extraneous mortality of marine life in fishing gear. Once lost, fishing gear and gear scraps catch many protected species, but some of the most seriously affected species are those on which commercial fisheries depend. In some cases, the catch by lost gear may approach bycatch levels in active gear. As discussed below, fishers and fishery managers should not neglect related problems posed by lost gear and should factor research and management needs concerning derelict fishing gear into decisions and plans to minimize bycatch.

Impacts of Lost Fishing Gear

Like other types of marine debris, lost fishing gear and gear scraps impact marine life in two ways: ingestion and entanglement. Some species, particularly turtles, eat pieces of fishing floats and line and die from blocked or damaged digestive tracks. For lost fishing gear, however, entanglement and entrapment are greater concerns. Fish and shellfish, and occasionally turtles and birds, are caught in relatively intact traps and nets. The numbers caught in individual nets can be surprising. A gillnet off Florida was found with 10 dead turtles (Ehrhart et al. 1990); a driftnet in the North Pacific had over 300 dead seabirds (Jones and Ferrero 1985); and a gillnet off New England had over 40 fish (mostly dogfish) and 50 crab (mostly *Cancer* crabs) (Carr and Cooper 1987). Most entangled seabirds, seals, and turtles, however, are found in small pieces of net and line. Once caught, animals unable to free themselves quickly become prey for predators, drown from exhaustion, starve because of limited mobility, or die from cuts or constriction injuries.

The extent to which marine debris affects marine life is not well known because animals killed in marine debris quickly sink or get eaten, and because marine debris is so scattered that systematic at-sea sampling is rarely practicable. Despite these problems, there are good reasons for concern about its impact.

The Number of Affected Species

It is now clear that marine debris is a broad-scale pollutant that affects many species (Table 1). Worldwide, records of marine debris ingestion and entanglement exist for at least 267 species (Laist, in press), with ingestion known in 177 species and entanglement reported for 136 species. Entanglement records alone include all but one of the world's eight sea turtle species, 58% of the world's seal and sea lion species, 60% of the baleen whale species, 16% of all seabird species, and many commercial fish and shellfish. The vast majority of reported entanglement cases involve small pieces of lost fishing gear, particularly trawl net, gillnet, and monofilament line.

The Hazard-Life of Lost Gear

Fishing gear almost always includes persistent materials that last for decades and accumulate in ocean areas. Before the 1940s, fishing gear was made mostly of cotton or hemp line and wood frames that decayed in weeks or months in seawater, thus limiting the time it could catch fish, crabs, and other biota. As synthetics came into use, however, the length of time lost gear could catch fish increased to years and became dependent on the speed it was buried, washed ashore, encrusted with algae, collapsed, or rolled into a tight bundle.

The length of time lost gear poses a hazard has been estimated in studies of ghost fishing. Most studies have focused on mortality and escapement of target species from lost pots and traps (High 1976, Pecci et al. 1978, High and Worlund 1979, Muir et al. 1984, Breen 1987, Parish and Kazama 1992, Stevens et al. 1993, Kimker 1994, and Paul et al. 1994). They generally conclude that ghost fishing is a problem for trap fisheries, but provide limited insight on how long traps may continue to fish. Based largely on guesses by fishers or gear manufacturers, Breen (1987) suggests Dungeness crab traps may remain operable for over 2 years and High and Worlund (1979) estimate king crab traps may last for 15 years. Lobster pots are made of various materials and deteriorate at different rates. Untreated wood pots may last only a few weeks, but wood pots treated with preservatives may last 2 years, metal frame pots up to 10 years depending on anticorrosion features, and plastic pots several decades (Smolowitz 1978). Most are now made of metal frames that are so durable, some fishers have switched from on-land storage in the off season to wet storage leaving unbaited, untended pots at sea (Carr and Harris, in press).

There are few estimates of longevity of lost gillnets but periods of a decade or longer seem likely. Two studies have tracked nets of unknown age when found, for three-year periods. High (1981) used scuba gear to examine nets caught on a shipwreck in Puget Sound; Carr and Cooper (1987) used a submersible off New England. In both cases, nets retained varying degrees of vertical and horizontal profiles and continued to catch fish and crabs throughout the study periods. Based on configuration, fouling, and net integrity, Carr and Cooper (1987) estimated that the lost nets off New England were catching fish at a rate of about 15% of what active gillnets catch.

Amounts of Lost Gear

The amount of gear lost also suggests ghost fishing is a serious problem (Breen 1990). Losses may be caused by at least seven factors—weather (e.g., storms and ice conditions), bottom snags, ship collisions, fishing methods, human error, vandalism, and gear failure. Systematic records of gear loss are not kept, but estimates generated as part of ghost fishing studies for trap fisheries typically range from about 10% to 30% of the traps used annually. Breen (1987) estimates annual trap losses at 11% (2,834 traps in 1984) in the Fraser River Dungeness crab fishery; Muir et al. (1984) estimate 18% (6,577 traps in 1975-1976) in the Columbia River Dungeness crab fishery; Stevens et al. (1993) estimate 10%-20% (10,000-20,000 traps) in the Bering Sea king crab fishery; and Smolowitz (1978) estimates 20%-30% (420,000-630,000 traps) in the New England lobster fishery.

Table 1. The number and percentage of marine species worldwide with records of marine debris entanglement and ingestion by species group (Laist, in press).

Species Group	Total No. of Species Worldwide	Species with Entanglement Records No.	%	Species with Ingestion Records No.	%	Species with Entanglement and/or Ingestion Records No.	%
Sea Turtles	7	6	86	6	86	6	86
Seabirds (total)	312	51	16	111	36	138	44
Penguins	16	6	38	1	6	6	38
Grebes	19	2	10	0	0	2	10
Albatrosses, Petrels, & Shearwaters	99	10	10	62	63	63	64
Pelicans, Boobies, Gannets, Cormorants, Frigatebirds, & Tropicbirds	51	11	22	8	16	17	33
Shorebirds, Skuas, Gulls, Terns, & Awks	122	22	18	40	33	50	41
Other Birds	-	5		0		5	
Marine Mammals (total)	115	32	28	26	23	49	43
Baleen Whales	10	6	60	2	20	6	60
Toothed Whales	65	5	8	21	32	22	34
Fur Seals & Sea Lions	14	11	79	1	7	11	79
True Seals	19	8	42	1	5	8	42
Manatees & Dugongs	4	1	25	1	25	1	25
Sea Otter	1	1	100	0	0	1	100
Fish	-	34		33		60	
Crustaceans	-	8		0		8	
Squid	-	0		1		1	
TOTAL		136		177		267	

Loss rates for gillnet fisheries are less well known. One estimate places losses at 1% per year (Natural Resources Consultants, Inc. 1990), but higher rates in some years seem likely. For example, when offshore trawling areas for groundfish were closed in New England in 1994, some trawlers moved into areas fished by gillnetters prompting many complaints of net loss. Some fishers also set old, worn-out nets near rocks or wrecks where fish may aggregate, but nets are more likely to be lost. This practice may actually be encouraged by landfills that refuse to accept old nets for disposal and ports that have no system to handle them. Some surveys for lost nets have been done in New England using a submersible. Extrapolating survey data for a small area, Carr and Cooper (1987) estimate that perhaps 2,240 lost nets were in a 64 sq. mi. area in two major fishing areas, an amount they considered to be of low significance. Estimates of annual losses for other gear types include 2%-5% for bottom trawls and 0.1% for longlines and purse seines (Natural Resources Consultants, Inc. 1990).

In many fisheries gear loss has probably increased even if loss rates have stayed constant. That is, to maintain catch levels as target stocks have declined, many fishers have increased the amount of gear fished and/or the time it is actually deployed. Also, to catch increasingly scarce resources, fishing has moved into areas where gear loss risks are higher, such as near wrecks, rocky bottoms, or areas of gear conflict. Given loss rates and gear persistence, even low loss rates may lead to problems. In some areas, the amount of lost gear may far exceed the amount of gear actively being fished.

Population Level Impacts

Finally, ghost fishing and entanglement problems are suggested by various impact analyses. Some of the greatest impacts may involve commercially valuable species. Lost traps have been estimated to catch an amount equal to 7.2% of the Fraser River Dungeness crab fishery landings in 1984 (Breen 1987), 7.5%-30% of the British Columbia sablefish fishery landings between 1977 and 1983 (Scarsbrooke et al. 1988), and 5% (577 mt) of the New England lobster fishery landings in 1976 (Smolowitz 1978). These losses, however, do not consider ghost fishing by all types of lost gear. For example, lobster are caught in lost gillnets. During annual visits to a lost net off New England over a three-year period, four lobsters were seen caught in the first year's visit, three in the second year's visit, and seven in the third year's visit (Carr and Cooper 1987). If such catches occur year-round in lost gillnets, and lobsters are also caught in other types of lost nets, combined ghost fishing levels could be much greater than estimates for lost lobster pots alone.

The estimates also may underestimate the effect of traps on predator-prey interactions. For example, there is evidence that octopus are attracted to Dungeness crab traps (High 1976) and king crab traps (Pers. comm., B.G. Stevens, NMFS, Kodiak, AK 99615) where they find an easy meal of crabs and fish temporarily using old traps for shelter. By such interactions, lost gear may indirectly increase mortality of crabs and fish by increasing their vulnerability to predators.

There also is evidence of ghost fishing problems by gillnets from efforts in Newfoundland, Canada, to retrieve lost nets (Brothers 1992). Using a grappling device to recover lost nets, researchers retrieved 148 nets in 20 days in 1975, 167 nets in 24 days in 1976, and 16.5 nets in 20 days in 1984. Together, the 315 nets pulled up in 1975 and 1976 had 7,860 kg of fish and 4,053 kg of crab; nets recovered in 1984 had no fish or crab. The catch rates are hard to interpret given that some fish and crab may have been caught during the retrieval process while others may have dropped out. They do, however, raise concern.

Small scraps of net and line from fishing gear also are the most common items found on entangled turtles, marine mammals, and seabirds (Laist, in press). For some species entanglement-related mortality is a key conservation issue. The best known example is probably the northern fur seal population on the Pribilof Islands. Modeling studies suggest that 50,000 fur seals may have been killed annually by entanglement in pieces of trawl web and other debris during the 1970s, and that this was the major cause of the population's decline in the late 1970s and early 1980s (Fowler 1982). Problems also may exist for endangered Hawaiian monk seals and sea turtles. Entanglement rates seen on short field visits to the Hawaiian monk seals' five major breeding sites range from 0 to 7.5% per year for individual colonies (Laist, in press). For sea turtles, 6% of the 800 loggerhead turtles collected at sea near the Azores for tagging from 1990 to 1993 carried entangling debris (Bjorndal and Bolton 1994). In both cases, net and line from fisheries was the principal entangling material.

Solutions to Ghost Fishing and Entanglement Problems

To date, efforts to reduce ghost fishing and entanglement have concentrated on two areas: (1) encouraging disposal of old fishing gear and trash on land, and (2) designing escape panels for lost traps and pots. Although progress has been made in both areas, far more could be done in these and other areas.

Disposal of Old Fishing Gear

The arsenal of management actions to limit discharges of old fishing gear focus on promoting land-based disposal. They stem from requirements in Annex V of the International Convention for the Prevention of Pollution from Ships, which took effect in 1989. Annex V, now signed by more than 65 nations, requires its parties to adopt conforming rules to reduce pollution caused by discharges of ship-generated garbage and to ban the disposal of plastics at sea. Because most fishing gear has plastic components, intentional dumping of old gear or scraps from net repair at sea is prohibited. The only exceptions are throwing back plastics caught incidentally in retrieved fishing gear, and accidental gear loss.

The Coast Guard is responsible for enforcing Annex V in the United States. To date, fines up to a $500,000 maximum limit have been assessed for illegal discharges of garbage from ships. Enforcement, however, faces obvious challenges. Illegal dumping is not easily observed in remote areas or at night, and once gear is discarded at sea, it is almost impossible to trace its source or determine if it was lost accidentally or thrown overboard illegally. Thus, it is generally acknowledged that preventing illegal discharges will depend less on enforcement and more on education and positive incentives.

In this regard, public awareness has long been recognized as a fundamental starting point.

Perhaps the first such effort was in the 1970s when the North Pacific Fur Seal Commission distributed posters to North Pacific trawlers urging that pieces of trawl net and strapping bands be kept for on-land disposal to avoid entangling northern fur seals. As concern about fishing debris in the North Pacific increased, regional industry leaders attempted to broaden industry awareness by convening a North Pacific Rim Fishermen's Conference on Marine Debris in 1987 (Alverson and June 1988). Education also has been a cornerstone of the National Marine Fisheries Service Marine Entanglement Research Program since its inception in 1986. Over one-third of its annual budget has been spent on education. The Coast Guard also is implementing a major public outreach effort. Such efforts must be continued and vigorous involvement by the fishing industry is needed to maintain high awareness levels.

In a practical sense, however, availability of convenient port reception facilities for old fishing gear and other ship-generated garbage may be even more important than education. For only when convenient alternatives to at-sea disposal are readily available, will compliance be a reasonable expectation. Port reception facilities for vessel garbage are mandated by Annex V and the Coast Guard is working with port operators to meet this mandate. The Marine Entanglement Research Program has also been helping address the special needs of the fishing community by funding pilot projects to develop reception facilities in fishing ports (Recht 1988), and encouraging gear recycling programs in fishing ports. While these efforts are beginning to address port needs, much work is needed to develop gear disposal strategies and to assure that port facilities to handle old fishing gear are widely available. Industry organizations and vessel operators should both work closely with port operators and government agencies to demand their development.

Gear Design to Reduce Ghost Fishing

Another approach to ghost fishing is degradable escape mechanisms. This approach has focused on pots and traps and involves incorporating trap panels or flaps secured with a material known to degrade within a set time. When the degradable fastener fails, the panel or flap opens, minimizing the risk of entrapping target species. Such escape mechanisms have been investigated since at least the 1970s. The state of Alaska began requiring use of degradable cotton twine on all crab pots and fish traps in 1977 and similar requirements now exist for most trap fisheries. Effectiveness of the measure, however, is uncertain. Little has been done to assess mortality in traps with open panels over the long term, and enforcement is difficult because of the similar appearance of pure cotton and blended cotton-synthetic twine (Kimker 1994).

In addition to enforcement problems, the cost of time release devices, maintenance requirements, and reliability have slowed the adoption of time-release escape panel requirements in many fisheries. Nevertheless the concept underlying the approach is sound and further development of cost-effective gear disabling mechanisms should be pursued vigorously for traps and pots, as well as other types of gear. For example, degradable floats or float-release mechanisms for gillnets could reduce the time lost nets maintain vertical profiles that increase ghost fishing rates. Degradable netting and line also might be used more widely with degradation rates established to last somewhat longer than its normal gear life expectancy.

Other Approaches

Other ways to resolve ghost fishing and entanglement problems include: (1) dedicated efforts to retrieve lost gear, (2) modifying fishing practices, (3) technology to help locate lost gear and reduce the likelihood of loosing gear, and (4) further research on the nature and extent of the problem. These have received little attention but offer some promising opportunities.

Several possibilities exist for recovering lost fishing gear. First, concentrations of lost gear may be large enough in some areas to make grappling a cost-effective clean-up action. Efforts to retrieve lost gillnets met with some success in Canada and further assessment of its feasibility in selected areas should be done. Second, lost nets, traps, and line caught by trawlers, draggers, and other fishing vessels is often thrown back (an action allowed by Annex V since it was not generated by the retrieving vessel). Encouraging greater effort to retain this debris or to strip all netting and line from it for disposal in port is another way of reducing derelict gear. Third, greater effort should be made to record where gear is lost and to recover it. As a part of National Coast Week or another suitable occasion, industry groups might organize an annual derelict gear retrieval day and encourage members to voluntarily return to recorded sites to attempt its recovery.

Fishing practices also might be changed to avoid gear loss situations. In particular, steps could be taken to reduce fishing in known hazard areas, or fishing in fringe seasons when sudden storms or ice conditions make it less likely gear will be tended regularly, and increase the risk of gear loss.

New options also may be possible to improve chances of locating lost gear or preventing its loss in the first place. For example, low-cost sonar reflectors or sonic devices might be designed to attach to nets and traplines to help locate them if they are lost. Automatic radio-operated float releases also might be designed as back-up markers. Then, if a primary marker or high flier is lost due to a ship collision, storm, or other cause, the device could be activated by a tending vessel to help locate and recover the gear.

Finally, better data is needed on the nature and extent of the problem. In particular better information is needed on the rates, location, and primary causes of gear loss, the hazard-life and catch rate of different types of lost gear (including gear with escape panel mechanisms) over the long term, catch rates in unbaited lobster traps left at sea for wet storage in non-fishing seasons, and estimates of total ghost fishing losses for selected species (particularly crabs and lobster) by all types of lost gear that can be factored into stock assessments.

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Sources of Accounted and Unaccounted Fishing Mortality

Frank Chopin, Yoshihiro Inoue, and Y. Matsushita
The National Research Institute of Fisheries Engineering, Ebidai, Hasaki-Machi Kashima - Gun, Ibaraki, 314-04, Japan

Takafumi Arimoto
Tokyo University of Fisheries, 4-5-7 Konan, Minato-Ku, Tokyo 108, Japan

Discarding of nontarget species and sizes of fish by commercial fishing vessels is a common practice in many fisheries around the world and is currently estimated at 27 million tons globally. Efforts to reduce discarding through mechanical selection were started over 100 years ago and were the precursor to mesh selectivity research in many European countries. The release of fish through mechanical selection is now a preferred management tool in many fisheries. In recent years, research into fish mortality after escape has shown that mortalities vary by gear type and species, may be immediate or delayed, and may be due to injuries or stressors associated with capture-escape trauma. In addition to escape mortality, there are other unaccounted mortalities associated with different capture technologies. This paper reviews sources of unaccounted fishing mortality, presents a general model of the capture process, and proposes a set of conservation technology penalties for discards, ghost fishing, and escape mortalities for each gear type and fleet sector. An effective conservation philosophy for reducing resource waste must include a shift of research to the commercial sector and a review program to allow for penalty reductions when new technologies are introduced.

The current level of world marine fish catch is estimated at 83×10^6 tons, and levels of discards, estimated at 27×10^6 tons (33%), suggest that the number of fish being killed globally is in excess of the world's oceans' theoretical potential yield of 100×10^6 tons (Gulland 1971). From a global food security perspective, it has been estimated that the world's population will increase from its present level of 5.3 billion to around 8.9 billion by the year 2030 and it is anticipated that this dramatic rise in population will put increased demands on fish resources which are already assumed to have reached, or are close to reaching, a harvest limit. In light of the fact that most fish resources are considered to be either fully, or over, exploited (FAO 1993), and with future growth in global population placing additional demand on available food resources, the need to identify, quantify, and reduce sources of resource waste in all areas of food production will become critical.

Mortalities associated with fishing may be termed "accounted" if they are specifically measured, as in the case of reported catch, or "unaccounted" as in the case of escape and discard mortalities. In addition to discards, there is a wide variety of other unaccounted fishing mortalities including ghost fishing, non-reporting or under-reporting of landed catch, and mortalities of fish encountering fishing gear but not caught. While some types of unaccounted mortality are a function of landing practices and may be common to all gear types (illegal landings, under-reporting, etc.), others may be directly attributable to the type of harvesting technology employed.

The development of conservation harvesting technologies within a framework of ensuring food security and minimizing all sources of resource waste, requires a detailed investigation of the levels of total fishing mortality associated with each gear type and development of methods to quantify and reduce resource waste in commercial fisheries. This paper reviews recent research in this field and suggests a collaborative framework between industry and government for identifying, reducing, and regulating harvesting technology.

Methods

Three sources of data were used to identify sources of unaccounted fishing mortality. The primary source of information on discards was Alverson et al. (1994). Data on fish mortality after escape or release was from Chopin and Arimoto (1995) in which we reviewed data from a wide variety of commercial, recreational, aquaculture, and research fisheries. The source of information on ghost fishing was provided by He (Pers. Comm., Dr. P. He, Memorial University, Box 4920, St. John's A1C 5R3, NF, Canada) from a review of ghost fishing technologies. Assistance in categorizing some types of unaccounted fishing mortality was provided by members of the ICES Study Group on unaccounted fishing mortality, Aberdeen, Scotland, 1995.

Results

Mortalities after escape were recorded in a wide variety of fishing gears and fish species, and occurred within the gear immediately after release or were delayed for up to several weeks. Specific causes of death were not always recorded but were attributed to stress, injuries, fatigue, and exhaustion (Table 1). Fish in poor condition after escape were suggested as being more susceptible to disease or predation. In addition to escape mortalities that result from gear selection, mortalities also occurred in fish that were discarded by fishers (human selection) either because they are not marketable due to regulatory control, or had little or no market value (Table 2). Ghost fishing mortalities were only recorded for a variety of fish pots and gillnets (Tables 3 and 4) for fishing gears used in North America.

Discussion

While the objectives to reduce discards of non-target species and sizes through improving the selective characteristics of fishing gears has to some extent been achieved, much of this work has been based on the assumption that fish escaping from fishing gears are not damaged, minimally stressed, and able to make a complete recovery after escape. However, in many cases, escape only occurs after the fish have been subjected to a wide variety of capture stressors and possible damage due to contact with other fish, debris, or the fishing gear (Chopin et al. 1995). Ghost fishing was found to occur in pots and traps with some evidence that the gear may continue fishing for many years after being lost (High 1985). While discard, escape, and ghost fishing mortality represent three types of unaccounted fishing mortality currently under investigation, there is a variety of other fishing-induced mortalities in reported catches, non-reported or under-reported catches, and fish that drop off or out of the gear during retrieval or are eaten by predators (Fig. 1). In addition, fishing mortality may occur as a result of changes in habitat caused by the fishing gear.

Based on the information provided by the reviews, a general fishing mortality equation can be developed:

$$F = (F_{CL} + F_{AL} + F_{RL}) + F_B + F_D + F_O + F_A + F_E + F_G + F_P + F_H$$

Where:

$(F_{CL} + F_{AL} + F_{RL})$ represent fishing mortality associated with commercial, artisanal, and recreational fish landings respectively

F_B Illegal and mis-reported landings

F_D Mortality associated with discards

F_O Mortality associated with fish passively dropping off or out of fishing gears

F_A Mortality associated with fish avoiding the fishing gear

F_E Mortality associated with fish after escape from fishing gear

F_G Mortality associated with ghost fishing

F_P Mortality associated with predation after escape

Table 1. Mortality of fish escaping or released from fishing gears. Chopin and Arimoto 1995.

Fishing Gear	Species	Mortality %	Comments	Reference
Surrounding gear	Scomber sp.	50 - 90	Simulated purse seine experiment	Lockwood et al, 1983
Seine nets	Cod & haddock	0 : <10	Fish retrieved at surface	Soldal and Isaksen, 1993
Seine nets	Striped Bass	1-17	Beach seine. Mortalities of released fish reduced through improved handling techniques	Dunning et al. 1989
Seine nets	Freshwater Drums	84.7	Beach seine. Estimated mortality after release due to stress and injury	Fritz and Johnson, 1987
Trawls	Haddock	7 - 78	Fatigue mortality experiment. Fatigue mortality estimated at 0 - 27%	Beamish, 1966
Trawls	Gadoids		Otter trawl and Danishs seine. 39% - 100% surface tagged fish. 12% - 65% surface non-tagged fish. 0% - 50% bottom tagged fish. 4% - 32% bottom non-tagged fish	Hislop and Hemmings, 1971
Trawl	Various	varied	Discarded fish study in shrimp trawls. Mortality rates depended on time on deck but all fish did not survive 20 mins on deck	Wassenberg and Hill, 1989
Trawls	Haddock & whiting	9-27 :10-35	Codend mortality. Figures quoted from tables. Large variation between species and years	Sangster and Lehmann, 1993
Trawls	Melanogrammus sp.		Otter trawl. Dead and injured fish found in the wake of the trawl. 163-169 dead fish/hr tow	Zaferman and Serebrov, 1989
Trawls	Gadoids	14 - 100	Otter trawls. Large variation in mortality between cages, species and years	Main and Sangster, 1990
Trawls	Haddock & whiting	9-27 : 10-35	Otter trawl	Anon, 1993
Trawls	Cod & haddock	0 : 1 - 32	Otter trawl codend	Soldal et al. 1991
Trawls	King and Tanner crab	21-22	Otter trawl. Non target catch	Stevens, 1990
Trawls	Lobster	21	Nontarget catch. Mortality varied depending on moult condition	Smith and Howell, 1987
Trawls	Atlantic halibut	65	65% mortality after 48h compared to 23% mortality for longline caught fish	Neilson et al. 1989
Trawls	Clupea harengus	85-90:75-85	Diamond mesh mortality : Sorting grid mortality	Suuronen et al. 1993
Trawls	Scup, flounder, cod	0-50: 0-15:0	Otter trawl	DeAlteris and Reifsteck, 1993
Dredges	Pecten sp.	78 - 86	Boat operated scallop dredge. Mortality from gear, predation and disease	McLoughlin et al 1991
Dredges	Placopecten sp.	10 - 17	Boat operated scallop dredge	Caddy, J.F. 1973
Gillnets and entangling nets	Pacific salmon	80 -100	Cumulative mortality in captive fish	Thompson et al, 1971
Gillnets and entangling nets	Pacific salmon	80	Cumulative mortality due to scale damage and stress	Thompson and Hunter, 1973
Gillnets and entangling nets	Clupea sp.	1.9	Actual mortality was v. high but attributed to disease	Hay et al 1986
Hooks and Lines	Oncorhynchus sp.	12 - 69	Catch and release mortality estimates	Vincent-Lang et al 1993
Hooks and Lines	Oncorhynchus sp.	34-52:40-86	Coho salmon : Chinook salmon	Parker et al 1959
Hooks and Lines	Salmo sp.	0	No mortalities after 3 days but measurable stress	Wydowski et al 1976
Hooks and Lines	Rainbow trout	39 : 3 - 5	Hook swallowed corn bait : artificial lure	Barwick, D.H. 1985
Hook and Lines	Cutthroat trout	0.3 : 3	One time hooked mortality : multiple hooking	Schill et al 1986
Hooks and Lines	Trout	0-8.6	Angling mortality	Dotson, 1982
Hooks and Lines	Smallmouth Bass	0 : 11	Artificial lures : live bait	Clapp and Clark,1989
Hooks and Lines	Esox sp.	3	Angling mortality	Schwalme and Mackay, 1985
Hooks and Lines	Chinook salmon	9 - 32	Trolling. Small fish had higher mortalities	Wertheimer, A. 1988
Hooks and Lines	Pacific salmon	41	Trolling. 34% immediate mortality and 7% delayed mortality.	Milne and Ball, 1956

F_H Mortality due to changes in habitat associated with fishing gear

The validity of any general equation used for measuring fishing mortality requires that each category of mortality can be measured reliably. With the exception of reported catches, the category that has received most attention to date has been discard mortalities (assumed at 100%). These are estimated at 27×10^6 mt globally and for specific fisheries may be in excess of reported catches. Almost no information is available on avoidance mortality and habitat degradation. The level of illegal, non-reported, or under-reported catches will vary by fishery and, although not measured, may be one of the largest sources of unaccounted fishing mortality.

Techniques are now available that allow us to measure at least three major sources of unaccounted fishing mortality—discards, escape, and ghost fishing mortality. If accurate measurements could be made of each category of fishing mortality, it might be possible to develop a strategy for conservation technology penalties. For example, consider a multi-gear fishery in which the level of discards, escape mortality, and ghost fishing could all be measured. Their inclusion with reported catch for a particular gear type may be more representative of the actual fishing mortality. Such that:

$$F_{ij} = F_{Cij} + F_{Dij} + F_{Eij} + F_{Gij}$$

Where:

F_C represents reported catch

F_D represents discards

F_E represents mortalities due to escape

F_G represents mortalities due to ghost fishing

Table 2. Global marine discards on the basis of the FAO International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP) species groups. Alverson et al. 1994.

ISSCAAP	Mean Discard weight (mt)	Landed catch weight (mt)	Ratio of discarded weight to landed weight	Ratio of discarded weight to total weight
Shrimps, prawns	9,511,973	1,827,568	5.20	0.84
Redfishes basses, congers	3,631,057	5,739,743	0.63	0.39
Herrings, sardines, anchovies	2,789,201	23,792,608	0.12	0.10
Crabs	2,777,848	1,117,061	2.49	0.71
Jacks, mullets, sauries	2,607,748	9,349,055	0.28	0.22
Cods, hakes, haddocks	2,539,068	12,808,658	0.20	0.17
Miscellaneous fishes	992,356	9,923,560	0.10	0.09
Flounders, halibuts, soles	946,436	1,257,858	0.75	0.43
Tunas, bonitos, billfishes	739,580	4,177,653	0.18	0.15
Squids, cuttlefish, octpuses	191,801	2,073,523	0.09	0.08
Lobsters, spiny lobsters	113,216	205,851	0.55	0.35
Mackerels, snooks, cutlassfishes	102,377	3,722,818	0.03	0.03
Salmons, trout, smelt	38,323	766,462	0.05	0.05
Shads	22,755	227,549	0.10	0.09
Eels	8,359	9,975	0.84	0.46
Total	27,012,099	76,999,942	0.35	0.26

Table 3. Ghost fishing impacts of gillnets, North American data. He 1995.

Fishing Gear	Losses or Ghost Fishing Impact	Reference
Cod Gillnet - Nfld Canada	5000 nets lost annually	Fosnae 1975
Groundfish Gillnet - Atlantic Canada	8000 nets lost annually (2%) 3600 tonnes fish caught annually	CFCL 1994
Groundfish Gillnet - New England USA	39 nets lost per sq. nautical mile	Carr et al. 1988
Groundfish Gillnet - New England USA	Cumulative catch (74 days) = 25 fish + 48 crabs per net	Carr et al. 1985
Groundfish Gillnet - New England USA	Ghost nets fish at 15% efficiency of standard nets	Carr & Cooper 1988
Cod Gillnet - Nfld Canada	Recovered nets contained 20 kg fish per net, 10 kg crab per net	Way 1976
Cod Gillnet - Nfld Canada	Recovered nets contained 29 kg fish per net, 15 kg crab per net	Way 1976
Herring Gillnet - BC Canada	Nets ghost fish for 7 years	Breen 1990
Salmon Gillnet - W. Coast USA	Net continues to fish for 2 years (fish) and 6 years (crabs)	High 1985

Table 4. Ghost fishing impacts of pots, North American data. He 1995.

Fishing Gear	Losses or Ghost Fishing Impact	Reference
Dungeness Crab Pot - BC Canada	11% pots lost annually, 16.9 caught per pot per year, 59% mortality	Breen 1987
Dungeness Crab Pot - Calif. USA	10,000 pots lost annually (2%)	Kennedy 1986
King Crab Pot - Alaska USA	10% pots lost annually, 12% ghost fishing mortality	High and Worland 1979
Snow Crab Pot - Nfld Canada	8.3% pots lost annually, ghost fishing mortality 0.5% landed catch	Miller 1977
Snow crab pot - NB Canada	2,466 pots lost annually, 44.3 crabs per pot = 100 tonnes annually	Mallet et al. 1988
Lobster Pot - New England USA	Ghost fishing rate = 10% of standard pot	Pecci et al. 1978
Lobster Pot - E. Coast USA	93,000-187,000 pots lost annually	Breen 1990
Lobster Pot - E. Coast USA	Ghost fishing catch = 670 tonnes	Smolowitz 1978
Sablefish Fish Pot - BC Canada	Ghost fishing catch = 326 tonnes per year (1977-1983)	Scarbrooke et al. 1988

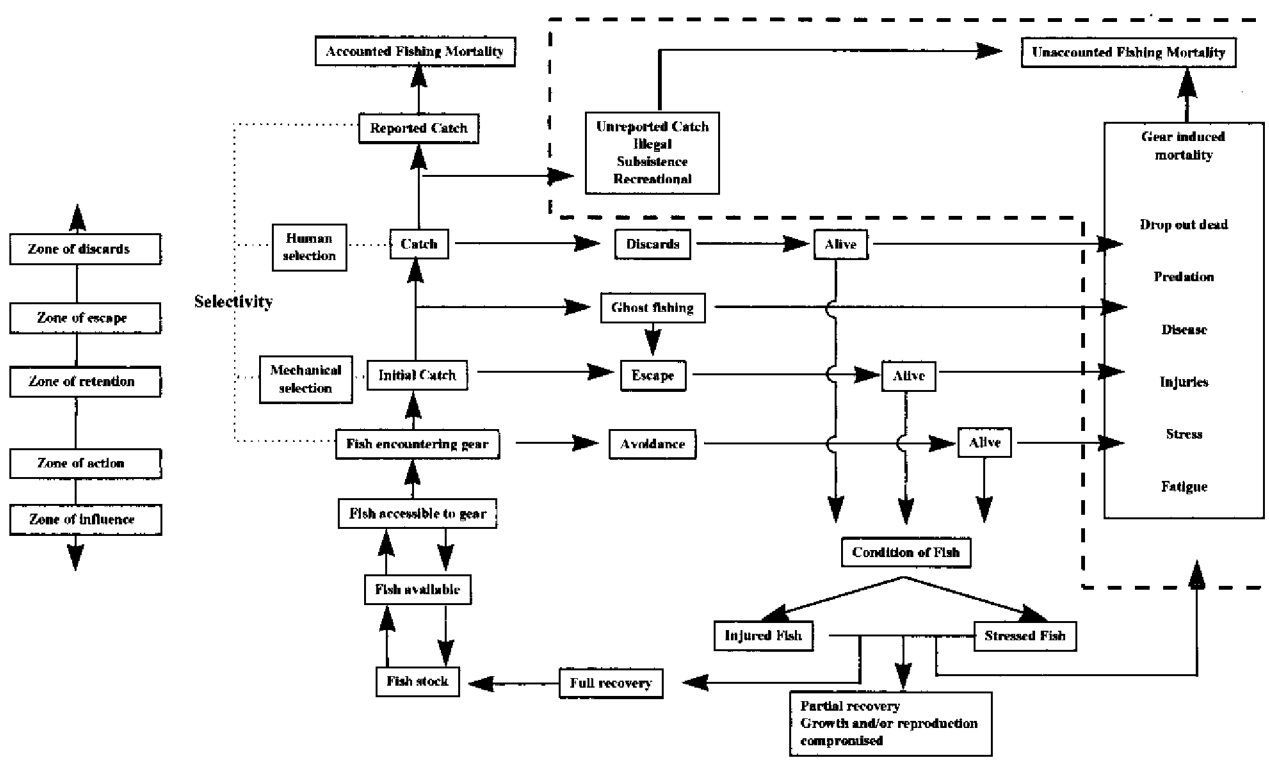

Figure 1. General capture-mortality model for fish and other animals encountering fishing gears (Chopin et al. 1996).

i represents the size of fish

j represents the gear type

While implementing a strategy for management and development of harvesting technology appears to be an appropriate step toward rational utilization of fish resources, there are still significant problems that need to be resolved before industry and fisheries managers might adopt technology penalties as a part of a resource conservation management plan. Much of the current research on unaccounted fishing mortality has not been carried out in commercial fisheries. To date, there are no standard experimental protocols for escape, ghost fishing, or most other categories of unaccounted fishing mortality. For example, escape mortality has been estimated from laboratory experiments using wild and cultured fish (Thompson et al. 1971) and during non- commercial fishing trials (DeAlteris and Reifsteck 1993). Post release observation periods have ranged from 12 h for discard mortalities (Wassenberg and Hill 1990) to in excess of 40 days for otter trawl escape mortalities (Sangster and Lehman 1993). The lack of appropriate experimental protocols, time series data, and repeat experiments make it difficult to have a high degree of confidence in much of the data collected to date.

While shifting the research base to commercial fishing vessels will make the results more representative of commercial fishing fleets, the final objective of the research is not only to identify and quantify levels of unaccounted fishing mortality, but to seek ways of reducing or eliminating all sources of resource waste. For this to be achieved, practical technological solutions must be found and a review process put in place to reward industry when it has been able to reduce or eliminate one or more sources of technological waste. This has more chance of success if industry takes a lead role in R&D planning and execution of conservation technology projects, since there are both biological as well as economical investments at stake. If a technology review policy

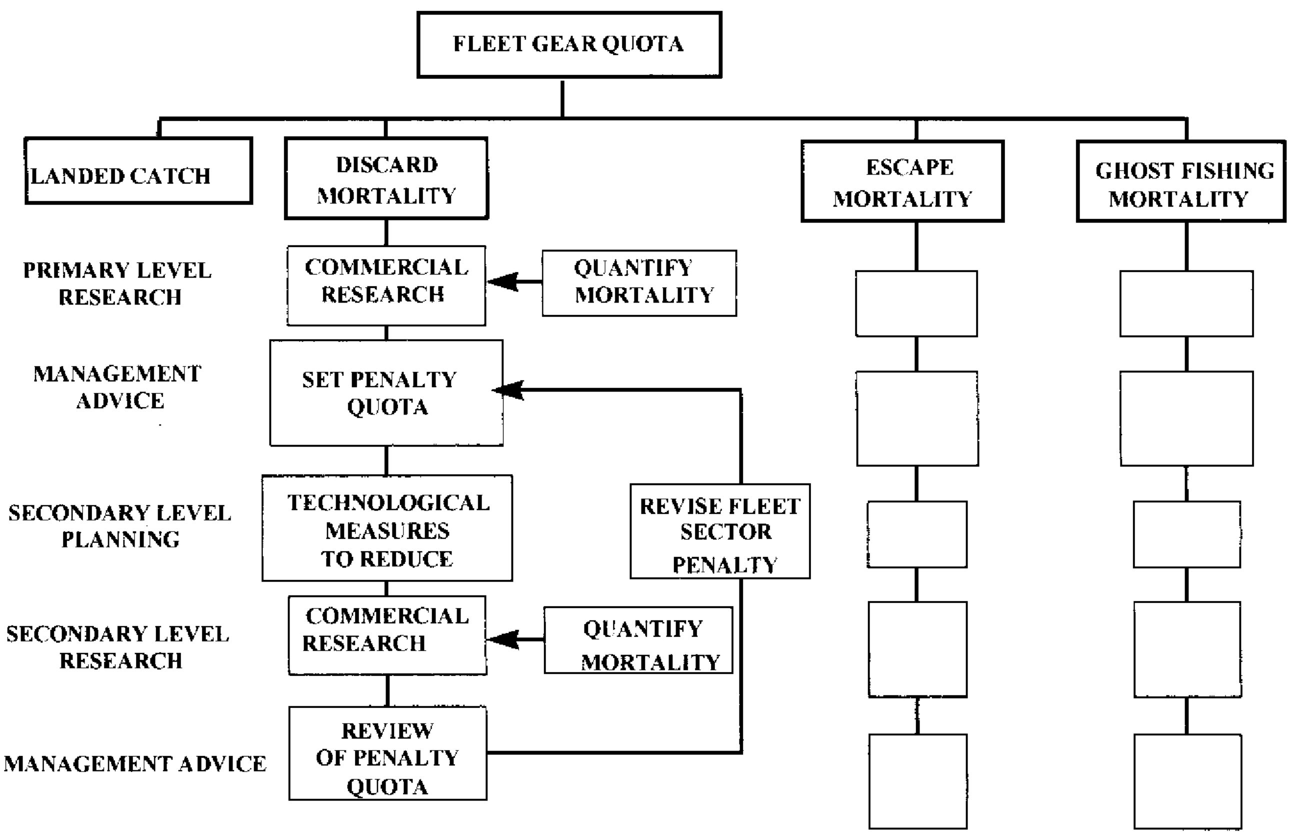

Figure 2. A flow chart illustrating the primary and secondary research required for assessing and reviewing technology penalty quotas associated with discards, ghost fishing, and escape mortality.

were incorporated into the management process (Fig. 2), the willingness of industry and managers to cooperate in developing a conservation philosophy would be greatly enhanced.

Acknowledgements

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Win-Win Bycatch Solutions Phase II: The Federal Role

Rolland A. Schmitten
National Marine Fisheries Service, 1335 East-West Highway, Silver Spring, MD 20910

Solutions to bycatch problems will come from a strong industry-government partnership that makes good use of the energies and skills of the conservation and academic communities. The proper role of government is not to force bycatch regulations and systems on an already heavily burdened industry. Instead, it should be to provide planning support, sponsor and coordinate research, disseminate bycatch data and other information, educate the public on the real issues and progress being made, and perhaps most important, listen to what the industry is saying. Examples of what government is doing are described. The paper ends by describing, in general terms, what has been learned so far about resolving bycatch problems.

You may be familiar with Jim Martin's bycatch parable, captured by Brad Warren in the January 1995 issue of *National Fisherman*. Jim, the former Oregon Chief of Fisheries, was a real general in the bycatch wars, and all of us would do well to remember his "Riders of the Lost Ark" story:

> Indiana Jones is creeping up a tangled passageway in an ancient, cobwebbed temple, trying to avoid all kinds of little booby traps. He almost gets by all the traps when suddenly, he steps down and hears a little "click." All of a sudden, a huge rock comes rolling down the passageway at him! He's got to figure out how to beat the rock or get out of the way, but there is no place to get out of the way.

Jim relates that story to bycatch: "We just heard the click."

That click is driving the National Marine Fisheries Service toward resolving some of our fisheries' most difficult problems. I believe in the "win-win" philosophy that Brad and others have defined, and we are committed to:

- Work in a real partnership with industry
- Seek new paradigms and solutions
- Carefully coordinate our internal research and grant programs
- Leverage funding and other resources to get the best "bang for the buck," and
- Listen . . . to everyone who has something to teach us.

I believe most of us are beyond the finger-pointing of past years and recognize that solutions will have to come from a strong industry-government partnership that also makes good use of the energies and skills of the conservation and academic communities. This paper describes what the government has been doing in the area of bycatch since the conference at Fish Expo '94.

As I see it, the proper role of government is not to force bycatch regulations and systems on an already heavily burdened industry. Instead, we should be providing planning support, sponsoring and coordinating research, disseminating bycatch data and other information, educating the public on the real issues and progress we are making, and perhaps most important, listening to what the industry, suffering the double-barreled assault of economic loss and public hostility, are telling us. I think we've made some real headway. Here are some examples of what we've done.

In the area of planning, we've helped sponsor many workshops, including this symposium and its proceedings. We gave contracts to the Alaska Fisheries Development Foundation, Gulf and South Atlantic Fisheries Development Foundation, National Fisheries Conservation Center, and Rhode Island Sea Grant for industry workshops to identify bycatch needs and generate solutions, especially those that are market-driven or non-regulatory in nature. Information from these sources will be used in the National Strategic Bycatch Plan being developed by the National Fisheries Conservation Center. I emphasize that this plan is industry-led and industry-coordinated, and that there will be many opportunities for input by everyone before it is finished.

National Marine Fisheries Service (NMFS) expanded its research support, too, especially under the Saltonstall-Kennedy (S-K) program. NMFS awarded more than $1 million for bycatch-related research grants; and the southeast's MARFIN bycatch grants totaled over $400,000. Bycatch will be a very high priority for both of these programs in 1996. We have also expanded our internal bycatch research in every region, with NMFS scientists and economists collecting data, conducting studies and analyses, and developing conservation gear to reduce incidental take in more than 20 fisheries nationwide.

In addition, we've undertaken some special bycatch research. We will be sponsoring a special S-K project of almost $1 million to help reduce bycatch in the North Pacific pollock fishery, and we contracted with Woods Hole Oceanographic Institution specifically to look at market-driven, non-regulatory methods for solving bycatch problems. This information will be used in the strategic planning process.

The agency is also improving its research coordination and substantially upgrading staff expertise in the area of bycatch. I have directed the agency to establish an internal bycatch work group to integrate our bycatch studies with research conducted under our grant programs. This will result in far better leveraging of available funds, in long-term research strategies, and in closer cooperation between NMFS and university researchers. We have also distributed to hundreds of our employees and to the Regional Fisheries Management Councils copies of the National Fisheries Conservation Center's "Win-Win Bycatch Solution," (Brad Warren, editor, 1994) and the FAO paper, "A Global Assessment of Fisheries Bycatch and Discards," (D.L. Alverson, M.H. Freeberg, S. Murawski and J.G. Pope, 1994).

I am also convinced that we must assist industry to disseminate accurate and timely information on bycatch, and to educate the public about progress in reducing bycatch. We are developing new outreach and communications systems to do this, and, of course, we are doing a lot better job of listening to the industry.

What have we learned from this focused effort? Following are the highlights; keep in mind that we are still very much on the ground floor in this endeavor.

1. The nature and scope of bycatch problems are different for each fishery. For example, in the seriously depleted New England groundfish fishery, even small incidental takes of juvenile haddock and sole can have a detrimental impact on the biological viability of those species. On the other hand, the low bycatch rates in the very viable North Pacific groundfish fisheries are perceived by the general public as horrendously wasteful, because even low rates mean hundreds of millions of discarded fish.

2. Solutions must consider regional needs. For example, using observers may be a good approach in Pacific fisheries where the greatest catches are taken on a relatively few large vessels landing their catches in a moderate number of ports. In the southeast, however, with its many thousands of shrimp trawlers and hundreds of landing sites, using observers to verify bycatch rates is much more problematic. Perhaps we can develop automated technologies that may be useful in such fisheries.

3. Many problems cannot be solved by regulations. Implementing and enforcing regulations is costly and in some cases, not very effective. Especially where concerns are for better utilization of waste and discards, where public understanding is faulty, or where there is inadequate scientific information for sound industry and government decisions, we should seek non-regulatory solutions. In fact, we are beginning to question whether some regulations to address bycatch problems (e.g., closed fishing grounds in Alaska) may actually contribute to a multitude of new bycatch problems as a result of forced changes in fishing effort and normal variations in the distribution and abundance

of both target and bycatch species. Our industry-government workshops and our research projects are yielding remarkable ideas about incentive-based programs, funding mechanisms for research and monitoring, and many other ingenious approaches.

4. There are many barriers to overcome in addressing bycatch. Some of these are legal; current statutes and regulations may not permit the application of some innovative and useful approaches that the councils and industry would like to try. Too, there are currently statutory prohibitions on the collection of industry fees to fund research and monitoring of fisheries. That relates to the barrier of fiscal limitations; there will simply never be adequate federal or state funding to conduct all the scientific and management activities that are necessary to resolve these issues.

Another concern is that there are sometimes serious philosophical differences within the industry, especially concerning the public nature of fisheries resources. For example, one good idea is individual bycatch quotas, but these are likely to be tied to limited access schemes that are opposed by some fishers. As I mentioned before, a major impediment is the lack of adequate scientific, economic, and social information about some fisheries. I have been heartened to learn, over and over again, of industry's belief that good statistical information on their catches and bycatch is the linchpin for a good bycatch reduction program, and I am also very much encouraged by industry's growing belief that we must also get a much better understanding of the effects of discards on fisheries ecosystems. This tells me that industry has its eyes on its own long-term well-being, and not just on short-term financial gain.

Finally, there are the serious barriers of poor communications and faulty public perception mentioned earlier. We must communicate accurate information among fishery participants, and to the public. This is especially vital where industry must spend precious resources fighting an unjustly negative image—resources that could be better used to address real problems.

5. Options must consider net economic and social benefits. We simply cannot implement regulations or promote other solutions that, while favoring one harvesting or processing sector, seriously damage other, perhaps broader societal elements. We must have the will to think in terms of what is best for the entire fishery and for our nation, and to eschew parochial political solutions.

6. Market-based incentives may offer great flexibility. Incentive solutions assume that such programs reward, rather than penalize, innovation and accountability of individuals. Some examples are: "penalty boxes" (industry-enforced times-out, with corresponding loss of fisheries income, for those who continue to fish "dirty"); individual vessel quotas, as for dolphins taken in the Tropical Pacific tuna fishery, and halibut bycatch taken by Japanese groundfish vessels in the 1970s; and product endorsements and certification, as with the dolphin-safe tuna. These, and many other exciting ideas are expected to surface in the national strategic bycatch plan.

One of the most encouraging lessons we've learned is that industry at all levels is eager to contribute to this new partnership. We also learned that problem-solving must involve all the players in a fishery. Depending on the fishery, this may mean several industrial sectors and their organizations (including recreational interests), state and local governments, a Fishery Management Council and Interstate Marine Fisheries Commission, one or more international commissions, conservation groups, educational institutions, and others. We've learned that there will never be enough money to do all that's needed, so we must seek new funding paths and leverage our available resources very carefully.

The most important thing we discovered, however, was that if we learned to listen better, to hear what the stakeholders are really saying, we will hear the solutions to bycatch problems.

Where do we go now? It's not quite time to make a definitive long-term plan, although we now know what the next steps are. We're still listening.

Solving the Bycatch Problem: An Economic Perspective

Terrence P. Smith
National Marine Fisheries Service, Northeast Fisheries Science Center
166 Water St., Woods Hole, MA 02543

Because most fishing gear is not completely selective, fishing operations result in the incidental catch of species not targeted. This incidental catch, or bycatch, can occur in two contexts: (1) in a mixed species or multispecies fishery where the species caught are managed as a unit or by a single management agency, or (2) in fisheries where the bycatch of species regulated by a different management entity must be minimized. From an economic perspective, the first kind of bycatch can be dealt with using traditional management tools. Regulating the second kind of bycatch, however, creates additional costs. The "bycatch" fishery experiences control costs—foregone revenue from the loss of target species that might have been taken, and in addition, the increased operational cost associated with avoiding bycatch. The "other" fishery experiences impact costs—foregone revenue because the bycatch fishery reduced the potential yield from the fishery. This second class of bycatch control problem is common and exists, for example, in the groundfish fisheries off Alaska, where the bycatch of halibut, red king crab, Tanner crab, herring, and salmon is limited. It also exists in the gillnet fisheries for groundfish off New England, where time/area closures limit target catch to reduce harbor porpoise bycatch mortality. Controlling bycatch is thus another allocation issue and amenable to cost/benefit analysis. An examination of current bycatch management systems in the Alaskan groundfish fisheries and the northeast groundfish gillnet fisheries illustrate considerable differences between control and impact costs.

Fishing gear is not completely selective and will catch species other than those targeted. The incidental catch of species not targeted is the most general definition of bycatch and the one used for the purposes of this discussion. Note that this definition restricts bycatch to fish harvesting operations, as opposed to fish processing, or fish processing at sea.

Within this basic definition of incidental catch, however, there are many subcategories. Here, I define two types of bycatch: (1) mixed assemblages of regulated species taken by a gear (e.g., northeast trawl-caught groundfish), and (2) species taken incidentally that cannot be retained because of regulatory restrictions. In the mixed species case, it may be that the occurrence of a species other than that targeted is a relatively rare occurrence, such as groundfish species other than pollock in the spring midwater pollock fishery in the Bering Sea, or a true mixed species fishery where even the target species is difficult to identify. Examples of the latter category include the Alaskan bottom trawl fishery for pollock, cod, and yellowfin sole, or the northeast bottom trawl fishery for cod, haddock, and other demersal species.

In the definition of the mixed species case I include both retained species and market discards—fish thrown overboard for economic reasons. Examples include discard of fish smaller than that desired by the market; discarding due to a lack of a market, or because of quality considerations, high-grading, or culling the catch so as to fetch the highest payment for a given landed weight; and harvesting discard such as might occur when a fishery is targeting on roe-bearing females and discarding males.

For the regulated discarding subcategory, regulations may exacerbate market discarding or may create new categories of discards. Examples include discarding to comply with minimum size regulations, discarding to maintain compliance with a target fishery definition (e.g., for the purposes of enforcement, you are considered to be operating in a cod fishery if 20% of your total catch by weight is cod). Discards may be a result of the management regime such as a tendency toward high-grading in an individual transferable quota (ITQ) fishery, or discarding in fisheries controlled by trip limits.

Direct prohibition on all retention of a species occurs in situations where a regulatory entity other than that controlling the directed fishery is responsible for managing a fishery for the species taken incidentally, or where society has determined that the bycatch of the species should be at an absolute minimum. Examples of the former include the Prohibited Species Catch (PSC) controls in the groundfish fisheries off Alaska, and examples of the latter include management to protect harbor porpoise from bycatch mortality in the sink gillnet fisheries off the coast of New England. For the most part, this paper focuses on this type of bycatch, known as prohibited species catch.

I will not discus further the very first subcategory of bycatch, the mix of retained species that occurs in most fisheries. I do note, however, that where management of mixed species fisheries is a problem; from a biological, economic, enforcement, or even allocational perspective, standard management techniques and standard economic analysis can be applied. This does not mean that the management of mixed species or multispecies management is an issue easily dismissed. To the contrary, mixed species management, or what I prefer to characterize as multispecies management, is extremely important, and every bit as complicated and intractable as the bycatch issues we discuss below (see, e.g., MAFMC 1996).

The Costs of Bycatch

To provide an economic perspective on bycatch, I want to focus on regulatory discards and prohibited species. To do this we need to address costs.

The cost concepts I define are based on who bears the impact of bycatch reduction strategies. To begin, there are bycatch impact costs. I define these to be the sum of the costs (in foregone profits) to the harvesters who target the bycatch species. Reduction in bycatch reduces these costs and, thus, benefits the traditional harvesters. In the Alaska example, these are the harvesters of crab, halibut, herring, and salmon; species which may not be retained in the groundfish fisheries. Since the animals taken as bycatch may be juveniles not yet recruited to the legal target fishery, the time lag between bycatch mortality and fishing mortality in the directed fishery is often relevant and used to calculate the present value (as opposed to future value) of impact costs so as to allow comparability between impact cost and control cost (defined below).

In the context of protected or endangered species, the impact cost is the value placed by the public on an animal or, depending on the situation, a population of animals, threatened with bycatch mortality in a fishery. Specialized methodologies are often needed to estimate this type of impact cost.

Control cost is the other side of the bycatch cost equation and is represented by foregone profits realized by the sector that causes the bycatch. Control costs exist because, presumably, reducing bycatch will constrain the existing fishery either by raising costs or reducing revenues, or both. Obviously, if a fishery can reduce its bycatch without cost, bycatch management ceases to be a problem. Ironically, bycatch reduction strategies often implicitly assume zero control costs, when, in fact, significant costs exist.

With regard to one of the general themes of the workshop, bycatch reduction through technological development and intervention, both control and impact costs can be minimized if effective bycatch reduction devices or technologies are successful in reducing or eliminating bycatch while not reducing the harvest of retainable species. This is clearly a win-win situation.

Other potentially important cost components are management and enforcement costs. These third-party costs are generally borne by managers, enforcers, or implementers of regulations that affect the natural level of bycatch. These costs can be large if implementing, monitoring, or maintaining bycatch control systems is costly, or if compliance with regulations is poor. This category of costs will be additive to the impact or control costs mentioned above depending on where responsibility for implementation and enforcement of bycatch regulations lies. Customarily, responsibility for bycatch mitigation rests with the managers of the fishery taking the bycatch, and thus, these third-party costs are additive with control costs in the cost/benefit sense.

Bycatch Management

Now that I've defined several types of bycatch and talked about costs, let's consider the crucial question of bycatch management. Why or when do we have to manage bycatch? Most fundamentally, the answer is that the bycatch problem is not self-regulating. This is especially true in the context of the category of bycatch I've been talking about—prohibited species bycatch, true by definition in the regulated discard category, and generally true in the market discard category. For this last case, however, fishers discard part of the catch because the benefits of doing so (increased landing revenue) outweigh the costs of discarding (handling and sorting costs, potential lost future revenue and, perhaps, the costs of additional fishing effort).

Therefore, the simplest and most important lesson to be learned from an economic perspective on bycatch is this: If managers intervene to control bycatch, that intervention will cause a reallocation of fishery resources. Reallocation of fisheries resources is, therefore, the economic issue and the basis of all cost/benefit analyses of proposed bycatch management regimes. Said in a different way: bycatch management will change harvesting and management costs—impact, control, and other costs.

Management Objectives

Management should be effective, it should actually reduce bycatch; it should be efficient, it should be done at the least cost, it should be fair or equitable, it should balance the various costs across the affected parties. The last two of these objectives are in part economic concepts; thus, they are the economist's interest in bycatch management. An important economic fact is that ignoring the principles of efficiency and equity can lead to ineffective bycatch management strategies through non-compliance and prohibitively expensive control systems.

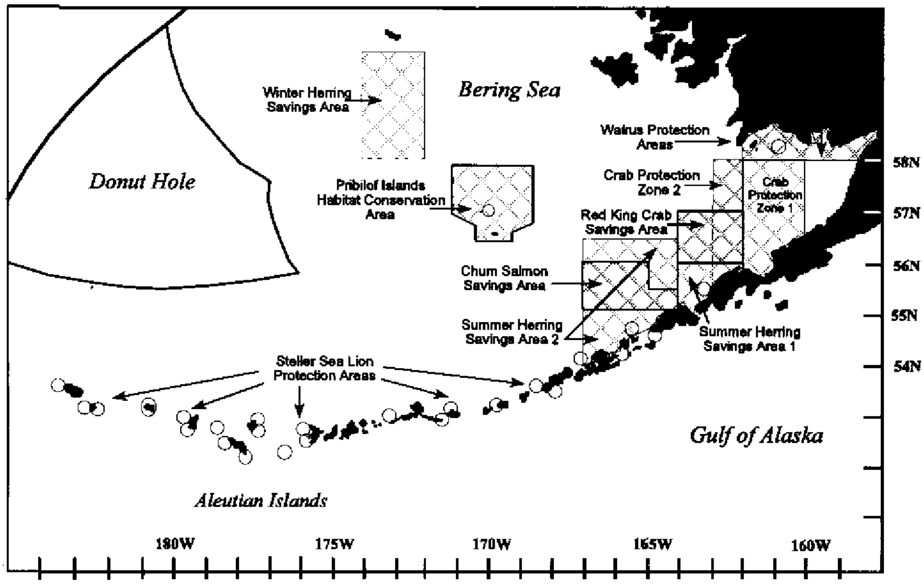
Management Examples

PSC Limits in the North Pacific Groundfish Fisheries

Since 1986, the North Pacific Fishery Management Council has placed limits on the total harvest of prohibited species taken as bycatch in the groundfish fisheries of the Bering Sea and Aleutian Islands (BSAI) and Gulf of Alaska (GOA). The program, which began with PSC limits on red king crab and *C. bairdi* Tanner crab bycatch in the joint venture fishery for yellowfin sole in the BSAI, was extended to the entire fleet in 1989 (NPFMC 1989). At the same time, Pacific halibut was added to the list of prohibited species. In 1990 the management system was amended twice to add the domestic rock sole and deepwater sablefish and turbot fisheries to the list of regulated groundfish fisheries (NPFMC 1990a), and to include time/area closures to limit the PSC of herring (NPFMC 1990b). The system has evolved over the last several years to include more target fisheries and more prohibited species (Witherell and Harrington 1995). Additional PSC limits on chinook salmon and *C. opilio* Tanner crab are under consideration (Pers. Comm., Dave Witherell, NPFMC, Anchorage, AK 99501, Sept. 21, 1995).

The management system is complicated with time/area closures in effect year-round or seasonally, partial or complete closures of areas (generally described as bycatch management zones, see Fig. 1), and allocation of the overall PSC limits to individual target fisheries (or gear groups) on a seasonal basis. Currently there are several hundred individual bycatch limits explicitly or implicitly established by the management regime.

As a rule, halibut PSC limits constrain a number of fisheries although some fisheries are limited by *C. bairdi* Tanner crab bycatch (Witherell and Harrington 1995). The controls on bycatch are now so pervasive that it is the PSC apportionments in a fishery rather than the catch quota (total allowable catch or TAC) that often determine the total harvest in the fishery (Smith 1992). Overall 1995 PSC limits in the BSAI are shown in Table 1. (The North Pacific Council also limits the bycatch of halibut in the groundfish fisheries in the GOA but the example presented is only applicable to the BSAI management system.)



Proposed Northern Bristol Bay Area: closed year-round to all trawling (proposed).

Chum Salmon Savings Area: closed to all trawling August 1-31 with provisional extention to October 5.

Bristol Bay Red King Crab Area: closed seasonally to non-pelagic trawling.

Pribilof Islands Habitat Conservation Area: closed year-round to all trawling.

Crab Protection Zones: Zone 1 closed to trawling year-round.
Zone 2 closed to trawling March 15 - June 15.

Walrus Protection Areas: closed to all fishing April 1 - September 30.

Steller Sea Lion Protection Areas: closed to all trawling year-round with some extended seasonally on January 20.

Herring Savings Areas: closed to all trawling when trigger reached.
Summer Area 1 closed June 15 - July 1
Summer Area 2 closed July 1 - August 15.
Winter Area closed September 1 - March 1.

Figure 1. Bering Sea species protection sreas. North Pacific Fishery Management Council.

Table 1. NPFMC prohibited species catch limits in the groundfish fisheries of the Bering Sea/Aleutian Islands.

Red king crab	200,000	animals	Zone 1
C. bairdi crab	1,000,000	animals	Zone 1
C. bairdi	3,000,000	animals	Zone 2
Halibut	4,675	mt	BSAI
Herring	1,861	mt	BSAI
Chum salmon	42,000	animals	

Table 2. Control versus impact costs in the PSC management system for groundfish in the Bering Sea/Aleutian Islands, 1992.

	Millions of Dollars
Impact Cost	$22.6
Control Cost	$100.1
Control – Impact	$77.5
Impact:Control (Benefit:Cost)	0.23

Table 3. Estimates and 95% confidence intervals for harbor porpoise bycatch in the Gulf of Maine sink gillnet fishery, 1990-1993.

Year	Bycatch #Animals	Confidence Interval
1990	2,900	1,500-5,500
1991	2,000	1,000-3,800
1992	1,200	800-1,700
1993	1,400	1,000-2,000

Table 4. Fleet size and characteristics for the Northeast sink gillnet fishery, 1993

	Class 2 (5-50 GRT)	Class 3 (51-150 GRT)
Vessels	233	7
Average crew size	2.6	4.0
Annual trips/vessel	51	41
Landings (all vessels)	22,700	mt
Ex-vessel revenue (all vessels)	$24.8	million

In an analysis of the costs and benefits (in terms of control and impact costs defined above), I examined the actual costs of controlling and saving bycatch in the BSAI management areas for the 1992 fishing year. These costs were contrasted with those estimated by a fishery simulation model which forecast the fleet behavior under various PSC limits and apportionments (Smith 1993). That analysis indicated that control costs (in foregone gross ex-vessel revenue) to the groundfish fleet were about $100 million, while impact costs (the present value of future profits from landing more crab, halibut, and herring) were about $23 million (Table 2). The unattractive benefit:cost ratio of about 1:4 is, of course, characteristic of a situation where control costs greatly exceed impact costs, and indicates that more efficient, equitable solutions are possible.

Northeast Groundfish Gillnet Fishery

The opposite situation exists on the East Coast where an emerging bycatch problem has been referred to the New England Fishery Management Council (NEFMC) for management solution. The management problem is the capture, and subsequent drowning, of harbor porpoise in sink gillnets in the Gulf of Maine. The gillnetters are targeting a mixed assemblage of groundfish species and are managed under the NEFMC's Northeast Multispecies Fishery Management Plan. Regulations currently in place impose regional time/area closures on the fleet designed to both limit harbor porpoise bycatch mortality and target fishery effort; the latter to reduce fishing mortality on depleted groundfish stocks.

The Numbers

Harbor porpoise in the Gulf of Maine/Bay of Fundy are recognized as a single management stock within a larger western North Atlantic population (Blaylock et al. 1995). Recent estimates of population size are variable, with a 1991 estimate of 37,500 animals and a 1992 estimate of 67,500 animals. The current best estimate of population size is 47,200 animals, a blend of the results of the 1991 and 1992 survey estimates (Blaylock et al. 1995). Potential biological removal (PBR), called for by the Marine Mammal Protection Act, is a function of minimum population size, productivity rates, and a recovery factor for stocks whose status is unknown with respect to optimal sustainable population levels (Blaylock et al. 1995). The current estimate of PBR is 403 animals.

Estimated bycatch mortality, although imprecisely determined, is considerably above this level (Table 3). Estimated total harbor porpoise mortality in the Gulf of Maine sink gillnet fishery has ranged from 2,900 animals in 1990 to 1,200 animals in 1992. The 1993 estimate of bycatch is 1,400 animals (NEFSC 1994). These are likely minimum estimates, as the totals do not include Canadian bycatch mortality or drownings occurring in the coastal gillnet fisheries. Preliminary 1994 data indicating higher bycatch rates than in the recent past imply that 1994 bycatch may be higher than these estimates.

In 1993, the Northeast gillnet fleet comprised about 240 vessels, mostly in the 5 to 50 gross registered ton class (NEFSC 1995) (Table 4). Most of the vessels are day boats, setting four or five strings of nets to be hauled the next day (NEFSC 1994). Collectively, the gillnet fleet landed 22,700 mt of mixed species in 1993 worth about $25 million at the ex-vessel level (NEFSC 1994).

Ted McConnell and Ivar Strand at the University of Maryland are completing a study designed to determine the public's willingness- to-pay to eliminate the harbor porpoise bycatch described above (McConnell and Strand 1995). In a draft manuscript reporting on a part of the study designed to test whether scientists' and the general public's preferences on harbor porpoise bycatch mitigation differ, McConnell and Strand estimate, for a sample of Massachusetts residents, a willingness-to-pay (to eliminate all bycatch) of $240 per household. Expanding this to all Massachusetts households implies a total willingness-to-pay in excess of $500 million. This number represents an estimate of the reduction in impact costs possible through elimination of bycatch mortality.

The control costs associated with elimination of this bycatch problem are overstated on the revenue side by gross, rather than net, revenue since complete elimination of the fishery implies elimination of the fixed and variable costs in the fishery. The estimate of $25 million mentioned above, however, does not include estimates of costs associated with the elimination of a traditional fishery including, for example, transitional assistance, family assistance, the costs of retraining captains and crews, and job placement assistance.

Nevertheless, in this case impact costs, or the gains to society of eliminating this bycatch problem, are likely to greatly exceed control costs. An important aside to this story is the possibility of a win-win solution through the use of innovative technology. Experiments in Canada and in the Gulf of Maine with pingers, devices that transmit an acoustic signal purportedly offensive to harbor porpoise, are encouraging in that bycatch is apparently greatly reduced without adversely affecting target catch. (Conservation Aspects of Fishing Gear: Cetaceans and Gillnets, by Jon Lien, in this volume).

Discussion

The preceding examples illustrate one reason that economic analysis of bycatch management actions is useful. In both of the prohibited species catch cases above, overall costs to society could be decreased through reallocation of resources. This is not surprising since bycatch in general, and prohibited species discard specifically, represent a classic case of an unaccounted external cost (known as an externality). Hence, the cost imposed on the consumers of the bycatch species should be estimated. Knowing the magnitude of the externality and identifying the individuals realizing these costs provides real opportunity for redress. Further, from both a management and equity perspective, it is important to identify the costs of controlling the bycatch. Quantifying this component allows for the design of more effective management systems as well as a more balanced impact/control cost tradeoff.

Most importantly, however, failure to properly account for the costs of bycatch can lead to serious misallocation of scarce living marine resources. Ignoring control costs or failing to recognize situations with great disparity in impact and control costs can result in failed bycatch management. For bycatch management systems to be effective, they must be efficient (attempt to minimize total impact and control costs) and equitable (result in the best use of the scarce resource). Consideration of these simple economic principles, therefore, is a necessary component to solving the bycatch problem.

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Perspectives on the Global Fisheries Crisis

Traci Romine
Greenpeace International, Rua Pinheiros, 240-CJ23, Pinheiros, São Paulo, Brazil

I will present some perspectives from Greenpeace on bycatch and fisheries issues in general. Greenpeace is an international environmental organization with offices throughout North and South America, the South Pacific, Asia, Europe, and Africa. For more than a decade, Greenpeace has been involved in fisheries issues both at the national as well as the regional and international levels.

Bycatch is an important ecological issue in fisheries today and one linked to overfishing. Defined as the incidental catch, take, or harvest of all marine life not directly targeted by fishing, bycatch has serious implications for marine life populations and the overall health and sustainability of ecosystems. As a coalition of North Pacific commercial and sports fishermen, Alaskan Natives, coastal residents, and environmentalists recently pointed out, bycatch results in the removal of fish that would be better left in the sea alive as part of the intricate food web. Bycatch is not exclusive to any particular gear type or any particular region of the world.

The images of bycatch and the waste it represents are issues through which the public and fishers come to understand the overall problems plaguing world fisheries. On one hand, minimizing and eliminating bycatch will significantly improve fisheries. On the other hand, even the most comprehensive bycatch strategies will only be partial solutions if broader overfishing and structural issues in fisheries are not addressed.

In many countries, the public's perception and that of fishworkers is that something is seriously wrong in world fisheries. On the front pages of international magazines such as the *Economist*, in newspapers such as *The New York Times* or the *Boston Globe*, the stories clearly indicate that fisheries worldwide are in crisis. Headlines such as, "Stripping the sea's life," in the *Boston Globe* are more and more commonplace.

Thousands of fishworkers, their families, and residents of coastal communities on the east coasts of Canada and the United States, or Peru, Brazil, or Iceland need not read the newspaper, they feel the impacts of the crisis every day with lost jobs and livelihoods, and the destruction of their cultures. Weber concludes, "Human action has already caused significant declines in individual marine fisheries. Ironically, the primary problem facing fishers is their own capacity to catch fish." Quoting James McGoodwin, Weber continues, "Indeed, what is fascinating, and also tragic about the fishing industry is that it so actively participates in its own annihilation."

Bycatch cannot be separated from the need to grapple with other, perhaps more difficult problems confronting fishers, fisheries, and marine ecosystems today. Overfishing, waste, and discards leading to ecosystem degradation and collapse are tied, in large part, to over-capacity, non-selective technologies and the lack of cooperative systems of management, control, and enforcement based on strong conservation principles and objectives. Driven often by short term economic objectives and trade, these conditions drive an extremely destructive cycle that if allowed to continue into the future, will result in more social dislocation and environmental destruction.

In the last five or six years, fishermen have begun to realize that working with environmental objectives and achieving clean and responsible fisheries, rather than fighting against them, is in their best interests. In an article about the perceived threat from environmental organizations, Reed wrote, "With pollution still pouring into the seas, haven't we gotten together with fishermens' groups across Europe and spoken with a united voice against it? We're the ones who stand to loose the most financially and yet it's the greens who, publicly at least, seem to be fighting our fight for us. We may have a few embarrassing questions to answer—black fish, discarding, rule-bending, etc. But we should spread the idea that a 'green' fishing industry is in our long-term interests." Reed continues, "It's a message that many of us have yet to learn. Recently we saw a pelagic buyer warning of impending disaster if the North Sea herring fleet continued to misreport catches. It would be ironic if the jobs of workers both on and offshore are ultimately saved by the green threat."

In many parts of the world, fishworkers and environmentalists are finding common ground in working for a sustainable future and incorporating environmental principles into their demands for better, more responsible fisheries. Since 1992, there has been a growing movement willing to work together to find solutions to mutually compatible interests of conserving the environment and the livelihoods of those who depend on fisheries to survive.

In July 1992, a declaration in support of urgent global fisheries reforms, a call for action by environmental, fishworker, and other nongovernmental organizations (NGOs) was endorsed by 104 organizations from North and South America, Asia, Europe, and Africa. These represented millions of people in poor and rich countries, from fishing communities and fishing companies, to environmental conservation and development organizations, to a magazine and a German canning company. This declaration was presented in July 1995 to more than 100 nations participating in the United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks, which concluded a new global fisheries treaty in August that included some but not all of the crucial reforms outlined in the declaration.

The declaration represents a recipe of urgently needed reforms in fisheries, and contains some fundamental ingredients for moving in this direction.

The declaration in its complete form follows. It is important to continue to share ideas, research, and innovations to solve bycatch. Action on this front will require the continued commitment of scientists, the political will of nations, governments and management authorities, the cooperation and contribution of industry and the broad participation of fishworkers, environmental, and development NGOs and consumers. These are the keys to a sustainable future that is both socially equitable and environmentally secure.

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NGO Declaration in Support of Urgent Global Fisheries Reforms: A Call for Action by Environmental, Fishworker, and Other NGOs

1. A diverse group of non-governmental environmental, fishworker, and other groups worldwide present this declaration to call attention to the problems of the global fisheries crisis and the need for urgent reforms at global, regional, national, and local levels. While reforms at all levels are essential, this declaration focuses on what is needed internationally—at global and regional levels—as a benchmark or foundation for more stringent measures; and where needed, at the sub-regional, national, and local levels.

2. This declaration draws upon the NGO Fisheries Treaty of June 1992, the July 1993 NGO Statement to the United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks (UN Fisheries Conference), the March 1995 NGO Statement to the Rome Ministerial Meeting on Fisheries, and various NGO statements and interventions, individually and collectively. It also draws upon the relevant provisions of UNCED Agenda 21, the Convention on Biological Diversity, the World Summit for Social Development, the International Covenant on Economic, Social, and Cultural Rights, the Ministerial-level Rome Consensus on World Fisheries, and other instruments, resolutions, and declarations.

3. Building on these prior statements and agreements, this declaration is intended for use in relation to several important meetings and fora. These include, among others, the final session of the UN Fisheries Conference (24 July-4 August 1995), the meetings of the FAO Council and Conference at which the FAO Code of Conduct for Responsible Fisheries will be finalized and adopted (October 1995), the UNEP Conference for the Protection of the Marine Environment from Land-based Activities (23 October-3 November 1995), the second Conference of the Parties to the Convention on Biological Diversity (6-17 November 1995), and the Fourth Session of the UN Commission for Sustainable Development (late April 1996), which will focus, inter alia, on the Oceans Chapter of Agenda 21.

The Context for Urgent Action

4. The increasing sophistication in the technology to harvest, process, store, and transport fish and fish products, coupled with rising demand and the expanding scope of international trade, markets, and investment, has been a driving force behind fisheries development over the past several decades. Many countries have pursued policies designed to maximize export earnings and fisheries production, often under pressure to service foreign debt, and often to the detriment of fish stocks, marine biodiversity, and coastal communities.

5. Most major fisheries are fully exploited, overexploited, or depleted. In addition to the 80-85 million tons of fish landed annually, the most conservative estimates of bycatch and waste indicate that 17 to 39 million tons of fish are caught and discarded every year. These estimates do not include marine species such as marine mammals, sea turtles, seabirds, and some invertebrates. Industrialized fishing fleets worldwide are grossly overcapitalized, operating at significant losses and fishing well beyond the limits of sustainability as a result of unsustainable fisheries development policies and investment. The FAO has estimated that the world's fishing fleet incurs losses of more than (US) $50 billion annually and that an outrageous 46% of the value of all fish landed is required as return on capital invested in fishing fleets. Yet, large-scale industrial fleets continue to be heavily subsidized. As nations and fleets compete for declining fish stocks, conflicts will only continue to occur with increasing frequency throughout the world.

6. Artisanal fishworkers, both men and women, are increasingly struggling to maintain or regain traditional access to marine resources, protect the environment, and sustainably

manage their fisheries. In spite of the fact that artisanal fisheries supply at least 50% of the world's fish supplies for human consumption, they receive little recognition, support, or protection. Marine and coastal areas are being increasingly degraded by land-based sources of marine pollution and environmentally inappropriate coastal development (e.g., ecologically unsound tourism, industrial projects, etc.). In particular, the environmental damage and socio-economic disruptions associated with intensive coastal aquaculture for high value species such as shrimp, prawns, and salmon are an issue of great concern to our organizations.

7. Substantial political will is required to address the deteriorating condition of fisheries and ocean health in general. With the November 1994 entry into force of the UN Convention on the Law of the Sea, that global agreement serves as a foundation for more fully elaborating and strengthening requirements regarding the rights and responsibilities of nations in order to ensure effective fisheries conservation and marine environmental protection. Though all relevant mechanisms or instruments should be viewed as opportunities to advance these issues, we would like to emphasize that codes of conduct, resolutions, declarations, or other agreements that are voluntary in nature are unacceptable substitutes for legally binding agreements.

8. At the same time, the negotiation of international agreements must serve as more than just an exercise in rhetoric or a means of advancing national self interest to the detriment of the broader common or social good. Where they exist, agreements that advance fisheries conservation, the protection of the marine environment and the rights and interests of artisanal and offshore fishworkers must be fully reflected in state practice at the local, national, and international levels.

Needed Actions and Reforms:

9. With regard to specific action needed, this declaration addresses several fundamental issues for attention and, more importantly, urgent action. While this is not an exhaustive list, it is intended to highlight critical areas of concern. These include:

10. Conservation—While important steps in the right direction have been taken, given the severity of problems facing world fisheries, and the increasingly adverse impacts on oceans in general, neither the UN Fisheries Conference Treaty nor the FAO Code of Conduct for Responsible Fisheries reflect the level of action and commitments required to ensure long term conservation. The UN Fisheries Conference treaty has the potential to set important precedents in international law for the conservation and management of fisheries generally as well as the protection of associated, dependent, and ecologically-related species. However, this will require serious commitments and implementation, both at the regional and national levels, in addition to strengthening a number of its provisions as discussed below. The FAO Code of Conduct, though only voluntary, does contain some provisions which, if adopted, could serve to advance fisheries conservation. At the same time, however, many of the principles contained in the code are so severely compromised by the addition of such phrases as, "where appropriate," "to the extent possible," and "in accordance with national laws," that the code risks being of limited value, if any, on a number of issues of importance to NGOs.

11. Bycatch, Waste and Discards—Bycatch and waste in fisheries worldwide must be addressed more thoroughly at the international level. Apart from the serious implications for the sustainable management of fisheries and the protection of associated and dependent species, non-selective fishing gears and techniques threaten severe economic and social impacts. Agenda 21, the 49th United Nations General Assembly, and the FAO Ministerial-level Rome Consensus have called for urgent measures to reduce the levels of bycatch in fisheries worldwide. The FAO estimates that at least a 60% reduction in bycatch is possible by the year 2000. At a minimum, international agreements, in particular the UN Fisheries Conference Treaty (e.g., Article 5(f)), must contain provisions that require, rather than merely promote or encourage, the use of selective gears and techniques. In addition, this obligation must be followed up with concrete policies and programs to reduce and ultimately eliminate bycatch, waste, and discards in fisheries.

12. Precautionary Approach—In recent years there has been a shift toward increasing recognition of the need to develop and manage fisheries from a precautionary approach. While this shift needs to become much more pronounced, the recognition, acceptance and mandatory application of a precautionary approach, as contained in the provisions of the UN Fisheries Conference Treaty, has been a significant step forward. However, this approach to fisheries management on both the high seas and within Exclusive Economic Zones (EEZs) must be reinforced. All fishing needs to be brought under more concrete and precautionary controls. Moreover, the stringency of such controls, and the speed with which they are implemented should be directly proportional to the magnitude of fishing effort and/or the potential for environmental harm.

13. Over-Capitalization, Excess Capacity, and Subsidies—Neither the UN Fisheries Conference Treaty nor the FAO Code of Conduct come anywhere close to adequately addressing these issues. Massive government subsidies which support large-scale industrial fishing and fish processing must be phased out. Rather, funding should be directed toward promoting ecologically sound and socially and culturally equitable fisheries management and development. The problem of excess fishing capacity must be urgently addressed and, in so doing, must not result in shifting fishing capacity to fisheries or regions of the world vulnerable to overfishing. This should particularly apply to the practice of northern corporations or countries seeking access to southern countries' waters and fisheries to the detriment of coastal fishworkers and the environment.

14. Consistency and Compatibility—Even with the establishment of EEZs, overfishing has continued to be rampant throughout the world both within EEZs and on the high seas. As Chairman Satya Nandan of the UN Fisheries Conference stated in March 1995, two years after the UN Fisheries Conference began, "... the situation regarding fisheries resources has not improved since this Conference began. In fact, it is steadily deteriorating." The general principles for fisheries conservation contained in the UN Fisheries Conference Treaty must unequivocally apply to fisheries inside the EEZs as well as fisheries on the high seas.

15. Monitoring, Control, Surveillance, and Enforcement—Enforcement measures must be stringent enough to ensure fisheries conservation and the protection of the marine environment. Strict management measures and effective enforcement are both necessary; without both, conservation cannot be ensured. The UN Fisheries Conference Treaty does contain measures which should improve the ability of countries to take enforcement action against vessels fishing on the high seas. It is critical, though, that measures to ensure compliance of both fishing fleets and states be developed and agree in relation to regional and global fisheries conservation agreements.

16. Marine Environmental Protection—Protection of coastal areas and the marine environment is critical to the conservation of marine species in general and fish stocks in particular. It is imperative that governments recognize the importance of this, and act accordingly. Among other initiatives, the UNEP sponsored global conference on land-based sources of marine pollution in October 1995 provides an important opportunity to take effective action at the international level. Among other requirements, the Global Program of Action adopted by the conference participants must agree to phase-out and ban the production of persistent organic pollutants, especially organohalogen compounds and PCBs, and to address sewage-related problems much more effectively. At the regional level, the issue of nuclear testing—which is widely opposed by peoples around the world—is of great concern in the South Pacific, particularly in relation to atolls and lagoons. As part of the follow-up to the recent extension of the Treaty on the Non-Proliferation of Nuclear Weapons, it is incumbent on governments to agree expeditiously on a comprehensive test ban treaty (CTBT) as part of ongoing efforts to ensure effective marine environmental protection.

17. Biodiversity—Excessive and indiscriminate exploitation of fish stocks and the use of destructive fishing technologies have serious implications for marine biodiversity. The clear

obligation to protect marine biodiversity and the application of the precautionary approach to fisheries should be both reaffirmed and further strengthened through ongoing consideration of marine biodiversity especially in the framework of the Convention on Biological Diversity. In this regard, special measures are needed to ensure the use of environmentally appropriate fishing technologies and practices, to establish and maintain marine reserves or protected areas recognizing ecologically appropriate traditional use and customary fisheries practices, as well as to ensure that critical habitats such as coastal mangrove forests, wetlands, nursery areas, and foraging grounds are protected.

18. Rights and Interests of Fishworkers—Access to fisheries must recognize the needs of communities and be based on equitable principles and respect for the environment. The rights and interests of subsistence, small-scale, artisanal, indigenous, and women fishworkers, and dependent communities are increasingly being recognized as important issues in fisheries and marine negotiations. Agenda 21, the UN Fisheries Conference Treaty, the Convention on Biological Diversity, and the FAO Code of Conduct for Responsible Fisheries incorporate some recognition of these interests.

19. The rights and special interests of subsistence, artisanal, indigenous, women, and other fishworkers traditionally and culturally dependent on fish for food and livelihood must be firmly established in international law. In addition, given the critical contribution of small-scale fisheries to world food supplies and the health and well being of coastal communities, concrete programs to meet their needs will be needed at the national and international levels. These should include mechanisms and funding for research into the role and importance of small-scale fisheries; participation in fisheries decision-making; training in fisheries conservation, fishing, appropriate fishing technologies, fish handling, and marketing, especially for women.

20. Programs also must be established to facilitate the incorporation of traditional knowledge in fisheries management and recognize the needs of fishworkers in relation to basic safety and labor rights, poverty alleviation, employment, and social integration. In this regard, governments must implement the commitments contained in the Declaration and Program of Action of the 1995 World Summit for Social Development. In addition, the rights of offshore fishworkers to organize, engage in collective bargaining, and obtain social security must be recognized to ensure safe and dignified working conditions. Whether through the FAO Code of Conduct, or other relevant agreements, all nations as well as the International Labor Organization (ILO) and the International Maritime Organization (IMO) should be encouraged to establish and implement effective international standards with respect to working conditions on offshore fishing vessels.

21. Fisheries Trade and Consumption—Fish is a critical source of food for hundreds of millions of people worldwide, particularly, though not exclusively, in developing countries. The International Covenant on Economic, Social, and Cultural Rights recognizes the right of all peoples to adequate supplies of food and obligates nations to ensure the equitable distribution of world food supplies. Among relevant resolutions, the Universal Declaration on the Eradication of Hunger and Malnutrition, endorsed by UN General Assembly Resolution 3348, and the World Declaration on Nutrition from the 1992 FAO/WHO-sponsored International Conference on Nutrition both assert the rights of peoples to adequate supplies of food.

22. Rising demand in industrialized countries for high-value species of fish is driving destructive fisheries practices worldwide, including shrimp trawl and aquaculture, with negative impacts on coastal wetlands, mangroves, marine biodiversity, and coastal fishing communities. Both unsustainable fishing practices and the promotion of trade to the detriment of peoples traditionally dependent on local supplies of fish for food and nutrition are serious threats to global food security. Unfortunately, the UN Fisheries Conference Treaty makes only a passing reference to the role of fisheries in nutrition, and the FAO Code of Conduct places excessive emphasis on unrestrained international trade in fisheries products. Governments must take the commitments in relation to nutritional rights contained in

relevant agreements and fora, and fully incorporate and act upon these commitments at the global, regional, and national levels.

23. Transparency and Public Participation—The historical lack of transparency and broad-based public participation has contributed to weak fisheries and ocean-related policies and programs. Improving access to information, transparency, and public participation is crucial to ensuring the success of fisheries conservation and management and the protection of marine and coastal environments. The need to ensure effective NGO participation has increasingly been recognized within the UN system, and, with respect to fisheries, in Agenda 21, the Ministerial-level Rome Consensus, and the FAO Committee on Fisheries in relation to the drafting of the FAO Code of Conduct. Yet, although the UN Fisheries Conference Treaty contains a general provision related to transparency, it does not recognize public participation as a general principle. In addition, the treaty will fail to prevent regional fisheries management organizations from adopting policies (exorbitant entry fees, denial of observer status) which serve to exclude NGOs from participation.

24. Whether at the local, national, or international level, we believe that fishworkers, environment, development, women, trade union, consumer, and other NGOs need to be fully involved in the decision-making with respect to fisheries conservation and management, development, law, investment, and aid. Overall, national, regional, and international fisheries management organizations and other relevant inter-governmental agencies must ensure effective public participation, transparency, and accountability in their decision-making and all other activities.

25. Conclusion—The crisis in world fisheries continues. The July 1993 NGO Statement to the United Nations Conference Straddling Fish Stocks and Highly Migratory Fish Stocks, endorsed by more than 130 organizations worldwide, emphasized that, ". . . absent major reforms, this crisis promises increasingly harmful ecological, economic, and social impacts." At present, while some progress has been achieved, major reforms are still required to ensure conservation and an ecologically sound approach to fishing both on the high seas and within EEZs, to protect and preserve marine and coastal habitats and ecosystems, and to support and strengthen subsistence, artisanal, indigenous, women, small-scale, and traditional fishers, fishworkers, and communities worldwide. We urge representatives of all nations to heed the recommendations for action in this declaration to ensure that our oceans and marine life are conserved and protected and that the needs of humanity are met—now and in the future.

The NGO Declaration Has Been Endorsed by the Following (104) Non-Governmental Organizations as of August 1995

Argentina

Sindicato de Obreros Maritimos Unidos—SOMU

Australia

Australian Marine Conservation Society

Brazil

Associacao Brasiliera de Defesa da Ecologia
Associacao Gaucha de Protecaos de Ambietal Natural—AGAPAN
Associacao Moradores Amigos da Serra dos Orgaos—AMASO
Conselho Pastoral dos Pescadores
Fundacao Brasileira para Conservacao da Natureza
Grupo Ambientalista da Bahia—GAMBA
Movimento dos Pescadores do Ceara
Movimento Nacional dos Pescadores—MONAPE
Protecao Internacional Contra Crueldade a Animais—PICAP
Sociedade Brasileira para Progresso da Ciencia—SBPC
SOS Sobrevivencia

Canada

Environmental Coalition/Prince Edward Island—ECO/PEI
The Tatonka Foundation
Reach for Unbleached Foundation

Chile

Confederacion de Gente de Mar—CONGEMAR
Confederacion Nacional de Pescadores Artesanales de Chile—CONAPACH

Colombia

Federacion Colombiana de Pescadores Artesanales—FECOLPA PACIFICO

Ecuador

Federacion de Organizaciones Pesqueras Artesanales y Afines de Manabi
Federacion Nacional de Cooperativas Pesqueras de Ecuador—FENACOPEC

Fiji

Women and Fisheries Network

France

Comite Catholique Contre la Faim et pour le Developpement—CCFD

Germany

Aktion Seeklar—Verein zum Shutz der Meere e.V.
Bund fuer Umwelt un Naturschutz Deutschland e.V.—BUND
Bund gegen de Missbrauch der Tiere e.V.
Bundesverband der Deutschen Fischindustrie und des Fischgrosshandels e.V.
Schutzstation Wattenmeer
World Wide Fund for Nature—WWF (Germany)

India

Center for Development Studies
International Collective in Support of Fishworkers—ICSF
National Fishworkers Forum—NFF
Indonesia
BAILEO-Maluku
Fisheries Working Group

Italy

Comitato Internazionale Per Lo Sviluppo Dei Popoli—CISP/MOVIMONDO
Movimento Liberazione e Sviluppo MOLISV-Movimondo

Malayasia

Asia Pacific Peoples' Environment Network—APPEN
Third World Network

Mexico

Grupo de los Cien
Movimiento Nacional de Pescadores Riberenos
Pacto de Grupos Ecologistas
Red Mexicana del Accion Frente el Libre Commercio

Netherlands

Both ENDS
Greenpeace International

Nicaragua

Federacion Nacional Nicaraguense de Pescadores—FENIC PESCA

Peru

Federacion de Pescadores del Peru

Philippines

PAMALAKAYA

Senegal

Centre de Recherches Pour le Developpement des Tecnologies Intermediaires de Peche—CREDETIP
Collectif National des Pecheurs Artisanaux du Senegal—CNPS

Spain

AEDENAT
ALIMENTACION Y DESARME
AMIGOS DE LA TIERRA IBIZA
Amigos de los Indios
ASOCIACION PRO DERECHOS HUMANOS
Centro de Investigaciones para la Paz
COMISIONES OBRERAS—CC.OO.
COMISION VASCA EN DEFENSA DE LA AMAZONIA
COOPERACCIO
COORDINADORA DE ONGS PARA EL DESARROLLO (83 member organizations; some also listed individually)
Coordinadora de Organizaciones para la Defensa Ambiental—CODA (180 member organizations; some also listed individually)
Federacion de Cofradias de Pescadores de Guipuzcoa
Federacion de Cofradias de Pescadores de Vizcaya
Federacion Estatal de Transportes y Telecomunicaciones de la Union General de Trabajadores (UGT), Sector del Mar
Fundacion Largo Caballero
GRAIN
GRUP BALEAR D'ORNITOLOGIA DE FORMENTERA (G.O.B.)
GRUP D'ESTUDIS DE LA NATURALESA (G.E.N.-G.O.B. EIVISSA)
Grupo de Educacion Ambiental Landra
IEPALA
Instituto para la Promocion y Apoyo al Desarrollo

Instituto Sindical de Cooperacion al Desarrollo
INTERMON
Itsas Geroa (Avenir de la mer/Futuro de la mar)
JUSTICIA Y PAZ
LAS SEGOVIAS
Manos Unidas
MEDICOS MUNDI
Movmiento 0.7%—Tercer Mundo
Organizacion de Cooperacion y Solidaridad Internacional
PAZ Y COOPERACION
SIAL
SO DE PAZ
Solidaridad Para el Desarrollo y la Paz
S.O.S. AFRICA—SERVICIO AFRICANO DE SOLIDARIDAD

USA

Alaska Marine Conservation Council
Antarctica Project
Center for Development of International Law
Fish Forever
International Rivers Network
Mangrove Action Project
Mayaguezanos Por la Salud y El Ambiente (Puerto Rico)
Natural Resources Defense Council—NRDC
Ocean Advocates
Rainforest Alliance
World Federalist Movement

UK

Christian Aid
The Ecologist (magazine)
Environmental Investigation Agency
Intermediate Technology Development Group
Third World First
Wildlife Trusts
Women's Environment Network
World Wide Fund for Nature—WWF (UK)

Uruguay

REDES/Friends of the Earth Uruguay

Cod Trawl Separator Panel: Potential for Reducing Halibut Bycatch

Mike Stone
Victory Fishing Gear International Ltd., P.O. Box 71069, Seattle, WA 98107

C.G. Bublitz
University of Alaska Fairbanks, Fishery Industrial Technology Center
900 Trident Way, Kodiak, AK 99615

Trawl nets fitted with experimental separator panels were tested at sea during commercial fishing operations as part of a project conducted by the Alaska Fisheries Development Foundation. Data from the sea trials indicate that the use of separator panels in trawl nets may effectively reduce the bycatch of halibut when harvesting Pacific cod. Catch data indicate a significant percentage of halibut and arrowtooth flounder escaped through the separator panels while only a small percent of the cod escaped. Flatfish escape appeared to be directly related to size.

The incidental catch of Pacific halibut during commercial fishing operations using non-selective gear is a significant concern. The problem, in terms of conservation and economic loss, is severe. Fishermen have been unable to harvest ocean resources to full utilization, as allowed under the current management scheme, due to bycatch closures. In 1994, approximately 16,000 mt of flatfish remained unharvested, due to forced closures caused by excessive halibut bycatch, resulting in a loss of about $6 million to the U.S. fishing industry.

The environmental impact of trawls on groundfish stocks in particular have been the focus of international concern for many years. Debate over the merits of trawling and, in fact, the future management of the commercial fishing industry as a whole, continues today. The goal of maintaining profitable operations for our fishing fleet requires a new approach to harvesting target species in a rational and economically feasible manner. Changes in gear technology and fishing methods may improve catch selectivity. This could benefit both the trawler fleet and the environment, through greater efficiency and less waste.

In order to examine possible technical solutions to reduce incidental catches of halibut in trawl nets, the Alaska Fisheries Development Foundation (AFDF), with project funds provided through the Saltonstall-Kennedy program, solicited gear designs from private industry in June of 1993, and evaluated the potential effectiveness of these designs. AFDF's goal was to help develop a design that might exploit behavioral differences between halibut and cod. Information on the interaction of halibut with trawl gear was obtained from recent studies by the National Marine Fisheries Service (NMFS), conducted in cooperation with the International Pacific Halibut Commission (IPHC), and University of Alaska Fairbanks Fishery Industrial Technical Center (FITC) (Bublitz 1988, 1996).

Gourock Trawls of Seattle, Washington, offered a design that incorporated many of the basic principles believed to be advantageous for selectivity. The design focused on modifications to existing trawls, rather than a radical new approach that could require extended testing before being introduced into the fleet. Rigid panels made from plastic or stainless steel materials were avoided, since these devices might cause handling or durability problems on the net drums, and, therefore, might not be readily accepted by commercial fishermen. The proposed design also specifically attempted to release the halibut as close to the front of the trawl as possible, rather than near the codend, where most selective devices have traditionally been located. It was the opinion of the net designer that the codend was the last resort for escape. If the non-target species could avoid contact with the gear in the early stages of the capture process, the possibility of injury to the fish would be minimized. This would avoid the potentially detrimental effects of netting and bottom debris causing abrasion, descaling, and possible trauma to the fish.

Based on its submitted proposal, Gourock Trawls was awarded the contract and manufactured two trawls as part of this experiment: one a conventional design representative of commercial trawl nets currently used in the fishery, and the other a prototype version incorporating various modifications to improve selectivity. Gourock drafted detailed AutoCad drawings, manufactured models, and completed flume tank trials using 1/5 scale models at the Marine Institute in St. John's, Newfoundland during October 1994. As part of the proposal, noted gear experts and fisheries scientists, as well as a group of commercial fishermen, took part in evaluating the trawl designs. The general tailoring, the effect of netting color on fish behavior, and practical handling of the gear at sea were addressed in group discussions. After the tank tests were completed, two full-scale trawls were manufactured and shipped to Kodiak, Alaska for trials at sea.

Methods

Prototype Design

The trawls used in the study were four panel Kodiak Combo designs, similar to traditional Aberdeen whitefish trawls, but with full lower wings rather than small wedges. This type and size of net (340 meshes in circumference × 140 mm stretched mesh) is representative of typical nets used for harvesting cod and sole species in Alaska. Trawls were constructed entirely from orange color braided polyethylene netting. Riblines of braided polyester rope 25 mm in diameter, to provide strength for retrieving large catches, ran the entire length of the trawl, along all four gathered netting selvages (gores). Forty trawl floats, 200 mm in diameter, were attached to the headline. Both the prototype selective trawl and the standard trawl were made to identical specifications, except for the following modifications.

The selective trawl was fitted with two separator panels made from 140 mm mesh netting. The panels were located approximately 4.5 m aft of the trawl footrope, at about 0.5 m above the lower belly, and 0.5 m apart, extending from one side panel to the other horizontally. Panel dimensions were about two-thirds the number of meshes of both the depth and the width of the lower belly. The reduced width of each panel was achieved by using a slower cutting rate. This insured that the panels would remain tight and rigid above the lower belly. Each separator panel was cut on "drop meshes" along the front edge to create a curvature to the headrope. Triangular holes were made in the lower belly, just forward of the intermediate section, to allow fish that swam under the panels to escape, prior to entrance into the codend. Details of the trawl design are shown in Figs. 1 and 2.

Underwater observation of trawl gear by NMFS and the Scottish Marine Lab has shown that certain colored netting is more visible than others at fishing depths. Based on the speculation by fish behavior experts that changes in visual contrast might illicit responses from the fish, certain materials were introduced into the selective trawl. It was decided that the separator panel should be made from green netting, to provide a contrast against the orange netting of the main trawl body.

Netting along the headrope of the separator panel was selvaged with a border of "glow twine," a polyethylene material designed to be luminescent in the dark after very brief exposure to natural light. Glow twine was also used in a diagonal pattern along the netting bars leading from the footrope and up to the separator headrope, in the belief that this might lead the cod up and over the panel. The standard trawl was fitted with a roller gear footrope of 37.8 m overall, using 400 mm laminated rubber bobbins. Steel toggles using 300mm long dropper chains, were fitted every 600mm. The footrope extensions were attached via a Dan Leno plate to the lower wingend. The towing bridles were 15 fathoms long, the upper of bare cable, and the lower of "mudgear" using wire rope covered with small rubber discs, a common rig in the fishery.

A special "long dropper rig" footrope configuration was used in the selective trawl. This used rubber "rockhopper" discs spaced every 1.2 m

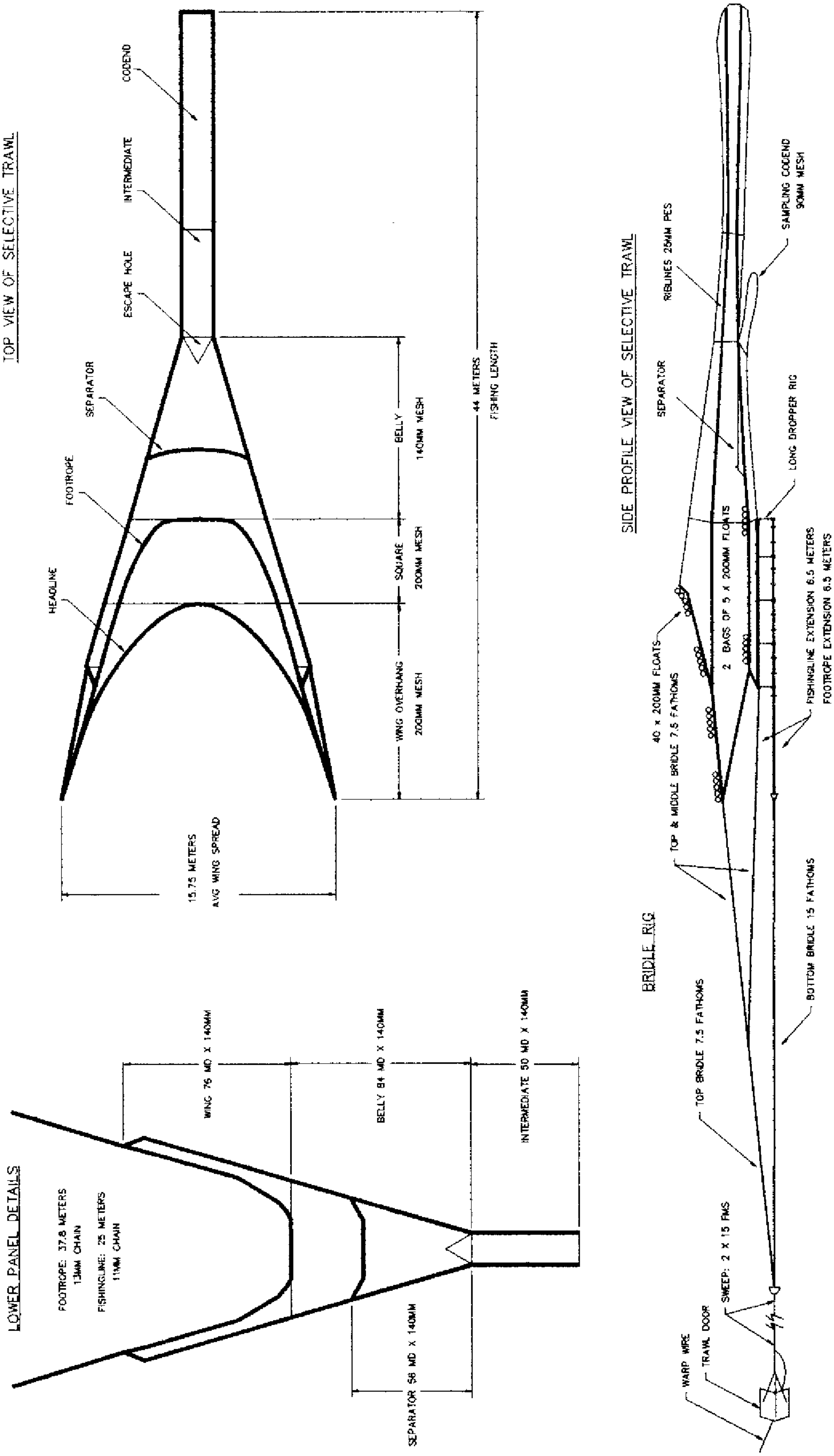

Figure 1. Selective trawl Gourock-FITC tests. Alaska Fisheries Development Foundation Halibut Bycatch Reduction Project. Drawing by M. Stone.

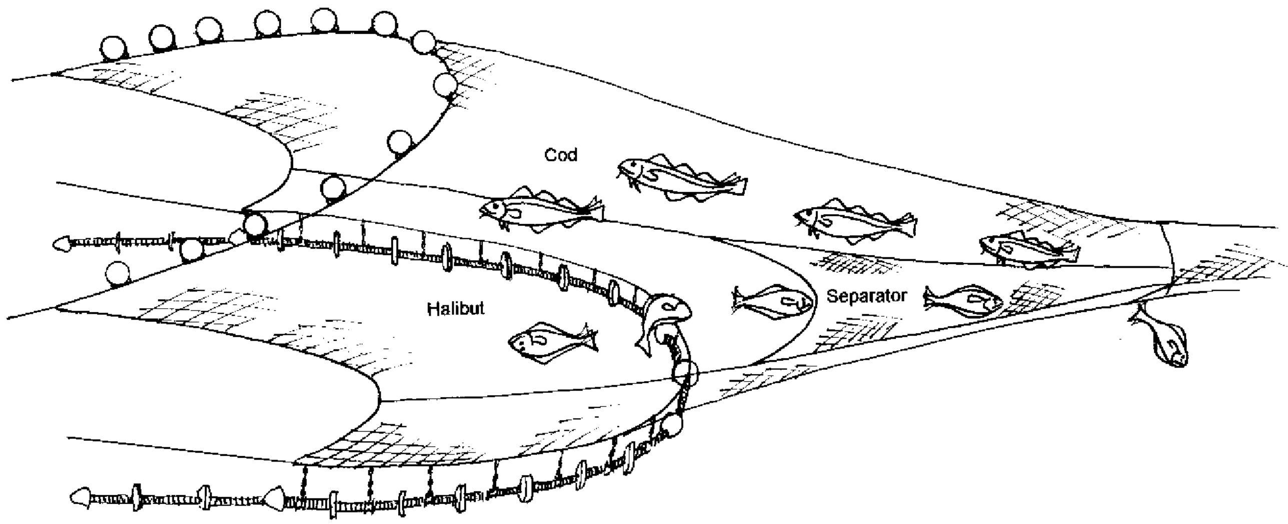

Figure 2. Separator panel showing fish behavior in trawl (not to scale). Drawings by M. Stone.

throughout the main footrope, rather than shaped rubber bobbins. The steel toggles were spaced every 1.2 m. In addition, the dropper chains were increased to a length of 1 m. A grid was created using a series of lines made from glow rope of 12 mm diameter, first strung through the toggle chains, and then shackled to an up-and-down chain at the lower wingtip. The 150 mm horizontal spacing of the ropes, which were colored in alternating black and off-white strands, was designed to prevent escape of roundfish under the trawl's fishingline. No wingend Dan Leno plate was used, so the trawl was free to lift up, independent of the footrope.

A cable was attached from the lower wingend to the midpoint of the upper bridle (7.5 fathoms), effectively creating a 3-bridle rigging. This cable was made slightly shorter than the upper and lower bridles, in order to take a greater percentage of strain, allowing the toggle chains to hang vertically. The trawl was designed to have the fishingline fly 1 m above the seabed, and the footrope to have minimal contact with the bottom. Estimated weights in sea water of the prototype selective footrope and standard trawl footrope were nearly identical, but the increased spacing of the discs was designed to reduce damage to the ocean fauna, crab, and other bottom-dwelling organisms.

Two small cylindrical bycatch codends, made of 90 mm mesh netting, were fitted to the selective trawl, and attached to escape holes under the lower belly. These miniature codends were designed to sample the species and size of fish that escaped under the panels. The mesh size used was smaller than the primary codend, in order to retain juvenile fish. They were positioned under the intermediate, and during haulback the small codends were taken aboard prior to the main codend.

Field Trials

The FITC subcontracted with Gourock to work on scientific testing of the model(s), and then to gather and analyze catch data at sea to study the effectiveness of the selective trawl. This involved direct field sampling techniques as well as extensive video sampling procedures using underwater film footage of the trawls in action.

The F/V *Taasinge*, a 22 m stern ramp trawler, fitted with a net reel forward and one on the aft gantry, was chosen as the test vessel, and was chartered for the duration of the trials. The boat was powered by a 750 horsepower main engine and fitted with a propeller nozzle. Comparative sea trials consisting of over 30 experimental tows were conducted in March and April of 1993, and again in March through April 1994, in the area of Chiniak, Marmot Bay, Albatross Bank, Gore Point, and Port Lock Bank, (all in waters near Kodiak Island). Trials were conducted in depths of 30-45 fathoms using only natural light. The majority of tows took place in the course of normal fishing operations, during the commercial cod seasons.

The NMFS Alaska Fisheries Science Center, Seattle, provided an Osprey OS1323 SIT low-light level video camera, with a wide angle lens for the sea trials. The camera was attached to the trawl using a rigid frame, with a video recorder and batteries installed inside pressure resistant housings. A 7 cm square hole was cut into the trawl's top belly, and the camera system was attached using a zipper line. This gave a view of the separator panel from above and forward. Later, the camera was also moved to the lower bunt wing, in order to view the trawl separator panels from the side.

Results

Footrope

In the initial trials it was determined that the long dropper rig was having problems. The ropes used in the rig were fouling and suffering from abrasion damage requiring their removal. Also, high catch rates of starfish, clams, sea anemones, etc., later confirmed by video footage, showed that the trawl was not maintaining the desired vertical distance from the seabed. The toggle chains were wrapping around the trawl footrope, and the netting was being pulled down to the bottom. The toggles were replaced with a new type, which could spin more freely and had less tendency to bind, in January 1994. The problems persisted however, and despite removal of nearly all the chains in attempts to get the trawl to stay high off the bottom, testing of the long dropper rig was discontinued. It appears that changes in geometry over irregular bottom and unequal load distribution during fishing operations, caused differences in curvature between the footrope and fishingline that were not discovered in tank testing. The spreading force of the 5 square meter v-type doors was also much higher than the 3.5 square meter doors used during tank trials. The footrope rig was altered to a more conventional 300 mm toggle chain length for later trials, but the 3 bridle rigging was still used, to keep the gear off bottom and the toggle chains straight up and down as much as possible. Although the long dropper rig was unsuccessful, video footage taken during the brief periods when the footrope toggles were extended suggests that the rig did effectively reduce the catch of flatfish, and was staying well clear of the seabed and mud cloud.

Separator Panels

Video observation of the trawl and separator panel showed that the green netting, colored twines, and rope framelines were clearly visible as dark contrasts against the lighter shade of the ocean floor at depths of over 40 fathoms. The video footage showed only scales of gray, but it was apparent that the orange body netting had very little contrast, and was nearly invisible to the human eye. The "glow" twines showed as a light gray, and the luminescent quality, or the possible effect on fish behavior could not be determined. Mud clouds obscured the lower belly netting in some tows, especially over soft ground.

The separator panel tailoring was good, although some distortion was evident, suggesting that the headrope curvatures could be improved. The vertical position of the lower separator was estimated at 1 to 2 feet off the lower belly, varying with trawl speed and rigging. Aside from the problems associated with the long dropper rig, the trawls could be set and hauled in the traditional manner, and required no special handling methods. A series of trials was conducted in 1994 using multiple separator panels and codends, to study if panel height affected halibut catch.

Catch Results

Fig. 3 shows percent captured of cod, pollock, and flatfish in the main and separator panels. The total captured in the main codend, compared to those escaped into the separator codends, indicates 41.4% of the halibut and 5.7% of the cod escaped through the separator panels. In addition, 74.5% of the arrowtooth flounder, 33.5% of the rock sole, 11.6% of the pollock, and 2.9% of the rockfish also escaped through the separator panels. Of these amounts, the majority of the arrowtooth flounder, pollock, rockfish, and cod were lost through the upper separator panel while the majority of the halibut and rock sole were lost through the lower separator panel.

An evaluation of the number of halibut captured by haul and codend indicates the number of halibut taken varied considerably for each haul, ranging from 0 for hauls 12 and 14, to 506 for haul 13. With the exception of haul 13, the data indicate that the earlier tows (hauls 1-6) captured considerably more halibut than later tows. An analysis of the percentages of halibut captured in each codend by haul are given in Fig. 4. These data indicate that halibut escape (separator panel counts) in tows 1-15 were considerably lower than escape for tows 16-22. For the former tows, an average of 34.7% (range 0% to 54.5%) of the halibut escaped into the separator codends; whereas in the latter tows an average of 86.2% (range 70.6% to 100%) of the halibut escaped into the separator codends.

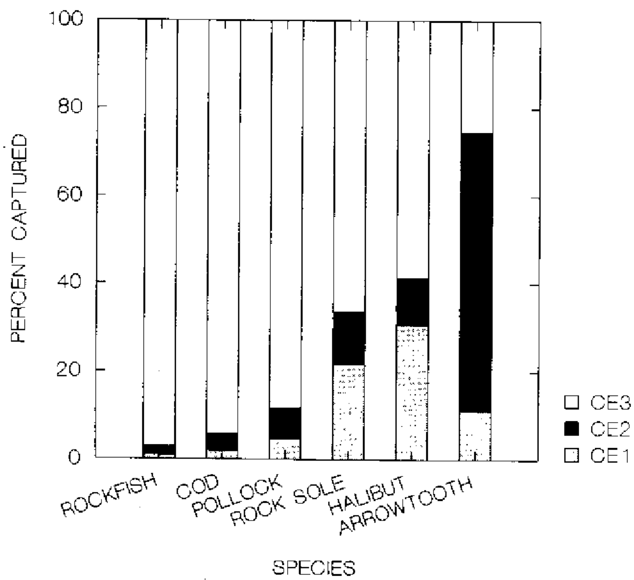

Figure 3. *Percent of species captured by codend. CE1 and CE2 are lower and upper separator panels, and CE3 is the main codend.*

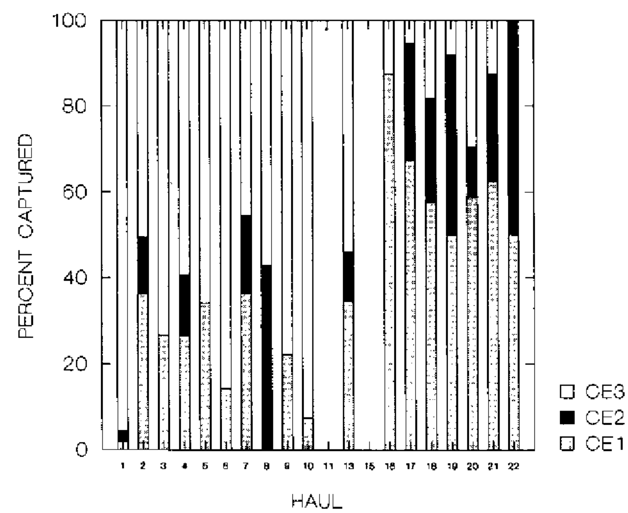

Figure 4. *Percent of halibut captured by haul and codend. CE1 and CE2 are lower and upper separator panels, and CE3 is the main codend.*

Percentages of halibut captured by location are given in Fig. 5. Data from this graph show a distinct difference in halibut escape by location. The highest escape (76.5%) occurred on the Albatross Banks with the Gore Point area and Port Lock Bank exhibiting considerably lower halibut escape, 22% and 36.1%, respectively. These data directly correlate with the percent escape noted by haul (Fig. 2): hauls 15-22 were from Albatross Bank, hauls 7-12 from the Gore Point area, and hauls 1-6 and 13 were from Port Lock Bank.

Catch curves for total halibut captured in each codend are given in Fig. 6. These curves show a distinct difference in size of halibut taken in the main and separator codends. For all tows, those captured in the main codend were larger, L_{50} = 59.1 cm (length at the 50% capture point), than those captured in the upper and lower separator codends, L_{50} = 51.5 and 51.1 cm, respectively. An analysis of capture length by main codend vs. separator panels, time of year, and location, exhibited similar trends. Halibut captured in the main codend during January 1994 had an L_{50} = 58.3 cm, those in the upper codend had an L_{50} =48.9 cm, and in the lower separator codend the L_{50} = 53.2 cm.

During the spring season, the L_{50} increased to 60.4 cm in the main codend and 53.6 cm in the upper separator, and decreased to 51.5 cm in the lower separator panel. The trend in halibut L_{50} strongly indicates that size is a determining factor in halibut escape through the separator panel. The increase in L_{50} between January and March 1994 in the main codend suggests either natural growth trends or possibly the result of normal migration patterns.

The AFDF study suggests that adaptation of separator panels to conventional trawl nets may significantly reduce the bycatch of halibut, with very little impact on the capture of cod. The possible effectiveness of reducing halibut catch through alterations to the footrope rigging requires further study. From the author's perspective, the use of separator panels is a simple, cost-effective means to make major improvements in catch selectivity. The panels can easily be retrofitted to existing gear, or made an integral component to a new trawl net. They create no major changes in traditional methods of handling the gear aboard ship using net reels, aside from some additional problems associated with potential damage from crab pots or boulders. Panels can be constructed to simply zipper in place to expedite repairs at sea.

Conclusions

Several minor adaptations to current trawl rigging, combined with the use of separator panels, may result in even greater reduction in halibut

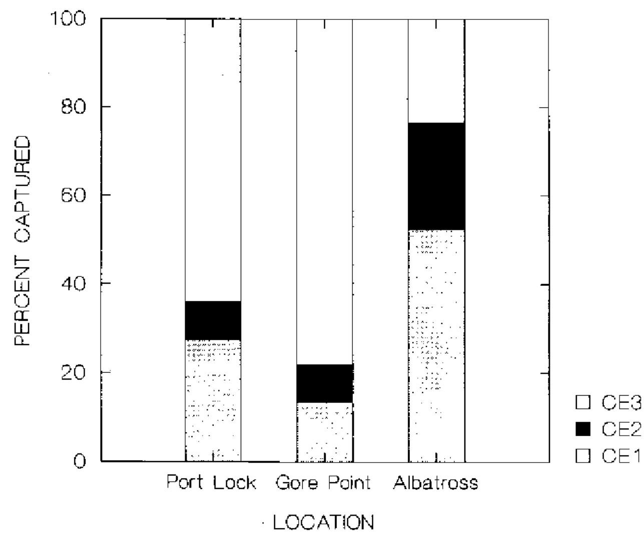

Figure 5. Percent of halibut captured by location and codend. CE1 and CE2 are lower and upper separator panels, and CE3 is the main codend.

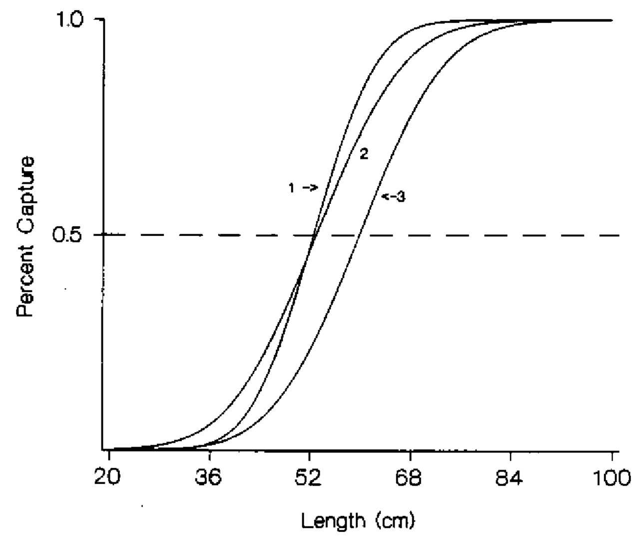

Figure 6. Halibut catch curve for all hauls. Numbers indicate codend (1 is lower and 2 is upper separator panels, and 3 is main codend).

bycatch. More fine-tuning of gear by net makers and fishermen is required to ascertain adjustment details.

Based on the AFDF tests, some possible means to reduce halibut bycatch in trawl nets include:

1. Fitting of separator panels, or other possible openings in the lower belly, to allow routes of escape for low swimming fish.

2. Reduction in the weight in water of the footrope, and/or increased flotation on the trawl, to minimize digging and friction on the bottom and subsequent mud cloud.

3. Increased spacing of large rubber discs or bobbins to provide greater escape for small flatfish under the sweeps and roller gear.

4. Use of trawls that feature flying wings to reduce netting contact close to the bottom.

5. Bridle rigging that takes a portion of the towing load of the trawl on the fishingline, so that the trawl wings are tensioned and fly free, off the bottom.

6. Using slightly longer toggle chains to provide an area of escape under the trawl net.

7. Choosing net and rope colors that offer high or low visual contrast against the background to exploit fish behavior traits.

The future adaptation of this technology into the U.S. fleet is uncertain. Currently, the method of assigning bycatch quotas is to share the total value among the entire fleet. This reduces the incentive by any individual fisherman to take an initiative toward improving the selectivity of his gear. By experimenting with a new device, the skipper of the trawler takes the risk of losing valuable fishing time and incurring additional costs of operation, while other competing vessels continue to fish using non-selective nets.

Unless there becomes an economic advantage to fish cleanly, such as in the case of individual bycatch accountability, there is not likely to be any large-scale trend toward the use of improved fishing methods.

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John Watson, NMFS, Pascagoula, MS, fish behaviorist
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Bob Starr, relief captain, F/V *Taasinge*
"Jersy" Powack, crewman, F/V *Taasinge*
Don Johnson, crewman, F/V *Taasinge*

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Implementation of a Voluntary Bycatch Avoidance Program in the Flatfish Fisheries of the Eastern Bering Sea

John R. Gauvin
American Factory Trawler Association, 4039 21st Ave. W, #400, Seattle, WA 98199

Karl Haflinger and Mary Nerini
Sea State, Inc., 6247 29th Ave. NE, Seattle, WA 98115

The bottom trawl industry in the North Pacific operates within a veritable labyrinth of regulations governing bycatch of prohibited species such as halibut, herring, and several species of crab. In addition to areas closed to prevent bycatch, the industry must work within aggregate bycatch caps that close the fishery when a certain amount of bycatch occurs. There are also individual bycatch rate regulations that attempt to create individual incentives for companies to minimize their bycatch by assessing violations when rates are above prescribed levels. Data from NMFS at sea observers are not available to managers or the fleet on a fast turn-around basis. For companies to attempt to minimize bycatch, information on their bycatch rates and bycatch hot spots needs to be available almost instantaneously. This paper describes the bottom trawl industry's voluntary use of a data reporting program called Sea State to identify bycatch hot spots. The program functions through satellite transmission of unprocessed observer data which are rapidly converted into plotted reports and bycatch rate assessments. The goal of the program is to allow the fleet to rapidly respond (both individually and collectively) to high bycatch rates. In this way, bycatch of prohibited species can be minimized and the industry can more effectively stay within its overall prohibited species bycatch caps.

Bottom trawl fisheries targeting flatfish pose an interesting challenge for bycatch reduction. Despite recent improvements to the selectivity of trawls, when the species to be avoided is another flatfish of approximately the same size and characteristics as the target species, the potential for gear modification is inherently limited. Avoidance of crab in flatfish fisheries is also problematic because most species of crab live directly on the sea floor with flatfish.

Thus far, excluder devices and modifications in gear rigging for bottom trawls have tended to reduce bycatch of nontarget flatfish and crab at a large cost in terms of reduction in target catch. This is why the flatfish fisheries of the North Pacific have begun experimenting with other bycatch reduction approaches instead of concentrating on gear modifications alone.

On January 20, 1995, factory trawlers fishing for rock sole in the eastern Bering Sea began implementing a bycatch reduction program based on rapid communication of data to identify areas where bycatch rates are particularly high. The program was also used for the fall of 1995 yellowfin sole fishery. The rock sole fishery contracted with Sea State, Inc. of Seattle to administer this information service. The basic idea is that the fleet can make use of bycatch rate information from all participants to avoid areas where high bycatch rates are likely to occur.

Program Implementation and Results

One necessary condition for success with this approach is that there must be a legitimate data source to systematically calculate bycatch rates and fishing locations on a tow by tow basis. National Marine Fisheries Service (NMFS) observers calculate catch and bycatch information in North Pacific fisheries where observer coverage is required. Observers also record location data for sample tows to the level of detail of one minute of latitude and longitude. The vast majority of vessels in the rock sole fishery are longer than 37 meters (120 feet) and are thus required to have 100% observer coverage. This means approximately one-half of the hauls are sampled, because although vessels carry an observer at all times, observer work schedules do not allow every haul to be sampled.

In our program, observer data on catch and bycatch are electronically transmitted from each vessel to the Sea State office in Seattle. Sea State conducts statistical expansions from observer data to calculate an average bycatch rate per vessel for the 24 hour period. Daily bycatch rates are then placed into a format where the relationship between bycatch rates and locations is accessible to skippers and their companies. The format currently in use plots each vessel's daily bycatch rate on a chart of the fishing grounds. Sea State relays this information to the vessels and owner companies every 24 hours via fax or by a computer file loaded into a plotting program provided to the vessel.

The need for a private contractor to implement this program exists because NMFS does not have sufficient resources for data processing and transmission of bycatch information in a time frame suitable for bycatch avoidance. Further, government rules pertaining to confidentiality allow individual companies to receive only their own fishing data which is not always useful for establishing bycatch trends. The contract with Sea State works through a general clearance agreement between participating companies, NMFS, and Sea State. This allows for the calculation of bycatch rates per ton of target catch while providing protection from general dissemination of individual catch data.

For the identification of bycatch hot spots to be effective, there have to be identifiable patterns based on time and areas. This may seem obvious, but this is a condition that is not always met. Efforts to avoid chinook salmon in the North Pacific trawl fisheries have been thwarted by the simple fact that there is little or no time/area relationship to salmon bycatch that allows for salmon avoidance based on micro-adjustments to fishing locations. If the species to be avoided are randomly located and randomly encountered with fishing gear, then the probability is very low that a solution other than gear modification will be successful.

For halibut, red king crab, and C. *bairdi* Tanner crab bycatch in flatfish fisheries, there is ample evidence that bycatch rates are not random and, in fact, do vary by location and season. Figs. 1-3 demonstrate this by showing different size circles depicting the magnitude of bycatch rates by location. Larger circles depict high rates, medium size circles indicate moderate rates, smaller circles indicate low rates, and small cross symbols indicate rates approaching zero. Extremely high rates are indicated by numbers on the plots. In these figures, numbered rates as well as medium and larger circles indicate high bycatch rates that could lead to a premature closure of the fishery. Sea State uses this circle format for fax communications or shows rate differences through color patterns displayed on the Sea State plotting program. The color display is helpful when a large number of data points are depicted.

Figs. 1-3 show clearer patterns of bycatch locations for red king crab than for halibut and *C. bairdi* Tanner crab. In general, however, *bairdi* and halibut bycatch rates are higher to the west. A comparison of the1995 rock sole bycatch data to data corresponding to the same time period for the rock sole fishery over the last five years shows that some of the same areas have consistently high rates every year. Other areas are hot spots for a given year or season, but do not have particularly high rates in other years. Thus, the fleet can make use of this information on a rapid turn-around basis to confirm known bycatch hot spots, to decide on areas that are consistently high and may be better off closed from the outset, and to identify, on a real time basis, new hot spots or areas that no longer appear to produce high bycatch rates.

Although the fleet's use of Sea State is a relatively simple approach to bycatch reduction, a number of factors determine its success. One might expect that participation and cooperation would be easily obtained based on the common benefit of improved public image for the fishery through bycatch avoidance. Realistically, however, participation means that a company's fishing locations and bycatch rates will be known to its

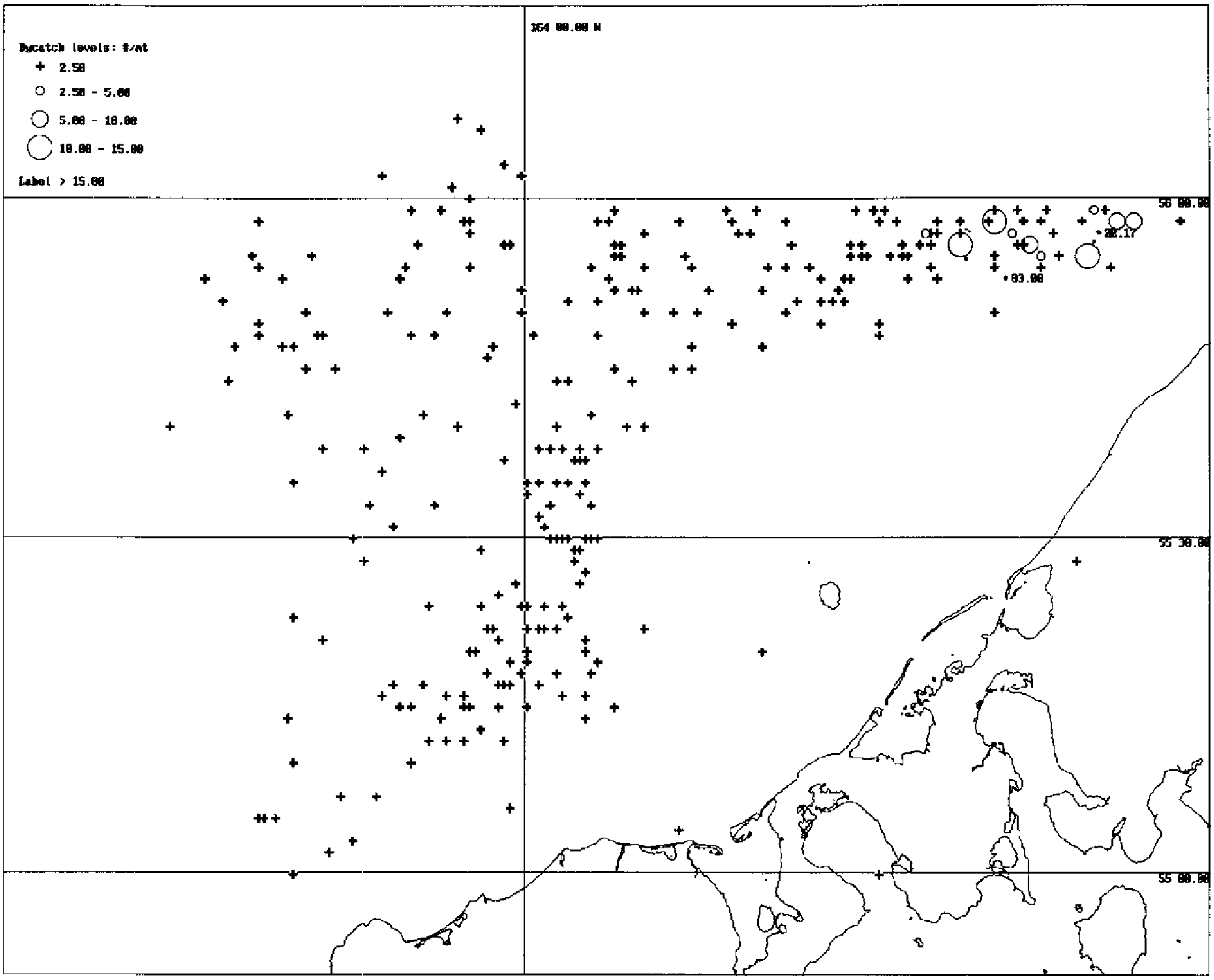

Figure 1. King crab bycatch rates in the Bering Sea rock sole fishery. Rates are computed as numbers of crab per metric ton of catch. Jan. 20-Feb. 21, 1995.

competitors, even though Sea State keeps catch information confidential. Given the competitiveness of the commercial fishing industry, it is not difficult to imagine that some companies could be reluctant to participate.

To understand the factors that determine participation, the systems in place to manage North Pacific bottom trawl fisheries must be considered. To regulate the incidental take of certain species reserved for non-trawl gears, prohibited species catch caps (PSCs) for the trawl fishery have been established. The PSCs of concern to the North Pacific flatfish fishery are halibut, red king crab, and *C. bairdi* Tanner crab. Once annual PSC caps are reached, the fishery closes for the year regardless of whether the total allowable catch (TAC) has been taken. Because so many flatfish fisheries close for PSC bycatch instead of TACs, the fleet as a whole would benefit from collective avoidance of PSCs because more of the target species TACs would be processed.

A critical determinant of success for any voluntary program is to obtain a critical mass for participation. Further, there must be a legitimate reason why a company would want to participate because volunteerism normally wanes when there is no tangible reward. If the program successfully prevents premature closures of fisheries, then there is clearly a common benefit to the fishery. Our experience shows that sometimes the common benefit is adequate motivation for participation and sometimes the motivation for private gain can outstrip the incentive for common benefit.

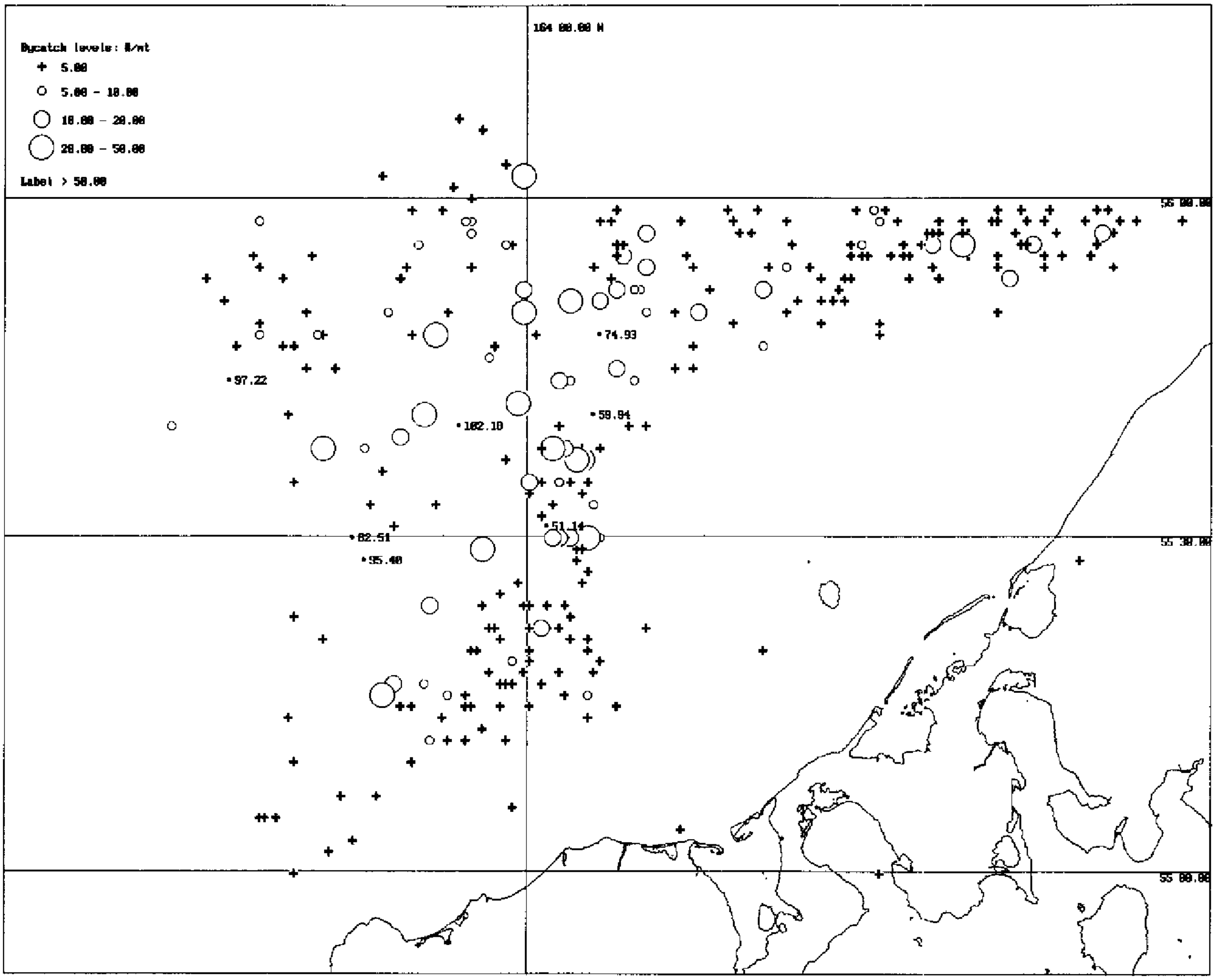

Figure 2. Bairdi Tanner crab bycatch rates in the Bering Sea rock sole fishery. Rates are computed as numbers of crab per metric ton of catch. Jan. 20-Feb. 21, 1995.

A discrepancy between self interest and common interest occurs when catch rates for the target fishery are higher in the same locations where bycatch rates are high. Under these conditions, firms would have to sacrifice target catch to keep bycatch rates low if a location with high target catch rates and low bycatch rates cannot be found. Since the cap is a common pool, the economic benefits of high catch rates are individual while the economic consequences of high bycatch rates are shared. We believe this is a fundamental limitation to any voluntary bycatch reduction program based on common bycatch caps.

Peer pressure stemming from an agreement to participate in the program is ample incentive for most companies to opt to avoid areas of high bycatch rates. If everyone holds the line and continues to move away from high bycatch areas regardless of the individual incentive for high target species catch rates, then the distribution of target catch between fishing vessels will not be affected by participation in the bycatch avoidance program. In fact, the fishery should remain open longer under that scenario because the PSC caps would not have been taken. Likewise, new fishing areas may be found where high catch rates and low bycatch rates occur.

The rock sole fleet encountered high red king crab bycatch rates at the outset of the fishery. As a response to high king crab rates, the fleet moved west and found that red king crab bycatch rates dropped. At the same time, the move west did not affect rock sole production rates significantly. Rock

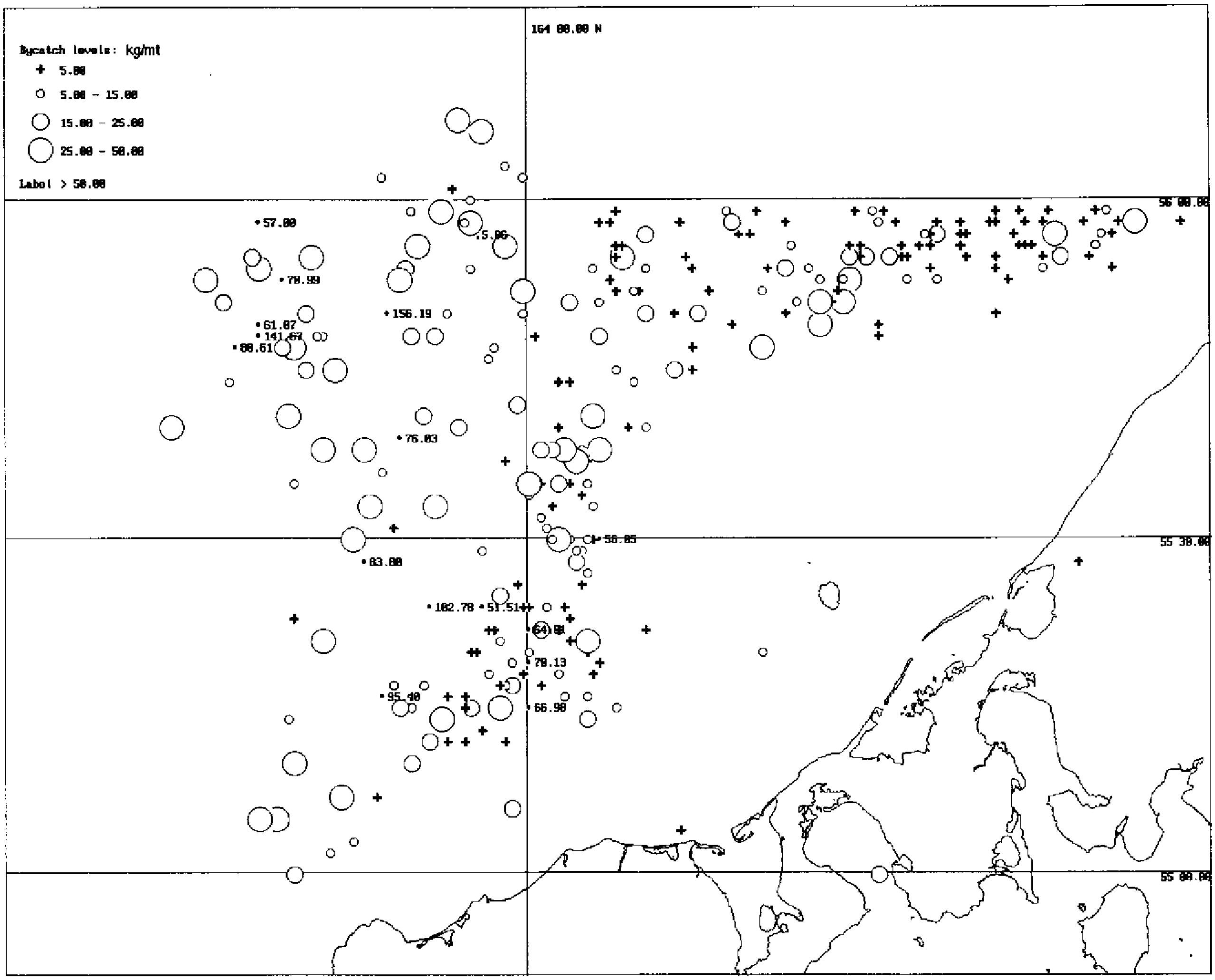

Figure 3. Halibut bycatch rates in the Bering Sea rock sole fishery. Rates are computed as kg of halibut per metric ton of catch. Jan. 20-Feb. 21, 1995.

sole catch in the 1995 roe rock sole fishery was down from 1994 catch by approximately 35% (22,600 mt in 1995 compared to 34,841 mt in 1995), but the reduction is generally thought to be attributable to a closed area for king crab protection. Within the areas available to the fleet, the move west decreased red king crab bycatch at little or no reduction in rock sole catch.

One important side effect of the fleet's move west was that higher halibut bycatch rates occurred. Hence the movement of the fleet effectively resulted in trading halibut for king crab. In response to those halibut rates, the fleet was later able to move away from several halibut hot spots by concentrating fishing to the south. This brought halibut bycatch rates down. Not only was the fishery extended by these avoidance actions, but the overall amount of bycatch used by the rock sole fishery in 1995 was lower than it would otherwise have been.

High bycatch rates can rapidly close a fishery because the PSC caps are designed to be binding constraints. In fact, the rock sole fishery exceeded its red king crab cap in 1994 because rates were so high that the NMFS reporting system was unable to track the caps in a timely manner (Table 1). This year, the rock sole fleet supported a number of measures to prevent another overage. One was a proposal by the rock sole fleet to close an area where bycatch rates for red king crab have traditionally been high. The closure that was implemented by NMFS was, in fact, slightly larger than the one proposed by the fleet (by ten minutes of latitude). Another measure was to require 100% observer

Table 1. Numbers of red king crab, bairdi Tanner crab, and tons of halibut bycatch in the roe rock sole fishery. (The roe rock sole fishery defined the Jan. 20-Mar. 3 window.)

	# Red king crab	Tons halibut	# Bairdi crab
1994	140,747	296.8	308,299
1995	19,341	418.9	304,227

coverage for all vessels including those under 37 meters in the rock sole fishery and mandatory daily reporting of observer data to NMFS.

From the fleet's perspective, the most important step to avoid an overage of the red king crab cap was the decision to adopt the Sea State voluntary bycatch avoidance program. Just prior to the 1995 season, the fleet agreed to systematically track its own caps and shut itself down in 1995 even if NMFS was unable to do so in a timely manner. Overall, the experience in the roe rock sole fishery was positive and cooperation was unprecedented. One of the most impressive accomplishments for the rock sole fleet was the reduction of red king crab bycatch to approximately 19,341 crab (sevenfold decrease from 1994, Table 1).

Discussion

In other years, the PSC cap for red king crab would likely have been taken before the fleet could respond by moving away from the area with high bycatch. In the past, the rock sole fishery was frequently unable to control the pace of bycatch. In the absence of a formal bycatch avoidance program, a reluctance to respond to high bycatch rates occurs because skippers may believe their own rates are relatively low compared to others, when this is not in fact the case. Another possibility is that skippers may feel that although they are not individually keeping bycatch rates low, other vessels are low so that a premature closure of the fishery is not at risk by fishing a particular area.

Despite underlying reasons or justifications, there is no way to respond to the collective incentive if there is no information on the implications of individual behavior and no means of creating peer pressure because rates are not general information. Under our program, each vessel's bycatch rates are commonly known and fishermen can compare the bycatch implications of the fishing location and practices they are employing. The simple fact is that a skipper fishing a given location and encountering high bycatch rates should feel the pressure from others if his or her rates are high relative to others.

In contrast to the success in the rock sole fishery, collective incentives to induce participation in the bycatch avoidance program may not always work adequately. This is occurring in the yellowfin sole fishery. For the first four weeks of the fishery (August 1-31, 1995), one company with five of the 20 vessels in the fishery elected not to participate in the program. Over 50% of the overall halibut bycatch in the fishery during the first four weeks of the yellowfin fishery is believed to have been taken by those five vessels. This figure was arrived at by calculating the rest of the fleet's halibut bycatch for that time period (as reported to Sea State) and subtracting it from the NMFS total for the appropriate week. Further, as reported by NMFS, the bycatch rates of those five vessels have consistently been among the highest in the fishery and as high as 20 times the legal level according to the NMFS vessel incentive program standard.

The consequences of a failure to keep bycatch of halibut low in the yellowfin fishery are large. The yellowfin sole fishery will almost certainly close with between 40,000 and 60,000 mt of yellowfin sole left unharvested. This is because only one-fourth of the 440 ton final semester halibut cap for the fishery is left, and rates for the remainder of the fishing period would have to be next to nothing for the balance of the TAC to be taken. That quantity of yellowfin sole left unharvested would represent roughly 20-30% of the overall TAC. Valued at the current price of approximately $600 per ton (round weight), the loss to the fishery as a whole would be approximately $24 to $36 million (gross revenue).

Participants in the Sea State program for yellowfin sole firmly believe that the owner and skippers of non-participant vessels decided to put individual gain ahead of the collective interest. It is believed that these non-participant vessels are experiencing high yellowfin sole catch rates and high bycatch rates of halibut whereas the participating fleet has generally moved away from areas where catch rates and bycatch rates are both high. This has created a sacrifice for participant companies.

This situation has also created an enticement for participating vessels to stop participating in the program and begin sharing in the high target catch at any bycatch cost. Although participating companies have thus far continued to resist this temptation, if the fishery closes prematurely, some potentially severe economic consequences may befall participants. Despite this failure to get all parties to participate, the program has served to keep bycatch rates lower than they would have otherwise been. It is hoped that even more pressure can be applied to the non-participating companies to curb their high bycatch rates before they force a closure of the fishery. If a premature closure is avoided, the program will provide benefits even if these benefits are smaller than those potentially obtainable.

The program has served another purpose as well. This year, as many as 14 boats that predominantly fish pollock have been fishing for yellowfin sole as well. Some of these vessels fished prior to the opening of the pollock B season and are planning to return to yellowfin sole after pollock closes. We have found that the bycatch incurred while a vessel searches for clean fishing grounds is often an order of magnitude higher than what can be achieved once clean fishing grounds have been located. Thus another benefit from the program will hopefully be realized when vessels reentering the yellowfin fishery are provided with an overview of the bycatch conditions by area, based on data from vessels that have continuously been fishing for yellowfin sole.

Summary

The 1995 rock sole roe fishery is a good example of the potential for voluntary efforts to reduce bycatch through avoidance of hot spots. The yellowfin sole fishery is a good example of the potential pitfalls of this approach when an individual company, or group of companies, puts self-interest before collective interest. The bottom trawl fleet targeting flatfish in the North Pacific is committed to further efforts to reduce bycatch rates on a voluntary basis, but also seeks ways to make bycatch reduction more effective and potentially less disadvantageous.

Some members of this fleet believe the only real solution, in the long run, will be a management system of individual accountability wherein an individual company directly affects its own economic performance by its efforts and ability to reduce bycatch. Such a system might be one where individual vessels have an annual allotment of PSC bycatch and must stop fishing as soon as that allotment is used up. Under such a system, companies would have incentives to use their bycatch wisely and lower their rates, to the maximum extent practicable, to extend their fishing time and increase production.

Under a system of individual accountability, a company doing its best to reduce bycatch, even at a cost of target species catch, would not be affected by a company unwilling to sacrifice target species catch to reduce bycatch. A system of individual bycatch quotas would not penalize the good actors while allowing bad actors to gain economically. While the spirit of cooperation characterized by the rock sole fishery demonstrates the potential for a voluntary approach to yield results, the experience in the yellowfin sole fishery has convinced many in the fleet that voluntary programs will never be completely successful. Lacking a system to penalize companies for nonparticipation in a bycatch reduction program opens the possibility for too much economic reward for failing to participate.

Bycatch Reduction: Achieving New Objectives by Innovative Footrope and Net Configuration

Brent C. Paine and John Gruver
United Catcher Boats, 1900 West Emerson, #212, Seattle, WA 98199

Over the past decade, a major shift in focus has occurred in fisheries management policy makers and fishery managers. Since bottom trawl gear was first developed, fishermen have had but one objective in mind: to catch as much fish as possible, while keeping trawl damage to a minimum. Trawl designers and technicians have long shown fishermen how to fine tune the net-footrope relationship. However, the world in which fishermen compete has not allowed much time for technical trawl adjustments, especially changes that may lower catch rates of target species to achieve lower bycatch. There are some practical solutions to reducing the bycatch of bottom dwelling animals, such as crab, that do not require drastic changes in trawl design, but in bridle rigging, footrope attachment, and attentive maintenance. There are techniques that enable the net to fish lightly across the bottom, which results in achieving lower bycatch of bottom dwelling animals. The merits of a fisherman can no longer be measured solely by how much he catches, but also on what he does not.

An Industry Perspective—The Good, Bad, Ugly, and Politically Influenced

Steve Hughes
Natural Resources Consultants, Inc., 4055 21st Ave. W, #100, Seattle, WA 98199

As in the past, Alaska groundfish bottom trawl fisheries will continue to experience some levels of bycatch, notably king crab, *C. bairdi* and *C. opilio* Tanner crab, and Pacific halibut. Current government management practices to regulate these groundfish fisheries and their bycatch have truly been "good, bad, ugly, and politically influenced."

Marked improvements can be made by doing away with the bad, the ugly, and much of the politically influenced. This industry needs "vessel bycatch accountability." Individually, vessels must be accountable for their own bycatch. The "dirty dozen" must not be allowed to shut down entire fleets.

Midwater Trawls and the Alaskan Pollock Fishery: A Management Perspective

Walter T. Pereyra
ProFish International, Inc., 400 North 34th St., #306, Seattle, WA 98103

Studies have shown that the midwater trawl fishery for Alaskan pollock in the Bering Sea is one of the cleanest fisheries in the world in terms of bycatch of prohibited and nontarget species. Despite this desirable attribute of midwater trawling for pollock, fishery managers have been reluctant to promulgate regulations establishing midwater trawling as the only legal fishing method for directed fishing of this species. The primary reason for not requiring midwater trawling exclusively for pollock is that the midwater trawls reportedly capture smaller-sized fish than bottom trawls. Increased capture of smaller-sized pollock results in lower product yields, and products of lower quality and diversity. Moreover, with smaller-sized fish, discard rates of pollock may increase.

There is some speculation that if expanded use of midwater trawls results in an increase in the removal of pollock smaller than the critical size, population yields could be lowered. There is also a suggestion that limiting pollock fishing to only midwater trawling could make pollock less available in certain areas and at certain times, which could increase harvesting costs and possibly exacerbate intrafishery gear conflicts.

The Alaskan pollock fishery is the largest groundfish fishery in the world. In U.S. waters in recent years, annual catches have been around 1.3 million mt. Midwater trawls (also known as pelagic trawls), which are large-meshed trawls or rope trawls fished off-bottom, have been used extensively by U.S. fishermen to exploit pollock since the expansion of the U.S. groundfish fisheries off Alaska in the mid 1980s. Bottom trawls are also fished at certain times and in certain situations when the pollock are available near bottom.

Because of the magnitude of the pollock fishery, bycatch of nontarget species—particularly crab, halibut, salmon and herring—and undersized pollock have received considerable attention. Fishery managers have taken various initiatives to lower the bycatch rates of these species.

This paper focuses on midwater trawling in the pollock fishery as it relates to bycatch, and the management perspectives which can be gained from these efforts.

Fishery data from the foreign, joint venture, and U.S. fisheries for pollock indicate that bycatch rates of prohibited species such as halibut and crab are typically low when fishing with midwater trawls. When comparing bycatch rates in fisheries throughout the world, Alverson et al. (1994) identified the Alaska midwater trawl pollock fishery to be among the cleanest fisheries in the world in terms of bycatch and discard rates. The primary reason reported for the small bycatch rates is that the meshes in a midwater trawl are very large, or wing ropes have spacing which facilitates escape of most crab and halibut through the large meshes or between the ropes. Even when the midwater trawl is fished in close proximity to the seabed, such escape can occur because the belly of the midwater trawl rises obliquely aft of the fishing line, allowing room under the belly of the net for halibut and crab to escape.

This is not always the case when fishermen fish in close proximity to the seabed and slow their fishing speed. In this case, the meshes of the midwater trawl tend to collapse, resulting in the belly not rising obliquely behind the net. There is then insufficient room under the belly of the trawl to allow halibut and crab to escape, resulting at times in higher bycatch rates.

One method by which the bycatch of halibut and crab are minimized in the pollock fishery, is by setting the maximum quantity of bycatch which can be taken in bottom trawls. Once this cap is reached, all future directed fishing for pollock is required to be only with midwater trawls. For example, in 1995 the bycatch cap for the category which included the pollock fishery was set at 555 mt of halibut mortality. The pollock B season opened on August 15 and closed on September 20 for the offshore fishery (36 days duration) and September 23 for the inshore fishery (39 days duration). The halibut bycatch cap was reached on August 22, just seven days after the opening of the B season. For the remainder of the B season, directed fishing for pollock with on-bottom trawls was not permitted. Thus, to minimize the bycatch of halibut (and indirectly crab), more than 80% of the pollock B season had to be prosecuted with midwater trawls.

Allowing the use of midwater trawls for directed pollock fishing during times when bottom trawling is prohibited, has presented fishery managers with some unique challenges. One of these has been to devise an enforceable definition of a midwater trawl.

The original definition of a midwater trawl prohibited the use of discs, bobbins, rollers, or other chafe protection gear attached to the footrope of the net. It also required very large mesh, or parallel ropes, aft of the fishing line for a length of several meshes (56 FR. 2700, January 24, 1991).

During the 1991 and 1992 fisheries, some fishermen were able to defeat the purpose of this midwater trawl definition by reconfiguring their trawl in such a way that it met the definition of a midwater trawl, but functioned as a bottom trawl. Other fishermen apparently were able to fish their unmodified midwater trawl for large-sized pollock, which are found close to the seabed, and which normally would be caught with bottom trawls. As a result, bycatches of halibut and crab were higher than anticipated, even when directed fishing with bottom trawl gear was prohibited (58 FR. 17196, April 1, 1993).

This circumvention of the midwater trawl definition frustrated the overall management objective of maximizing groundfish catches within the prohibited species catch (PSC) limits. Given these management concerns, it was deemed necessary to amend the definition of midwater trawl in order to allow the pollock fishery to continue as a true midwater fishery after the PSC cap was reached. The most logical avenue was considered to be some type of performance standard for midwater fishing.

Fishermen who fished with midwater trawls off-bottom caught very small amounts of bottom dwelling life forms, other than free swimming fish, while fishermen who used bottom trawls, or who fished with midwater trawls for pollock on or near the seabed, at times caught large amounts of bottom dwelling life forms. National Marine Fisheries Service (NMFS) observer reports showed these life forms were usually Tanner crabs. Therefore, the presence of crabs in trawl catches was assumed to be the result of fishermen deploying midwater trawls on the seabed.

When true midwater trawls were used in the midwater pollock fisheries, catches of crab occurred in very small numbers. In 1991 for example, information reported by NMFS observers showed that in 14,591 observed hauls catching 763,985 mt of groundfish, 14,484 of these hauls or 99.3% caught no bottom life forms (Unpub. discussion paper, A performance based description of a pelagic trawl, NMFS, Alaska Region, Juneau, AK 99802, June 1992). Therefore, numbers of crab in the codend of a trawl was selected as the performance standard to accompany the definition of a midwater trawl.

In determining the appropriate number of crabs to establish as the midwater fishing standard, it was important that the application of this standard to the pollock fishery afford protection to halibut as well. A halibut bycatch rate of 0.1% had been established as the maximum rate allowed under the Vessel Incentive Program (VIP). A halibut bycatch rate greater than 0.1% is considered a violation of the VIP. In analyzing the number of crabs associated with this proportion, NMFS reported that the 1991 observer data showed that when the halibut bycatch rate doubled from 0.0012 to 0.0024, the number of crabs increased to 20 animals or more per groundfish haul. Therefore, the presence of less than 20 crabs in a haul or on board a vessel was established as the performance standard for midwater trawling to accompany the definition of a midwater trawl (58 FR. 39680, July 26, 1993).

The combination of a midwater trawl definition together with this performance standard has allowed managers to enforce restrictions on the use of bottom trawls in the pollock fishery once the PSC cap for halibut and crab have been reached. The effectiveness of these enforcement actions has only been possible due to the high levels of observer coverage in the pollock fishery. Without this observer coverage it would be almost impossible to insure compliance with the regulations.

Discussion

Considering that midwater trawling for pollock has demonstrated significantly lower bycatch rates of crab and halibut, the question arises as to why managers have not insisted that pollock be fished exclusively with midwater trawls. Effective enforcement is no longer an issue with the development of a workable performance standard for midwater fishing. The fact that the pollock fishery itself only lasts about two months suggests there should be no adverse impact on quota attainment. From a regulatory sense, the North Pacific Fishery Management Council (Council) could easily make pollock a midwater trawl–only fishery by just setting the halibut PSC cap at zero for the pollock fishery, thereby requiring that all fishing for pollock be done with midwater trawls.

Why hasn't this been done when such an action seems so obvious within the context of bycatch reduction? The answer to this perplexing question lies in the open access nature of the fishery coupled with the differential availability of pollock to bottom and midwater trawls, and the composition of the fleet and the pollock markets that they serve. Following are some of the relevant issues fishery managers have had to consider regarding the issue of regulating the manner in which pollock are harvested:

1. In general, the larger older-aged pollock tend to be found near bottom and in the southeastern Bering Sea, while the younger, smaller-sized pollock reside in the water column and farther north. Fishing operations harvesting pollock for fillet production prefer the larger pollock found near the bottom due to higher product yields, larger fillets of greater value, and lower production costs. Surimi operations on the other hand, while preferring larger fish, can operate successfully on smaller pollock found off bottom or in midwater. Restricting or prohibiting on bottom fishing for pollock negatively impacts fillet operators and possibly those fishermen dependent on markets along the southeastern Bering Sea coast. Forcing fishermen to fish entirely in midwater also could increase pollock discards due to the smaller-sized fish encountered off bottom.

2. Pollock stocks are characterized by year classes of variable strength. During certain years when there are no strong year classes of younger-aged pollock in the fishery, fishable concentrations of pollock may be more available to bottom trawls. Thus, prohibiting the use of bottom trawls may negatively impact lower horsepower vessels which cannot fish midwater trawls as effectively as those vessels with higher horsepower.

3. Requiring that pollock be fished only with midwater trawls will most likely increase the harvest of smaller pollock than would be the case with bottom trawling. If these smaller pollock are less than the critical size (critical size is the size at which a cohort or year class of fish begins to decrease in biomass due to increases in cohort growth being less than losses from mortality), then population yields (yield per recruit) could be reduced which might result in lower quotas. Furthermore, considering that Steller sea lions, a threatened marine mammal, are reported to prefer smaller pollock, one could argue that increasing the harvest of smaller pollock might be counter to sea lion recover efforts.

4. Results from the pollock fishery conducted pursuant to the Community Development Quota (CDQ) program support the notion that if we eliminated the open access free-for-all nature of the pollock fishery and changed it to one based on individual transferable quotas (ITQ), we could avoid the negative allocative consequences of restricting the use of bottom trawling in the pollock fishery and at the same time reduce the bycatch of crab and halibut. The CDQ fishery operates in somewhat the same manner as an ITQ fishery in that those fishermen in the CDQ fishery fish on an individual pollock quota. As such, they are not constrained by diminishing quotas as to where and how they fish for pollock as now occurs with the race for fish in the open access fishery.

Results to date from the CDQ fishery demonstrate that the bycatch of halibut and crab would be reduced in an ITQ pollock fishery, as would pollock discards (Pers. comm., Dr. Joseph Terry, NMFS, Seattle, WA 98195). Furthermore, it has been shown that we could greatly mitigate the fishery impacts from requiring a midwater-only pollock fishery by combining such a restriction on fishing method with the implementation of an ITQ program for pollock. Some of these gains could also probably be realized through the implementation of an individual bycatch quota (IBQ) program in the current fishery. Although an IBQ program should create an incentive to fish cleaner, it unfortunately would still leave in place those intractable problems associated with the race for fish in the open access pollock fishery.

Conclusion

The bycatch of halibut and crab in the pollock fishery could be reduced by requiring that pollock be harvested only with midwater trawls. Unless individual accountability is established at the fisherman level, restricting the use of bottom trawls in the pollock fishery will most likely increase the discards of pollock and could exacerbate intragear fishing conflicts by limiting fishing grounds with fishable concentrations of pollock. In addition, such a regulatory action could have allocative impacts to the smaller horsepower vessels, those with markets along the southeastern Bering Sea coast, and those whose pollock catches are processed into fillets. Fishery managers will continue to be faced with a trade-off between gains associated with a reduction in halibut and crab bycatch, and the increased allocative and utilization costs, including increased discards, caused from restrictions on the use of bottom trawls in the pollock fishery.

Reference

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Mesh Size and Shape: Reducing the Capture of Undersized Fish

C.G. Bublitz
Fishery Industrial Technology Center, University of Alaska Fairbanks
900 Trident Way, Kodiak, AK 99615

Yield in a commercial fishery is directly influenced by the age (size) at which fish are first captured in any significant amount. Therefore, it is undesirable not only to capture animals that are smaller than can be sold, but also to capture sizes that are below some target value. Two main approaches can be used to reduce the take of undersized individuals: controlling exploitation rates, and adjusting harvesting methods to control the size of individuals taken. Adjusting harvesting techniques can be accomplished by providing escape routes, avoiding areas where small animals are abundant, and using methods which do not capture smaller sizes. Once captured, the most obvious method to allow the escape of small fish is the use of an appropriate mesh. The use of mesh size and shape has been shown to significantly reduce the catch of undersized fish in single species, directed fisheries such as the Alaska pollock fishery. This paper provides an overview of a technique for determining the most appropriate mesh size for reducing the catch of undersized fish and the application of this technique to reducing the catch of undersized pollock.

A major concern in national and international fisheries is the catch, discard, and resultant mortality of undersized fish. Size selection by varying mesh characteristics is considered one of the most efficient and practical means of reducing the take of undersized fish, thus ensuring fishery conservation and the utilization of fish stocks at their maximum potential. The application of mesh size to reducing the catch of undersized fish, however, appears to be sporadic, and consequently has not been used effectively. This stems, in part, from a lack of understanding of the escape process and application of that understanding to maximize escape potential and efficiency.

Fish retention is determined by the physical parameters of the gear, fishing technique, and biological characteristics of the fish. Gear parameters and fishing techniques that are known to affect retention include: gear dimensions; mesh configuration; twine type, flexibility, stretching characteristics, and methods of fabrication; tow duration; catch size and composition; and towing speed. Biological characteristics affecting capture include: inherent behavior patterns, physical condition, body form, and morphology. Of these factors, mesh configuration, mesh opening coefficient, fish behavior, and body morphology appear to be the most critical parameters in determining escape through mesh.

An example of the relationship between mesh opening coefficient (ratio of diagonals) and body form is given in Fig. 1. It is evident that as mesh opening coefficient decreases, the available opening for escape changes to a flattened, more elongated configuration. In conjunction with changes in mesh configuration, the fish body form that can escape changes from round to flat (Efanov et al. 1988). This relationship has implications for the escape of fish from conventional diamond mesh codends. During fishing operations, drag and loading forces on the

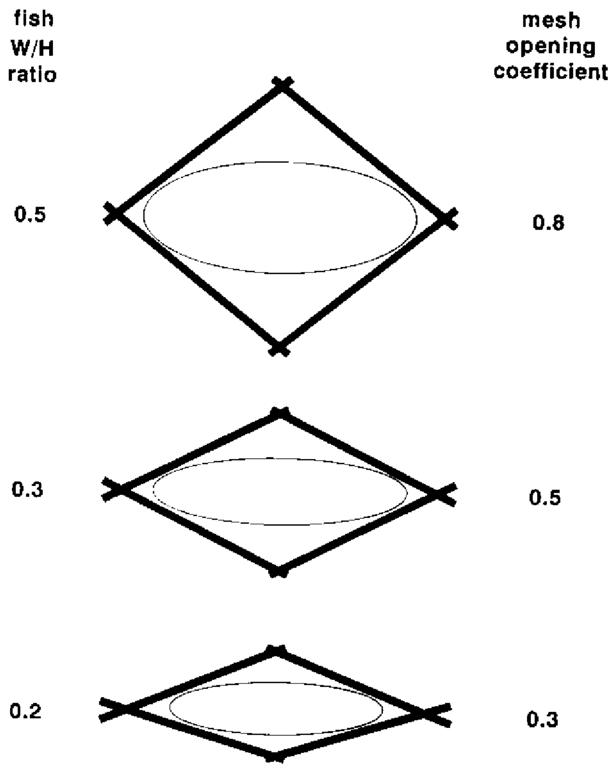

Figure 1. Relation between mesh opening coefficient and fish body form, width over height (adapted from Efanov et al. 1988).

codend are applied across the opening of diamond mesh. These forces tend to collapse the diamond mesh opening; the amount of collapse is determined by the magnitude and direction of the applied forces. This produces a variety of mesh opening coefficients throughout the codend. Escape, therefore, is limited only to areas where the mesh opening coefficient and body shape most closely correspond.

Square mesh, however, does not change shape with applied forces and, therefore, maintains a constant opening coefficient of one. Longitudinal and transverse forces on the square mesh are applied along the horizontal and vertical bars maintaining them in an open, rigid, and stiff condition. Varying drag and loading forces, therefore, do not affect the mesh opening. Mesh configuration remains constant throughout the codend resulting in little or no difference in mesh selectivity from mesh to mesh. The square mesh configuration, therefore, maximizes the available openings through which roundfish can escape.

Determining Mesh Size

Body length has traditionally been the parameter used to denote fish size in mesh selectivity studies; however, body cross-sectional shape is a more critical parameter in evaluating selection. A given mesh size has been shown to be differentially selective for fish of the same length but different cross sectional profiles (Robertson 1983). To effectively assess mesh selectivity, the interactive effects of fish size, shape, and behavior as well as mesh size and shape need to be considered. For example, in order to determine an appropriate mesh size, the relationship between total length and height, width, and girth must be established. These relationships can then be used to model the cross-sectional shape of fish, which can be approximated as an ellipse at the maximum girth. The cross-sectional shape for a given species is not constant, but varies with sex, state of maturation, and feeding condition. To address this problem, morphological data over a range of years and seasons should be obtained. The mesh size/body shape relationship can then be evaluated at the median condition. The appropriate mesh size to eliminate fish less than a specified total length can then be calculated from the regression model using the boundary conditions:

$$2a \geq T\ 4 \leq \sqrt{2}(a^2 + b^2) \qquad (1)$$

where T/4 is the between knot bar length, a is one-half the fish height, and b is one-half the fish width. The values for a and b are estimated from the regression models of total length vs. height and total length vs. width at the target length.

In most cases, fish behavior during escape through the mesh is unknown; consequently, specific attributes of fish behavior when approaching and attempting to escape through the mesh must be assumed. The main behavior assumption which can be made is that fish do not maintain a constant swimming position when encountering the mesh, i.e., the longitudinal body axis and center of the mesh tend to coincide during escape. In conjunction with this assumption, several behavior scenarios can be considered in determining the selection range. First, fish will only attempt to pass through the mesh if the body is oriented in a normal vertical swimming position (Fig. 2a). Second, fish will actively change swimming posture when passing through the mesh, i.e., vertical orientation of the body would change to coincide with the diagonal of the mesh during escape (Fig. 2b). Third, fish will not struggle during escape

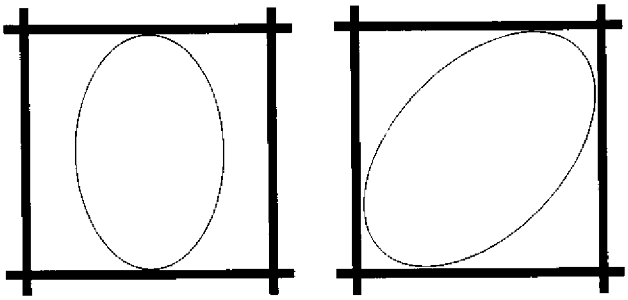

Figure 2. Relation between fish body and square mesh assuming: (left) vertical body orientation and (right) diagonal body orientation during escape.

and will attempt to pass through the mesh only if the body is not constricted during passage. Under this condition fish will not attempt to escape if the cross-sectional shape defined by the maximum girth is larger than the maximum inscribed ellipse. Fourth, fish will actively struggle to pass through the mesh, compressing the body to the minimum cross-sectional area in attempting to escape. Under this condition fish will escape up to the point at which the cross-sectional area, defined by compressed girth, reaches the maximum inscribed ellipse.

Results of Pollock Selection Experiments

To test the hypothesis that mesh size can be determined from body shape and morphology in the Alaska pollock fishery, a square mesh codend was constructed and fished under commercial conditions using a commercial trawler from Kodiak, Alaska. A total length of greater than 39 cm was selected as the target range for capture. The mesh size was determined from the regression model at 39 cm using formula (1) and pollock morphology data collected at shore-based processing plants in Kodiak. The square mesh codend was constructed from 800 ply UC braided web with chain riblines. The mesh size used was 60 mm (2 ¼") between knot (BK) bar length (120 mm BK stretch diagonal measure). Both the square mesh and a standard pollock codend were fished from the same commercial midwater trawl. The midwater trawl and standard codend were supplied by the vessel and were the same gear used in its commercial pollock operations. The two codends were interchanged on the trawl gear using a random block sampling design.

The theoretical selection curves obtained from an evaluation of the four behavior scenarios are given in Figs. 3 and 4. These curves provide an estimate of the percent of fish of specific size classes that can escape through the mesh. Sizes to the right of the curve can escape, whereas sizes to the left cannot. Within the range of the curve (from 0 to 100%) only a percentage of the fish for a given size can escape. For example, using scenario A_1, all fish less than 25 cm are capable of escaping, 50% of the 33 cm fish will escape, and all fish greater than approximately 35 cm will be captured. Scenarios A_1 and B_1 (Fig. 3) assume that fish do not actively struggle during escape. Scenario A_1 indicates selection obtained if the fish maintains a vertical position and B_1 represents selection if the fish changes body orientation to coincide with the mesh diagonal. Scenarios A_2 and B_2 (Fig. 4) assume fish actively struggle (compress the body) during escape. Body orientation is maintained in a vertical position in A_2 and changes to coincide with the diagonal in B_2.

Changes in selection represented by behavior changes are evident as a positive displacement of the selection curves along the X axis. For example, the 50% selection point for scenario A_1 is 33 cm, whereas, the same point for scenario B_2 is 49 cm. These graphic representations of behavior can now be compared to actual catch composition to determine the type of behavior that pollock exhibit during escape. Note that these selection scenarios only indicate ideal selection characteristics of the mesh. They do not indicate the number or volume of fish that will be caught and thus actual selection. Differences between ideal and actual selection represent variations introduced during actual fishing operations (i.e. length of tow, catch volume, etc.).

Size frequency of pollock caught using the square and diamond mesh codends are given in Fig. 5. These data indicate that the square mesh codend significantly reduced the catch of pollock less than 39 cm. Pollock catch between 39 and 45 cm was also reduced, whereas, the catch of pollock greater than 45 cm was increased. Table 1 gives the change in catch of various size classes. The most significant point of these data is that the square mesh codend used in this research reduced the catch of pollock less than 39 cm total length by 73%. Another significant aspect indicated by these data is that although the number of marketable pollock (fish greater than 39 cm) caught was reduced by 3%, the weight of marketable pollock caught was increased by 5% (Table 2).

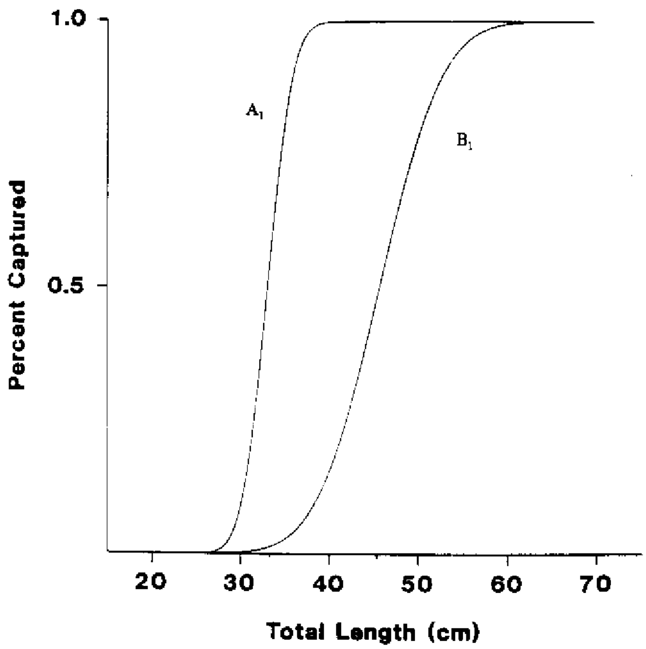

Figure 3. *Pollock selection model assuming escape accomplished without struggle: A_1 vertical and B_1 diagonal body orientation.*

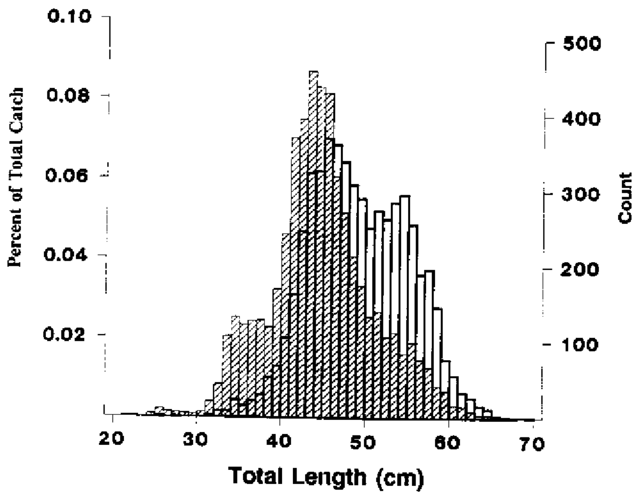

Figure 5. *Length frequency of pollock taken in diamond (crosshatched) and square (bold outline) mesh codends.*

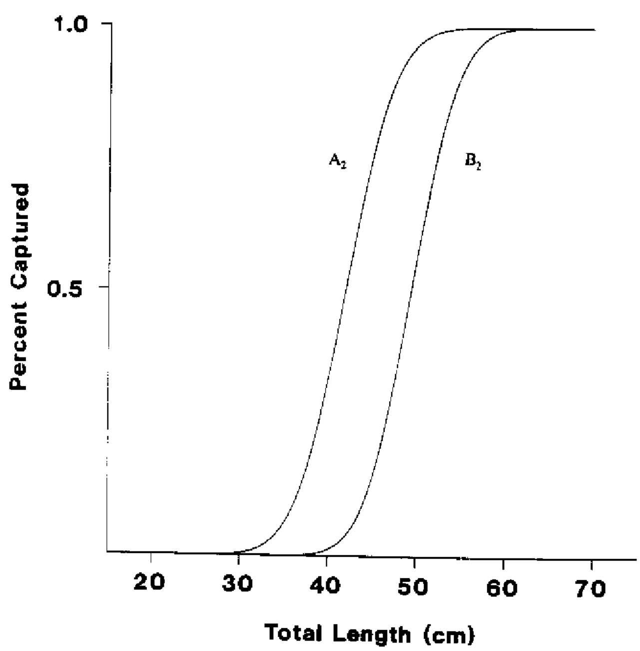

Figure 4. *Pollock selection model assuming escape accomplished by struggling: A_2 vertical and B_2 diagonal body orientation.*

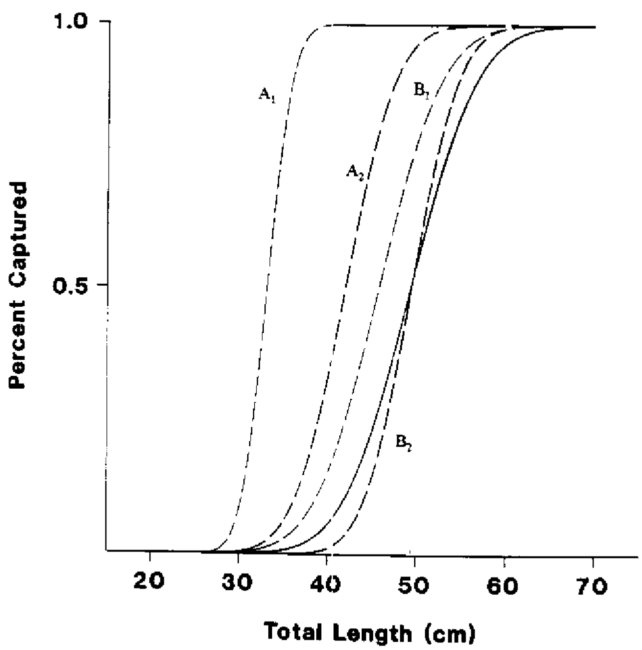

Figure 6. *Comparison of pollock selection models and actual catch (letters refer to behavior scenarios explained in text and Figs. 3 and 4).*

Table 1. Number of pollock caught in various size categories using square and diamond mesh codends (total catch).

Size	Square	Diamond	% Change
<39 cm	29,394	109,252	- 73
39-45 cm	229,667	339,884	- 32
46-50 cm	230,717	217,702	+ 5
>50 cm	273,691	204,154	+ 34

Table 2. Weight of pollock caught in various size categories using diamond and square mesh codends (pounds in total catch).

Size	Square	Diamond	% Change
<39 cm	35,160	97,894	- 64
39-45 cm	343,170	493,212	- 30
46-50 cm	434,920	421,022	+ 3
>50 cm	837,205	619,742	+ 35

A comparison of pollock selection models and actual pollock catch is given in Fig. 6. There is a close relationship evident between the actual catch and behavior scenario B_2. This suggests that pollock actively struggle to escape the net by compressing and turning the body to coincide with the mesh diagonal.

Conclusions

The use of the appropriate sized square mesh can significantly reduce the catch of undersized fish in a single species, directed fishery such as the Alaska pollock fishery. The 60 mm bar length square mesh codend used in this study not only significantly reduced the catch of undersized pollock but also increased total catch weight. The development and use of behavior selection curves provides a predictive capability which can be used to assess future mesh selectivity needs in the pollock fishery.

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Thinking Beyond the Traditional Codends

Gary F. Loverich
Ocean Spar Technologies, LLC, 7906 Day Road W, Bainbridge Island, WA 98110

Virtually all of the fish landed aboard modern trawl vessels end up in the trawl's codend. This part of the net is, therefore, a good location for devices and designs that reduce bycatch in such a way that the escaping fish have the highest probability of survival. This means that they must escape so as to avoid injury and physical stress, either of which can cause eventual mortality. Most bycatch reduction devices (BRDs) are passive, relying on the activity and behavior of the bycatch to carry out the escape.

Well designed passive BRDs are most effective if bycatch species have enough opportunity and energy to attempt multiple escapes. The trend of higher towing velocities in modern trawling tends to go against this necessity by overpowering the ability of the fish to maintain station inside the trawl or codend. The trend toward larger trawls and codends also reduce the likelihood that any individual fish will attempt an escape through a BRD, since the ratio of netting surface area to interior volume is lower on larger trawls than on smaller trawls.

Possible codend designs that will make BRDs more effective include codends made of very small mesh sizes or impermeable materials so that the codend creates a "dead water" region moving with the trawl, which becomes somewhat of a fish refuge. Any large codend that is fitted with a bycatch reduction device must also take into account the escape area to volume ratio. Active BRDs under the control of a bycatch specialist in the pilot house may ultimately prove more reliable and effective at reducing bycatch than the passive BRDs now being proposed.

Virtually all of the fish landed by trawlers end up in the codend, the cylindrical section of netting that trails the trawl. However, fish are often surrounded by the trawl net during a tow, yet are never retained by it or the codend. These fish escape alive or are lost dead through the meshes. Collectively, we are now developing reliable techniques to determine the fate of the fish that escape alive though the trawls and the codends. Over the past decade we have been developing ideas, tactics, and devices that reduce the amount of fish mortality resulting from fish interactions with trawl gear. Since the forward part of trawl gear has the function of herding fish to the codend, and since all of the catch is delivered to a vessel from the codend, this important piece of fishing equipment should not be overlooked in the effort to reduce bycatch.

Codend performance is rarely dependent upon trawl design or rigging. The codend is attached to the trawl and acts nearly independent of the trawl gear forward of it. This means that most codends of a given design act the same no matter what net design it is used with. Therefore, resulting bycatch reduction occurring in one codend design has the potential to apply to all trawl designs in all similar fisheries, and thus has the greatest potential to significantly reduce bycatch in all oceans. Rather than to dwell on past codend developments, this paper discusses how contemporary codends can be further modified to enhance the performance of bycatch devices. In this paper "codend" designates the entire cylindrical net section attached to the back end of the funnel shaped trawl, including what is usually termed the lengthening piece or intermediate. "Fishes" is used to broadly describe any marine creatures that are captured by a trawl, even crustaceans. Experiences related in this paper occurred in the Bering Sea and North Pacific Ocean.

Codend Design

Traditional codends encompass the class of cylindrical net that is characterized by diamond mesh construction. This codend class has no longitudinal support ropes that resist the tendency of the mesh to close under load. Because the meshes can change configuration, the traditional codend goes through a wide range of shape changes as it is loaded. Although still used in many trawl fisheries, the traditional codend generally does not serve as a stable base for bycatch reduction devices (BRDs). More importantly, since the meshes can completely close under load, they do not effectively use mesh size as a means for allowing undersized fish to escape. For these reasons, traditional codends should be abandoned as sustainable harvest tools and are not discussed further.

In general, contemporary codends are those similar to the ones developed and employed in the Bering Sea over the past decade which use meshes shaped in diamond configurations with stable mesh openings fixed by longitudinal and circumferential ropes, or those employing knotless square meshes that need no support ropes to hold a given mesh shape. Fixed diamond and square mesh codends, or combinations thereof, are used by virtually all of the trawlers, both large and small, in the Bering Sea. Detailed designs and descriptions of these codends can be obtained from the developer and major supplier, Net Systems Inc. The main characteristics of contemporary codends are the uniform mesh shapes and the relatively fixed overall cylindrical dimensions which are maintained whether or not the codend is loaded. The codends use high strength materials, single twine knotless netting in single layer constructions. These characteristics are necessary if the codend is to serve as a firm foundation for bycatch reduction devices and if mesh size is to be an effective means of regulating fish size. Fig. 1 contrasts the shape of traditional and contemporary codends under fishing conditions.

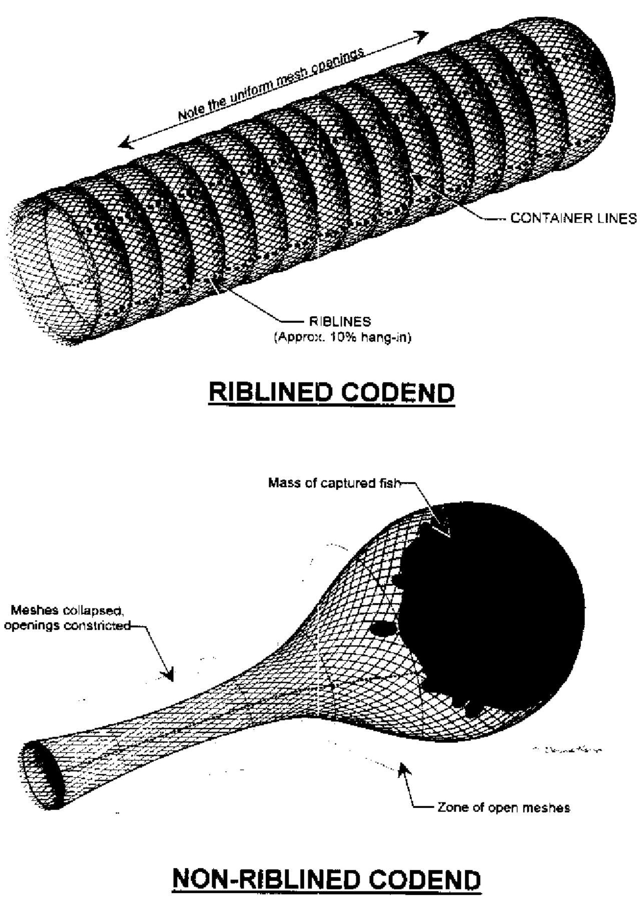

Figure 1. Codend shapes under fishing conditions. Top: contemporary, riblined codend, bottom: traditional non-riblined codend.

Codend Performance Goals

If a BRD is located in the codend to reduce bycatch, once the fish are in the codend it is desirable that the following occur:

- The bycatch in the codend should have multiple opportunities during the tow to escape through mesh openings or BRDs installed for that purpose.
- The physical condition of the escaped fish must be favorable to their long term survival.
- Sufficient numbers of the target species must be retained by the codend to insure an efficient and economic trawl operation.
- Target species must be delivered in good enough condition to maximize their value to the vessel operator.

Future codends must be designed with these goals in mind, or trawling will not achieve its potential as a sustainable harvest technique. Studies show that even though fish escape through the codend meshes, they can still die due to stress and/or injuries received during the process of escape. Even if fish escape uninjured, the physical exertion of maintaining station in the trawl can cause mortality due to decreased ability to feed or inability to escape predators. These mortalities can be termed consequences of fatigue stress. Other mortalities after escape can be directly related to trawl depth changes or physical injuries due to contact with the net during escape.

Codend Performance and Bycatch

As trawl fishing tactics become more sophisticated and trawls become larger, the impact on the species captured in the trawl becomes potentially greater. Larger trawls and faster towing speeds have the advantage of faster catches, which in turn mean that the net spends a minimum amount of time in the water which may mean that fewer unwanted species interact with the trawl. This indicates that shorter tows may be better. However, for the marine creatures captured in the trawl, faster towing speeds can have a negative effect and larger size codends may have the effect of reducing the utility of a given BRD design.

Contemporary trawling techniques center around an aggressive attempt to herd fish into the net through larger net size, higher towing speed, and real-time information about trawl performance which is delivered directly to the wheelhouse electronically. Lower horsepower vessels targeting finfish generally tow in the range of 1.25 m/sec (2.5 kts) to 1.75 m/sec (3.5 kts). At these speeds the action of the trawl can be likened to a filtering process where the fish are confused and slowly fatigued until they end up in the codend. The speeds are low enough to allow fish to escape at a variety of points in the trawl. In the codend, the quantity of fish and the drag of the forward part of the trawl form a wake moving in the direction of the tow. The codend is towed in this wake and thus water velocities through the codend are actually less than the towing velocity of the trawl in general. To a stationary observer, this wake appears to be following the trawl and to the fish it appears as a "slow water" region where some fish find it easier to maintain station in the trawl.

On the other hand, higher horsepower vessels that tow at speeds greater than 2 m/sec (4 kts) potentially change the function of the trawl from filtering to forcibly straining fish. In this case, the velocities are high enough that the fish are eventually pinned against the netting where they might remain until the tow ends and the trawl is hauled, or the water flow might force them through meshes where they escape injured. This can happen in the trawl body forward of the codend or in the codend itself.

The idea of a trawl filtering or straining fish based upon towing speed is a great simplification of what actually happens. I have taken some liberty with the specified speed ranges since ability of the fish to swim or move in a trawl is dependent upon many factors including: species, size, age class, visual acuity, water temperature, water depth, schooling behavior in the net, etc. However, the idea of filtering or straining fish has important implications if we are to use the fishes' own behavior to find safe escape openings provided by BRDs. By safe, I mean escape avenues in the net that do not leave the fish injured and likely to die after escape. Among other things, higher towing speeds restrict the ability of fish to observe and react to passive escape devices. Higher water velocities mean the fish get fewer chances to attempt escape from a BRD located at a single position in the trawl or that it must work harder to escape.

In most U.S. fisheries, codends are hauled on board the fishing vessel up stern ramps. The codends vary in capacity from a few tons to 200+ tons. Codend diameters vary from 1.25 m to 2.75 m. Bycatch devices or openings in the codend are often surface oriented and might not be scaled-up in proportion to the codend being used. Larger codends, such as those used by factory trawlers, surround a larger volume with less surface area of netting and thus leave fewer opportunities for fish to find and test the surface oriented release devices. As an example, a codend of 1.25 m diameter has an area to volume ratio of 0.80 while the codend of 2.75 m diameter has a ratio of 0.46, indicating that more fish in the larger codend have less chance at attempting escape from a single mesh or surface-oriented BRD. Most BRD studies have used research and data obtained from the smaller codends used on lower horsepower vessels. BRDs developed on smaller vessels may not be as successful on larger codends unless speed and relative size are considered in the design stage. Yet net size and increased towing speeds increase the efficiency of trawls, and can reduce bycatch simply by more effectively achieving optimum trawl configurations.

To reconcile the catch advantages of net size and increased towing speed with the need to provide safe escape from the net by lowering towing speed and decreasing net size, I suggested that the codend be designed to become a refuge for fish by reducing the relative water velocity inside. If the codend is made of a very fine material (even an impermeable material), the inside water flow could be regulated to move forward with the trawl at nearly the towing speed. This type of codend will be designated as a flow-control codend. The result would be the low impact transport of fish from ocean depths to ocean surface, rather than the filtering or straining of fish from the water that now takes place. The effect would be similar to pulling a bucket through the water, the bucket surrounding and carrying a volume of water with it in the direction of motion. Small openings in the trawl could be used to regulate water flow. In this case, any fish inside this "dead water" region (relative to the trawl motion) would be at rest relative to the trawl. Fatigue stress could possibly be reduced and the fish would then be able to make many attempts at escape openings provided by BRDs. The target species that remain in the codend would be in relatively good condition when brought aboard the vessel since fatigue stress, which reduces flesh quality, will be reduced. Typical mesh marks or damage due to gilling in the meshes would be greatly reduced or eliminated. Towing speed would be irrelevant once the fish entered the codend, so the advantages of higher towing speeds could still be realized. A flow-controlled codend might be a refuge with safe escape attributes for fish that would otherwise be landed as bycatch or escape injured. The idea of a codend with a very small mesh size goes contrary to traditional thinking and many regulations which tend toward increased mesh size as a conservation measure, but I believe there are excellent reasons to rethink the approach.

Past Experiences with Flow-Control Codends

The use of a water zone moving with the trawl has been documented (Net Systems, Inc. 1989, Natural Resources Consultants, Inc. 1988). There are numerous unpublished experiments investigating the concept. In most experiments, fish vigorously attempt to remain outside of the dead water region. This behavior has been used to direct target species of fish away from BRD openings. In a reversal of thinking, it becomes necessary to encourage the fish to enter the controlled-flow codend. It is relatively easy to design a codend that gradually forms the dead water zone so that fish avoidance response is reduced or eliminated. All codends are affected by the flow in the trawl's wake. As fish accumulate in the codend, their presence reduces relative flow velocity, and in some cases restricts it. The idea of actually controlling the flow is not far removed from what happens in the codend in an uncontrolled way, but to a lesser extent. I suspect that the trawl operation will proceed as usual when using a flow-control codend.

During the 1987 bycatch study in the Bering Sea, fish avoidance of entering a dead water region was used in a crab chute prototype, a device to exclude large king crab from the catch of yellowfin sole. Fig. 2 illustrates this prototype concept. In this case, the crab found the dead water region a refuge, and once in it, usually found the escape hole. The fish, on the other hand, vigorously attempted to swim around the dead water zone and thus missed their one chance at the escape opening. During this intensive study no significant loss in yellowfin sole was observed, while the catch of large king crab was significantly reduced. No attempt to refine this technique has ever been undertaken, but I believe a second generation production model of the crab chute could easily be made to eliminate all large crustaceans from the codend uninjured, while retaining most of the target finfish species.

This idea was developed further in an attempt to reduce halibut bycatch in the Bering Sea cod fishery. A special codend was fabricated at Net Systems, Inc. The last 20 ft of the codend was made of impermeable fabric and a ladder-like pattern of rectangular openings was installed in the bottom. The idea was to provide a large dead water zone into which halibut and cod would swim effortlessly and make many attempts at escaping from the opening in the bottom of codend. Since the openings were rectangular, it was thought that many more halibut (flatfish) would escape than cod (round fish). During this experiment (performed by NMFS, Seattle), cameras were installed in the codend to observe the fish. Very few of either species entered the dead water zone. The primary reason for this was probably the low towing speed (less than 3 kts), and the fish were able to swim easily in the net portion of the codend, which they preferred. Furthermore, the dead water zone was abruptly established which encouraged fish avoidance. However, a few small halibut did enter the dead water zone and were seen to escape through the bottom openings. No

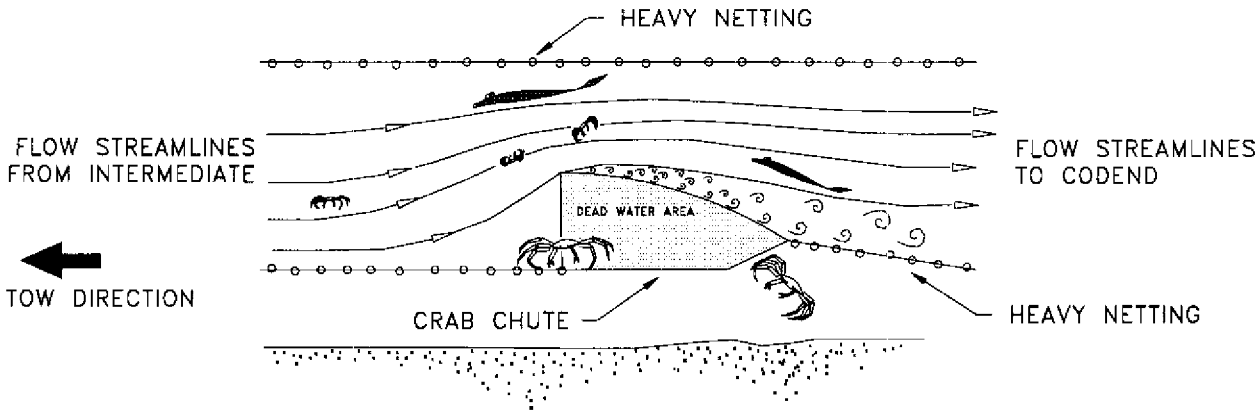

Figure 2. Crab chute operation between codend and intermediate.

cod were observed escaping. Prototypes rarely work perfectly, but it is obvious that the limited success shows this concept to have merit, especially since no other solutions have performed better while promising at the same time to achieve all of the goals for codend performance.

Active Bycatch Devices

To date most BRDs have been passive, i.e. relying on the particular fish to search for an escape opening in the net, or by straining the fish through various deflectors or around barriers. Since a trawl is 90% holes and acts as a barrier with deflectors, this passive type of BRD is certainly not a high-tech solution to the problem of bycatch. Can we only imagine using unpredictable fish behavior to effect escape from a trawl? Little attempt has been made to develop active methods for bycatch release; techniques by which trawl operators actually observe the catch and control the device that selects and releases the unwanted species. With an active BRD, fish behavior might become a minor consideration in the design. If active BRDs are ever attempted, the most likely location for them will be the relatively small area of the codend where all of the catch accumulates. Since identification will be absolutely necessary, the fish must be able to maintain station within the range of the sensing device which will require dead water zones in the codend. If the fish speed past the visual sensor, identification will be as futile as trying to distinguish individual snowflakes in a strong wind. With today's high-tech equipment being used in much of our daily lives, it is not too much of an imaginative step to visualize a bycatch specialist in every pilot house monitoring the catch as it enters the codend and selectively releasing unwanted species. In the case of active BRDs, the problem becomes more identification and engineering oriented rather than fish behavior oriented. Since few engineers are involved in solving the bycatch problem, contemporary thinking comes from fishers and fisheries experts who are generally behavior oriented.

Experience suggests that fish behavior may not be as simple and predictable as we would like it to be. For example, we know that the same species of fish will behave differently depending upon season, towing speed, distance from the bottom, and perhaps habitat, as well as changing biological factors. If this proves to be the case, passive BRDs as defined above will be severely limited in effectiveness. Each fishery will have to develop its own specialized BRDs. The modern trawler already has a large array of electronic gear that rides on the net so it is not too difficult to imagine that the next step will be video cameras in the codend to identify species, and devices that selectively activate BRDs to reduce waste and improve efficiency. This area of product development should fit very well within the capabilities of equipment companies providing the trawl monitors used on trawl gear. All that is needed for this development are market incentives.

Summary

The real promise of active BRDs lies in the control that can be exercised by the trawl operator. The problems to be overcome are mainly engineering. Less effort can be spent on learning fish behavior patterns. The promise of passive BRDs lies in simplicity and low cost. The needs are a thorough understanding of fish behavior and obtaining consistent reproducible results. The idea of the flow-control codend fits well within the goals of the active and passive BRDs and promises to make them potentially most effective. In fact, the flow-control codend may be absolutely necessary for future trawl gear and the requirement of sustainability. If the future prototypes of flow-control codends perform as well as the initial experiments indicate, I confidently predict that trawl caught fish will be delivered from ocean bottom to ocean surface in as good condition as fish delivered in fish pots.

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Codend Size-selection: Good Concept, But Does It Really Work?

Ellen Pikitch, Daniel Erickson, and Jose Antonio Perez-Comas
University of Washington, Fisheries Research Institute, Box 357980, Seattle, WA 98195

Petri Suuronen
Finnish Game and Fisheries Research Institute, P.O. Box 202, FIN-00151, Helsinki, Finland

Most codend mesh size studies have been conducted for small catches relative to the corresponding commercial fishery. Even for some of these cases, researchers have provided evidence that escapement of undersized fish through codend meshes may decrease as catch volume increases. We discuss results of two field studies that illustrate the effect of catch volume on escapement of fish through pelagic trawl codend meshes: (1) pollock (*Theragra chalcogramma*) in the Bering Sea (catches ranged from 0.3 mt to 79 mt), and (2) herring (*Clupea harengus*) in the Baltic Sea (catches ranged from 0.2 mt to 2.6 mt). In both studies, escapement decreased as catch volume increased, regardless of mesh size or mesh type (i.e., diamond, square, or hexagonal mesh). This reduced selectivity is due to increased mesh blocking with increasing catch volume. Similar conclusions have been reached by other researchers for various trawl fisheries (pelagic and demersal). These results suggest that codend mesh size management may be ineffective for certain high-volume fisheries (e.g., high volume pelagic trawl fisheries). The deleterious result of "meshing" and "blocking" of codend meshes may be reduced or eliminated by using sorting devices that permit escapement of undersized fish before they reach the codend.

One concept in mesh-size selection of trawl codends is that fish can and do escape through mesh openings if the openings are large enough to permit fish below a certain size to pass through (MacLennan 1992). Minimum codend mesh sizes are often regulated to optimize the yield from a particular stock (Armstrong et al. 1990) and to reduce the catch of fish that are smaller than the minimum marketable size (Beckett 1988).

Traditionally, size selection of trawl codends is described by a sigmoid-shaped probability curve (ogive; Fig. 1). For any particular fish size (length or girth) the ogive illustrates the probability of retention inside the codend (MacLennan 1992). In most cases, selection is described by the 50% retention length (L_{50}), which is the body length at which 50% of the fish entering the codend are

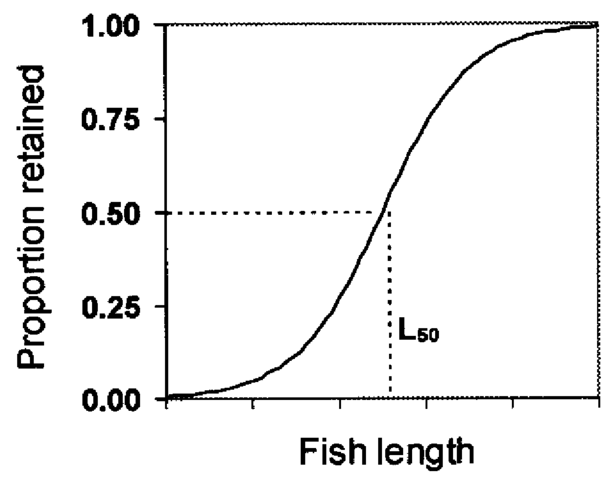

Figure 1. Selection ogive illustrating the 50% retention length (L_{50}).

Table 1. References that illustrate or suggest a catch-volume effect to codend selection.

Species	Trawl-type	Codend mesh	Experimental method	Catch volume	Reference
Cod	Demersal	Diamond	Cover	5-110[a]	Beverton (1959)
Redfish	Pelagic	Diamond	Cover	100-2,500[b]	von Brandt (1960)
Redfish	Pelagic	Diamond	Cover	300-1,300[b]	Bohl (1961)
Haddock	Demersal	Diamond	Cover	350-3,100[b]	Clark (1963a)
Redfish	Pelagic	Diamond	Cover	250-2,400[b]	Clark (1963b)
Haddock	Demersal	Diamond	Cover	200-3,000[b]	McCracken (1963)
Cod	Demersal	Diamond	Cover	200-3,000[b]	McCracken (1963)
Cod	Demersal	Diamond	Cover	5-110[a]	Beverton (1964)
Haddock	Demersal	Diamond	Alternate	3-396[a]	Hodder & May (1964)
Cod	Demersal	Diamond	Cover	48-661[c]	Hodder & May (1964)
Cod	Demersal	Diamond	Cover & Trouser	0.1-2[d]	Isaksen et al. (1990)
Haddock	Demersal	Diamond	Cover & Trouser	0.1-2[d]	Isaksen et al. (1990)
Herring	Pelagic	Diamond & Hexagonal	Trouser	0.2-2.6[d]	Suuronen et al. (1991)
Mackerel	Pelagic	Square	Alternate	3-60[d]	Casey et al. (1992)
Herring	Pelagic	Diamond & Square	Trouser	0.1-2[d]	Suuronen & Millar (1992)
Whiting	Demersal	Square	Cover	0.2-0.7[d]	Madsen & Moth-Poulsen (1994)
Pollock	Pelagic	Diamond & Square	Alternate	3-60[d]	Erickson et al. (submitted)

[a] baskets (1 basket = 43 kg); [b] individual fish; [c] kg; [d] mt

retained (i.e., do not pass through the meshes; Fig. 1).

Five experimental methods are typically used to estimate codend selectivity: (1) covered codend, (2) alternate haul, (3) parallel haul, (4) twin trawl, and (5) trouser trawl (Pope et al. 1975). Regardless of the method used, most experiments sample small catches (relative to commercial catches) to estimate the selectivity of trawl gear. We question whether selectivity results of small-volume research catches should be applied to large-volume commercial catches without knowing whether a relation exists between catch volume and size selection. Many investigators have addressed the potential relation between catch size and selection (Table 1). However, most of these studies were conducted using the covered codend method, and Pope et al. (1975) cautioned that results may have been due to the presence of the cover (e.g., masking effect).

The purpose of this paper is to illustrate the effect of catch volume on size-selection properties of trawl codends using methods other than the covered codend. Numerous experiments have shown that as codend mesh size is increased, the L_{50} also increases. Is this true when catch volumes are large? Does escapement through codend meshes diminish as catch volume increases?

Methods

Results of two very different field experiments were used to illustrate the effect of catch volume on codend size selection; both studies were designed to estimate selectivity of codends attached to pelagic trawls. The two studies differ in primary target species, sampling method, and range of catch sizes. The first, an alternate haul experiment conducted in the Bering Sea (Fig. 2), illustrates the effect of catch size (0.3 to 79 mt) on codend selectivity for walleye pollock (*Theragra chalcogramma*) caught in pelagic trawls (Erickson et al. submitted). The second, a trouser trawl experiment conducted in the Baltic Sea (Fig. 3), was designed to estimate codend selectivity for herring (*Clupea harengus*) caught in pelagic trawls (Suuronen et al. 1991). The catch volumes of the treatment codends ranged from 0.2 to 2.6 mt.

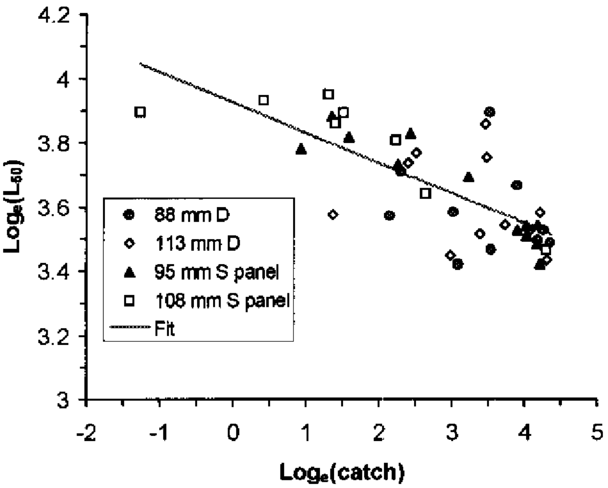

Figure 2. Relation between natural log of catch weight (mt) and the selection parameter estimate $log_e(L_{50})$ for pollock. D = diamond, S panel = square mesh top panel. Figure from Erickson et al., submitted.

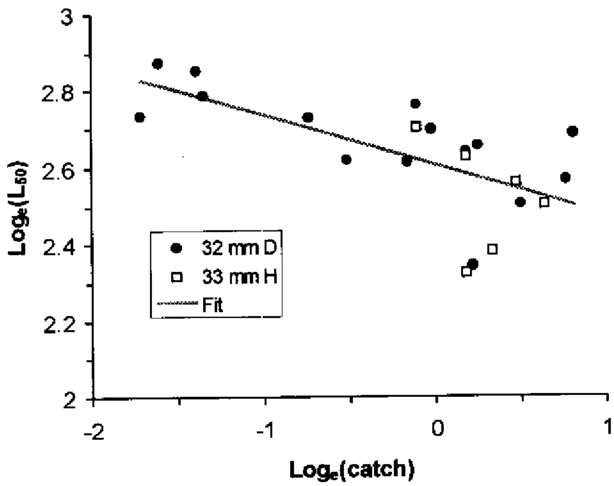

Figure 3. Relation between natural log of catch weight (mt) and the selection parameter estimate $log_e(L_{50})$ for herring. D = diamond, H = hexagonal. Data from Suuronen et al. (1991).

Pollock

Four stern trawlers (catcher vessels) operated in the Bering Sea north of Unimak Island during 1994. Catcher vessels towed commercial pelagic gears and detachable codends. Catcher vessel lengths ranged from 26 to 38 m, and engine sizes ranged from 980 to 1,900 horsepower. Catches were delivered to the factory trawler *American Triumph* where sampling took place. Approximately 500 pollock were measured each tow for body-length measurements.

Five codend types were included in this experiment. A double layer polyethylene all-diamond mesh codend was used as the standard; mean mesh sizes of the inner layer of meshes ranged from 82 to 83 mm. Side and bottom panels of two treatment codend types consisted of double layer polyethylene diamond meshes (same as the standard codend), whereas the top panels of these codends consisted of a single layer of 800 ply Ultra Cross (UC) polyethylene hung square to the riblines. Nominal mesh sizes of these square mesh top panels were 95 mm or 108 mm. The remaining treatment codends were single layer all-diamond mesh; nominal mesh sizes were 88 mm or 113 mm.

Experimental codends were towed following a randomized complete block design. Blocks were organized around each catcher vessel (Bergh et al. 1990). Sequential tows with each treatment codend and the standard codend by a particular vessel constituted one block. Every attempt was made to ensure that all tows within blocks were comparable (e.g., made in the same area, on the same day, under similar circumstances).

Selectivity curves for the four treatment codends were obtained by fitting the observed length frequency distributions to a multinomial model (Perez-Comas and Skalski 1995). As for many other methods based upon the alternate-haul approach, this model assumes that both standard and treatment codends were towed through fish aggregations showing the same length composition. Thus, the length frequency distribution of the standard codend is assumed to represent the length composition encountered by the treatment codend.

Multivariate analysis was used to evaluate potential relations between catch size (mt), selectivity parameter estimates (L_{50} and σ, the slope of the selection curve at L_{50}) and codend type (Erickson et al. submitted). A logarithmic transformation (natural log) was applied to catch size and the selectivity parameter estimates. The initial model consisted of codend type as a categorical variable, natural log of catch size as a covariate, and an interaction term. Model fit was tested using three multivariate statistics (Wilk's L, Pillai trace, and Hotelling-Lawley trace).

Guided by the results of these tests, a simpler model without interaction and codend effect was fitted to the transformed estimates of L_{50} and σ.

Herring

Selectivity trials were conducted in the western part of the Gulf of Finland during 1989 and 1990. Two 24 m Estonian stern trawlers (engine size = 300 horsepower) towed a commercial pelagic pair trawl that was modified into a trouser trawl. A small mesh standard codend was used in conjunction with the larger mesh treatment codend. Standard codends were composed of 16 mm diamond meshes. Treatment codends were made of either 32 mm diamond or 33 mm hexagonal meshes (nominal full mesh size). Samples of 6-9 kg were taken from each codend on each haul. Herring samples (i.e., measured fish) contained 250-400 fish.

Traditional analyses of trouser trawl data assume that the number of fish of each length class that enter the treatment codend is given by the number in the catch of the standard codend, possibly scaled if a different fishing efficiency of the treatment and standard codends is suspected. Cadigan and Millar (1991) showed that the resulting selection curves can give highly biased estimates of model parameters (e.g., L_{50}). To accommodate this potential bias, selection curves were fitted using SELECT (Share Each Lengthclass's Catch Total) model (Millar and Walsh 1990).

Selection curves were evaluated for each tow. In some cases, the standard error about the L_{50} was large, indicating that estimate of L_{50} was unreliable. Three tows presented by Suuronen et al. (1991) were therefore excluded from the analysis reported herein because of large standard errors. Standard errors (of L_{50}) for excluded tows were 9.3, 21.3, and 59.3. Standard errors for the remaining L_{50} were less than 6.

Analysis of covariance was used to evaluate potential relations between catch size (mt), codend type, and the selection parameter L_{50}. A logarithmic transformation (natural log) was applied to catch size and L_{50}. The initial model consisted of codend type as a categorical variable, natural log of catch size as a covariate, and an interaction term.

Fish behavior and codend performance were observed using an underwater video camera (Silicon Intensified Tube, SIT) mounted on a towed, remote-controlled foil. Observations were made during daylight and evening hours.

Results

The selection parameter L_{50} decreased as catch volume (C) increased, regardless of codend mesh size or mesh shape for both pollock (Fig. 2) and herring (Fig. 3). Power was insufficient to detect differences in $\ln(L_{50})$ among codend types (p = 0.16 and p = 0.70 for herring and pollock, respectively), whereas ln(C) significantly affected $\ln(L_{50})$ for herring ($p = 0.005$) and pollock ($p < 0.001$). Because neither the interaction or codend type were significant ($p > 0.05$), the relation between natural log of catch size and L_{50} was described as:

$\ln(L_{50}) = 3.924 - 0.094 \ln(C)$ for pollock ($r^2 = 0.53$; Fig. 2), and

$\ln(L_{50}) = 2.605 - 0.130 \ln(C)$ for herring ($r^2 = 0.44$; Fig. 3).

To illustrate the effect of catch size on selectivity for pollock, length frequency distributions were pooled by catch size category (i.e., treatment codend catch weights <15 mt, 15-40 mt, and >40 mt) prior to estimating L_{50}. For each catch category, two pooled length distributions were obtained—one for the standard codend and one for all treatment codends combined, given that differences among codend types were not significant (see above). Length distributions for each codend type were given equal weight prior to this pooling procedure. Fits of the pooled length frequency distributions to the multinomial model showed decreasing L_{50} with increasing catch size (Fig. 4). For catches less than 15 mt, the L_{50} was 49 cm. The length at 50% retention decreased to 37 cm and 22 cm as catch size increased to 15-40 mt and > 40 mt respectively. The reason for the decreasing L_{50} with increasing catch size is that the length frequency distributions of treatment and standard codends became increasingly indistinguishable as catch size increased (Fig. 4). This same trend was observed for herring.

Decreasing L_{50} with increasing catch volume is likely due to the blocking of codend meshes with the catch. As the volume of the catch increases, the ability of fish to reach "open" and unobstructed meshes decreases. Mesh blocking is probably a continuous process; selectivity may be good early in a tow, but diminishes as catch volume increases.

Codend mesh blocking can occur in several ways, including:

1. Meshing or gilling (e.g., fish wedged or gilled between the codend meshes) decreases the number of open meshes (Fig. 5).

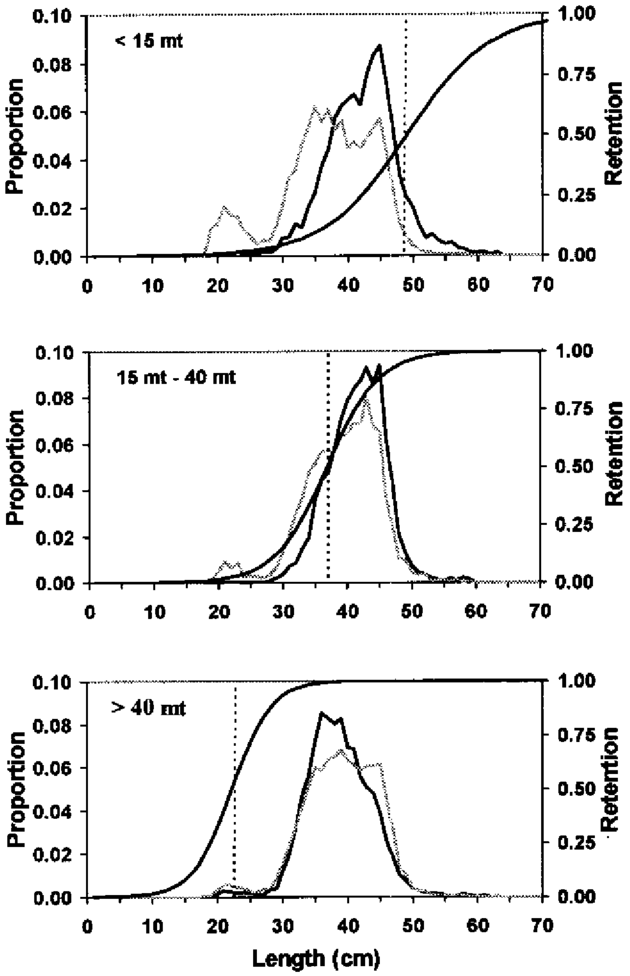

Figure 4. *Pooled length frequency distributions of pollock catches made with standard (gray) and treatment codends (black), estimated 50% retention lengths (L_{50}; vertical dashed line), and predicted selection ogives for three catch sizes (<15 mt, 15-40 mt, and >40 mt). Figure from Erickson et al., submitted.*

2. Codend meshes may become blocked with exhausted fish pinned against the codend walls, thus forming a "hollow cylinder" of fish inside the codend (Fig. 5), or with fish swimming near the codend walls.

3. High density of fish swimming in the codend may preclude other fish from dropping back from the intermediate (sometimes made of small meshes) until haul-back. This mechanism of mesh blocking becomes more extreme as the catch bulge advances toward the intermediate.

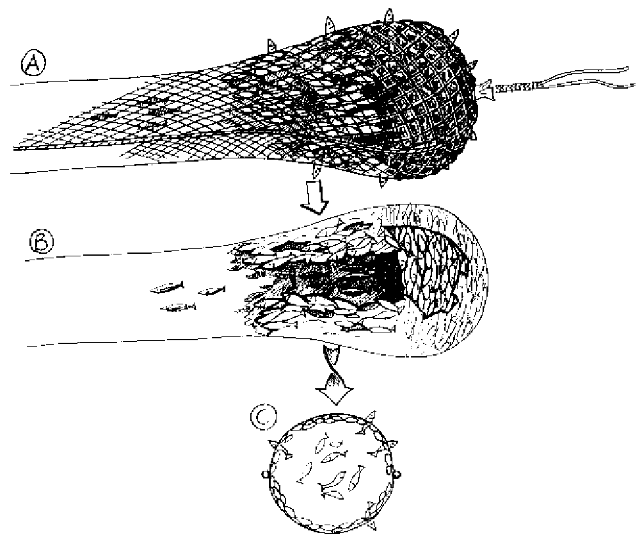

Figure 5. *Schematic presentation of exhausted fish lining codend walls forming a "hollow tube," and of fish gilled in the codend meshes. Views are (a) outside, (b) longitudinal section, and (c) cross section of the codend. Illustration by Vesa Tschernij from Suuronen 1995.*

Cases 1 and 2 above were observed for herring using underwater video (Suuronen and Millar 1992, Suuronen et al. 1993); herring were pressed against the netting of the codend walls by the outward flow of water (Fig. 5), especially during longer tows. The codend walls often became lined with exhausted herring and gilled fish for several meters in front of the catch bulge, leaving an open space in the center axis of the codend (i.e., "hollow cylinder").

Discussion

Relation Between Selectivity and Catch Volume

Erickson et al. (submitted) and Suuronen et al. (1991) show that catch volume may significantly affect codend selectivity. As catch volume increased, the length at 50% retention decreased. Other researchers have shown or suggested this effect for various pelagic and demersal trawl fisheries using alternate haul, trouser trawl, and covered codend methods (Table 1). Casey et al. (1992) found no difference in length distributions of pelagic trawl caught Atlantic mackerel (*Scomber scombrus*) between standard and treatment codends; they cited high catch rates as the reason for this result. Negative correlations between L_{50} and catch volume were shown by Beverton (1959, 1964), Bohl (1961), von Brandt (1960), Clark (1963a, 1963b), Dahm (1991), Hodder and May (1964), Isaksen et al. (1990), Madsen and Moth-Poulsen (1994) and McCracken (1963) for various species and trawl types (Table 1). A catch volume effect on selectivity was suggested for herring using 36 mm diamond and square mesh codends (Suuronen and Millar 1992); however, the relation was not statistically significant.

It is noteworthy that codend catch volumes in many of these experiments are low to medium with respect to commercial catches. The average commercial herring catch is about 4-5 mt per haul (maximum catches reach 50 mt), whereas treatment codend catches in the experiments by Suuronen et al. (1991) never exceeded 3 mt. Even though the study presented by Erickson et al. (submitted) was designed to evaluate selectivity for large catches (to 80 mt), maximum catch volumes for the Bering Sea pelagic trawl pollock fishery exceed 200 mt.

Mesh Blocking and Underwater Observations

The rate of mesh blocking by the catch may be dependent on the size of the codend in relation to the size of the catch. For instance, even though Erickson et al. (submitted) showed that pollock length distributions were similar between standard and treatment codends when catches exceeded 40 mt, it is uncertain at what point the distributions might become similar using larger capacity codends. Erickson et al. (submitted) studied 80 mt capacity codends; a detectable reduction in L_{50} may occur at larger catches for larger codends (e.g., 200 mt codends).

The blocking of codend meshes by the catch may begin soon after the catch starts to accumulate in the codend. Underwater observations show mesh blocking early in the tow for pollock and flatfish (Pers. comm., Craig Rose, National Marine Fisheries Service, Seattle, WA 98115, Sept. 1995) and herring (Suuronen, personal observation). Dahm (1991) presents a set of individual hauls which show a strong decrease in L_{50} already occurring at rather low catches (0.1-0.2 mt). However, Dahm (1991) conducted tows with a covered codend, and this may have influenced his results. As the codend filled with catch, the cover in his experiment may have masked (obstructed) the codend meshes and prevented "undersized" herring from escaping though the meshes. Recent advancements have reduced this codend cover masking effect (Main and Sangster 1991).

The hollow cylinder mechanism of mesh blocking (see case 2 in the results) observed for herring has also been observed for pollock and flatfishes using underwater video (Pers. comm., Craig Rose, National Marine Fisheries Service, Seattle, WA 98115, Sept. 1995). Although we feel this is one of the important mechanisms of mesh blocking (especially at lower catches), case 3 (i.e., fish inhibited from dropping back from the intermediate and into the codend due to high concentration of fish swimming in the codend and the advancing catch bulge) may become extremely important once the codend becomes relatively full with catch. Underwater observations of pollock being captured in a codend showed a much lower packing density of fish while the codend was fishing (at-depth) than when the codend was brought on-board (Pers. comm., Craig Rose, National Marine Fisheries Service, Seattle, WA 98115, Sept. 1995). Most packing took place as the codend was hauled up the stern ramp and onto the deck. Hence, it is likely that for codends landed on the trawl deck near-full to full (to the intermediate), many landed fish never encounter the selective codend meshes (i.e., they do not drop back from the intermediate portion of the trawl and into the codend) until haul-back.

We contend that the mesh blocking mechanisms listed in the results (cases 1-3) can seriously impact codend selection early in the tow, and that mesh blocking becomes more severe as catch volume increases relative to codend volume. Mesh blocking can occur because of high catch rates (e.g., high density of fish entering the codend in a short period of time) or because of increasing catch volumes (regardless of catch rates).

Implications to Management

For certain fisheries (i.e., high volume fisheries/catches), regulating codend mesh sizes may be of little benefit to the resource. Dahm (1991) suggested that square meshes in herring trawls were optimally selective only under conditions of small catches. He concluded that, for herring, use of square meshes or other constructional changes to the trawl gear would not benefit the stock or reduce labor on deck. Casey et al. (1992) emphasized that codend meshes were blinded at high catch rates of Atlantic mackerel, and that while square mesh codends may conserve juveniles of certain roundfish species by allowing their escape, they are likely ineffective for directed midwater trawling at the densities normally associated with commercial fishing. Bohl (1961) summarized that because redfish (*Sebastes marinus*) L_{50} decreased with increasing catch sizes, conservation of stocks by codend mesh regulation was not possible. Indeed, captains of catcher vessels fishing for the study presented by Erickson et al. (submitted) indicated that if large mesh codends were implemented as a regulation in the North Pacific pollock fishery, they would simply make longer tows until "the codend meshes became plugged with fish . . . once meshes were blocked, then the codend would retain any size that entered the net."

Potential Solutions

One potential solution to this mesh blocking problem is to regulate catch volume in relation to codend capacity. Clearly, this potential solution would be difficult to regulate, difficult for fishers to control under many circumstances (e.g., extremely high catch rates), and economically difficult. Furthermore, we showed that mesh blocking may occur early in the tow (i.e., at small catch volumes) for some fisheries; therefore, this action may not provide the result desired. Another option, that may permit adequate escapement of undersized fish regardless of catch volume in the codend, is the placement of a size sorting device (e.g., sorting grid) in the rear of the net body immediately in front of the codend (e.g., Larsen and Isaksen 1993; Suuronen et al. 1993). The problems associated with meshing and blocking of codend meshes (i.e., lower L_{50}) may be reduced or eliminated by using sorting devices that permit escapement of undersized fish before they reach the codend. Proper placement of a size sorting device in the net, along with suitable water flow and other means to stimulate escapement through the device, could prove beneficial to these high volume fisheries (i.e., allow escapement of undersized fish without restricting catch size).

Acknowledgments

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Finfish Bycatch from the Southeastern Shrimp Fishery

Gary L. Graham
Marine Advisory Service, Texas A&M University, 4700 Ave. U, Galveston, TX 77551

Finfish bycatch from the southeastern U.S. shrimp fishery clearly represents a major concern to industry, government, and the environmental sectors. Currently, a concerted effort to address bycatch in the shrimp fishery involves an intensive cooperative effort between government and the commercial fishing industry. An ongoing program to characterize trawl bycatch, and evaluate various excluders for trawl bycatch reduction, has been implemented. Special emphasis is being placed upon the catch of juvenile red snapper in the Gulf of Mexico and weakfish in the South Atlantic. Perceptions of bycatch and specific species captured in trawl gear present unique problems and considerations regarding management decisions. This paper is directed toward ongoing work associated with a coordinated plan to address trawl bycatch and detailed aspects of fishery management.

Finfish species that are incidentally harvested in shrimp trawls clearly represent a major concern to marine resource users. As much as 600 million pounds of finfish are estimated to be harvested in shrimp trawls annually in the southeast region. Fisheries managers report that populations of certain species, such as red snapper (*Lutjanus campechanus)*, are severely impacted due to trawling mortality. Amendments to the Magnuson Fishery Conservation and Management Act contain definitive mandates directed toward evaluating the potential impact of trawl bycatch and the feasibility of reducing this catch.

Design and Implementation of a Research Program

The initial steps in developing a research plan for shrimp trawl bycatch involved various user groups. The Gulf and South Atlantic Fisheries Development Foundation, Inc. (GSAFDF) organized a 34-member Finfish Bycatch Steering Committee, which, in turn, devised a comprehensive framework for the development and implementation of a bycatch research plan. The steering committee included a broad spectrum of marine-related representatives, with members from the commercial and recreational sectors, the environmental community, regional marine fisheries commissions, fishery management councils, state management agencies, National Marine Fisheries Service (NMFS), Sea Grant programs, and universities. A 15-member technical review panel and an eight-member gear review panel were established to advise the steering committee. As a result of much dedicated effort, these groups developed and published *A Research Plan Addressing Finfish Bycatch in the Gulf of Mexico and South Atlantic Fisheries* in 1992.

The Research Plan

It is significant to note that the research plan represents a consensus of the various user groups and provides for an orderly and effective approach to the bycatch dilemma in the southeast region. It entails a comprehensive four-year program directed toward research and development projects, and includes the following eight major objectives:

1. Update and expand bycatch estimates temporally and spatially including offshore, nearshore, and inshore waters.

2. Improve assessments of the status and condition of fish stocks significantly impacted by shrimp trawl bycatch.

3. Identify, develop, and evaluate gear options for reducing bycatch in the Gulf of Mexico and South Atlantic shrimp fisheries.

4. Identify, develop, and evaluate non-gear and tactical fishing options for reducing shrimp fishery finfish bycatch.

5. Evaluate the biological, sociological, and economic impacts of management options to reduce finfish bycatch in the shrimp fishery.

6. Provide continued cooperative oversight of research plan implementation and develop an information transfer and education program for commercial shrimp fishermen and other parties affected by finfish bycatch.

7. Evaluate the magnitude and distribution of fishing mortality on current and potential bycatch species by sources other than shrimp trawl fishing activity.

8. Develop and operate a standardized data management system for the cooperative research program.

Although each of these objectives is clearly essential to a comprehensive bycatch research plan, this paper will address those components that have been undertaken by the GSAFDF.

Trawl Bycatch Characterization

For many years, estimates of shrimp trawl bycatch have varied considerably. Ratios often appearing in the media indicate catch rates to be as high as 20 pounds of finfish to one pound of shrimp. Tremendous concern exists for this apparent waste of marine organisms among conservation groups, while industry representatives often question the reliability of such information. Gulf shrimp fishermen have long claimed that adoption of the quad trawl array and the use of turtle excluder devices (TEDs) substantially reduce bycatch. These divergent views were initially addressed as a result of the research plan. In fact, the Texas Shrimp Association (TSA) was one of the first organizations to obtain funding and begin investigating composition of trawl bycatch.

An established protocol was developed by NMFS and published in *Shrimp Trawl Bycatch Research Requirements*. As a result of an approved scientific sampling procedure, both certified NMFS and industry observers (through TSA and GSAFDF) were deployed throughout the fleet to document bycatch during actual fishing conditions. These observers received identical training and used the same approved data collection techniques. The cooperative effort between industry and government has clearly been the most significant in the history of the southeastern shrimp fishery.

From early 1992 through August 1994, data were collected from 3,296 tows encompassing 2,549 sea days from the southeastern region. These data have been assembled into one database at NMFS Galveston and have been closely analyzed. As indicated in Fig. 1, the ratio of finfish to shrimp caught in the South Atlantic has been determined to be 1:6 by number, or 2.3:1 by weight. Commercial shrimp consist of 29% of the total catch by number and 20% of the harvest by weight. Finfish account for 46% of the catch by number and 47% by weight.

Similar shrimp trawl bycatch is documented for the Gulf of Mexico. The catch composition depicted in Fig. 2 shows a 4.3:1 ratio of finfish to shrimp by weight and 2.0:1 by number. The major difference between the Gulf and South Atlantic bycatch composition is cannonball jellyfish. The South Atlantic, which has a relatively shallow water fishery, produces considerably more of these organisms, which, in turn, offers a different perspective from the standpoint of invertebrates in the catch.

Although catch composition is presented in a simplistic manner, recent efforts have resulted in a very comprehensive database of all bycatch organisms. During characterization tows, observers collect data on length/frequency and weights of organisms captured during representative samples of commercial tows. This extensive bycatch characterization work provides an excellent vehicle to examine various aspects of trawl catch closely.

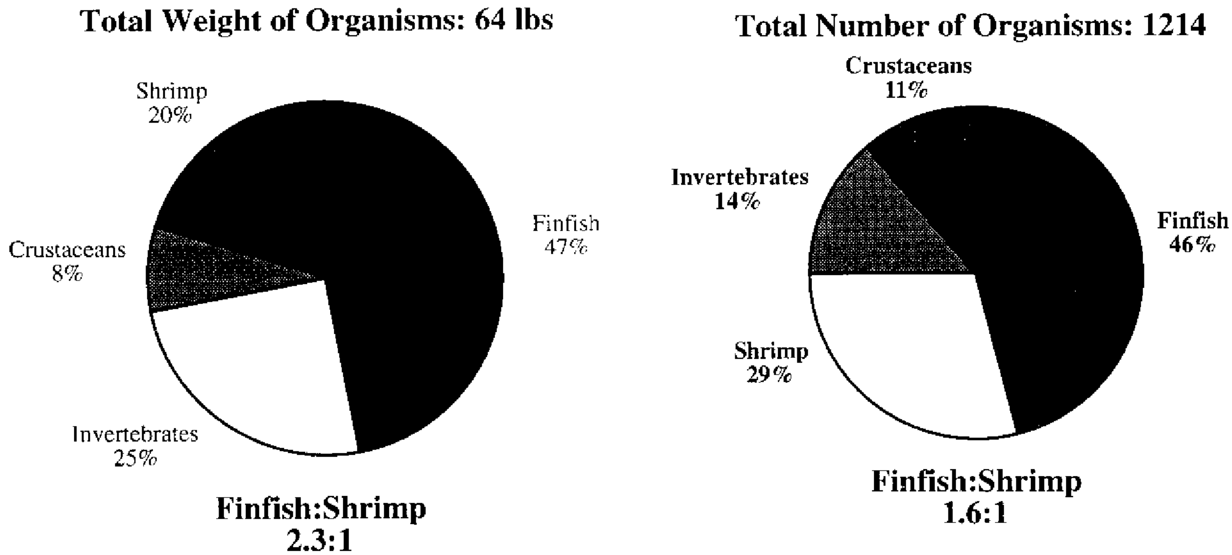

Figure 1. Average shrimp trawl catch per hour in the South Atlantic.[1]

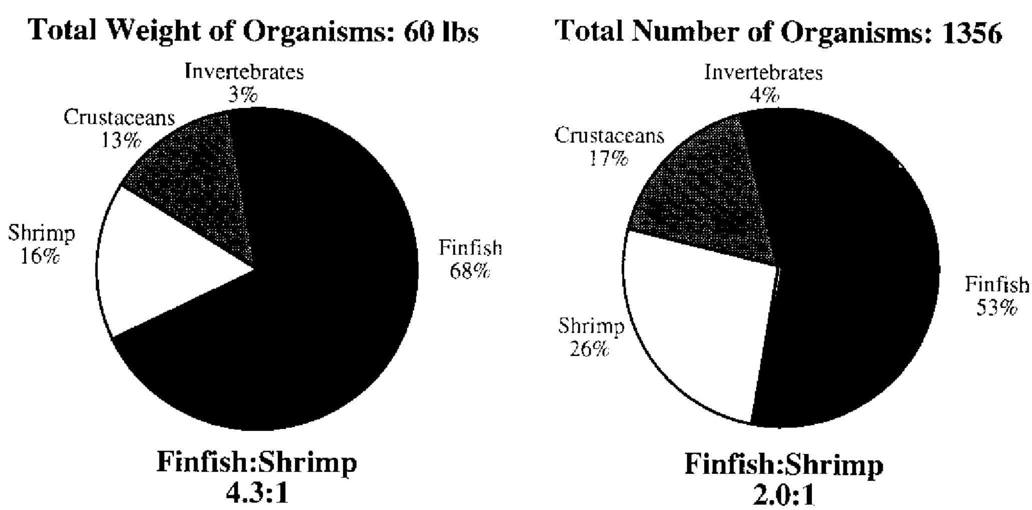

Figure 2. Average shrimp trawl catch per hour in the Gulf of Mexico.[1]

Red Snapper Dilemma

The red snapper resource in the Gulf of Mexico is a particular concern of fishery managers. At one time, stock assessments of these fish indicated severe overfishing. The extreme pressure of both commercial and recreational fisheries is further compounded by the incidental taking of numerous small snapper in gulf shrimp fishery trawls. Previous bycatch research in the Gulf shows juvenile red snapper to be highly susceptible to capture in shrimp trawls. While large quantities of these juvenile fish are not usually harvested in individual tows, the collective capture by the large numbers of trawlers fishing in the Gulf has a definite impact on recruitment of this species.

In 1993, fishery scientists indicated that the Gulf of Mexico trawl fishery was responsible for the death of 35 million juvenile red snapper. By analyzing data from bycatch characterization efforts, the median size of snapper harvested in trawls was 105 mm (about 4 inches). Investigations have revealed that the shrimp fishery is incidentally harvesting snapper in the age 0 to age

1 class range. A bycatch reduction goal of 50% has been established to reduce the impacts from shrimp trawling.

Excluding juvenile red snapper from shrimp trawls presents a challenge. Juvenile snapper are attracted to any object, including shrimp trawls. Because of this phenomenon, red snapper have been more difficult than many other species of fish to exclude from trawls by using bycatch reduction devices (BRDs). It has been recently revealed that the larger, age 1 fish can be excluded from BRD-equipped trawls at the target rate of 50%. Scientists indicate that exclusion of these older fish is of more biological importance than are the 0 year fish. Natural mortality rates of 0 year class fish are very substantial and the preservation of an older fish that has survived this period of higher mortality is substantially more valuable to the resource.

BRD Development and Evaluation

Substantial effort has gone into developing and evaluating potential BRDs to reduce bycatch in the Gulf shrimp fishery. The Harvesting Branch at NMFS Pascagoula has evaluated 82 BRD prototype designs for feasibility. From this large number of designs, 24 models were selected for proof-of-concept testing. This phase incorporates the evaluation of finfish exclusion and shrimp retention for the selected BRDs. A research vessel or contracted commercial vessel is used to determine if 50% bycatch reduction can be achieved with a minimum of 3% shrimp loss. From these tests, three gears have been selected for operational testing in the commercial shrimp fishery. A gear review panel coordinated through the GSAFDF provides input into gear to be tested and the evaluation process.

Operational testing aboard commercial fishing vessels with trained observers has been extensive. BRDs are installed into at least one trawl and compared to a control net with no BRD under actual fishing conditions. During 1993-1994, the GSAFDF conducted 838 tows in the western Gulf, 321 tows in the eastern Gulf, and 385 tows in the South Atlantic for a total of 1,544 tows. This was done in addition to NMFS BRD testing efforts that also incorporate observers aboard commercial vessels.

Observer evaluation efforts have focused on two BRD types aboard commercial shrimp trawlers in the Gulf. The fish-eye (Fig. 3) and the extended funnel BRD (Fig. 4) currently show the most promise for finfish reduction. The fish-eye is an industry-developed design which consists of a football- or round-shaped frame inserted into a trawl extension or codend to provide an opening for fish to escape. Dye flow tests indicate the water flow entering the opening of the device was reduced, providing a stimulus for fish escapement. The fish-eye was tested in three different positions; in the top of the codend, in the bottom of the extension, and on the sides of the extension behind a grid-style TED. The extended tunnel BRD design consists of a small-mesh webbing funnel surrounded by a large-mesh escape section held open by one plastic-coated cable hoop. One side of the funnel is extended to form a lead panel that creates an area of reduced water flow on the backside of the funnel. It is placed behind the hard-grid TED between the TED and the codend. Interestingly, these gears have opposite characteristics. The fish-eye is a simple and inexpensive gear type that is quite easy to install. Its major problem is that of shrimp loss (3-7% depending upon placement into the trawl). Expanded mesh

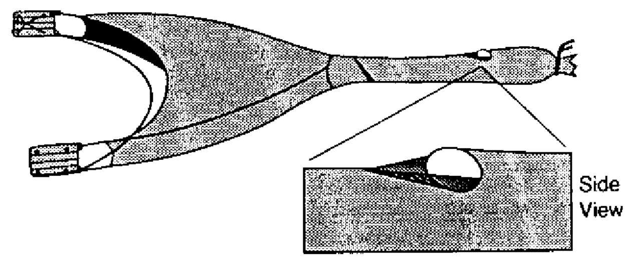

Figure 3. Fish-eye BRD.

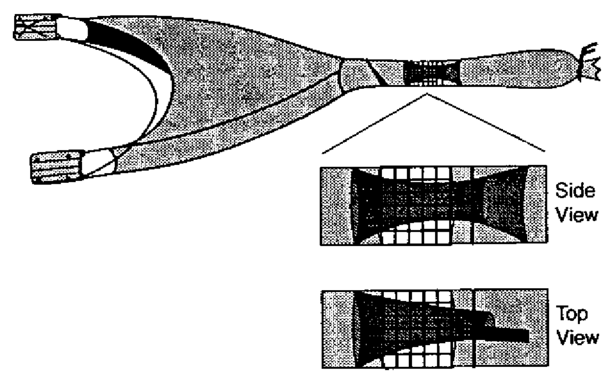

Figure 4. Extended tunnel BRD.

is more complex in construction and its appearance has a tendency to intimidate fishermen initially. Extensive testing of the gear has shown no shrimp loss on commercial vessels.

Table 1 shows the reduction rates of various finfish species as well as shrimp retention percentages. It should be noted that additional efforts are being directed toward improving shrimp retention with the fish-eye BRD. Recent underwater video footage of the fish-eye taken by the Texas Marine Advisory Service indicates that some shrimp loss can be attributed to various methods of trawl retrieval and related handling methods. Hopefully through educational efforts, shrimp loss can be ameliorated with this gear.

Table 1. Results of BRD tests conducted by the Gulf and South Atlantic Fisheries Development Foundation during 1993 and 1994. Mesh references on fish-eyes are meshes back from the start of the bag.

Gulf of Mexico ex. Florida Keys	Biomass	Shrimp	Fish	Snapper
5x12" fish-eye @ 30 meshes	-24%	-3%	-29%	-41%
5x12" fish-eye @ 45 meshes	-30%	-7%	-41%	-24%
3-bars expended mesh	-14%	no loss	-26%	-26%
5-bars expanded mesh	-12%	-1%	-21%	-25%

Bycatch Reduction with TEDs

Industry has regularly reported that bycatch reduction has been enhanced through use of TEDs. Numerous TED types are now being used in the southeastern shrimp fishery. It is apparent that certain types of TEDs have decreased trawl bycatch. Preliminary evaluations by the GSAFDF of the Andrews 5-inch TED have shown exciting reduction potentials for finfish. Red snapper reduction of more than 70% was initially obtained from trials with this gear in 1994. Further evaluations began in October 1995. It should be noted that the Andrews 5-inch TED also contributes to shrimp loss (initial tests showed approximately 11%), a fact that many fishermen would find objectionable.

Lower reduction rates would be expected with other TED types. A bottom excluding grid-type TED with an extended flap over the escape hole probably will not reduce finfish substantially. The GSAFDF plans to investigate TED exclusion potentials further.

Technology Transfer and Outreach Efforts

The GSAFDF has taken a leadership role in transferring bycatch-related technology to industry. Since 1994, 27 regional workshops have been conducted for fisherman in ports along the Gulf and South Atlantic coasts and at industry association and fishery council meetings. Staff from the University of Georgia Marine Extension, Texas Marine Advisory Service, and other Sea Grant institutions have worked extensively to disseminate bycatch information and BRD technology to the fishing industry. NMFS has provided support with outreach efforts to compliment this educational effort.

The southern shrimp fishery has undergone much transition in the past two decades. The efficient use of TEDs in the fishery has been a problem for many fishermen. Although difficulties relating to TEDs seem to be decreasing, enough problems continue to create obstacles in generating interest toward new gear types.

Summary

Extensive efforts have been conducted in the southeastern region to address shrimp trawl bycatch. Cooperative efforts within the fishing community have been substantial and a comprehensive database of bycatch characterization has been established. Red snapper is a priority species for bycatch exclusion; unfortunately, it is one of the more difficult species to eliminate from the trawl. Several gear types have been shown to be partially effective in reducing catches of juvenile red snapper. Ongoing efforts to evaluate BRDs continue to receive priority in the Gulf with several gear types showing promise of ameliorating the bycatch dilemma.

Endnote

[1] Cooperative Research Program Addressing Finfish Bycatch in the Gulf of Mexico and South Atlantic Shrimp Fisheries: A Report to Congress. U.S. Department of Commerce, 1995.

Fishermen and Scientists Solving Bycatch Problems: Examples from Australia and Possibilities for the Northeastern United States

Steven J. Kennelly
Manomet Observatory for Conservation Sciences, P.O. Box 1770, Manomet, MA 02345

Matt K. Broadhurst
NSW Fisheries Research Institute, P.O. Box 21, Cronulla, 2230, NSW Australia

A framework for solving bycatch problems that involves a pairing of the different areas of expertise of scientists and fishermen is described. Initially, large-scale observer programs are used to identify and quantify bycatches and determine problems without relying on anecdotal information. These involve scientists collecting information at sea from normal commercial fishing operations and are a necessary prerequisite for any attempt to ameliorate bycatch problems. Once the species-specific distributions and abundances of bycatches are determined, manipulative experiments using chartered commercial fishing vessels doing controlled, replicated, paired comparisons are conducted to test gears modified for improved selectivity. For prawn trawl fisheries in Australia, modifications such as the Nordmore grid and square-mesh panels have been found to reduce the unwanted bycatch of small finfish while maintaining catches of prawns and other desired byproduct (slipper lobsters, squid, octopus, etc.). It is vital to involve fishermen in such work so that: (1) they are seen to be the driving force in addressing any conflicts that may come from their bycatches, (2) scientists can fully use industry's unique practical knowledge of the relevant fishing technology, and (3) solutions can be implemented into normal fishing operations quickly and, in some cases, voluntarily. The scientists' role is to organize, analyze, and disseminate the work, provide information on possible solutions through access to the international literature, and to ensure the scientific rigor of the experiments. In New South Wales (NSW), Australia, this framework and its inherent involvement of fishermen has led to a substantial improvement in solving bycatch problems in estuarine and oceanic prawn trawl fisheries. This has been achieved via the voluntary acceptance of modified trawl gears by industry and the consequent publicity. Possibilities for a similar approach to New England's trawl fisheries are discussed.

As predicted some time ago, bycatch has become the fisheries issue of the 1990s (e.g. Klima 1993, Tillman 1993). This is apparent not only from the number and frequency of bycatch conferences, but from the enormous concern and publicity that the issue has attracted from a wide variety of people and interest groups. Recently declining fish stocks in many of the world's fisheries has led to commercial and recreational fishermen, conservationists, environmentalists, politicians, fisheries managers, and scientists all identifying bycatch as a key problem and calling for ways to reduce it. Virtually all fisheries in the world have some bycatch

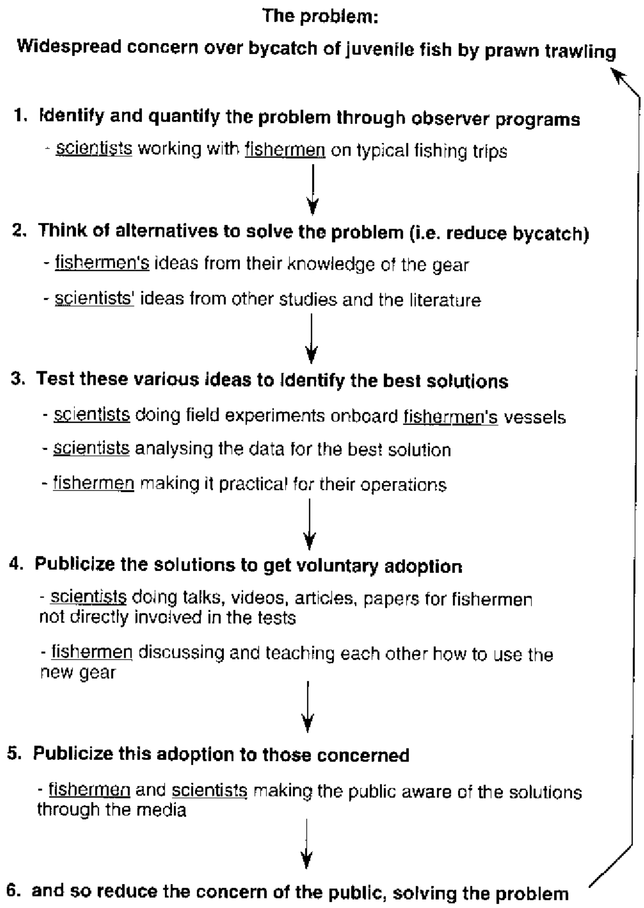

Figure 1. The framework used to address bycatch problems in the estuarine and oceanic prawn trawl fisheries in NSW, Australia.

associated with them, but some types of fishing are recognized as having more bycatch than others; one of the most infamous being shrimp (or prawn) trawling. This type of fishing involves vessels pulling one or more nets made of small mesh over the bottom to catch the quite small, but very valuable, shrimp. Unfortunately, this practice usually results in the capture of most other organisms in the path of the net, and often includes juvenile fish that, when larger, are targeted in other commercial and/or recreational fisheries. This bycatch has led to shrimp trawl fisheries attracting controversy from a variety of sources (in particular other commercial and recreational fishermen) for many years.

In recent years, fishermen and scientists in some parts of the world have successfully solved some of these bycatch problems in shrimp fisheries. In considering the methods used in developing these solutions, it quickly becomes apparent that a relatively simple and logical framework has been used which involves fishermen and scientists each applying their respective areas of expertise to the problem. In general, this framework involves identification and quantification of the relevant issue (via observer programs) and then solving the problem through modifications to commercial fishing gears and/or practices.

In NSW, Australia, we have experienced quite high-profile bycatch problems in our estuarine and oceanic prawn fisheries for many years (as far back as the late 19th century, Dannevig 1904, for review see Kennelly 1995). In the late 1980s these concerns reached a maximum and resulted in threats to close certain prawn fisheries to stop the bycatch of juvenile fish. At this time we discovered that, despite some anecdotal information, there were very little scientific data concerning this problem and so we began our study of this issue by following the framework outlined below.

The Framework Used in NSW

Observer Work

Fig. 1 outlines the logic and framework used to address the problem concerning the bycatch of juvenile fish in NSW's prawn trawl fisheries. The first step (and one of the most vital) was to identify and quantify the problem. This involved determining spatial and temporal variabilities in bycatches at a species-specific level, and could only be done by scientists recording such information onboard commercial vessels during normal fishing operations. Such data could not be collected from information on landings, nor could we rely on fishermen to provide accurate data on discards (it can be argued, in fact, that it is in fishermen's best interests *not* to provide such information). Therefore, the only way to obtain such information was for scientists (and/or scientific observers) to work alongside fishermen on their own vessels and to collect the data in situ by sorting, identifying, measuring, counting, and weighing the catches and bycatches from each tow. We began such an observer program in 1989 by going out on replicated, randomly selected vessels doing typical fishing trips in several estuaries and from several oceanic ports throughout NSW.

During this stage of the work the fishermen and our scientists forged good working relationships that later proved vital in solving the identified bycatch problems. These relationships did not arise out of port meetings, conferences, or workshops (these occurred later), but were developed on the back deck of many different trawlers, at sea, in rivers, during long days and nights, working alongside each other sorting catches from codends. Without working together in such an observer program, we would not have been in a position to solve bycatch problems for two major reasons: (1) we wouldn't have obtained the necessary data on bycatches which identified the particular issues that required solving; and (2) we wouldn't have had the respect from industry that was needed to work with them on solutions.

The data from the observer program led to quite uncompromising information on the bycatches of juvenile fish by the various prawn trawl fleets (Kennelly 1993, Kennelly et al. 1993, Liggins and Kennelly, 1996). For example, in the Clarence River estuarine fishery in 1991-1992, we estimated that in catching 270 t of prawns, this fishery discarded 123 t of bycatch, including approx. 0.8 million individuals of the recreationally important yellowfin bream. In the oceanic fishery offshore from this river in the same year, we estimated that in catching 288 t of prawns, 4,022 t of bycatch was caught (including about 6 million red spot whiting). Of this bycatch, an estimated 725 t was landed for sale as byproduct (including various species of slipper lobsters, squid, octopus and large fish) while the remaining 3,297 t were discarded.

This information was given to fishermen throughout NSW as reports on each fishery and discussed in various meetings. After some debate on the data, these meetings eventually led us and the fishermen to identifying the key bycatch problems in some detail and allowed us to focus on possible solutions. In the above examples, the bycatch and discarding of large numbers of yellowfin bream was clearly seen as a problem for the Clarence River estuarine fishery. For the Clarence River oceanic fishery, the bycatch of large numbers of small red spot whiting and other finfish was seen as a problem but, unlike the estuarine fishery, any solution in this fishery needed to take account of the fishermen's desire to keep certain species of bycatch for sale as byproduct.

Alternative Solutions

Developing alternative modifications to trawl gears to reduce unwanted bycatches in NSW was a joint exercise undertaken by scientists, fishermen, and key net makers. The scientists brought to the table information gleaned from other studies, particularly from the scientific literature, conferences and workshops, and from liaising directly with colleagues throughout the world. The local fishermen and net makers from the Clarence River brought to the table their unique practical knowledge of their fishing gears, vessels, and grounds, and how various modifications may be applied in their operations. In this way we could identify which modifications warranted further consideration and field testing.

Testing the Alternatives

After these discussions, we decided to test several kinds of square mesh panels and Nordmore grids in these estuarine and oceanic fisheries via manipulative experiments onboard chartered commercial vessels set up to trawl in the conventional way. The decision to use commercial vessels rather than research vessels to do this research was important because: (1) it supplied us with a skipper and crew who possessed vital local knowledge of the conventional methods used and the prawn grounds in the test areas, (2) it supplied us with the control gears (conventional nets) against which we tested our modifications, and (3) it ensured the involvement of the rest of the fleet who weren't chartered for the research because it was being done alongside them, in their grounds, using similar gear and vessels. Details of these experiments are found in Broadhurst and Kennelly (1994, 1996), Broadhurst et al. (1996a, 1996b). In general, these experiments took the form of paired comparisons of modified nets with conventional nets and were analyzed using paired t-tests.

After preliminary trials, refinements to various modifications, re-testing, refining again, retesting, etc., we came up with a few modifications that seemed to work quite well in the two fisheries. Because the targeted eastern school prawns in the estuarine fishery were smaller than the bycatch to be excluded, we concluded that some type of Nordmore grid would be most suitable for this fishery (Fig. 2). For the oceanic fishery, we concluded that such grids were not appropriate because the targeted eastern king prawns were much larger and the grids tended to exclude most of the byproduct species (slipper lobsters, octopus, squid, larger fish, etc.) which the fishermen wished to retain. For this fishery we decided that some form of square mesh panel anterior to the codend might be suitable (Fig. 3); the theory being that small fish could swim out of the codend with the water flowing through the panel while the less mobile prawns, slipper lobsters, squid,

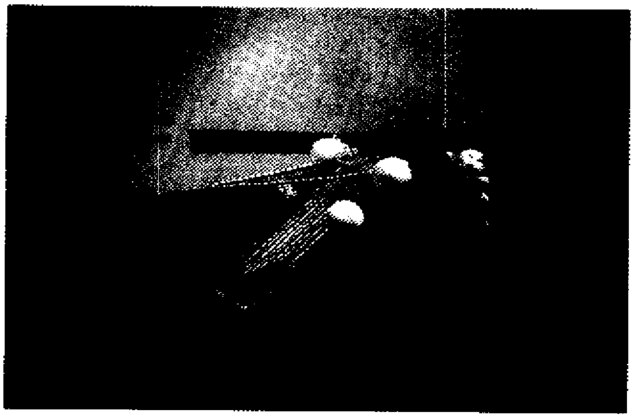

Figure 2. The Nordmore grid design tested in the Clarence River estuarine prawn trawl fishery.

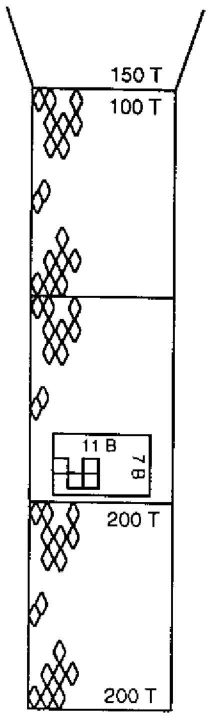

Figure 3. Diagrammatic representation of a modified codend incorporating a square mesh panel as tested in the Clarence River oceanic prawn trawl fishery. T = transversals, B = bars (from Broadhurst et al. 1996b).

and octopus would go to the back of the codend. The sizes of fish excluded in this way could be selected by adjusting the mesh size in the square mesh panel.

Examples of the results from the formal testing of these two alternatives are seen in Figs. 4 and 5. The photographs in Fig. 4 show the striking difference in bycatches that came from using the Nordmore grid in the Clarence River estuary. Similar results occurred from using a simple square mesh panel in the oceanic fishery. The graphs and analyses of the data from these trials (Fig. 5) confirmed the effects seen in the photographs where the modifications greatly reduced bycatches, especially that of the unwanted fish, while maintaining catches of prawns.

Informing Other Fishermen of the Results

While the graphs and analyses of the data from the above trials convinced us and other scientists of the usefulness of the modifications, it was the photographs (e.g. Fig. 4) and videos, and meetings between the scientists and chartered fishermen that illustrated the success of these modifications to fishermen who were not directly involved in the research. We distributed the photographs and videos to fishermen in the relevant ports and encouraged the circulation of the information to other ports. The fishermen involved in the trials discussed the modifications with other fishermen and assisted them in making and using the modifications. These new users then informed other users and before long, the majority of fishermen in the Clarence River estuarine and oceanic fisheries were using these gears and reducing their unwanted bycatches—all on a purely voluntary basis, without any changes in regulations. News of these modifications spread to other fisheries throughout NSW and Queensland, and several fishermen in these other ports are now also using these gears. We are recommending to fisheries managers the legislative adoption of these modifications to ensure 100% compliance in these fisheries. Because of the voluntary acceptance of the new gears, we believe that this last step should be a relatively painless process.

Informing the Public of the Solutions

Unfortunately, the success outlined above of reducing bycatches is insufficient by itself to solve the overall bycatch problem. While this work has gone a long way in nullifying the problem of unwanted bycatch, we haven't yet explained how we

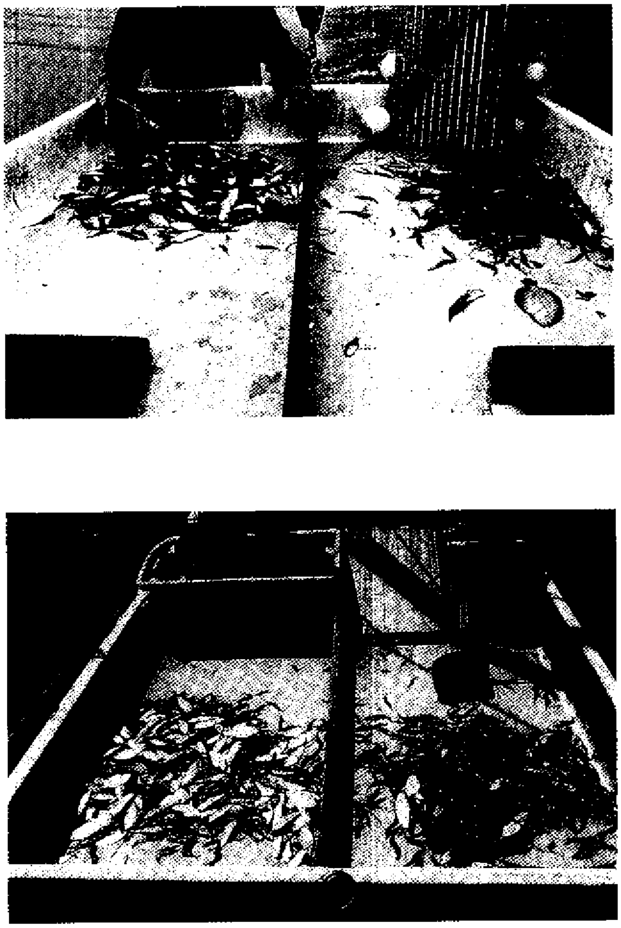

Figure 4. *Two examples of the catches from paired comparisons in the Clarence River estuarine prawn trawl fishery using a conventional codend (on the left) and one with a Nordmore grid (on the right).*

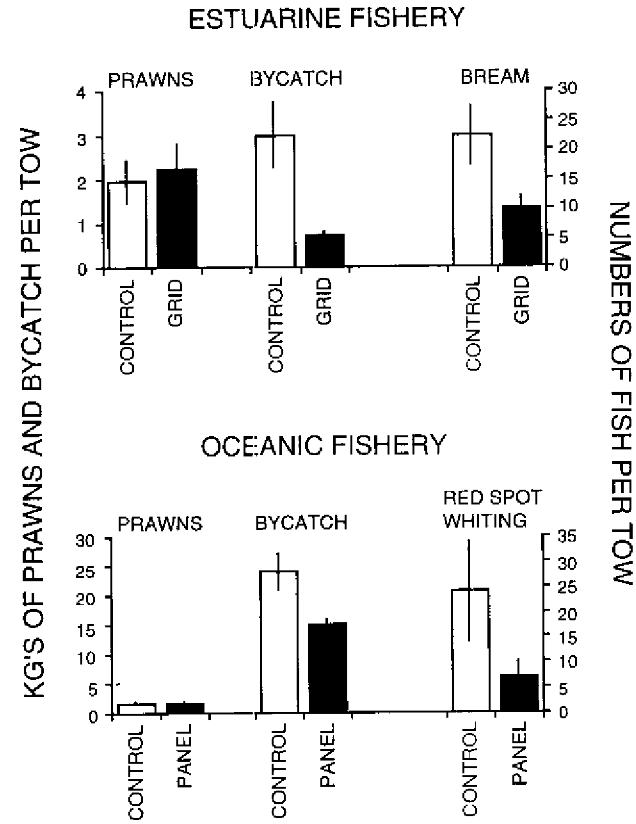

Figure 5. *Summaries of data (for weights of prawns and bycatch and numbers of key fish species) from comparisons of a codend with the Nordmore grid and a conventional codend in the Clarence River estuarine prawn trawl fishery and those from comparisons of a codend with the square mesh panel and a conventional codend in the Clarence River oceanic prawn trawl fishery.*

addressed the public concern over the issue. This could only be done by widespread publicity of the solution, its development, testing, and voluntary acceptance by fishermen to those most concerned with the issue. In our example, this was achieved by the fishermen and ourselves making presentations to committees (representing other commercial and recreational fisheries) and releasing photographs, videos, interviews, etc. to the print, radio and television media. Armed with such evidence (in addition to the publication of the results in scientific journals), we were able to reduce perceived problems concerning this issue in these fisheries. This approach has led to a marked decrease in the conflict associated with bycatch in these fisheries and, in general, a more popular prawn trawl industry in the Clarence River region.

Possibilities for the Northeastern United States

In an effort to apply this approach to similar bycatch problems in a completely different part of the world with very different fisheries, we considered the trawl fisheries of the northeastern United States. In examining these fisheries, we are struck by many similarities in the approach already used by fishermen and scientists to solve bycatch problems. A large observer program has been running in this region's fisheries for the past six years (by Manomet Observatory under con-

GROUNDFISH TRAWLING OFF THE NORTH-EAST UNITED STATES (JULY 1990 - JUNE 1994)

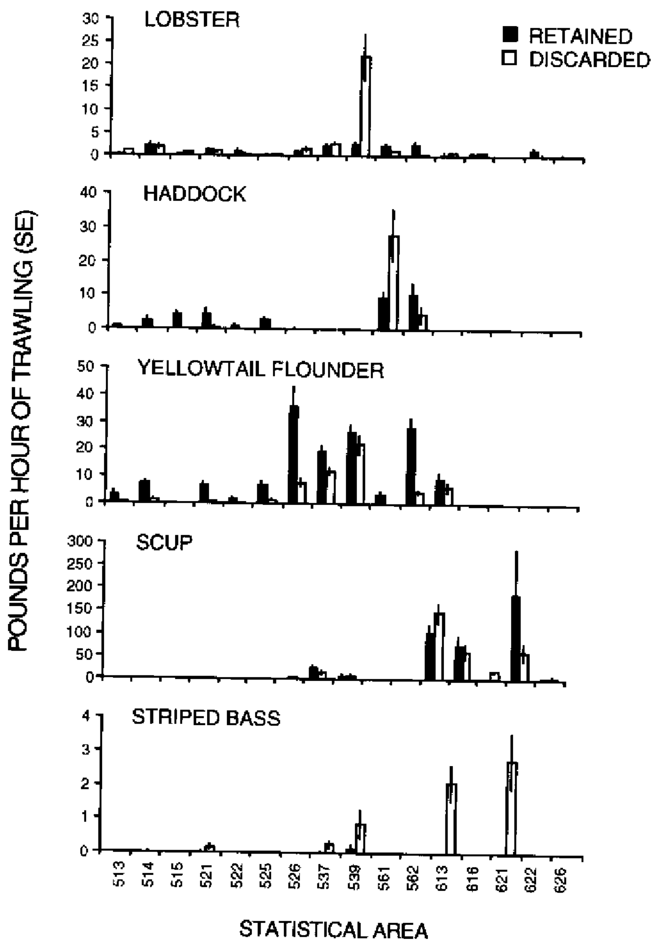

Figure 6. Summaries of observer data from the NMFS northeast sea sampling program.

tract to the National Marine Fisheries Service) which forms the chief source of information on discards prerequisite to solving perceived problems (Murawski et al. 1995). The data from this program identified problems in the bycatch from the oceanic shrimp fishery in the Gulf of Maine and, after a period of development by scientists and fishermen, a Nordmore grid system is now being used to reduce unwanted bycatches (Kenney et al. 1991, Richards and Hendrickson 1995). While the introduction of these grids into this fishery was not done voluntarily but was mandated, there is now reasonable acceptance of the gear by fishermen.

The groundfish trawl fisheries of the north-eastern United States have also attracted their share of attention with regard to their bycatch and subsequent discarding of other species and undersize individuals of target species. Preliminary examination of the observer database for these trawlers from 1990 to 1994 is seen in Fig. 6 which shows the average catch and discard rates per trawl hour of several important species in this region. The data come from groundfish trawlers sampled over a four year period and are arranged according to the various statistical areas where there was sufficient sampling. The data show quite significant discarding rates of the five species shown, but these catch rates depend on the area in question. For example, quite large weights of the commercially and recreationally important lobsters were discarded from trawls done in area 539 (just south of Rhode Island) while in other areas, a lower level of catch was observed with approximately similar weights of lobsters being discarded and retained. The discarding of haddock mainly occurred in areas 561 and 562 (east of Georges Bank) and may have been due to 500 lb. catch limits being placed on the fishery in recent years. Yellowtail flounder appeared in catches throughout New England with fairly high levels of discarding evident. Scup (an important recreational species) was discarded in quite large quantities from trawls done in areas 613 to 622 (from New York to Delaware) and the discarding of small weights of striped bass (another key recreational species) occurred in areas 613 and 621.

The levels of discarding described above clearly suggest some potential problems for these trawlers in terms of their bycatches and is also being manifested as substantial conflicts with other user groups. In particular, the discard of lobsters by trawlers has caused conflict with lobster trappers and the discarding of scup and striped bass has caused some problems with recreational fishing groups.

While the solutions to these problems for fish trawl gear may not be quite as simple as using Nordmore grids or simple square mesh panels in shrimp trawl gear, recent developments in sorting devices for finfish and other species in fish trawl gear may provide some possible solutions. Such modifications as downward sorting grids and horizontal panels in nets have been shown to have great potential for reducing the bycatches of unwanted species and unwanted sizes of certain species in groundfish trawls (Fig. 7, Isaksen 1994, Engas and West 1995). Together with scientists from the Marine Laboratory in Aberdeen, Scotland, Institute of Marine Research in Norway, the

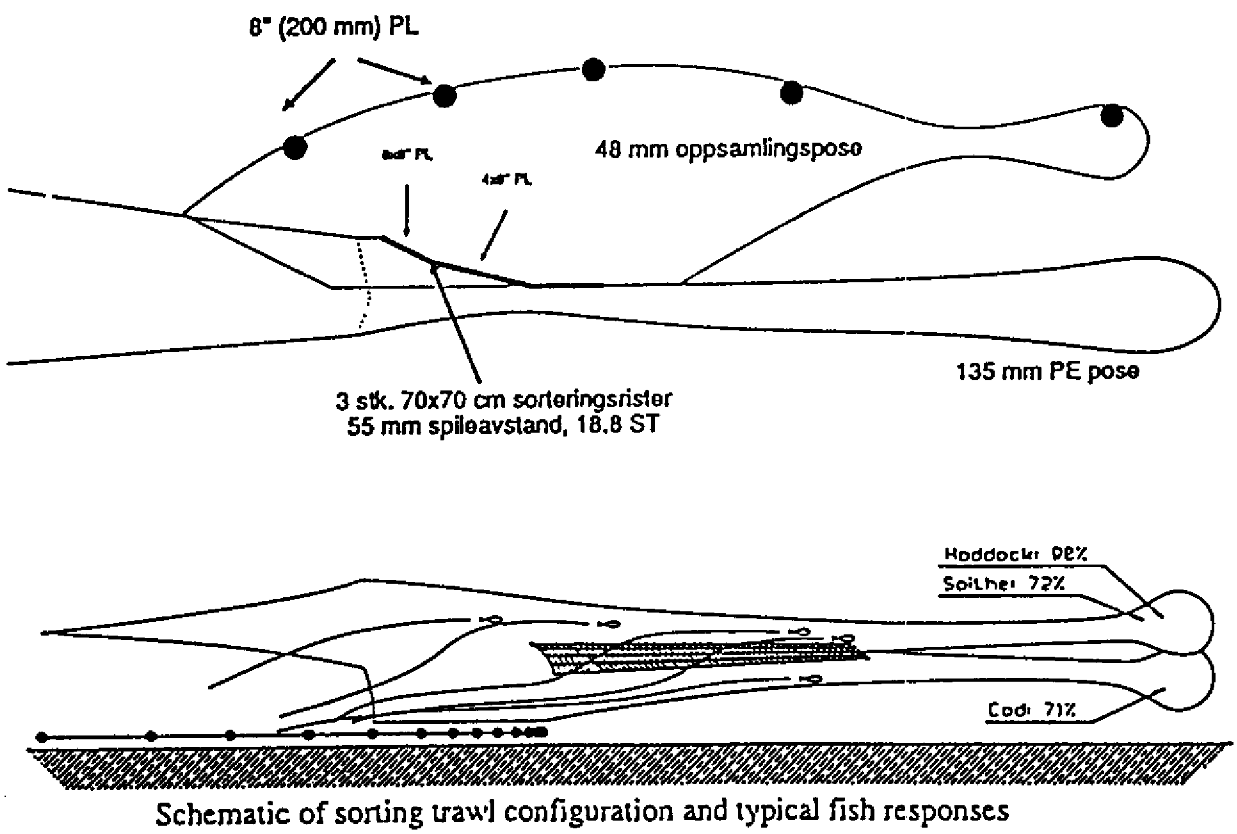

Figure 7. A finfish sorting grid (from Isaksen 1993, top) and a horizontal sorting device (from Engas and West 1995, bottom) being tested in Norway to separate different species and sizes of groundfish.

Massachusetts Division of Marine Fisheries, and local fishermen, we plan to test the effectiveness of some of these designs in the groundfish trawl fisheries off the northeastern United States in the near future. Because of the existence of the large-scale, long term observer program, the most difficult job in solving such bycatch problems is already in hand: (1) we already have good observer data that identifies and quantifies the problems and, more important, (2) we have established a working environment with fishermen that hopefully will enable such solutions to be found and eventually adopted.

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Shrimp Trawl Bycatch Reduction in the Southeastern United States

David L. Harrington and Richard A. Vendetti, Jr.
University of Georgia Marine Extension Service, 715 Bay St., Brunswick, GA 31520

Prior to a bycatch reduction mandate in the Gulf and south Atlantic shrimp fishery, the industry must be acknowledged for the reduction contributions of the twin trawl system in the mid-1970s and the use of turtle excluder devices (TEDs) in the late 1980s. As greater reductions are desirable for political, recreational, non-utilizational, and biological reasons, research has shown that simple bycatch reduction devices (BRDs) such as the fish-eye and the expanded mesh are successful at reducing bycatch. TED and trawl modifications, and combinations such as reduced bar spacing in TEDs and short codends in trawls, further reduce finfish capture. Proper placement of a BRD in the codend and changes in haul-back methods and techniques are critical for maximum shrimp retention. The total removal and/or shortening of hard TED flaps also increase finfish reduction with insignificant shrimp loss, and may eventually serve as an approved BRD. As fishermens' ideas are brought forth and tested, bycatch reduction in the shrimp fishery will continue to improve. Both Georgia and South Carolina DNRs (departments of natural resources) have acknowledge a bycatch reduction "credit" for TEDs and plan to implement bycatch regulation in 1996.

The University of Georgia Marine Extension Service (UGA MAREX) has played an active role in resolving the southern shrimp industry/sea turtle crisis. A collaborative university/industry effort resulted in the development of effective TEDs and their acceptance by shrimp fishermen. This collaboration continues in the current effort to reduce the amount of nontarget species caught in shrimp nets by developing effective BRDs which are compatible with fishing operations and do not result in loss of shrimp.

BRD preference in the southeastern U.S. shrimp fishery is narrowing down to three basic types: the Louisiana fish-eye; the expanded mesh/extended funnel designed by the National Marine Fisheries Service (NMFS); and the Kiffe BRD designed by C.J. Kiffe, a former highliner/shrimp boat captain from Cameron, Louisiana. These BRDs were tested and evaluated on the R/V *Georgia Bulldog*, a 22 m shrimp boat, and on commercial shrimp trawlers with trained observers onboard. Observer support was provided by the Gulf and South Atlantic Fisheries Development Foundation (GSAFDF).

This paper reports on the effectiveness of these BRDs in reducing bycatch without reducing shrimp catch. Simultaneous side-by-side towing with commercial shrimp fishermen on the same grounds, under the same weather conditions and tidal stages, provided a unique opportunity for researchers and fishermen to cooperate and collaborate.

Methods

Depending on whether fishing on brown or white shrimp, the R/V *Georgia Bulldog* was quad rigged with either 13.7 m or 12.1 m trawls, each fitted with a Super-Shooter TED with 6.6 cm bar spacing and an accelerator funnel. The trawls were pretuned to ensure that they were catching similarly. This included checking TED grid angles which are critical to shrimp retention in both wet and dry tests. Dry test measuring (out of the water) first verified the proper and legal angles of the TED grids in both vertical and horizontal tests. Grid angles ranged from 47 to 53 degrees. The angles were later confirmed underwater at the completion of all required tows with Scandinavian Marine (SCANMAR) electronic grid-sensoring equipment.

Using quad rigs, three trawls were equipped with experimental treatments and the fourth was designated as the control. Tows were conducted in 20 tow sets and zippers were sewn into each net to facilitate rotation of the treatments. The control and all three treatments were rotated one position after every five tows to eliminate position bias.

Fish-eyes

Just as the TEDs in use today were derived from devices developed years ago to shunt jellyfish from the catch, the fish-eye has been used by a Louisiana shrimp fishermen for over half a century to exclude finfish from their nets. Designed by fishermen, it is simple and low cost.

Earlier UGA MAREX research involving 80 tows with fish-eyes on the top, bottom, and sides of the codend (Fig. 1) verified fishermens' reports that a fish-eye in the top of the codend was most effective in eliminating fish. Not known was the optimum placement relative to the distance from the codend tie-off (Fig. 2). Another unknown was the efficiency of different sizes of fish-eyes in eliminating fish and retaining shrimp (Fig. 3).

One-hundred one-hour tows, consisting of five 20 tow sets during the day and at night, were conducted. The configurations in Table 1 were used.

As a follow up, 16 additional two-hour tows were completed in North Carolina waters during side-by-side towing operations. Treatments were rotated every tow during these tows.

Expanded Mesh/Extended Funnel—NMFS Standard Model

The expanded mesh/extended funnel BRDs are placed aft of the TED and vary in square mesh length and mesh size. Twenty-five centimeter stretched meshes (12.7 cm bar) were tested on the R/V *Georgia Bulldog* and cooperating vessels. Figure 4 is a descriptive schematic of the BRD. By the end of 1995, UGA MAREX will have conducted 120 tows using this standard model.

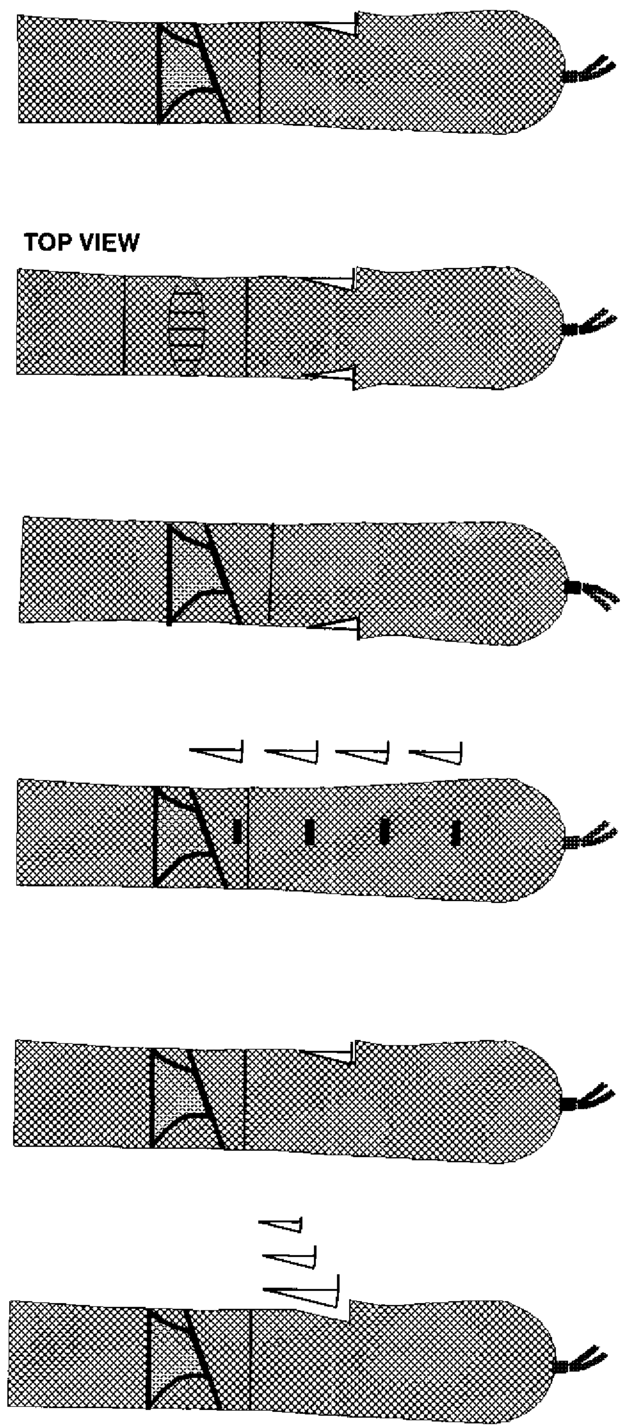

Figure 1. R/V Georgia Bulldog fish-eye research testing location in the top, bottom, and sides, and placement ahead of the codend tie-off and size. Side view shown except where indicated.

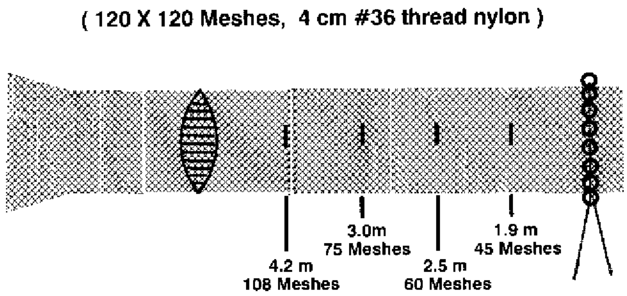

Figure 2. Fish-eye placement research conducted on R/V Georgia Bulldog.

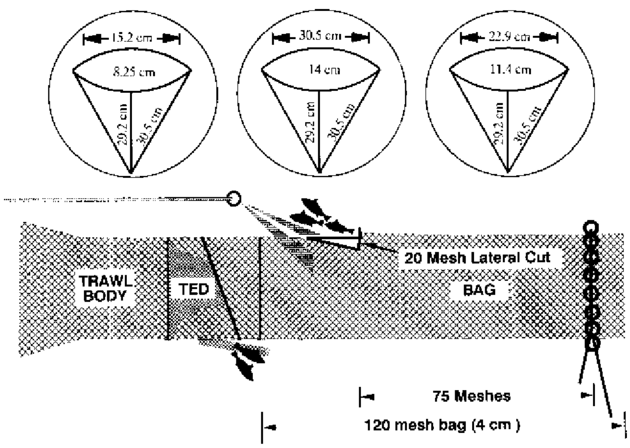

Figure 3. Fish-eye sizes tested on R/V Georgia Bulldog.

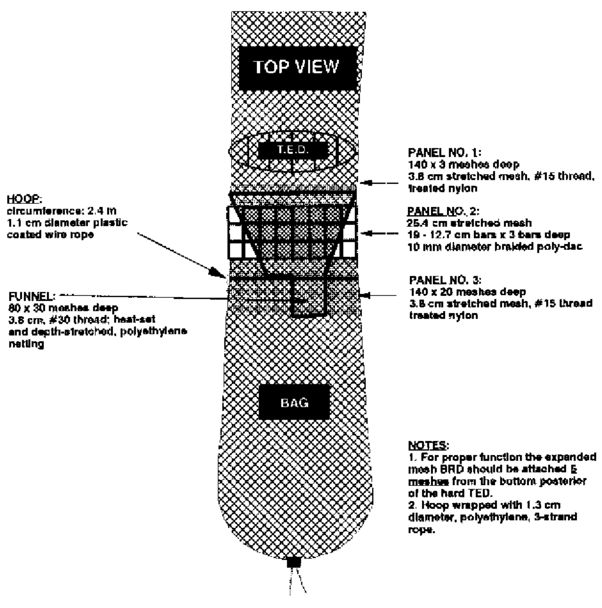

Figure 4. Schematic and description of NMFS expanded mesh/extended funnel BRD as tested on R/V Georgia Bulldog.

Expanded Mesh Modifications

1. *Expanded mesh/extended funnel with top flap.* This modification to the expanded mesh BRD consists of a polyethylene flap of 3.8 cm stretched mesh webbing sewn on the top center of the BRD. The flap is 25 meshes across by 18 meshes down and has a 13 cm × 8 cm polystyrene float tied halfway down in the center of the flap. The leading edge of the flap is attached one mesh in front of where the funnel is sewn and the webbing is heat-set and depth-stretched.

2. *Expanded mesh/extended funnel with bottom flap.* Constructed of the same material as the above modification and located similarly, this version differs in that it is located on the bottom center of the BRD, and it has 27 links of 0.63 cm chain sewn laterally in place of the float.

3. *Expanded mesh/extended funnel with skirt.* A nine mesh skirt encircles the entire BRD at its leading edge and is sewn on in the same position one mesh in front of where the funnel is attached. The same material as the funnel is used without floats or chain.

The following is a list of the different expanded mesh BRDs being tested in the south Atlantic by UGA MAREX and the North Carolina Division of Marine Fisheries (NCDMF). The measurement in cm refers to the stretched mesh dimension.

1. 25 cm (3 meshes deep with extended funnel, UGA)
2. 25 cm (3 meshes deep with extended funnel and top flap, UGA)
3. 25 cm (3 meshes deep with extended funnel and bottom flap, UGA)
4. 25 cm (3 meshes deep with extended funnel and ballerina skirt, UGA)
5. 20 cm (4 meshes deep with extended funnel, NCDMF)
6. 20 cm (5 meshes deep with extended funnel, NCDMF)
7. 10 cm (12 meshes deep with cone shaped funnel, NCDMF)

Tabe 1. Testing fish-eyes for size and placement in the top of the codend.

Area	Tow(#)	Position	Placement[1]			Size (in centimeters)		
			T1	T2	T3	T1	T2	T3
S. Carolina	21	Top	75	60	45[2]		30.5×14	
Georgia	20	Top	108	75	60		30.5×14	
Georgia	20	Top	108	75	60		30.5×14	
Georgia	20	Top	75	75	75	30.5×14	22.9×11.4	15.2×8.25
NE Florida	20	Top	75	75	75	30.5×14	22.9×11.4	15.2×8.25

T=Treatment; Bag mesh size = 4 cm

[1] Meshes ahead of codend tie-off.

[2] Placement discarded due to significant shrimp loss.

Kiffe BRD

This BRD is essentially a bag within the codend between 0.75 m and 1.2 m long. The front part is like a triangular snow plow made either of aluminum or webbing panels with an escape port on each side behind the blade. At the request of the designer/manufacturer, we tested it separately in both the top and bottom of a trawl. The current project is testing each version with a minimum of 20 tows. Three versions of this BRD are shown in Fig. 5.

Results

Fish-eyes

Based on total finfish reduction and shrimp retention, the most effective fish-eye was a 30.5 cm by 14 cm placed 75 meshes forward of the codend tie-off. Locations closer to the end of the bag can result in greater reduction of fish, but higher losses of shrimp. The 22.9 cm × 11.4 cm size accomplished better shrimp retention but slightly less fish reduction.

Special attention was focused on the weakfish, *Cynoscion regalis*. Because weakfish stocks have declined in the Chesapeake Bay area, the Atlantic States Marine Fisheries Commission (ASMFC) formulated a Weakfish Fishery Management Plan in which Amendment 2 requires all shrimp-producing states to have a plan to reduce the bycatch of weakfish in shrimp trawls by 50%—despite the lack of evidence that weakfish in the Chesapeake Bay area have any relation to weakfish in southeastern U.S. waters.

In these studies, weakfish were not abundant, and the effectiveness of the fish-eye BRD on this species could not be well defined. Of the 100 one-hour tows made, only 20 tows had 25 or more weakfish in the control net. However, in these 20 tows excellent reduction was achieved. Based on these 20 tows, the 30.5 cm × 14 cm fish-eye in the 75 mesh position forward reduced the catch of weakfish by 49.8% by number and 53.5% by weight. These rates were proven statistically significant with a 99% confidence level in both paired T-tests and general linear model calculations. There is some indication that larger fish were excluded more effectively.

Other finfish that made up the majority of the total catch showed excellent reduction. Marine species are not randomly distributed and results from small samples (less than 25 tows) can vary greatly in different conditions, i.e., moon phases, tidal stages, bottom substrates, seasonal abundances of fish, etc. The method of research that has evolved at UGA MAREX is one that requires 80 tows, conducted in sets of 20 over a full range of seasons and differing marine conditions. The reductions of finfish caught using the 30.5 cm × 14 cm fish-eye have been stable and the range of reductions for predominant species in different sets of tows in the south Atlantic are shown in Table 2.

Placement of the fish-eye (distance ahead of the codend tie-off) greatly affects the catch of both fish and shrimp. As shown in Table 3, a 60 to 75 mesh placement results in significant finfish reduction, while a 108 mesh placement allows little fish escapement. The 45 mesh placement was removed after the first set of tows because of a significant loss of shxrimp.

In terms of shrimp retention, the losses or gains experienced in the nets equipped with fish-eyes were statistically insignificant. However, it is important to note that some shrimp may be lost during rough weather, net retrieval, and by "running-off" at the end of a tow when the nets reach the surface.

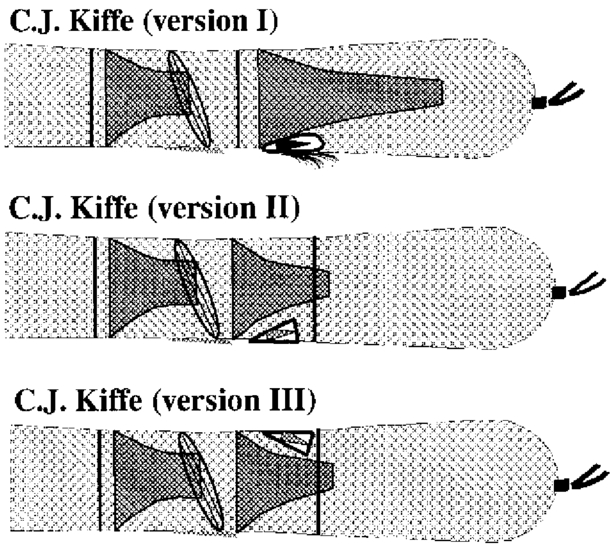

Figure 5. Three versions of the C. J. Kiffe BRD as tested on the R/V Georgia Bulldog.

Table 2. Reductions in numbers of individuals.

Species	Range between tow sets (%)	Total # (%)
Atlantic Spot	-44 to -64	-50
Atlantic Croaker	-51 to -69	-65
Southern Kingfish	+ 8 to -66	-26
Atlantic Menhaden	-49 to -62	-58
Weakfish	- 8 to -54	-42

Table 3. Reduction of finfish catch by different fish-eyes.

Fish-Eye Placement[1]	Size[2] (cm)	Reduction by No. (%)	Reduction by Wt. (%)	No. Tows
108	30.5×14	5.27	7.3	40
45	30.5×14	55.0[3]	58.8[3]	20
60	30.5×14	50.7[3]	52.2[3]	40
75	30.5×14	47.0[3]	45.0[3]	101
75	22.9×11.4	40.9[3]	37.6[3]	41
75	15.2×8.25	28.9	18.8	41

[1] Placement indicates number of meshes in front of the cod end tie-off
[2] Size represents the dimensions of the fish-eye opening
[3] Statistically significant at 95% confidence level

Expanded Mesh and C.J. Kiffe

Due to the urgency of the bycatch issue, and because the current project will not be completed until early 1996, Table 4 shows the preliminary results from the NMFS standard expanded mesh BRD from tows completed in 1995. Findings are in line with the fully analyzed results from work conducted by the NCDMF. Any differences may be attributable to substrate variations and differences in fisheries between the offshore shrimp fishery of Florida, Georgia, and South Carolina and the Pamlico Sound inshore shrimp fishery.

Discussion

The testing of BRDs on the university's research vessel, formerly a conventional shrimp trawler, towing on the same fishing grounds side-by-side with the commercial fleet, proved to be an exceptional form of technology transfer and outreach. The shrimp and finfish caught by the BRD-equipped nets were compared instantaneously by radio with those caught by the commercial fleet. Fishermen sensed the importance of direct involvement in the research effort and made valuable suggestions on gear modifications. They were kept informed by the *Bulldog* crew on the exact type of BRD being tested at a given moment and the amount of shrimp and fish caught in all nets. Knowing the horsepower of the *Bulldog* and the type of trawl being used, the captains could easily determine any effect of the BRD on the shrimp catch. They not only believed the results, but developed an interest in testing the BRDs themselves. The *Bulldog* crew accompanied the vessels to their docks, provided instruction, and installed BRDs, supplied by GSAFDF, in their nets. The side-by-side fishing sites and dockside workshops are shown in Figure 6.

As an outgrowth of this collaboration, 13 informal dockside workshops and one formal workshop were conducted. Fishermen had a firsthand look at the various BRDs and installation techniques. This resulted in the distribution to the commercial fleet of over 300 BRDs furnished by the GSAFDF. In addition, UGA MAREX collaborated with the Texas A&M Sea Grant Program to hold 24 workshops, supported by GSAFDF, in major fishing ports along the Gulf of Mexico and south Atlantic coasts (Fig. 7).

The concern with bycatch by fisheries managers, recreational fishermen, and wildlife conservationists lead to the establishment of guidelines to reduce bycatch by specific levels. As mentioned

Table 4. Preliminary results of 1995 BRD research aboard R/V Georgia Bulldog.

BRD	No. Tows	Average kgs/tow	% Fish Reduction (kgs)	% Shrimp Difference
EM–Standard	61	12	-45	+1
EM–Top Flap	20	12	-43	-2
EM–Bottom Flap	20	11	-27	+4
Kiffe I–Bottom	21	14	-52	+1
Kiffe II–Bottom	20	10	-30	-12
Kiffe II–Top	20	14	-33	+8

EM = Expanded Mesh
Kiffe I = device with aluminum panels
Kiffe II & III = device with webbing panels
Control net average kgs/tow = 22 kgs

above, the decline in weakfish stocks in the Chesapeake Bay area resulted in a requirement by south Atlantic shrimp producing states to reduce the amount of weakfish caught in shrimp nets by 50%. The question is if the Chesapeake weakfish stock does not recover after the shrimp industry reduces its bycatch by 50%, will the industry be required to reduce the bycatch further? True identification of the problem is paramount to finding effective solutions.

TEDs as BRDs

When TEDs were made mandatory on a seasonal basis in 1988 and year-round in 1991 on the offshore shrimp grounds of the southeastern United States the amount of bycatch caught by the shrimp industry was significantly reduced. The prototype on which TEDs are based was designed to eliminate large jellyfish from shrimp nets. The capability of TEDs to reduce bycatch was evident during our initial TED certification trials at Cape Canaveral in 1986. This observation was subsequently confirmed by state and university researchers throughout the region.

Gear research on TEDs should be pursued further to increase their finfish exclusion efficiency. The efficiency of hard TEDs in reducing finfish retention is dependent on both bar spacing and diameter, grid angle, use of an accelerator funnel, and modifications to the flap over the turtle escape hole. Depending on the combinations of these factors, finfish reduction rates using hard TEDs can range between 4% and 40%, and can be significantly higher for individual fish species.

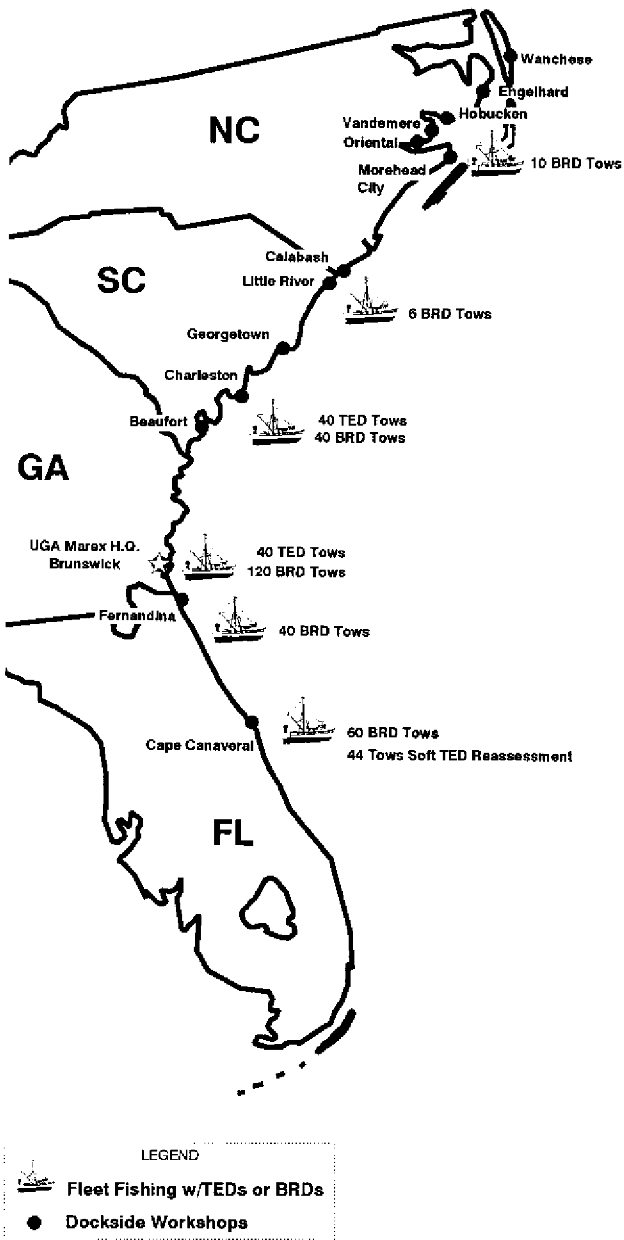

Figure 6: Location of fleet side-by-side towing by BRD rigged R/V Georgia Bulldog and corresponding workshops.

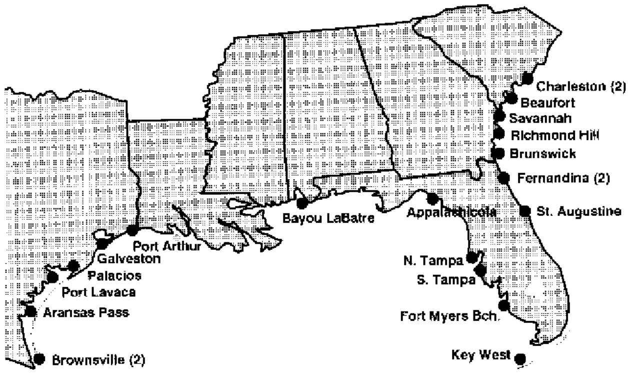

Figure 7. Location of joint Texas A&M, University of Georgia, Gulf and South Atlantic Fisheries Development Foundation bycatch workshops, 1994, 1995.

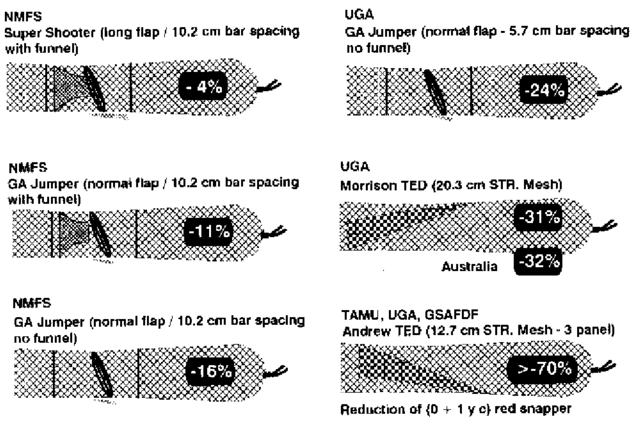

Figure 8. TED exclusion rates collected by NMFS and UGA MAREX.

Many shrimp fishermen do not use an accelerator funnel, and many also shorten the TED flap so it does not extend beyond the grid. Three to four meshes of polyethylene bag webbing are sewn to the terminal end of the flap, and under tow, this rises to form an oval, much like a fisheye device in the bottom front of the grid. Using this rig, shrimpers report significant reduction in finfish compared to the same TED with the long, extended flap. Research is underway to evaluate this modification.

Soft TEDs are credited with higher finfish exclusion rates than hard TEDs, and bottom-shooting soft TEDs are even more effective than top-shooting soft TEDs. A recent study of the Andrew 13 cm TED in the Gulf of Mexico showed a 70% exclusion rate of 0 and 1 year class red snapper.

TED bycatch exclusion data collected by NMFS throughout the fishery, and by UGA MAREX during the TED certification trials are shown in Figure 8.

It is encouraging to report that both the Georgia and South Carolina DNRs have recognized the value of TEDs as BRDs and have given credit to TEDs for 23% reduction in bycatch. This percentage will be refined by future research.

Bycatch reductions resulting from earlier gear adaptations by the industry, most notably twin trawls, have been overlooked. In the early to mid-1970s, the industry replaced the traditional double rigs with the twin-trawl/quad system which resulted in a major reduction of fish in the catch. The smaller twin trawls tend bottom lighter (less bottom debris) and catch less biomass overall than the old large double rigs.

Bycatch in the Louisiana Shrimp Fishery

William S. "Corky" Perret, Philip E. Bowman, and L. Brandt Savoie
Louisiana Department of Wildlife & Fisheries, P.O. Box 98000, Baton Rouge, LA 70898-9000

Concern over large volumes of fish bycatch has surfaced as a major fisheries management issue in the 1990s. The Louisiana Department of Wildlife and Fisheries realized the need to document the occurrence of bycatch since the inception of its ongoing shrimp monitoring program. Department personnel have recorded the numbers and sizes of all species taken with 4.9 m otter trawls as early as 1967, and continue to record this data. The Louisiana shrimp industry, its vessels and boats, and the gear used in harvesting operations is extremely diverse and has changed significantly since 1900. The otter trawl replaced the seine during the 1920s and has been the primary harvesting gear since that time. The butterfly net first introduced in the 1950s, became popular, mainly with part-time fishermen in the 1970s. The skimmer net is the most recent gear innovation; it has been licensed as a legal gear since 1992. Preliminary studies indicate that the ratio of finfish to shrimp was lower in butterfly nets than in trawls, and the survival of the bycatch was higher in the butterfly nets. Skimmer nets also had a higher rate of survival for bycatch than did otter trawls.

Concern over large volumes of fish bycatch has surfaced as a major fishery management issue in the 1990s. The Louisiana Department of Wildlife and Fisheries (LDWF) realized the need to document the occurrence of bycatch since the inception of its ongoing fishery independent shrimp monitoring program. LDWF personnel have recorded the number and sizes of all species taken with 4.9 m trawls as early as 1967, and continue to record this data.

Bycatch is an issue which affects all forms of fishing. The primary concern is not simply the number of individuals and species taken incidentally, but the mortality of those species. If all bycatch could be released unharmed, there would be no concern for the unintentional taking of nontarget species. Every fishing activity currently practiced, with the possible exception of spear and harpoon fishing, produce some level of bycatch mortality. In many cases, bycatch can be released unharmed or with little mortality and is of little biological or ecological consequence. In other cases, bycatch species suffer some level of mortality and the incidental taking of nontarget species may or may not be of biological concern.

Most of the bycatch work completed to date has been limited to studies aimed at simply quantifying the level of bycatch in various fisheries. Large quantities of bycatch do not automatically result in significant biological and ecological impacts. The impact of bycatch mortality on nontarget populations depends on the life history characteristics of the impacted species. Impact studies, which bridge the gap between bycatch quantities and the consequences of these losses at the population and community levels, are necessary if we are to intelligently address the bycatch mortality issue.

This issue must be approached on a regional basis. Even though fisheries may seem similar on the surface, past experience clearly indicates that blanket regulations often do not adequately address specific issues. Bycatch mortality may differ substantially within similar fisheries throughout the country, and regulations designed to protect particular species may work well in some geographic areas but would not be effective or necessary in other areas.

The Fishery

The Gulf of Mexico is the major supplier of domestic shrimp contributing approximately 70% of the annual total United States production. In the Gulf, shrimp production occurs off all five states with the greatest harvest occurring in Louisiana and Texas and their adjacent offshore waters.

The Louisiana shrimp industry is as diverse as any fishing industry in the world. The harvesting sector is divided into three general segments. These are the: (1) bait shrimp fishery, (2) inside (bay) fishery, and (3) outside (gulf) fishery. The bait shrimp fishery is extremely small (approximately 25 permits annually). The inside fishery has two seasons (the spring season, generally mid- to late May through early July; and the fall season, generally late August to late December). The offshore shrimp fishery operates year-round in the Gulf of Mexico with some restrictions as to seasonal closures in the state's territorial waters (from the beach seaward to 3 miles). The processing sector has evolved from primarily a fresh, headless, and drying market, allowing for only local distribution and consumption, to both a local and international network which exports shrimp to all parts of the globe.

The gear used to harvest shrimp has also undergone dramatic change. Prior to 1917, the principal gear used to catch shrimp was the seine. With the introduction of the otter trawl in 1917, the gear used in the fishery changed almost overnight, and by 1920, the otter trawl was the principal gear used although seines remained in the fishery until the early 1960s (Table 1).

In the 1950s, the wing net (also called the butterfly net or "paupier"), was introduced (Fig. 1). These nets are attached to a rigid frame and fished primarily during night hours in the upper portion of the water column. These nets are arranged so the codend can be emptied on the deck of the boat without interrupting fishing. Initially, these nets were fished on a falling tide, either from a stationary position, or pushed by boat into the current to increase water flow. Recently, fishermen in some areas have begun successfully fishing these nets on incoming tides. With the dramatic human population increase that occurred in Louisiana's coastal areas during the 1970s, as a result of the nation's gearing up to produce more oil, the popularity and use of the butterfly net grew significantly. Also, since butterfly nets were fished primarily at night, they were especially suited for Louisiana's part-time shrimp fishery. The butterfly net fishery has expanded to the point where competition for ideal fishing locations has become significant and conflicts among competing fishermen have erupted (Perret and Bowman 1992). White and Boudreaux (1977) found the makeup of the inshore Cameron, Louisiana shrimp fleet to be primarily a butterfly net fishery producing 80% of the inshore catch in that area.

In Louisiana, skimmer nets (Fig. 2) are the newest legal shrimping gear. Developed in 1990, skimmers are legally defined as a net attached on two sides to a triangular frame and suspended from, or attached to, the sides of a boat, with one corner attached to the side of the boat and one

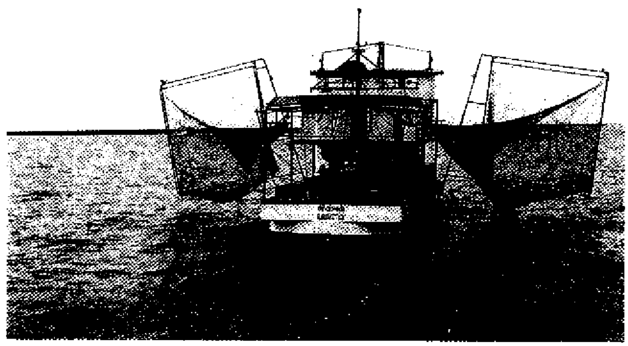

Figure 1. Back view of double wing nets and vessel.

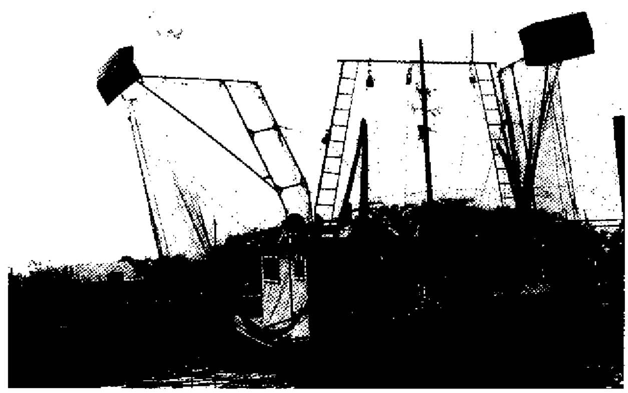

Figure 2. Back view of double skimmer nets and vessel.

Table 1. Number of shrimp gear licenses in Louisiana.

Year	Seine	Trawl	Butterfly net[3]	Skimmer[4]	Rec. trawl[5]	Total
1960	7	4,896[1]				4,903
1970		11,170[1]				11,170
1980		29,892[1]				29,892
1985		30,051[1]	3,951			34,002
1990		20,833[2]	8,176		4,600	33,609
1991		18,712[2]	8,032		5,000	31,744
1992		17,320[2]	4,778	3,790	4,224	30,112
1993		14,565[2]	4,528	4,639	3,833	27,565
1994		13,604[2]	3,334	4,938	4,225	26,101

[1]Includes resident and non-resident commercial and recreational licenses.
[2]Includes resident and non-resident commercial trawl licenses.
[3]Butterfly nets defined and licensed in 1985; prior to 1985 licensed as trawl.
[4]Skimmer nets defined and licensed in 1992; prior to 1992 licensed as butterfly net.
[5]Recreational trawls only (16 feet or less).

corner resting on the water bottom. A ski and one end of the lead line are attached to the corner of the frame that rests on the water bottom and the other end of the lead line is attached to a weight suspended from the bow of the boat. The skimmer, like the butterfly net, is pushed in pairs on each side of the boat. This allows the codend of the net to be picked up and emptied, as a rule, every 20-30 minutes, without interrupting fishing. These nets appear to be a cross between a trawl and a butterfly net, seem well suited for Louisiana's shallow coastal bays, and can be fished effectively during both day and night hours.

Since their development, skimmers have become extremely popular with many fishermen. One major difference between the butterfly net and skimmer is that the butterfly net is designed to fish only the upper portion of the water column, while skimmers generally fish the entire column.

Administration

LDWF is the agency within state government that has the constitutional authority and legislative responsibility for providing research and management of the state's marine fisheries resources. Within the Department is a Marine Fisheries Division, which has a professional staff that performs the necessary research to provide information for management recommendations.

Fisheries independent information required to assist in the management of selected fisheries and information on bycatch species have been collected continuously from Louisiana's coastal estuaries since 1967, and now provides an extensive and continuous baseline data set. A continuous inshore monitoring program utilizing 4.9 m flat otter trawl of 3.2 cm mesh wings and 0.6 cm mesh codend, towed for 10 minutes at set geographical locations, was conducted by LDWF from 1967 through 1994. This data provides information on long-term changes in the abundance and size distribution of various species representing a diverse range of fisheries assemblages.

This data set contains information on 268 species (over 7 million specimens); 183 finfish, 62 crustaceans, 14 molluscans, 2 reptiles, and 7 miscellaneous invertebrates. This resulted in a catch per unit effort (CPUE) per 10-minute tow of some 391 organisms per sample based on 18,012 samples for the 27 year period (Perret et al. 1993).

Results

The results from the fisheries independent monitoring program in Louisiana's inside waters provide an excellent database to assess any impact that bycatch mortality from the shrimp fishery may have. The evaluation of a 28-year database provides information on long-term trends of estuarine-dependent species. Individual species abundance fluctuated greatly from year to year over the 28-year span of the data. This is expected of those species with annual or relatively short life cycles with high reproductive potential that can be greatly influenced by hydrological and environmental conditions. Rayburn (1992) suggested that these short-lived species may have adapted to the high level of capture in the trawl fisheries of Texas.

This data set contains extensive information on species while in estuaries and provides insight into long-term trends in abundance. For the purpose of this paper, five bycatch species, one crustacean, and four finfish were selected. These include blue crab, an important commercial and recreational invertebrate; bay anchovy, an abundant forage species; spotted seatrout and sand seatrout, commercial and recreational finfish; and Gulf menhaden, an industrial finfish.

Blue Crab

The CPUE ranged from a low of approximately 2 in 1976 and 1977 to a high of about 14 in 1980 (Fig. 3). As expected, fluctuations varied greatly from year to year over the 28-year data span, with the long-term trend indicating almost a twofold increase in abundance for this species.

Bay Anchovy

The overall CPUE was 186 and ranged from approximately 79 in 1973 and 1974 to 377 in 1980 (Fig. 4). CPUE showed great annual diversity, with the long-term trend indicating a substantial increase for this species.

Spotted Seatrout

This is a highly mobile species, not readily susceptible to capture by 4.9m trawls, which consequently explains the very low incidence of captures (Fig. 5). The CPUE for any one year never exceeded 0.6. They were taken in such small numbers by this gear that very little trend is evident.

Sand Seatrout

The CPUE ranged from a low of 1 in 1970 to a high of slightly over 14 in 1993 (Fig. 6). Annual fluctuations are well expressed, but a long-term increasing trend is evident. CPUE rose steadily from 1970, peaked in 1979, was followed by a ragged decline through 1988, and subsequently rose to a new high in 1993.

Gulf Menhaden

The overall CPUE trend showed a steady increase (Fig. 7). Annual CPUE was low in the late 1960s and early 1970s, fluctuated greatly between highs and lows for the mid-1970s through the mid-1980s, then fell for the remainder of the period.

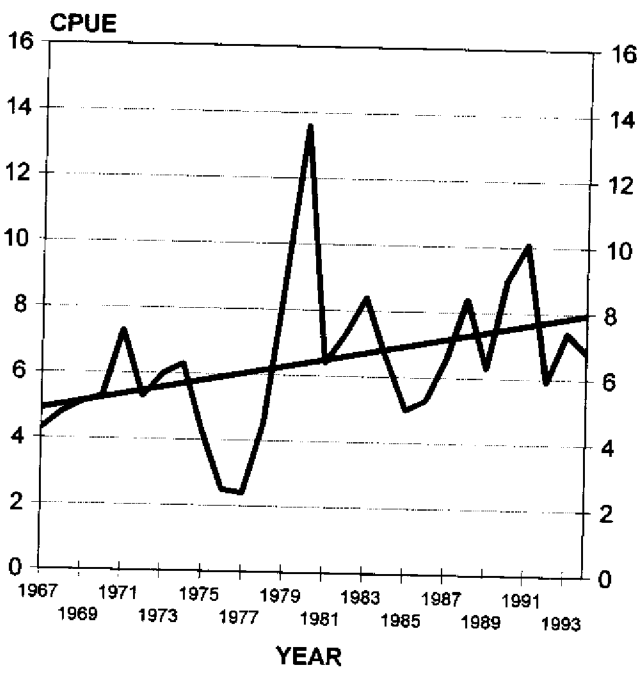

Figure 3. Blue crab CPUE 1967-1994. Source: LDWF.

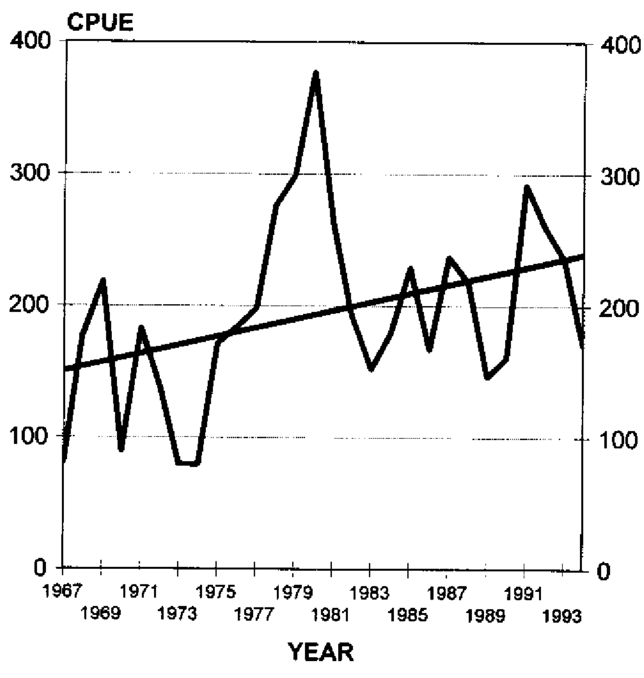

Figure 4. Bay anchovy CPUE 1967-1994. Source: LDWF.

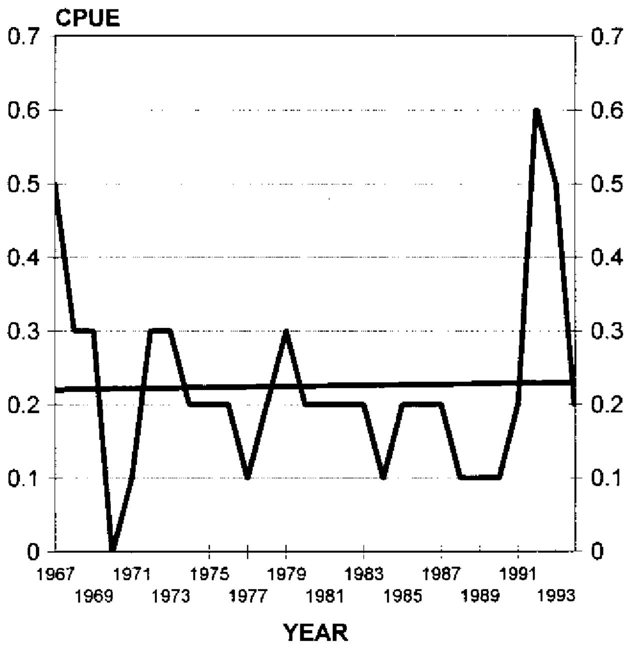

Figure 5. Spotted seatrout CPUE 1967-1994. Source: LDWF.

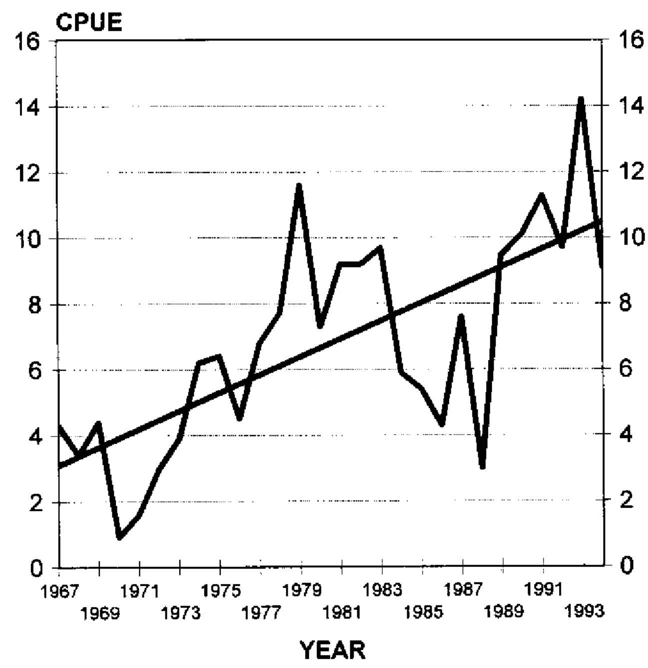

Figure 6. Sand seatrout CPUE 1967-1994. Source: LDWF.

Discussion

While it is obvious that numerous species, and oftentimes large numbers of estuarine finfish and crustaceans, are taken incidental to shrimp harvested in the inshore waters of Louisiana, long-term CPUE does not indicate a downward trend with most of these species. These findings are consistent with an earlier study by Gunter (1956), who found that stocks of estuarine-dependent finfish fluctuated primarily in response to environmental conditions, i.e., salinity and water temperature. Whitaker et al. (1989) reported that species of commercially and recreationally important finfish were taken in relatively large quantities as trawl bycatch with no apparent long-term decrease in their population. They further concluded that fish and shrimp stocks on the grounds of South Carolina had not been negatively affected by commercial shrimp trawling from a biological standpoint.

Over the years, shrimpers have developed a number of devices to reduce the take of nontarget species. For example, trawlers have used the test trawl not only to check shrimp catch, but also to monitor bycatch rate. Data from the test trawl is the primary information used in making the decision to begin, continue, or discontinue fishing in a given area.

In January 1992, shrimpers from Louisiana identified 11 specific bycatch reduction devices (BRDs) that fishermen developed and are currently using when conditions warrant (Rogers et al. 1994). Fishermen have also developed catalogs of areas where bycatch concentrations are too large to trawl for shrimp, and simply avoid them.

There have been a number of studies dealing with bycatch in the shrimp trawl fisheries; however, little data is available on the butterfly net and skimmer net fishery. Capone (1985) found that the mean ratio of pounds of finfish to shrimp in Calcasieu Lake, Louisiana was lower than in trawl studies. Also, a coastwide study by Adkins (1993) concluded that the bycatch mortality rate was lower in the butterfly net than that observed in the trawl, and since butterfly nets fished the surface waters, were generally fished at night when water and air temperatures were cooler, and the codend was emptied more frequently, survival of the bycatch was enhanced.

Since the skimmer is a recent gear development, very little data on bycatch rates are available. Adkins (1993) reported preliminary investigations indicated skimmers were much

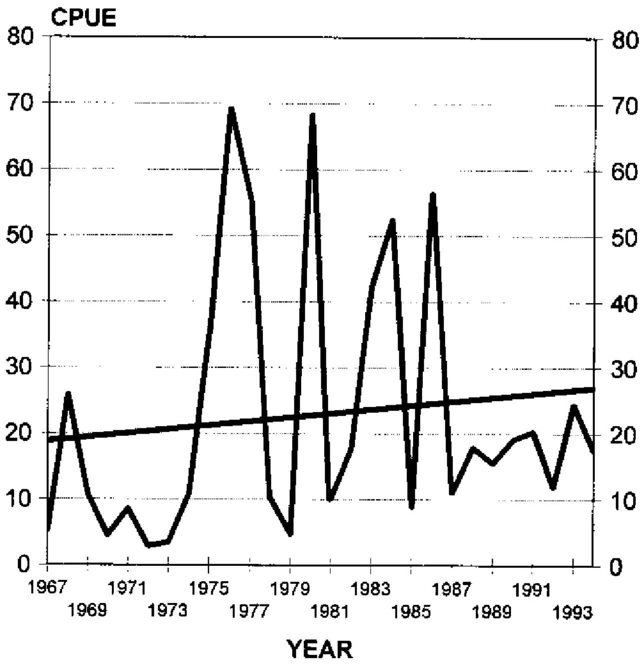

Figure 7. Gulf menhaden CPUE 1967-1994. Source: LDWF.

more effective at harvesting shrimp while allowing nontargeted species to be released alive.

In a North Carolina study, Coale et al. (1994) found on average that skimmer nets caught fewer kilograms of bycatch per minute than the otter trawl, skimmer nets exhibited a lower fish-to-shrimp ratio than the otter trawl, and organisms taken in the skimmer nets exhibited increased survivability compared to those collected by the otter trawl. They concluded that use of skimmer nets may increase white shrimp catch and reduce bycatch and mortality rates of most other species. Additional work is needed to determine the skimmer net's effectiveness in the brown and pink shrimp fisheries.

Conclusion

Bycatch is certainly not a new issue, yet it has only recently garnished national acclaim. For our purpose, bycatch is defined as "the catch of any species, sex of a species, or size of a species of fish, shellfish, or other marine species which is unintentionally harvested, and which is subsequently retained or discarded because of market or legal requirements."

While some previous studies suggest that trawl bycatch has had little effect on fish populations, and the CPUE data from LDWF's inshore trawl monitoring program shows no long-term detrimental biological effects on estuarine species, it does present serious problems due to the sociological and political consequences, perceived or real. Today there is much criticism of the commercial fishing industry due to the bycatch issue. The industry must view itself as others see it, and must provide facts to help document its cause and combat misleading information.

The commercial shrimp fishing industry is a major component in the bycatch equation and, thus, must be a major source of the solutions to this issue.

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Critical Elements for Sustainable Harvests of King and Tanner Crabs in the Eastern Bering Sea, with a Focus on Bycatch Regulations

Arni Thomson
Alaska Crab Coalition, 3901 Leary Way NW, #6, Seattle, WA 98107

Bycatch and associated waste in fisheries have become a priority conservation issue for the major fishing nations, including the United States. Fisheries managers are eager to develop and implement management measures that will have the effect of reducing bycatch. Such measures are of particular urgency for fisheries in which growing numbers of vessels and increasing efficiency of gear are escalating fishing pressure on declining and often depleted stocks. The productivity of the fisheries resources and viability of the fishing industry are at stake.

In the fisheries off the coast of Alaska, fishermen and fisheries biologists and managers have sought solutions to the bycatch problem since the early 1960s. The record shows that determined leadership and a firm commitment to resource conservation on the part of industry and government have been essential to the development and enforcement of effective bycatch reduction measures. Recent experience has also demonstrated that intelligently engineered individual transferable quota programs for target species can lead to substantial reductions in bycatch waste. Although traditional management measures, such as time and area closures and bycatch caps, have had beneficial effects on nontarget resources in past years, the escalating pressures of excessive fishing capacity and increased harvesting efficiency have made it impossible for fisheries managers to apply such measures with sufficient timeliness and precision to ensure that conservation goals will be achieved. Individual quotas hold the promise of reducing capacity and slowing the pace of harvests in a way that will assure the public and the industry of sustainable fisheries for the indefinite future.

Looking back 10 years to 1986, the Alaska Crab Coalition (ACC) started with the issue of king crab bycatch. Upon its formation, the ACC Board of Directors established two parallel goals: (1) to work with the North Pacific Fishery Management Council (NPFMC) to restore the Crab Pot Sanctuary in the eastern Bering Sea, and (2) to work with the Alaska Department of Fish and Game (ADF&G) to develop management measures that would encourage sustainable harvests of king and Tanner crabs. After 10 years it is appropriate to identify and evaluate the methods the NPFMC has employed to reduce bycatch. At the same time, it is appropriate to review and evaluate the management actions ADF&G has taken to reduce the bycatch of crabs (regulatory discards) in the directed crab fisheries. Under a special delegation of authority in a federal fisheries management plan developed in 1989, the Bering Sea and Aleutian Islands King and Tanner Crab FMP, the state of Alaska has management jurisdiction over Bering Sea/Aleutian Islands king and Tanner crabs. However, the NPFMC manages prohibited species bycatch under the groundfish management plans for the Gulf of Alaska and the Bering Sea/Aleutian Islands. This has created a bifurcation in the overall management of the crab fisheries, that has been an impediment to the rebuilding of the stocks.

Fishermen and fisheries managers involved in the crab, halibut, salmon, herring, and groundfish fisheries in the Gulf of Alaska and the Bering Sea have been aggressively pursuing bycatch reduction solutions since the early 1960s. Reduction of the bycatches of prohibited species in the foreign groundfish fisheries was a major stimulus for the development of a series of bilateral treaties between the United States and the U.S.S.R., and the United States and Japan, that were ongoing throughout the 1970s.

Methods of accounting for groundfish tonnage and bycatch of prohibited species, and later the reduction of prohibited species bycatch mortality were developed during the period of foreign fishing in the exclusive economic zone (EEZ) off the coast of Alaska. Substantial closed areas, both seasonal and year-round were adopted as a primary mechanism for reducing bycatches. In some areas, all trawl gear was prohibited and in other areas, non-pelagic trawl gear was prohibited. After the passage of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1976 establishing the 200-mile EEZ, the U.S. government was successful in imposing 100% onboard observer coverage on the foreign fleets (1986), under the direction of the NMFS. Payment for the program was extracted from tonnage fees. In addition, a ratchet down system of bycatch rates and a company-by-company individual bycatch accountability program (IBQ) was enacted. Vessels that could not maintain standardized bycatch rates were sent back to their home port by the their companies, and penalized by the lost fishing quotas that were reassigned to other company boats. These methods were highly successful in dealing with the foreign fleets, and they provided a model bycatch reduction plan for curtailing prohibited species bycatch in groundfish fisheries.

Despite the lessons learned during the foreign fishing period, the fledgling NPFMC, when developing its preliminary Fishery Management Plans in 1980-1981, relaxed the bycatch regulations developed for foreign fleets. This included opening the protection zones to encourage the Americanization of the bottomfish fisheries in the Bering Sea and the Gulf of Alaska.

By 1986, in response to demands from crab and halibut fishermen critical of uncontrolled bycatches of prohibited species in domestic groundfish fisheries, the NPFMC channeled industry protagonists into negotiations, then took decisive action to begin reinstituting a matrix of bycatch reduction measures that are still being revised and improved today (Fig. 1).

NPFMC Actions to Reduce Bycatch Mortality in Groundfish Fisheries

1. Crab, halibut, herring, and salmon: non-trawl, time and area closures, and year-round protection areas.

2. Use of aggregate prohibited species caps (tonnage or number of animals).

3. Use of bycatch rates and bycatch mortality rates for both prohibited species and nontarget groundfish species.

4. Allocation to selective gears with lower bycatch mortality (Bering Sea Pacific cod fishery).

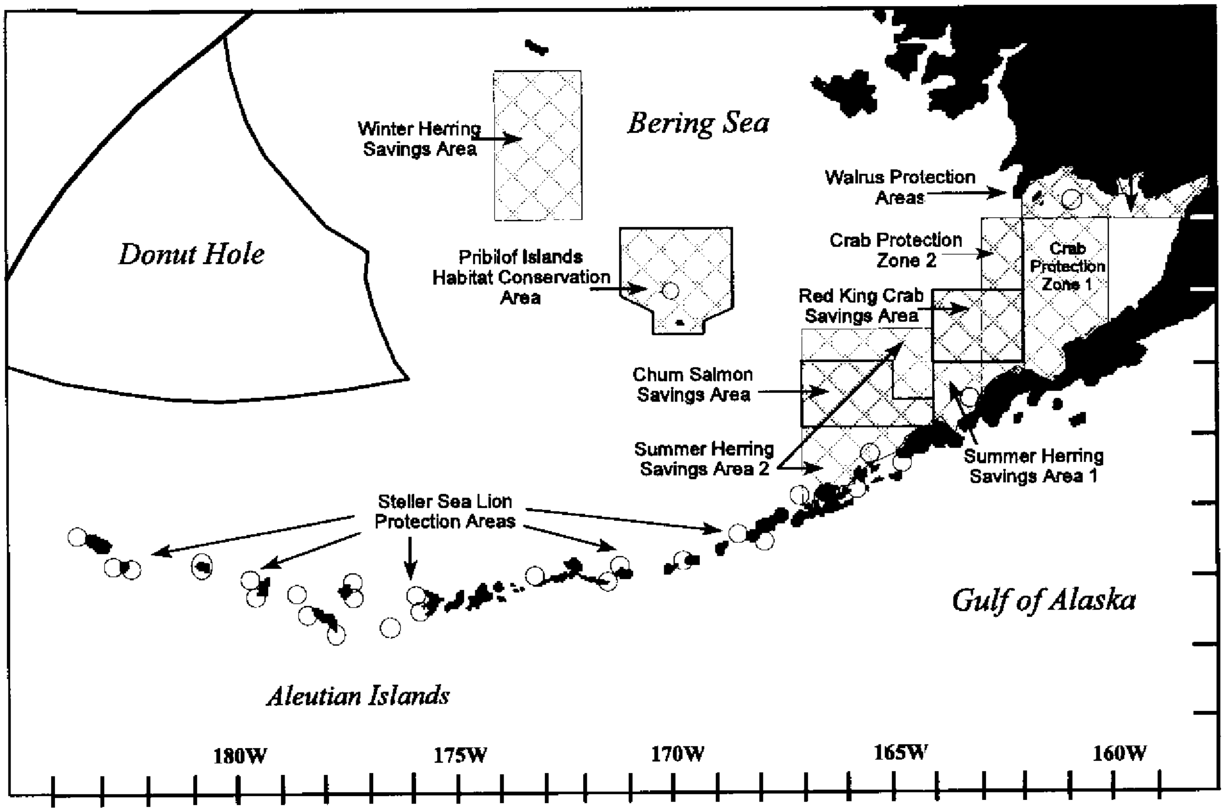
5. Thirty to 100% pay-as-you-go domestic onboard observer programs for groundfish and crab fisheries.

6. NMFS comprehensive system of catch and bycatch data production and analysis and computerized electronic bulletin board reports available to the public on a timely basis.

7. Publication of vessel-by-vessel bycatch rates, which identify the "dirty dozen," a peer pressure mechanism that is effective.

8. Performance trawl definition (20 crabs per tow).

9. For groundfish pots: minimum size tunnel height openings and halibut excluder devices, exemption from halibut prohibited species cap (PSC) (incentive for clean gear type), reduction from 100% to 30% observer coverage for vessels 125 feet and over, mandatory use of #30 cotton thread sewn into 18-inch strip of



Proposed Northern Bristol Bay Area: closed year-round to all trawling (proposed).

Chum Salmon Savings Area: closed to all trawling August 1-31 with provisional extention to October 5.

Bristol Bay Red King Crab Area: closed seasonally to non-pelagic trawling.

Pribilof Islands Habitat Conservation Area: closed year-round to all trawling.

Crab Protection Zones: Zone 1 closed to trawling year-round.
Zone 2 closed to trawling March 15 - June 15.

Walrus Protection Areas: closed to all fishing April 1 - September 30.

Steller Sea Lion Protection Areas: closed to all trawling year-round with some extended seasonally on January 20.

Herring Savings Areas: closed to all trawling when trigger reached.
Summer Area 1 closed June 15 - July 1
Summer Area 2 closed July 1 - August 15.
Winter Area closed September 1 - March 1.

Figure 1. Bering Sea species protection areas. Source: North Pacific Fishery Management Council, March 3, 1995.

mesh on the bottom of pots to minimize ghost fishing in lost pots.

10. For longline hook and line: observed careful release of halibut has resulted in the reduction of the halibut bycatch mortality rate from 18% to 11%, allowing the longline fleet to optimize their catch.

ADF&G Management Actions to Reduce Bycatches of Undersized Crabs (Regulatory Discards)

1. Minimum mesh size restrictions for king crab fisheries to encourage escape of females and undersize recruits and pre-recruit crabs.

2. Mandatory use of 18-inch strip of #30 cotton thread sewn into the bottom of all crab pots to minimize ghost fishing in lost pots.

3. King crab excluder devices that reduce tunnel height openings in Tanner crab fisheries.

4. Combining of Bristol Bay king and *C. bairdi* Tanner crab season to reduce handling mortality.

5. Establishment of a female and juvenile king crab protection zone, closed to directed *C. bairdi* fishing when king crab are below threshold levels.

6. Fisheries pot limits to reduce gear concentrations, lost pots, and ghost fishing.

7. The state of Alaska is conducting laboratory and field research on crab stock dynamics; evaluating crab harvesting strategies relative to minimum threshold limits; and the impacts of minimum size limits on reproduction, sex restrictions, and seasons (Kruse, Murphy, Zheng, et al. 1993, 1994, 1995).

Conclusions

North Pacific Fishery Management Council

The bycatch methods employed have been successful to the extent they can be, given the constraints of the NPFMC/ NMFS/ADF&G management framework. However, Bristol Bay king and *C. bairdi* crab stocks are still depressed and in need of improved coordination between the NPFMC and ADF&G.

1. It is recommended that the Bristol Bay king crab protection area be enlarged in accordance with the findings of Armstrong et al. (1993) and Witherell (1995) with relevance to the original crab pot sanctuary and the need to protect larvae settlement areas and juvenile habitat. Recently, scientific and regulatory information on management of the king crab stocks off the west coast of Kamchatka (Sea of Okhotsk) has been provided to an ACC member, that supports Armstrong's focus on the significance of habitat and the need for crab refuges. This information has been provided to the NPFMC. The ACC member has also produced papers for the NPFMC focusing on the impacts of the rock sole fishery to king crab stocks. Another ACC member, a fisherman with more than 20 years experience in Bering Sea crab fisheries, has long advocated the need for restoration of adequate protection zones as a key management measure to encourage crab stock rebuilding in the eastern Bering Sea. He has produced a number of papers for the NPFMC suggesting necessary changes in bycatch management of groundfish and management of the directed crab fisheries to stimulate sustainable harvests.

2. The *C. bairdi* PSC needs to be reduced, the overall cap has been non-constraining for 10 years and a cap also needs to be established for *C. opilio* crabs.

3. The need to move to a PSC framework that creates incentives for groundfish fishermen that reward clean fishermen and modify behavior, i.e., vessel bycatch accounts (IBQs) that will promote individual vessel accountability on bycatch and individual vessel quotas for target groundfish species. Gear development is only a small part of the solution (Pers. comm., Steve Pennoyer, RD, NMFS, AK Region, Juneau, AK, August 1995).

Alaska Department of Fish and Game

1. The need to accelerate research on life history, harvest strategies, discard mortality, and size limits, and to encourage dual species fisheries, where possible, to maximize retention.

2. Use of pot limits, particularly the restrictive limits of 40 to 75 pots in the Pribilofs and St. Matthews king crab fisheries is leading to rapid cycling of pots and increased handling mortality and the overall number of discards. These pot limits need to be re-evaluated as soon as possible as they are likely having an adverse impact on the stocks.

3. Encourage the development of individual vessel quota crab management framework for the Bering Sea/Aleutian Islands king and Tanner crab fisheries. This will slow down the race for crab and relieve the pressure on rapid cycling of pot lifts to maximize CPUE. With individual vessel quotas, pot limits will become a minimal factor in the management of the fisheries. Gear selectivity can be optimized under long soak conditions to allow for escape of small animals at the point of capture, prior to the pots being retrieved. Reference is hereby made to the case history of the IFQ management of the Southern Gulf of St. Lawrence *C. opilio* crab fishery (Atlantic coast of Canada).

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Crab Bycatch in Pot Fisheries: Causes and Solutions

Bradley G. Stevens
National Marine Fisheries Service, Alaska Fisheries Science Center, Kodiak Laboratory
P.O. Box 1638, Kodiak, AK 99615

This paper summarizes some recent research on crab bycatch in crab pot fisheries. The problem has three major aspects: (1) Reducing the catch of unwanted crabs. Bering sea crab fishermen discarded almost 6 crabs for every legal king crab retained in 1992. Use of a circular excluder panel can significantly reduce capture of small snow crab. Escape rings will allow 80-95% of undersized crab to escape from pots. Careful design can improve the ability of pots to capture and retain only targeted species-sex-size groups. (2) Effects of handling and discarding unwanted crabs. On-board studies indicated that 2% of king crabs and 10% of Tanner crabs died within 48 hr as a result of handling. However, long-term studies in controlled environments were unable to demonstrate any significant mortality of king or Tanner crabs as a result of damage or repeated handling. Handling, therefore may not be a major source of mortality to healthy crabs except under unusual circumstances. (3) Unseen bycatch due to ghost fishing by derelict pots. A sonar survey of Chiniak Bay, Kodiak, Alaska, revealed 190 lost crab pots in an area of about 4.5 km^2, for an average density greater than 42 pots/km^2. Eight intact pots recovered from this area contained an average of 4 crab, and 0.5 octopus. Observations by remote camera and submersible showed that crabs and fish are common residents of crab pots, whether or not the pot mesh is intact. Crabs left in pots over long time periods will starve, weaken, and subsequently die. Mortality in ghost pots can be reduced by adding pot retrievers, more degradable mesh, and other changes.

Bycatch of commercially valuable crab species is commonly considered to be a problem in trawl fisheries for groundfish, where crab mortality can range from 20% to 100% (Stevens 1990). This has created considerable debate within the North Pacific Fishery Management Council, and led to the imposition of limitations on crab bycatch in commercial trawl fisheries. Crab discard rates in directed crab pot fisheries, however, rival or exceed those in trawl fisheries. In 1992, Bering Sea trawl fisheries captured and discarded about 179,000 red king crab (*Paralithodes camtschaticus*) (NPFMC internal documents) representing about 0.5% of the total population in Bristol Bay (Stevens et al. 1992). The total trawl bycatch of red king crab has varied from 0.1 to 2.9% of the total population in Bristol Bay (Armstrong et al. 1993) but rarely exceeds 0.5%. Despite potentially high mortality rates of crab bycatch in trawl fisheries, these low catch rates probably have little overall impact on the population. In contrast, 6.3 million crabs of all species, including 5 million red king crabs, were discarded during the capture of 1.2 million red king crabs during the 1992 Bristol Bay fishery (Fig. 1). As a result, 5.87 crabs were discarded for each red king crab retained (Tracy 1993). For comparison, discard ratios (number discarded per number retained) in other crab fisheries range from 0.09 for the 1994 Bering Sea snow crab (*Chionoecetes opilio*) fishery, to 9.9 for the 1994 Dutch Harbor golden king crab

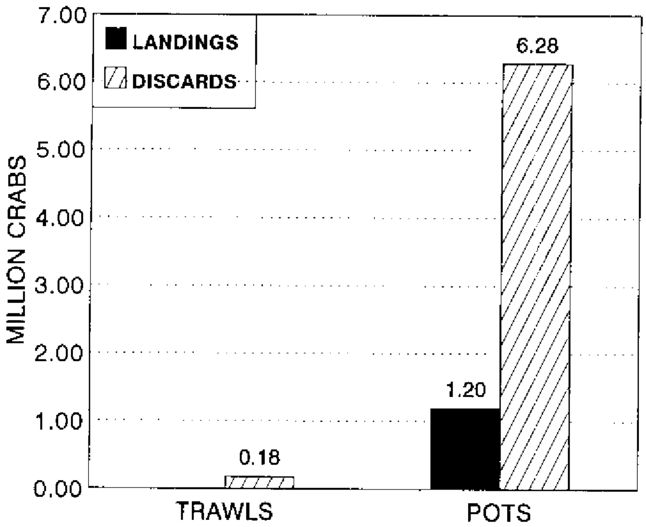

Figure 1. Numbers of crabs captured and discarded in groundfish trawl fisheries and directed pot fisheries in the Bristol Bay region of the Bering Sea in 1992. Bycatch of red king crab in finfish trawl fisheries was 179,000 crabs, whereas 6.3 million crabs of all species were discarded during the red king crab fishery.

(*Lithodes aequispina*) fishery (Alverson et al. 1994, Tracy 1995). These data emphasize the need to look more closely at bycatch and mortality of crabs in pot fisheries.

This manuscript discusses the results of recent research on crab trap design and efficiency, survival of discarded crabs, and ghost fishing. Emphasis is placed on currently used and potential methods to reduce bycatch-related mortality of North Pacific and Bering Sea crab species.

Crab Trap Design and Effectiveness

The terms trap and pot are used interchangeably in this paper. The three trap designs which are most commonly used in the Gulf of Alaska and Bering Sea are the conical, pyramidal, and square (see High and Worlund 1979, for detailed descriptions). Conical and pyramidal pots have a single round entrance through the top, which is usually fitted with a plastic collar to prevent escapement. Square pots are the most common gear type used in the Bering Sea crab fisheries, and typically have two funnel-shaped entrance tunnels on opposite sides. All three trap types have steel frames and are covered with synthetic nylon mesh.

Much thought has gone into improving the ability of pots to capture and retain crabs, and to release undersized crabs. Less effort, though, has been spent devising ways to prevent the catch of unwanted animals or to prevent crabs from entering a pot after it is lost. Minor alterations may improve the selectivity of a pot (the ability to select or retain just the desired or target animals) as well as its efficiency (the ability to capture target animals at a high rate, or to catch a large proportion of those available).

Factors Affecting Crab Entry to Pots

The simplest way of reducing bycatch is not to capture unwanted crabs in the first place. One way to achieve this is by the addition of an "excluder ring," a narrow strip of plastic placed in a vertical orientation around the upper portion of a conical crab pot. Chiasson et al. (1993) showed that excluder rings could significantly reduce the capture of undersized, soft, or female snow crabs, while not affecting or even increasing the catch rates of hardshell legal sized males.

Pot efficiency can also be maximized by altering pot shape, entrance location, and bait location. Crabs are extremely adept at following an odor trail to a pot, but will not go around a pot looking for an entrance (Miller 1979). Studies with rock crabs *(Cancer irroratus)* and spider crabs *(Hyas araneus)* showed that pots with entrances oriented parallel to the current caught seven times more crabs than those with entrances at angles to the current (Miller 1979). Pots with three entrance tunnels caught 60% more crabs than pots with two tunnels. Pots with top entrances caught more crabs than those with side entrances (Miller 1979).

Vienneau et al. (1993) observed conical pots with a video camera. They found that snow crabs were only attracted from downstream, and 95% entered the trap from the downstream side. More crabs were caught when bait was placed in the center of the pot, whereas bait placed near the side of the pot attracted crabs to the outside of the mesh, but fewer crabs entered the pot. Vienneau et al. (1993) suggest that, because crab tend to follow odor trails upstream, placing pots in rows perpendicular to the current should be more efficient than placing them parallel to the current.

Improving Escapement of Small Crab

Once unwanted crabs are captured, there should be a way for them to escape. One very simple device which improves trap selectivity is the escape ring or panel. Most square pots used in Alaska have a hinged mesh panel on one side which, when raised, exposes an area of larger mesh and allows escapement of Tanner crabs and small king crabs. Marshall and Mundy (1985) showed that a panel of 166 mm mesh (horizontal diagonal measure) on one side of a square pot would retain 95% of legal red king crabs, and 27% of sublegal ones.

Escape rings have been required in Dungeness crab (*Cancer magister*) traps for many years. Jow (1961) showed that the addition of two 114 mm i.d. (4.5 inch i.d.) rings to a Dungeness crab pot reduced the capture of non-marketable crabs by a factor of 28. Studies conducted by the National Marine Fisheries Service (NMFS) in Kodiak, show that escape rings can also improve the ability of undersized Tanner crabs to escape from small mesh pots (R.S. Otto, NMFS, P.O. Box 1638, Kodiak, AK, unpublished data). After 5 days in pots with two 127 mm i.d. (5.0 inch i.d.) rings, 93% of legal sized crabs remained, but only 20% of sublegal crabs remained. Escape rings have been used voluntarily in the Dutch Harbor and Adak fisheries for golden (brown) king crab (*Lithodes aequispina*), which resulted in a decrease of nontarget crab bycatch in those fisheries by 49-61% (Beers 1991). Thus, escape rings or panels are low cost modifications that can dramatically improve the selectivity of crab pots, and should be considered for use in all crab pot fisheries.

Stevens et al. (1993) used a remotely operated vehicle (ROV) to observe red king crabs escaping from square pots. Crabs wandered randomly around the pot until they encountered the opening, whereupon they exited the pot in less than a minute. Escape was quicker for larger crabs or those which stepped on top of others. Within the pot, crabs tended to aggregate in corners on the upstream side. For this reason, the corner might be a good location for an escape ring or panel.

Discard Mortality Due to Damage While Culling Unwanted Crabs

Once captured, unwanted crabs must be sorted out of the catch and discarded. This process can lead to injuries and exposure that results in subsequent mortality. However, despite some claims that such mortality may have significantly affected stock conditions (Reeves 1993, Alverson et al. 1994), recent research indicates that discard mortality is either extremely low or nonexistent for some species.

In 1992, the NMFS Kodiak lab determined the injury and mortality rates for discarded Tanner crab and undersized red king crab during simulated (i.e., slower than normal) fishing by a chartered commercial vessel (R.A. MacIntosh, NMFS, P.O. Box 1638, Kodiak, AK, unpublished data). During this study, 15% of 981 red king crabs and 27% of 834 Tanner crabs received injuries (including minor ones like broken spine tips and autotomized legs). After 48 hr in seawater, only 2% of 55 red king crabs and 10% of 287 Tanner crabs died as a result of handling. Zhou and Shirley (1995) subjected red king crabs to a simulated capture and handling process up to three times, and then held the crabs in seawater up to 4 months. While body damage (mostly broken spine tips) increased with increased handling, there was no significant change in mortality, feeding rate, righting response, or bacterial infections as a result of handling.

Studies on Tanner crab by MacIntosh et al. (In press.) produced similar results. In three separate experiments, Tanner crab were either: (1) dropped into water from a height of 2.5 m once or 4 times (n=240), (2) subjected to artificially induced injuries of the legs, shoulder, or carapace (n=288), or (3) subjected to four cycles of being placed into a crab pot, lowered to the sea floor, raised to the surface, and removed from the pot, to simulate repeated capture and recovery (n=144). All crabs were held in seawater for 60 days after treatment. Compared to control (untreated) crabs, none of these treatments resulted in significantly increased mortality.

Watson and Pengilly (1994) compared recovery rates of red king crabs which were tagged in October 1993 and released in two ways: control crabs were released into the water right side up from a height of 38 cm from a stationary vessel, whereas treated crabs were dropped into the sea upside down from a height of 168 cm, while the vessel moved at 7.5 knots. Crabs were recovered from fishing vessels between 1 and 10 November 1993. Recovery rates for new shell crabs were significantly higher than for old shell crabs, but there was no difference in recovery rates between control and treated crabs (Watson and Pengilly 1994).

Kruse et al. (1994) found that softshell Dungeness crab tagged with spaghetti tags on the suture line were recovered at significantly lower rates than tagged hardshell crabs, and attributed the difference to mortality induced by handling. However, they did not eliminate other possible causes or demonstrate that any mortality actually occurred.

Sublethal effects may still occur, and are more difficult to determine. Brown and Caputi (1985) showed that exposure of rock lobsters (*Panulirus cygnus*) to air during handling, as well as accidental leg loss, could result in decreased growth at subsequent molts. Carls and O'Clair (1990) found that exposure to sub-zero air temperatures caused decreased growth at subsequent molts for female red king crabs, and decreased feeding rates and increased leg loss for Tanner crabs. Exposure to 0-degree temperatures can cause apolysis (separation of underlying tissues from the exoskeleton) in at least 13 species of crabs in seven families (O'Brien et al. 1986). Apolysis is a normal part of the molting process, but, if initiated at the wrong time, could lead to death of the crab.

While some subtle sublethal effects may occur at a later date, the overwhelming evidence in these studies suggests that present-day handling and discarding procedures may not be a major source of crab mortality under the circumstances studied.

Unseen Bycatch Due to Ghost Fishing by Derelict Pots

Crab pots may be lost for a variety of reasons, including weather, fouling, being run over by boats, entangled in trawls or longlines, trapped in ice, or sanded in or snagged on the bottom. Many studies show that crab pots do continue to catch and kill crabs even after loss (for an extensive review of ghost fishing see Breen 1990). Analysis of ghost fishing by pots has two components: pot loss rates and crab capture/mortality rates.

Pot Loss Rates

In April 1994, the NMFS used sidescan sonar to survey 4.5 km^2 of Chiniak Bay, an area of relatively concentrated crab fishing in Kodiak, Alaska (B.G. Stevens, NMFS, P.O. Box 1638, Kodiak, AK, 99615, unpublished data). This survey revealed 190 lost crab pots, for an average of greater than 42 pots/km^2. Eight pots were subsequently recovered from this area by dragging in February 1995. All but one were mostly intact, and contained an average of 4 crab and 0.5 octopus. Crab fishing in this area had been closed since February 1993, so all these pots had been lost for at least one year. Observations of 15 of these pots by remote camera and submersible showed that crabs and fish (sculpins and cod) were common residents of crab pots, whether or not the pot mesh was intact. Apparently, crabs seek out pots for potential shelter. This behavior can be fatal, however, since octopus also commonly occupy pots. Intact mesh is not required for ghost pots to capture and kill crabs; pots recovered by NMFS during trawling in the Bering Sea occasionally contain dead crabs trapped in loose webbing (author's personal experience).

Estimates of pot loss rates range from 20,000 per year in the eastern Bering Sea (Alaska Board of Fisheries, cited in Paul et al. 1994) to 100,000 per year for the west coast Dungeness crab fishery (Breen 1990). High and Worlund (1979) reported that Alaskan king crab fishermen lose about 10% of their pots annually. In 1993, 71,000 pots were registered for use in Bering Sea crab fisheries (Pers. comm., D. Tracy, ADF&G, 211 Mission Rd. Kodiak, AK, 99615, Sept. 1995). Breen (1987) conducted a survey of Dungeness crab fishermen in the Fraser River district of British Columbia, and concluded that 5.8% of their pots were lost (as opposed to stolen) annually, that each lost pot had a "fishing life" of 2.2 years, and killed 9.3 Dungeness crab per year, resulting in a loss of $83,323 per year, or 7.2% of the reported landings. In a typical year (1975-1976), Washington state Dungeness crab fishermen lost 17.6% of their pots (6,577 total) (Northup 1978, cited in Muir et al. 1984).

The effective fishing life of a pot (i.e., the length of time it continues to fish after loss) is unknown. High and Worlund (1979) cited an estimate of 15 years for (unspecified style) king crab pots. Pot decay can be modeled (Fig. 2) as an exponential process, and described with a half-life. Pots with half-lives of 1, 2, or 4 years decay at a rate of 50% every 1, 2, or 4 years. At these rates, a group of pots that were lost in the same year would decline to 10% of their initial number at 3.3, 6.6, or 13.3 years, respectively. If 7,000 pots were lost per year (10% of 70,000 pots), and pots decayed at an exponential rate, the number of lost pots should eventually reach a steady state. Based on these assumptions, the number of lost pots would reach a maximum of 14,000 after 10

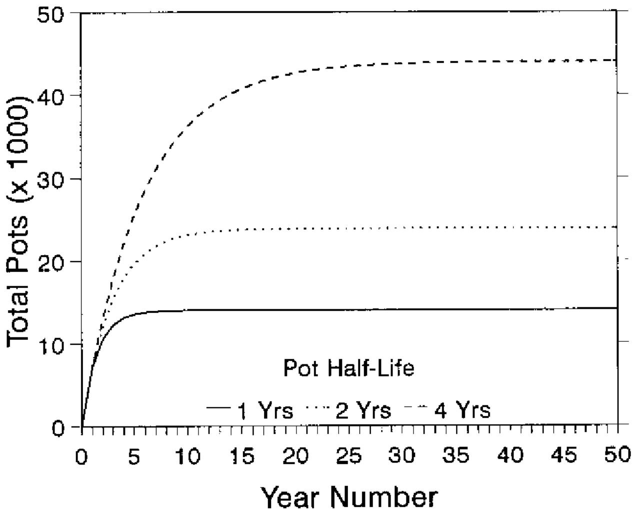

Figure 2. Numbers of crab pots accumulated over time, assuming a loss rate of 7,000 pots per year, and half-lives of 1, 2 or 4 years (See text for explanation).

years (assuming a half-life of 1 year), or 24,000 pots after 20 years (assuming a half-life of 2 years), or 44,000 pots after 40 years (assuming a half-life of 4 years). On the other hand, extrapolation of Kodiak pot densities to a 200 × 200 km area around the Pribilof Islands (an area of heavy crab fishing for red king crab, snow crab, and Tanner crab) yields 1.68 million pots. Since Chiniak Bay pot densities probably exceed those in most areas of the Bering Sea, the actual number is probably somewhere between these extremes.

Crab Capture and Mortality Rates in Lost Pots

Many studies show that crabs trapped in derelict pots may die from starvation or predation. High and Worlund (1979) placed red king crab in unbaited square pots; after 16 days 20% of legal sized crabs remained in the pots. Those which escaped after prolonged enclosure were recaptured at lower rates than those which escaped quickly. Crabs that were placed in closed unbaited square pots exhibited mortalities of 4% to 12% after 16 days. High (1985) placed Dungeness crabs in pots with triggers and escape rings; after 12 days only 45% of 22 legal sized males had escaped, and 23% had died. After 74 days in pots without escape rings, only 21% of 44 legal crabs had escaped, and 26% had died. High (1985) also observed octopuses preying on trapped crabs on three occasions.

Breen (1987) estimated that lost Dungeness crab traps in Departure Bay, British Columbia, Canada, caught 16.9 crabs per year, of which 52% died. In his study, pots continued to entrap crabs long after the bait was gone; catch rates after 1 year were as high as they had been 2 weeks after loss. Muir et al. (1984) captured 185 Dungeness crabs in baited pots; after 28 days, 111 (60%) had escaped, and 35 (19%) had died. Most crabs which escaped did so within 2 days of capture, and relatively few escaped after 12 days. Kimker (1994) held 132 large adult male Tanner crabs in pots for 119 days, during which time 39% died.

The effects of starvation may cause increased mortality even after captured crabs are released. Tanner crabs that were starved for periods up to 90 days did not increase their feeding rates after starvation, and suffered mortalities of 40-100% during prolonged holding with access to food (Paul et al. 1994). Dungeness crabs that received the same treatment suffered 40-80% mortality while the control group, which was fed continuously for 230 days, suffered 20% mortality. Thus these crabs were susceptible to stresses caused by capture, handling, and captivity. In the wild, these stresses could translate to a reduced ability to forage, feed, reproduce, or survive even after escape from a pot.

Prevention of Ghost Fishing

A number of methods have been developed to release crabs from lost pots, including escape rings (discussed above), degradable twine, and galvanic timed releases (GTRs). The state of Alaska requires that all crab pots have one escape opening of at least 457 mm (18 inches) secured by a length of degradable twine or a GTR. While the degradation time for cotton twine is not well known, and probably quite variable, GTRs can be manufactured to degrade after a predetermined time with fair accuracy (Paul et al. 1993). However, one opening of 18 inches may not be particularly effective; more openings, of larger size, placed closer to the bottom would probably improve escapement significantly. Scarsbrooke et al. (1988) tested several escape mechanisms in sablefish pots, and found that a square panel, secured by cotton butchers twine, released twice as many fish per unit time as a single 20 cm length of degradable twine. Entry of crabs to a lost pot might also be prevented if the tunnels were constructed with GTRs such that they would collapse or close after some time period.

The best way to prevent ghost fishing would be to prevent pot loss in the first place. Use of solid buoys to prevent buoy puncture, and attaching non-floating line near the surface are simple and effective adaptations (Breen 1990). One potentially useful device is a pot retriever, which incorporates a coil of line attached to a buoy in a mesh bag sealed with a GTR[1] However, these are not yet widely used by the fishing fleet due to their additional weight and cost. Loss of the surface buoys might be prevented by replacing them with pot retrievers.

Additional Considerations

Management Measures

In addition to gear modifications, management measures can effectively reduce bycatch mortality. The most common measures employed are time and area closures. In eastern Canada, the snow crab fishery is closed when the proportion of softshell crabs in the catch exceeds 20% for two consecutive weeks (Hebert et al. 1992). Opening dates for crab fisheries in Alaska are almost always set to avoid handling of soft-shelled crabs, and frequently have been closed by emergency order to avoid such handling. In 1994 and 1995, fishing for Tanner crab in Bristol Bay was prohibited east of 163 degrees longitude to avoid bycatch of red king crab, when the latter fishery was not opened due to low stock conditions.

Inter-species Conflicts

Most gear modifications are designed to affect the target species, but much of the bycatch in crab fisheries consists of nontarget species. Escape rings designed to allow escapement of small Tanner crab may be too small for king crab to escape. Excluder panels designed to reduce the catch of small snow crab may allow entry of large king crab. These interactions should be considered in the design of pots that are used for more than one species, or in fisheries where several species are present.

Conclusions

The best methods of reducing bycatch-related mortality in crab pot fisheries are to: (1) reduce capture of unwanted crabs, especially softshells, (2) reduce handling mortality of discarded crabs, and (3) prevent loss of pots or prevent entry of crabs after loss.

Prevention of bycatch is most easily achieved by gear modifications or time/area closures. An ideal crab pot would: (1) catch crabs at all or most current angles, (2) reduce escapement of large crabs, (3) prevent entry of, or allow escapement of small crabs, and (4) stop fishing if lost. For Tanner or snow crab, the design that best meets these conditions is a conical or pyramidal trap with a circular top opening, a bait container near the center of the pot, a plastic collar to prevent escapement, an excluder ring around the top of the pot, escape rings near the bottom, and large areas of degradable mesh. However, different configurations might work better for different species of crabs. In addition, choice of pot style is an economic consideration; it may be more economical to adapt a single pot style (e.g., square) to different species, than to purchase and maintain several different styles of pot, which might be more effective for particular species.

Handling mortality is a questionable problem. While most fishermen and scientists agree that it occurs, well designed scientific studies suggest that it is not a major problem. The most that can be said is that crabs which are handled carefully under normal conditions probably suffer little or no mortality, whereas crabs handled poorly or under extreme conditions of temperature or sea state may suffer higher mortality. Softshell crabs are generally more susceptible to damage from handling than are hardshell crabs.

Ghost fishing is very difficult to quantify, but may be a significant problem. More effort should be made to prevent loss of pots, or to prevent crabs from entering lost pots.

Acknowledgments

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Endnote

[1] Neptune Marine Products, P.O. Box 17417, Seattle, WA. (Use of trade names is for information only and does not imply endorsement by the National Marine Fisheries Service, National Oceanographic and Atmospheric Administration.)

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Bering Sea Red King Crab: Resolving Bycatch Equals Stock Rebuilding?

Kris Poulsen
Kris Poulsen & Associates, 1143 NW 45th St., Seattle, WA 98107

Bristol Bay red king crab (*Paralithodes camtschaticus*) was Alaska's premier fishery in the late 1970s. It subsequently crashed in 1981 and was closed in 1984. The red king crab stocks failed to rebound and the fishery was shut down in 1994 and again in 1995. Has bycatch played a role in the diminishing abundance of king crab, and is it even possible to control it? In examining these issues, first-hand personal knowledge of the fishery was incorporated with scientific facts presented in various research papers. The result is a firm belief that Bristol Bay red king crab has been plagued by bycatch and management's inability to accept this reality. Difficult decisions need to be made in the trawl industry as well as the crab industry to reduce the amount of crab bycatch produced by these two groups. Bycatch may be the downfall of all commercial crab fishermen if fishermen and managers alike continue to ignore the importance of the long-term health of the crab stock itself.

In commercial fishing, bycatch is inevitable much like death and taxes; it cannot be avoided. However, just as managing your money wisely can reduce your taxes, or living healthfully can increase your life span, bycatch can be reduced. We are just now beginning to understand the great significance of bycatch and how to prevent it.

Bycatch is the most critical issue facing world fisheries today. The immediate results of bycatch can be arduous to ascertain due to natural swings in the populations of stocks as a result of climatic effects. As an example, a fishery with a high rate of discarding of its own species may not detect any noticeable decline in the legal population of a stock for over five years if the climate is advantageous to the stock. But when the natural climatic cycle is no longer advantageous to the stock, the legal population of the species may collapse. This may have occurred to Bristol Bay red king crab in 1981.

Over 20 years experience fishing in Alaskan waters has taught me that nearly all fisheries have bycatch of one sort or another. This position paper will focus on bycatch issues with regard to the commercial crab industry. Bycatch of crab in the trawl and crab industries, as well as the future implications of crab bycatch, will be discussed.

Results

Trawlers pose a real and substantial risk to crab stocks. During the early 1970s, Japanese trawlers caught more *Chionoecetes bairdi* crab as bycatch than the crabbers did in their directed fishery. *C. bairdi* stocks subsequently collapsed. Also, in 1983 the Bristol Bay red king crab fishery was shut down, but trawlers were allowed into the crab grounds which damaged the already depleted stock. More recently, the Bristol Bay red king crab fishery has been shut down for two years while trawlers are allocated a king crab bycatch.

Prior to 1981, a pot sanctuary was in place in the Bristol Bay area which protected the vast majority of crab stocks, including the nearshore juvenile habitat. According to Armstrong et al.

(1993) the current refuge does not protect successful spawning grounds north of Unimak Island nor nearshore juvenile habitat from trawling. This may account for the long-term depressed status of king crab stocks since the early 1980s. Reintroduction of the original pot sanctuary might be required for a full recovery of the red king crab population.

Trawlers should not take the full blame for crab bycatch. Most crab fishermen do not recognize the fact that they contribute to the problem of crab bycatch as well. Many scientists do not believe that discard mortality is a problem in the crab industry. However, the best scientific knowledge appears to tell us that this is not true. Tagging studies demonstrate that alarmingly few tagged crab are returning. Many discarding studies have been conducted to demonstrate survivability of discarded crab. However, all of these studies occurred under controlled conditions. This results in information which is misleading and essentially meaningless. It is my belief that under normal fishing conditions in the Bering Sea, which includes extreme weather, handling conditions, and the presence of predatory fish, the majority of these crab do not survive being discarded. This would explain why so few tagged crab are found.

Another reason bycatch is a problem in the crab industry, is that the escapement of nontargeted crabs is not easily achieved. Large pot mesh size in conjunction with sufficient soak time would allow nontargeted crabs to crawl out and escape being discarded. The recently introduced pot limit (in most crab fisheries in the Bering Sea/Aleutian Islands region) would certainly seem a great step backward in the management of these fisheries. The worthwhile intent to reduce the effort on crab stocks, which the pot limit was designed to do, has actually backfired. Even with a license limitation, gear is being hauled much more often than it was prior to the pot limit. Fishermen now haul their pots as often as twice each day. This further intensifies the pressure applied to crab stocks.

The bottom line crab fishermen must face is that the crab they throw overboard may not be surviving.

Discussion

There are solutions for the problems crabbers are facing in relation to bycatch. Most prominent is the introduction of an individual transferable quota (ITQ) based management system. Under an ITQ system, pot mesh sizes could be increased along with increased soak time in order to sort crab while on the bottom of the ocean. Small males and females would be able to escape before being harvested. ITQs would also allow for the retention of multiple species of crab to be harvested at the same time. Instead of fishing for *C. bairdi* and discarding *C. opilio*, and then fishing for *C. opilio* and discarding *C. bairdi*, it should be legal to target one species while keeping the bycatch and allowing it to go against the GHL.

As it is now, the Bristol Bay red king crab GHL is based on the population of crabs greater than 6 in. However, the legal size limit is 6.5 in. Why are the crab between 6 in. and 6.5 in. factored in while they are not legals? The legal size limit for red king crab should be reduced from 6.5 in. to 6 in. while the GHL is held constant. This will lower the amount of discards while allowing more crabs to be counted against the GHL. Crab populations will benefit from this since the formerly discarded crabs, which may have died anyway, are now being counted against the quota. This results in a net reduction of fishing pressure on the crab stocks, and results in more large male crab on the crab grounds. Incidentally, it is these large male crab which have the highest chance of successful breeding with large females.

Crab management must be changed to lower the effects of bycatch on the crab stocks. Threshold levels should be enacted for male king crab, and raised to a conservative level for females. This will give a solid base for the king crab population to build upon. Bycatch of king crab would not be as signficiant if stocks were healthy as seen in the *opilio* fishery.

One positive note on bycatch in crab management is the enactment of regulations specifying crab pots must contain an area of cotton twine which will disintegrate within months. This allows crab to escape from lost pots and eliminates the problem of ghost fishing, or pots fishing for years to come after they are lost. However, enforcement of this issue has been very light and, thus, this regulation is often not adhered to.

Of course bycatch will never be eliminated, but it can be manipulated. Bycatch should be diminished by closing certain areas to trawlers, implementing ITQs, and lowering the size limit.

One much needed step forward with regard to crab bycatch is to have the state of Alaska manage crab stocks instead of crab fishermen.

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Options for Reducing Bycatch in Lobster and Crab Pots

Robert J. Miller
Canada Department of Fisheries and Oceans, P.O. Box 550, Halifax, NS, Canada B3J 2S7

Bycatch is easier to control in baited pots than in most other fishing gears. There are four chances to reduce bycatch: (1) select bait with an odor that repels unwanted species, (2) choose the size, shape, location, and construction material of the pot entrances to admit only the desirable catch, (3) choose the size, shape, location, and construction material of escape openings to retain the desirable catch and release bycatch, (4) sort the bycatch on deck and promptly return it to the water. Examples of baits, entrances, and escape openings are presented. Sorting bycatch on deck is a better option in pot fisheries than in most other fisheries because the pot catch is usually landed uninjured; therefore, survival of discards is high if they are quickly returned to the water. Fishers can use well-conducted experiments to answer questions about the effectiveness of different trap designs or baits.

Bait can be selected to repel unwanted species (Fig. 1). Including a dead crab or lobster with the usual bait greatly reduces the catch of the same species. Table 1 shows a 2- to 17-fold catch reduction resulting from this practice. However, baiting with a species such as king crab can be an expensive method of excluding that species. In these cases processing wastes might be substituted for the whole animal. I recently found that a small quantity of internal organs of American lobster, when added to the regular bait of frozen mackerel, reduced the catch of lobsters by half. I am unaware of any reports that baiting with finfish reduces the catch of conspecifics.

Entrance

The entrance to the pot is the next opportunity for selecting the catch. Selectivity can be achieved by adjusting the shape, size, location, and construction material of the entrance. For example, a round entrance can exclude flat bodied crabs while admitting lobsters and round fish (Fig. 2). A rectangular entrance can admit crabs while excluding the lobsters and fish. Of course, the size of these openings must be adjusted for the sizes of animals to be admitted or excluded.

Because of behavioral differences among species, the location of the entrance is also selective. For example, a side entrance pot captured more shrimp than a top entrance one (Table 2). A study by Stasko (1975) provided a good example of using entrance size, shape, and location to select catch. He wanted a pot that could be used for catching rock crab (*Cancer irroratus*) during the months when it was illegal to take American lobster (*Homarus americanus*). He blocked the side entrances of a conventional lobster pot and placed a rectangular entrance in the top (Fig. 3). This modification was effective because crabs more readily crawled to the top of the pot than lobsters and because the width of the slot was sized (based on crab body depth) to permit entry of all rock crabs and exclude all but sublegal size lobsters. Round escape gaps permitted escape of any lobsters small enough to enter.

Attaching a slippery plastic skirt at the bottom of a pot (Fig. 4), or lining the entrance fun-

Table 1. Crab and lobster catches in traps baited with and without dead conspecifics (Miller 1990).

Target species	Bait	Catch/trap	Source
Carcinus maenas	Salted skate	3.6	Hancock (1974)
	Salted skate + dead crab	1.4	
	Dead crab	0.7	
Panulirus cygnus	Cattle hock + fish head	10.2	Hancock (1974)
	Cattle hock + fish head +dead lobster	0.6	
Panulirus cygnus	Cattle hock + fish head	12.9	Morgan (1974)
	Cattle hock + fish head +dead lobster	5.2	
Chionoecetes opilio	Squid	31.0	Miller (1977)
	Squid + dead crab	7.6	
	Dead crab	0.6	
	No bait	0.3	
Cancer pagurus	Fish	5.5	Chapman and Smith (1978)
	Fish + dead crab	2.5	
	Dead crab	0.8	
Paralithodes camtschaticus	Fish	11.8	High and Worlund (1979)
	Dead crab	0.7	
	No bait	1.0	
Libinia dubia or *L. emarginata*	Fish	23.5	Richards and Cobb (1987)
	Fish + dead crab	8.0	
Panulirus interruptus	Dead lobster	1[a]	Zimmer-Faust et al. (1985)
	No bait	3	

[a]Ratio of total catches in tank experiments; number of observations not given.

nel with plastic, could exclude crawling species (crabs and lobster) while admitting swimming ones (shrimp and fish).

Escape

The size, shape, location, and construction material of escape gaps can also be selective. Because crabs and lobsters have rigid shells, the size selectivity of an escape opening can be quite precise. An increase in the height of an opening from 42 mm to 44 mm caused a three-fold reduction in catch of sublegal American lobster (Fogarty and Borden 1980). Of course, the escape gap only works if the captured animal can find it; more than one is usually recommended (Brown and Caputi 1986). Stasko (1975) offered a useful rule of thumb: the smallest opening a crab or lobster can be pushed through by hand is also the smallest opening that it can pass through unaided.

Examples of escape gaps which favor swimmers like fish and shrimp are illustrated in Fig. 5. An inverted plastic funnel fitted to the top of a side entrance pot would provide a large target for escape of swimming species while retaining crabs and lobsters. A hole in the side of a trap surrounded by plastic would also favor the escape of swimmers.

Finfish often become injured escaping through the codend mesh of an otter trawl, or die from the stress of capture and escape (Chopin and Arimoto 1995). Escaping from pots is almost certainly less injurious, but I know of no study that has measured survival of escaped animals.

Fishing Crew

The last opportunity for selectivity is on deck by the fishing crew. This five-fingered sort can be discriminating, choosing among species, sizes, sexes, shell hardness, or any external characteristic of the catch. Pot catches are usually uninjured; therefore, if discards are returned to the water promptly and with reasonable care, survival should be high.

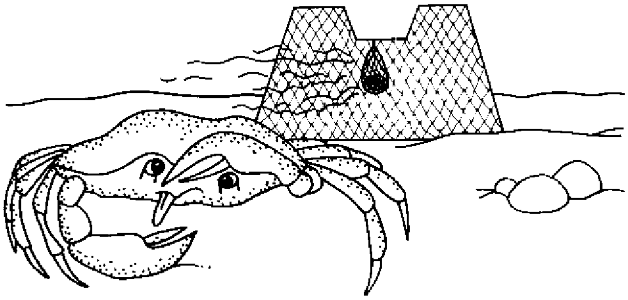

Figure 1. Bait odor can reduce the catch of unwanted species.

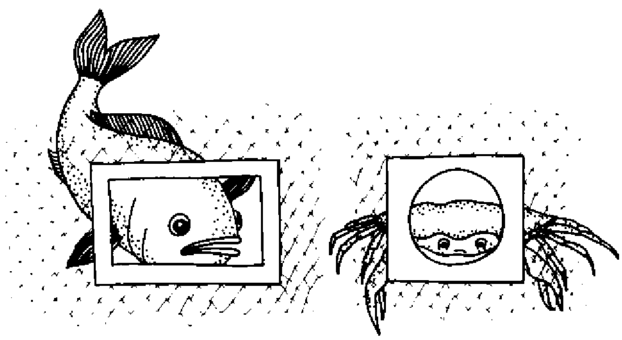

Figure 2. Entrance size and shape can be used to select between animals to be captured and excluded.

Experiments for Fishers

Fishers can conduct experiments to compare the effectiveness of different baits and pot designs (Fig. 6). Steps for conducting an experiment, using the example of comparing catches of crabs in top and side entrance pots are as follows.

1. Write down the question to be answered so it is clear in your mind. Make sure the question is also clear to all crew members, and that they understand their responsibilities in carrying out the experiment. *Example*: Do top-entry pots catch more rock crabs than side-entry pots?

2. Try to keep all the fishing procedures the same except for the modifications being compared. *Example*: Use the same type and amount of bait in both pot types. Fish both pot types in the same day.

3. Don't change the experiment part way through. Other questions always occur to us when we are conducting an experiment, and there is a strong temptation to add a new question. Don't, or you won't get a good answer to either question. (Instead, use a different experiment for each question.) *Example*: Avoid temptations to set some pots for a one-day soak and some for two, to change the bait type, or to set some pots deep and some shallow.

4. Alternate the fishing order of the modifications being compared. *Example*: Before you start, flip a coin. If you get heads, set a top-entry pot first then alternate side, top, side, top, etc.; if you get tails, set the side-entry pot first. If you set your pots in strings, flip a coin to choose the pot type to start each string.

5. Keep careful records. Do not, ever, trust your memory! *Example*: Put all crabs caught in top-entry pots in one box and all those caught in side-entry pots in another box. Label the boxes "top" and "side" so there is no mix up. At the end of the day count (or weigh) all the crabs in each box. It is OK to extend the experiment to a second or third day and add the results, as long as you use an equal number of pots of each type each day.

6. Do a large enough test. Some differences in catch will occur by chance. The test must be large enough to decide whether the difference in catch is caused by the modification to the trap or bait, or to chance. If you repeat the experiment over a few fishing days (and keep careful records), you will get a feel for whether the difference between experimental variables is larger than that due to chance. *Example*: You could find that one day the side-entry pots caught 200 crabs and the top-entry 250. Another day the side-entry might catch 300 crabs and the top-entry 240. With this result you would conclude that the variation in catch was due to chance, not to pot type.

7. The larger the test the smaller the difference will be due to the variable you are testing for, and not just to chance. For data analysis, especially for small differences, you may want to consult someone familiar with statistics. However, if the experiment is conducted using

Table 2. Comparison of catch rates for traps with top and side entrances (reprinted from Miller 1990).

Species	Entrance	Catch/trap	Source
Pandalus platyceros	Long side funnel	5.3	Kessler (1969)
	Medium side funnel w/pipe extension	3.8	
	Short side funnel	2.8	
	Top	1.3	
	Side ramp	0.3	
Pandalus borealis	Side funnel	22.0	Kioke and Ishidoya (1978)
	Top	9.0	
Homarus americanus	Side funnel	1.1	Stasko (1975)
	Top	0	
Cancer irroratus	Side funnel	5.7	Stasko (1975)
	Top	8.1	

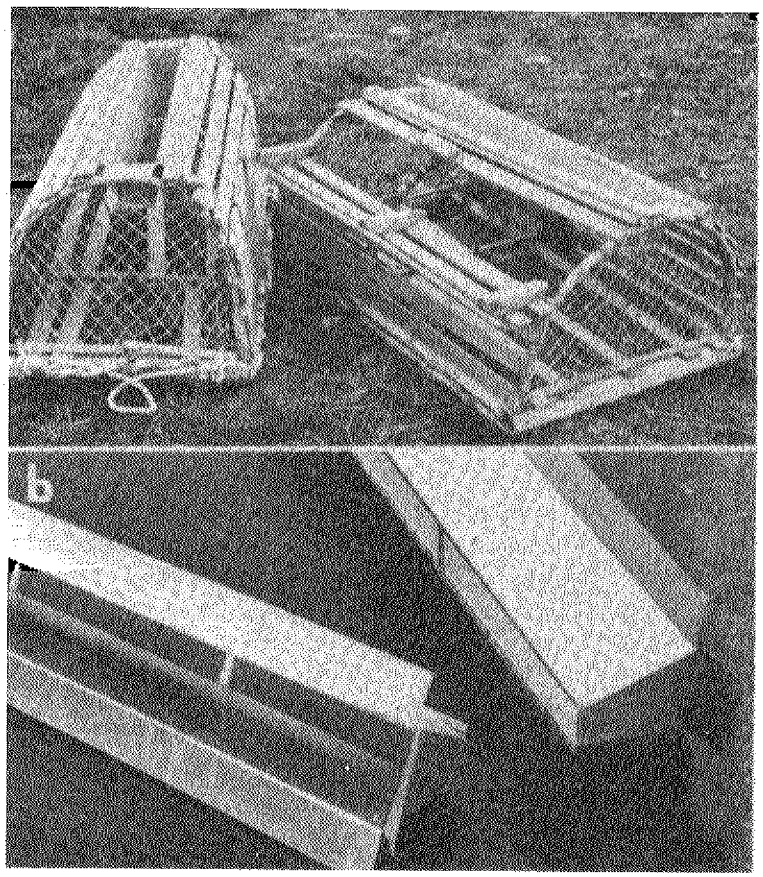

Figure 3. Modification of an American lobster trap to admit rock crab (Cancer irroratus) and exclude lobsters (Homarus americanus). (Source: Stasko 1975).

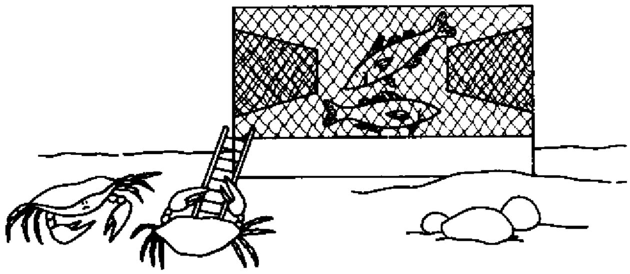

Figure 4. A plastic skirt at the bottom of a trap could be used to exclude crawling species while admitting swimming ones.

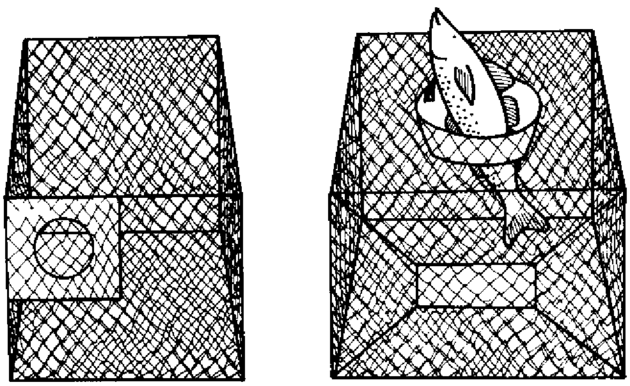

Figure 5. Swimming species can escape through plastic escape gaps whereas crabs and lobsters could not crawl over the plastic to reach the openings.

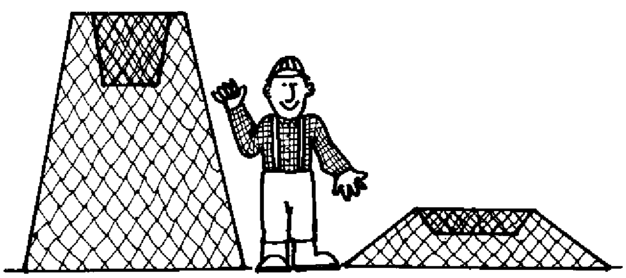

Figure 6. Well conducted experiments can answer fishers' questions about effectiveness of different trap designs.

the above steps, the result is usually clear. (Note to statisticians: please skip the following sentence.) I have found that conducting the experiment properly is more important in answering the question addressed by the experiment than is the data analysis. *Example*: If you want to decide whether top-entry pots do or do not catch at least 50% more crabs than side-entry pots, you need to fish only enough pots to catch about 250 crabs. However, if you want to say that top-entry pots do or do not catch as little as 10% more than side-entry pots, you will need to catch on the order of 3,000 crabs in your experiment. Stated another way, if you are looking only for big differences, you can conduct a small experiment; but if you want to find small differences, you will need a big experiment.

Summary

Traps can be very catch selective. The tools for catch selection are size, shape, location, and construction material for entrances and escape gaps. Bait can be chosen to repel as well as to attract. Deck sorting is effective because the catch is usually uninjured. Fishers can profit from experimentation to test the usefulness of modifications of their own invention, but need to be careful about following the rules for experimentation.

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Selective Groundfish Pots Offer Solutions to Bycatch Problems

Ed Wyman
Neptune Marine Products, 5330 Ballard Ave. NW, Seattle, WA 98107

The pot fishery for Pacific cod in Alaska has developed rapidly over the past six years. During this period, modifications in the design of cod pots have resulted in a gear type that selectively harvests Pacific cod, without a halibut or crab bycatch problem. In addition to being species selective, pots can also be size selective by using the proper web size or escape rings that allow the escape of juvenile fish. These selective features in the Pacific cod pot fishery can be incorporated in other groundfish pots as well. Development of selective flatfish pots may offer a solution to bycatch problems experienced in some existing flatfish fisheries.

The use of pots to catch groundfish is a relatively new gear type that has evolved rapidly over the past 20 years. New pot designs and entrance devices have been developed by innovative fishermen and gear manufacturers to increase catches and reduce the bycatch of non-target species. One of the inherent benefits of pot gear is its ability to be fished in a passive manner that keeps the catch alive until the pot is pulled. This capability has the potential to reduce bycatch mortality for any discards returned to the sea. Modifications have been developed to make pots fish in a selective manner. Pot gear can be modified to be species selective through the use of excluding devices to prevent halibut and crab from entering the pot. Pot gear can also be modified to fish in a size selective manner through the use of web size or escape rings. These modifications allow juvenile fish to escape, and they also allow pot gear to target larger fish. These selective features can be incorporated in groundfish pots for other species in addition to the ones now being targeted. The potential for pot gear to continue its evolution is apparent to those in the industry who fish and build groundfish pots. While the groundfish pot fishery is relatively new compared to existing longline and trawl fisheries, I hope to show that there are some inherent advantages to this method of fishing. I'd also like to offer a glimpse at the potential for future applications of pot gear. Before looking to the future, we need to look at the lessons learned from the past.

The pot fishery for groundfish has not always been without its share of detractors. The two main concerns with pot gear involve the potential waste caused by "ghost fishing" pots, and the preemption of fishing grounds when pots are fished on longlines.

In the late 1970s, the pot fishery for sablefish on the west coast of the United States and Canada started to develop. The introduction of pot gear for sablefish brought the issue of ghost fishing pots to the attention of fishery managers. Ghost fishing pots are pots that continue to fish after they've been lost by fishermen. Ghost fishing pots were recognized as having the potential to cause a waste of valuable fishery resources if not dealt with.

The solution to the problem of ghost fishing pots was easily solved by using a piece of untreated cotton thread incorporated in the pot's web. When the cotton thread degrades and breaks, an escape panel is created that allows trapped fish to escape. The use of cotton thread has been required in various pot fisheries since the early 1980s in Washington, British Columbia, and Alaska.

Currently, the required length of cotton twine is designed to fail in about 30 days. The cotton twine has proven to be effective in reducing the impacts of ghost fishing on both fish and shellfish pots. The only drawback to the use of cotton twine is its unpredictable breaking time.

Another option to prevent ghost fishing pots is the use of Galvanic Timed Releases (GTRs). These underwater timers corrode at a predicable rate and can be visually inspected. In 1992, the state of Alaska legalized the use of 30 day GTRs as an alternative to the unpredictable cotton twine. The 30 day GTR costs more than the cotton twine, but it offers the benefits of being a "time certain" method to open an escape panel, and it is easily inspected every time the pot is pulled. The required use of cotton twine, or GTRs, in all crab and groundfish pots, has greatly diminished the harmful effects of ghost fishing pots.

In the mid 1980s another problem surfaced when a few boats started to longline sablefish pots in southeast Alaska. The problem that surfaced involved the preemption of the fishing grounds by the pot boats that were using heavier gear than the traditional hook and line longline fleet. This preemption of the narrow band of fishing grounds caused an uproar in the traditional longline fleet and in the coastal communities that were adversely affected. The fishing grounds preemption issue was strong enough that the North Pacific Fishery Management Council (NPFMC) passed Amendment 14 which phased out longline pot fishing for sablefish throughout Alaska, with the exception of the Aleutian Islands. The grounds preemption problem had more to do with the way the groundfish pots were fished on longlines rather than the capabilities of pot fishing in general.

The lesson learned concerning grounds preemption by longlined pots was applied to the developing Pacific cod pot fishery. Recognizing that cod pots fished on longlines could create problems for existing gear types, the NPFMC passed regulations in the early 1990s that mandated the Pacific cod pot fishery be conducted using pots fished as singles rather than on longlines. This action greatly reduced the issue of gear conflict involving the cod pot fishery.

The development of the Pacific cod pot fishery probably had its real beginning with the introduction of the cod trigger in the late 1980s. The original cod trigger was used by Bering Sea crab boats to modify pots into cod pots to catch bait for their other pots. These modified crab pots proved to be very effective in catching Pacific cod. In 1988 a few Kodiak-based boats pioneered the directed Pacific cod pot fishery.

With the development of very effective entrance devices, it became evident that the cod pots could certainly catch cod, but it also had the potential to catch halibut. Recognizing this could be a problem to the development of the fishery, I initiated a project in 1989 with the Alaska Fisheries Development Foundation (AFDF) to look for methods to solve the problem. The obvious solution was to break the existing tunnel opening into smaller openings that would exclude most of the halibut, yet allow the cod to enter the pot. AFDF worked with the Alaska Department of Fish and Game (ADF&G) on this project to determine the optimum size of the openings to minimize halibut bycatch. The results of the project proved that halibut could be excluded from cod pots if the pot openings were broken down into smaller openings. The dividers that create these separate openings in a cod pot entrance are called halibut excluders and are made with stainless steel rod or wire. The current regulation adopted by NMFS requires the entrance to have a maximum dimension of 9 inches. This makes a 9×9 inch entrance the legal maximum opening. The results of this gear research project were instrumental in documenting the selective capabilities of cod pots if rigged properly with halibut excluders.

In addition to keeping halibut from entering the pot, the excluders were also effective in keeping most crab out of the cod pots. Any crabs that find their way through the excluders are brought to the surface alive and returned to the sea. Observer reports indicate the crabs were in excellent condition with good chances for survival. Low cost modifications to keep virtually all crab out of groundfish pots are available if the need arises.

The current cod pot fishery in Alaska is split between the Gulf of Alaska and the Bering Sea. The Gulf of Alaska fishery began in 1988 and has continued to grow. The Bering Sea fishery started in the early 1990s. The makeup of the fleet varies considerably between the Gulf of Alaska and the Bering Sea. The vessels in the Gulf are generally smaller than the Bering Sea fleet. The vessels used in the Gulf are representative of the combination boats that have evolved in the past 30 years. Most of the vessels in the Gulf have engaged in numerous fisheries using a variety of gear types. The Gulf has seen big changes in the characteristics of its fisheries over the past 30 years. This forced the fleet to adapt to stay in business. The development of the cod pot fishery is the latest change in the evolving nature of the Gulf of Alaska fleet. The Bering Sea cod pot fleet is mostly composed of crab vessels that engage in the fishery when the crab fisheries are closed. The decline of the crab stocks has prompted many crab boats to start fishing for cod with pots.

In 1992, the NPFMC recognized that the Pacific cod pot fishery was very selective in its pursuit of cod with a minuscule amount of halibut bycatch. The NPFMC exempted the cod pot fishery from the halibut prohibited species catch (PSC) cap for 1992, and has renewed this exemption annually since then. This clean fishing capability has resulted in additional fishing time when other gear types have been shut down for exceeding bycatch caps for PSC species. This action by the NPFMC was one of the first instances where clean gear types were given preferential treatment.

A look at the catch and bycatch statistics for the major gear types in the Bering Sea Pacific cod fishery for 1994 and 1995 (Table 1) will show why the NPFMC granted the exemption to the pot fishery.

It's obvious from these figures in Table 1 that one of the easiest ways to eliminate a good portion of the halibut bycatch would be to limit the Pacific cod fishery to fixed gear participants. In 1995, a fixed gear fishery for Pacific cod would have resulted in a reduction of halibut bycatch of over 3 million pounds.

Certain bycatch issues do not lend themselves to a consensus on what's the best course of action. It's obvious that the Pacific cod fishery in Alaska is one of these. The boats using trawl gear to harvest Pacific cod will certainly object to their preferred fishing gear being excluded from future harvests. I offer the following observation to dispel the notion that these boats will be forced out of the P-cod fishery. The history of vessels taking part in various fisheries of the North Pacific is well known. Crab vessels in the early 1980s converted into trawlers when crab stocks collapsed. Other vessels went from crabbing to longlining. In recent years, we have seen trawlers fishing crab when the situation availed itself. Looking at the history of the vessels engaged in the North Pacific fisheries, we see a fleet of fishing vessels that are capable of changing gear types to suit present economic or political situations. The notion that a crabber is only a crabber and a trawler is only a trawler does not jibe with what has happened in the past. The North Pacific fishing fleet has the capability to convert vessels to change gear types. History and common sense confirm this is a fact.

Table 1. Bering Sea catch and bycatch 1994-1995 (in metric tons).

Gear type	Cod catch	Halibut mortality	Ratio of cod to halibut
	1995 (to 9/95)		
Trawl	113,060	1,489	75 mt : 1
Longline	89,479	482	185 : 1
Pot	17,823	7	2,546 : 1
	1994		
Trawl	96,921	1,262	77 : 1
Longline	102,984	891	116 : 1
Pot	8,453	2	4,226 : 1

As mentioned previously, some bycatch solutions don't lend themselves to gathering a consensus among competing gear groups. Some of these bycatch solutions come down to the basic allocation issue, a political issue of who gets the fish. Fixed gear has shown the ability to harvest the Pacific cod resource in a selective manner with a minimal amount of impact on the ocean bottom and other species. This selective capability should be recognized by those making fisheries policy. Rather than calling this a preferential allocation issue, it should be referred to as being a preferential management issue that recognizes the benefits of selectively harvesting a target species using gear types that minimize the bycatch of PSC species.

The cod pot fishery does have some bycatch of nontarget species. One of the most common bycatch species is octopus. Since there is no directed fishery for octopus at this time, the bycatch of this species does not present a problem. The other species caught in cod pots are various flatfish species such as yellowfin sole or rock sole. While the amount of flatfish bycatch is not substantial, it does show that pots have the capability to catch flatfish. We know from the past that pots were capable of catching halibut prior to the addition of the halibut excluders. In addition to observer reports, I've also heard from fishermen that sometimes they would have substantial amounts of yellowfin sole in their cod pots. This prompted me to think that there might be another application for groundfish pots.

While I'm not about to suggest that we will see trawlers shooting strings of flatfish pots off their stern ramps any time soon, I do think that the passive fishing capabilities of pots might have the potential to harvest certain species with less bycatch and discard mortality than current harvesting methods. The logic behind my thoughts is based on the fact that pots can be rigged to fish selectively in a nonlethal manner. This capability allows undersized fish, or fish of the wrong sex or species, to be released unharmed after the pot is hauled. While it is always better to avoid nontarget species, releasing them unharmed is preferred to fishing methods that are lethal to unwanted species or sizes. In order to prove that a pot fishery for flatfish is viable, we need to show more than its ability to catch the odd flatfish or two. We need to show that sufficient quantities can be caught to make it worthwhile.

Over the past 2 years, I have been working with gear researcher Chris Bublitz at the Fishery Industrial Technical Center in Kodiak. We have attempted to get funding to test our idea that flatfish pots might be feasible, only to be shot down twice. Reviewers cited the previous problems with ghost fishing pots and grounds preemption concerns as some of the reasons for turning down the funding request. Political resistance from established user groups certainly didn't help in getting a positive review for our project.

We finally received a limited amount of funds on our third attempt to look at the feasibility of flatfish pots. Initial fishing trials will be conducted in November around Kodiak. We will be using a variety of experimental pot designs donated by industry. Each one of these pots will be fished for a limited amount of time using an underwater video system to observe the interaction between the fish and the pot. We will also be trying out various baits during our trials. If our initial project shows positive results, we will pursue additional funds to engage in a comprehensive test looking at ways to increase the catch and reduce any future bycatch problems.

Just because we prove that we can catch flatfish with pots, it doesn't mean that it will create a new pot fishery. There are several obstacles to the development of a flatfish pot fishery. The main obstacles can probably be classified as economic obstacles and political obstacles.

In order for the flatfish pot fishery to be economically feasible, it has to make money for those involved. The low price for a number of flatfish species means that adequate volumes must be caught to generate enough income to justify the fishery. Will the pots catch enough to make it worthwhile at today's prices? Will the price always be this low? These are questions that need to be asked. Nobody can provide the answer to the first question until we conduct our fishing trials. The future price for flatfish is also unknown. Any future shortage in the worldwide supply of such fishery products will obviously have a positive effect on the value of Alaskan flatfish prices. There is a somewhat finite supply of whitefish available in the world, and demand continues to increase. This is one of the big unknowns in looking at the economics of a flatfish pot fishery.

The other obstacle to the development of a flatfish pot fishery is classified as political. The existing flatfish fishery is conducted using bottom trawls. I would really be surprised if the trawl industry were to support such a project, much less a fishery, that competed with their gear of choice. A number of trawl flatfish fisheries are restrained by the bycatch of prohibited species such as halibut or crab. I suggest that after the trawl fishery is shut down, a flatfish pot fishery could commence. I think that fishing the pots on longlines would increase the productivity of such a fishery. This might seem to be a contradiction to my previous statements about the preemption of the fishing grounds by longlined pots, but after trawl fishing is closed, it is unlikely that there would be any competing gear types on the same fishing grounds. Longline fishermen who fish the same gear type, such as hook and line longliners!, are usually capable of communicating with other fishermen about the location of their string of gear. This avoids a majority of the gear conflicts that occur when competing gear types try to fish the same grounds.

The previous scenario might seem a little far fetched to those who engage in the trawl fishery for flatfish. To those that doubt even the most remote possibility of this occurring, I would like to ask you to step out of your perception of the world in its present state, and look at the amount of change that has occurred in the North Pacific fisheries over the past 20 years. Twenty years ago, the "Americanization" of the North Pacific's groundfish fisheries was just a dream; today it is a reality. Ten years ago, the development of a longline fishery for cod that selectively harvests half of the cod quota would have seemed far-fetched to most people in the industry; today it is a reality. Five years ago, the development of a selective pot fishery for Pacific cod seemed farfetched to even optimists like myself; today it's a growing reality. The changes of the past 20 years will probably seem mild when compared to the changes between 1995 and the year 2015.

Just as much as change is a constant in life, change and innovation in the fishing industry should also be acknowledged as a constant. I hope that fishery managers and policy makers will recognize that future fisheries management should allow for the expansion of gear types that show a capability, and ability, to be more selective in their pursuit of fishery resources.

Bycatch in the United States and Canadian Sea Scallop Fisheries

William D. DuPaul, Jeffrey C. Brust, and James E. Kirkley
Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA 23062

Scallop dredges used by fishermen on the U.S. and Canadian East Coast and in Alaska are large, heavy, and unforgiving as a fishing gear with relatively poor species-specific and size selectivity. Bycatch issues in the U.S. scallop fishery can be characterized as the harvest of undersized or juvenile scallops, the harvest of finfish that are either retained or discarded, the harvest of miscellaneous invertebrates some of which are retained, and the collateral damage to all bycatch animals resulting from either contact with the gear or from handling and exposure on deck. Significant reductions in the harvest of juvenile scallops, or discards, have been achieved by increasing scallop dredge ring sizes and by reducing or omitting chaffing gear. However, collateral damage to discards resulting from the handling of the scallop dredge, culling, and deck operations can exceed 10%. The bycatch of finfish by scallop dredges can be significant and can pose serious problems if retention is not allowed or desirable since mortality rates are high. Dredge rings ranging in size from 3.0 to 4.0 inches (76.2-101.6 mm) are not conducive to the escapement of juvenile fish. Research to determine the effectiveness of scallop dredge modifications for the escapement of finfish has been limited. Modest success in finfish escapement has been reported by changing the mesh of the dredge twine top. The bycatch of crustaceans and other invertebrates by scallop dredges has been documented for the Alaskan scallop fishery, but little has been done elsewhere. Quantities of bottom debris and substrate are often retained in the dredge bag along with bottom dwelling invertebrates. Potential solutions to scallop dredge bycatch include increasing dredge ring sizes, reducing chaffing gear, modifications in dredge design, changes in fishing strategies, and educational programs for the fishermen.

The sea scallop (*Placopecten magellanicus*), supports a large and valuable commercial fishery throughout much of its distribution in the Exclusive Economic Zone (EEZ) of both the United States and Canada. It is found in commercial quantities from Belle Isle, Newfoundland to near Cape Hatteras, North Carolina (MacKenzie et al. 1978). U.S. scallop meat landings for 1991-1993 totaled 33,301 mt valued at U.S. $427.1 million (New England Fishery Management Council 1995); Canadian landings for 1992-1994 totaled 21,664 mt valued at Can. $312.1 million (Pers. comm., C.G. Cooper, Department of Fisheries and Oceans, Sept. 1995).

Sea scallops are primarily harvested by dredges or drags which are towed across the bottom at speeds ranging from 4.0 to 5.5 knots. In the process of harvesting scallops, the dredges also capture a variety of finfish and invertebrates as bycatch. Unfortunately, dredges inherently have poor selection characteristics (Bourne 1966). Bycatch in the sea scallop dredge fishery can be significant in terms of quantity and landed value.

National Marine Fisheries Service (NMFS) data for 1991-1993 indicate that over 23,192 mt (whole weight) of finfish and invertebrates were landed as bycatch by the U.S. scallop dredge fishery. There is virtually no available information on the amount of bycatch discarded at sea. Recent changes in groundfish management strategies in the United States and Canada have focused considerable attention on bycatch in the scallop fishery. One concern is simply an allocation issue between the scallop dredge fishery and the groundfish trawl fishery; another is more of a conservation issue concerned with the mortality of finfish discards.

Attention, however, has increasingly focused on the harvest and potential for significant discard mortalities of small or juvenile sea scallops. The growth of scallops through age 5 is typically very rapid with gains in meat weight in excess of 200% between ages 2 and 4. The harvesting of small scallops is of substantial concern to management authorities because of the lost economic opportunities and the reduction of potential spawning stock biomass.

Issues surrounding the harvest and/or discarding of small scallops have been mostly addressed by an evaluation of larger scallop dredge rings as a conservation measure (Medcof 1952, Bourne 1966, DuPaul et al. 1989, DuPaul and Kirkley 1994, Brust et al. 1995). Researchers have generally concluded that larger dredge rings offer a partial solution to the problem of the unintentional harvest of small or unwanted scallops.

In this paper, we present preliminary analysis of bycatch of finfish, invertebrates, and juvenile scallops in the dredge fishery. We initially explore sources of bycatch mortality. Subsequently, we discuss possible options for reducing bycatch in the scallop fishery. Our analyses and observations are based on information obtained from several at sea experiments conducted between 1987 and 1995.

The Standard Scallop Dredge

The most common gear in use for the offshore scallop fishery is the "New Bedford type" dredge or drag. This gear has been described in detail by Bourne (1965) and Posgay (1957). The standard dredge is constructed with a heavy metal frame from 12-17 ft. (3.7-5.2 m) in width (Fig. 1). Attached to the dredge frame is a bag constructed of steel rings joined together by chain links. The top of the bag is fitted with a twine top or rope back.

As of March 1994, U.S. regulations for the northwest Atlantic sea scallop fishery restricted the total width, or combined width of two dredges, to 30 ft. (9.1 m). Additional regulations also limited the mesh size of the twine top to a minimum of 5.5 in. (139 mm) and ring size internal diameter to 3.25 in. (82.6 mm). Prior to March 1994, there were no restrictions on dredge width but ring sizes could not be smaller than 3.0 in. (76.2 mm). Effective January 1996, the minimum ring size allowed in the U.S. northwest Atlantic sea scallop fishery is 3.50 inches (88.9 mm). Canadian scallop dredges are constructed with 3.0 in. (76.2 mm) rings.

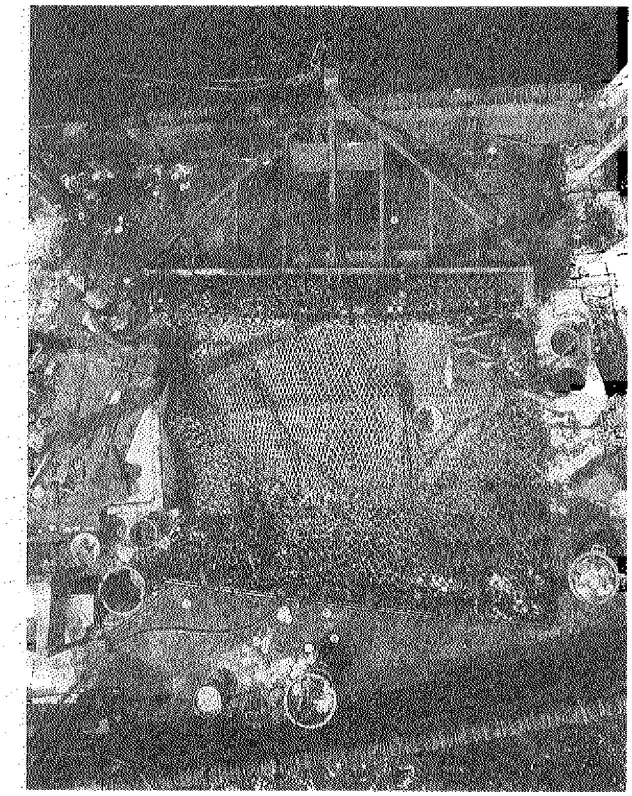

Figure 1. Standard sea scallop dredge with sweep chain and rubber chaffing gear on bottom portion of bag. Modifications for hard fishing include the use of rock chains in the mouth of the bag.

Bycatch of Undersized Scallops

The unintentional harvest of undersized scallops as bycatch is problematic for most scallop dredge configurations. If there are small scallops in the population, there will be some retention by most commercial dredges. Retention of small scallops is more pronounced when there is an unusually large pre-recruit year class. Retention may also increase in areas with substantial quantities of shells, sand dollars, starfish, and crabs. In general, particular characteristics of the scallop fishery such as vessel size and power, bottom type, and spatial distribution of the scallops influence the performance and selectivity of the gear.

In the mid-Atlantic resource area during the latter part of 1993, large numbers of sea scallops from the strong 1990 year class were retained by 3 in. (76.2 mm) ring scallop dredges and subsequently discarded because they were too small to comply with the prevailing fishery regulations. Ninety percent of the scallops harvested in this resource area were 70 mm or less; of the remaining 10%, those greater than 70 mm were retained for shucking.

Based on research data obtained from 42 tows comparing 3 in. (76.2 mm) and 3.25 in. (82.6 mm) rings in the mid-Atlantic in November 1993, it was observed that 154,538 scallop discards were harvested with the 76.2 mm ring dredge and 84,592 were harvested with the 82.6 mm ring dredge. The 82.6 mm ring dredge reduced the harvest of small scallops by 45% (Fig. 2). If relative efficiency ratios for the 88.9 mm ring dredge were applied to these resource conditions, scallop discards would have been reduced to 50,306, a 67% reduction in scallop discards.

Irrespective of the particular aspects of the numerous studies on scallop gear selectivity, all reach a similar conclusion. As ring or mesh size increases, the escapement of smaller scallops increases. Consequently, changes in ring or mesh size have been used as a regulatory strategy to advance the age of scallops at first capture. For this purpose, minimum ring size regulations can be accompanied by minimum shell size or maximum meat count restrictions.

Size selectivity and subsequent quantities of discards, however, are not only based on gear characteristics. Selection or culling practices of the crew may also have important ramifications for the size and quantity of discards. During several gear experiments, it was observed that culling practices varied with the size and quantity of other scallops harvested, crew size, prices received, and production costs. Changes in gear characteristics, thus, offer only a partial solution to the problem of harvesting and discarding small scallops.

Brust et al. (1995) conducted an evaluation of 82.6 mm and 88.9 mm ring dredges in response to the scallop gear changes scheduled in Amendment 4 of the Sea Scallop Fishery Management Plan (SSFMP). During 1994-1995, four commercial scallop trips were made in the mid-Atlantic region to evaluate the selectivity of 82.6 mm and 88.9 mm ring dredges. Data from 209 of 781 paired tows revealed that a total of 57,592 undersized scallops were left on deck as discards by the crew; 35,918 from the 82.6 mm ring dredge and 21,674 from the 88.9 mm ring dredge (Fig. 3).

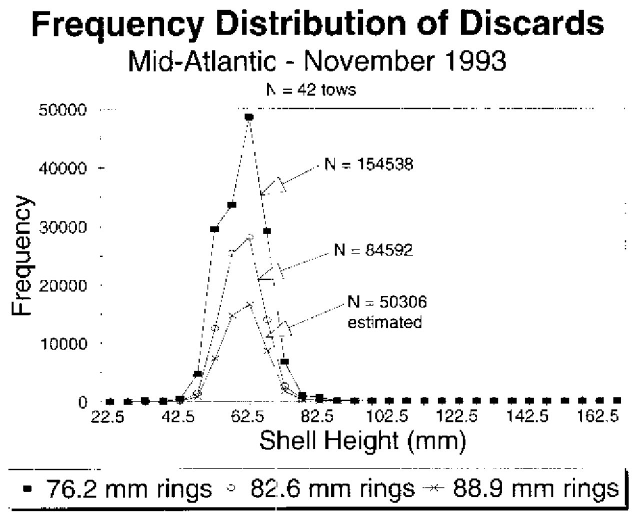

Figure 2. *Size frequency of sea scallop discards during November 1993 in the mid-Atlantic region (Del-Mar-Va) for three dredge ring sizes. Data for 88.9 mm rings were estimated using efficiency ratios derived from gear trials conducted in 1988 and 1994-1995.*

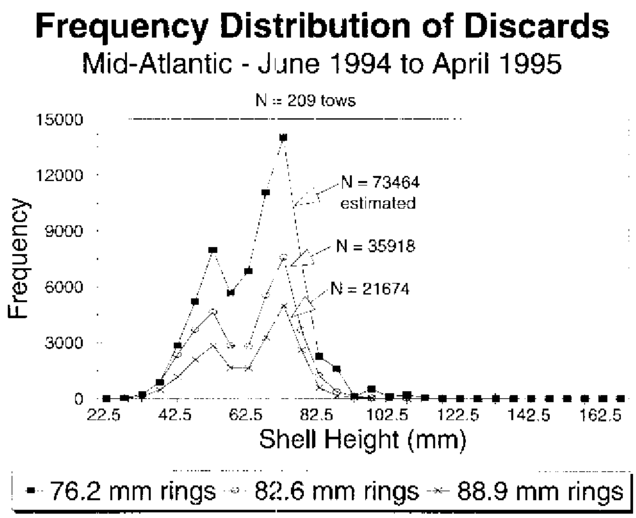

Figure 3. *Size frequency distribution of sea scallop discards during four commercial trips from June 1994 to April 1995 in the mid-Atlantic region (Del-Mar-Va) for three dredge ring sizes. Data for 76.2 mm rings were estimated using efficiency ratios derived from gear trials conducted in 1988 and 1993.*

The size distribution of scallops in the resource area had changed significantly since November of 1993. From June 1994 through April 1995, there were always 2 or 3 year classes present in the population. By April 1995, scallops in the 1990 year class had grown to 90-95 mm and the 1991 year class, 75-80 mm; only 13% of the harvested scallops were less than 70 mm. If we apply efficiency ratios for the pre-Amendment 4 dredge with 76.2 mm rings and chaffing gear to this particular data set, the number of discards would be 73,464, 35,918 and 21,674, respectively. Consequently, it can be concluded that increasing ring size can significantly decrease the number of scallops discarded as bycatch even with favorable resource conditions.

In the context of bycatch as currently defined, the harvest of small scallops is a consideration only if they are discarded by the crew. The primary problem and concern is the mortality associated with harvesting and the practices associated with culling and discarding.

Changes in Culling Practices

As mentioned before, the culling of retainable scallops by the crew has a significant influence on the number and size of discarded scallops. This selection process is not necessarily influenced by regulatory constraints. Amendment 4 does not restrict the size of scallop meats which is the predominant product form of the dredge fishery. In the Canadian fishery, however, a maximum meat count per kg is currently enforced. A ring size constraint, as an age of entry control, is thus only partially successful in reducing the harvest of undersized scallops because of the poor selectivity characteristics of the dredge.

An increase in dredge ring size, however, can be successful in reducing fishing mortality in strong incoming year classes, and extend the age composition in the fishery until a year class is fully recruited by the gear with larger rings (Brust et al. 1995). Size frequency distribution of scallops in commercial catches from June 1994 through April 1995 indicate that the 1990 year class continued to be a major portion of the catch. As a result, the size of scallops in the catch, and those retained by the crew, showed progressive increases in size. At the same time, the size at which 50% of the scallops were retained (or discarded) increased from 60-65 mm to 75-80 mm (Fig. 4). These data indicate that the change in ring size from 80.6 to 88.9 mm not only changed

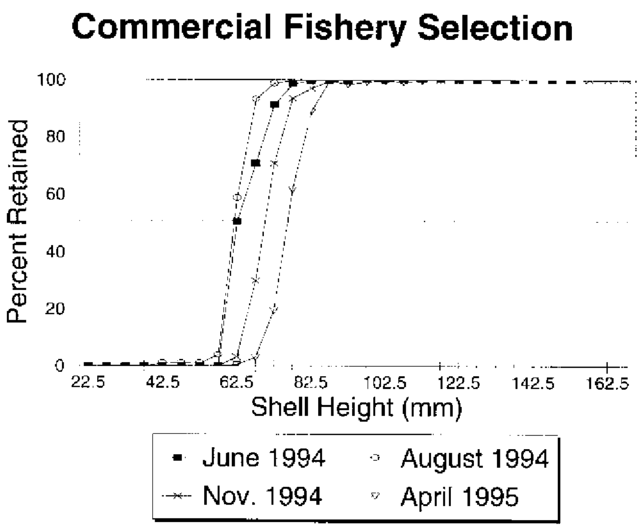

Figure 4. Size distribution of sea scallops retained by crew for four commercial trips in the mid-Atlantic region (Del-Mar-Va). There were no significant differences in crew selection between 88.9 and 82.6 mm ring dredges. Size at 50% retention were significantly different for August 1994 and April 1995.

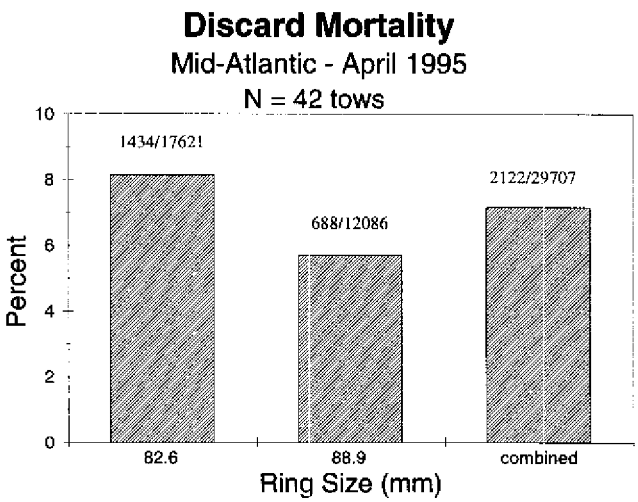

Figure 5. Sea scallop discard mortalities observed for 82.6 and 88.9 mm dredge rings. Quantity harvested and percent mortality for the 88.9 mm ring dredge were substantially lower.

the scallop size composition in the catch over time, but in turn changed the size composition of scallops discarded by the crew.

Discard Mortality

When small or undersized scallops are harvested, they are discarded after the catch has been culled for larger, retainable scallops. Scallop discards can be damaged during the process of emptying the dredge, culling the catch, and shoveling (or kicking) the trash and unwanted scallops overboard. Medcof and Bourne (1964) recognized that discard mortality, under certain conditions, could exceed 20%.

Data obtained from 42 tows indicate that in the process of emptying the dredge and culling the catch, 7.3% of the discards were fatally damaged (separated shells, broken shells, exposed mantle, crushed scallops; Fig. 5). The percentage of fatally damaged discards was less for the 88.9 mm ring dredge than for to the 82.6 mm ring dredge, 5.4% and 8.1% respectively. The advantage of the larger scallop dredge rings is compounded both by the decrease in the overall numbers of discards and the decrease in discard mortality.

Finfish Bycatch

Finfish, and some commercially valuable invertebrates such as crabs and lobsters, are often harvested as bycatch in the sea scallop dredge fishery. U.S. summary data for 1991-1993 bycatch species, in terms of landings and revenue, indicates that monkfish (*Lophius americanus*), yellowtail flounder, (*Pleuronectes ferrugineus*) and winter flounder, (*Pleuronectes americanus*) were most common (Table 1).

Total landings of bycatch for the period was over 51 million pounds (23,181 mt) valued at $28.7 million, or nearly 7% of sea scallop revenue. Although the reported revenue from bycatch appears minor, it can be considered important especially during certain times of the year and when scallop abundance is low.

Retained bycatch of finfish in the Canadian scallop fishery for 1992-1994 totaled 2400 mt with monkfish, cod (*Gadus morhua*), and winter flounder comprising most of the bycatch (Table 2). The amount of bycatch for the Canadian fishery was significantly less than the U.S. totals. This may be due to fewer vessel days at sea and fishing company policies with regard to finfish bycatch being retained or discarded.

Table 1. Bycatch landings and ex-vessel value for U.S. sea scallop dredge vessels, 1991-1993.

Species	Catch (kgs.)	Revenue ($)	% Scallop Revenue
Scallops	33,301,542	427,071,875	
Monkfish	18,880,112 *	17,528,659 **	4.1
Cod	258,480	506,195	0.1
Summer Fl.	571,268	1,842,215	0.4
Yellowtail Fl.	1,473,677	4,225,889	1.0
Winter Fl.	911,839	2,409,555	0.6
Other Fl.	550,720	1,455,289	0.3
Other species	545,720	771,553	0.2
TOTAL	23,192,380	28,739,355	6.7

* Whole weight, ** Tails

NMFS data summarzied by the New England Fishery Management Council (A. Applegate, Pers. comm.)

Table 2. Bycatch landings for Canadian sea scallop dredge vessels, 1992-1994.

Species	Catch (kgs)	Revenue (C$)
Scallops	21,664,000	$312,081,000
Monkfish	1,568,106 *	—
Yellowtail Fl.	88,448	—
Winter Fl.	96,650	—
Cod	256,858	—
Other	384,837	—
TOTAL	2,400,618	—

* Whole weight

Department of Fisheries and Oceans Canada (C.G. Cooper, Pers. comm.)

For both the U.S. and Canadian sea scallop fisheries, little information is available on discarded bycatch of undersized finfish, damaged lobsters, crabs, and other invertebrates. More important, there is virtually no information relative to the mortality/survival rates of discarded bycatch. Most individuals who are familiar with the fishery indicate that mortality rates could be very high. Animals are often damaged in handling the dredge, when the catch is culled for retainable scallops and bycatch, and in the process of shoveling sand, shells, rocks, and unwanted animals overboard.

The disposition of monkfish was examined during one commercial trip in the southern New England/mid-Atlantic region (Fig. 6). Analysis of data from 49 of 176 tows indicates that the culling size of monkfish was about 380 mm total length. It was observed that out of 1,321 monkfish harvested, 1,047 were discarded (Carnegie and DuPaul 1995). On a cautionary note, it must be recognized that monkfish distribution, both in size and numbers, is greatly influenced by season and geography. However, this data was obtained on traditional scallop fishing grounds with significant fishing vessel activity.

Reduction of Finfish Bycatch

There has been little published on methods for reducing finfish bycatch in the sea scallop dredge fishery. Research will begin soon in the U.S. to evaluate gear modifications in an attempt to reduce bycatch. In Canada, gear modifications to reduce bycatch have been tested by the scallop industry with some modest success (Pers. comm., C.G. Cooper, Department of Fisheries and Oceans, Canada, Sept. 1995).

The Canadian work found that the use of large square mesh in the twine top resulted in a decrease in the catch of roundfish (cod, haddock) but not in flatfish (winter flounder, yellowtail flounder). Windows, or open squares, in the back of the twine top and tickler chains attached to the forward frame of the dredge resulted in similar decreases in the catch of roundfish by approximately 25%. Dredge modifications to reduce the harvest of flatfish may be problematic; it is clearly an area of needed research.

While a modest but welcomed reduction of cod and haddock has been achieved, questions remain about strategies to reduce the bycatch of small and undersized monkfish and flatfish. Bycatch mortality of discarded fish appears to be high as many small monkfish and flatfish are dead by the time they are discarded overboard. Additional research is needed to evaluate gear modifications and changes in fishing strategies to reduce finfish bycatch mortalities

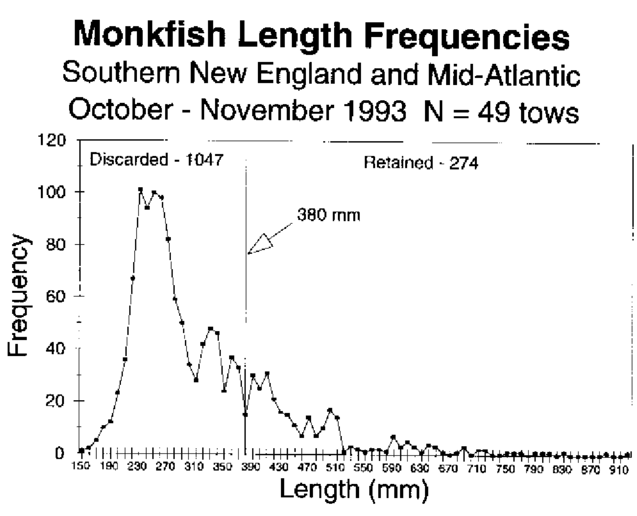

Figure 6. *Size frequency distribution of monkfish (Lophius americanus) harvested by a commercial sea scallop dredge vessel in the southern New England / mid-Atlantic region, November 1993. Data is from 49 of 176 tows. Culling size was determined to be approximately 380 mm total length (Carnegie and DuPaul 1995).*

Deck Management

Another potentially important, but undocumented source of discard mortality is poor deck management. Finfish, scallops, crabs, and other invertebrates are often left on deck for extended periods of time after the catch has been culled. When this occurs, mortality occurs either because of prolonged absence from the water or damage inflicted by the crew while working. Immediate steps could be taken to discard live, but unwanted, animals overboard. In addition, fish, undersized scallops, and crabs should not be left on deck between haul-backs. With very modest effort, the crew could minimize discard mortality by cleaning the deck of the vessel immediately after culling retainable scallops. Although deck management may or may not make a significant difference in discard mortality rates, it is something the crew could accomplish with minimal effort.

Acknowledgments

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Management of Alaskan Longline Fisheries to Reduce Halibut Bycatch Mortality

Robert J. Trumble
International Pacific Halibut Commission, P.O. Box 95009, Seattle, WA 98145

Longline fisheries targeting groundfish in Alaskan waters have effectively reduced mortality of Pacific halibut discarded as bycatch, and have diminished the threat of early fishery closures caused by reaching limits on bycatch mortality. Mortality reductions resulted from lower bycatch rates, lower mortality rates of discarded halibut, and converting an open access fishery to individual quotas which allowed for halibut retention. Success resulted from a strong cooperation among management agencies and the industry, and from recognition by the industry that halibut bycatch mortality reduction was in their best interest. In some cases, benefits were delayed until fishermen learned to adapt their fishing practices to the regulations. The basis for the bycatch estimates and confirmation of the successes is data collected by on-board observers, one of the key ingredients in the bycatch reduction program.

The commercial fishery for Pacific halibut began off the north Washington coast in 1888 from sailing schooners deploying dories (Bell 1983, Trumble et al. 1993). Handlining from dories gave way to longlining, which became the standard gear for the fishery. The U.S. and Canada ratified a treaty in 1923 that established the International Fisheries Commission (later changed to the International Pacific Halibut Commission [IPHC]), charged with managing the halibut resource for the two countries. The treaty has been modified several times, most recently in 1979 (McCaughran and Hoag 1992). In 1943, the IPHC banned nets from the fishery, leaving hook and line as the only legal gear. Regulations required all halibut caught with other gear or out of season to be discarded.

Few halibut were caught by any gear other than domestic longline until the foreign fleets started fishing in the northeast Pacific off U.S. and Canada during the late 1950s and early 1960s. The foreign fleets, and later the joint venture and domestic fleets, caught halibut (and other species) incidentally in their groundfish and shellfish fisheries (Williams et al. 1987). Bilateral negotiations with the foreign countries to control and reduce halibut bycatch and subsequent North Pacific Fishery Management Council (NPFMC) rulings established a mosaic of time-area closures for trawl and longline fishing operations (Fredin 1987, Trumble 1992). In 1981, the NPFMC required all foreign nations fishing in the U.S. zone off Alaska to reduce bycatch rates by 50% over 5 years.

NPFMC mandates in the early 1980s drove the foreign-dominated halibut bycatch mortality in 1985 to the lowest recent level (Fig. 1). As the domestic groundfish fisheries replaced foreign and joint venture fisheries, the halibut bycatch mortality increased to levels comparable to the early 1980s. Bycatch mortality from the Americanized groundfish fleet increased for two primary reasons: initially, the developing domestic fleets were spared the bycatch restrictions imposed on the foreign and joint venture fleets to help Americanization; and as the fleets grew, overcapitalization in the open access fishery caused a competitive race for fish which led individuals to increase their catch rates, even though higher harvest costs and higher bycatch resulted.

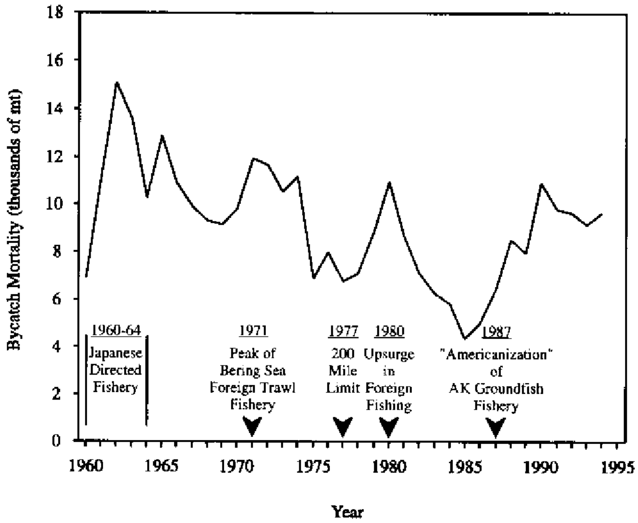

Figure 1. Pacific halibut bycatch mortality from 1960 through 1994.

To control the amount of halibut bycatch mortality, the NPFMC established limits on the bycatch of several species in the groundfish fisheries, and closed groundfish fisheries that exceeded limits (Wilson and Weeks, In press). The NPFMC first placed domestic groundfish fisheries under bycatch limits in 1986 (Sadorus 1994), but the limits became most effective after 1990 when the domestic observer program began. The hook and line fishery in Alaska is dominated by longlines, but also includes jig and handline gear. The initial limits were set as actual bycatch, but later changed to bycatch mortality to reflect the survival of discarded halibut. The NPFMC also allocated the limits among areas, fisheries, and in some cases, seasons.

Bycatch in the Alaskan groundfish fisheries is a lose-lose proposition for both the groundfish fisheries that cause bycatch mortality and the fisheries that target the species caught as bycatch. Bycatch limits for king and Tanner crab, salmon, and herring, in addition to halibut, often close various groundfish fisheries before the total allowable catch (TAC) is reached or force the fisheries to less productive areas. Thousands of metric tons and millions of dollars worth of groundfish go unharvested, and harvesting costs go up because of bycatch. The IPHC subtracts the amount of halibut bycatch mortality, on the order of 10,000 mt annually, from the commercial halibut fishery quota, and lost growth of the largely sublegal halibut causes additional lost yield to the halibut fishery (Sullivan et al. 1994). Bycatch mortality represented 19% of the 1994 halibut TAC, and was equal to 29% of the commercial harvest. Both halibut and groundfish fisheries would benefit with more harvest and less costs from reductions in halibut bycatch mortality.

Individual fishermen in Alaska have a difficult time reducing their bycatch or bycatch mortality, even though they and the fleet would benefit in the long run. The open access groundfish fishery in Alaska greatly increases the cost of bycatch reduction because of competition in an overcapitalized fleet. Each individual must catch as much as possible before the target quota is taken. Any actions taken by individuals that slow down fishing success, such as changes that decrease bycatch, penalize those individuals relative to others who do not try to reduce bycatch. Effective management actions must apply to all fishermen, and are best if the fishermen support them. Fishermen will circumvent regulations that they do not support. Better yet, the management actions will provide incentives for individual fishermen to act in a way that their individual best interests are the same as society's interests. So far in Alaska, several fleet-wide actions for the longline fleet have resulted in reduced bycatch, but individual incentives are well over the horizon.

Bycatch Mortality

Bycatch mortality has two components: the actual bycatch, and the mortality rate of the discarded fish (discard mortality rate). In the NPFMC area, halibut bycatch mortality reductions are approached in two ways: (1) reduce the bycatch rate by decreasing the encounter rate between fishing gear and halibut or by increasing selectivity of the gear, and (2) reduce the discard mortality rate of discarded halibut. Although halibut are widespread, they are not uniformly distributed, and bycatch rates may change over time and area (Adlerstein 1994). Behavioral differences between halibut and other species provide an opportunity for improving gear selectivity. Halibut is a very hardy fish and survives capture and discard to the sea, if treated moderately well. Halibut has no swim bladder to inflate, scales buried in the skin are difficult to dislodge, and the body is strong and muscular. In the case of hook and line fisheries for groundfish, potential survival of discarded halibut is very high. Circle hooks and semicircle hooks used by the majority of hook and line fishermen catch halibut in the mouth, and cause little inherent damage. However, inappropriate release methods cause severe wounds that lead to higher probability of death (Kaimmer 1994).

Both bycatch rates and discard mortality rates are estimated for most Alaskan fisheries from observer data. Species composition of the catch provides the bycatch rates (weight of halibut per weight of groundfish), and tallies of condition factors (excellent, poor, and dead, each with an estimated survival) convert to discard mortality rates. Since 1990, the NPFMC has required industry-financed, mandatory observers for the domestic fisheries. Vessels longer than 125 feet must carry observers 100% of the time, vessels from 60 to 125 feet must carry observers 30% of the time, and smaller vessels carry observers only on demand. Observer data for foreign and joint venture fisheries date back to the 1960s, first voluntary under bilateral negotiations, and then required by NPFMC rules.

The majority of groundfish fishing off Alaska occurs by trawling, and most of the bycatch mortality limits are allocated to the trawl fisheries. Hook and line fishing has caused around 15-30% of the total halibut bycatch mortality by groundfish fisheries in Alaskan waters (Table 1). Small additional bycatch mortality occurs in the shellfish fisheries. The total halibut bycatch mortality in the hook and line fisheries in Alaska since the domestic observer program began in 1990 increased through 1992 before declining in 1993 and 1994 (Table 2). In the Bering Sea, the Pacific cod fishery has dominated the landings of the hook and line fishery (NPFMC 1994). The Pacific cod fishery in the Bering Sea started small, and the hook and line fishery caused only 263 mt of halibut mortality in 1990. The fishery grew over the succeeding years with new vessels entering the fishery, but the actual harvest fluctuated as the hook and line fishery competed with the trawl fishery for Pacific cod. In 1992, the trawl fishery reached its halibut bycatch limit and left Pacific cod accessible for hook and line. As a result of more hook and line fishing effort, the mortality of halibut bycatch peaked at 1,357 mt. In 1993, on the other hand, the trawl fishery did not reach its halibut bycatch limit, and caught more Pacific cod. Consequently, little Pacific cod remained for the hook and line gear, and the mortality of halibut bycatch from hook and line decreased to 550 mt. In 1994 the hook and line fishery received additional Pacific cod because the trawl fishery reached its halibut bycatch limit. Allocation of Pacific cod among gears in 1994 should stabilize future hook and line harvest, and should reduce fluctuations of halibut bycatch. The hook and line fishery in the Gulf of Alaska mainly harvests sablefish, which is the main source of hook and line halibut bycatch mortality in this area.

Management and Industry Actions

Mortality Limits

The halibut bycatch mortality limits are fixed in the Bering Sea/Aleutian Islands (BSAI) Groundfish Fishery Management Plan, while the Gulf of Alaska (GOA) mortality limits may be adjusted year to year. The NPFMC allocates the mortality limit among various fisheries (Table 3), and by season for some fisheries. The initial hook and line bycatch mortality limit for the Gulf of Alaska was set at 750 mt in 1990, and that level continued through 1994. Sablefish has been the dominant species caught. In recent years, the fast-paced sablefish fishery occurred more quickly than its monitoring. The hook and line fishery exceeded its halibut bycatch mortality limit before the fishery could be closed from 1990 through 1993. Halibut bycatch mortality reached 998 mt in 1990, 832 mt in 1991, 851 mt in 1992, and 1,284 mt in 1993. Only in 1994 did the halibut bycatch mortality stay within the limit.

The NPFMC first applied a 750 mt bycatch mortality limit for the combined hook and line and pot fisheries in the BSAI in 1992, but implementation did not occur until October. By that time, bycatch mortality reached 1,357 mt. In 1993 and subsequent years, the NPFMC set a 900 mt limit for hook and line only, and exempted pots. Pacific cod dominates the longline fishery in the Bering Sea area, and most of the bycatch mortality limit is allocated to that fishery, 680 mt in 1993, 725 mt in 1994 and 1995.

Bycatch limits effectively prevent growth of bycatch, but provide no incentives to individual fishermen for bycatch reductions. In the competitive atmosphere of open access fishing, fishermen racing to catch as much as possible before a bycatch limit shuts down the fishery often increase bycatch rates or decrease survival of discarded fish over what would be experienced in a more rational fishery. However, fishermen generally do not take voluntary steps to reduce discard mortality, even though the fleet as a whole would benefit: slower production from those who take extra time leaves more target species for those who do not.

Table 1. Halibut bycatch mortality (mt) by gear group in Alaskan waters, 1990-1994.

Year	Trawl	Hook & Line	Misc.	Total
1990	7103	1261	37	8401
1991	7360	1204	8	8572
1992	5073	2446	9	7528
1993	5176	2287	2	7465
1994	5993	1800	6	7799

Table 2. Distribution of halibut bycatch mortality (mt) for hook and line groundfish fisheries in the Bering Sea-Aleutian Islands (BSAI) and Gulf of Alaska (GOA), 1990-1994.

Area/ Fishery	Year				
	1990	1991	1992	1993	1994
BSAI					
P. Cod	216	315	1320	391	871
Other	47	57	37	159	87
Total	263	372	1357	550	958
GOA					
Sablefish	940	665	688	1632	601
Other	58	167	401	106	241
Total	998	832	1089	1738	842
TOTAL	1261	1204	2446	2288	1800

Table 3. Halibut bycatch mortality limits and estimates of bycatch mortality for hook and line groundfish fisheries in the Bering Sea-Aleutian Islands (BSAI) and Gulf of Alaska (GOA), 1994.

Area/ Fishery	Mortality Limit (mt)	Mortality (mt)
BSAI		
P. Cod	725	891
Other	175	76
Total	900	967
GOA		
Other	740	750
Demer Shelf Rockfish	10	10 *
Total	750	760

* No data are collected for demersal shelf rockfish; assumed value for actual mortality.

Individual Fishing Quotas

The NPFMC began work on an individual transferable quota (IFQ) system for halibut in 1980, only to have the program killed by political pressure in 1983. After a decade hiatus, the NPFMC finally achieved an IFQ system that went into effect in 1995 for halibut and sablefish. Previous to IFQs, longline fisheries for halibut, sablefish, and other species had different seasons that required discard of all but the target species. With halibut seasons in the GOA down to two days per year, GOA sablefish down to a few weeks, and an excess of vessels, competition among fishermen was high. In the GOA sablefish fishery, limited fishing grounds forced fishermen off the deep continental slope areas best for sablefish, and up onto the continental shelf areas of high halibut abundance (Adams 1996). As a result, both halibut bycatch rates and discard mortality rates were higher than necessary. In 1993, the sablefish fishery not only exceeded its TAC, but went over the halibut bycatch mortality limit by about 50%. In 1994, conservative management actions kept the sablefish fishery within the halibut mortality limits, but the fishery harvested only 84% of the sablefish. With the advent of IFQs, halibut and sablefish seasons run concurrently from mid-March to mid-November. IFQ regulations require retaining other groundfish as well as halibut and sablefish if fishermen have IFQs. IFQs have converted bycatch of halibut and sablefish from waste to retention.

However, bycatch limits may drive a race for fish. The benefits of the IFQ program could have been reduced or eliminated if fishermen believed they needed to catch their sablefish shares as quickly as possible to prevent bycatch by other fishermen from closing the fishery with individual quotas remaining. Such belief becomes a self-fulfilling prophecy. Confidence in the potential halibut bycatch reduction led managers to remove the bycatch mortality limit from the sablefish fishery in 1995, leaving no excuse for fishing in high bycatch areas or causing high discard mortality rates. The IPHC estimated that the sablefish fishery would harvest its quota for only 250-350 mt of halibut bycatch mortality. NMFS set a 1995 halibut bycatch mortality limit of 300 mt for other longline fisheries in the Gulf of Alaska. Anything less than 450 mt of halibut bycatch mortality in the sablefish fishery will mean an overall halibut bycatch reduction.

Careful Release Requirements

Halibut discard mortality rates of 18-20% observed for the longline fleet can only occur if the fishermen abuse halibut during release. Automatic hook strippers that rip halibut from the hooks, gaffing during release, leaving halibut on deck before return to the sea, or sand flea (amphipod) infestation were typical sources of mortality. Simply releasing the halibut over the side without added injury would significantly decrease discard mortality rates. The IPHC met with industry representatives in 1991 to propose a regulation that would require careful release. The initial proposal specified two techniques: careful shaking (rolling the hook out with the gaff), and gangion cutting. Fishermen suggested adding hook straightening as an approved technique. Video taken of hook straightening during a NMFS survey demonstrated its effectiveness. With industry support, the IPHC proposed the careful release requirement to the NPFMC in 1992 (NPFMC 1992). In the analysis prepared for the NPFMC, IPHC estimated that the discard mortality rate of observed vessels under careful release would drop to 12.5%, halfway between the observed rate of 18% and the potential rate of 7%. For unobserved vessels, the estimated rate was 15%, halfway between the 12.5% value and the 18% value. The NPFMC accepted the proposal, and specified careful shaking, gangion cutting, and hook straightening as prescribed techniques. NMFS established 12.5% as the discard mortality rate for observed vessels and 15% for unobserved vessels. Regulations went into effect May 15, 1993.

No observer data became available for analysis of careful release until mid-1994, so the fishery was managed with the assumed values for 1993 and 1994. However, the discard mortality rates for the longline fishery calculated in 1994 from 1993 data were still high, at 18%. While some fishermen achieved discard mortality rates considerably below 12.5%, others more than tripled the assumed rate. Did careful release fail? Did fishermen improve in 1994? Would careful release be effective in 1995? Should the 1995 fishery be managed with the higher or lower rates? These questions faced the NPFMC, the longline industry, and the IPHC late in 1994 during establishment of the 1995 groundfish management regime. If the careful release was not working, and the higher 18-20% discard mortality rates were appropriate and used, the longline fishery would reach its bycatch limits about 50% faster, and would forego harvest because of bycatch mortality limit closures. If the higher rate was appropriate but not used, the fleet would exceed the mortality limit by 50%. But if the higher rate was used and careful release was working, the fleet would lose a large amount of harvest, even though well under the mortality limit.

Sablefish is under IFQ in 1995, and exempt from halibut bycatch mortality limits. The Bering Sea Pacific cod fishery was most affected by the decision on discard mortality rates. That fishery used 857 mt of halibut bycatch mortality in 1994 calculated with the assumed rate of 12.5%. Already above its mortality limit, an 18% discard mortality rate would lower Pacific cod harvest by tens of thousands of metric tons, and millions of dollars. The IPHC recommended a conservative stance, that the 18% rate should be used in the absence of actual data showing lower rates. Industry representatives presented a compelling case that actions taken in 1994 by the fleet, for which observer data were not yet available, and more intensive actions proposed for 1995, would assure that the discard mortality rate would be near the assumed 12.5% (Smith 1996). A major problem in 1993, according to the industry representatives, was owners supporting the careful release in principle, but not assuring compliance. Owners did not always adequately instruct operators on board to reduce mortality, or operators did not monitor the actual release methods. Inexperienced, unaware, or uncaring fishermen jeopardized the program.

The self-monitoring program proposed by industry led the NPFMC to recommend using the 12.5% rate for 1995, but recognized the potential for exceeding the halibut mortality limit. They asked the IPHC to obtain in-season observer data on halibut condition from the Bering Sea Pacific cod fishery to monitor the discard mortality rate. If necessary, the NPFMC and NMFS could adjust the discard mortality rate to reflect fleet performance. The IPHC normally opposes in-season changes to important management parameters, because the normal review process cannot occur. However, the IPHC agreed to an in-season analysis, and to report results to the NPFMC at its June meeting.

The IPHC arranged with the Observer Program for weekly reporting by observers of the 1995 viability data so that a discard mortality rate could be calculated in-season. IPHC staff performed preliminary editing and entered the data. However, potential errors or violations of sampling standards by the observers prevented us from using the data at that point. To finalize editing, IPHC staff interviewed each returning observer from a Bering Sea Pacific cod longliner to determine the actual procedures used to collect viability data. The data that met rigorous quality standards were used in the analysis. Meanwhile, industry representatives mobilized to educate the fleet on the proper halibut release techniques and the importance of using them (Smith 1996). The IPHC staff provided instructions so that each vessel operator could calculate the weekly and cumulative discard mortality rate for the vessel from the weekly observer data. A component of the fleet contracted with a private consultant for weekly calculations and reporting of individual weekly and cumulative discard mortality rates by participating vessels. In this way, vessel operators could make changes if necessary to keep discard mortality rates low. Although the consultant used unedited data, the data were adequate to identify discard mortality rate magnitude and patterns for each vessel. The 1995 in-season discard mortality rates for individual vessels ranged from high to low values (Fig. 2) as in 1993, but nearly all vessels had lower rates than in 1993.

As a result of the intense self-monitoring by the Pacific cod fleet, discard mortality rates for Pacific halibut in the winter and spring of 1995 dropped to 11.5%, even lower than the assumed rate.

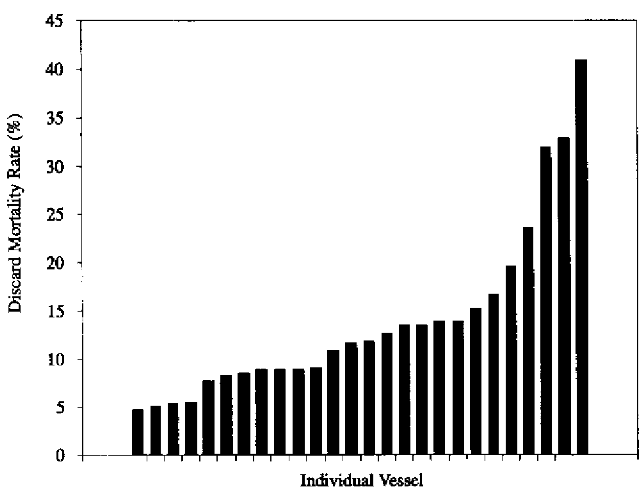

Figure 2. Distribution of halibut discard mortality rates by individual hook and line vessel in the 1995 Bering Sea/Aleutian Islands Pacific cod fishery.

Time-Area Management

The IPHC has long been aware that seasonal movements of halibut can affect the bycatch of halibut in other fisheries (Trumble et al. 1993). Adult halibut move from summer feeding grounds on the continental shelf to winter spawning grounds along the upper continental slope. Juvenile halibut in the Bering Sea aggregate along the outer continental shelf in winter to avoid subzero degree Celsius temperatures in shallower water, but spread throughout the Bering Sea flats as waters warm (Best and Hardman 1982). Juveniles in the Gulf of Alaska move much less than in the Bering Sea, because the change of bottom temperatures is small in the Gulf of Alaska. Fisheries that occur on the bottom have different chances of encountering halibut depending on location and season, and may also encounter small or large halibut differently.

Analysis by the IPHC of observer data from 1990, 1991, and 1992 indicates that the longline fishery for Pacific cod in the Bering Sea experienced statistically higher ($\alpha = 0.05$) bycatch rates in the late spring and summer than during the rest of the year (Adlerstein 1994). Pacific cod live on the continental shelf, and have a distribution similar to halibut, especially juvenile halibut. During summer, the overlap of halibut and Pacific cod increases as the adult halibut move from deep water onto the shelf. In general, highest bycatch rates occurred from April through August, but not always in the same months. June and July were usually among the months with the highest rates. The rates from high bycatch periods typically ranged from two to five times higher than the rates from low bycatch periods, depending on the year and area.

In 1993, when the NPFMC was deciding how to allocate Bering Sea Pacific cod among trawl, hook and line, and pot fishermen, the longline fleet asked that the hook and line Pacific cod fishery close during the summer period of high bycatch rates. The IPHC provided the results from the analysis of seasonal bycatch rates to the NPFMC. Additional analysis (NMFS 1993) also showed higher bycatch rates in summer. The NPFMC subsequently set a very small bycatch limit for the summer months, effectively closing summer to Pacific cod longline fishing.

Estimating Discard Mortality Rates

The IPHC initially estimated discard mortality rates of trawl-caught halibut in the 1970s using tag and release (Hoag 1975), but no similar research for longline bycatch occurred until recently. Halibut bycatch released from hook and line vessels are categorized by observers as condition factors excellent, poor, or dead, according to the following criteria established by the IPHC (Williams and Wilderbuer 1991).

Excellent: No sign of stress

- Hook injuries are minor (limited to the hook entrance/exit hole, torn lip) and located in the jaw or cheek.
- Bleeding, if present, is minor and limited to jaw area.
- No penetration of the body by sand fleas (check eyes, fins, anus).
- Muscle tone or physical activity is strong.
- Gills are deep red.

Poor: Alive but showing signs of stress

- Hook injuries may be severe: broken jaw; punctured eye.
- Vital organs are not injured.
- Bleeding may be moderate but not from gills.
- No penetration of the body by sand fleas (check eyes, fins, anus).
- Muscle tone or physical movement may be weak or intermittent; little, if any, response to stimuli.
- Gills are red.

Dead: No sign of life or, if alive, likely to die from severe injuries

- Vital organs may be damaged: torn gills; gaff wound to head or body; jig injury to viscera; side of face torn loose or missing jaw.
- Sand fleas have penetrated the body (they usually attack the eyes first, but also fins and anus).
- Severe bleeding may occur, especially from the gills.
- No sign of muscle tone; physical activity absent or limited to fin ripples or twitches.
- Gills may be red, pink, or white.

A mortality rate for each condition factor (3.5% mortality for excellent, 52% mortality for poor, and 100% mortality for dead) and the number of observations in each condition are used to determine the overall discard mortality rate. These survival rates were based on research at IPHC that was designed to answer other questions, rather than on direct observations of longline discard mortality.

In 1993 and 1994, the IPHC tagged and released about 13,000 halibut from a chartered fishing vessel using three careful release methods (gangion cutting, careful shaking, and hook straightening) and an automatic hook stripper that ripped the hook from each halibut (Kaimmer and Trumble 1994). By recording the injury of each released halibut, injuries with similar tag return rates may be grouped to improve condition factors and criteria, and to recalculate survival rates for each condition. Normally, release occurs without bringing halibut onto the vessel, but the experiment required halibut to come on board for tagging and biological measurement. Thus, the careful release injuries observed during the experiment were somewhat worse than should occur from proper use of careful release. Using the existing criteria, the estimated survival for the careful release methods showed cut gangions to have the highest rate, followed by careful shaking and hook straightening (Fig. 3). We observed that fish in the hook straightening category suffered additional injuries from being brought on board for release, that are not typical of release over the side. The automatic hook stripper caused far higher mortality than the careful release methods.

When sufficient tag returns occur, probably at the end of 1996, the IPHC will determine what, if any, changes are needed in the condition factors, the criteria defining the factors, and the mortality rates for the factors.

Discussion

The first choice of actions for bycatch management is usually a limit on the amount of bycatch or on the bycatch mortality. Such limits keep bycatch from increasing or force a reduction in bycatch. But without some other action, the limits often cause a race for fish that leads to higher by-

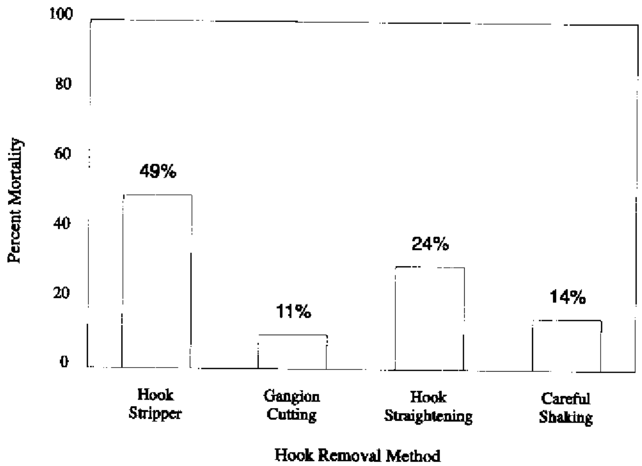

Figure 3. Survival rates of Pacific halibut bycatch released from a chartered longline vessel using different release methods (releasing halibut on board instead of over the side added injuries).

catch rates and to lower harvest. Bycatch limits are usually necessary, but are not sufficient by themselves to maximize groundfish harvest and reduce bycatch. The two largest hook and line groundfish fisheries in Alaska, Pacific cod in the Bering Sea and sablefish in the Gulf of Alaska, are now managed with measures that could eliminate closures caused by halibut bycatch mortality limits. Other hook and line fisheries, especially in the Gulf of Alaska, still face closures.

One of the most successful bycatch reduction programs for an Alaskan longline fishery—careful release—nearly failed before we had enough information to evaluate it. No improvements in discard mortality rates appeared during the first year of the program, 1993. Analysis of the data during 1994 meant that the 1993 data were the best available information for use in setting the rate for 1995. The rate from 1993 was about 50% higher than the assumed rate used for 1993 and 1994, and would have caused the mortality limit to be reached far below the harvest of the longline allocation of Pacific cod in the Bering Sea. Longline operators were ready to abandon compliance with the requirement if they did not get credit for the efforts they claimed to have made, but for which no data were available to confirm. The special in-season analysis of observer data plus pressure the industry placed on itself to comply with the requirements demonstrated the benefits of the program. The longline fleet demonstrated an ability to lower discard mortality rates. Now that this first battle has been won, can they keep up the efforts to win the war, by establishing a self-monitoring system that will keep discard mortality low for the long term?

The change from open access fishing to IFQ for the sablefish and halibut fisheries converted several separate single-species fisheries into a multiple species fishery. This change has the potential to greatly reduce discards because it greatly reduced gear competition in time and space. Converting discards into retention should increase over the next few years as fishermen change their mindset from the race for fish that resulted from years of competitive fishing.

The Observer Program, required by the NPFMC and administered by the NMFS, is an integral part of the success of longline bycatch management in Alaskan waters. The observers have only a data gathering role on board fishing vessels, and have no active enforcement responsibilities. However, observer data, including affidavits, may be used by enforcement officers investigating violations. Observer information is available to operators of vessels upon request. The observer data are critical to monitoring bycatch, bycatch mortality, and the effectiveness of bycatch measures. Full debriefing of observers by well-trained staff is essential to understanding what observers are doing and seeing. Observers obtain large amounts of information that may never be passed on except through debriefers. In-season monitoring of observer data can provide feedback to vessels participating in industry efforts to reduce bycatch.

The measures to reduce bycatch in the Alaskan longline fisheries work because of cooperation among management and industry groups. Development of the concepts included full participation by industry, although some measures, especially IFQs, are controversial and not universally accepted. The industry played a key role educating active fishermen and encouraging compliance, for example by making sure fishermen understood the requirement and implications for careful release or the problems caused by fishing for sablefish in the areas that overlap halibut distribution. Self interest is a major motivating factor for industry to participate in these bycatch management measures, for without them, harvest declines and costs increase.

Enlightened self-interest could go one step further by placing responsibility for bycatch on the individual vessels participating. Assigning bycatch limits to individual vessels or vessel pools would effectively eliminate the race to harvest fish before bycatch limits are reached. Complex legal and logistic issues need resolution before a comprehensive individual incentive program can be developed. But with such a program, the fishermen's interest in making best use of bycatch would closely match society's in decreasing waste and increasing utilization.

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Bycatch in Western Atlantic Pelagic Longline Fisheries

John J. Hoey
National Fisheries Institute, Blue Water Fishermen's Assoc., 1525 Wilson Blvd., #500
Arlington, VA 22209

Bycatch in pelagic longline fisheries is of increasing interest to fishery managers and environmental groups because of its potential or perceived impact on incidentally harvested species. This results from increased public concern regarding waste in worldwide commercial fisheries and the international high-seas characteristics of these fisheries. This report describes longline operations and gear characteristics and summarizes data from more than 5,000 observed sets by Japanese longliners in the U.S. Exclusive Economic Zone (EEZ) and more than 1,500 observed sets by U.S. longliners in the western North Atlantic. The report describes operational and gear characteristics that influence the magnitude, species composition, and survival rates of incidentally harvested and target species. Discussions about the relative selectivity and conservation characteristics of different fisheries and gears must be based on quantitative data. Practical management actions that emphasize low cost modifications to operational procedures and gears have the potential for significantly reducing negative impacts of incidental longline capture.

Pelagic (free floating) longline gear is extensively used in international fisheries for several highly migratory species of tunas and for swordfish. The fleets and fish are both wide-ranging and highly mobile. Market forces play a major role in influencing fleet deployment and species specialization. While most of the catch (tunas, swordfish, and marlin) is taken from international waters, several nations rely primarily on harvests of these species from their own economic zones. Atlantic longline fleets have been deployed by Japan, Korea, Taiwan, Spain, the United States, Canada, Brazil, Portugal, Uruguay, Cuba, the Soviet Union, Venezuela, Trinidad and Tobago, Barbados, Grenada, Morocco, Denmark, and South Africa. Pelagic longline gear consists of a continuous mainline which is supported by float lines and includes regularly spaced branch lines that end with baited hooks. This gear is generally considered appropriate for harvesting non-schooling oceanic predators including tunas, swordfish, sharks, billfishes, and other large piscivorous fish such as dolphin (*Coryphaenidae*) and wahoo (*Acanthocybium solanderi*).

As in many fisheries, several ecologically related species are frequently caught and sold forming the economic basis for the fishery. The impact of pelagic longline fisheries on target and incidentally captured populations depends on the total number captured, the proportion that are dead and either retained or discarded, the number of live releases that survive, and the magnitude of other sources of mortality. From a scientific resource management perspective, "bycatch" is a dead discard estimation problem. It results in cryptic mortality that is difficult to estimate because the fish are not landed or sampled unless there is observer coverage. Effective management of internationally shared, highly migratory species must involve limiting total fishing mortality from all high-seas fisheries, as well as the more localized coastal fisheries, including artisanal (subsistence) and recreational fisheries. Quantitative data on fishery characteristics and statistically reliable estimates of the resulting multispecies catch from all of these fisheries are essential for effective management. The extent of pelagic longline fisheries, the unknown magnitude of its incidental mortality, and the potential or perceived impact on international stocks, has focused the attention of fisheries managers, scientists, and activists on this issue.

Although relatively simple in general design, the gear can be deployed in specialized ways (i.e., nighttime, deep rigging) to catch more of a desired species and to avoid or reduce catches of other species (Suzuki et al. 1977, Sakagawa et al. 1987). Operational and gear characteristics including area, month, time of set, surface temperature and frontal structure, fishing depth, bait, etc., have been found to significantly affect the catch rates and mix of species caught. Hoey (1983, 1992) documented differences in species composition and selectivity between tuna, swordfish, and shark directed effort. Boggs (1992) used hook timers and time-depth recorders on longline gear to evaluate measured capture depth by species and to compare the effectiveness of different gear configurations at catching selected species. Subsequently, Boggs and Itto (1993) attributed increasing relative proportions of shallow-swimming species (yellowfin, blue marlin, mahimahi) in the Hawaiian longline fishery between 1989 and 1991 to specific fishing practices relative to night versus day sets and the use or absence of line throwers to increase fishing depth. The analysis of gear and operating characteristics may reveal feasible options to minimize bycatch mortality, reduce waste, and improve selectivity and economic performance at a minimal cost and with little disruption to current operating patterns. Boggs (1992) and others have recognized that enhanced live release procedures represent an important mitigation option for pelagic longline fisheries.

Bycatch Terminology

Unfortunately, the term bycatch is so broadly used, and has developed such a negative connotation, that it detracts from clearly identifying problems, prioritizing research and management questions, and evaluating practical approaches to avoiding or mitigating incidental catch. Murawski (1992) indicated that the term "bycatch" itself added confusion to the topic of multispecies catch, that it was an imprecise and judgemental term, and might be inaccurate when used over time to describe either historical or future catches. The term has become highly politicized in national and international press accounts. While scientific reports have used the term in a variety of ways, the most recent FAO review on world bycatch (FAO 1994) included retained nontarget catch with discarded catch under the bycatch rubric. That report, however, did note that this bycatch definition was probably "inappropriate in terms of the reality of many multispecies fishing practices." The latter statement explains why fishermen usually object to the inclusion of retained and sold catch with discards as bycatch.

In an attempt to sidestep the bycatch definition problem, that term will be avoided in subsequent descriptions of species composition data from observed longline sets. Total catch will be divided into retained catch and discarded catch. The *retained catch* will include the *primary target species* sought by fishermen and *secondary market species* (sometimes called nontarget catch, incidental catch, byproducts, etc.) that are incidentally caught and retained for sale or personal consumption. Primary target species include swordfish, yellowfin, bigeye, bluefin, and albacore tuna for the observed fisheries described in this report. Secondary market species include several other tunas, pelagic and coastal sharks, and a variety of edible fish. The *discarded catch* includes both live and dead discards that result from economic, legal, or personal decisions. The discarded catch can include target and secondary market species, inedible species (lancetfish, oilfish, pelagic rays, etc.), and protected species. The dead discard and secondary market components of the catch are sources of fishing mortality that must be quantitatively described and evaluated relative to other sources of fishing mortality.

Data: Observer Records For Western Atlantic Longline Fisheries

Data has been collected by U.S. observers on domestic and Japanese longline vessels from 1978 through 1994. These programs have been managed by different administrative and research offices over time. This has resulted in changes in the operating instructions given to observers, changes in the specific information that has been collected, and changes in how variables are coded. These program differences will be described when they influence analyses and interpretation of results. The observer data sets are as follows:

- U.S. observer records of sets by Japanese vessels operating inside the U.S. EEZ from 1978 to 1982. Data from approximately 5,475 longline sets account for about 385,000 animals caught. In this data, the live or dead status of a capture species was recorded when the gear was retrieved. However, the Japanese were required by U.S. law to release in the water (discard) all marlin, swordfish, and sharks regardless of their status. Observers therefore did not record disposition information for tunas and other species caught, and codes were not established to track the number of fish that were damaged by shark or whale predation. Information on live release rates for marketable tunas is not available.

- Louisiana State University (LSU) received federal grant funds to establish an observer program for the yellowfin tuna fishery in the Gulf of Mexico (Russell 1989, 1991, 1992). Records currently account for 320 sets between 1987 and 1992. LSU observers were deployed on Vietnamese-American vessels which occasionally use live bait and tend the line. Catch status and disposition was recorded for all species.

- The National Marine Fisheries Service (NMFS) observer programs are run out of the Northeast and Southeast Fisheries Science Centers (NEFSC and SEFSC). Records available at this time account for 1,523 sets between 1991 and 1994. Each center samples the longline fishery within its respective geographical area of responsibility. Observer training and data protocols are generally standardized.

Although the gear looks rather simple, scientists have managed to identify more than 150 variables for observers to code on each set, before they identify the catch (by individual animal) and its status and disposition. Time, location, and weather and sea surface temperatures are recorded during the setting and hauling of the gear. Gear dimensions and construction details are recorded for each trip. Daily or set-specific changes in how much gear is set, or how the longline is rigged are also recorded. Biological samples are collected and released individuals are occasionally tagged.

To simplify the description of species composition from observer data, it is necessary to combine many of the rare incidental species into species groups. To the extent possible, these groups reflect U.S. Atlantic management categories established under federal fishery management plans (FMPs). Separate FMPs exist for swordfish, billfish (blue and white marlin, sailfish, and spearfish), bluefin tuna, and other Atlantic tunas. Sharks are separated into pelagic sharks (including makos, threshers, porbeagle, oceanic whitetip and the blue shark) and large coastal sharks, commonly known as the "brown sharks" (including hammerheads, sandbar, dusky, bull, blacktip, silky, bignose, Caribbean reef, lemon, nurse, night, spinner, tiger, sand tiger, great white, basking, and whale sharks). The other finfish category includes a large number of species four of which (the dolphin fish, lancetfish, oilfish, and escolar) account for 82% of the other finfish caught (excluding tunas, swordfish, and marlin).

Regional and seasonal fishing practices significantly influence catch rates and species composition. Regional differences in the species composition of U.S. longline landings was described by Hoey et al. (1995). The U.S. long-line fishery primarily harvested swordfish prior to the mid-1980s; more recently the fishery is landing a dominant proportion of tunas (Fig. 1). U.S. tuna fisheries occur in the Gulf of Mexico where yellowfin is the target, and off the northeast coast where bigeye tuna is the primary target with significant associated landings of yellowfin tuna and swordfish. Within the range of the U.S. fishery, effort is primarily associated with the edge of the continental shelf, sea mounts and oceanic canyons, and thermal frontal zones. These areas are subject to dramatic seasonal change in sea surface temperature and thermal stratification. Subsequent summaries will be presented by region, where the five regions reflect consolidation of coastal Atlantic areas as described by Hoey et al. (1994) and Lee et al. (1994). The following region designations are followed: 1-Caribbean, 2-Gulf of Mexico, 3-Southeast U.S. Coastal, 4-Northeast U.S. Coastal, and 5-Northeast Distant (Grand Banks).

Results: Regional Summaries of Catch and Species Disposition

In order to minimize the number of figures used, catch (Fig. 2) and disposition (Fig. 3) data are presented in stacked column format by area and species or species management group. Management groupings were revised in the catch disposition figure to keep the number of categories

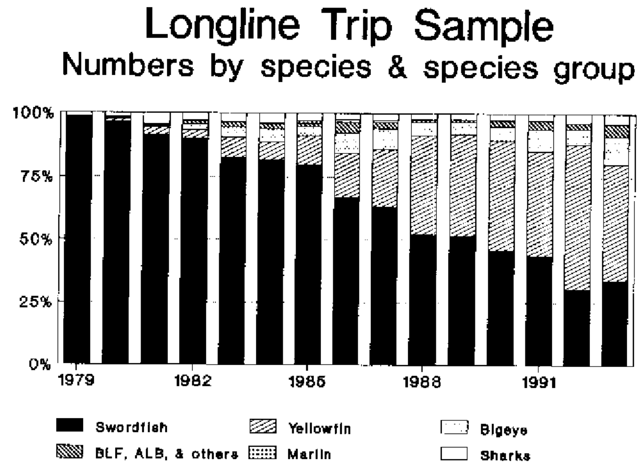

Figure 1. *Landings by species in numbers from a sample of trip unloading reports for the U.S. longline fishery operating in the western North Atlantic.*

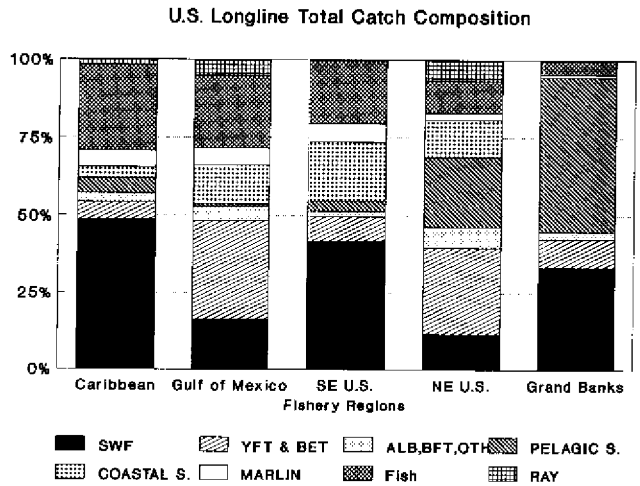

Figure 2. *Catch composition from observed U.S. longline sets in the western North Atlantic by area and species management group, 1991-1994.*

manageable given the need to display information on retained catch, catch discarded alive, and catch discarded dead. Swordfish and all tuna kept are considered separately. The other kept category includes secondary marketable species including several sharks and finfish. In most regions, the other kept category is dominated by the dolphin fish, mahimahi. The portion of the catch that is discarded alive is separated into the shark component, which includes pelagic and coastal sharks and rays, and an others alive category, which includes swordfish, tuna, marlin, other finfish, and protected species. The dead discard portion of the catch is separated into marketable dead discards, which includes swordfish and tuna, fish dead discards which includes all other finfish and protected species, and shark dead discards. This presentation pattern facilitates direct comparisons between regions in terms of species proportions and disposition patterns. Additional details are provided in the subsequent regional summaries.

Caribbean

Between 1991 and 1994, U.S. observers recorded catch and disposition information for 158 sets by U.S. vessels in the Caribbean and in international waters of the western tropical Atlantic. The sets accounted for a total catch of 3,329 animals, which was dominated by swordfish (49%) and other finfish (27% excluding tuna and marlin). Three species (dolphin fish, lancetfish, and oilfish) account for 94% of the other finfish category. Tuna accounted for an additional 8%, followed in declining order of abundance by marlin and pelagic sharks with 5% each and coastal sharks with 3.5%. With respect to the total tuna catch (8% overall), bigeye tuna account for 48%, albacore for 27%, and yellowfin for 25%. No bluefin were reported on the 158 observed sets. Blue and mako sharks accounted for 70% of the pelagic shark catch and silky and sharpnose sharks accounted for 72% of the coastal shark catch. The total catch per set averaged 20.3 individual animals (25th% = 14, 50th% = 19, 75th% = 25). Overall survival of all species in terms of the percentage alive at gear retrieval was 34.5% (25th% = 24, 50th% = 33, 75th% = 45). In terms of disposition, 60.3% of the catch was kept, 17.1% was released alive, and 22.6% was discarded dead. The marketable dead discards were dominated by discarded swordfish, attributable to minimum size regulations, and small or damaged tunas. The fish dead discards were dominated by oilfish and lancetfish.

Gulf of Mexico

U.S. observers recorded catch and disposition information from 462 sets made by U.S. vessels in the Gulf of Mexico. The sets accounted for 13,817

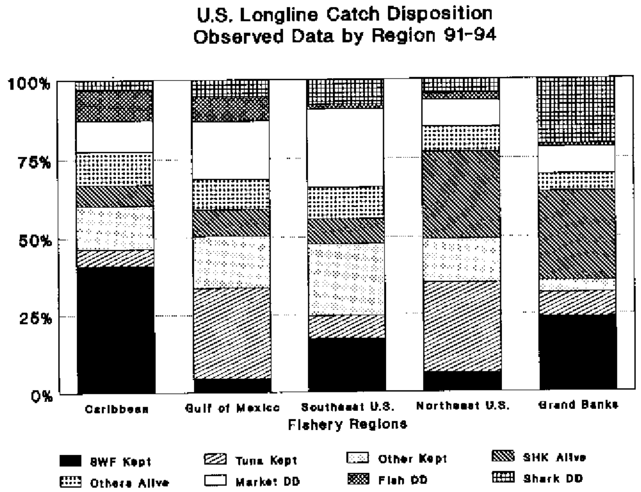

Figure 3. Catch disposition from observed U.S. longline sets in the western north Atlantic for retained catch and discarded catch released both live and dead.

animals, which was dominated by yellowfin tuna (31%) and finfish (23% excluding tuna and marlin). Four species (dolphin fish, lancetfish, oilfish, and wahoo) account for 89% of the other finfish category. Swordfish (16%) were the next most abundant species followed by coastal sharks (12%), marlin (6%), rays (5%), and pelagic sharks (1%). Whereas bigeye, albacore, and bluefin combined accounted for 1% of the catch, smaller tunas including skipjack, bonita, and blackfin account for 4%. All tuna combined represent 36.6% of the total catch. The total catch per set averaged 29.9 individual animals (25th% = 18, 50th% = 26, 75th% = 38). Overall survival of all species in terms of the percentage alive at gear retrieval was 47.1% (25th% = 36, 50th% = 47, 75th% = 58). In terms of disposition, 50.5% of the total catch was kept, 18% was released alive, and 31% was discarded dead. The marketable dead discards included small swordfish, unmarketable small tuna, and a significant portion representing shark- or whale-damaged tuna and swordfish. Whereas most of the dolphin fish and wahoo were retained for sale, oilfish and lancetfish were again predominant in the fish dead discard category. There was generally a greater species diversity represented by the other fish component, reflecting the diversity of the operating styles and gears used in the region.

Between 1978 and 1981, U.S. observers monitored 765 sets (1,596,052 hooks) by Japanese longline vessels in the Gulf of Mexico. These sets accounted for a total catch of 22,347 animals (Fig. 4), which was dominated by yellowfin (32%) and bluefin (22%) tuna. The other finfish category ranked third at 13.6%, while bigeye, albacore, and smaller tunas accounted for an additional 4.5%. Coastal sharks account for 7.5%, swordfish for 7.4%, marlin for 6.7%, and pelagic sharks for 5.2%. Rays and protected species accounted for 0.5%. In total, tunas, swordfish, and marlin, the traditional target species complex for the Japanese longline fishery, accounted for 72.5% of the total catch. U.S. regulations required that the Japanese vessels discard all swordfish, marlin, and sharks. Overall survival of all species combined was 40% alive at retrieval. Only 18.6% of the swordfish were reported alive, compared to 43.4% for the marlin. Pelagic sharks, coastal sharks, and rays were reported alive 73%, 80%, and 85%, respectively.

LSU observers recorded data aboard Vietnamese-American longline vessels which used live bait to target yellowfin tuna. On 126 live bait sets which accounted for a total catch of 3,773 animals, yellowfin tuna represented 51% of the total catch. Other tunas accounted for an additional 8.7%, other finfish 20.2%, marlin 10%, all sharks and rays 7.2%, and swordfish 2.4%. In terms of disposition of the catch from live bait sets, 68% of the catch is retained, 9% is released alive, and 23% is discarded dead. The live bait sets produced about 60% tuna (yellowfin, bigeye, albacore, bluefin, and small tunas), which is comparable to the Japanese tuna proportions, but higher than the proportion observed recently (37%) on 462 Gulf sets. The later sample included a greater variety of fishing practices in the Gulf including nighttime effort targeted at swordfish, and small numbers of live bait and bottom longline sets, the later reflecting shark effort. In terms of the simple total catch per set, the live bait sets produced the same overall mean value (29.9/set) as observed on the 462 Gulf sets. However, with respect to yellowfin catch per set, the previous sample averaged 9.4 yellowfin per set compared to 15.3 for live bait sets. The increased efficiency of live bait also occurred for marlin where the live bait catch per set was 3.9 as compared to 1.7 marlin per set for the larger sample.

In order to evaluate operational characteristics to compare against the LSU live bait observations, the recent Gulf sets (n=462) were categorized according to different starting set times and starting haul times. Although the observations were dispersed over a number of

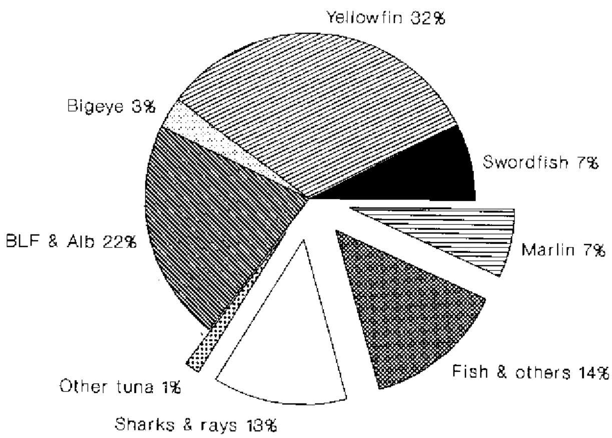

Figure 4. Catch composition from observed sets aboard Japanese longline vessels operating in the U.S. EEZ in the Gulf of Mexico, 1978-1981.

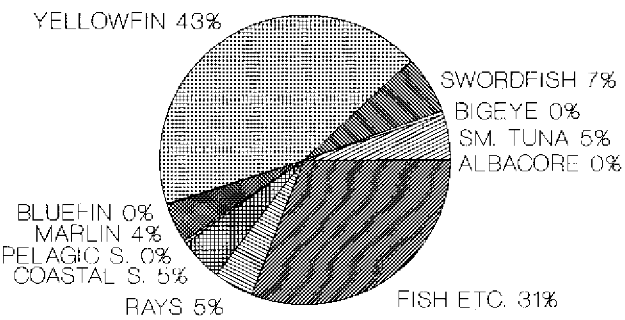

Figure 5. Species composition from observed U.S. longline sets in the Gulf of Mexico that were set early in the morning (2 am-10 am) and retrieved at night from 5 pm till midnight (126 sets–catch 3,911).

combinations of set and haul starting times, two clusters were predominant. Early morning sets (2 am-10 am) with haulback starting after 5 pm accounted for 126 sets, and night sets (5 pm-midnight) with morning haulback (5 am-10 am) accounted for an additional 116 sets. The remaining 185 sets were distributed among 10 paired combinations of set and haul times. The species composition for these morning (Fig. 5) and evening (Fig. 6) sets are dominated by yellowfin and swordfish respectively. The relative proportions of these key target species is reversed, while the finfish catch is higher in daytime sets and the coastal shark catch is higher in the nighttime sets. Preliminary analyses of the effect of the number of hooks between floats (catenary depth increases as hooks between floats increases—compare 2 to 4 hooks between floats vs. 5 to 8 hooks between floats) for the yellowfin dominated set and haul pattern indicted that the overall catch per set increased from 22.1 fish/set (n=35) to 34.5 fish/set (n=91), with a higher catch per set for tuna (11.5 - 14.0), swordfish (1.7 - 2.2), and marlin (0.97 - 1.5) observed as the number of hooks between floats increased. With respect to the swordfish dominated set and haul pattern, there was little overall difference in catch per set (26.3 [n=87] vs. 25.2 [n=29]), yet the shallow night sets outfished the deeper night sets for swordfish, 13.7 swordfish/set vs. 5.1 swordfish/set, respectively. These differences clearly point to the large number of possible temporal setting and hauling patterns that can be combined with gear parameters to influence catch rates and longline performance.

Southeast United States Coastal

U.S. observers monitored 345 pelagic longline sets between 1991 and 1994 from the Southeast U.S. coastal region, which covers the east coast of Florida and South Atlantic Bight to Cape Hatteras, NC. The observed sets accounted for a total catch of 7,518 animals. Swordfish was dominant, accounting for 41.8% of the total catch, followed by finfish (excluding tuna and marlin) which account for 19.8%, and coastal sharks which account for 19.1%. Dolphin fish accounted for 74% of the finfish category, whereas sandbar, dusky, silky, and scalloped hammerhead sharks accounted for 72% of the coastal shark catch. All tuna combined accounted for 9.7%, marlin for 5.8%, and pelagic sharks for 3%. Yellowfin and bigeye accounted for 82% of the tuna (9.7% overall), while blue and mako sharks account for 64% of the total pelagic shark catch (3% overall). The total catch per set averaged 21.8 individual animals (25th% = 12, 50th% = 19, 75th% = 28). Overall survival (all species) in terms of the percentage alive at gear retrieval was 39.0% (25th% = 25, 50th% = 38, 75th% = 50). In terms of disposition, 47.7% was kept, 18.2% released alive, and 34%

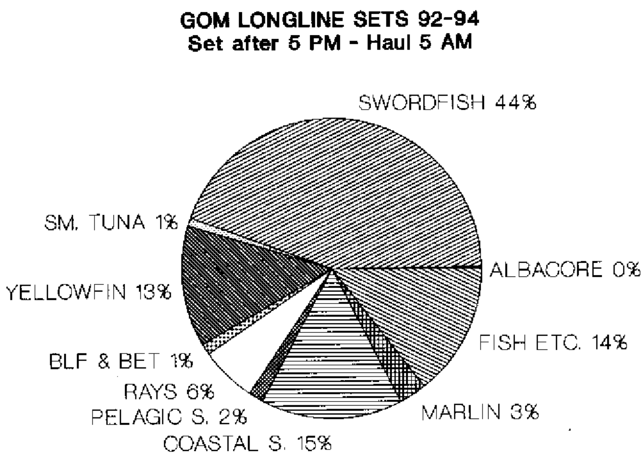

Figure 6. Species composition from observed U.S. longline sets in the gulf of Mexico that were set in the evening from 5 pm till midnight and retrieved in the morning from 5 am to 10 am (116 sets–catch 3,022).

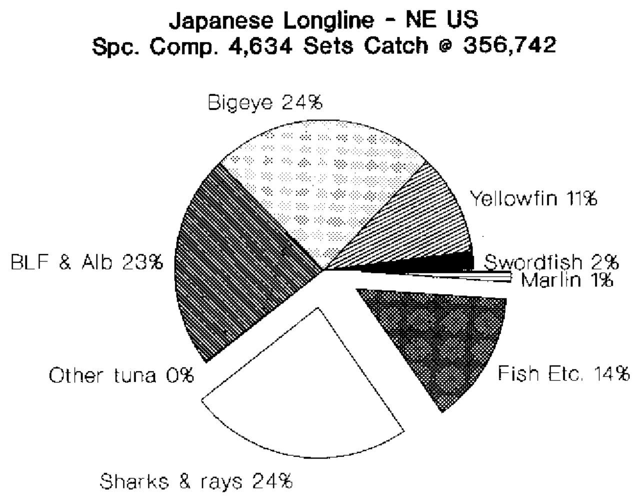

Figure 7. Species composition from observed sets aboard Japanese longline vessels operating in the U.S. EEZ off the northeast coast of the U.S, north of 35 degrees north, 1978-1988.

discarded dead. The marketable dead discards were primarily small swordfish, with a small proportion of shark or whale damaged carcasses. This area had the largest relative proportion of retained fish of any of the areas examined, reflecting dolphin fish abundance.

Northeast United States

U.S. observers recorded catch and disposition information from 388 sets made by U.S. vessels north of Cape Hatteras and west of the Canadian EEZ. These sets account for 14,355 animals. The blue shark accounted for 19.2% of the total catch (all pelagic sharks account for 22% of the total), followed by yellowfin tuna at 16%, and bigeye tuna at 12.2%. Coastal sharks (12%), swordfish (11.6%), other finfish (9%), and rays (6.7%) account for the remaining portion of the catch. The total catch per set averaged 37.0 individual animals (25th% = 19, 50th% = 30.5, 75th% = 47.5). Overall survival of all species in terms of the percentage alive at gear retrieval was 60.3% (25th% = 47, 50th% = 60, 75th% = 74). In terms of disposition, 49% of the total catch was kept, 35% was released alive, and 15% was discarded dead. As in the Gulf, the marketable dead discards include both small swordfish and small tuna, reflecting minimum size regulations and limited markets, respectively, and shark and whale predation damage. The proportional share of the marketable dead discard category is similar between this area and the Caribbean and Grand Banks areas. Blue sharks dominated the overall catch, the shark catch, and the shark release alive category.

Between 1978 and 1988, U.S. observers aboard Japanese vessels fishing in the U.S. EEZ off the northeast coast monitored 4,634 sets which accounted for a total catch of approximately 356,700 animals (Fig. 7). Bigeye tuna was predominant, accounting for 24% of the total, pelagic sharks accounted for 19.8%, and finfish (excluding tuna, swordfish, and marlin) accounted for 14%. Albacore, bluefin, and yellowfin account for 11.9%, 11%, and 10.9%, respectively. Rays (3%), swordfish (2%), and marlin (1.2%) are minor parts of the catch. The mean and median proportion of the total catch (all species) that was alive at gear retrieval was 60%. Swordfish (38%) and marlin (33%) had lower proportions of live releases. For pelagic sharks, coastal sharks, and skates and rays, 88%, 80%, and 94% respectively, were alive.

The observed Japanese longline sets off the northeast coast can provide observations of catch composition that reflect specific gear attributes. Previously referenced studies have pointed to fishing depth changes in the worldwide Japanese fishery, reflected in the numbers of hooks set between floats. Fig. 8 illustrates a shallow rigged longline set with seven or fewer hooks between floats. Fig. 9, on the other hand, reflects a deeper

Japanese Longline - NE US Shallow Rig

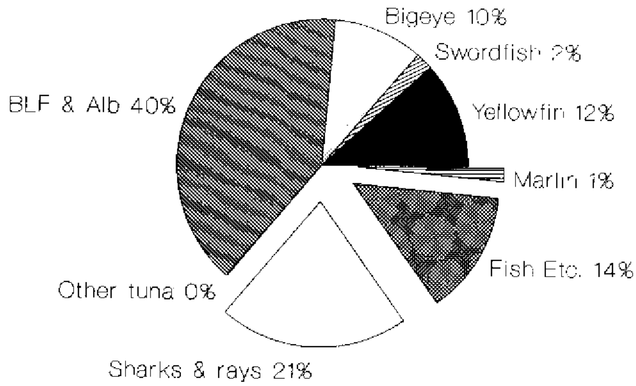

Figure 8. Species composition from observed sets aboard Japanese longline vessels operating in the northeast U.S. EEZ where the gear was rigged shallow with 7 or fewer hooks set between floats (1,495 sets–catch 142,095).

Japanese Longline - NE US Deep Rig

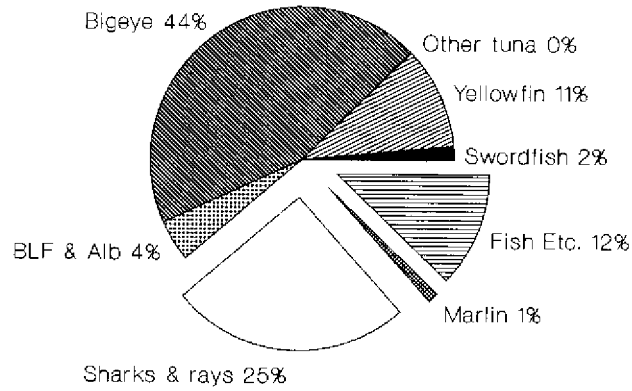

Figure 9. Species composition from observed sets aboard Japanese longline vessels operating in the northeast U.S. EEZ where the gear was rigged deep with more than 11 hooks set between floats (1,165 sets–catch 75,165).

rigged configuration with more than 11 hooks between floats. The change in the proportion of bigeye tuna is the most obvious difference between these operation styles. As rig depth increased from shallow to deep configurations, the overall species survival increased, while the total numbers of animals (marketable and non-marketable) caught declined from approximately 95 fish/set to 65 fish/set. However, the proportion of bigeye increased by a factor of 3 from 9.4 bigeye/set to 28.4 bigeye/set. In addition, swordfish survival increased from approximately 34% to 40%, the catch per set of coastal shark species declined by 62%, and the catch per set of marlin declined by 48%. It appears the gear was set through the community of surface dwellers and more selectively harvested the deeper dwelling bigeye. The bigeye is one of the most valuable components of the catch. This increased bigeye efficiency provides a significant economic incentive to fish deeper.

Northeast Distant (Grand Banks & Flemish Cap)

Observers monitored 170 pelagic longline sets between 1991 and 1994 from the U.S. Northeast distant water fishery on the Grand Banks and Flemish Cap. These sets accounted for a total catch of 11,085 animals. The blue shark alone accounted for 44.7% of the total catch (all pelagic sharks account for 48.1%). Swordfish were the second most abundant, accounting for 32% of the total catch, followed by bigeye tuna which accounts for 8%, other fish for 4.4%, all other tuna for 3.3%, and rays for 2.8%. The total catch per set averaged 65.2 individual animals (25th% = 43, 50th% = 62, 75th% = 81). Overall survival of all species in terms of the percentage alive at gear retrieval was 48.9% (25th% = 36, 50th% = 48, 75th% = 63). In terms of disposition, 36% was kept, 34% was released alive, and 30% was discarded dead. The relative proportion of marketable dead discards was comparable to the Caribbean and Northeast U.S. areas. The biggest difference between the Grand Banks disposition information and all other areas was the large proportion of dead discarded sharks. Given the predominance of the blue shark overall, and the high blue shark release alive rate observed in the northeast area, this was an unexpected discarding rate. This most likely reflects operational decisions by owners or captains to retrieve hooks from blue sharks to reduce the magnitude of the potentially large cost of replacing from 19 to 35 hooks/set on about 50% of the sets and far larger numbers when blue sharks are very abundant. Extremely large daily blue shark catches are more frequent in this region than off the U.S. northeast coast.

Region-Quarter and Gear Effects on Survival Rates

The preceding data clearly indicates that species composition and survival rates differ by area and operational characteristics. Within areas, seasonal changes in water temperature influence species composition and survival rates (Fig. 10). Overall average survival rates for the southeast and Caribbean fisheries, which primarily target swordfish, are lower than the survival rates observed in the northeast area. If the previously described problem with hook retrieval from blue sharks on the Grand Banks was addressed through the use of dehooking devices that enhanced blue shark live releases, the difference between survival rates north of 35 degrees N and south of 35 degrees N would be more evident. This trend is comparable to that observed in the Japanese data where overall Gulf of Mexico survival was 40% and survival in the northeast U.S. EEZ was 60%. Survival rates should be evaluated by species and compared with information on average sizes and mixing layer temperatures.

The Japanese data indicated that survival rates increased as fishing depth increased, adding an additional set of variables to consider. While the Japanese fishery in the Gulf was characterized by an overall 40% survival rate, 462 U.S. Gulf sets had an average survival rate of 47.1%. U.S. fishermen believe that this can be partially attributed to the monofilament gear which has less resistance or drag as it is pulled through the water and longer branch lines which allow greater movement of captured fish and higher survival rates. Additional analyses on gear parameters, including the diameters and strength of different mainlines, and the diameters, strengths, and lengths of branch lines, are planned.

Hook sizes and patterns have been evaluated in selectivity studies of demersal longline fisheries. A preliminary attempt was made to evaluate hook pattern differences for 427 observed Gulf longline sets. While there are a fairly large number of sizes and styles of hooks used, two specific patterns of Mustad brand hooks were represented by fairly large numbers of observations. A Mustad J hook (pattern 7698B) was used on 75 sets, while a Mustad circle hook (pattern 39960ST) was used on 122 sets. Sets that had missing data for hook pattern numbers were deleted, leaving 230 additional sets. Mean survival on the 230 sets that represented a mix of hook patterns was 47% (25th% = 35%, 50th% = 46.5%, 75th% = 57%).

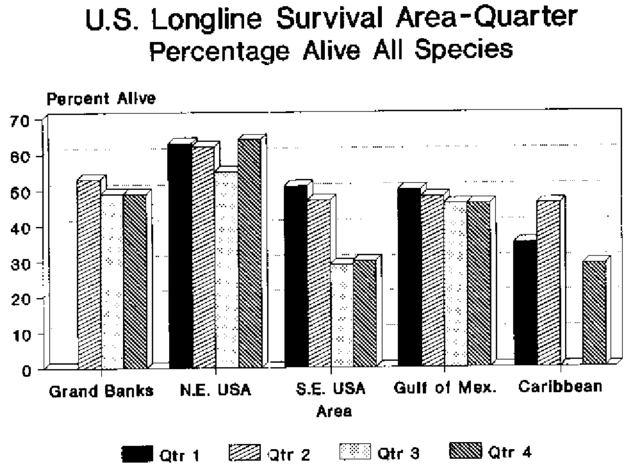

Figure 10. Mean survival rates of all species combined calculated by set for observed U.S. longline sets by area and quarter of the year. Total sets were 1,523 accounting for a total catch of 50,104 individual animals.

Within this group, there are a variety of hook styles, including Japanese designs, that are intermediate between J hook and circle hook designs. The Mustad J hook had a mean survival of 38% (25th% = 24%, 50th% = 38%, 75th% = 50%) compared to the Mustad circle hook with a 51% survival rate (25th% = 42%, 50th% = 51.5%, 75th% = 60%). In terms of the mean catch per set, the mean was 25.5 fish/set for the mixed hook group, 27.2 fish/set for the J hook, and 32.9 fish/set for the circle hook. Several studies have indicated that hook designs with the point angled toward the hook eye had higher catch rates and also frequently hooked the fish in the jaw as opposed to deeper in the throat or gut.

Discussion

In early pelagic longline fisheries, the gear was arranged in baskets which held a set length of coiled mainline and a specific number of hooks that depended on the spacing between hooks. Several baskets were connected end to end to make a single set. Subsequently, longline systems evolved into using a continuous mainline, which was stored either in large bins or on drums, with separate snap-on float and branch lines. Line setters or throwers were also introduced, which allowed for a deeper sag (catenary) in the mainline between floats, and thereby resulting in greater fishing depths. Snap-on gear and line throwers provided greater flexibility in gear configuration, through the use of different lengths of dropper and branch lines, different spacing between hooks, and differences in the number of hooks and distance between floats. All of these changes provided for increased selectivity of fishing depths that would maximize the catch rates for the primary target species.

Additional modifications of pelagic longline systems resulted from gear experiments undertaken by U.S. fishermen in the mid-to-late 1970s off the east coast of Florida (Berkeley et al. 1981). Fishermen experimented with complete monofilament rigs (mono float, branch, and mainlines), that had reduced drag in the Gulf Stream current and lower visibility in clear tropical water compared to the heavier multi-strand nylon mainline used by the Japanese and in the early U.S. and Canadian fishery. They also experimented with the use of chemical lightsticks and significantly increased the lengths of float lines (longer than 15 m) and branch lines (from 25 to 40 m) so that the gear would fish deeper. Because of the increased length of branch lines, spacing between hooks had to be increased to prevent tangles. Spacing increased from about 15 to 80 m, and occasionally to as much as 130 m or more. Increased spacing, greater lengths of the float and gangion lines, and the time required to handle them during set and retrieval limited the number of hooks that could be set per night or per km. These changes made the gear more adaptable and effective at capturing swordfish and bigeye tuna. Greater attention was paid to setting the gear at the optimal fishing depth within the frontal system. A conservation benefit of this improved efficiency was that the reduced number of hooks set per night at more precise depths presented fewer hooks capable of capturing nontarget species. Incidental catch as a proportion of the target swordfish or tuna catch probably declined, since the daily catch rates for the target species would have to have been comparable or better than the older gear or fishermen would not have made the change. In addition, fishermen believe that lighter and longer monofilament gear offers less resistance as it is pulled through the water, allowing greater movement of captured fish and higher survival rates. Fish that are landed alive can be bled and processed quickly to provide a premium quality food product. Lighter gear also increases the proportion of live releases for nonmarketable species.

Clearly there are differences between regional and seasonal fisheries. Species composition of the catch and survival rates can be influenced by how and when the gear is fished. Quantitative observer data can help identify potential problems as well as low-cost practical modifications that can minimize incidental capture or provide mitigation options by increasing the possibility that nontarget catch could be released alive. The ecological implications of live releases are particularly important for pelagic longline fisheries. Boggs (1992) reported that over 50% of 12 frequently caught taxa were alive when retrieved and for most species survival was higher than 70% in the Hawaiian fishery. This is consistent with results presented here, especially for observed sets north of 35 degrees N. If long-term survival rates are reasonably high, the incidental capture and discarding of that species should represent a relatively low priority resource management or bycatch problem. A comparison of recapture rates for swordfish, marlin, tuna, and sharks tagged aboard longline vessels compared to recaptures from recreational and scientific tagging programs would provide perspective on long-term survival. For the blue shark at least, longline recaptures have been frequent, including multiple tag and recaptures of the same individual. The blue shark data from the Grand Banks provides a clear example of a problem that could be significantly reduced by the adoption of operating practices that would reduce the economic incentive to retrieve hooks. A higher priority should be placed on dehooking devices. If dehooking devices are impractical on certain vessels, cheaper corroding hooks could be an economically appropriate option for that seasonal fishery.

In terms of a broad fishery perspective, the observer data generally indicates that dead discards in these longline fisheries are on the order of 20% to 30% of the total catch. This includes shark and whale damaged carcasses which may or may not have been included in previous studies, but can represent a significant contribution to the discard rate. Lee et al. (1994) reported that damaged carcasses accounted for 5% of the total yellowfin and swordfish catch in the SEFSC observer program (1,066 sets out of the total of 1,523). Clearly regulatory discards, especially the minimum size regulations for swordfish and the prohibition on retention of all marlin, are the major source of waste in this fishery.

Dead discard rates presented throughout this paper are based on numbers of individuals. Most dead discards are smaller individuals, especially within the marketable dead discard component and the fish discard component which is predominantly lancetfish. In comparison, the retained and released catch is predominantly larger fish. Therefore, a discard proportion expressed in terms of weight, as in the recent FAO assessment of bycatch and discards, for these longline fisheries would probably be less than 15% by weight. This means that approximately 85% of the weight harvested each day is either kept or released alive. In comparison to other world fisheries these operation styles would probably rate as very selective.

Additional research could contribute to improved longline selectivity. Increased availability of observer data and cooperation between fishermen and scientists will allow further development of analyses and at-sea experiments to evaluate options to further reduce the negative ecological effects of incidental capture. Gear characteristics relating to more precise fishing depths and characteristics that could increase survival, such as lighter and longer branch lines and circle hooks, could provide enhanced efficiency for target species. This would provide a benefit to fishermen, while also having a beneficial effect on other components of the ecosystem as fishing mortality declines on incidentally captured species.

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Reduction of Halibut Bycatch and Associated Mortality in the Bering Sea Cod Fishery

William Thornton Smith
North Pacific Longline Association, 4209 21st Ave. W, Seattle, WA 98199

In 1980 the North Pacific Fishery Management Council (NPFMC) Bering Sea Groundfish Plan Team recommended that if hook-and-line gear rather than trawl gear were used to prosecute demersal fisheries in the Bering Sea/Aleutian Islands Area (BSAI), significant bycatches of halibut, salmon, and crab would be virtually eliminated. Halibut bycatch remains a significant problem in the cod fishery. Longliners fishing for cod in the BSAI prevailed upon the National Marine Fisheries Service to implement a "Careful Release Program" which requires by regulation that all halibut bycatch on longliners be released by one of three techniques—shaking, hook straightening, or gangion cutting. Working with Fisheries Information Services of Juneau, Alaska, the freezer-longliner fleet established a real-time communication system to calculate halibut mortality rates for each vessel, and to communicate that information to the captains. In its first five months of operation, this program reduced halibut bycatch mortality from 18% to 11.5%—a 36% reduction, with only two-thirds of the fleet participating. Further reductions are anticipated. The NPFMC has been asked to consider expansion of the use of fixed gear (hook-and-line and pots) in the BSAI cod fishery.

Bycatch and discards in the successive trawl fisheries—foreign, joint venture, and domestic—have repeatedly brought turmoil, headlines, and extensive regulation to our industry. It is time to explore the use of passive gear in harvesting groundfish—particularly in the BSAI fishery for Pacific cod.

The Prohibited Species Problem

Prohibited species are those fully utilized in directed fisheries, such as crab, salmon, halibut, and herring. Regulations implementing the Fishery Management Plan (FMP) for Groundfish of the BSAI require that all such species caught in other directed fisheries must be returned to the sea in the best condition possible.

In the late 1970s foreign trawlers dominated the groundfish fisheries off Alaska. Prohibited species bycatch in these fisheries, particularly salmon bycatch, was so great that in 1980 Alaska Native groups sued the Secretary of Commerce, challenging the adequacy of federal regulations addressing bycatch in the BSAI. A flurry of restrictive regulation followed. During the 1980s a similar problem arose in the joint venture trawl fisheries. Bycatch of crab was so great in the BSAI that a new trade association was formed to protect crab interests, and a significant trawl closure was imposed. Today, bycatch and discard of prohibited species, target species, and other species in the domestic BSAI trawl fisheries is front-page news. In fishery management it seems as though George Santayana's famous dictum has gone unheard, "Those who cannot remember history are condemned to repeat it."

Prohibited Species Catch Limitations

The North Pacific Fishery Management Council (NPFMC) regulates the fisheries in the Exclusive Economic Zone (EEZ) off Alaska. In a direct attempt to limit prohibited species bycatch, the NPFMC has established prohibited species catch mortality limits or caps (PSCs), for the various fisheries in the BSAI. The trawl industry has an overall halibut PSC cap of 3,775 mt, which is allocated to various target fisheries. In 1995, 1,550 mt, or 41% of this overall cap was allocated to the trawl fishery for cod. This is the largest single allocation by a wide margin. The cod quota available to trawlers is 135,000 mt, only 7.2 % of the total groundfish quota available to trawlers—some 1,880,000 mt. The hook-and-line fisheries have an overall halibut PSC cap of 900 mt, 725 mt of which is devoted to the fishery for cod. Cod will account for 98% of the longline catch in the BSAI in 1995 (Fisheries Information Services). If there is a logical place to reduce halibut mortality in the BSAI groundfish fisheries, it is the trawl fishery for cod.

Other Attempted Regulatory Solutions

Other regulatory attempts to resolve these bycatch and discard problems are legion. Time and area closures, often linked to PSCs, have been or are being imposed on the trawl fisheries with such regularity that a regulatory chart of the BSAI area resembles nothing so much as a patchwork quilt (Fig. 1). There is a permanent Pribilof trawl closure to protect blue king crab. A permanent closed area to protect red king crab is being developed to supplement existing Prohibited Species Bycatch Limitation Zones and PSC caps (the caps are subdivided among the various trawl fisheries). Recently an emergency rule implemented a closed area to protect king crab during the fishery for roe rock sole. There are Tanner crab PSC Bycatch Limitation Zones, and PSC caps similarly subdivided. Halibut PSC caps apply to both longliners and trawlers, are apportioned among various target fisheries, and are allocated seasonally. There is a Summer Herring Savings Area 1, a Summer Herring Savings Area 2, and a Winter Herring Savings Area. All trawling is prohibited in these areas when a herring PSC limit is attained. There is a Chum Salmon Savings Area. A Chinook Salmon PSC Reduction Plan is awaiting approval by the Secretary of Commerce. The list goes on and on, and is summarized in a current draft Appendix D to the BSAI Groundfish FMP (Witherell and Harrington 1995).

Further regulatory initiatives have been undertaken, often at the insistence of industry, aimed at controlling trawl bycatch. Pelagic trawls, designed to avoid bycatch by staying off the bottom, just didn't work. The Vessel Incentive Program, aimed at penalizing individual vessels which exceed established bycatch standards, is widely counted a failure—a victim of insurmountable practical problems of proof and due process that render any program aimed at individual vessels impractical. It is claimed that wide-mesh codends will release juvenile fish, but preliminary investigations indicate that the survival of juvenile pollock strained through a codend is zero. The fish become disoriented and are subject to predation. Sorting grids over fish holds may save large halibut, but the small ones—which are the real concern—will pass through. In sum, these measures are of questionable value in reducing bycatch and associated mortality to any substantial degree.

The effectiveness of these measures can perhaps best be evaluated by examining the reasons for trawl fishery closures over recent years. Draft Appendix D to the BSAI groundfish FMP (Witherell and Harrington 1995) shows that since 1992, many major trawl fisheries have been shut down because PSC limits for halibut, red king crab, or Tanner crab were reached (Witherell and Harrington 1995 [Tables 5 through 8]). From this fact alone we can infer that generally speaking, efforts to reduce prohibited species bycatch aren't working very well. Halibut bycatch and mortality rates in the BSAI trawl fishery for cod remain essentially unchanged (Fig. 2).

The Target Species and Other Species Problem

Bycatch and discard of prohibited species is only part of the problem. Loud public protests have lately bemoaned the observed discard of target species and other species in the trawl fishery—ranging from 275,000 to 300,000 mt annually in the BSAI from 1992 to 1994—as much as 660,000,000 pounds (NMFS 1995). Significant amounts of pollock and cod are discarded in the directed BSAI trawl fishery for cod. Discards in the hook-and-line fishery are minuscule by comparison, according to National Marine Fisheries Service (NMFS) data on the 1993 BSAI hook-and-line and trawl groundfish discards in the Pacific cod fishery.

The Fixed Gear Solution—Theory

A considerable uproar followed the filing of the Alaska Native lawsuit challenging federal management of prohibited species bycatch in the

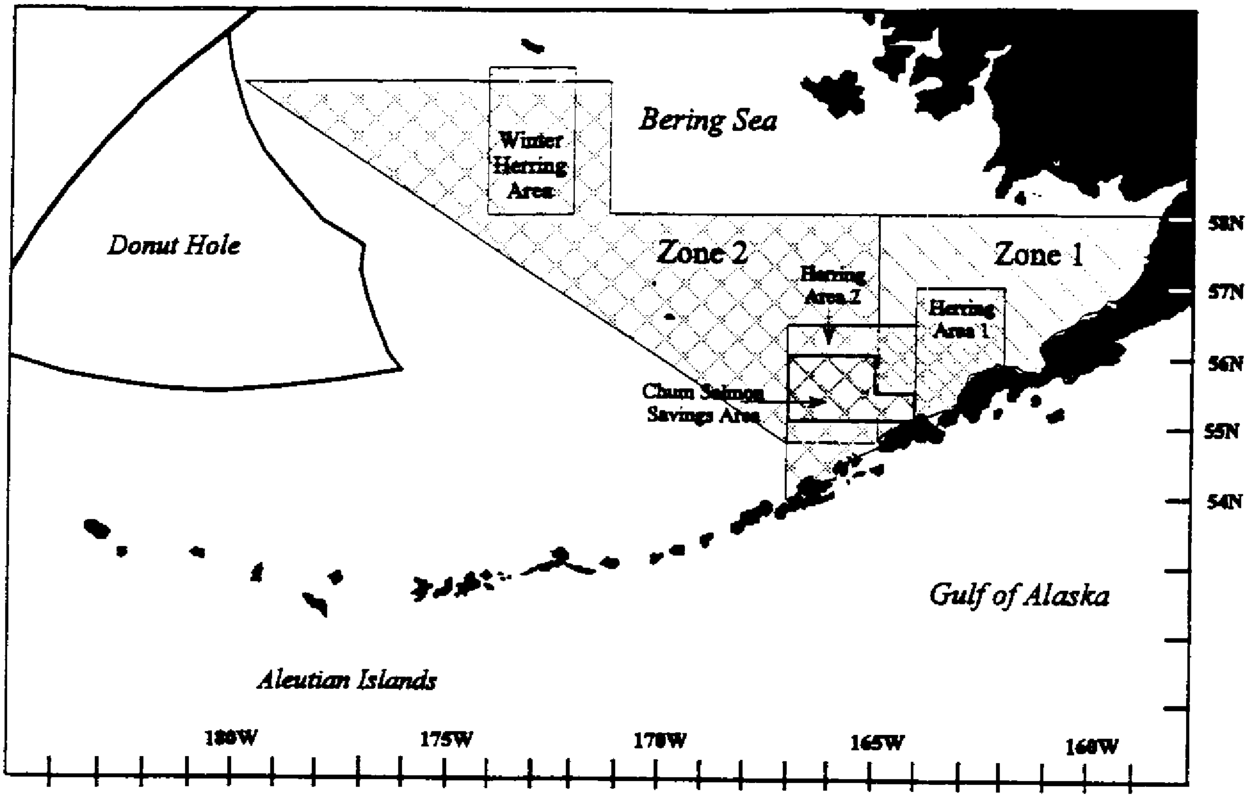

Figure 1. Prohibited species bycatch closure areas. Source: NMFS.

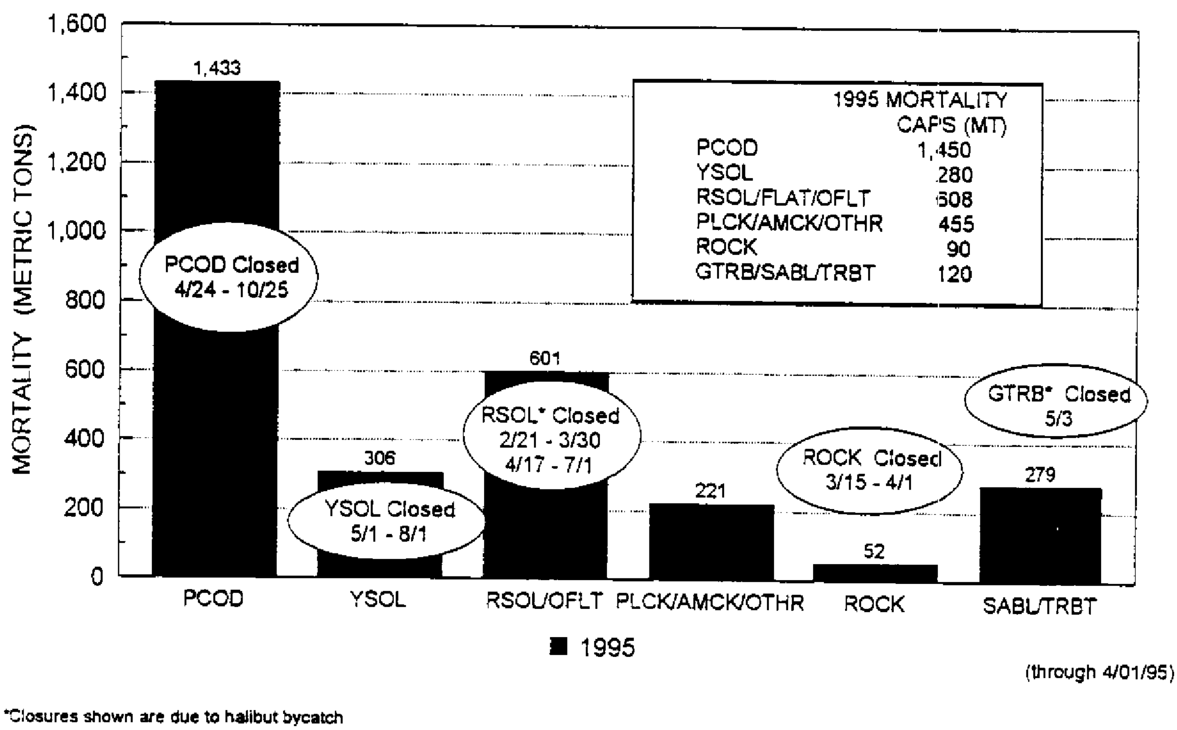

Figure 2. 1995 BSAI halibut bycatch mortality, trawl. Chart by Fisheries Information Services, 2007 Cohen Drive, Juneau, AK 99801. Data source: NMFS.

trawl fisheries. The North Pacific Fishery Management Council appointed an Ad Hoc Working Group on Prohibited Species, which, working with the NPFMC's Scientific and Statistical Committee, produced Council Document #13, Reducing the Incidental Catch of Prohibited Species by Foreign Groundfish Fisheries in the Bering Sea (April 1981), a collection of scientific papers describing the prohibited species bycatch problems and suggesting solutions. One of the papers (Wespestad et al. 1982) observes that the incidental catch of prohibited species is much less with longlines or off-bottom trawls (truly pelagic trawls which do not touch the bottom) than with on-bottom trawls, and recommended consideration of two management alternatives involving gear restrictions: (1) prohibit on-bottom trawls in all areas, i.e., groundfish will be harvested only with longlines and off-bottom trawls; and (2) on-bottom trawl gear will be allowed only in areas defined as yellowfin sole or turbot grounds.

Analysis revealed that the estimated savings of prohibited species would be dramatic. Alternative (1) greatly reduced the catch of all prohibited species: halibut catches were reduced by about 92%, Tanner crab and king crab catches by 99%, and salmon catches by over 80%. Alternative (2) also reduced catches of prohibited species, but the reductions were less than for alternative (1).

The Fixed Gear Solution—Practice

In June of 1991 the North Pacific Fixed Gear Coalition petitioned the NPFMC to give fixed gear preferential access to demersal groundfish species, based on these conservation considerations. The petition contains a synopsis of scientific, academic, and descriptive papers comparing hook-and-line gear to trawl gear (Committee on Merchant Marine and Fisheries 1994).

The NPFMC responded by dividing the annual BSAI cod total allowable catch (TAC), 44% to fixed gear (hook-and-line and pots), 54% to trawl gear, and 2% to jig gear. Fixed gear representatives also convinced the NPFMC to require by regulation that all halibut caught in the hook-and-line fishery for cod be carefully released by shaking, cutting the gangion, or hook straightening.

This program was in place for the 1994 season. It was assumed that the mortality rate of halibut bycatch in the hook-and-line fishery would be 12.5%. This estimate had not been substantiated in practice. Trawl halibut mortality was assumed to be 64%, based on observer data. The hook-and-line industry expected that NMFS would monitor mortality rates in-season, giving notice if rates exceeded 12.5%. It was also expected that NMFS observers would notify captains and crew if they saw halibut being killed or wounded, or if careful release was not being practiced. In the event neither communication came about, and only when the season was nearly over, did the International Pacific Halibut Commission (IPHC) inform the longline industry that its mortality rate for 1994 was 18%.

In response to this information, the hook-and-line fishermen organized an industry halibut bycatch mortality monitoring program with Fisheries Information Services of Juneau, Alaska (FIS) for the 1995 season. Each week the vessels fax raw observer data on the physical condition of halibut bycatch to FIS. FIS calculates the halibut mortality for each vessel and faxes it back promptly and confidentially. In this way a captain learns immediately if he is fishing in a high bycatch area, or if his crew is mishandling the halibut.

The program has been remarkably successful. Two-thirds of the fleet participated, and on June 1, 1995, the IPHC published an analysis. This study (Williams and Sadorus 1995)—which was rigorously conducted—determined that the halibut discard mortality rate during the first five months of 1995 was 11.5 %, a 36% reduction from the 18% calculated for 1994. Observer data also indicated that the primary cause of mortality in longline halibut bycatch is sand flea predation. Vessels using swivel gear had lower discard mortality rates, probably because the gear provides the halibut more mobility. The NPFMC recommended that the assumed halibut mortality rate for hook-and-line halibut bycatch be lowered to 11.5%, and that cumulative halibut mortality for the season be recalculated. With full participation by the fleet, we hope to do better. By comparison, trawl halibut bycatch mortality rates for 1994 and 1995 were 64% and 65%, respectively.

Potential Halibut Savings

Rocket science is not required to determine that the TAC for Pacific cod in the BSAI area could be taken entirely by fixed gear with a considerable savings of halibut, as the 1981 study predicted. Through May 27, 1995, hook-and-line operators harvested and retained 71,777 mt of groundfish in their directed BSAI fishery for cod, using 417 mt of halibut mortality. At that same rate, they could harvest the entire TAC available to directed fishing (250,000 mt TAC less 35,000 mt trawl bycatch = 215,000 mt) with 1,249 mt of halibut mortality. As things stand (September 1995), the cod will be harvested by a mix of fixed and trawl gear, using 2,275 mt of halibut PSC (1,550 mt trawl PSC cap plus 725 mt longline PSC cap = 2,275 mt). Subtracting the mortality of a longline-only fishery from that of the current mixed-gear fishery, we see that more than 1,000 mt of halibut could be saved if the directed fishery were prosecuted with longline gear only (2,275 – 1,249 = 1,026). There would also be considerable savings of pollock, cod, crab, and other species, according to NMFS data on the 1993 BSAI hook-and-line and trawl groundfish discards in the Pacific cod fishery.

Proposed Plan Amendment

Former NPFMC member John Winther and the Kodiak Longline Vessel Owner's Association, joined by a number of other fixed gear groups, have proposed an amendment to the BSAI Groundfish FMP which includes two options to make the BSAI directed fishery for cod a fixed gear fishery. Provision would be made for cod bycatch in other trawl fisheries. One alternative would accomplish this purpose immediately; the other involves a three-year phase-in period. Fixed gear would include hook-and-line gear and pots. Halibut bycatch in pots is so low that pots have been exempted from halibut PSC limits. If pots take part of the cod quota, halibut savings will be even greater. The proposals would also require full catch retention in the fishery, except for skates and sculpins.

It is interesting to consider the value of such savings, and what might be done with them. IFQ halibut shares are selling for $6 to $9 per pound, depending on the area in which the fish can be taken. Using an average of $7.50 per pound, we can calculate that 1,026 mt of halibut saved and harvested in the ITQ fishery should be worth some $17,000,000 (1,026 × 2,200 × $7.50 = $16,929,000). Halibut saved from the trawl cod fishery could be used in other trawl fisheries, enhancing their value. Finally, halibut saved could be apportioned to the hook-and-line fishery as a reward to encourage clean fishing.

Conclusion

The theory proposed by the NPFMC Work Group—that prohibited species bycatch in the BSAI groundfish fisheries could be greatly reduced if hook-and-line gear rather than trawl gear were used in bottom fisheries—has been proved in practice. While longline fishermen have halibut bycatch in the BSAI fishery for cod, they are able to reduce associated mortality significantly through careful release and industry bycatch monitoring. This latter program functions without any federal regulation or expense, and it is hoped that performance will further improve with the whole fleet involved. At least 1,000 mt of halibut PSC could be saved annually if the BSAI directed cod fishery were prosecuted with fixed gear only. Bycatch and discard of other species would be reduced significantly. No complex and expensive regulation would be required. No additional investment in vessels or gear would be required. Clean fishing would be encouraged and rewarded without creating problems of proof and due process. Halibut bycatch in the directed fishery for cod is the most solvable bycatch problem in the BSAI today.

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Bycatch and the IFQ System in Alaska: A Fisherman's Perspective

Dean J. Adams
F/V Quest, 10018 Richwood Ave. NW, Seattle, WA 98177

Rapid and unrestricted expansion of the Gulf of Alaska longline fleet during the late 1970s and early 1980s compressed the Pacific halibut (*Hippoglosus stenolepis*) fishery into one madcap 24-hour opening known as the "derby." The dynamics of the derby fishery encouraged vessel operators to opt for short-term incentives related to immediate financial needs and forego long-term economic incentives related to conservation of the fishery. Management response to expansion of the fleet was the development of a specialized Individual Fishing Quota (IFQ) system initiated in the spring of 1995 for the Pacific halibut and sablefish (*Anoplopoma fimbria*) longline fisheries.

One attraction of the IFQ system was that due to the legal retention of incidental bycatch of either halibut or sablefish made possible under IFQ regulations, reduction of bycatch discard mortality would be likely. When fishing for sablefish in derby fisheries, vessels were required to discard halibut, and vice versa. Before the first year of fishing was completed in 1995, reduction in bycatch mortality had been observed in these fisheries.

Changes in harvest strategy were responsible for further reduction of bycatch mortality. Loss of fish due to gear conflict between vessels became the exception, rather than the rule, because of the long season associated with the IFQ system. The long IFQ season was also responsible for the discontinuation of the practice, and legal requirement, of abandoning set-lines at the termination of the 24-hour derby fishery. The IFQ system halted mortality due to fish dying on unretrieved gear.

The IFQ system of management allowed fishermen to make decisions not affected by time or space constraints which are inherent to derby fishing. With the IFQ system, fishermen can be selective about such factors as fishing depth, bottom substrate, or time of day, month or year. These factors are directly related to incidental halibut bycatch mortality.

In its rookie year, 1995, the Individual Fishing Quota (IFQ) system in Alaska for the halibut and sablefish longline fisheries has directly manifested itself as an effective management tool for reducing halibut bycatch mortality. Preliminary analysis (Smoker 1995, Table 1) has shown that the halibut bycatch mortality rate by longliners in the sablefish fishery has dropped from 42% in the 1994 open-access fishery to 22% in the 1995 IFQ fishery. Within just one year of an IFQ fishery, a 61% reduction in mortality has been realized.

Preceding the application of the IFQ system, unlimited access to the halibut and sablefish resource generated fisheries called "derbies" that promoted harvest strategies which unnecessarily exacerbated halibut bycatch mortality to a tragic level. During the development of the Alaska IFQ system, reduction of excessive halibut bycatch mortality was designated as a primary goal of an IFQ fishery.

An IFQ system fundamentally provides additional time for fishermen to fish. Fishermen can choose when to fish their Individual Quota (IQ)

Table 1. Gulf of Alaska longline sablefish target catch, bycatch, and discard data (Smoker 1995).

	1994		1995		1995/
	mt	%	mt	%	1994%
All groundfish[1]					
Retained	1949	75.5	2374	90.4	
Discarded	631	24.5	251	9.6	39.1
TOTAL	2579		2624		
Sablefish					
Retained	1751	96.8	2173	98.2	
Discarded	58	3.2	39	1.8	55.1
TOTAL	1809		2212		
Other groundfish[2]					
Retained	197	25.6	201	48.7	
Discarded	573	74.4	212	51.3	69.0
TOTAL	770		412		
Halibut[3]	1073	41.6 *	578	22.0 *	53.0

[1]All groundfish taken in sablefish target fishery
[2]Groundfish other than sablefish (e.g., rockfish, skulpins)
[3]Halibut taken in sablefish target fishery
*Proportion halibut to total groundfish
Notes: Preliminary data. Observed vessels only; (not extrapolated to fleet). Source: NMFS Observer Program In-season Data.

at any time of the year, except in the winter months when the fisheries are closed due to biological considerations. The IFQ system spread out the Alaska fleet, temporally and spatially; two key elements to achieve reduction of halibut bycatch mortality. By providing more time and space, the IFQ system eliminated the infamous "race-for-fish" commonly exhibited in fisheries that lack effective, or economical, harvesting-power management. The race-for-fish and fishery management with derby openings were directly responsible for excessive halibut bycatch mortality in the halibut and sablefish longline fisheries.

Beginning in the mid-1980s, the U.S. longline fleet became a large player in halibut bycatch mortality—second only to the trawl fleet. Ironically, mortality due to the longline fleet was coming directly out of annual halibut quotas allocated to the longline fishery, with the effect of abbreviating the longliners' own halibut fishery. Even though the trawl fleet had historically been granted a greater halibut discard mortality allocation than the longline fleet, increased halibut mortality from longliners was subtracted from directed longline fishery quotas. Current politics of bycatch in the North Pacific have not given indication of any reduction of trawler-caused mortality of halibut under present time-area management regimes.

In the last decade of open-access management, the halibut fishery was reduced to an average of less than two days of fishing (without trip-limits) per year in the Gulf of Alaska (IPHC 1985-1994). Unrestricted access allowed uncontrolled expansion of the fleet and its harvesting-power, thereby shortening the season. As the halibut fishery became more abbreviated over time, wasteful harvest practices worsened as well. By 1994, bycatch discard mortality of the longline fleet was responsible for over 10% of total halibut mortality in the Gulf of Alaska (IPHC 1993).

This paper provides a perspective of the longline fishery and its bycatch, both before and after IFQs, that is valuable to managers of other fisheries. Details of the dynamics of longlining illustrate how subtle changes in fishermen's activities can have profound effects on bycatch mortality. Other fisheries, such as trawling, have subtleties that produce unnecessary bycatch mortality that could also be addressed by IFQs. I began longline fishing in 1972. My career spans the period from when halibut and/or sablefish long-liners could fish all year, to the recent era of one day halibut derbies in the Gulf of Alaska. From a fisherman's perspective, it is clear why the IFQ system is a success in reducing halibut bycatch mortality.

The following three components were responsible for halibut bycatch mortality by the longline fleet: (1) gear loss in the halibut fishery and subsequent loss of fish on gear, (2) mandatory discards of halibut bycatch in the sablefish fishery, and (3) incidental bycatch and mortality of sub-legal sized halibut in both the halibut and sablefish fisheries. By allowing fishermen to address these factors and change their harvesting practices, the IFQ system gave longline fishermen the opportunity to significantly reduce halibut bycatch in their own fisheries.

Overview of Halibut Bycatch in Alaska

To understand a major factor why the halibut and sablefish fisheries in Alaska have come under an IFQ management system, an overview of halibut bycatch is needed. The volume of incidental bycatch of halibut has gone through distinct phases in the evolution of Alaskan deep-sea fisheries. Halibut bycatch has reached critical levels in just the last 30 years of this 100-year-old fishery.

The Foreign Trawl Fishery in Alaska

In the 1960s, large factory-vessel fisheries were developed by foreign fleets (primarily USSR, Japan, Taiwan, and Korea) to exploit the massive groundfish resources on the continental shelf off Alaska. Bycatch of halibut was largely undocumented and not well quantified during the 1960s and the early 1970s. Bilateral agreements with the U.S. stipulated that retention of halibut was not allowed. Bycatch by foreign vessels was recognized as significant, but the degree to which bycatch occurred was largely unknown and estimated with incomplete information.

In 1976 with the passage of the Fisheries Conservation and Management Act (FCMA or Magnuson Act), factory-trawl harvests were monitored by National Marine Fisheries Service (NMFS) observers, and more effective management of halibut bycatch was initiated. Maximum allowable quotas or "caps" of halibut bycatch (or bycatch mortality) were placed on individual fisheries as well as vessels' country of origin. In many cases, foreign nations distributed their bycatch allotment among its own vessels, creating an Individual Bycatch Quota, or "IBQ," for each vessel.

Americanization and Joint Ventures

With passage of the FCMA came advantages for U.S. fishermen and companies to exploit U.S. waters within 200 miles by giving U.S.-owned vessels first opportunity at fish resources. The groundfish fisheries in all of the U.S. Pacific region became Americanized in the 1980s and quickly displaced the foreign fishing fleet. The Americanization process was accelerated by the collapse of the Bering Sea king crab fishery in the early 1980s. Many king crab vessels were converted into trawl catcher boats for foreign processing mother-ships during this period. The foreign joint-venture (JV) fishery was very successful and profits from these operations were invested in U.S.-owned factory vessels. Incidentally, the U.S. ownership of these vessels is somewhat dubious because many owners were simply U.S. companies that were based in foreign countries. Not surprisingly, the Americanized fleet inherited the same problems related to halibut bycatch experienced during the foreign dominated fisheries; however, they were not initially subjected to restrictions to control bycatch.

Bycatch by Gear Type—Trawl, Pot, and Longline

Since the 1960s, the main source of halibut mortality due to bycatch has been the groundfish fisheries conducted with bottom trawls. According to data collected by the National Marine Fisheries Service (NMFS), the 1994 U.S. bottom trawl fishery continues to be responsible for the largest proportion of halibut bycatch in all Alaskan fisheries, 6,149 mt out of 7,890 mt. The pot fishery for crab and groundfish has historically exhibited very low rates of bycatch and is not a significant source of halibut bycatch in Alaska.

Beginning in the 1980s, three U.S. longline groundfish fisheries (the sablefish fishery, the Pacific cod fishery, and the directed halibut fishery) began to take a heavy toll on discard mortality in the halibut resource. This paper focuses on halibut discard mortality and bycatch waste reduction in the halibut and sablefish longline IFQ fisheries.

Forces Behind Longline Bycatch of Halibut

A host of demands placed on the halibut fishery and its associated bycatch fisheries created an environment for accelerated and avoidable halibut bycatch. These species have viable markets and high value that stimulate fishermen to harvest them. The numbers of vessels fishing halibut and sablefish expanded rapidly in the late 1970s as fishermen from non-longline fisheries (primarily the limited-entry salmon fishery) took up longlining. The halibut and sablefish fisheries turned into derbies as the season compressed. In this environment, fishermen were influenced to make decisions based on short-term success rather than for the long-range benefit of the halibut resource and fishery.

Market Demand for Halibut and Sablefish

Halibut is a premier seafood product featured in North American restaurants. Among North Pacific fishes, halibut competes with chinook salmon for top billing on menus. Halibut commands a premium price if delivered to the market fresh, rather than frozen.

In contrast to halibut market characteristics, sablefish is distributed in an almost exclusive Asian market and is nearly always frozen when processed in Alaska. It retains quality very well when frozen and can be held in cold storage for several months without significant degradation.

Demands of Time and Money: The Derby

A lengthy season of longlining is not appealing to the senses of many people. However, with the dream of exceptional financial reward in a short period of time, many people can overcome resistance to this detraction. Shortening seasons beginning in the late 1970s, made the halibut fishery more popular to a larger population of potential (and inexperienced) fishermen. With more halibut available, high catch rates and shorter seasons, people with shore-based jobs found it not only attractive, but more feasible, because they could keep their regular job and still fish the derby.

Simple mathematical analysis will help illustrate the incredible economic force that was propelling fishermen in the derby. During each year's derby, a handful of boats in the fleet would commonly catch as much as 100,000 lb of halibut. During a halibut derby, vessels were generally being operated as though this opening could be their 100,000 lb trip. Bear in mind that hundreds of vessels and thousands of people were prepared for the halibut derby based on a dream with that scale of success. What is the monetary scale of that dream?

Multiply 100,000 lb by $1.50, a typical ex-vessel price for halibut, and you have a $150,000 delivery. Divide $150,000 by 24 hours, the length of a Gulf of Alaska derby, and that is $6,250 worth of fish coming into the boat per hour. That rate exceeds revenue of over $100 per minute. With that kind of income in such a short period of time, an atmosphere of high-stakes gambling settled on the industry.

Professional fishermen had an additional force to drive them during the derby. These short seasons represented the only opportunity they had to support themselves and their families. Most professional longliners have a modest background of skills to fall back on should their main profession fail them.

Derby Mentality

Over the years as the derby senesced, the term "derby mentality" crept into North Pacific fisheries management vocabulary as more people began to understand how the users of the halibut resource were behaving on the fishing grounds. Since I had fished halibut for many years of long seasons, I had many opportunities to learn about the distribution of fish while I was actually fishing; the derbies seemed to me like gambling. The opening was like a roll of the dice. It was illegal to sample on the fishing grounds for three days preceding a derby, so a halibut fisherman had no chance to find out if fish were present at a fishing spot before an opening. We just set out our gear and hoped for the best. The quality of a good fisherman swayed from the ability to find fish through the actual process of fishing, to the ability of a fisherman to haul as much gear as possible in 24 hours.

Components of Longline Bycatch

Gear Loss in the Halibut Fishery

For the decade of halibut seasons before the 1995s IFQ fishery, appropriate spacing for setlines of all vessels on the fishing grounds had become an acute problem. Longline gear is very long, and if it is not allowed to lie by itself in one linear "set" or "string," significant halibut discard problems immediately develop due to gear conflict and gear loss. To understand why halibut mortality from gear loss reached almost 500 mt per year (IPHC 1993), dynamics of longline fishing must be described in detail.

Gear Conflict Among Halibut Vessels

In its simplest form, an example of gear conflict between two fishermen is when fisherman A sets a string of gear, and later, fisherman B sets gear perpendicularly across fisherman A's string. In longliner jargon, string A has been "set down" by string B. Since string A was on the bottom first, it will typically be hauled first. When fishermen A picks up the first end of the string, he/she begins hauling and eventually the gear will start pulling against string B. Meanwhile below the surface, hooks from the opposing fishermen's gear are hooking on each other's gear and the hooks are either straightening or breaking off the main line. Any fish on these hooks will be lost to the fishermen, dead or alive. Invariably, hauling tension on string A will become very great.

Should fisherman A be able to haul string B all the way to the surface, fisherman A has three choices to clear up this problem: (1) cut string A and tie it back together, (2) cut string B and retie it, or (3) simply cut string B and not bother retying it. From a safety standpoint, cutting and releasing string B is not a bad idea because it normally has a tremendous amount of tension on it. The actual fishing gear always has hooks attached which can easily catch unsuspecting crew by the hand and possibly pull them overboard.

In pre-derby fisheries, most longliners would take the time to retie gear. More time was available in a non-derby environment to let tension be relieved on the gear before attempts to retie it were made. Retying gear was the norm rather that the exception.

When fisherman B hauls his/her gear, it will have been cut and the string will not be retrieved contiguously. Fisherman B will now have to run down the parted string and pick up the remaining end. This takes a lot of time, because vessels only travel at 10 nmph, and fisherman B's next string to haul would normally be set near the end of the now parted string. Another time-consuming run would have to be made after the parted section was retrieved.

The good news is when both sections of the parted section are retrieved. The only bycatch mortality here arises from those hooks lost with fish, but only those fish that were dead or eventually died from their hook injuries. The bad news comes if fisherman B's string parts before all of it is retrieved. Tension on either string of gear being retrieved in a gear conflict situation can grow to the point were it may part. Gear can also part due to natural causes such hanging-up on the bottom, but more frequently the source of gear loss during the derbies was gear conflict and multiple cuts of a string. If a string of gear is cut more than once, some gear will be lost on the ocean bottom. Lost gear equates to lost fish.

I tended to avoid some of the gear conflict hotspots such as Seward Gully or Portlock Bank. I was unusually lucky if I could avoid conflict with other vessels even though I was extremely vigilant their activities. Seward Gully and Portlock Bank are notoriously productive for halibut. Too many vessels would show up at these areas and vie for too little fishing ground. Vessels were literally crawling and hauling gear on top of one another.

During a derby about 10 years ago in Seward Gully my uncle estimated that about 8 strings of his gear had been set down and/or cut more than 14 times. He didn't know for certain how many times because he was unable to retrieve all of his gear.

Optimization of a Derby and the Associated Waste of Halibut

Perhaps the most sardonic cause of halibut bycatch mortality occurred at the end of the halibut derby. Recall derby mentality and put yourself in the position of a fisherman. What would you do if this was your last big shot at making payments for the year on your car and/or house? If you had a 24-hour opening, would you set out what you guessed to be 24 hours worth of gear, or 26 hours worth, or even 28 hours worth? To be confident that the vessel fished for the entire opening, only the latter choice—28 hours—would ensure that the vessel hauled gear at all times during the opening.

If a vessel gets really lucky and sets its gear on a lot of fish, gear retrieval can become aggravatingly slow particularly if the crew is inexperienced at longlining, or if the vessel does not have space on deck for more fish. Retrieving 24 theoretical hours of gear is impossible in such conditions and a vessel will be forced to leave gear at the end of the derby. In this instance, large numbers of fish will be left to die on unretrieved gear.

For the last five years of open-access fishing, mortality by lost gear due to natural causes, gear conflict, and derby closure was estimated by the IPHC (1989-1994) to be responsible for an average of nearly 1,500 mt of halibut mortality and waste per year.

Bycatch of Halibut in the Sablefish Fishery: The Bycatch Zone

Spatial Distribution of Halibut and Sablefish

The Pacific halibut is the largest of the flatfishes and is found in high densities anywhere from just beyond the ocean shoreline to depths greater than 500 m (275 fm). Sablefish inhabit very deep waters ranging from 200 m (110 fm) to over 1,500 m (800 fm). However, small juvenile sablefish are commonly found in shallow water. Halibut and sablefish range from California north to the Gulf of Alaska and as far west as eastern Asia.

The Bycatch Zone

Quite different from most bycatch headaches in world fisheries, clean catches of halibut and sablefish can be achieved in distinct areas or depths. The source of bycatch for halibut and sablefish is located where both species commingle at a depth range between 200 m and 500 m, along the entire continental shelf off Alaska (Fig. 1). I developed the term "bycatch zone" to describe this depth band for an article on the advantages of the IFQ system and bycatch reduction (Adams 1994). Fishing activity in the bycatch zone will produce mixed catches composed primarily of these two

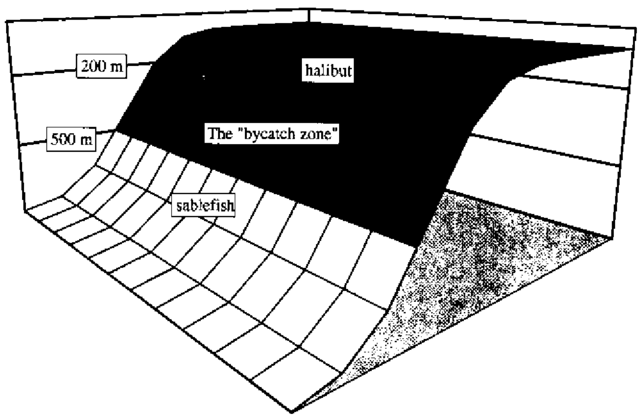

Figure 1. The halibut and sablefish bycatch zone (Adams 1994).

species. These depths are very popular for both directed halibut and sablefish fishing. When fishing in this zone I have seen very high concentrations of both halibut and sablefish, with one qualification, over time on productive fish habitat halibut can be found more often than sablefish. Sablefish are either abundant or virtually non-existent in this depth range. At depths below 500 m, sablefish are invariably present and can be harvested without halibut bycatch. Conversely, halibut can be found consistently at depths above 200 m without notable sablefish bycatch. So, why were longline fishermen becoming their own enemy guilty of large volumes of halibut bycatch mortality? Why were longline fishermen killing millions of pounds of halibut and discarding these valuable fish on the fishing grounds only to be scavenged on the ocean floor by crabs and sand-fleas?

Gear Saturation on the Edge

Until the early 1980s, the habitat on the continental shelf "edge," was equivalent to wide open rangelands with nary a fence post. On the average, the edge takes about 3 km to slope from 500 m to 1000 m in the Gulf of Alaska. An efficient length for a fisherman's sablefish set-line is also 3 km, so we would frequently set gear between these depths. Hauling longline gear below 1000 m becomes increasingly difficult, even with powerful hydraulic gurdies.

Until the late 1980s, the sablefish fishery was conducted on the edge between the depths of 500 m and 1000 m. In the late 1980s, this depth range became saturated with gear as the sablefish fishery quickly mirrored the senescence of the halibut fishery and evolved into a derby.

Before the fishing grounds were saturated with gear, fishermen would work set gear to seek out the lower depth of halibut distribution. To determine where the halibut were, we would bounce the shallow end of our gear up to halibut depth like a balloon would bounce on a ceiling. We would start deep, explore shallower depths until halibut were found, then bounce back to the deep.

The following factors provide logic for this fishing tactic:

1. 500 m is deep water which means that a lot of buoy-line had to be retrieved in order to start making money when you start hauling hooks. If you were not hauling hooks, you were not making money. If you could reduce your buoy-line, you could start fishing sooner.

2. The depth also impacts the tension of gear when picking up the shallow end of a string and beginning the haul. An end can be picked up faster in 500 m than in 600 m because of the extra tension resulting from the extra depth.

3. Sablefish can be abundant at 500 m and shallower. If halibut are not present, a fisherman can do very well without bycatch. Since halibut are not visible on depth sounding equipment, the only way a fisherman can find out what the fish are doing is to experiment and set gear, or talk to other fishermen.

Bycatch of Sub-legal Sized Halibut

In 1993, 806 mt of halibut mortality was attributed to the mandatory release of small halibut. Catch of sub-legal halibut is a bigger problem than it appears because mortality of smaller immature fish per unit of weight have a larger negative effect on stock production than would mortality of larger mature fish.

With the IFQ system, I hope that fishermen and fishery biologists can make some recommendations to the longline fleet to change harvest practices to reduce mortality of sub-legal sized halibut.

I know of a few areas on the edge where there are high numbers of small halibut during the spring months. With IFQs I have great latitude deciding where and when to fish. I will avoid these areas and halt unnecessary halibut mortality. Perhaps as the fleet becomes more relaxed with the IFQ system, fishermen will ask for scientific information regarding the historical distribution of sub-legal sized fish, and the fleet as a whole will make a real contribution to reducing this component of halibut bycatch mortality.

Conclusion

I believe that fishermen will be sharing more information, albeit selectively, in the IFQ fishery than in a derby fishery. With less competition for space on the fishing grounds under IFQ management, confidentiality of the characteristics of fishing spots or harvest strategies will become less important. I believe that more communication from fishermen to fishery biologists will also take place. Important characteristics of bycatch that are obvious to fishermen on their vessels can be ambiguous to fishery managers. The fundamentals of fishermen's activities are often left out of management deliberations. Information at this level needs to become an integral part of managers' understanding of the fisheries they control. With this understanding, managers can make decisions that will have greater results toward the goal of bycatch reduction.

Halibut bycatch has been a long standing issue in North Pacific fisheries management. When the longline fleet began to turn on itself through derby fishing activities there were two choices: take fish from the longliners' annual quota, or find a solution to the problem. With few exceptions in the world's major fisheries, I believe IFQs are a solution and one of the most effective fishery management tools for bycatch reduction.

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Conservation Aspects of Fishing Gear: Cetaceans and Gillnets

Jon Lien
Memorial University of Newfoundland, 230 Mount Scio Road, St. John's, NF A1C 5S7 Canada

Gillnets are frequently identified as primary sources for mortality in air-breathing marine animals including seabirds, turtles, whales, dolphins, and porpoise. In addition to conservation concerns for many local populations and species, the public attachment to these animals has placed urgent pressures for significant reductions in bycatch on fishing interests using gillnet technology. Failing reductions, area closures or total bans on gillnets are commonly sought by managers and the public.

To defend themselves in the past, fishing interests have frequently denied or minimized bycatch extent or impact, and resisted past efforts to modify fishing practices or technology which reduce bycatch. Currently, such a strategy is less successful because of the intensity of the public interest in ocean conservation and distrust of the industry.

Without industry help, managers, scientists, and engineers have often not been successful in achieving practical bycatch reductions. With industry help, techniques have been developed to reduce bycatch that appear promising. Such modifications of fishing technology or operation must be based on an understanding of the sensory function and behavior of both target and bycatch species, as well as fishing practices. For instance, adding sounds to gillnets appears to be one approach that is effective in reducing bycatch of whales, dolphins, and porpoise.

In the future, new partnerships between scientists, engineers, and fishing interests will be necessary to solve gillnet bycatch of these high profile species. A single whale, presented in the media while towing a gillnet which entraps it, is the worst possible advertising for gillnet fisheries. New technology using acoustic alarms will be available to prevent gillnet bycatch of whales and dolphins, but practical implementation of effective reduction programs will demand new attitudes, cooperation, and joint efforts among all stakeholders.

A whale caught in fishing gear can easily destroy nets or tow them away. This can represent a substantial loss to fishermen. Once a frightened animal is towing the gear, it can pose a serious threat to boats and other gear in the area. Such an incident, reported to the public, is like a huge billboard with an anti-gillnet message. One highly publicized whale caught in a net, or even suspicions of undisclosed dolphin bycatch, can do much to destroy the image of a gear sector. The public's attachment to whales and dolphins has placed urgent pressures for significant reductions in bycatch on fishing interests using gillnet technology. Bans on gillnet technology or time/area closures are commonly suggested by the public and managers as solutions. To defend themselves in the past, fishing interests have frequently denied or minimized bycatch extent or impact, and resisted efforts to modify fishing practices or technology that reduce bycatch.

Currently such a strategy is less successful because of the intensity of the public interest in ocean conservation and distrust of the industry. For these reasons, fishermen must learn to deal constructively with this new hazard on the fishing grounds.

It is likely that the problem will increase in the foreseeable future. Due to whaling, the numbers of many whale species were seriously depleted. It is also known that indirect and incidental mortality of whales and dolphins due to fishing operations has also seriously reduced some populations (for example, see Perrin et al. 1994). Such reductions in a group of marine species can produce serious impacts on ocean ecosystems, and even on commercial fisheries (Katona and Whitehead 1988, Butman et al. 1994, Butterworth 1995). Thus, management actions in the United States, Canada, and in most nations have attempted to halt declines in whale and dolphin populations and to increase their numbers. This is a sensible course, but while increased numbers of whales and dolphins may be good news indicating a healthy ocean, it does pose a direct challenge to fishermen who must cope with increased numbers of animals, and heightened public awareness of bycatch problems.

A Partnership Between Fishermen and Scientists

For over a decade and a half, scientific and engineering work to minimize bycatch of cetaceans in fishing gear has been conducted in the waters of Newfoundland and Labrador (Lien et al. 1995). These efforts have met with varying degrees of success depending on the animal, fishermen, gear type, and bycatch problem involved.

The approach we have taken, which has been detailed elsewhere (Lien et al. 1992, 1995), has been to work cooperatively with fishermen on a problem for which they are responsible. We have resisted the urge to define bycatch as a scientific or management problem, become the good guys, and solve it for them. Our approach is slow and presents difficulties for the scientist; but in the end, both scientist and fishermen have gained from such partnerships and in generally they have been effective in achieving reductions of cetacean bycatches. Such an approach to bycatch solutions is not unique; there are other more notable examples, such as the cooperation which has slowly reduced dolphin bycatches in the tuna industry. Within these partnerships fishermen provide expert knowledge of gear and fishing procedures, and scientists add their expert knowledge of the animals and their environment. Alternative approaches in which scientific or management experts impose technology or restrictions on fishery participants generally meet with resistance from the industry and in actual practice take longer to be effectively implemented.

Without industry help, managers, scientists, and engineers have had difficulties in achieving practical bycatch reductions. With industry help, techniques have been developed to reduce bycatch that appear promising. Such modifications of fishing technology or operations must be based on an understanding of the sensory function and behavior of both target and bycatch species, as well as fishing practices.

Why Whales and Dolphins Get Caught in Fishing Gear

The exact factors which produce collisions and entanglement in nets are little studied and poorly understood. Porpoise may fail to detect or attend to the nets, they may be attracted to fish in and around the nets, or other factors. If incidental catches are the result of accidents, whatever the mixture of factors that actually lead to such encounters, one approach to minimizing them would be to enhance or amplify salience of net cues used by the animal, thus making the net easier to detect and define as a barrier (Lien et al. 1995). Much basic knowledge of whales and dolphins, and their behavior around fishing gear remains uncertain. Thus, the urgency prompting field studies to reduce incidental catches has required efforts to be based on common sense and general approaches to accident reduction.

Accident prevention in most situations, whatever the factors that actually produce accidents, is based on amplification of existing cues in the object or barrier, or enhancement of the object's detectibility by adding additional cues to its location or characteristics. Thus, for humans, fire hydrants are brightly painted, sirens are used on emergency vehicles, edges of steps are painted in high contrast strips, etc. Such an approach with animals includes use of whistles on vehicles to minimize road kills, patterns placed on windows to prevent bird strikes, etc. The actual success of such approaches varies depending on the nature of the environmental threat, conditions that produce the accidents, and a variety of species characteristics (Lien et al. 1995).

Whales are believed to primarily orient to objects such as fishing gear using either passive or active acoustics (Todd 1991). Thus, acoustical cues added to fishing gear might indicate to the whale that something is ahead and facilitate detection and/or detour behaviors. For smaller cetaceans, early encounters with nets lead to entanglement and death; in such cases, no learning about avoiding nets occurs. Enhanced acoustical properties of nets may facilitate initial net detection by young or inexperienced animals. Repeated exposure to, and use of, these cues could facilitate learning to effect net avoidance and detour behaviors (Jefferson et al. 1992). A focus of the research in this area has been to select sounds that are effective in getting the animal's attention, planning ways of placing acoustic devices on gear to define the net as a barrier, and making such net add-ons compatible with fishing operations.

Acoustic Alarm Field Tests

Humpback Whales and Codtrap Collisions

Large humpback whales frequently collide with and become entrapped in fishing gear in Newfoundland (Lien 1994). Most costly to fishermen are those cases in which the whales collide with codtraps. Acoustic alarms that produced sounds to which the whales were attentive, and which codfish could not hear (4 kHz at 135 db re 1 micropascal at 1 m at 3 s intervals) were developed (Lien et al. 1992) and placed on fishing berths that had histories of whale problems. These berths averaged 1.4 whale collisions/year in previous years. Other high risk berths where traps had no alarms were also monitored. A total of 4,150 trap days were monitored. Probability of a collision per fishing day was significantly different; traps without alarms were three times more likely to have a whale collision, and gear losses due to whales were also three times as high. Best of all, fish catches by traps with acoustic alarms were on average significantly higher—not because of any effect on the fish. Codtraps without whale holes in them simply fish better (Lien et al. 1992).

Attempts to Reduce Porpoise Bycatch in Gillnets

The codtrap alarms were used in 1992 to add sounds to groundfish gillnets that fished in New England where porpoise bycatch is high (Smith et al. 1991). These alarms are large, were made for permanently fixed gear, and are not appropriate for lighter gillnets. However, at the request of fishermen, they were used in a pilot effort to assess whether or not sounds added to gillnets would have any effect on bycatches. The alarms were adapted for placement on the headrope of groundfish gillnets; experimental strings had alarms on each end, and eight additional alarms evenly spaced along the string. Sounds from alarms could be heard at both ends of even the longest strings from the middle of those strings with hydrophones. Each fishing crew used two strings with alarms (total of 2,468 net days); other strings used by these fishermen served as controls (total of 5,562 net days). Observers recorded numbers of marine mammals caught in the nets. They also recorded numbers of seal-damaged fish, and ensured that each alarm was functioning.

During the experiment, 10 harbor porpoise were caught, all in control nets. While the fishermen all agreed that the large codtrap alarms were not compatible with normal fishing of gillnets, they felt strongly that the alarms were effective in preventing porpoise bycatch (Lien et al. 1995).

An Acoustic Alarm Designed for Harbor Porpoise and Gillnets

An alarm specifically designed for groundfish gillnets and harbor porpoise was available in 1993 and was tested in a similar experiment in New England. These alarms are much smaller and vary individually in the sound that they produce; harmonic patterns vary, as does the amplitude. The base frequency is a 2.5 kHz 1 s pulse, repeated every 2 s. The PVC pipe housing for the electronics emphasizes harmonics of the basic sound so there is a broad frequency pattern of energy up to 17.5 kHz. Amplitude is about 115 db re 1 micropascal at 1 m. The base frequency is at 2.5 kHz.

The experiment was organized in a manner similar to the 1992 study except that only one end of a string and the first five nets were fitted with alarms; the rest of the string had no alarms on it. Additional strings without any alarms were also used as controls.

During nearly 11,000 net days which were observed (60% nets in no alarm strings; 25% no alarm nets in experimental strings, and 15% alarmed nets) a total of 39 marine mammals were caught (33 harbor porpoise, 4 dolphins, and 2 seals). All but one animal was caught in no alarm nets indicating that porpoise are 4.6 times more likely to become entangled in non-alarmed nets that in nets with added sound.

Further tests of the gillnet alarm for harbor porpoise have been conducted in the Bay of Fundy, Canada, an area reported to be high in harbor porpoise bycatch (Gaskin 1991, Tripple 1994). In this area, each fisherman typically uses 4-5 strings of three webs. Alarm strings were fitted with four of the gillnet alarms (one on each end, and at each bridle). Control strings were of two types. One set of control strings was fished without alarms, the second set of control strings was fished with alarms that did not emit sounds. Non-functioning alarm strings were used to examine whether or not the alarm changed fishing effectiveness in any way. A string was randomly designated as an alarm or control string at the time it was first placed in the water, and alarms were placed on the string at that time. Each fishing day was monitored by an observer and catches of target and nontarget fish species and bycatch was recorded.

There were no differences in number of fish taken between experimental conditions. A total of 43 harbor porpoise were caught during the summer. Mean catch per net day was 0.016; 0.010 in acoustic alarm nets, 0.018 in silent alarm nets, and 0.019 in control nets. The difference between acoustic alarmed nets and control nets is significant but not as dramatic as in earlier tests. Acoustic alarms were sometimes recorded at distances up to 50 m from source, although the alarm signal was difficult to detect at that distance. At times, however, it was difficult to hear alarm noise at distances greater than 25 m. Thus, the signal to noise ratio observed in this experiment is believed to have effected results and made alarms less effective.

To check this, in 1995 the experiment was repeated using the same alarms but using 10 equally spaced alarms on a string of 3 nets for the experimental condition; strings with no alarms were used as controls. Under this circumstance, the net as a barrier was well-defined even in spite of high ambient noise and relatively quiet alarms. To date, 24 (92%) porpoise have been taken in no alarm nets which account for 60% of the observed fishing effort; 2 animals (8%) have been taken in alarm nets which account for 40% of the observed fishing effort. This would seem to indicate that alarms need not be excessively loud to be effective, but it is the density and pattern of attachment that is important.

Discussion

Lower numbers of whales and dolphins have consistently been caught in traps and nets fitted with acoustical alarms. However, there were many constraints inherent in planning and conducting the investigations.

Given the low probability of actually catching a porpoise on any net day, and the likelihood that any net modification will work at less than 100% efficiency, the experiments were handicapped from the outset, and basically lacked the statistical power to demonstrate alarm effectiveness clearly. Each experiment would, conservatively, have to be doubled for adequate statistical power. It is clear that acoustic alarms can reduce incidental entrapments of harbor porpoise in gillnets. The degree to which bycatch can be minimized by add-on sounds, the cost effectiveness of this approach for fishermen, management costs/benefits of this approach compared to alternative conservation measures—such as effort control, time/area closures, and quotas—all remain to be completely determined.

However, as a whole, the experiments using acoustical alarms on groundfish gillnets to reduce harbor porpoise bycatch are extremely promising. Without exception, fishermen participating in each experiment have become convinced that the alarms reduce bycatch. Each of the present studies showed much lower bycatch rates in alarm-protected nets. Fishermen clearly have the opportunity to work further with scientists to reduce bycatch of whales and dolphins using acoustic alarms.

During the course of these experiments, communication channels that developed between fishermen and scientists greatly improved. Fishermen gained greater familiarity with marine mammals and strategies to modify fishing gear to reduce bycatch, and took responsibility for solving the bycatch problem themselves. Marine mammalogists gained experience with the technology and the ways of fishermen. Gear technologists learned the ways of marine mammalogists. Fishermen gained sufficient experience with alarm effectiveness to encourage further cooperative work with scientists on acoustic alarms to reduce whale, dolphin, and porpoise bycatch. That work must continue.

Acknowledgments

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We especially acknowledge the assistance and cooperation provided by the fishermen with whom we worked in these studies. They helped in rigging alarms to fit gillnets and endured our constant observation and our endless questions. It was a pleasure to work for them. Special thanks is also due the observers who participated in the studies. Without their fine efforts, our work would not have been possible.

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Public Awareness of Bycatch Issues and Political Pressure for Change

Donald D. Stuart
Salmon for Washington, 4209 21st Ave. W, #301, Seattle, WA 98199

In state after state in recent years, we in commercial fisheries have faced a flood of legislative issues and initiative battles. Many of these have addressed bycatch. The public generally doesn't understand bycatch issues, but they do understand that there is a problem—and they are demanding that it be solved. The latest of these public bycatch battles is Initiative 640 in Washington. While very poorly drafted, I-640 demonstrates how public concern about bycatch can easily translate into broadside attacks on the commercial industry by our worst enemies, and it proves how vulnerable we can be if we do not stay 100% on top of this issue.

Bycatch in fisheries is a ticking bomb; a bomb that has been set off many times in recent years—in state legislatures around the country, in Congress, in public ad campaigns, and in initiatives and referendums to the voters.

Very often, it seems, when this bomb has been detonated, it has not been by friends, and often not for the highest of motives. Rather, usually, it is by people who have some economic or political ax to grind; by people whose motivations are suspect. However, the effects have been the same: damage to fisheries with very little benefit to the fish.

We in fisheries must deal with bycatch issues within our industry, or ill-intentioned people will deal with it for us.

It is sometimes difficult for those of us who fish for a living to see that what we do is a public matter. We feel that once we untie from the dock, round that point, and disappear over that horizon, no one really knows or cares what we do on our own boat in our own way. But that is not the case. In fact, the reverse is true. Most of what happens in our industry is intensely public. What happens here in Washington affects people in New York, California, or Alaska. What happens in Florida, affects us in Washington. And in an open democratic society, that's the way is should be, and it's the way it always will be.

That is why bycatch is much more than just a public relations problem. It is real. We must deal with it realistically, or that ticking bomb will go off in our faces.

The reality and explosiveness of bycatch issues has come home to those of us in Washington recently with the certification for the November 1995 election ballot of Initiative 640, our home-grown version of the net-ban mania that is sweeping the country. With I-640, the growing public awareness of bycatch issues placed a weapon in the hands of bitter enemies of commercial fisheries. With bycatch, Washington's good ol' boy network of avid recreational fishers saw their opportunity to eliminate their only remaining competition for the salmon resource—and they went for it, as they have done lately in other states, like California, Florida, North Carolina, Louisiana, and Oregon. In nearly every instance, the themes of these campaigns of distortion and self-interest have been the same: "Eliminate wasteful fishing practices!" "Get out the nets!" "Save sea life!"

Recently, I was in a debate on the initiative right here in Seattle. A former TV newscaster was one of the speakers. I think it's fair to say that this gentleman is not a noted expert on bycatch issues. Nonetheless, he was sufficiently knowledgeable to repeat the hot buttons and catch words over and over again: "Wasteful fishing." "Walls of death." "Thousands of seabirds killed daily." "Untold numbers of marine mammals slaughtered." "Deadly ghost nets."

A member of the audience was astute enough to ask him just what he meant by "Wasteful fishing." In response to this question, another of the I-640 proponents stood up with a picture from the front cover of a recent issue of *Fisheries* magazine showing nontargeted bycatch in a shrimp trawl fishery in the gulf off Florida. What happens in Florida, affects us here; when the bycatch bomb goes off in Florida, we feel the impact.

Three years ago, the Endangered Species Act (ESA) listing of the marbled murrelet caused the U.S. Fish and Wildlife Service (USFWS) to become concerned with the catch of seabirds in the Puget Sound net fisheries. Our local fleet recognized the need to deal pro-actively with this issue, and we entered into a cooperative process with USFWS, with the Tribes, and with Audubon, to find solutions.

To date, this process has produced: (1) an initial review to determine if there was a problem (with murrelets; there was not, but there were concerns about other bird species), (2) a comprehensive study of the extent and nature of bird impacts in net fisheries in Puget Sound (a must if we are to deal with this problem), and (3) a study of potential gear and fishery modifications designed to identify solutions.

Much of the expense, coordination, labor, and risk for doing this work came straight out of the fishing industry—not at the expense of the public. Much of the credit for accomplishing so much in so short a time is owed to the fishermen who participated voluntarily, knowing that if they were to solve the problem, that was their best course.

Ask yourselves what use has been made so far of the information produced in this cooperative process? It will probably be reflected in next year's fishery regulations for Puget Sound—if there is such a fishery. The principle use has been to provide statistical bycatch ammunition to the pro I-640 campaign in their public effort to vilify the commercial industry and to eliminate the Washington fleet.

Whenever we all sat down at meetings on this, hopefully, cooperative process in our effort to find answers to bycatch, who do you suppose was present? A representative of the pro I-640 folks—duly taking notes. Never did this individual have any helpful answers to provide. No, he was gathering ammunition. We all knew that the next time we saw the material discussed or handed out during that meeting, it would be in the press. When asked about his reasons for being present at one of these meetings, the I-640 representative simply said, "It's a public meeting. I have a right to be here." That was true; it was, and he did. That's how an open democratic system works.

In politics it is sometimes hard to weigh the relative importance of appearance and reality. I say it's 50-50, exactly 50-50. That's because the minute you start to think reality is more important than appearance, something like I-640 comes along to prove you wrong. The minute something like I-640 starts you thinking that appearance is more important than reality, something like this bird issue proves you're wrong as well.

Those of us in fisheries have learned to face the need to deal with both appearance and reality. If we do not do so, sooner or later that bycatch bomb will blow up in our faces just like it has so many times before.

Size Selection in Purse Seines

Arvid K. Beltestad and Ole Arve Misund
Institute of Marine Research, P.O. Box 1870, N-5024 Bergen, Norway

In purse seine fisheries, size selection may be required because some of the fish in the catch are less than the legal size and/or because different size groups have different market prices. In Norway both are relevant in the coastal purse seine fishery for saithe (*Pollachius virens*), and even moreso in the North Sea mackerel (*Scomber scombrus*) fishery.

The Institute of Marine Research has developed a new technology for size selection of fish in purse seines based on the use of rigid metal sorting grids. The grid is mounted on the bunt of the seine when the net is being hauled back and thereafter lowered into the sea by use of the main deck crane. When the catch is concentrated in the bunt alongside the vessel, small fish below a certain size escape between the grid bars. The sorting efficiency achieved has been good and the measured size selection range very narrow.

Preliminary trials indicate about 60% survival of escaped mackerel and no mortality of saithe.

Bycatches of marine mammals, birds, and unwanted fish species are not common in Norwegian purse seining. The only exception may be a relatively small fraction of cod caught during purse seining for capelin and herring.

Unlike trawling, longlining, and gillnetting, purse seining has traditionally been categorized as a non-selective fishing method, aimed to catch all sizes of fish. Most countries in the world therefore have no mesh size regulation for purse seining in their fishing regulations.

In Norway, the demand for size-selective purse seines has been increasing in recent years, especially in the mackerel and saithe fisheries. Most of the mackerel caught by Norwegian purse seiners are frozen and exported to Japan. The Japanese market favors large mackerel above 600 g and it pays twice as much for large fish. Mackerel schools in the North Sea consist of different year classes and, therefore, different size groups. It has been claimed that fishermen sort the fish onboard and discard the smallest mackerel. If such a discarding process is of any magnitude, this is bad exploitation of the mackerel stock. If the smallest mackerel could be sorted out of the purse seine alive, thereby increasing the proportion of mackerel above 600 g in the catches, this would increase the value of the catches and, thus, the income of the fishermen. A 10% increase in the proportion of mackerel above 600 g would raise income by approximately US$80,000 per vessel per year. If most of the mackerel that escape through the sorting device survive, this will also lead to better stock management.

In the purse seine fishery for saithe, fishing grounds very often have to be closed because of the large proportion of undersized fish in catches. Closing fishing grounds reduces income since fishing vessels have to leave those grounds and search for new grounds with larger fish.

There is a similar price differentiation with regard to fish size in the saithe fishery to that in the mackerel fishery.

Metal sorting grids have been developed and successfully introduced in shrimp and bottomfish trawls (Isaksen et al. 1992, Larsen and Isaksen 1992), Danish seine, and in salmon farming. In 1992, the Fish Capture Division of the Institute of Marine Research started to develop a new technology for size selection of saithe and mackerel in purse seines based on rigid metal sorting grids mounted on the breast of the purse seine (Misund and Beltestad 1994). The first trials were conducted on saithe in net pens (Misund and Skeide 1992).

However, a fundamental issue regarding use of sorting grids for size selection in purse seines is whether fish survive after escape. Most of our research during the last two years has therefore been aimed at measuring the survival rates of the escaped fish.

Mackerel Experiments

In order to determine whether nets could be used for size selection in mackerel purse seines, two panels of relatively large-meshed, stiff, impregnated net were mounted in the bunt of a traditional mackerel purse seine. One panel was made up of 4 mm braided knotted netting with a mesh size of 84 mm (stretched meshes). The other consisted of 9 mm knotless ultra cross net produced by Nichimo, Japan, with a mesh size of 90 mm. Both net panels were mounted in a section of the bunt directly under the selvage and about 25 m from the breast of the purse seine. The panels were 9.5 m long and 3.5 m deep.

The first metal sorting grid tested was designed for use in conventional mackerel purse seines used in the North Sea. The grid consisted of an aluminum frame with bars of stainless steel of 25 mm diameter (Fig. 1). The size of the grid was 3×3.5 m, which gave a selection area of about 10 m^2. The distance between the bars was originally 40 mm. In the course of the experiments,

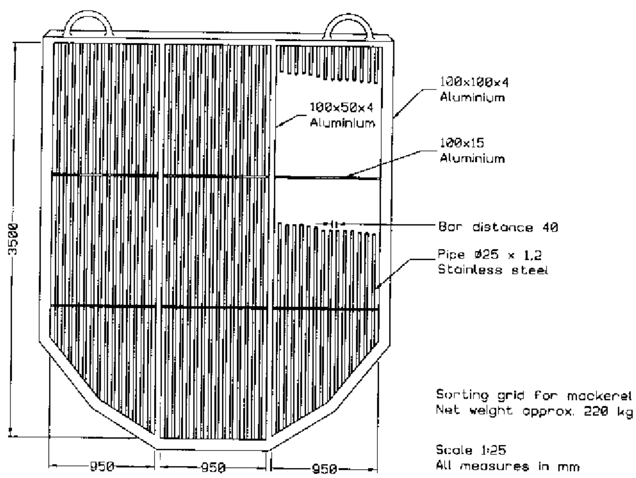

Figure 1. Prototype sorting grid for mackerel purse seine.

the inter-bar distance was adjusted to 44 mm and then to 42 mm. The weight of the grid was about 220 kg.

This year a new grid was built and tested. The frame of this grid was made of 75 mm aluminum tubing and with bars of 20 mm Glassfibre Reinforced Polyester (GRP). The distance between the bars was 42 mm. The size of the grid was 3×3 m, and it weighed about 160 kg.

The grid was mounted on the bunt of the purse seine by the following procedure: when the pursing of the seine was complete, the breast of the seine was hoisted on deck by the main deck crane and secured to the rail by a rope. The breast line of the bunt was then laced to the grid by an 8 mm twisted line. After most of the seine had been hauled back, the grid was attached to the crane, and the net released from the rail and hoisted overboard together with the bunt. The grid was lowered into the sea until most of it was submerged. When the purse seine was drying up the catch alongside the vessel, the grid formed a "wall" in the bunt (Fig. 2). During the drying-up process, the fish were forced toward the grid. After the selection process was complete and the catch had been pumped onboard, the grid was hoisted up alongside the rail and the purse seine released.

All trials were carried out with conventional North Sea purse seines for mackerel and herring.

The first experiments on size selection of mackerel in purse seining were performed on a cruise made by the chartered purse seiner M/V *Selvaag Senior* (67.5 m Loa.) in the North Sea in November 1992. The net panels were tested on the first five catches and the mackerel grid on three succeeding catches. The inter-bar distance in the first two trials was 40 mm, and before the last trial the bar distance was adjusted to 44 mm.

In order to collect fish that had escaped through the grid, a shrimp trawl bag was mounted on the mid-section of the seine on the outer side of the grid. The collection bag was about 10 m long and covered about one-ninth of the grid area. In order to provide length and weight measurements, samples of 100-200 individuals were taken from the collection bag and from the catch that was pumped onboard after the selection grid had been in action for about 15 min.

The experiments continued in September 1993 and 1994 along the western coast of Norway by the chartered purse seiner M/V *Ligrunn* (47 m Loa.) The grid was the same as that used in the 1992 trials, but the inter-bar distance was modified to 42 mm.

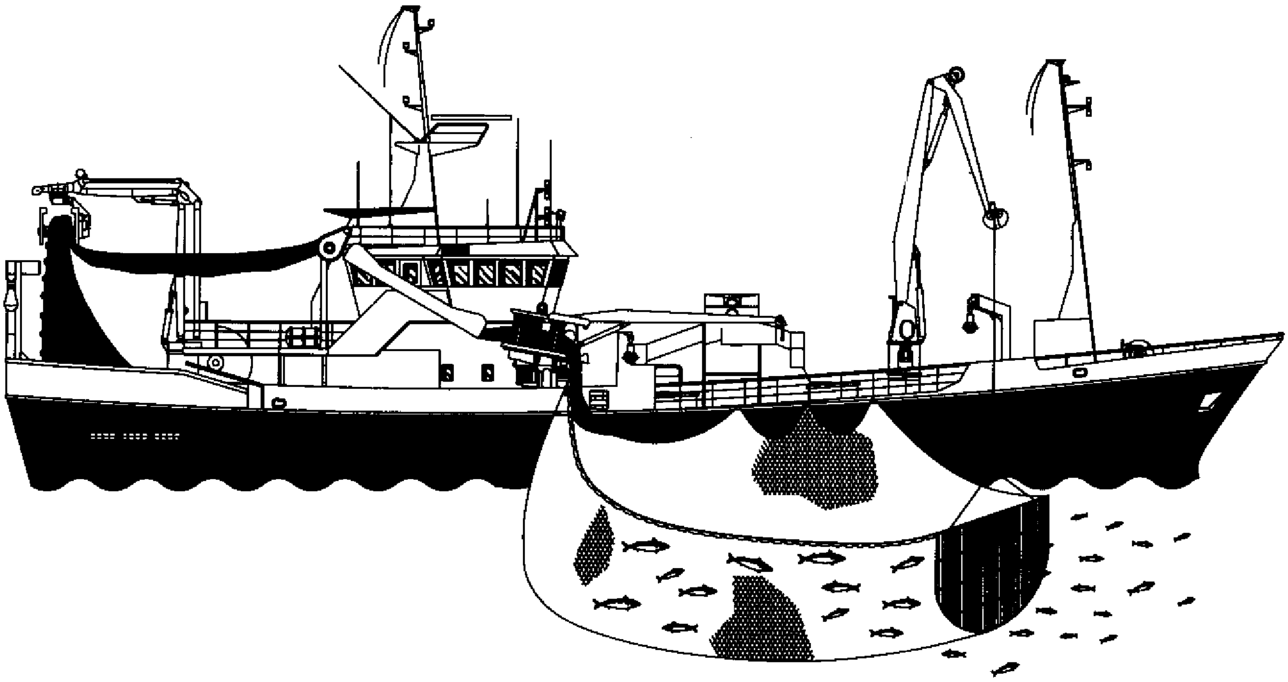

Figure 2. Sorting grid mounted in a mackerel purse seine.

In 1995 experiments were carried out with the chartered purse seiner M/V *Grete Krestin* (54.6 m Loa.). During this cruise the new grid with its aluminum tubing frame and GRP bars was tested. The bar distance was 42 mm during these trials.

Investigation of the survival rate of mackerel escaping through the grid started in 1993 by M/V *Ligrunn* and was carried out using the following procedure: for each trial, one control and one experimental group were established by collecting and storing the fish in 25×10×10 m net pens. The control group was established by lacing the floatline of the net pen to the floatline of the bunt and submerging it by means of weights. The mackerel swam freely to the net pen as the purse seine was carefully dried up. The experimental net pen was laced to the outer side of the grid and collected all the fish that escaped through the grid. The two net pens were then towed slowly (at about 0.5 m/s) inshore and moored. Survival rates were checked weekly for up to one month.

Saithe Experiments

Experiments on size selection of saithe in purse seines were carried out according to almost identical methods as for mackerel. Since the minimum legal size of saithe varies along the

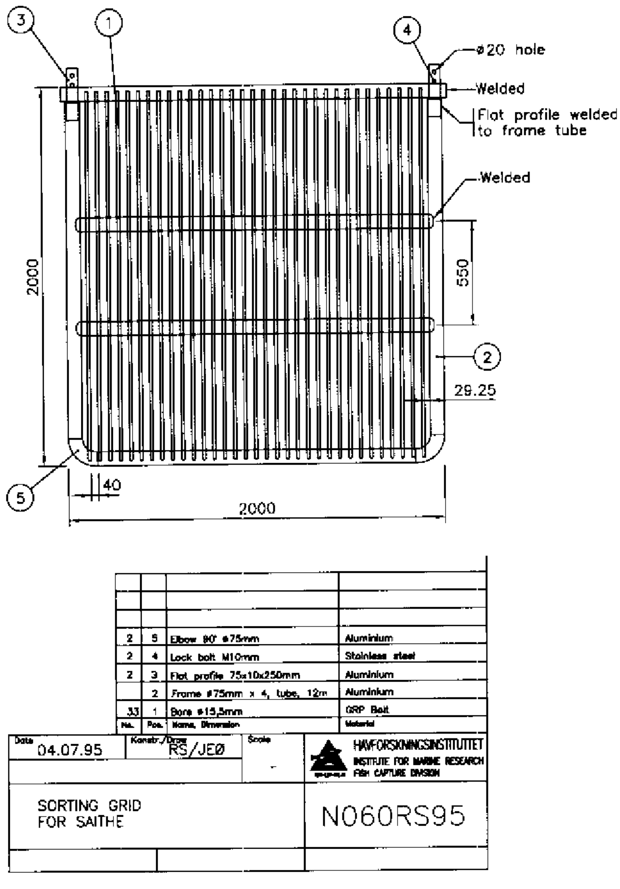

Figure 3. Present version of the sorting grid for saithe purse seine.

Norwegian coast, from 30 cm in the south to 40 cm in the north, inter-bar distances from 30 mm to 40 mm were tested.

The first size selection experiments were carried out with R/V *Fjordfangst* (14.7 m Loa.) in April 1994 in western Norway. The grids were designed for a small experimental purse seine of 320 m length and 45 m depth (Misund et al. 1992). One of the grids tested was made of aluminum and had dimensions of 2×2 m with an inter-bar distance of 35 mm. The other grid was of GRP and measured 1×2 m with an inter-bar distance of 30 mm.

In order to collect samples for length measurements, a small net pen (3×3×3 m) was laced to the outer side of the grid. Samples of about 100 individuals were taken from fish passing through the grid into the collecting pen and from the catch that remained in the purse seine.

Two net pens with saithe sorted through the grid were stored for one month in order to determine the survival rate of the escaped fish.

In August 1995 new selection trials for saithe were carried out with the chartered purse seiner M/V *Nargtind* (22.77 m Loa.) off the coast of Finnmark in northern Norway. The main aim of these trials was to measure the survival rate of the saithe that escaped.

The grid used during these trials (Fig. 3) was made of aluminum tubing and 15.5 mm GRP bars with an inter-bar distance of 40 mm. It measured 2×2 m and weighed about 60 kg.

Three sets of survival trials were conducted by similar procedure as for mackerel. The net pens were moored close to the shore and the fish were stored for one week.

Results

During the five selection trials with net panels in the mackerel purse seine of M/V *Selvaag Senior* in 1992, most of the meshes both in the knotted and the knotless ultra cross net soon became clogged by gilled mackerel. Size selection through these net panels therefore stopped rather quickly. The gilled fish also reduced the friction in the net hauling system and made hauling the net more difficult, especially for large catches, up to 220 tons.

In the trials using the mackerel grid, the selection process started when the schools "exploded" during drying up the catch in the bunt of the purse seine. Substantial amounts of small fish were observed escaping through the grid. Fish that were too large to pass through, rapidly swam away from the grid and back into the bunt. Just a few fish became gilled between the bars, mostly above the horizontal reinforcements. Selection continued for as long as the mackerel were actively swimming in the bunt, which was up to about one hour for catches of up to about 400 tons. The selection process gradually declined as the fish became exhausted and thereafter died, probably due to oxygen depletion. The dying and dead fish sank to the bottom of the bunt.

The selection curves for the 40 mm and 44 mm inter-bar distances of the mackerel grid were quite sharp, with regard both to the length and the weight of the mackerel (Fig. 4). However, the selection curves do not approach zero retention for the smallest fish sizes. This is because some of the small fish in the catch did not come into contact with the grid and therefore were unable to escape. It should be noted that the increase in inter-bar distance from 40 mm to 44 mm increased the 50% retention length by about one cm (from 36 cm to 37 cm), and the 50% retention weight by about 80 g (from about 420 g to about 500 g). Substantial amounts of small mackerel were sorted out during the tests with the 42 mm bar distance, but the selection curves for these trials are not presented here because inaccuracies in the inter-bar spacing seems to have seriously influenced the selection properties.

During three sets of trials in 1995 all the mackerel that were sorted out through the grid were collected in a net pen mounted on the outer side of the grid. The sorting rate varied from 25% to 40% of the total catch, and the proportion of mackerel above 600 g increased by about 10% after one hour of selection (Table 1).

The survival trials were conducted by M/V *Ligrunn* about 10 nautical miles off the west coast of Norway. One control group and one experimental group were established for each trial and the net pens were towed inshore and moored. The whole operation took approximately 24 hours. The fish were stored in the net pens for about one month. The first trials resulted in a 35% survival rate among the mackerel which had escaped through the grid and a 55% survival rate for the control group which swam directly from the purse seine into the net pen. The second trial gave a survival rate of 56% and 95% respectively.

The size selection of saithe in purse seine carried out in western Norway in 1994 gave a very sharp selection curve with a 25%-75% selection range of only about 3 cm (Fig. 5). The 1995 experiments showed that up to 50% of the total catch of saithe was sorted out through the grid within 15 min.

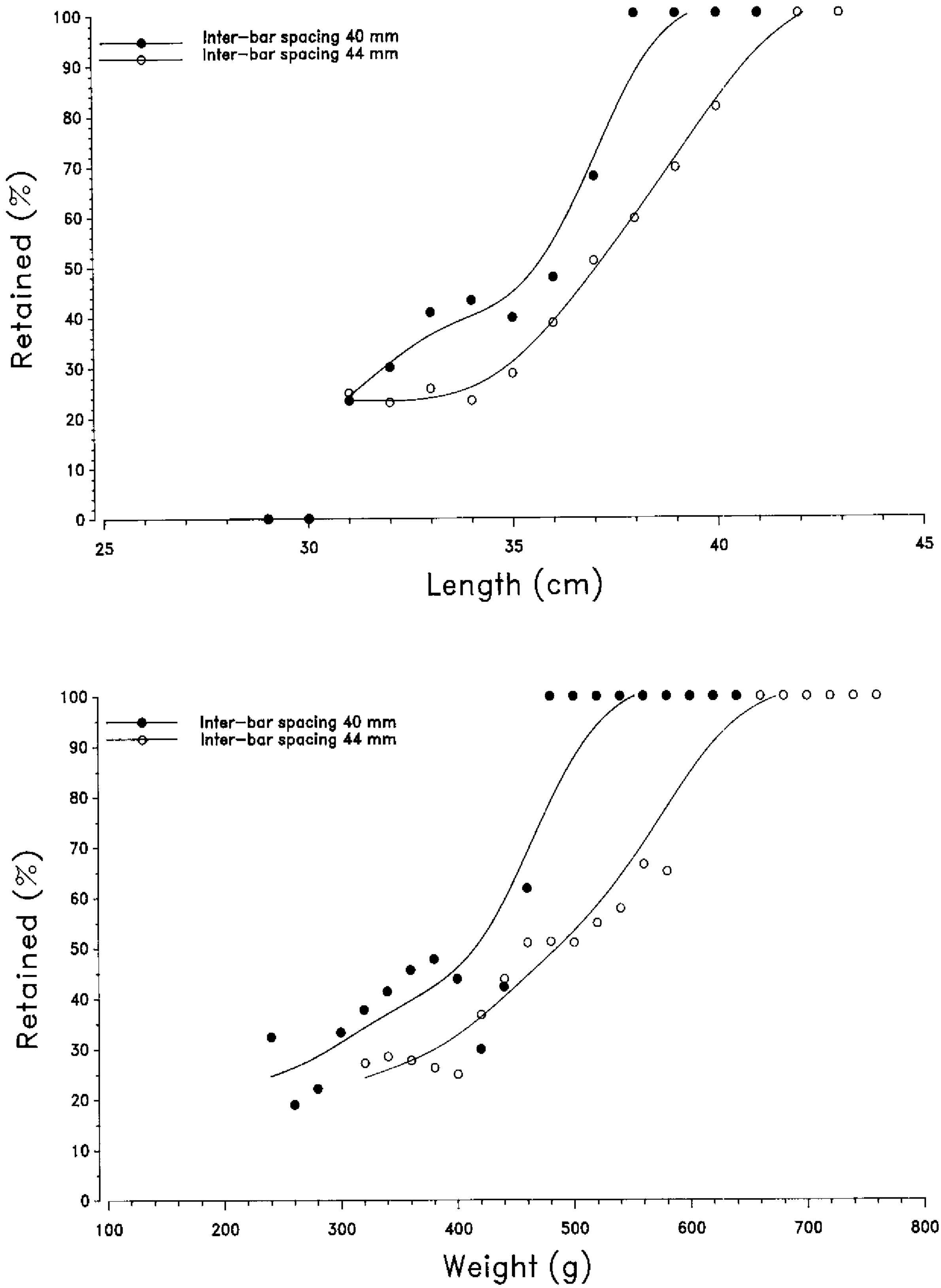

Figure 4. Length (top) and weight (bottom) selection curves for mackerel with 40 and 44 mm inter-bar spacing in the sorting grid.

Table 1. Sorting capacity.

Total catch (kg)	Sorted by grid (kg)	Sorting capacity (%)	Fish > 600 g total catch (%)	Fish > 600 g retained catch (%)
77000	19000	25	38	42
41000	16000	39	24	31
65000	24000	37	43	53

The experiments on survival of saithe that escaped through the grid, carried out both in western and northern Norway, resulted in no mortality in either the control or the experimental groups.

Discussion

The selection experiments using rigid metal grids in mackerel and saithe purse seines showed that such devices can be used for size selection of fish in purse seines. Large amounts of fish were sorted out through the grids used in the mackerel and saithe purse seines. The sorting capacity will depend on the inter-bar distance and fish size.

Experiments using net panels for size selection in mackerel purse seines showed that mesh clogging by gilled fish prevented effective selection through such panels in purse seine bunts. Gilled fish in meshes in the bunt also created difficulties during hauling caused by reduced friction in the net hauling system.

Mounting and handling of the rigid grids was accomplished without great difficulty for both mackerel and saithe purse seines. However, the first mackerel grid was large and heavy, necessitating handling by hydraulic crane. The grid occupied substantial deck space, and mounting and handling the grid may be a dangerous operation for the crew if not conducted carefully. However, the latest version of the grid was much easier to handle than the first one. The saithe grids were so small and light that they could be handled manually. Obviously, it is possible to further develop the design, construction, and handling of rigid size selection grids for purse seines. In small purse seines, it is possible to use light construction of synthetic materials. For larger purse seines, rigid grids must be strong enough to withstand substantial forces when handling catches of several hundred tons. Such grids should probably be built with a metal frame. The

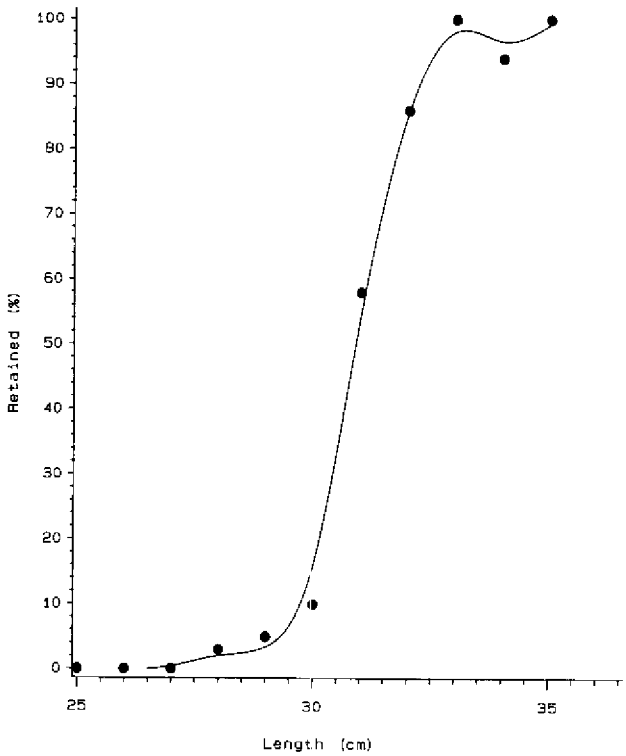

Figure 5. Length selection curve with saithe for a 30 mm inter-bar spacing in the GPR sorting grid for saithe.

1995 trials showed that it is possible to use bars of GRP to reduce weight. Another advantage of these bars is that they have a certain degree of flexibility, so that they return to their original shape if slightly bent during handling. Stainless steel bars were easily bent during handling, and the selection properties of the grids changed accordingly.

The selection curves of the rigid grids were fairly sharp, and selection occurred within a narrow range of sizes. For the mackerel grid, which was tested on large catches up to about 400 tons, the left part of the curve did not approach zero retention. This is because large amounts of small mackerel did not reach the grid and become sorted out, but were instead pumped onboard. In order to obtain high catch quality, pumping had to start almost immediately after the catch was concentrated in the bunt and the selection through the grid started. Even though some mackerel started to die quite rapidly in the bunt, the high sorting rate of up to 40% of the total catch showed that a lot of mackerel were able to escape through the grid even after one hour of concentration in the bunt.

The selection experiments with saithe were conducted with much smaller quantities of fish, and all the fish in the catches eventually came into contact with the grid. The left part of the selection curve for the 30 mm saithe grid therefore approached zero retention. It is possible that all the fish may eventually come in contact with the grid even for larger catches of saithe. The saithe did not seem to panic when concentrated in the bunt even in quantities of up to about 20 tons.

The fundamental issue regarding the use of rigid sorting grids for size selection in purse seines is the survival rate of the escaped fish. The mackerel and saithe grids allowed the fish to swim out between the bars and escape. It is possible that the selection process exposes the escaping fish to physical stress or injuries that lead to long-term mortality. Lockwood et al. (1983) found that mackerel suffered high mortality when stressed in small net pens. Our preliminary results may indicate that about 60% of the mackerel escaping through the grid survive. However, further trials to test the survival rates of mackerel that escaped through sorting grids in purse seines need to be conducted before any definite conclusions about the survival of escaped fish can be drawn.

The saithe seemed to tolerate the selection process much better than mackerel, and all the saithe survived the selection process. Rigid grids may therefore be recommended as a method for size selection in the purse seine fishery for saithe.

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Behavior of North Pacific Groundfish Encountering Trawls: Applications to Reduce Bycatch

Craig S. Rose
National Marine Fisheries Service, Alaska Fisheries Science Center, Seattle, WA 98115

Fishing gear selectivity is the result of differences in fish behavior. Behaviors of several important North Pacific target and bycatch species have been studied using low-light video cameras attached to trawls. Halibut, cod, sole, and king crab were observed interacting with a range of ground gear types in the wings and center of trawl footropes, and as they moved back through the body and intermediate into the codend of the trawl. A wide range of behavioral differences has been detected including herding behavior, tendencies to go over or under different kinds of ground gear, endurance while swimming ahead of the trawl, locations entering the trawl, paths through the body and intermediate, and activity in the codend. These differences are described, with emphasis on those that most affect selectivity and those that can be used to reduce bycatch.

National Marine Fisheries Service (NMFS) scientists, in cooperation with other research and industry groups, have conducted research on the behavior of fish encountering commercial fishing gear in the North Pacific Ocean. Bottom trawls have been the subject of most of the research to date. Our goal is to speed the development of gear-related solutions to bycatch problems by better understanding the processes that determine gear selectivity. This paper describes what we have learned about the behavior of fish in trawls and describes potential applications for improving trawl selectivity.

Bottom trawling is one of the most effective yet least selective fishing methods. It can be used to cover large areas of seafloor, retaining many fish in its path. The reactions of fish to the doors, bridles, and wings cause them to be concentrated in the mouth of the trawl before they are enclosed by the net. Historically, trawl development focused on fishing a greater area, and herding and retaining the fish more efficiently. In recent years, however, the importance of bycatch avoidance has put more emphasis on improving the selectivity of trawls.

The behavioral reactions of the fish to each element of the trawl are the principal determinants of whether or not they are caught. In addition to natural behavioral tendencies, the behavior of each fish is also affected by its physical capabilities, such as swimming speed and endurance, and its ability to sense a trawl. Differences in fish behavior appear to be the key to trawl selectivity. Research on fish behavior and fishing gear can include a range of techniques from laboratory studies to in situ research. While laboratory studies use controlled environments to isolate specific biological capabilities and reaction patterns, in situ research has most of the relevant conditions present simultaneously, but control is very limited. The in situ studies described in this paper rely on observations of fish encountering commercial fishing gear in the wild.

This paper describes the trawl-related behavior of several North Pacific species targeted by bottom trawl fisheries including Pacific cod, *Gadus macrocephalus*, and several species of small sole, principally rock sole, *Pleuronectes bilineatus*; butter sole, *Pleuronectes isolepis*; yellowfin sole, *Pleuronectes aspera;* and flathead sole, *Hippoglossoides elassodon*. The behavior of significant bycatch species (Pacific halibut, *Hippoglossus stenolepis*; king crab, *Paralithodes camtschaticus*; and Tanner crab, *Chionoecetes* spp.) is also described.

Methods

In 1990, the Resource Assessment and Conservation Engineering (RACE) Division of the NMFS Alaska Fisheries Science Center joined a cooperative research project with the International Pacific Halibut Commission and the American Factory Trawlers Association to find ways to reduce halibut bycatch in trawl fisheries. This project was the impetus for an ongoing effort by the RACE Division, with the cooperation of many scientific and industry groups, to study fish behavior and bycatch problems. The first objective was to develop an underwater video system for observing the behavior of bycatch and target species near trawls. A silicon-intensified target (SIT) video camera, sensitive to light levels as low as 10^{-3} lux, was selected for the project. The SIT camera permitted observations to a depth of 40-100 m without the use of artificial lights that could affect fish behavior.

Although towed remotely operated vehicles have been developed to independently maneuver a camera around a trawl during towing, these systems were deemed too expensive. Instead, it was decided to attach a video camera directly to a trawl. While limiting the mobility of the camera, this solution assured that the camera would be at the selected location throughout a tow.

To allow for real-time viewing flexibility, the camera was mounted on a manipulator which allowed the camera to be aimed in a range of directions. A custom aiming device with movable farings to avoid flow problems (Fig. 1) was designed and built for the project in 1993. A small scanning sonar was added to the video to provide range information and to monitor the operating shape of the trawl. The trawl-mounted observation package was linked to the surface with a 16 conductor electromechanical cable reinforced with a Kevlar strength member. To prevent cable breakage, a winch was used which paid out extra cable when cable tension exceeded a set value. The system was designed to be tied into the upper mesh panel of the trawl or towed within the trawl using auxiliary lines. Video and sonar data could be viewed during the tow with the sensors aimed anywhere below or to the sides of the mounting point.

A self-contained system using the SIT camera (Fig. 2) was also designed for observations where use of the cable-controlled equipment was not practical. The camera was mounted on a fixed plate attached to the fishing gear with a pressure housing trailed behind, which contained batteries and a video recorder. While lacking real-time viewing and control, this simple system has been very convenient for short cruises, for mounting locations where the cable would excessively distort the trawl, or for use aboard vessels during commercial operations. This system has provided useful data in a wide range of situations.

For field work from 1990 to 1994, test fishing grounds were near Kodiak Island, Alaska, where Pacific cod, Pacific halibut, and rock sole were found in depths less than 75 m. In our observations, halibut ranged from 65 to 85 cm in length, while cod were 55-75 cm, and rock sole 25-45 cm. Initial testing of the video system was conducted during short trips aboard industry-provided vessels in August 1990 and May 1991. Commercial vessels were chartered in July or August 1991-1995 for five research cruises to observe fish behavior around bottom trawls. The trawl used from 1990 to 1994 was an Aberdeen style bottom trawl fished behind 2×3 m steel V doors. Of the trawls available for the project, the Aberdeen style trawl was the most similar to those being used in the commercial fishery and was an appropriate size for the low horsepower vessels that the project used initially.

In 1995, operations were moved to the Bering Sea to study the behavior of bycatch species in that area, particularly king and Tanner crabs. The study trawl was also changed. A Bering Sea Combo trawl, fished with steel super-V doors, was selected as our study trawl. This gear was more similar to that used by commercial bottom trawlers in the North Pacific.

The camera systems were mounted on the top of the trawl between the headrope and the codend and near the sides of the trawl. To obtain close views of the groundgear, the cameras were towed in the mouth of the trawl from lines attached to the trawl wings. These camera positions allowed observations of fish behavior and fish reaction to trawl modifications over the entire length of the trawl. Some examples of our behavioral observations and testing of modifications to the footrope and intermediate areas are described below.

While the SIT cameras are extremely light-sensitive for video cameras, they are not as sensitive as the eyes of the fish being observed. In

Figure 1. The cable-controlled camera/sonar package is launched, mounted behind the headrope of a bottom trawl.

Figure 2. The self-contained video system mounted on a trawl. The camera is under the dome and batteries and recorder are contained in the black tube to the left.

reality, the observed fish were quite capable of seeing and reacting to the fishing gear. Fish behavior may differ in deeper waters or at night when less light is available.

Behavior Observations

Behavior Ahead of the Footrope

Fish behavior ahead of the trawl net appears to be most affected by swimming speed and endurance capabilities. Better swimmers stayed farther away from trawl components for longer periods.

Large (>50 cm) halibut were the strongest swimmers observed, swimming ahead of the trawl for up to 8 minutes. Most of this time was spent 2-10 m ahead of the trawl, swimming easily and steadily. At first, the halibut matched the towing speed of the trawl, slowly moving around the area enclosed by the trawl wings. As halibut tired, they showed a pattern of alternating slower swimming and dropping back into the trawl mouth, with short bursts of faster swimming each time they came within 1-2 m of the groundgear. Most of the halibut swam less than 1 m above the seafloor during the initial stages of capture and then rose more than 1 m off the bottom just before drifting or swimming back into the trawl.

The soles had less endurance than the halibut and swam much closer to the groundgear during all stages of capture. Sole were herded along the sweeps and wings of the net, either employing short swimming bursts away from the approaching trawl components or steadily swimming along them toward the trawl center. Upon reaching the trawl center, they occupied a small area less than 2 m ahead of the middle 3 m of the footrope, where they swam for 10 seconds to 1 minute at 3 knots before turning and swimming into the trawl or under the groundgear. Sole passed very low (<1 m) over the center section of the groundgear when they entered the trawl.

Pacific cod behavior depended on whether fish encountered the trawl singly or in schools. Behavior of single cod and small aggregations were similar to that of halibut. Though they did not swim as far ahead of the trawl or for as long as the large halibut, most cod stayed close to the seafloor and tended to rise shortly before they passed over the groundgear. Like the halibut, the points where cod crossed the footrope were spread across the trawl mouth, and were not limited to the center section. Where dense aggregations of cod were encountered, most of the cod were above the seafloor. These aggregations spent much less time ahead of the footrope than individual cod or halibut, with entire schools passing into the trawl in less than 2 minutes.

The few walleye pollock (*Theragra chalcogramma*) seen so far have shown unique behaviors. These pollock swam slowly until the ground gear was within 2-4 m at which time they put on a burst of speed, usually for enough distance to carry them out of the video image.

Crabs were not able to move as fast as fish and this limited their ability to avoid the trawl. Near the bridles and wings, they were observed to run away from the approaching gear toward the center of the trawl. Due to their slower locomotion, more of the crabs were overtaken by the bridles than even the smaller sole. Those that reached the center of the trawl mouth were overtaken immediately. Whether the crabs passed over or under the footrope depended on the type and size of groundgear at the point of contact. While crabs could not swim over the groundgear, some were observed to climb over trawl components. The crabs' legs also made them more vulnerable to entanglement with the trawl groundgear.

A variety of groundgear types have been used in our observations, including wrapped cable, small disks, and bobbins up to tire gear 60 cm (24 inches) in diameter. Overall, groundgear components that presented a bigger visual stimulus were more vigorously avoided by the fish. This was reflected in the range at which fish first react, the distance maintained while passing or swimming near the gear, and the time spent searching for ways to pass an element of the gear.

Fish Behavior in the Intermediate

In the intermediate section of the trawl (the narrow tunnel of net between the funnel-shaped body of the trawl and the closed codend where the fish accumulate) cod and halibut again showed similar behaviors. Both species spent most of their time swimming well above (>15 cm) the bottom panel of the intermediate. These fish were generally actively moving about, occasionally striking the side and top panels. Cod and halibut could maintain their positions or swim forward against the water flow, though they eventually were forced back toward the codend. Nearly all of the rock sole remained within a few cm of the bottom panel as they passed through the intermediate. Being weaker swimmers than cod and halibut, the rock sole were barely able to maneuver or to slow their progress into the trawl. Crabs were observed tumbling back through the trawl with little control. Crab were not exclusively limited to the bottom of the net, with a few individuals seen rolling along the side panels.

Fish Behavior in the Codend

Camera systems were inserted through the top panel of the codend to observe the sequence of fish behavior as the codend filled. The codends were constructed of small (<100 mm) double mesh, making escape through the mesh impossible for most of the fish observed. While flow was not objectively measured, it was obvious from the slower tail beats of fish that water flows were much slower in the codend than in the forward parts of the net. This was true even when the codend was empty and no fish were occluding the meshes. The first fish to enter the codend had room to swim around, occasionally testing the enclosing meshes. These tests consisted of light taps with the snout, with no deliberate attempts to escape. Flatfish would eventually come to rest against the meshes, forming a hollow tube, which provided an area of very slow water flow in the enclosed space. This space was occupied by the roundfish and newly arriving flatfish.

As the codend filled, fish could not avoid bumping into each other, which interrupted their swimming rhythm and forced more fish against the meshes. Crowding made escape attempts by both roundfish and flatfish near the mesh more vigorous, but interfered with their ability to achieve an orientation to the meshes that would make escape possible. Only a few glimpses of the core of the crowded codend were seen, but they showed that some fish were still able to swim.

During haul back, speed changes caused a resumption of movement by many fish that had settled into a fixed position. Increases in speed packed the fish more tightly and decreases in speed would allow some fish at the forward end to move forward. As the trawl neared the surface, swim bladder expansion caused the pollock and cod to become positively buoyant. If the trawl was slowed at that point, these fish began to swim downward to compensate for the excess buoyancy. By far the greatest increase in packing density occurred as the trawl was brought out of the water. The fish in the net shifted backward and finally became unable to move about.

These observations are based on a limited number of tows, none of which had catches larger than 8 mt. In addition, none of the pollock were small enough to actually escape through the net's meshes. These observations should be repeated with larger catches, higher catch rates, and with pollock small enough to escape. However, if the behaviors observed can be generalized, they suggest that there are some factors limiting the use of codend mesh size to achieve size selection. There may be a limited period when escapes are likely—after the codend becomes crowded enough to motivate serious escape attempts and before too much of the mesh is occluded by fish. If the codend were filling rapidly, this period could be very short. The large increase in packing density observed as the codend is brought out of the water also suggests that limited escape opportunities exist for the last fish caught in very full catches. Fish that end up in the forward end of a full codend would only arrive in the codend itself when the catch was compacted as the net was brought aboard. If larger mesh escape panels did not extend ahead of the codend, these fish would have had no opportunity for escape.

Testing Modifications to Reduce Bycatch

Underwater video technology has proven to be useful for evaluating the effectiveness of trawl modifications to reduce bycatch. With in situ video, researchers can quickly determine whether a species' expected reaction to a trawl modification occurs, and whether sufficient numbers of nontargeted or prohibited species escape while targeted species remain. If a change to a trawl appears successful, then more rigorous counts from a taped video are used to estimate escape and retention rates. For modifications that do not work, the video can show how fish behavior or gear deployment differed from expectations, making iterative improvements toward a working system possible.

A wide range of trawl modifications has been tested through the RACE Division's cooperative bycatch reduction project. These modifications have come from individuals and organizations in the fishing and fishing gear industries and from participants within the project. Distribution of video compiled from our field work has elicited further ideas for testing. The following sections of this paper will describe three modifications developed and tested during the program which show good potential for reducing bycatch in North Pacific fisheries.

Lower Wing Extensions and Herding Ahead of the Trawl

In situ observations of the ability of halibut to swim ahead of the Aberdeen style trawl suggest that it might be possible to herd halibut out of the path of the trawl while retaining target species. In many trawls the forward lower corners of the net where the trawl is attached to the towing cables are removed and replaced by a cable strung with bobbins or rubber disks. This design eliminates a section of netting that is very vulnerable to tears, but still herds most fish into the net. Underwater video observations showed that the gap between the lower wing extension and the upper wing is one area where halibut swim ahead of the trawl. Fowlweather Trawl, a trawl manufacturer in Newport, Oregon suggested arranging herding lines to direct fish ahead of the trawl toward the area of the lower wing extensions.

The self-contained camera system made it possible for researchers to view the area of the wing extensions closely. When viewed without the use of the herding lines, many halibut escaped between the extension and the upper wing, while most of the cod and rock sole were herded toward the trawl mouth. A camera in the cable-connected system mounted above the footrope made it possible to count the fish being caught for comparison with the number of fish escaping. These counts showed a difference between halibut and cod escapes, with 79% of the halibut escaping, while losing 41% of the cod. Herding lines were added ahead of the trawl to increase the number of fish moving near the wing extensions. This increased the proportion of halibut escaping to 88%, with little change in the number of cod escaping.

Groundgear to Eliminate Crab Bycatch

After studying video of crab and fish behavior ahead of trawls, an independent researcher, Sherif Safwat and Liam Massey of Pacific Nets provided a design for experimental groundgear to prevent crab bycatch consisting of a curtain of chains dangling from a footrope floated above the seafloor. In this arrangement, animals passing under the groundgear must only displace a few chains and thus should experience less damaging force than would be required to pass beneath conventional groundgears. In the configuration tested, the flotation and chain weight were adjusted so that the main footrope was between 15 and 25 cm off the seafloor, with the chain curtain (0.5 cm diameter galvanized chains, 75 cm long, spaced 10 cm apart) filling the space below it. The experimental groundgear was fished on a Bering Sea Combo trawl in an area of the Bering Sea with high crab abundance (king and Tanner crabs).

To evaluate this modification, video cameras were placed to observe crabs and fish as they encountered this groundgear at a variety of locations. This modification was extremely effective at keeping crab bycatch out of the bottom trawl. From counts made while viewing the video in real time, 260 crabs were observed passing under this groundgear while only one entered the trawl. The primary fish species encountered during these tows were rock sole and yellowfin sole. Preliminary results of video counts indicate that the flatfish escape rate is around 55%. Trawlers targeting sole species with this gear would have to accept much lower catch rates to avoid crab bycatch. Initial estimates for pollock and cod escape rates are 3% and 16%, respectively. Cod were encountered in small numbers, so the behavioral differences between single fish and schools of cod should result in lower escape rates if this gear were used on schooled cod. Continuing video analyses will provide more accurate estimates of these escape rates. An important follow-up to this work would be experiments to confirm the low damage and mortality expected for crab released by this gear.

Opening the Intermediate to Reduce Halibut and Roundfish Bycatch

The observed differences between the behavior of rock sole and those of cod and halibut in the intermediate section of the net showed potential for species separation. Because halibut and cod swam higher and contacted the intermediate side panels often, Dave Fraser, the captain of the *Muir Milach*, the fishing vessel chartered for the 1993 research cruise, suggested cutting holes in the sides of the intermediate. Initial tests of this idea showed both halibut and cod escapes with little loss of rock sole. A progression of larger holes has been tested in subsequent years, resulting in a design that removes the complete top panel and the top half of both side panels for a 40-mesh length of the intermediate.

The open top intermediate was tested under commercial conditions aboard the M/V *Topaz* in June of 1995. An accessory cover connected to a second codend was suspended over the escape hole to allow estimation of escape rates. Floats and horizontal spreading bars were used to prevent masking of the escape path to minimize the effect of the cover on escapes. During four tows of this gear at about 40 fathoms depth, 54% of the halibut escaped while only 11-12% of the target rock and butter sole were lost. Escape rates were different for large and small halibut. Higher proportions of the smaller halibut were retained, while most of those greater than 1 m (39 inches) in length escaped. The greater individual weights of the larger halibut caused them to dominate the weight-based escape rates described above. Only the smallest halibut could have been affected by the difference in codend meshes, and this would have resulted in an underestimate of escape rates. Cod and pollock, often discarded by the sole fisheries because of bycatch or market limitations were released at rates of 50% and 69%, respectively. Tests in deep-water fishing for Dover sole (*Microstomus pacificus*) were not as successful, reducing halibut catch by only 39% while losing 34% of the target species.

This modification was looked at again during the 1995 Bering Sea cruise. The cover was removed and a video camera was positioned to allow counts of both retained and escaping fish. These video counts indicated escape rates of 36% and 88% for cod and pollock, respectively, while only 6% of the sole, principally yellowfin and rock sole at the site, were lost.

An open top intermediate is a simple and easy-to-install modification that can provide useful species selectivity in some North Pacific bottom trawl fisheries. The next step in its development is for trawlers to try this concept, and to test and improve its design and application through day-to-day use.

Summary

Underwater video on full scale trawl gear is a useful method for studying fish behavior and testing gear modifications. Fish responses to gear components can be observed and analyzed in a setting unaffected by confinement of the test animals. Video observation is limited by the water clarity and light intensity and by the need for light at a level above that necessary for fish vision.

Species-specific differences in fish behavior have been observed, some of which have applications for improving trawl selectivity. The information provided by video observations allows iterative development and testing of modifications to gear and procedures to find effective ways to reduce bycatch. Three trawl modifications resulting from this behavior research have been tested and found to have good potential for reducing bycatch.

A Review of Fish Behavior in Relation to Species Separation and Bycatch Reduction in Mixed Fisheries

C.W. Glass and C.S. Wardle
SOAFD Marine Laboratory, P.O. Box 101, Victoria Road, Aberdeen, AB9 8DB, Scotland, UK

Clear differences in reaction behaviors have been observed between different species of fish and also between fish and invertebrates. These differences have led to the separation of many species of fish and invertebrates in fishing gears. The same observations have led to extensive basic studies of the physiological limits that determine the ability of each species to react to a stimulus. A summary of publications on the thresholds and limits to behavioral response, is presented. Recent examples of the applications of separation techniques involving differences in behavior are reviewed. It is clear that where research effort has been applied, there is rapid development of existing ideas to meet the needs of particular fishery problems. It is noticeable how successful the developments have been when the research effort is directed by effective teams to investigate and solve their local problems. This is particularly clear with the evolution of systems to separate shrimp or prawns from juvenile fish. One approach, and apparently the most successful, aims to exclude all active swimming fish; the other tries less efficiently to compromise and retain the larger fish as part of a sellable catch. There has been much less research published on techniques to separate fish species, yet there are many groups of fish species with potential for separation. Some examples, such as mackerel, herring, and horse mackerel have become the focus for attention in European research projects aiming to find practical answers for their separation.

Observations of species differences in reaction patterns of behavior when stimulated by towed gears have been made over the past 30 years by many different methods. However, the towed observation vehicles like the Aberdeen divers' vehicle and the remote controlled towed vehicle carrying TV and flash cameras, have been the main sources of observations since 1975 (Wardle and Hall 1994). Diving observations of the Scottish seine net, by a large team at the Aberdeen Marine Laboratory between 1965 and 1970 (Hemmings 1973), were the first to show clear examples of differences in the reaction behavior of fish species: flatfish herded close to the seabed by the ropes became exhausted in the mouth of the net and rose only enough to clear the ground rope when falling back; haddock stacking high in the narrowing net mouth with surplus fish overflowing the headline as it closed; and saithe diving under the raised ground rope when droppers were used. These studies were followed by many more diving and remote controlled towed vehicle (RCTV) observations since 1975 and form the foundation for many of the recent practical developments (Wardle 1983, 1985, 1993). The observations, such as those above, have led to practical experiments which demonstrated how fish species could be sent to different codends depending on their reaction behavior in the mouth of the trawl net (Main and Sangster 1982a).

Fish behavior was considered in the evolution of species specific gears. Danish seines for flatfish had a low headline and great care was taken to have the herding ropes and ground line press hard on the seabed. Prawn trawls were made wide to sweep the seabed but with low headlines to avoid those fish that rise. Beam trawls towed fast catch mainly flatfish and other ground-hugging species. Herring and haddock trawls need high headlines, and even kites rigged above the net, to drive the naturally rising fish down. Some of the separation issues are due to the economic need for fishermen to catch more than just the target species. This results in a high headline net for catching prawns that also catches haddock. It is then necessary to have a system to let out the increased numbers of trapped juveniles.

The issue of both fish and turtle bycatch in the northern Gulf of Mexico penaeid shrimp fishery, where 70% of the discarded fish are juveniles important to the demersal fishery, has generated a long series of research projects summarized by Watson (1988). These include development of diving observations and experimental work and culminated in a status report evaluating 51 conceptual designs for bycatch reduction (Watson et al. 1993). The objectives were to evaluate existing bycatch reduction techniques, collect data on the behavior of fish and shrimp when encountering shrimp trawls, and develop and evaluate new bycatch reduction techniques. It was found that reduction for individual fish species varied according to the design. In some designs they achieved 50% reductions of fish bycatch while retaining 90% of the shrimp. In both Norway and Australia major research efforts have been devoted to developing new approaches to separate species in trawl fisheries.

Since publication of the Bergen ICES symposium on fish behavior in relation to fishing operations in 1992 (Wardle and Hollingworth 1993, which presents a number of papers on both species and size separation), there have been many new developments and these publications lead the reader into the various practical aspects of bycatch reduction and species separation. These recent advances are reviewed here and their findings in this context briefly outlined.

Species Differences in Reaction Behaviors and Their Limits

General Principles

Observation of the differences in fish behaviors in nets led to basic research that looks into the reasons why. Most behavior can be explained as a response to a stimulus where the response is limited by the abilities of the fish. These responses result from the evolution of each species of fish as part of its biological ability to adapt to the natural environment (Ferno 1992). The ability of the fish to respond is limited by performance thresholds that are, in turn, set by the physiological adaptations of the particular species. In poikilotherms such as the teleosts and the invertebrates caught in commercial fisheries, change in sea temperature can raise or lower such thresholds. Some species can compensate for such changes, others cannot.

Swimming Ability

A simple example of species separation will occur in any trawl when similar sized pelagic and demersal fish are herded together in the mouth of the trawl. For example, a group of mackerel (*Scomber scombrus*) might out-swim a group of same-size saithe (*Pollachius virens*) which become exhausted and drop back to the codend. The saithe are caught and the mackerel swim away. The speed and size relationships are explained by studies of endurance swimming performance (He and Wardle 1988). A survey of thresholds for swimming ability are published in a review by Videler and Wardle (1991).

Light and Sound

Behavioral thresholds for light level reactions of some species have been demonstrated (Glass et al. 1986, Glass and Wardle 1989, Cui et al. 1990 and Walsh and Hickey 1993). The role of sound in towed fishing gears has been discussed (Wardle 1993), and more recently the sensitivity of fish to infra-sound seems to be species specific (Enger and Karlsen 1993). There may be room for careful application of sound, for example exploiting the very different hearing abilities of mackerel and herring; but sound applications do not yet appear to have been found in practice unless they occur unknowingly in purse seine or driftnet fisheries.

Local sound generated by humming wires attached to grids has been tried by Watson et al. (1993) to help deter fish from passing through shrimp grids.

A Review of Recent Research

Shrimp, Prawns and Juvenile Fish Separation

A major worldwide problem is the capture of large quantities of juvenile fish in trawls constructed with small mesh codends needed to capture the smaller shrimp and prawns. Many of the recent published studies are biased toward the assessment and development of methods to deal with shrimp/fish separation. In experimenting with the various gear modifications, some studies have incidentally shown changes in the range of fish species caught indicating that some effects are species specific.

The bycatch of a turbid water penaeid prawn fishery off South Africa showed 109 (mainly juvenile) species of teleost fish with only a few species dominating in weight and number. Slow towing speed was significant in avoiding capture of larger pelagic fish species. A detailed study showed that season (as cool and warm samples) and depth (as shallow and deep samples) had significant influence on availability of some teleost species, but all were present in significant quantities throughout the year (Fennessy et al. 1994).

A detailed study looked at the species caught in shrimp trawls off Greenland. It shows the importance of the conflict between capture of shrimp, in this case *Pandalus borealis,* and the damage to juvenile commercial fish species growing up in the same area, such as redfish, Greenland halibut, cod, and 40 other species sampled in the 40 mm shrimp nets (Pedersen and Kanneworff 1995).

A number of groups are tackling related problems in Australian shrimp fisheries, and productive experimental work is being reported. Andrew et al. (1991) compared the catch composition of a variety of rigs of one size of trawl net. These ranged from single trawl with no sweeps to trawl with long sweeps and triple trawl rigs where three trawls are towed side by side with no sweeps. The experiments were carried out at around 30-40 m at night in the summer. The authors show that numbers of the herded reactive swimmers such as the larger finfish (red spot whiting, *Sillago bassensis,* and sand flathead, *Platycephalus caeruleopunctatus*) are increased relative to the prawns (*Penaeus plebejus* and *P. esculentus*) and shovelnose lobsters (*Ibacus* spp.) when long sweeps are used on the single trawl. However, the triple trawl, which is now used by many of the Australian fishermen, catches more red spot whiting but not sand flathead.

The positive effect of sweep herding on the larger finfish is discussed by Andrew et al. (1991) relative to the findings of previously published studies made when the Vigneron Dahl gear was introduced in the 1920s. The non-reaction of the invertebrate species to the sweeps is compared to *Nephrops* reactions. The authors point out that species-specific differences in vulnerability to capture by trawls using long sweeps have clear implications in fisheries management confirming similar work such as that reported by Engas and West (1987), Engas and Godo (1989), and Mahon and Smith (1989). They conclude that long sweeps do affect the species composition of the trawl in this fishery, which could confidently be regulated to reduce fish catches.

A major problem in the Australian trawl fishery for prawn and shrimp species, as in many parts of the world, is that a large part of the catch is made up of juvenile fish trapped by the small meshes needed to trap prawns (Robins-Troeger 1994). In the Australian prawn fisheries these fish can weigh anything from 6 to 15 times the weight of the prawn catch (Robins-Troeger et al. 1995). Robins-Troeger (1994) describes how the Morrison soft turtle excluder device (TED), made from 150 mm monofilament mesh, eliminated catches of turtles and increased loss of unwanted juveniles of commercial species by 30%.

Andrew et al. (1993) showed how, in an offshore fishery, the use of the Morrison soft TED did not reduce the prawn or invertebrate catch but did reduce the discards by 32%. These contained 15-25 species of non-commercial benthic teleost fish and invertebrates and significant juveniles of commercial species. The very variable and conflicting findings of other studies are reviewed and discussed in Robins-Troeger (1994) and lead to the conclusion that these nets vary in their performance in different fisheries and conditions. The same research groups in Australia report the development of a more effective AusTED which, when tested in a variety of fishing conditions, did not lose any of the valuable prawn catch but did reduce the turtle and juvenile fish catches. The device is described by Mounsey et al. (1995) and results from the test are in Robins-Troeger et al. (1995). More recent work in Australia looked at the use of the Nordmore grid (Isaksen et al. 1992) in fish/shrimp fisheries.

Where the bycatch is not of value to the fishermen, this system is now used in preference to the TED types mentioned above (Pers. comm., Broadhurst 1995; Kennelly 1995).

An elegant example of how differences in reactivity between prawns and fish can be used in bycatch reduction is described by Broadhurst and Kennelly (1994) in a fishery where the adult fish are needed to supplement the catch.

Three species of prawns behaved quite differently from finfish in this study where 54% of the fish (mulloway) left the net via a square mesh panel ahead of the codend; the prawns did not show any loss. Prawns were lost if the whole codend was square mesh. The authors review observations of behavior and conclude that the reactive swimming responses of fish cause them to leave in a size selective fashion, whereas the non-reactive behavior of prawns lets them drift past the square mesh window to the codend. When square meshes are present in the rear-most part of the codend, the prawns leak out through the open meshes during the haul or haul back. This finding was similar to that of Briggs (1992) where RCTV observations showed how the invertebrate *Nephrops* scuttle along the base of the trawl whereas many of the small undersize whiting find their way up and through the top square mesh panel of this net. Comparative fishing with twin trawls showed the system to conserve the *Nephrops* within the net while losing most of the juvenile whiting.

The first studies in separation showed how *Nephrops* could be separated from finfish simply by introducing a horizontal separating panel 70 cm above the ground line in a high opening Boris dual purpose fish/prawn trawl (Main and Sangster 1982b). In this case diving observations had concluded that *Nephrops* never rose more than 70 cm from the seabed, whereas many of the small and large fish species tended to rise up over the ground line and the separating panel if it was staggered back from the ground line.

Use of Net Color

It is interesting that the square mesh panel used by Briggs (1992) is white whereas the net is darker. The author describes the whiting trying to pass through the diamond meshes just ahead of the white panel and then emerging through the first lines of open square white meshes. However, there is an indication that lights were used during the camera observations, and presence of artificial light would modify the net color pattern as seen by the fish from the inside. In natural light the behavior might be different.

Both of these approaches involve retention of the larger fish by the square mesh panels. The problem was to make all the active fish, whatever their size, attempt to leave via the selection panel so that all are tested for size. The natural reaction of fish to panels is that they keep clear of them and pass along the central space. However, recent findings show that natural behavior can be switched to trying to pass outside the codend tube if it is made to appear like an approaching predatory mouth to the fish funneled toward it from the net mouth. The illusion can be built into the net as a defined change in contrast of the net material. As mentioned above, this has been used unconsciously in a number of studies due to the random nature of the color of available panels of different mesh sizes. Other evidence of this effect can be seen where fish are observed to mesh themselves where netting changes from one color to another. The black mouth or black tunnel experiments and application in a codend are reported by Glass et al. (1995) and Glass and Wardle (1995) and have implications for both species and size selection devices of all sorts. This is emphasized by the most recent series of experiments in which fish were given a choice of black or white netting within the extension region of a codend (Glass et al. In prep.). Observations on the escape behavior of fish showed that when presented with such a choice, most fish passed out of the net through the white square mesh panel rather than the black panel. The details of such an effect may depend on the prevailing underwater lighting conditions, but nevertheless stress the importance of the visual stimulus of the netting on the reaction behavior of fish. Studies such as this also illustrate how knowledge of the visual underwater stimulus and the behavior and sensory physiology of fish can be used to identify novel means of addressing the problems of bycatch reduction.

Total Exclusion of Swimming Fish

A different approach for the separation of shrimp was used in developments in Norway (Isaksen et al. 1992). Here the inability of the shrimp to react and swim compared to the dynamic responses and avoidance behavior of even the smallest teleost fish was observed by Karlsen (1976) when a rising net panel was angled upwards across the funnel of the shrimp trawl. The shrimp pass through the panel to the codend while the majority of fish rise and pass out through an aperture at the top of the net. Following this finding, fishermen in the Norwegian fishery were obliged to use the panel whenever more than three cod or haddock were caught with each 10 kg of shrimp. One of the problems here was that certain sizes of red fish (*Sebastes marinus*) juveniles were meshed bursting the panel. In 1989, the Nordmore grid was developed and has now replaced this net panel, solving the problem with red fish. Many fishermen volunteered to use the grid even when not required by the law as they had less sorting of the catch. The results with this gear have been so convincing that there is now compulsory use of the grid in this fishery (Isaksen et al. 1992).

Separation of Fish Species

There have also been reports on experiments looking at specific effects on fish species by trawls, gillnets and longlines. The subtle differences in capture by towed sampling gears were indicated by Engas and Godo (1989) when one of the species was being lost under the bobbin rig altering the ratios of species sampled. Engas and Soldal (1992) showed the numbers of small (L<30 cm) haddock and cod were greater during day hauls than night hauls, and that the number of haddock was consistently greater than cod when hauls made in daytime were compared with hauls made at night. They were using a Campelen 1800 trawl with a 4 m headline height in autumn in the Barents Sea at 270-340 m. The same trend was not found in winter hauls although the catch rates were lower. The authors concluded that such apparent differences in capture rate probably reflect small differences in the reaction behaviors of the species; for example, at different light levels or temperatures. Interpreting these catch results as indices for 30 cm cod and haddock in October 1989, they suggest the daytime samples gave 3.3 and 21.5 times the night time value. Species specific reaction behavior can lead to some species being easily sampled by a particular trawl rig, whereas other species seen by other techniques are absent from the trawl catch. A series of related papers on this issue are introduced and discussed by Engas (1991).

Adams et al. (1995) compared a survey made using TV camera transects with trawl survey samples from the same deep water grounds which show big differences in the assessment of species and their abundance. A similar approach comparing observation from a manned submersible and the trawl catch was reported by Kreiger (1993) where densities of Pacific Ocean perch (*Sebastes alutus*) were estimated and found to be about twice the number estimated by observation from the submersible. The difference was attributed to the herding of this species by the trawl sweeps. Densities of other species approached unity with submersible estimates indicating less herding of these species by the sweeps.

Small differences between behavior of fish species result in numerous artisanal fishing devices being used to catch fish from different niches of a complex fish community. In a multispecies fishery such as that described by Gobert (1994) in Martinique, out of 186 species identified in the area, 124 are identified in fishermen's catches. It is suggested that the diversity of fishing methods used allows the fishermen to target any of the species and sizes of this demersal resource just by using the appropriate variations in gear, i.e., size, shape, mesh size, soak duration, fishing depths, and baits, etc. This implies that single species or groups of species can be selected by application of an appropriate technique. Angling is well known for its use of specific tackle for specific fishing aims. A comprehensive review of species selectivity of longlining by Lokkeborg and Bjordal (1992) indicates that species can be selected by strategic fishing at specific depths or in layers of the right temperature; that baits are related to foraging habits and preferences can be species specific, and that hook design can make the gear more appropriate for a particular species.

Although it might be concluded from some experiments that catch of driftnets would be light-level dependent (Fujimori et al. 1990), Yatsu et al. (1995) conclude that diel activity patterns are more important in determining the catch rates for different species. However, one must admit that visibility of the net (Cui et al. 1991), animal activity (Collette and Talbot 1972), and their distribution (Clark and Levi 1988) are all controlled by light level and each affects the behavior of the fish.

Some very similar species such as herring and sprat are found in closely mixed schools according to Tortensen and Gjosaeter (1995). In this case, it seems to be due to overlap in need for the same size food organisms (calanoid copepods). When caught by single small beach seine hauls, sprat can occur mixed with herring in any proportion when both species are between 6 and 12 cm (Tortensen and Gjosaeter 1995). As the herring grow quite rapidly larger than the sprat, their food changes and they are no longer found together.

Gillnets are highly selective gears where the use of appropriate mesh size avoids capture of the juveniles of the target species (Hamley 1975). A careful study by Petrakis and Stergiou (1995) shows that there is also potential for selecting single species where the net mesh matches the target and no other dominant species of the same size is present.

Problems arise within large commercial fisheries where quotas impose pressures on fishermen to be more precise in their fishing techniques. In pelagic trawling, mackerel, herring, and horse mackerel can be found apparently in mixed schools of commercially sized fish. A recent study, supported by the EU, reports experiments both in aquaria and at sea where a search for differences between these species might be used to separate them in a pelagic trawl. Mackerel sink in sea water and must continue to swim to maintain depth, horse mackerel are usually neutrally buoyant, and herring may be neutral at the surface, but become heavy at depth. These three species will form mixed schools in an aquarium tank and will separate out by gentle chivvying of the fish. In fast moving gears their swimming performance characteristics are very similar at the same size. In swimming experiments, where they are made to react to netting panels, funnels, and barriers, all three species show identical responses. There is some indication at sea that if the species are different in size they will show different responses to the presence of selective grids (Marlen et al. 1994).

Conclusions

This review of how fish reactions may be used to reduce bycatch is by no means a complete or exhaustive reference list. However, it outlines the basic ways of considering the subject of fish behavior in relation to fishing operations and points to the relevant principles. There is probably little point in trying to make fishing gear which is universally effective in releasing nontarget species. There does however, seem to be room for more awareness of how fish and gears interact in specific fisheries as this is likely to be the most effective starting point in any attempt to reduce bycatch.

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Multispecies Management: An Alternative Solution to the Bycatch Problem

Steven K. Davis
LGL Alaska Research Associates, Inc., 4175 Tudor Centre Dr., #202, Anchorage, AK 99508

This paper proposes a new, philosophical approach to managing fisheries. It is based on the pretext that most species are found in association with other species and that as an alternative, quotas be established for different gear types which explicitly recognize the species mix typically encountered by the gear. Total fish removals would be monitored and accounted for with the quota being set based on the assessment of the species mix as a whole. By definition, there would no longer be any target catch and bycatch, but rather total catch. The paper concludes with an assessment of the risk associated with continued single species management, and the current drive to use technology to further isolate certain species from the ecosystem with little thought of the ecological consequences.

At the Newport, Oregon Bycatch Conference, it was clear that the fishing industry has a public perception problem concerning bycatch. As managers and industry have become more knowledgeable about bycatch through experience and education, so must the public if the misunderstandings surrounding bycatch are to be addressed. The public must become aware that catching fish for food in commercial quantities will require some bycatch.

The government's use of a single species approach to managing fisheries tends to discount or ignore characteristics of bycatch that commonly occur. As a result, some environmental groups claim that the industry and management agencies are "hiding the truth" from the public. On the contrary, perhaps it is a feature of a single species focus that has led to this misperception.

This paper falls into the "food for thought" category. It presents some conceptual ideas which may provide a solution to the bycatch problem.

Do we really know what the effect of fishing is on fish and shellfish populations? How the gear affects behavior and bottom habitats? How fishing affects the ecology of fishes?

We assume that within certain limits, fishing has little or no effect on the marine environment. But are we sure? Are our limits reasonable? How many of our limits are based on good science? How many have been set more for political or economic reasons? Are we being too conservative in our management? Or, are we not conservative enough?

Science is the building of knowledge based on the premise that theories and hypotheses can be tested and retested and that the results are repeatable. Scientists are taught to revisit assumptions and common beliefs to determine whether in fact new interpretation might reveal answers to important questions. Fisheries science is an applied form of scientific thought. Fisheries management is but one field within this discipline. I believe it is crucial that, on occasion, we reexamine current management regimes to determine if new science reveals more attractive alternatives to solving fishery problems.

Bycatch is a problem that is most often blamed on fishermen, but in truth it may be as much a result of the management regime as it is of fishing. In Alaska, and in many places throughout the United States with few exceptions, fisheries are managed on a single species basis where individual quotas for each targeted species are established. Until 1984, little attention was given to the incidental catch taken routinely as part of the domestic groundfish fishery in Alaska. Prior to that time, incidental catch, or bycatch, was ignored by managers, and not even counted. Since 1984, there has been a growing concern over bycatch in the domestic fishery. Much of this concern was originally stimulated by competing users for limited fish resources. Such allocation battles have become widespread resulting in intense social-economic conflicts. More recently, environmentalists have added their voice to the debate, arguing that this nation's conservation goals cannot be fully achieved without commercial fishery reform.

Many people don't realize that it was just five years ago when federal fishery managers in Alaska first began to include incidental catches as part of establishing and monitoring annual species quotas. Fishery management regimes in Alaska have evolved significantly in the last seven years, incorporating more science, new knowledge about the species themselves, and advances in analytical and inseason management technology. Many of these advancements have been used to develop bycatch reduction measures.

Likewise, the fishing industry itself has changed dramatically with more efficient harvesting and processing of groundfish species. The fishing industry is currently under intense pressure to develop gear technologies that minimize bycatch and further isolate target species from its species assemblage. While significant advances in gear technology have been accomplished, bycatch will never be totally eliminated. In fact, the presence of certain species in the catch may be a reflection of natural ecological relationships which exist in nature. That realization, given the tremendous financial cost of each incremental gain of lowering bycatch, just sets up the fishing industry for failure and further public criticism. It is unfair to expect the fishing industry to shoulder all the blame and assume all the responsibility of solving the bycatch problem. Fishery management reform is necessary if, together with the industry's technological advances, a complete solution to the bycatch problem is to be achieved.

Perhaps most important of all, it hasn't been until recently that managers have begun to think about the ecological relationships fish and other species have with one another and consider the effects of their management on the ecosystem as a whole. What cost to the ecosystem will continued single species management have? What species will fill the ecological niche vacated by a harvested species? Will it remain a high-value species, or will it be replaced by a low-value species?

This paper proposes a different philosophical approach to managing fisheries. It is based on the pretext that most species are found in association with other species and that, as an alternative, quotas be established for different gear types which explicitly recognize the species mix typically encountered by the gear. Total fish removals would be monitored and accounted for with the quota being set based on the assessment of the species mix as a whole. By definition, there would no longer be any target catch and bycatch, but rather total catch.

Comparison of a Single Species vs. a Multispecies Management Regime

In Alaska, fisheries are managed using a single species management approach. Table 1 identifies a total of 29 groundfish species that are independently managed by gear type in the Gulf of Alaska, Bering Sea, and Aleutian Islands areas. There are 32 groundfish fisheries currently being managed in Alaska. Each of these fisheries is issued a quota, or Total Allowable Catch (TAC) based on an annual analysis of the status of stocks, recruitment trends, and expected natural mortality. Until relatively recently, the TAC was the lone governing constraint on these fisheries. When the reported catch equaled the TAC, the government closed the directed fishery for the remainder of the year. Any additional catches (i.e., bycatch) of the closed species in other directed fisheries was required to be discarded. This illogical approach can be readily understood in Fig. 1. This illustration shows how current single species fisheries are prosecuted during the year. Essentially all fisheries and groundfish quotas are available to fishermen in January. (Note: some quotas have been subdivided and allocated to various periods; for example, the pollock "A" winter and "B" fall season.) As one quota after another is reached, further incidental catches of those species must be thrown away.

Since 1977, managers have been aware that incidental catches of certain species occur in the groundfish fisheries. The catch of these incidentally caught species was an issue because they were already fully utilized by domestic fishermen and processors. These species were considered prohibited species in terms of a standing regulation and fishermen were required to return these

Table 1. Current single species management regime.

1995 Bering Sea/Aleutian Islands Area			
Species	TAC (mt)	Gear Types	# Gears
Pollock	1,307,600	Pelagic	
		Bottom Trawl	2
Pacific cod	250,000	Bottom Trawl	
		Longline	
		Pot	3
Yellowfin sole	190,000	Bottom Trawl	1
Greenland turbot	7,000	Longline	
		Bottom Trawl	2
Arrowtooth flounder	10,227	Trawl	1
Rock sole	60,000	Bottom Trawl	1
Flathead sole	30,000	Bottom Trawl	1
Other flatfish	19,540	Bottom Trawl	1
Sablefish	3,800	Longline	
		Bottom Trawl	2
Pacific Ocean perch	19,811	Trawl	1
Other rockfish	1,022	Trawl	1
Atka mackerel	80,000	Trawl	1
Squid	1,000	Trawl	1

1995 Gulf of Alaska Area			
Species	TAC (mt)	Gear Types	# Gears
Pollock	65,360	Pelagic	
		Bottom Trawl	2
Pacific cod	69,200	Bottom Trawl	
		Longline	
		Pot	3
Deep water flatfish	11,080	Bottom Trawl	1
Rex sole	9,690	Bottom Trawl	1
Shallow water flatfish	18,630	Bottom Trawl	1
Flathead sole	10,000	Bottom Trawl	1
Arrowtooth flounder	35,000	Bottom Trawl	1
Sablefish	21,500	Longline	
		Bottom Trawl	2
Pacific Ocean perch	5,630	Trawl	1
Shortraker/Rougheye	1,910	Trawl	
		Longline	2
Other slope rockfish	2,235	Trawl	1
Northern rockfish	5,270	Trawl	1
Pelagic shelf rockfish	5,190	Trawl	1
Demersal shelf rockfish	580	Longline	1
Thornyhead rockfish	1,900	Trawl	1
Atka mackerel	3,240	Trawl	1

catches to the sea with a minimum amount of injury. These traditional prohibited species included all salmonids, Pacific halibut, king and Tanner crabs, and Pacific herring.

Until 1984, there were no formal limits on either the prohibited species catch or the incidental catch of other groundfish species. Bycatch, as an issue, surfaced before the North Pacific Fishery Management Council (NPFMC) following its adoption of a set of comprehensive fishery management goals which included a commitment to consider a fishery's interaction with other elements of the ecosystem. This goal, in turn, generated a series of management objectives for groundfish which included a commitment to "account for all fishery-related removals by all gear types for each groundfish fishery. . . ."

In response, Davis (1986) developed the first model for estimating the bycatch of halibut and other bycatch species in groundfish fisheries. This model became a valuable tool to the NPFMC as it weighed the costs and benefits of changing groundfish TACs in terms of their effect on bycatch levels. Once accepted by the NPFMC and the fishing industry, the use of the model made people increasingly aware of the bycatch that occurred in Alaska's groundfish fisheries. Managers' efforts to control and limit bycatch have resulted in a series of regulations that currently allocate specific quantities of certain species to directed fisheries. Proposals are now circulating that would apply these measures to the individual vessel level as opposed to a fleetwide basis. With the public's increased awareness of bycatch, we now have fisheries that are closed when they reach a bycatch limit as opposed to their preferred TAC. The management regime's focus is now centered on stimulating the industry to develop means of reducing its bycatch which, in turn, would make more of the TACs available to fishermen.

As managers learned more about the fisheries, it soon became apparent that all fisheries had at least some bycatch. The winter pollock-roe fishery, which targets large spawning schools of fish, was believed by many to be a relatively clean fishery with no bycatch problems. While true, examination of observer data shows that indeed a number of other species are taken (Table 2), although their catch pales in comparison to the amount of pollock harvested. The point here is that, even with winter pollock, some bycatch occurs.

Table 3 presents a review of the species composition typical of selected trawl, longline, and pot fisheries. All fisheries and gear types have bycatch, with some species appearing in the catch more often than others.

In Alaska, there are two distinct pollock fisheries: the winter fishery for roe, and the fall fishery when pollock are more dispersed but in suitable condition for fillet and surimi production. The number and variety of incidental species is different between the two fisheries. In the winter fishery pelagic trawl gear is used, which works well in capturing pollock throughout the water column. In the fall fishery a benthic or bottom trawl is customarily used. In this fishery, we expect to see a greater variety of species caught as bycatch since they are associated with the bottom and would be in greater proportion to the target species.

Isn't Bycatch Just a Problem with Definition?

What would happen if we had a management regime where fisheries were managed as a complex of species? For instance, a North Pacific bottom trawl fishery where pollock, Pacific cod, or some other species was defined as the principal target, would also be allocated a quota for all other species in the complex. Ratios of target to incidental species would be determined using historic and current season fishery data. Ratios could be flexible and would change during the year to reflect changes in the season, behavioral and migration patterns, and the fishes' ecology. An argument against this approach might be that it's too complicated or too data-intensive. This argument can be dismissed in that many of today's managed fisheries are moving toward ever-increasing mi-

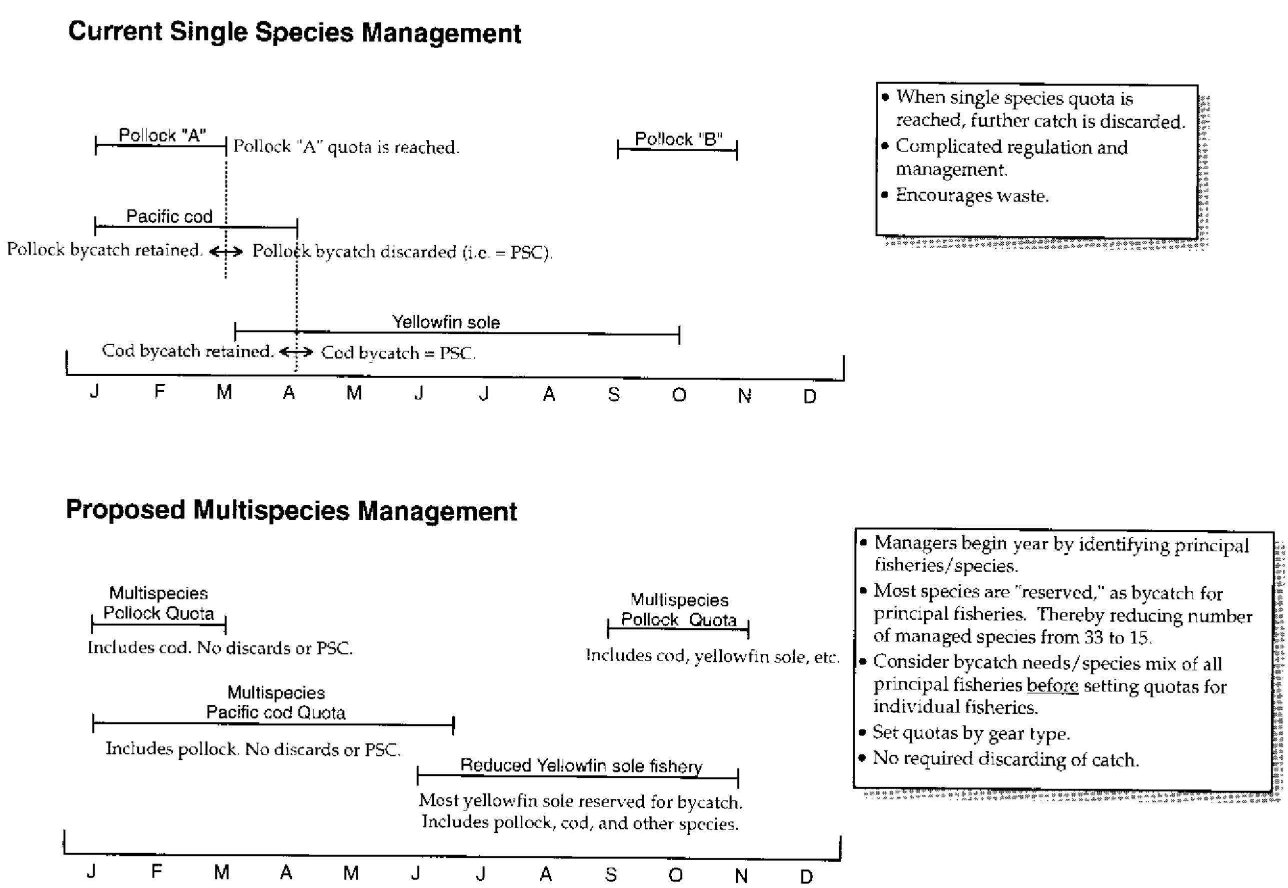

Figure 1. Example of single species vs. multispecies management regime.

Table 2. Sample of data records compiled by the NMFS Domestic Observer Program (source: NORPAC database).

AK_Plaice	Sculpin	Chinook	C.bairdi	C.opilio	RedKingCrab	BlueKingCrab	Snail	Haul_Wt
0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	24.29

Month	Haul	Gear	Pollock	P.cod	Halibut	Flathead	Skate	Arrowtooth	Yellowfin	Starry_Flndr	Rocksole
1	35	1	23.40	0.59	0.06	0.02	0.00	0.02	0.00	0.00	0.07
2	59	1	34.55	0.89	0.20	0.10	0.00	0.03	0.00	0.00	0.94
2	101	2	31.36	1.02	0.08	0.32	0.72	0.04	0.00	0.00	0.00
3	288	1	10.49	0.16	0.06	0.29	0.00	0.01	0.02	0.00	1.00
7	231	2	13.31	0.98	0.10	0.11	0.00	0.03	0.00	0.00	0.09
2	39	1	400.59	11.83	1.12	15.43	0.00	2.24	5.54	0.00	12.28
6	568	2	12.40	0.36	0.09	0.43	0.00	0.03	0.03	0.00	3.11
6	5	2	10.23	1.37	0.07	0.76	0.79	0.05	0.00	0.00	0.13
1	42	1	48.33	0.07	0.19	0.02	0.00	0.20	0.00	0.00	0.48
2	48	2	16.01	0.65	0.13	0.32	0.00	0.02	0.13	0.00	4.08
1	1	1	69.62	0.17	0.06	0.05	0.04	0.15	0.00	0.00	0.00
2	79	1	10.25	0.77	0.03	0.49	0.28	0.04	0.14	0.00	0.34
10	16	1	10.25	0.31	0.11	0.31	0.00	3.72	0.00	0.00	0.00
2	75	2	10.93	0.97	0.99	0.55	0.00	0.12	0.00	0.00	0.27
2	190	2	26.82	3.07	4.30	1.06	0.00	0.44	0.00	0.00	0.23
6	146	2	10.54	0.17	0.05	0.07	0.03	0.60	0.00	0.00	0.05
12	14	2	15.66	0.05	0.04	0.34	0.00	0.46	0.00	0.00	0.00
3	168	2	30.20	0.24	0.11	0.90	0.00	0.12	0.02	0.00	0.46
12	296	2	20.36	3.06	0.47	0.73	0.00	3.41	0.00	0.00	0.00
12	361	2	17.67	1.35	0.14	0.34	0.00	1.69	0.00	0.00	0.00
7	203	2	45.11	0.15	0.03	0.26	0.00	0.71	0.00	0.00	0.00
6	366	2	14.98	4.40	0.12	0.85	0.00	1.71	0.00	0.00	0.71
8	4	1	16.79	0.84	0.38	5.67	0.00	0.56	0.00	0.70	11.60

cro-management anyway. The data needed to implement a multispecies program in Alaska already exist and, with recent advances in computing power and at-sea communication, managers now have the tools necessary to analyze and monitor the fisheries more efficiently.

There would be no bycatch, per se, because those species would already be included in the setting of the quota. All of the species would be included as part of the catch. All of the catch would be counted against the multispecies quota. The quota would be based on scientific and fishery-generated information. This approach could be made part of a full-utilization framework, whereby fishermen and processors would develop means for utilizing many different species. Fishermen would have already paid a cost because money would have already been spent in harvesting these species, and it would have all counted against the quota. The public will become more informed about the costs paid by fishermen and the logical occurrence of some bycatch in fisheries.

For this approach to work, government must share in both the rewards and costs of its management policy. Government can provide financial incentives to industry for the advancement of new gear technology, as well as for the development of new products utilizing low-value species. These products could go toward meeting a number of world food, pharmaceutical, and agricultural needs.

At the beginning of the year, the managers would identify those species to be managed as directed fisheries. All other species, based on biological and economic analysis, would be used as bycatch in support of directed fisheries. Utilizing computer models, managers and industry would be able to determine the bycatch requirements for each gear type used in a directed fishery. Fig. 1 illustrates how a series of multispecies fisheries may unfold during the course of a year. For example, amounts of pollock would be set aside in advance of the directed pollock fishery in order to allow cod and yellowfin sole fishermen to keep their pollock bycatch. As a result, the pollock TAC would be reduced for the directed fishery. The consumer would see little change since the pollock would be delivered to the marketplace via several fisheries rather than just one. The difference between current single species management

Table 3. Typical species mix in selected target fisheries.

Fishery	Target Species	Gear Used	Incidental Species	Frequency of Occurrence
Winter	Walleye Pollock	Pelagic trawl	Pacific cod	common
			Alaska plaice	rarely
			Arrowtooth flounder	rarely
			Chinook salmon	rarely
			Flathead sole	rarely
			Pacific halibut	rarely
			Sculpin	rarely
			Skate	rarely
Fall	Walleye Pollock	Bottom trawl	Pacific cod	common
			Pacific halibut	occasionally
			Rock sole	occasionally
			Alaska plaice	rarely
			Arrowtooth flounder	rarely
			Chinook salmon	rarely
			Flathead sole	rarely
			King crab	rarely
			Pacific herring	rarely
			Rex sole	rarely
			Sculpin	rarely
			Skate	rarely
			Snail	rarely
			Tanner crab	rarely
			Yellowfin sole	rarely
Summer	Yellowfin sole	Bottom trawl	Alaska plaice	common
			Pacific cod	common
			Pacific halibut	common
			Rock sole	common
			Sculpin	common
			King crab	occasionally
			Starry flounder	occasionally
			Snail	rarely
			Tanner crab	rarely
Year-round	Pacific Ocean perch	Pelagic trawl	Arrowtooth flounder	common
			Pacific cod	common
			Chinook salmon	occasionally
			Pacific halibut	occasionally
			Atka mackerel	rarely
			Harlequin rockfish	rarely
			Northern rockfish	rarely
			Rex sole	rarely
			Rougheye rockfish	rarely
			Sablefish	rarely
			Sculpin	rarely
			Sharpchin rockfish	rarely
			Shortraker rockfish	rarely
			Skate	rarely
			Walleye pollock	rarely

Table 3. Typical species mix in selected target fisheries. (continued)

Fishery	Target Species	Gear Used	Incidental Species	Frequency of Occurrence
Spring	Pacific cod	Bottom trawl	Arrowtooth flounder	common
			Pacific halibut	common
			Rock sole	common
			Sculpin	common
			Walleye pollock	common
			Atka mackerel	occasionally
			Blue king crab	rarely
			Flathead sole	rarely
			Northern rockfish	rarely
			Pacific Ocean perch	rarely
			Rex sole	rarely
			Rougheye rockfish	rarely
			Skate	rarely
			Tanner crab	rarely
			Yellowfin sole	rarely
Year-round	Pacific cod	Pots	Pacific halibut	common
			Sculpin	common
			Octopus	occasionally
			Rock sole	occasionally
			Arrowtooth flounder	rarely
			Atka mackerel	rarely
			Blue king crab	rarely
			Sea cucumber	rarely
			Snail	rarely
			Tanner crab	rarely
			Yellowfin sole	rarely
Year-round	Pacific cod	Longline	Octopus	common
			Pacific halibut	common
			Sculpin	common
			Skate	common
			Arrowtooth flounder	occasionally
			Atka mackerel	occasionally
			Flathead sole	occasionally
			Rougheye rockfish	occasionally
			Sablefish	occasionally
			Turbot	occasionally
			Walleye pollock	occasionally
			Dog fish	rarely
			Northern rockfish	rarely
			Rock sole	rarely
			Tanner crab	rarely

Table 3. Typical species mix in selected target fisheries. (continued)

Fishery	Target Species	Gear Used	Incidental Species	Frequency of Occurrence
Spring	Rock sole	Bottom trawl	Pacific cod	common
			Pacific halibut	common
			Sculpin	common
			Walleye pollock	common
			Arrowtooth flounder	occasionally
			Blue king crab	occasionally
			Butter sole	occasionally
			Flathead sole	occasionally
			Skate	occasionally
			Starry flounder	occasionally
			Yellowfin sole	occasionally
			Alaska plaice	rarely
			English sole	rarely
			Rex sole	rarely
			Sablefish	rarely

Table 4. Proposed multispecies management approach.

Gear Type	Principal Target Species	Quota
Pelagic Trawl	Pollock	Q1
Benthic Bottom Trawl	Pollock	Q2
Bottom Trawl	Pacific cod	Q3
Bottom Trawl	Rock sole	Q4
Bottom Trawl	Yellowfin sole	Q5
Pelagic Trawl	Pelagic rockfish	Q6
Bottom Trawl	Benthic rockfish	Q7
Pelagic Trawl	Atka mackerel	Q8
Longline	Pacific cod	Q9
Longline	Halibut/Sablefish	Q10
Longline	Demersal rockfish	Q11
Pot	Pacific cod	Q12

Table 5. Example of multispecies quota determination.

Bering Sea bottom trawl Pacific cod fishery
1995 Pacific cod TAC (a) = 135,000 mt
Multispecies quota for bottom trawl/Pacific cod = $\sum_{i=1}^{n} Q_i$

Species Mix	Analysis of Fishery Data	Q_i (mt)
Pacific cod	23.75	135,000
Arrowtooth flounder	0.05	285
Rock sole	1.25	7,105
Walleye pollock	5.52	31,377
Atka mackerel	trace	50
Flathead sole	0.02	114
Rex sole	0.01	60
Yellowfin sole	trace	50
Northern rockfish	trace	50
Pacific Ocean perch	trace	50
Rougheye rockfish	trace	50
Skate	trace	50
Sculpin	0.11	626
King crab	trace	5,000 [a]
Tanner crab	trace	100,000 [b]
Pacific halibut	0.05	750 [c]
	Quota =	175,617 mt

[a] TAC allocated to trawl gear = 54%.
[b] Number of animals; arbitrarily set at ½ the current PSC limit.
[c] Arbitrarily set at ½ the current PSC limit.

and multispecies management is that bycatch of species would be considered first when determining quotas for directed fisheries rather than considered last.

As mentioned previously, the federal government currently manages 32 single species groundfish fisheries in the Gulf of Alaska and Bering Sea/Aleutian Islands areas. Using the multispecies approach, 12 fisheries are identified (Table 4), each being issued a quota composed of the species mix common to a gear type. All species would be retainable and available for use. There would be no bycatch.

Multispecies quotas may be constrained should a member of the complex be depressed or at a minimum threshold. Individual target quotas may be reduced so the sum of all expected catches of a species does not exceed the predetermined biological levels. At current stock levels, target quotas would likely remain unchanged from current TACs.

An Example

To test this multispecies approach to management, I examined data records collected by fishery observers working for the National Marine Fisheries Service. In Alaska fisheries, catch, bycatch, and a variety of other scientific data have been collected by U.S. observers since 1977, making the observer database rare in terms of both its long time series and its scope. For purposes of this paper, I selected records for one year collected from domestic fishing vessels using benthic or bottom trawl gear and targeting Pacific cod. Analysis of these records produced results presented in Table 5.

The observer data indicate that in bottom trawl hauls where Pacific cod was the principal target, 15 other species of fish and shellfish were encountered to varying degrees. Applying the observed multispecies relationship to the current Pacific cod TAC produced a set of quotas which sum to 175,617 mt. All of these quotas fall within levels experienced by the fishery over the last 18 years.

The difference between this management approach and the current single species approach is that now I am explicitly recognizing those species which are taken incidentally as part of the catch and including them in the quota. This cursory analysis even suggests that significant reduction in prohibited species (halibut, king, and Tanner crab) catches could be achieved.

One possible argument against this approach is that such a system would allow fishermen to exceed the current 135,000 mt quota on Pacific cod by providing an opportunity to increase the proportion of cod in the catch. My response is to let the fishermen try. They certainly haven't demonstrated that they have that ability. Should fishermen become more successful in targeting Pacific cod, the multispecies composition in the catch would change, and managers would be able to incorporate this new data into their quota-setting process. With the current levels of observer coverage, such changes could even occur inseason.

This multispecies approach has several obvious benefits:

1. It addresses the fact that under single species management it is likely impossible to develop technology that would allow only single-species removal from the ecosystem.

2. It may eliminate the need for regulations which penalize fishermen for taking species of fish and shellfish which naturally occur with the target species. Use of multispecies management regimes will help educate the public as to the natural occurrence of a variety of species in the catch.

3. At the fisherman level, there would be fewer and simpler regulations. There would only be one quota to worry about as opposed to a series of quotas and bycatch limits.

4. The concept is universal and could be applied to a number of regions where observer or logbook data exist.

5. We, as scientists, don't know what the ecological effects are of targeting on a single species. A multispecies approach to management may better reflect nature's balance.

Reference

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Bycatch Management on the United States East Coast

Jake Dykstra
2708 Vanderbilt Ave., Raleigh, NC 27607

Two bycatch conferences have been held on the East Coast. They were mainly concerned with local problems, but included speakers from other areas. Management of bycatch on the East Coast has occurred in almost all fisheries, but attention has been focused on a few—sink gillnets, pelagic longliners, and northern and southern shrimp trawls. Mesh size and fish size have been used with varying success in the finfish trawl fishery. The situation is complicated by the division of management authority among 15 states, the Atlantic States Marines Fisheries Commission (ASMFC), and three federal management councils. Managers are becoming more aggressive as stocks decrease in abundance. This posture is reflected in the application of bycatch control as a management tool. Gear modifications, which managers incorporate as mandatory in management plans, have been the most effective to date. However, as more and larger areas are closed to fishing, areas of traditionally heavy bycatch will serve to better demonstrate the effectiveness of closed areas as a tool to reduce bycatch.

Two bycatch conferences in the past few years have been held on the East Coast—in 1992 and 1995. The 1992 conference, and another in 1989 I am told, would be more accurately described as conservation engineering conferences. Those conferences mainly addressed East Coast problems but included speakers from other areas. East Coast representatives participated in the 1992 International Shrimp Bycatch Conference in Florida and in the 1992 National Bycatch Conference in Newport, Oregon.

Those East Coast fisheries under direct bycatch regulations are being addressed in other papers. They include the sink gillnet, pelagic longline, and southern shrimp trawl fisheries and will be addressed by other speakers.

One fishery with regulations directed at general bycatch, is the shrimp fishery off of New England. It is a seasonal fishery with seasons set by the Atlantic States Marine Fisheries Commission shrimp board. It is traditionally a trawl fishery, but the last couple of years have seen an explosion of the pot gear in the fishery. The trawl fishery was plagued by a substantial bycatch of groundfish until the Nordmore grate was introduced for the 1993-1994 season. Most of these groundfish were juveniles.

Although some fishermen complained bitterly that they could not survive without the bycatch of legal size groundfish, a regulation calling for no retention of groundfish accompanied the introduction of the grate. The learning period was marked by much anguish, as is the introduction of any such device, and some fishermen will always hate towing the grate. Others would continue to tow it even if it were not required because they believe that a clean fishery with reduced labor and improved quality is more profitable. One big advantage was that the Nordmore grate did not have to be developed for use in New England. It was imported after having been successfully used in other areas.

The lobster fishery, the most valuable fishery in some areas, must also be addressed. Over 90% of the lobster catch is made in pots (traps). The remainder is caught by trawl, dredge, and gillnet or trammel net. Eighty percent of the catch is from state waters and the state laws vary greatly though there is a uniform size limit. Possession of lobsters on a trawler is forbidden in Maine waters and similar laws have been introduced in the Massachusetts Legislature for years. Trawlermen and lobstermen do not agree on the amount of damage done to lobsters by bottom trawling. It is alleged by some pot lobstermen that trawl gear maims or kills most of the lobsters it encounters. The trawlermen deny this and assert that pot fishing inflicts substantial bycatch mortality and the war goes on.

In 40 years of fishing on trawlers I have observed that in some areas when lobsters are shedding, mortality, mutilation, and crushing is a serious problem. Trawling on bottom in these areas should be prohibited at such times. These are not large areas or long periods, but especially in nearshore areas where gear conflicts are involved, there have been rammings, gunplay, and other mayhem. The past year has seen an effort to amend the federal lobster plan with no success. At any rate, all state plans as well as the federal plan have escape vent provisions which are universally observed and minimize bycatch of undersized lobsters. Some fishermen use escape vents slightly larger that those required by law on the premise that the gear can be handled so much more efficiently with less bycatch that they are more than compensated for the possible loss of legal lobsters. Other bycatch in the lobster fishery is limited to crabs and small quantities of finfish, none of which is jealously coveted by anyone, so bycatch is not a big problem.

The scallop dredge fishery is a major fishery on the East Coast. On January 1, 1996 the ring size in the scallop dredge fishery went from 3¼ to 3½ in. Regulations are already in place that prohibit multiple connectors between rings and chaffing gear or other obstructions on the ring bag that were traditional. Some scallopers say that these measures will not only reduce the bycatch, they will reduce the catch to nothing but rocks.

What is different about bycatch on the East Coast? In the major mobile gear fisheries, i.e., the George's Bank and Gulf of Maine groundfishery, the southern New England/mid-Atlantic mixed trawl fishery, and the scallop fishery, there has been no bycatch regulation saying "thou shalt not catch any or more than so much bycatch" or "thou shalt not kill unwanted fish." Rather, the regulation is based on mesh size, ring size, fish size, closed areas, no codend liners, etc. These measures have been aimed primarily at avoiding juveniles of the species addressed in that particular management plan. The limitation of these measures is that fishermen could capture a high volume of unwanted fish, throw them back, and still not be in violation of any regulation. Consequently there are some fishermen who are still in denial, insisting that they do not have any bycatch problems or that the problems are inconsequential and will go away if ignored. This may be changing. The most recent groundfish regulations have a provision that no small mesh may be towed in an area where more than 5% groundfish catch has been observed. Blunt instrument that it is, this is a start on direct bycatch regulation that closes an area where there is deemed to be excessive bycatch.

Authority to manage fisheries on the East Coast of the United States may be the most fractured of any national jurisdiction in the world. International management regimes are in some cases worse, but with 15 states, the Atlantic States Marine Fisheries Commission, and the federal government (with three regional fishery management councils and the National Marine Fisheries Service) all having power to regulate, a fisherman venturing forth to ply his trade faces a formidable array of regulations. Not only are there many places where the boundaries of two states' waters and the federal waters meet, but there is one place where the waters of three states, New York, Connecticut, and Rhode Island, meet with federal waters. Many species of fish migrate between or inhabit the waters under the jurisdiction of two or three federal councils, as well as the waters of several states, but at least each species of fish in federal waters is managed by a single council.

As a result of the Atlantic Coastal Fisheries Cooperative Management Act, passed on December 20, 1993, the Atlantic States Marine Fisheries Commission has regulatory powers. For nearly half a century it had powers only to recommend and coordinate, but under current law it writes and passes management plans for all significantly fished species found in the waters of the 15 coastal states. These plans can and do contain coastwide regulations, but for the most part leave regulation up to the individual states with the requirement that fishing mortality must be reduced to or fall below a specified level. Thus these states, while having a variety of regulations, can be in compliance with the plan. Different bycatch provisions or no bycatch provisions are in place in neighboring states or in several states. The surprising thing is that under this cumbersome arrangement, the ASMFC has been able to put plans in place more expeditiously and effectively than have the federal councils.

The substantial work being done with gear modification around the country and around the world can lead to, and is effecting, very significant bycatch reduction. However, while mesh size, pingers, ring size, excluders, escape vents, grates, and nets designed to fish clean are all in use on the East Coast, and promising work is being done on ever more selective gear design, they are not as effective as they could be. On the East Coast, where there are thousands of small units fishing in highly fractured jurisdictions, it is difficult to apply and enforce the proper use of these tools. Those who are impatient to see quick, clean, and effective solutions are frustrated.

In response to pressures from several sources to restore depleted stocks, East Coast managers at all levels of jurisdiction are enacting measures that are much more restrictive than would have been politically acceptable in the past. Groundfish in New England has been declared to be in crisis. Amendment 5 to the New England Fishery Management Council groundfish plan, which followed an emergency action, went into effect April 13, 1995. That amendment, among other things, closes about 6,000 square miles of the most productive fishing grounds off New England to trawling. Though not specifically and solely designed as a bycatch measure, this closure has to be the most effective bycatch measure put in place in this fishery. Other closures, although not as extensive, are being put in place to protect marine mammals and turtles and to reduce gear conflicts, etc. Many of these closures are in areas which in the past should have been closed, or at least closed to trawling with small mesh, but were not closed even when fishermen requested the closures because the management apparatus was unable to respond. The effect of any bycatch regulation is difficult to measure, but one thing is for sure: if an area or a fishery is closed to fishing, there is no bycatch in that area or fishery during the closure.

In the mixed trawl fishery conducted primarily in the southern New England and mid-Atlantic area, a number of species are caught together. Unfortunately, the most profitable of these species, squid, requires the smallest mesh. Some progress is being made on educating fishermen to move off excessive bycatch, and minimum fish sizes are in place for the important species.

I fished for many years when bycatch was not viewed as a management problem. Now an array of measures and equipment is being used to minimize bycatch. On the East Coast, as elsewhere, there are still situations where excessive bycatch can occur while the fisherman is not in violation of any regulation. Although such situations are rapidly being reduced, there is a long way to go. Stringent regulations and harsh penalties will not do the whole job, especially when enforcement is underfunded and/or inept. In my view, good research and statistics, along with a combination of a carrot, a stick, and education, is the most productive approach.

Shrimp Trawl Bycatch and Possible Solutions

Julius Collins
Gulf of Mexico Fishery Management Council, 163 Creekbend Dr., Brownsville, TX 78521

The Gulf of Mexico Fishery Management Council plans on shrimp trawl bycatch of finfish in the Gulf of Mexico. Our options will be determined by what Congress or the Magnuson Act allow us to do without having too great an economic impact on the people involved in the fishery.

Industry is working to help eliminate the incidental bycatch of sea turtles in the shrimp trawl fishery in the Gulf of Mexico and has come up with its own study and plan to eliminate or drastically curtail the sea turtle problem in the Gulf of Mexico.

I am current Chairman of the Gulf of Mexico Fishery Management Council. I am past president and also serve on the Board of Directors of the Texas Shrimp Association. I will address the bycatch issue from the perspective of the industry with possible solutions from the Council's perspective.

Trawl bycatch of finfish has occurred since the inception of the Gulf shrimp fishery. Shrimp fishermen have tried to eliminate fish bycatch and have done so, to a certain extent, without too much economic loss. Fish taken as bycatch are largely what Congress would classify as "economic discards," that is, fish with little economic value due to small size or predominance of unmarketable species. The seafood industry has spent millions of dollars over the years attempting to develop products for the markets from this bycatch, with no success. Typically, the cost of refrigerating the fish with ice has exceeded its value. The only species considered overfished in the Gulf of Mexico is the red snapper which took center stage in 1990. Since then, trawl bycatch has become a major regional issue because biological assessments of the overfished red snapper stock indicated the stock could not be fully restored without reducing shrimp trawl bycatch of juvenile red snapper. National Marine Fisheries Service (NMFS) stating that as much as 10 pounds of finfish bycatch was caught for every one pound of shrimp landed. Because the Council was considering courses of action to address this issue without good data, Congress amended the Magnuson Act, and at the request of the industry, provided for a four year research program addressing shrimp trawl bycatch.

The research program was carried out by NMFS, the Gulf and South Atlantic Fishery Development Foundation, Texas Shrimp Association, state and academic institutions, and the shrimp industry and included more than 3,300 days of sampling at sea. The program not only characterized trawl bycatch by species, size, and number, but also included development and evaluation of bycatch reduction devices (BRDs). Characterization data indicated that instead of the 10 pounds previously stated, only 3-4 pounds of fish was taken for each pound of shrimp. This was quite a bit less than was first reported by NMFS data but regardless, over 80 BRD designs were evaluated. While many of these significantly reduced finfish bycatch, they also caused considerable amounts of shrimp loss—some as high as 30-40%. Only two designs reduced bycatch of juvenile red snapper by 50% (or more) and had high retention rates for shrimp. More study is needed on these two designs. Even though the four year study is not yet completed, based on this research the Council is developing a Fisheries Management Plan (FMP) amendment which will require shrimp vessels to use NMFS approved BRDs in all or part of the Gulf Exclusive

Economic Zone (EEZ). Currently, Council staff and NMFS are drafting the Supplemental Environmental Impact Statement for this amendment.

Over the years, other actions have occurred that contributed to reduction of bycatch. One major action was a shift by the industry to flat twin and quad trawls from single, standard balloon trawls which significantly reduced the bycatch. Other factors were the use of electronic devices such as Loran C, plotters, etc. that positioned you away from concentrations of finfish. In 1989, shrimp vessels were required to use Turtle Excluder Devices (TEDs) which excluded larger fish and, we believe, significantly reduced bycatch of finfish. Also, in the last decade the number of ocean going vessels in the fleet has continuously declined. It is safe to say that the red snapper population is strongly rebounding. As proof, last year's commercial quota of three million pounds was landed in 51 days compared to over 70 days two years ago, and the recreational quota of three million pounds was doubled.

Although the data and information are better, the industry still has concerns over a number of aspects of the data being used for management. One of the more significant is the effort data used by NMFS for the fleet to project bycatch levels for species such as red snapper. A peer group review indicated these data were not collected randomly, introducing bias in the estimates. In the industry transition from standard trawls to TED-equipped trawls, NMFS did not properly document the bycatch reduction capabilities of the TEDs. A major concern by all the industry is that after bycatch levels are reduced by BRDs to the technically feasible level (about 50%), the environmental community will continue to lobby for even further reductions that cannot be achieved by gear technology. This is what is currently happening on the Gulf Council with shrimp trawl bycatch.

The other shrimp trawl bycatch is the threatened or endangered sea turtles. For years, the shrimp industry has been accused (again according to NMFS data) of catching over 40,000 sea turtles (Kemp's ridley, loggerhead, green, leatherback, and hawksbill) each year in shrimp trawls; and of these, 11,000 drowned. Industry denied that claim. They said that if they were catching that many turtles that they should not be on the endangered or threatened list to begin with, but to no avail. The environmental community threatened to sue NMFS to get industry to protect the sea turtles. They launched research and, with the help of industry, developed and had approved the Turtle Excluder Device or TED. Industry finally, though reluctantly, adopted the TEDs. Everything was fine until 1994 when a rash of sea turtle strandings occurred on the Texas coast. Again, the environmentalists sued, and again NMFS obliged. NMFS came up with what they called an emergency response plan that would, or could, close down shrimp fishing on all or part of the Texas-Louisiana coast if strandings continued. This time, industry which is at 100% compliance with the use of TEDs, got into the act and filed suit against NMFS. Industry also raised funds and hired a consultant to go through all of the NMFS data on sea turtle strandings and asked them to come up with the best solutions to eliminate turtle bycatch in shrimp trawls.

After thorough evaluation of the NMFS data, the consultant proposed a somewhat different approach, beginning with the establishment of a sea turtle conservation zone (STCZ) in the Gulf of Mexico. This zone included inshore and nearshore waters out to a distance of about 10 km (6.1 statute miles) offshore in most areas of the Gulf. In parts of NMFS statistical areas 17 and 18, around the Sabine River where the density of Kemp's ridleys appears highest, they proposed extending the offshore boundary seaward some 18 statute miles and made modifications in the Tortugas-Sanibel pink shrimp fishing grounds off southwest Florida. As proposed, the STCZ would also afford protection for juvenile loggerheads as well as Kemp's ridley sea turtles.

Inside the STCZ, TEDs would be required at all times and places. While up to four nets could be towed, all trawls, in combination, could not exceed a total of 100 feet of headrope as measured from outside hanging to outside hanging. Now the average is 200 feet of headrope. In addition, a 15 foot trynet could be used. Trynet doors could not exceed 18 inches in height or 36 inches in length. Night fishing would be prohibited in statistical areas 17-21 along the whole Texas coast up to 10 km. The inshore portion of the proposed STCZ would continue to be managed by the respective states. The STCZ would, for all practical purposes, be considered to be equivalent to critical habitat. As such, all or part of inshore or offshore STCZ would be subject to emergency time/area closures should these be considered necessary. In order to prevent abuses, no user group could be exempt from a closure. Texas inshore and nearshore shrimpers have been contacted and endorse the concept. This would reduce shrimping effort by more than 50% where turtles are during certain times of the year. Restrictions of activity within the STCZ should not apply to the shrimp industry alone.

There are many human activities other than shrimp trawling that can result in sea turtle mortality, and the authors of the report stated that these should be addressed and reduced. Of particular importance in this regard is the Kemp's ridley abundance zone centered around Sabine Pass. All human activities known to result in sea turtle mortality could have higher than normal effects in this region because of the high density of Kemp's ridley sea turtles in the area. For example, recreational fishing is not normally considered a threat to sea turtles. Yet, in the Sabine Pass area, Kemp's ridleys are commonly caught by recreational fishermen to the detriment of the turtles. Other threatening activities in this region in particular, and the STCZ in general, include boating, gillnetting, dredging, longlining, menhaden fishing, mullet fishing, oil and gas activities (seismic exploration and platform removals using explosives), and military maneuvers involving explosives. Collectively or individually any one of these activities can result in turtle mortality rates high enough to create a shrimp fishing closure situation regardless of whether shrimp fishing was a contributor to the mortality or even blameless. All user groups of the STCZ should therefore be identified, and required to file a conservation management plan if they are to continue to use this region. Likewise, a closure of a region of the STCZ, in part or in its entirety, should apply across all user groups. The greatest effect will be on the offshore sections of the proposed STCZ. Large vessels will likely not fish this area due to the net-size and time-of-day fishing restrictions and TED requirements. In the consultant's proposal, TEDs would not be required seaward of the proposed STCZ. Offshore shrimping vessels electing to fish this zone without TEDs would, however, be required to mobilize and demobilize from a fishing mode seaward of the STCZ. Failure to do so should result in forfeiture of the catch or more severe penalties.

These, we think, are the best solutions to the bycatch of sea turtles in shrimp trawls.

Management Perspectives on Waste and Discards in North Pacific Fisheries

Clarence G. Pautzke
North Pacific Fishery Management Council, 605 W 4th Ave., Anchorage, AK 99501

Waste and discard in marine fisheries may be one of the three most defining fisheries issues of this decade; the other two being sustainable resources and overcapitalization. Certainly fisheries managers and industry are under the spotlight to see how we respond to this critical issue, particularly as the country wrestles with reauthorization of the Magnuson Act.

Policy momentum is building internationally and nationally. Few if any policy makers are saying we are doing OK in our current practices, or that increased waste and discards are acceptable. Indeed, the policy vector is firmly in the other direction: action needs to be taken to clean up our fisheries; action needs to be taken to promote, even mandate, responsible fishing practices.

I will first describe policy formation at the international level and how it trickles down through national and regional policy making. I will then discuss North Pacific Fishery Management Council (Council) efforts toward reducing the bycatch of prohibited species, and reducing groundfish discards. I will touch on implementational issues toward requiring improved utilization, and a proposal that may address some of these problems. Finally, I will describe what steps the Council may take by 1998 to reduce waste and discards in North Pacific fisheries.

Internationally, there has been an ever increasing drumbeat of policy initiatives calling for more responsible fishing. The United Nations Convention on the Law of the Sea transmitted to the U.S. Senate on October 7, 1994 for advice and consent has been around for many years in one draft or another, and perhaps is the most venerable of the policy documents on management of marine resources. Articles 61 and 62 speak to the conservation and utilization of living resources, specifically imploring coastal states to consider effects of fisheries on other than targeted species.

The International Conference on Responsible Fishing in May 1992 in Cancun, Mexico, produced the Declaration of Cancun which declared that nations "should promote the development and use of selective fishing gear and practices that minimize waste of catch of target species and minimize bycatch of nontarget species." The UN Conference on Environment and Development (UNCED Agenda 21) in June 1992 in Rio de Janeiro adopted an objective to promote conservation and sustainable use of marine living resources, urging nations to ". . . take measures to increase the availability of marine living resources as human food by reducing wastage, post-harvest losses and discards. . . ."

These concerns culminated in the UN Food and Agriculture Organization (FAO) Committee on Fisheries developing in March 1993 a draft International Code of Conduct for Responsible Fishing. Article 19 speaks to the issues of avoiding wastage and incidental damage to the marine resource, minimizing the risk of long-term or irreversible effects on fishing operations, and maintaining biodiversity. In a subsequent, related, Inter-American Conference on Responsible Fishing, in July 1993 in Mexico City, the resulting Communiqué suggested that the Code should urge nations to promote the development of gears to permit greater selectivity in catches and establish criteria governing the use of all types of fishing gear considered destructive and unsuitable. It was the consensus of that meeting that the UN should declare the 1990s the "Decade of Responsible Fishing."

In last year's meeting of the UN General Assembly, a resolution was passed on fisheries bycatch and discards and their impact on the sustainable use of the world's living marine resources. The General Assembly noted the important role that fisheries play in contributing to a sustainable food supply and stated its belief that bycatch and discards in fishing operations warrant serious attention by the international community. It then urged the FAO, the Conference on Straddling Stocks, and all international and regional fisheries management organizations to review ways to address the discard and waste problem.

The recently approved straddling stocks agreement,[1] dated August 3, 1995, embraces much of the language developed in earlier international agreements. Four of the 12 General Principles in Article 5 in some way or other urge nations to consider nontarget species and ecosystems effects when conserving and managing fisheries. In particular, principle (f) urges nations to minimize ". . . waste, discards, catch of nontarget species, both fish and nonfish species, and associated species." Principle (g) calls on nations to protect biodiversity in the marine environment.

The 50th session of the United Nations will include waste and discard in world fisheries as an agenda item. The FAO also had a technical committee meeting in Rome on 25-29 September 1995 to finalize the 11 articles contained in the draft Code of Conduct for Responsible Fishing and the Code will be presented to the FAO Conference on 25 October 1995.

These lofty pronouncements at international levels trickle down into national fisheries policy. We see NOAA's 1995-2005 Strategic Plan embracing an Environmental Stewardship Program Portfolio which has six key program elements. One is reducing bycatch of young or nontarget species. Further, we likely will see in the current reauthorization of the Magnuson Act new language on the need to reduce and minimize bycatch and discard. There may even be a new national standard to that effect.

Despite the high level pronouncements, the nuts-and-bolts response must be hammered out at the regional level, where it all comes down to a majority vote by a regional council to move ahead to address an identified problem. I think we are going to feel ever increasing pressure to clean-up the fisheries off Alaska, even though we are not among the world's worst transgressors in terms of discard performance.

North Pacific Council Activities on Prohibited Species

The issue of bycatch of unwanted species is, of course, not new to the Council. Much of the past 18 years has been spent by the Council developing and implementing various measures to control the bycatch of salmon, halibut, and crab by the groundfish fleet. We have prohibited species caps (PSCs) that close the groundfish fishery down. That which is taken must be discarded immediately, except for our special program that allows fishermen to retain their salmon bycatch for donation to food banks and the needy. We split the PSCs between gear groups and fisheries, between seasons, and areas.

We are very fortunate to have a progressive industry which is forever searching for ways to modify gear and fish more cleanly, and which is developing systems to make data rapidly available to each other on the grounds. Over time, these efforts will bear the fruit of better utilized groundfish resources and diminished bycatch of PSC species. We will likely be taking a very close look in the coming year at individual accountability systems, such as vessel bycatch allowances, that could yield very substantial increases in the amount of groundfish taken per unit of PSC bycatch. It is still in question whether this sort of mechanism will be a savings of PSC that can be turned over to the directed fishery, or just an increase in the amount of groundfish that can be caught at the current PSC levels. We will, however, need to come to grips with the fact that these new individualized programs come at a tremendous cost in manpower and data monitoring, which most likely will not be furnished free of charge by the federal government. From what I hear, the industry is aware of that and will work with us to make the programs successful.

Regardless of how many advances are made in addressing the PSC problem, I predict, by the time we turn the calendar over to the year 2000, we still will not have resolved it completely to everyone's satisfaction. Fishermen will still be bickering over how much to ratchet down the groundfish fishery to minimize bycatch of these high-valued PSC species. The only bright spot is that these bycatches usually do not affect the sustainability of the PSC fish resource because the bycatch is taken into account when setting annual harvest quotas.

Let's get on to where we can make major gains in showing the world that we have a responsible fishing industry. I am referring to measures to address the high discard and waste of nontarget groundfish species, the so-called economic discards, in the groundfish fisheries. They are called economic discards because the fisherman has the choice to discard or not, depending on whether he has a market for a particular species, sufficient processing equipment, time, or inclination to process that species.

Economic Groundfish Discards

Total groundfish discards for both Bering Sea and Aleutians Islands (BSAI) and Gulf of Alaska (GOA) for 1994 were about 341,000 mt, or 15% of a total groundfish catch of about 2.2 million mt. Fifteen percent of the total harvest in the Bering Sea and Aleutians was discarded, 93% by trawlers. In the Gulf of Alaska, 19% of the total harvest was discarded, 88% by trawlers.

To place this discard in perspective, it should be noted that worldwide commercial fisheries discards are about 27 million mt, or 26% of total world catch. Shrimp fishery-related discards are particularly egregious, accounting for 35% of the discards. The Bering Sea rock sole trawl fishery, and the Gulf of Alaska flatfish trawl fishery are on the top 20 list. Conversely, among the 10 lowest discard rate fisheries are the Bering Sea midwater pollock trawl fishery, Bering Sea Pacific cod pot fishery, and Gulf of Alaska midwater pollock trawl fisheries.

Though most Alaska groundfish fisheries have intermediate or low bycatch rates compared to discard practices in other world fisheries, the very high volume of our fisheries yields very impressive discard weights. The 15% rate, though well below the 26% world average, still amounts to 752 million pounds of fish. Thus, we have a public policy issue, which we cannot just duck saying that our neighbors across the street are doing worse than we are.

Current Proposed Solutions

The North Pacific Council is moving ahead on this issue. It has instructed staff to examine implementational issues surrounding potential programs to reduce waste. Two reports will be presented at the current Council meeting. Two fisheries in the spotlight include the Bering Sea rock sole fishery which has a discard rate of as high as 69%, and the Bering Sea midwater trawl fishery for pollock which, in contrast, has a very low discard rate of 2%-4%, but a high volume because the fishery is so large. The two main alternatives are to require either full retention of the target species in the rock sole and pollock fisheries, or full retention of all species in those two fisheries. The Council could set an effective date of January 1, 1996 or 1997, or phase in the program over three years to achieve 100% retention in the third year after implementation. The Council is also considering mandating processing for human consumption and will examine three minimum percentages, 50%, 70%, and 90%, to be applied as a percentage of a delivery.

A preliminary analysis of implementational issues has identified the following eight concerns with the above approach:

1. Observers are overtasked under current conditions because there is only one observer per vessel. If full retention were required, any discard at all would constitute a violation, and therefore, an observer may be able to report that violation. If, however, only a specified percentage of catch must be retained, then monitoring compliance would require accurate and precise estimation of catch of all species if a violation were to be successfully prosecuted in court. This level of catch estimation would not be achievable with current observer coverage.

2. Absent full retention, a retention requirement probably is not enforceable. The constraints on observers and on data would make it impossible to prosecute a violation in any but the most egregious cases. Even with good data, it would be difficult to make a case because product recovery rates, which are used to estimate how much is actually caught, are highly variable.

3. For reasons given in 1. and 2. above, monitoring a phase-in program or variable retention

rates would be nearly impossible with current observer levels and data availability.

4. Vessel operations could be manipulated to change a vessel's directed fishery to escape retention standards and move to some other target species category that had no standards. Consequently, the program cannot be implemented in a piecemeal fashion.

5. There will be conflicts between any full retention program and regulations that require discard.

6. Stability and loadline considerations will make it nearly impossible for some vessels, particularly smaller vessels, to comply with full retention standards.

7. Onshore processors cannot be regulated by the Council.

8. Full retention will result in additional processing wastes. Some processors may no longer be able to meet environmental restrictions on waste discharge, ocean dumping, and landfilling. Also, the Council will need to carefully and explicitly define the human consumption standard, which forms are acceptable, and how this will be monitored after initial primary processing.

To address these eight concerns, I will recommend to the Council that they concentrate their limited staff resources on a middle ground alternative, a species-by-species approach to full utilization, dwelling on the top two to three most highly discarded species in the two fisheries: (1) pollock and cod in the midwater BSAI pollock fishery, and (2) rock sole, pollock, and cod in the BSAI rock sole fishery.

I believe that this approach will give us the most gain for the pain that will be inflicted on the industry. Here is how the numbers shake out using 1994 to illustrate. Total catch in the 1994 midwater trawl pollock fishery was 1,220,712 mt, of which 28,725 mt or 2.4% was discarded. Requiring full retention of just pollock and cod would reduce discards to only 2,917 mt of assorted other species, and the discard rate by an order of magnitude to 0.2%. For the rock sole fishery, full retention of all rock sole would save 23,572 mt, of all pollock another 14,432 mt, and cod another 3,766 mt, for a total savings of 41,770 mt. These top three species amounted to 81% of the discards in the rock sole fisheries in 1994 and 88% in 1995 (through August 12).

For both fisheries together, the total savings in discards would be 67,578 mt. The overall discard tonnage for the entire BSAI groundfish fisheries would decrease from 293,391 mt (15.9% of total catch of 1,842,626 mt) to 225, 813 mt, giving a new rate of 12.2%. This new rate represents a 23% reduction in the discard rate from the 15.9% that occurred overall in 1994. Going the extreme step further of requiring retention of all species would yield only an additional 4% reduction in discards, and thus diminishing returns.

This simple switch in approach to full retention for a limited number of species, rather than something less than full retention for all species presents a middle ground between the current two alternatives, and will help address the eight implementational issues raised in the preliminary analysis. Observers will still be the first line of monitoring, but will not have to track rates of discards. They will need to track the two species in the pollock fishery and three species in the rock sole fishery, but the retention requirement will make it a violation for any of those species to go overboard. We will need to still use product recovery rates (PRRs) to back calculate how much fish was caught vs. the product on board. This will give us another check on discards. We may only be able to catch the most egregious offenders, but overall, I think we will see a significant reduction in discards through such a program.

If the Council directs the staff to proceed with the further impact analyses required to make a final decision, I think we can have it back before the Council in April 1996 to approve for public review in May. A final decision may be made in June. The program could be implemented as early as 1997, but the Council may allow until 1998 for full implementation. This will give the fleet time to adjust their operations and equipment to respond to the new regulations.

In any case, we should be able to show a much reduced discard in North Pacific fisheries by the end of 1998, which is about the time everyone will start spinning up for another reauthorization of the Magnuson Act in the year 2000. At the same time we may be in process of finalizing or possibly even implementing a new program for ITQs for pollock in the BSAI midwater trawl fisheries. Our sablefish and halibut IFQ program will mark its fourth year of operation in 1998. This will also be the first year of full implementation of the groundfish and crab license limitation system passed by the Council in June, if the Secretary of Commerce approves the program. If our fish stocks continue to be in good shape, the industry and the Council can be very proud of their progress in addressing the big three defining policy issues of the 1990s, waste and discard, overcapitalization, and sustainable resources.

Postscript

At the June 1996 Council meeting, the Council approved for public review, a draft analysis for requiring full retention of Pacific cod and pollock in all groundfish fisheries in the Bering Sea and Aleutians. Yellowfin sole and rock sole may be added to that list, or their full retention may be phased in over a two- or five-year period. Various options for requiring full utilization of the fish retained also are analyzed. The Council has decided to extend full retention and utilization requirements to the Gulf of Alaska groundfish fisheries, but development of that amendment will be on a different schedule. Implementation of retention requirements in both the Gulf of Alaska and the Bering Sea and Aleutians is intended to occur in 1998. The Council will make its final decision on the Bering Sea amendments and their exact form in September 1996. The Gulf of Alaska requirements will be decided in early 1997.

Endnote

[1] Officially called the Draft Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks.

National Panel on Management Solutions: Discussion

Gary Stauffer, Moderator
National Marine Fisheries Service, Alaska Fisheries Science Center
7600 Sand Point Way NE, Seattle, WA 98115

QUESTION: If I catch 100% of the bycatch with my vessel, the vessel behind me is not going to catch anything. I don't have to turn around when I make a good drop, because I caught 100% of the bycatch. We have 30 boats fishing in one area, we're getting 500 pounds every 24 hours. That's 150 boxes of shrimp caught in one day. I only caught 500 pounds. If I'm catching 100%, why do I only have 500 pounds? The reason I'm bringing this up is that the public is misled in believing that we get 100% of everything. We keep the shrimp and we kill everything else. My trawls are 2 in. mesh trawls with 2 in. in the tails. I've got a 60% reduction in bycatch from the vessel that's fishing on the beach because of mesh size. I've reduced bycatch further by using 4 in. knotless webbing in a section of my net. I've cut my bycatch considerably from what I was catching. In the industry, we have tried and done a lot of things. We will never, never get rid of all the bycatch in the shrimp fishery. For the shrimp fishery in the Gulf, 90% of the bycatch is Atlantic croaker. Even if you take all the nets off the water, 100% of the croaker are going to die within the year from natural mortality. We don't brag about our bycatch. I've been trawling for 25 years, and I'm still catching the same bycatch I caught 25 years ago. The bycatch is also seasonal. I can't see how the Gulf Council would mandate that the Gulf shrimpers pull a device for research projects. When the study is completed, I'm going to show a shrimp loss.

COLLINS: If you show an 11% loss by letting the bycatch go after the perch and after the shrimp, that is considerable. We will be looking at that very seriously before we mandate this to the shrimpers.

QUESTION: My question is for Dr. Pautzke. You expressed your concern for incentive-based bycatch reduction programs. A number of programs have been mentioned over the last few days. The only one that's really been put forward here by members of a previous panel, in particular, has been the vessel accountability program, which although similar, is still quite different from harvest priority. It is also part of the old VIP program, which is an offshoot of Penalty Box Program. All of these things, in one form or another, have been around since 1987, but they haven't worked; usually because of legal problems with General Council or the legal system. I know that you've had some concerns, and I was wondering if you would share your concerns with us?

PAUTZKE: First of all, I think that we are going to be taking a good look at the various vessel bycatch accounting schemes. I think that's probably the next wave of progress that we can make on PSCs species management. I would love to see individual quotas assigned to individual fishermen so they are not forced to race against time, or race against their brethren. They could actually tailor their operations to do a better job at conserving PSC species. One problem with these programs is that they are very labor intensive. For instance, the one that United Catcher Boats is putting forward has a check point at 75% of your catch. Someone will have to convene a meeting at that point with representatives from industry and the government, as I understand it, and check the data. Then you'll be advised whether or not you're doing a good job and whether or not you can continue fishing. The vessel waits to find out if it can continue to fish, or figures out what fisheries it's going to go into next. I don't know if this will work, maybe it's doable. On one hand, we're hearing from Congress that it's downsizing; yet on the other hand, these programs are very labor intensive. I don't know where the equilibrium is. That's one of my concerns. My other concern is what happens when a fisherman questions the panel and says, "I don't believe this industry government panel. They tell me that I'm at 75% of my catch. My data shows that I'm not, and I'm going to appeal their decision." If they can fish while they're appealing, which is what we understand they can do, then the program will be crippled. We're hearing from the General Counsel that these appeal procedures could take two or three years. That's been one of the major problems with harvest priority programs. I would love to give people harvest priority, and say, "Fish the first six months of the year; we're going to determine if you can fish the last six months based on your performance in the first six months." That would be great. I have no problem with it. The General Counsel says, if you decide not to allow someone to fish, and during the two to three years they have while appealing your decision, they fish anyway, what good is the program? I've got a limited number of staff, and the National Marine Fisheries Service has only so much staff that they can direct at any particular management issue. I want to see something done, and I think the Council wants to see something done. Therefore, we've got to focus our staffs on one particular issue. I suggest that we focus on full utilization as we have been directed to do earlier by the Council. If we come up with incentives in the process, that would be great.

QUESTION: My question is for Mr. Davis. What are the most important research issues that need to be executed to implement your idea for multispecies management in the Bering Sea fisheries?

DAVIS: I think that looking at the available fishery data, from observers, log books, or other sources, should be the first step in determining what might be to identify the principle species of interest, and then try to identify the other species that are commonly taken by each particular gear group. The second step is to examine the findings from initial analysis to determine if some of the results are counter-intuitive, or don't seem consistent with some of the other programs being undertaken by industry or by management. Following this analysis, and understanding where industry and management are going, you might discover other areas that need to be explored in terms of research. Thinking back to the Newport bycatch conference of a few years ago, neither the industry nor the managers were doing a good enough job educating the public on what the costs are to the fisheries of providing seafood to the consumer. This realization was probably one of the consensus views that came out of that conference. We need to do a better job educating the general public about what to expect in our fisheries, that fishermen aren't blatantly trying to catch all different species, and certainly they wouldn't throw anything away there was a market for. The management system and the way that the fisheries have evolved over time have made the situation unacceptable to the public. In Alaska, both industry and management have learned a great deal over the last few years. There have been a number of technological improvements on the industry side; management has evolved and incorporated a variety of management bycatch control measures. As Clarence (Pautzke) pointed out, people still aren't happy with what progress has been made. Our cleanest fishery is still being identified as one of the more problematic ones. The multispecies approach I described is one of many that certainly could be developed. Many people look at how we manage fisheries and say, we'll give you a target catch and your bycatch cap. Because we don't air all of our dirty laundry and don't describe all the species that we commonly encounter in our gear, it appears to the general public that we're hiding something. I think that the data are there, and I think we can speak to the issue, based on that data. If we can explicitly acknowledge that when targeting on a particular species, we also capture some other species, after full-utilization or other types of polices, we can encourage the development of new products to use those species. The point is that we're not hiding anything. Maybe we're not happy with current levels of some bycatch species; maybe there are things that can be done to reduce these levels. Through this process we're being more upfront about what is naturally occurring in our fisheries. In this way, we're educating the public a little more about the nature of our fisheries and what can be expected.

QUESTION: Is there any sympathy for, or mechanisms for reducing the number of gear sectors in Alaskan fisheries? It seems a lot of the conflict is not over porpoises or whales or turtles; it's over halibut, cod, and herring. It's just a conflict over who takes it. You have your players, you have your conflicts.

ANSWER: Yes, The longliners want the trawl fishermen eliminated, the trawlers want the longliners eliminated, and the pot guys will take whatever's left.

QUESTION: Clarence (Pautzke), what you were talking about, if I understood, is that full utilization or retention at this point is aimed largely at non-prohibited species, and smaller undersized fish. You catch undersized pollock when the fishery really wants to target larger sized pollock. This may be fairly easily dealt with by technology that could process all sizes of fish. When you get into full retention for something like the rock sole fishery, in particular, are you dealing with the problems of retaining prohibited species? How do you handle that?

PAUTZKE: The suggestion I've made is not for full retention of all species. We would still have the regulatory discard of PSC species. What I'm suggesting is that the Council look at two or three of the top target species. In the pollock fisheries, some of the catch is going to be small fish. The fishery doesn't have any real good use for small fish in the pollock fishery. They want fish that are big enough to go through the processing line; but the fishery would develop ways to utilize small fish. Maybe it's fishmeal, I don't know. People don't like fishmeal because they think fish should be used for something besides being ground up into meal. In the rock sole fishery, some nice size pollock and cod are taken that the fishery would have to do something with if the Council were to go for full utilization. On the other hand, a number of serious problems would arise if the rock sole fishery were required to retain PSC species such as halibut. People have suggested that the trawl fisheries should be allowed to retain and sell their bycatch of halibut rather than throw it overboard. Researchers have been doing viability studies, and find that trawl-caught halibut may have, for example, a 70% chance of dying; so why not process it? Halibut longliners would go crazy over that because they don't want the trawlers keeping PSC species, and they don't want the trawlers to have any reason to target those high value fish. That's why we require the trawlers to throw the halibut overboard. The only advance that we've really made in the utilization of PSC bycatch has been with trawl-caught salmon. There's an on-going program for chinook salmon where the trawl fleet is allowed to keep chinook salmon and to turn them over to the food banks, but they are not allowed to sell them. This is the type of step that can be taken with the bycatch of a PSC species that we know are going to die anyway. The fish is put to good use, but no profit is made from it.

QUESTION: Davis, does your proposal effectively deal with the problem of additional burdens on observers in the fishery that Pautzke described?

DAVIS: I don't think so. At the current levels of observer coverage, we have a data stream that appears, at least at initial glance, to be adequate to generate the information needed to develop all the species quotas. Given the current mission of the observers, I don't think there is a need to expand the program.

QUESTION: An issue that needs to be added to any bycatch policy is a study of the fish returned to the sea to minimize the effect on the environment. Someone mentioned seagulls getting the discards, which meant to him that the bycatch was being used. That doesn't mean that the use is necessarily good. The discards of some species are probably benefiting others, but not all of them, at least not in the same proportion. Another side of the issue that needs to be considered is looking for the best way to dispose of the discards, in concentrated local areas or diffusely over broad areas.

ANSWER: Patty Livingston found that Pacific cod were eating large amounts of discarded fish. This food source was a major portion of the diet of some of the fish she sampled. Can anyone tell us anything about that?

ANSWER: Much of the discard is being cycled through a number of fish species. Regarding waste and discard, one thing that gets the public's attention is discarding into a low-energy environment, like a bay, where it piles up on the grounds. It tends to sit there and turn the surroundings anaerobic. In most instances in the North Pacific fisheries, discharge is trailing out over the back of the vessel, and it's being recycled through crabs and other critters. Nothing lies on the bottom for very long, but we do have to worry about where it's being discarded.

ANSWER: When I put 4 in. knotless web in my shrimp net, my bycatch was reduced by 30-40%, but the sharks ate my nets and everything in them. In the Gulf, the discard is the fish that are getting out. I had to change the net and remove the 4 in. webbing when I was offshore. At the time, I was told to release my bycatch in the Gulf. The predators would get released and eat everything up. That's what the public doesn't understand. All they hear about is the senseless killing.

I took a taxi from the airport to get here. The taxi has bycatch—just look at the front of that automobile. It's got butterflies and other insects; those creatures were killed for the convenience of riding in that car instead of walking. There are lots of insects, so there's no problem. In the Gulf shrimp fishery, we don't fish outside of 50 fathoms. The fishing grounds for the Gulf shrimp trawlers are so narrow, they wouldn't even show up as a line on a diagram of the area. When we do pass over the fish, we catch a very small percent of the shrimp; we don't catch everything. I get two baskets of shrimp and ten baskets of fish when I'm dragging. The vessel behind me gets the same, and the one behind him also gets the same.

Fisheries Bycatch and Discards: A Report from FAO

G.V. Everett
Department of Fisheries, FAO, Viale delle Terme di Caracalla, Rome, Italy

The United Nations General Assembly (UNGA), at its 49th Session, in resolution 49/118, recognized that in relevant provisions of the United Nations Convention on the Law of the Sea (UNCLOS),[1] states are called upon to take into consideration the effects on associated or dependent species when establishing conservation and management measures for target fisheries using the best scientific evidence available.

The resolution recalled that the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in 1992, and the International Conference on Responsible Fishing, held in Cancun, Mexico, also in 1992, agreed to promote the development and use of selective fishing gears and practices that minimized waste in the catch of target species and minimized bycatch of nontarget fish and nonfish species.

Resolution 49/118 invited relevant subregional and regional fisheries management organizations and arrangements as well as the United Nations Food and Agriculture Organization (FAO) to review the impact of fisheries bycatch and discards on the sustainable use of living marine resources. FAO was invited to formulate fisheries bycatch and discard provisions in its Code of Conduct for Responsible Fishing, taking into account work being done elsewhere.

The FAO promotes national and international action for the rational management and development of world fisheries. It does this not only through the regular program activities at its headquarters, but also through the field and regional offices, regular consultation with regional (FAO and non-FAO) fishery bodies, the fishing industry, and other institutions.[2]

The definition of bycatch is all "species captured other than target species."[3] Discards may constitute a small-to-significant fraction of the identified bycatch, depending on the nature of the fisheries and local customs.

Since the creation of FAO in 1945, the fishery scientists working outside and within the framework of FAO fishery activities have been aware, in the context of fishery management, of the importance of gear selectivity in minimizing the bycatch of undersized fish of target species, nontarget fish species and nonfish species. Several FAO regional bodies have introduced regulatory measures for gear[4] including the regulations concerning the use of minimum mesh size in gears used for the catch of certain target species.

Fishery managers and conservation/environmental groups have been concerned that bycatch, and discards, may be contributing to biological overfishing and altering the structure of marine ecosystems.

The recent global assessment of fisheries bycatch and discards estimated an annual discard range of between 17.9 and 39.5 million mt with a mean estimate of 27 million mt. However, no estimate could be given of the mortality level of escapees from fishing gear during operations. Although many of the discards include nontarget or low value species, undersized fish of target species are also discarded. The combined effect of this practice may threaten the maintenance of biodiversity and the long-term sustainability of fisheries.

The discard range may be an underestimate in that recreational fishery discards are not included; the database for some areas of the world is incomplete; and discard rates are not included for marine mammals, seabirds, turtles, and, for many areas, invertebrates.

Although discards in tropical industrial shrimp trawl fisheries are generally high, in many of the world's artisanal fisheries a variable share of the shrimp bycatch may be species retained for human consumption or for other purposes. Further, discard rates and numbers may misrepresent the impacts because for a number of species some fraction of the discard survives.

Without good estimates of the biomass discarded, the survival rate, other fish-related losses, and the landed catch of a particular species, it will be impossible to assess overall impacts of fishing.

In general, since the UNCED, fisheries conservation and management practice emphasizes an ecosystem approach, taking into account the need to exploit fisheries in a precautionary manner. The ecosystem approach differs significantly with past approaches to fisheries conservation and management whereby the primary concern was the impact of fishing on the target species, with lesser concern for impacts on nontarget fish and animal populations.

The ecosystem approach to fisheries management necessitates that fisheries research extend beyond an emphasis on target species and single species approaches to stock assessment to determine optimal exploitation. A new research emphasis, including development of new methods, is required to make research effective for fisheries management within the ecosystem. Additional research and data collections are particularly needed to assess the biological impact of bycatch. The status of the stocks of nontarget species and their biologically allowable mortality are frequently not determined regardless of their importance for rational fisheries management.

Some of the impacts resulting from discarding may include: (1) foregone catch as a result of mortalities imposed on recruits to the target fishery, (2) foregone catch resulting from mortalities imposed on target fisheries by fisheries targeting other species, (3) reduction of fishing time resulting from bycatch quotas, (4) costs of purchasing gear adapted to comply with discarding measures, (5) loss of catch and time (when a gear type is outlawed and no efficient alternative gear type is available or can be deployed due to vessel or other restrictions), and (6) loss of catch due to capture of immature fish being subtracted from the Total Allowable Catch (TAC). There may well be an economic impact due to the introduction of required observer programs and sorting costs. Much more work is needed to adequately assess the true economic cost of discards on fishers and the benefits and costs of potential solutions to society as a whole. In some cases, mortalities associated with discards may decrease key predator or competitor populations and enhance system productivity. Furthermore, discarding practices may permit fisheries to remain cost effective.

There is growing global recognition that the world's fishing effort already exceeds what is necessary to harvest sustainable yields of marine fish.[5] The single action that will provide the greatest improvement to the bycatch and discard problem in certain fisheries is the reduction of these effort levels. Without such control, other solutions to the bycatch and discard problem will be less effective, and real success in efforts to better manage the ocean's resources will be more difficult to attain.

The Rome Consensus on World Fisheries, adopted by the Ministerial Meeting on Fisheries, held at Rome on 14 and 15 March 1995 states that improved fisheries conservation and management, along with better protection from harmful sea- and land-based activities, are crucial to maintaining world fish resources and aquatic ecosystems. The Ministerial Meeting urged that governments and international organizations take prompt action to adopt policies, apply measures, and develop techniques to reduce bycatches, fish discards, and post-harvest losses.

On a number of occasions, FAO and other agencies have organized activities to address the question of the utilization of bycatch as a matter of food security. This was addressed at a consultation organized in 1981,[6] and has been addressed at a Technical Cooperation between Developing Countries (TCDC) workshop on the utilization of bycatch from shrimp trawlers, organized by the Government of Madagascar, the UNDP/Special Unit for Technical Cooperation among Developing Countries, and FAO, at Nosy Bé, Madagascar, on 6-8 June 1995. Although shrimp fisheries account for the largest share of discards in global fisheries, it should also be noted that much of the shrimp produced in tropical waters is harvested by artisanal traps, and other species caught along with shrimp are rarely discarded, but rather consumed in the fishing villages.[7]

The United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks

Data and related information concerning high seas fisheries are poor and incomplete resulting in weak conservation and management of high seas resources. Consistent with the 1982 UNCLOS, the United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks (convened during 1993 and ending in August 1995), as a consequence of the 1992 UNCED, sought to improve and strengthen the conservation and management of these two types of stocks and to enhance data collection and its timeliness.

The Draft Agreement for the Implementation of the Provisions of the UNCLOS of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (the Agreement),[8] takes a strong ecosystem approach to high seas fisheries conservation and management and requires that high seas fishing activity be assessed in terms of the

> . . . impacts on fishing, other human activities and environmental factors on target species and species belonging to the same ecosystem or dependent upon or associated with the target stocks.[9]

and to

> . . . adopt, where necessary, conservation and management measures for species belonging to the same ecosystem or dependent on or associated with the target stocks, with a view to maintaining or restoring populations of such species above levels at which their reproduction may become seriously threatened.[10]

and to

> . . . minimize pollution, waste, discards, catch by lost or abandoned gear, catch of nontarget species, both fish and nonfish species, (hereinafter referred to as nontarget species) and impacts on associated or dependent species, in particular endangered species, through measures including, to the extent practicable, the development and use of selective, environmentally safe and cost-effective fishing gear and techniques.[11]

As part of this ecosystem approach to fisheries conservation and management, high seas fishers are obligated to comprehensively report, through appropriate subregional or regional fisheries management organizations or arrangements, on all target and nontarget (bycatch) species taken in the course of fishing operations. Comprehensive data must be provided on target and nontarget species caught and retained, as well as other species that are discarded.[12] The requirements and standards to be established for high seas catch reporting represent a significant departure from conventional fisheries catch/effort reporting whereby retained target species data are normally the only data reported.

If fully implemented through effective flag state control, the Agreement will facilitate the collection and reporting of reliable catch and related data not only for target species, but also for bycatch and discarded fish and animal species. The availability of these data will enable assessments to be made to more accurately determine the effects of fishing both on target species and on the ecosystem as a whole. However, to obtain a complete and comprehensive evaluation of the impact of fishing on the ecosystem, similar requirements for fisheries falling under zones of national jurisdiction will also be required.

Draft Code of Conduct for Responsible Fisheries

According to instructions of FAO governing bodies, the draft Code of Conduct for Responsible Fisheries[13] has been formulated to be consistent with the 1982 UNCLOS, taking into account the 1992 Declaration of Cancun, the 1992 Rio Declaration and the provisions of Agenda 21 of UNCED, the strategy endorsed by the 1984 FAO World Conference on Fisheries Management and Development, and other relevant instruments. It also takes into account the outcome of the UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks (Sixth session, New York, 24 July-4 August 1995), where a draft agreement for the implementation of the provisions of the UNCLOS of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks was adopted.

Certain articles of the draft code of conduct address matters of concern pertaining to bycatch and discards in follow-up to the UNGA resolution 49/118.

Article 6.2.2 of the draft code of conduct is concerned with objectives within the overall issue of fisheries management, and the relevant text (subject to revision) notes that

> States and fisheries management organizations or arrangements should ensure that long-term management objectives are set to provide a high probability that, *inter alia*, waste of catch of target and nontarget species, the incidental catch of nonutilized species and impacts on associated or dependent species, in particular endangered species, are minimized to the greatest extent possible.

Within the framework of references to management measures, Article 6.6.8 notes that

> In order to protect juveniles and spawners and minimize the waste of catch of target and nontarget species and impacts on associated and dependent species, in particular endangered species, States and subregional or regional fisheries management organizations or arrangements should, *inter alia*, promote the development and use of selective, environmentally safe and cost-effective fishing gear and techniques and implement measures such as minimum landing sizes, mesh or gear regulations, closed seasons, closed areas, reserves, or access zones particularly for artisanal fisheries.

Article 7.4.3 is concerned with fishing practices within the overall issue of fishing operations, and the relevant text notes that

> States should make every effort to ensure that documentation with regard to fishing operations, retained and discarded fish (fish and nonfish species), as well as information on the origin of the catch is maintained. States should, as far as possible, establish programs, such as observer schemes, in order to verify documentation with regard to fishing operations, catches and discards.

Article 7.4.5 notes that

> States, with relevant groups from industry, should encourage the development and implementation of technologies and operational methods that reduce di!scards. The use of fishing gear and practices that lead to the discarding of catch should be discouraged and the use of fishing gear and practices that increase survival rates of escaping fish should be promoted.

Article 7.5.1 is concerned with fishing gear selectivity, also within the overall issue of fishing operations, and the text notes that

> States should require that fishing gear, methods and practices are sufficiently selective so as to minimize the waste of catch of target and nontarget species, the incidental catch of nonutilized species and impacts on associated or dependent species, in particular endangered species, and that the intent of related regulations is not circumvented by technical devices. In this regard, fishers should cooperate in the development of selective gears and methods. States should ensure that information on new developments and requirements is made available to all fishers.

With regard to protection of the marine environment, Article 7.7.1 reads

> States should introduce and enforce laws or regulations based on the International Convention for the Prevention of Pollution from Ships, 1973, as amended by the Protocol of 1978 (MARPOL 73/78).

Article 10.1.8 of the draft code of conduct is concerned with responsible fish utilization, within the overall context of post-harvest practices and trade, and the text notes that

> States should encourage those involved in fish processing, distribution and marketing to reduce post-harvest losses and waste, and improve the utilization of bycatch to the extent that it is consistent with responsible fisheries management practices.

Article 11.10 is concerned with fisheries research, where

> States should carry out studies on the selectivity of fishing gears to target species and on the behavior of target and the nontarget species to the fishing gear with a view to minimizing nonutilized catches and safeguarding the biodiversity of ecosystems as an aid for management decisions.

CONCLUSION

A major strategy to reduce the level of bycatch would be improvement in the selectivity of fishing gear and fishing methods. While there has been an increase in activity to develop selective gears and techniques, much of the research has been carried out in the higher latitudes and is not readily transferable to multispecies tropical fisheries, where the tropical shrimp trawls still produce high rates of bycatch.

The strategy to reduce the negative impact of bycatch would include: (1) a specific emphasis on decreasing bycatch of stocks reduced below their optimum levels, (2) better disposal of bycatch or utilization of bycatch for human consumption, and other purposes benefiting people, especially if the stocks remain above optimal levels. This strategy necessitates the determination of the status of stocks, individuals of which constitute the bycatch, and the biologically allowable mortality for these stocks. Until this can be carried out, a precautionary approach to fisheries management may need to be applied.

FAO[14] estimates that about a 60% reduction in discards by the year 2000 could be achieved by: (1) a concentrated effort to improve the selectivity of fishing gear, (2) the development of international standards for research and additional research designed specifically to address problems resulting from bycatch, (3) greater interaction between research staff, industry, and fisheries managers, and (4) the possibility to join the technological approach with an institutional approach to examine effectiveness of user rights in limiting discards. To achieve this goal, FAO and national research institutes will need to strengthen and widen the scope of current programs on gear selectivity, and economic and institutional incentives.

As a consequence of a decision of the FAO Council (108th session, 5-14 June 1995) an open ended technical committee was set up to review and agree on the form and content of the Code of Conduct for Responsible Fisheries prior to its submission to the 109th Session of the FAO Council and the 28th Session of the FAO Conference for approval and adoption.[15]

ENDNOTES

[1] Official Records of the Third United Nations Conference on the Law of the Sea, vol. XVII (United Nations publication, sales No. E.84.V.3), document A/CONF.62/122.

[2] FAO has consulted with its own regional fishery bodies (the General Fisheries Council for the Mediterranean, the Fishery Committee for the Eastern Central Atlantic, the Indian Ocean Fisheries Commission, the Asia-Pacific Fisheries Commission, and the Western Central Atlantic Fisheries Commission) in compiling this report.

[3] D.L. Alverson, M.H. Freeberg, J.G. Pope, and S.A. Murawski. 1994. A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper No. 339. Rome, Italy. 233 pp.

[4] Mesh size and other regulatory measures to reduce bycatch have been examined by FAO and its regional bodies over many years. For example the FAO Fishery Committee for the Eastern Central Atlantic (CECAF) at its third session in 1972 recommended the introduction of a provisional minimum mesh size of 70 mm for use by vessels fishing for hake or sea bream in the CECAF area.

[5] Summarized in the FAO document: The State of World Fisheries and Aquaculture (FAO, Rome, 1995, 57 pp.), prepared for and discussed at the FAO Twenty-First Session of the Committee on Fisheries (COFI) held from 10 to 15 March 1995 in Rome, as well as the FAO Ministerial Meeting on Fisheries held on 14 and 15 March 1995 in Rome.

[6] Fish bycatch, bonus from the sea. Report of a Technical Consultation on Shrimp By-catch Utilization. Georgetown, Guyana, 27-30 October 1981. Ottawa, Canada, IDRC, 163 pp.

[7] F. Teutscher. 1995. By-catch in tropical shrimp fisheries, prepared for the TCDC workshop on utilization of bycatch from shrimp trawlers, 6-8 June 1995, Nosy Bé, Madagascar, 7 pp.

[8] Document A/CONF.164/33 dated 3 August 1995.

[9] Article 5 (d).

[10] Article 5 (e).

[11] Article 5 (f).

[12] See Annex 1 of Document A/CONF.164/33 dated 3 August 1995, Standard Requirements for Collection and Sharing of Data

[13] Document WP/1 prepared for the Technical Committee of the Council on the Code of Conduct for Responsible Fisheries, Rome, Italy, 25-29 September 1995.

[14] The State of World Fisheries and Aquaculture. 1995. FAO, Rome, 57 pp.

[15] The Code of Conduct was subsequently adopted unanimously by the 28th Session of the FAO Conference on 31 October 1995, with some revisions to the draft articles as listed above. Copies of the Code an be obtained from FAO.

Fleet-operational, Economic, and Cultural Determinants of Bycatch Uses in Southeast Asia

Daniel Pauly
University of British Columbia, 2204 Main Mall, Vancouver, BC V8T1Z4, Canada, and International Center for Living Aquatic Resources Management (ICLARM), Manila, Philippines

A brief history of demersal trawling in Southeast Asia (here: Philippines, Thailand Malaysia, and Indonesia) is given. It is argued that this fishery, through its overwhelming emphasis on penaeid shrimps, imported the concept of "trash fish," which had been previously alien in this region, and which still generates considerable unease.

In the long term, and for reasons not necessarily related to bycatch issues, the competition between small-scale fishers (who do not generate bycatch) and trawl operators (who do) for access to nearshore demersal resources may well be won by the former. This would lead to a resolution of the bycatch problem that would not only reduce social conflicts, but would also be culturally more acceptable than the current bycatch discarding practices of the trawling industry.

The bycatch of marine fisheries is a global issue (Alverson et al. 1994), though it may manifest itself differently, and consequently have different solutions in different parts of the world.

This brief contribution discusses the origins of, and a possible long-term solution to, the bycatch problem in Southeast Asian demersal trawl fisheries, adding to the diversity of mainly North American views presented in this volume. Diversity of views is part of the crane that lifts us to new insights (Bennet 1995).

History of Demersal Trawling in Southeast Asia

Prior to World War II, several attempts were made to introduce demersal trawling to Southeast Asia, notably by the Dutch in Indonesia, the French in Indochina, and the British in Malaysia. All attempts failed, however, because the gear tested was inappropriate, as were the economic and social conditions. Other attempts by Japanese vessels were more successful, but were never intended and did not lead to the development of local trawl fisheries (Shindo 1973, Pauly and Chua 1988).

The development of indigenous Southeast Asian trawl fisheries started just after WW II in the Philippines, and was largely, and literally, driven by landing crafts and other gear and motors left by U.S. forces. By the late 1950s, Manila Bay exhibited all the symptoms of what would later be called ecosystem overfishing, and fishing effort began to spill over into other areas of the country.

More important is that the Manila Bay trawl fishery was then being studied by a German FAO expert (Dr. K. Tiews), who subsequently went to Thailand on behalf of a German bilateral development agency. Having seen a Southeast Asian demersal fishery in full swing, it was easy for him to convince the Thai Department of Fisheries to follow suit. An appropriate light, high opening trawl net was designed, resource surveys were conducted (the first in 1961), and the Asian Development Bank provided massive, subsidized credit to would-be investors. A boom occurred that has now become a fisheries classic, along with the bust that followed (Pauly and Chua 1988, Pauly 1988 [Fig 13.2.]).

In the 1970s, Thai trawlers, which had made a clean sweep of the Gulf of Thailand demersal resources, were operating in other Southeast Asian countries such as Burma and Indonesia—sometimes illegally, sometimes not—and once even reaching as far as the coast of Oman on the Arabian Peninsula.

More important than these Thai incursions was the adoption of the Thai model of fisheries development by neighboring countries, notably Malaysia and Indonesia. Here, as previously in Thailand, the introduction of demersal trawling led to serious conflicts between trawl operators and small-scale fishers.

Trawlers and Their Bycatch

Southeast Asian trawlers must operate close inshore, for two interrelated reasons: (1) on tropical shelves, demersal fish biomass declines rapidly with depth, far more so than in temperate or boreal shelf ecosystems (Longhurst and Pauly 1987, Pauly and Chua 1988 [Fig. 3]), and (2) penaeid shrimps, the real target of the demersal trawlers, occur only in shallow waters.

For centuries, Southeast Asian inshore waters have provided a livelihood to thousands of small-scale fishers using a variety of (mainly) stationary gear. Thus, demersal trawlers operating close inshore not only compete for the same resource as the small-scale fishers, but also often destroy their passive gears.

Further, Southeast Asian trawlers use material to line their codend which has extremely small meshes, usually of 2 cm when stretched (less than one inch from knot to knot). They sometimes cover that with even smaller mosquito netting when aiming for small shrimps or anchovies. Recent efforts have been made in several countries to increase codend mesh sizes, but their success has been limited, not only because it is inherently difficult to enforce such regulation, but because of the nature of Southeast Asian demersal resources and the size of penaeid shrimps. This tropical region is the world center of marine biodiversity; therefore, these resources consist of an extremely large number of small, "r-selected," fish species. The bulk of the biomass is contributed by species not exceeding 15 cm (Sinoda et al. 1979, Azhar 1980). Thus, most fish are as small as the penaeid shrimps which, because of their high value relative to the fish (around 10:1), are targeted by the trawlers. Given that shrimps contribute about one-tenth of the catch weight, most of that will consist of bycatch (the small species mentioned above, and to a lesser extent the juveniles of large, "K-selected," species including snappers, groupers, etc.).

The situation is different with small-scale fishers; they tend to catch larger fish and land all of their catch. They are bound to be wary of trawlers, especially when they operate close inshore.

There is much in the literature dealing with the ensuing conflicts, but this cannot be reviewed here. Suffice to say that these conflicts, as they turned violent, became destabilizing enough for demersal trawling to be banned in the heavily populated western half of Indonesia (Sarjono 1980), and in some areas of the Philippines; and strictly regulated in Malaysia.

Southeast Asian Fisheries Products

The catch of small-scale fishers, in Southeast Asia, tends to be marketed in one of three basic forms:

a. fresh or live, as high-quality product (e.g. grouper);

b. salted and sun-dried, as medium to low quality product that can be moved across large distances, and which supported (in the nineteenth century) a vast international trade (Butcher In press);

c. salted and fermented, leading to various "fish sauces" which are added to rice.

I will deal briefly with items (b) and (c) because the existence of these traditional products largely shaped perceptions in Southeast Asia concerning the bycatch discard practice of the trawlers.

The product in (b) is one of the major sources of animal protein in the rural parts of Southeast Asia—even inland. It is a highly nutritious product, beneficial not only for the protein it contains, but also as a source of iodine, and of calcium because the bones are also eaten. This product is affordable in a way larger fish, which tend to be sold whole, are not. Further, many groups in Southeast Asia, e.g. the Javanese, simply like small fish (Leiognathidae), and hence do not perceive them as trash fish, even if trawl operators do.

Several of the products in (c) are poorly described as "sauce." The most important of these products is hard to imagine when one has not seen, smelled, or tasted it. It has the fluidity, and sometimes the color, of olive oil (and is often lighter, hence its name "fish water" in Thai and Vietnamese). It smells "fishy," and has a taste that is mostly salty. It consists of whole fish liquefied by a fermentation process driven by the fishes' own enzymes (Mizutani et al. 1987).

(The Ancient Romans consumed enormous quantities of a similar product, called *garum,* that was traded throughout the Mediterranean in amphorae—not all were used for wine!—and which seems to have been produced, at least in Spain, until the Middle Ages.)

The key advantage of this product, called *nam pla* in Thailand, *nuoc mam* in Vietnam, *petis* in Indonesia, *patis* in the Philippines, is that it can turn large quantities of tiny, and sometimes partly decomposed, fish into a highly esteemed and stable product (a bit like smelly cheese in France). This allows for continuous use of the seasonal raw material that otherwise would be lost, especially when refrigeration was not available (Ruddle 1986).

The products in (b) and (c) may be considered Southeast Asian "pre-adaptation" to the emergence of the trawl fisheries, and the "trash fish" they trawlers create. Trawlers have become the major suppliers of raw material for such products. Efforts are also being made to develop new products (Table 1). These efforts have been quite successful in some parts of Southeast Asia, but discarding continues elsewhere (Alverson et al. 1994).

The creation of "trash fish" by the trawl industry occurred at two levels: (1) *conceptually*—before the emergence of the trawl fisheries, the concept itself did not exist, as all fish that were caught were also consumed; and (2) *actually*—by reducing the fraction of large fish in the non-penaeid catch, and increasing the fraction contributed by their juveniles (one kind of trash fish), and of various, smaller fish (the other major kind of trash fish).

Item (1) was discussed above; item (2) is due to the combination of growth overfishing (which removed most older representative of large species, leaving only the juveniles) and of ecosystem overfishing (which saw large K-selected species replaced by smaller r-selected species) that characterized trawling in Southeast Asia (Pauly 1988).

Table 1. Some Southeast Asian fish products based on bycatch.

Product	Remarks and Source
Fish "sauces"	A common food item throughout Southeast Asia (Mizutani et al. 1987)
"Duckfish"	Feeding small fish to ducks is mostly done in Thailand
Fish meal	Often of variable quality (Ismail and Abdullah 1983)
Fish balls	Based on minced fish (Snell 1978; Suwanrangsi 1986, 1988)
Surimi	Some production exported to Japan (Suwanrangsi 1988)
Fish satay	Both for local (Thai) and export markets (Suwanrangsi 1986, 1988)
Fish cakes	Experimental in mid-1970s (Snell 1978); does not appear successful

A Future

Marine fisheries resource conflicts in Southeast Asia, particularly conflicts between small-scale fishers and trawl operators, will tend to abate if economic growth continues and population growth does not. There are already indications of trends in several countries toward returning the exploitation and management of inshore resources to the small-scale fishers, and protecting the fishing grounds from trawlers (by spiking shallow water areas with artificial reefs). Because of the selective nature of their gear, and of the type of products marketed by small-scale fishers, this would markedly reduce the bycatch problem in Southeast Asia.

This scenario might also be a future for other parts of the world.

Acknowledgments

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Ways in Which Norway Is Solving the Bycatch Problem

Viggo Jan Olsen
Directorate of Fisheries, Strandgaten 229, Bergen, Norway

All discards of fish are forbidden. Fishing grounds with too many juvenile fish are closed. The use of sorting grids is compulsory in shrimp fisheries, and will be introduced in cod fisheries. The development of selective gear in other fisheries has priority.

Increased awareness of the need for managing sustainable fisheries led to intense focus on problems concerning the unwanted species other than the target species vessels are authorized to catch. In a management regime where vessels are permitted (through licenses and quotas) to catch only authorized target species, it is crucial that the regulations and harvesting techniques chosen enable the vessels to conduct a viable fishery. It is often difficult to strike a balance between these objectives, and the different fisheries may demand specifically adjusted sets of rules and technical measures.

Over the last decade, Norway has introduced strict and detailed bycatch regulations and has intensified their enforcement. Important objectives for the Norwegian fishery management regime are to keep the total catch within the TAC, and to aim for a fishery conducted to avoid catches of undersized fish and bycatches of unwanted species.

A crucial principle in the Norwegian management system is the requirement to register and deduct all catches from the quotas. In conjunction with this principle, a prohibition against discarding any catches of protected species has been introduced.

Norwegian fisheries legislation is directed toward the actual fishing operation. With this basic position in mind, I will outline the essence of Norwegian bycatch regulations.

Traditionally, bycatch problems have been associated with the trawl fishery; especially those using small meshes. More recently, the fishery has, in general, been regulated more strictly. This led to the development of bycatch problems in fisheries conducted with other kinds of gear. Four typical situations where bycatch problems occur follow.

Bycatch Rules Relating to the Quota/License System

All major Norwegian fisheries are regulated by quotas, licenses, and a number of other measures. Catching species for which a vessel is not licensed puts the vessel in non-compliance with the regulations. In some fisheries, a vessel may have great difficulties conducting a fishing operation without catching species not included in its license. Where this is defined as a real problem, a solution has been sought by accepting a certain percentage of species other than the target species. This bycatch is deducted from the TAC of the specific species.

Bycatch of Protected Species

Bycatch also causes problems when fisheries for a specific species are closed for a limited time as occurred recently with Greenland halibut in Norwegian waters. The Greenland halibut intermix with other species in such a manner that avoiding bycatch of Greenland halibut in the trawl fishery is practically impossible. In such situations, the regulations permit an "unavoidable bycatch." This solution was chosen over a total ban on Greenland halibut which would prevent any catches of the target species. The unavoidable bycatch of Greenland halibut may under no circumstances exceed 5% of the catch.

Bycatch Rules Relating to Quotas

Bycatch also causes problems in determining the annual quotas. Norwegian fisheries legislation mandates that the yearly TAC will not be exceeded. This implies that regulations for determining the quotas for each species must include an estimated amount of bycatch of the specific species when fishing for other species. To solve the bycatch problems created in this situation, two alternative solutions have been chosen. This can be illustrated by a regulation from the cod fishery. The authorities divide the total share of the trawl quota among the participating vessels. Each vessel is then responsible to plan its fishing activities in such a way that the bycatch does not exceed the vessel quota. This means that the trawler must make sure that not too much cod is caught in a directed fishery to fill the cod quota, if the vessel plans to later trawl for saithe that will include cod as bycatch. The other means of regulating bycatch pertains to those vessels that do not use trawls. The regulations fix an amount of the quota to cover the anticipated bycatch. The regulations then permit the individual vessel a certain percentage of cod to be caught as bycatch when fishing for other species, after the vessel quota of cod is caught. Norway also seeks agreement on bycatch-limiting measures when developing quota agreements with foreign countries. In the quota agreement between Norway and the EU, the parties have mutually allowed each other an "others quota." The agreement emphasizes that this quota will cover bycatch of species not incorporated in the quota agreement.

Bycatch Rules Relating to Fishing Gear

Vessels fishing with trawls cause considerable problems when catching prohibited species in areas closed to trawls for directed fisheries for this species. This is a problem especially in the shrimp fishery. Not only is there a problem with the species only allowed to be caught with nets of a larger mesh size, but the unwanted bycatch may involve undersized fish. Resolution of these situations resulted in detailed regulations that permits a certain amount of bycatch in certain fisheries. In this situation, and for certain other fisheries, rules that only limit or prohibit the right to take bycatch have not been adequate because enforcement of the rules may prevent the fishermen from conducting the fishery for the target species.

Norway has, therefore, invested considerable resources in developing techniques and gears that enable the vessels to sort out bycatches of unwanted species and undersized fish. This has led to rules which prohibit rigging and constructions likely to reduce the selectivity of the gear. However, of greater importance is the development of the sorting grid technology. The breakthrough came in 1990. The excellent results this technology has shown led the authorities to prescribe the use of a certain sorting grid system when trawling for shrimp. Species that otherwise would be caught as bycatch when fishing for shrimp, are sorted out and led away from the gear by the sorting grid.

Of no less importance is the fact that the predominant portion of undersized fish is sorted out. The use of the sorting grid system enables trawlers to fish without breaching the rules in areas that otherwise would be closed. Experiments using the sorting grid technology have been carried out in other fisheries using other types of gear. Many tests using the sorting grid technology have been done on trawl vessels in demersal fisheries where the main objective is to sort out undersized fish. The test results have been very encouraging, and Norway is now ready to introduce a grid sorting system in the cod and haddock fisheries in the Barents Sea. Since 1994, permits have been granted to trawlers to fish for cod in areas closed for fisheries due to occurrence of undersized fish, on the condition that the sorting grid system is used. This fishery is still somewhat of a test fishery since the trawlers are required to fulfill several detailed conditions in order to conduct the fishery. In addition, substantial scientific test work is still being conducted to develop sorting grid technology to enable selectivity in other types of fisheries where bycatch is a problem.

Norway introduced a system to survey certain fishing areas in the Barents Sea as early as 1984. The objective was to be able to immediately and temporarily close an area for a certain fishery if the amount of undersized fish in the catches became too large. This survey system augments permanent closures of certain areas. The surveillance is conducted continually by hired commercial vessels. In addition to the regular vessel crew, an inspector who conducts the tests is always on board. During vessel inspection, the Norwegian Coast Guard surveys the mix of undersized fish in the different areas. An area is immediately closed if the survey shows that a 10 kg catch of shrimp contains more than 10 undersized cod and haddock. The final decision whether or not an area will be closed is made by the Director General of Fisheries. By closing the area, fishermen are not put the in a position of operating where catches of undersized fish are unavoidable. The fishermen support the arrangement. To maintain the fishermen's support, it is important that the authorities keep close surveillance of the area, and open it for fishing as soon as justifiable. In our view, this is the most efficient way to deal with the problem.

As mentioned initially, a very important principle in the Norwegian management system is that bycatches are deducted from the TAC of the species in question, and in pursuit of this principle, the prohibition of discards for all significant species has been introduced. In addition, the detailed regulations demand the vessel master demonstrate a high degree of awareness while conducting the fishing operation. It is the master's duty to avoid illegal bycatches; he is required to leave the fishing ground if he suspects the catch will include too much bycatch.

Research on development of gear to avoid bycatches of protected species and gear better adapted to selecting target species should have the highest priority. Research related to stock assessment is of utmost importance, but it is not enough.

Meaningful, sensible—and sustainable—stock management has to take into account how fish react to various types of gear, and how the fishing gear itself can help avoid prohibited species and juvenile fish.

The authorities responsible for the sustainable development of the fishing industry must accept responsibility for funding this type of research.

Conservation Harvesting Technology—A Perspective from Japan

Frank Chopin, Yoshihiro Inoue, and Y. Matsushita
The National Research Institute of Fisheries Engineering
Ebidai, Hasaki-Machi, Kashima-Gun, Ibaraki, 314-04, Japan

Takafumi Arimoto
Department of Marine Science and Technology, Tokyo University of Fisheries
4-5-7 Konan, Minato-Ku, Tokyo 108, Japan

Efforts to reduce discarding in North Sea fisheries were initiated over 100 years ago and led to development of mesh selectivity research by many European countries. This was not the case in Japan and some other Asian countries where all of the harvested species and sizes were traditionally used for human consumption and discarding was minimal. In recent years, however, declines in the sorting labor work force and opportunities for hi-grading some high value fish have led to an increased level of discards. In addition, Japan has embarked on a series of projects to enhance stocks of coastal food fishes. Artificially reared juveniles released into the wild are now appearing in the catches of coastal fisheries and has resulted in new research efforts to introduce selective fishing gears. The heavy reliance on coastal fisheries as a major source of coastal revenue generation, as well as being a contributing factor in Japan's food security program, has led industry and government to develop a collaborative approach toward community based resource management. This paper briefly reviews the various approaches taken toward conservation harvesting research in Japanese coastal fisheries and describes the role Fishery Cooperative Associations (FCAs) and fishers have taken in developing and promoting conservation technology.

In 1990 over 40% of the world's fish catch came from Asian fishing nations. Of a total 96,925,900 mt, Japan, China, Indonesia, Thailand, North and South Korea, Myanmar, the Philippines, and Vietnam accounted for approximately 38,000,000 mt of the world's catch, illustrating the importance of southeast Asia has in world fish production (Fig. 1). The importance of fish in the diet of Japanese can be seen from the per capita consumption figure for fish which at 69 kg per person is the highest in the world and over three and a half times higher than for the United States (19 kg per person per annum). Japan is heavily reliant on its coastal fisheries as a provider of food fishes and is cognizant of the need for resource protection for the purpose of food security. In 1991, the coastal fishery caught 3.2×10^6 mt of fish, employed around 310,000 fishers and 170,249 fishing vessels, and generated US$ 14.2×10^9.

Japan has an extensive and diverse fishing industry composed of coastal, offshore, and far seas fishing fleets as well as a highly productive coastal aquaculture industry. In addition to these traditional users of marine resources, a sharp rise in marine recreation has increased the stress on the coastal waters. While many of the fish resources around Japan are either stable or increasing, others are in a state of decline (Fig. 2) requiring a comprehensive resource conservation counter-measure program to prevent further declines and/or to rebuild stocks to their previous

	1980	1988	1989	1990
World total	75,651	103,196	104,709	101,583
China	5,840	12,004	13,065	13,870
Japan	11,122	12,785	11,913	11,052
Russia	9,659	11,511	11,450	10,514
Peru	2,709	6,642	6,854	6,875
U.S.A	3,817	6,009	5,846	5,921
Chile	2,891	5,376	6,633	5,424
India	2,445	3,127	3,641	3,791
South Korea	2,408	3,210	3,320	3,238
Indonesia	1,916	2,875	3,035	3,169
Thailand	1,799	2,643	2,783	2,651
Philippines	1,671	2,268	2,369	2,501
Norway	2,536	2,012	2,091	1,944

Source: "Yearbook of Fishery Statistics-Catches and Landings", FAO

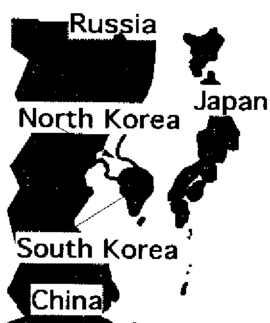
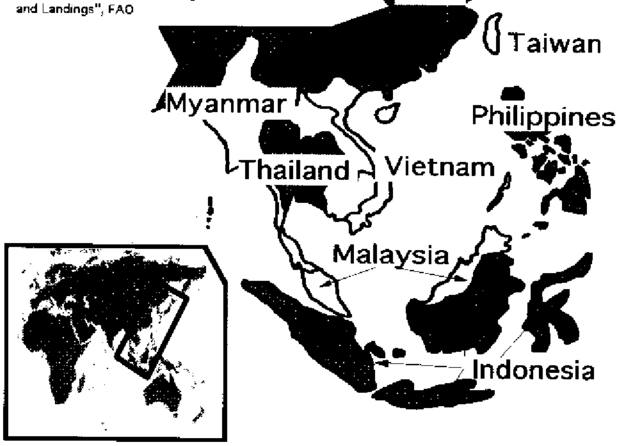



Figure 1. Map of southeast Asian countries and annual catch of fish (Source: FAO).

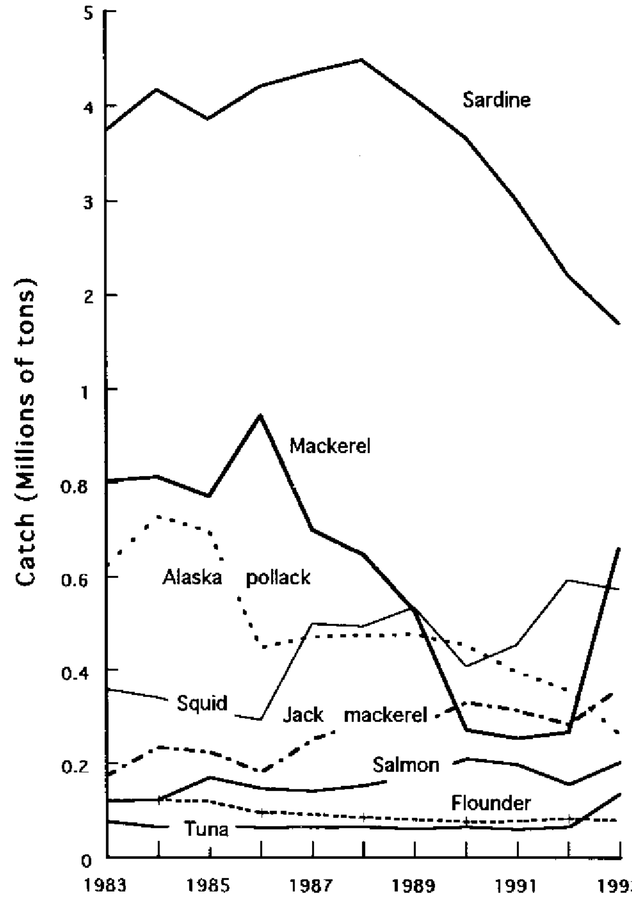


Figure 2. Trends in reported landings of selected coastal fish species in Japan (Source: Fishery Agency, Japan).

levels. Many of the technological measures taken to date are similar to those found in other fisheries around the world. These include reducing the capture of nontarget species and sizes of fish in fishing gears and measures to reduce the mortality of fish associated with mechanical and human selection processes (Fig. 3). Catch control limits are also implemented through spatial and temporal closure of fishing grounds and prohibiting fishing during periods of spawning. In addition to catch control measures, hatchery reared juveniles are released into the ocean to enhance stocks of coastal food fishes. What makes these programs quite different, is the leadership role taken by local Fishermen's Cooperative Associations (FCAs) and fishers in promoting, developing, and managing coastal fisheries.

A key component of Japan's resource conservation program has been a successful partnership role between industry and government in developing and managing coastal fisheries through a community based fisheries management plan. The purpose of this paper is to provide some background information on the role of fishers and fishermen's associations in Japanese coastal fisheries, to review the general objectives of conservation harvesting technology programs, and to summarize various initiatives that have been carried out by coastal fishers.

Establishing an Industrial Research Network

Japan has a complex and extensive network of fisheries research and development institutes, universities, prefectural research stations, and fishermen's cooperatives involved in planning and developing capture technologies. Overall direction is provided by the National Fisheries Agency which partly funds the R&D. The nine national

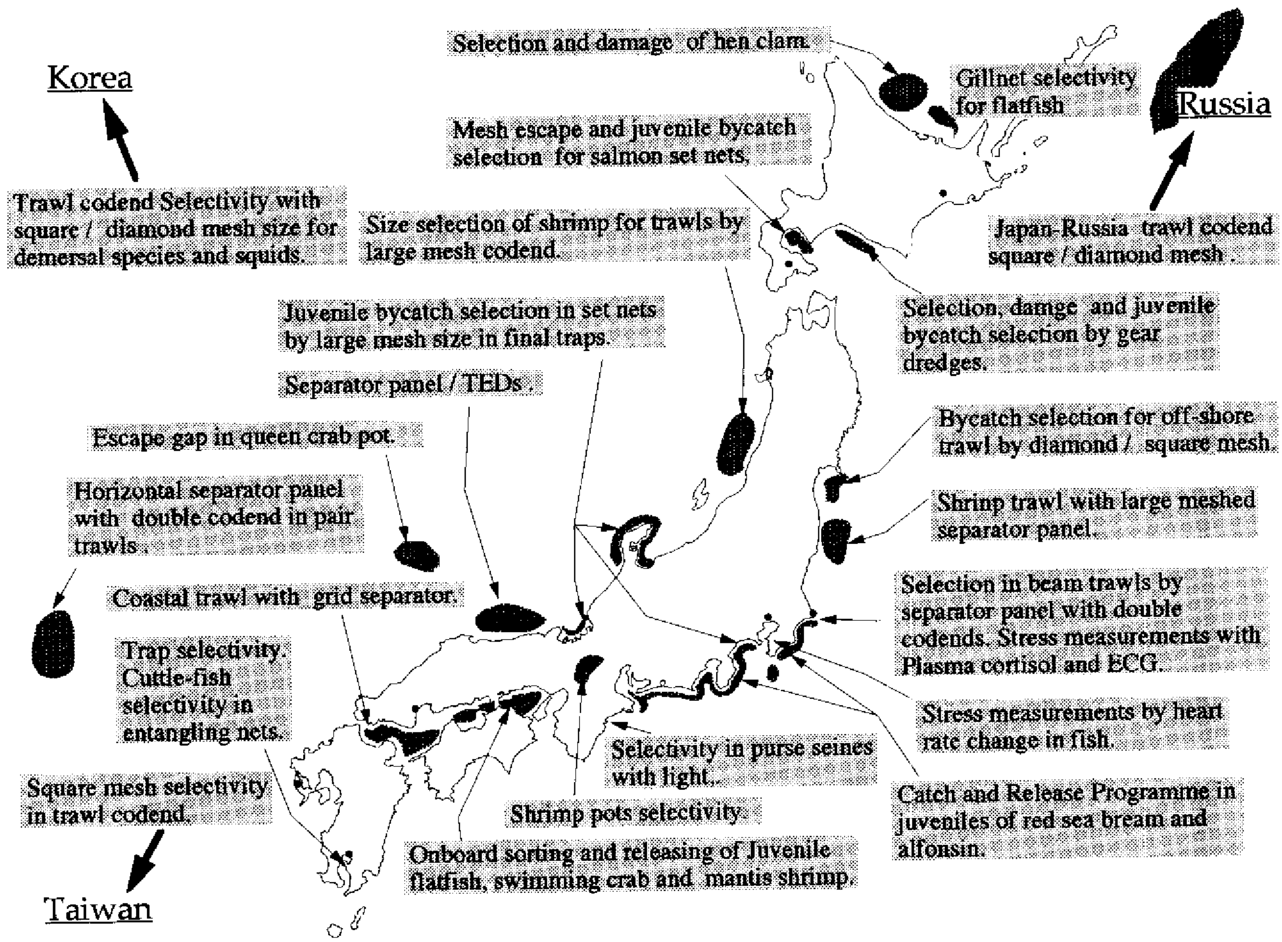


Figure 3. Current research and development projects in selectivity, ghost fishing, and survival in Japan.

research institutes provide supervision and advice and also conduct their own practical R&D programs. The National Federation of Fishermen's cooperatives provides support in disseminating research results, and a network of 47 prefectural research stations and regional fishermen's cooperatives undertake practical research in each prefecture. The universities may take part in the above research or conduct their research independently through financial support from the Ministry of Education.

Organizing the Work Force

There are about 1,800 FCAs along the coast of Japan with a membership of around 310,000 true fishers (total membership numbers 500,000). The local FCA is a focal point of each fishing community with responsibility for managing the local fishery resources and fishing grounds and plays a role in financing, marketing, education, and guidance. Each local FCA is organized into a federation at the local prefectural level and into a national federation at the national level. The National Federation of Fishery Cooperatives Association (NaFFCA) promotes mutual assistance and cooperation between its members with objectives to promote ocean and marine stewardship. The NaFFCA strives to stabilize and expand the economic base of the FCAs and takes the lead role in supporting and planning fishing operations and providing technical extension services. In particular, the FCAs have been engaged in developing the scientific and technical skills of young fishers since 1953 for the purpose of establishing a new generation of fishers to take lead roles in management of marine resources. Over the last few years, much of this work has been directed toward conservation technology reflected by the number of papers presented on this theme by fishers in the Youth Fishers Study Conference.

Fishermen's R&D Plan

Fishers and the FCAs strongly support resource management in fisheries where there is a need for resource recovery or to increase production to meet consumer demand. Much of this effort is volunteered by fishermen in each region who best understand the local fishing conditions. This has been achieved through strengthening the fishermen's organizations, providing them with scientific data on fisheries, and by joint arrangements with institutes and government to understand the economic impacts of resource management strategies. The general objectives of the FCAs with respect to conservation harvesting technology are:

1. To understand the present nature and condition of fishery resources through research on local fish stocks, their behavior as governed by physical and environmental conditions, and spawning and feeding patterns.

2. To protect spawning fish and juveniles through self-regulated fishing seasons and areas.

3. To take part in the enhancement of commercial food fishes through the maintenance and release of hatchery reared fish into the ocean.

4. The reduction of nontarget species and sizes of fish through developing selective fishing gears, the reduction of discard mortality through improved on deck handling practices, and reduction of habitat damage through gear modifications.

Through collaboration, fishermen, prefectural research stations, the national institutes, and local government have developed a strategic plan for resource enhancement and protection. The general objectives of this program are shown in Fig. 4 which illustrates the sequential roles taken by government and industry in the decision-making process and operating the practical aspects of the program. The time frame from information gathering to full operation of the enhancement program varies by species and fishery. It can be as low as 4-5 years for coastal species or as high as 10-11 years for migrating species.

The overall strategy for resource conservation technology in the small coastal trawl fleets is shown in Fig. 5. Several conservation technologies are reviewed under this resource enhancement and protection umbrella for the coastal trawl fishery.

Enhancement Programs—The Fukushima Flounder Fishery

In Fukushima prefecture, the annual landing of Hiarame flounder (*Paralichthys olivaceous*) rose dramatically between 1984 and 1986 to around 600 tons then fell into a steady decline from 1987 to 1991 (Fig. 6). Traditional catch control measures such as spatial and temporal closure of fishing grounds were implemented to reduce effort as well as to prevent fishing when fish were spawning. To offset further declines, a joint industry-government project was set up to enhance the natural stocks with hatchery reared fish. Table 1 shows the number of Hiarame flounder released in Fukushima prefecture. Because hatchery released fish have a different color than wild fish, it is easy to determine their presence in the catch. The ratio of wild and hatchery released fish in the catch during commercial fishing operations can be seen from Table 1.

The percentage of different year classes of hatchery released fish appearing in the commercial catch of coastal gillnet and trawl fisheries was measured in 1991 (Table 2). The appearance of significant numbers of older year class hatchery released fish in the commercial catch indicates success in preventing further collapse of the stock. However, the appearance of large numbers of younger year classes in the catch is of concern since much higher returns on investment could be achieved if the fish were left in the sea for another 18 to 24 months. These findings led to research and development of ways to reduce the capture of hatchery released fish by trawls or handle them after sorting the catch.

Mechanical Selection

In addition to an FCA marketing campaign to promote the concept of harvesting only older year classes of fish from the Hirame Bank (Table 3), various technological solutions are being sought to reduce the probability of capture of small fish. For example, Fig. 7 shows the percentage of hatchery released fish appearing in the coastal otter trawl catch. Various gear selectivity experiments are being conducted such as the use of

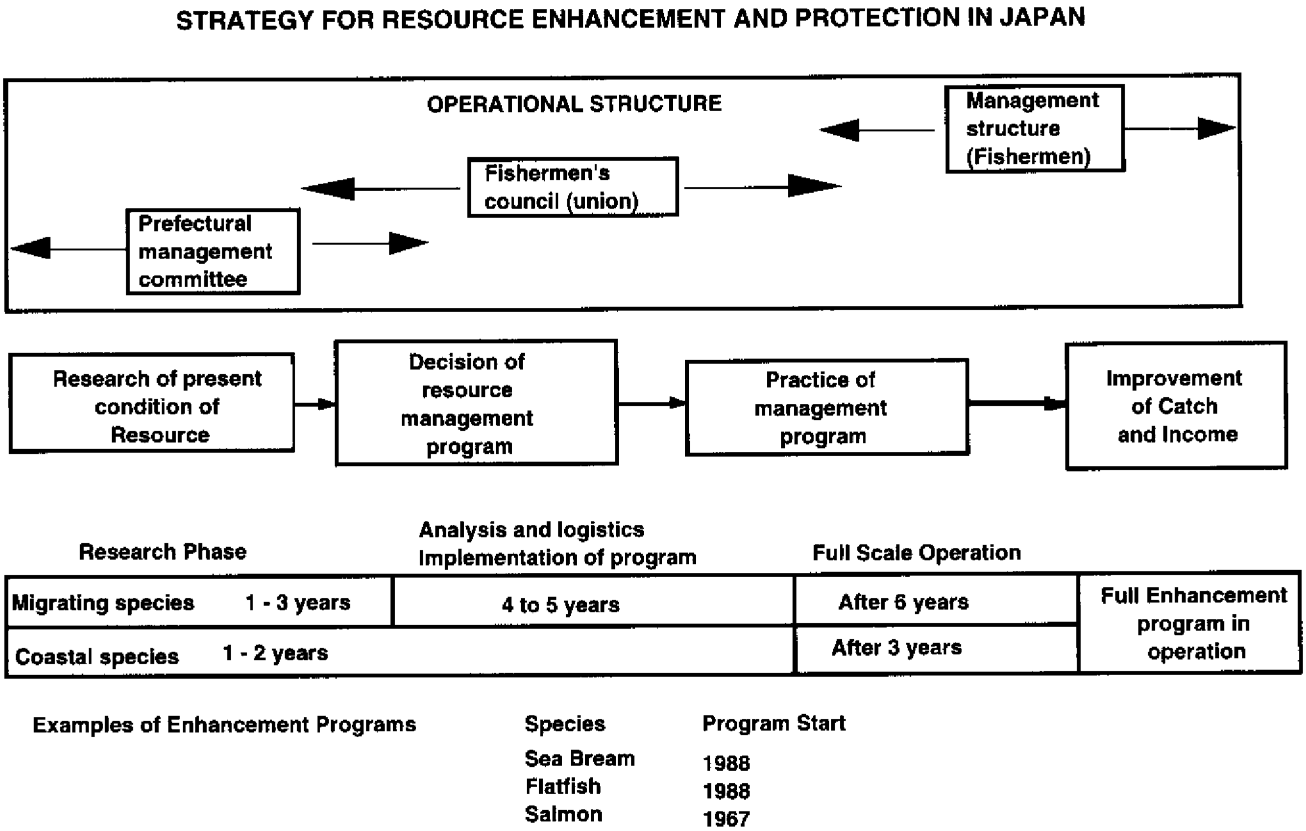


Figure 4. The role of local government, researchers, and the fishing industry in various stages of resource enhancement and protection programs in coastal fisheries.

bycatch reduction devices to eliminate their capture. Results to date show that larger Hirame can be diverted to a second codend, although how nontarget sizes of Hirame can be released without loss of other species such as shrimp has not yet been solved. Also the question of survival of fish after mechanical selection and release has not yet been investigated.

Human Selection

In a separate series of experiments conducted by fishers in Settu and Mitoyo, the survival rate of fish after human selection (on deck sorting) has also been investigated. Traditional deck sorting and discarding practices were compared to sorting fish and shrimp using a water bath or spray by fishermen in the Settu and Mitoyo regions respectively. The results showed that discard mortality rates could be reduced from 90% to

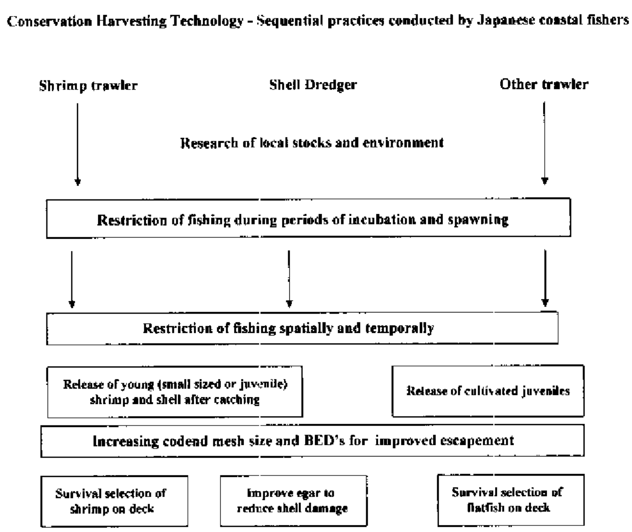


Figure 5. Specific conservation technology objectives of the Japanese small coastal trawl fleet.

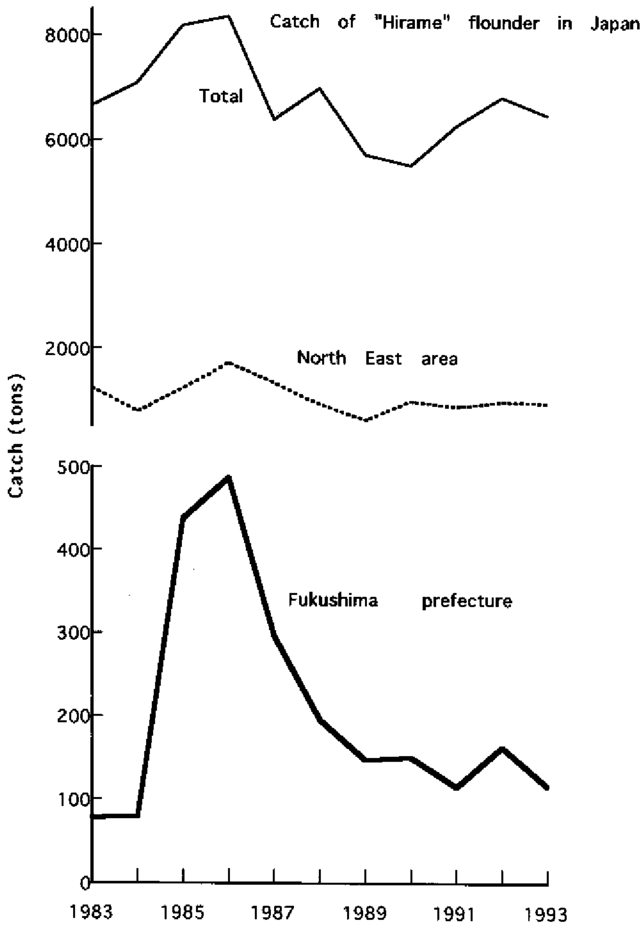


Figure 6. *Catches of flounder in Japanese coastal fisheries, with specific reference to catches on the northeast coast and Fukushima prefecture.*

Table 1. **The number of hatchery reared fish released into the sea in Fukushima prefecture, Japan, presence in commercial catches and estimated value (100 Yen = US$1.00).**

Class	# Released (in 1000s)	# Captured (in 1000s)	# Captured (%)	Value (US$)
1987	246	40	16.3	831500
1988	336	97	28.9	993300
1989	217	67	30.9	816900

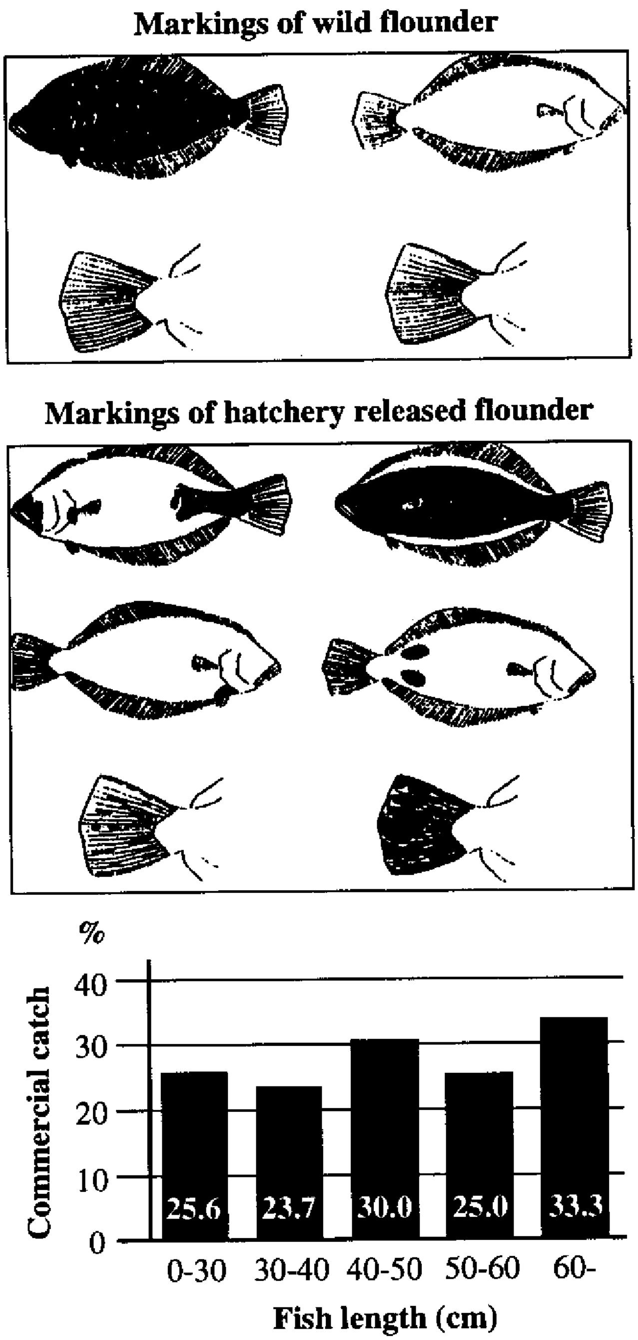
Table 2. **The number of hatchery reared Hirame flounder appearing in the commercial catch of coastal trawl and gillnet fleets by year class in Fukushima prefecture, Japan.**

Year Class	# Caught (in 1000s)	# Hatchery fish caught	Ratio (%)
1987	15,184	3,657	23.1
1988	41,346	12,559	30.3
1989	43,917	13,788	31.4
1990	36,676	12,319	35.0

Table 3. **The concept of the Hirame Bank—a promotional campaign by local FCAs to support the concept of live release and costs of early harvest.**

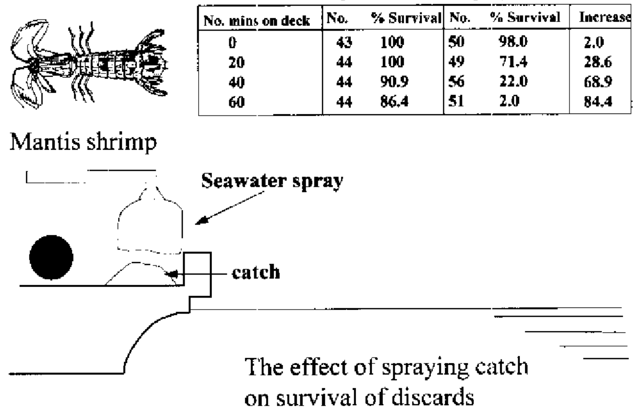
Time to harvest	Total lenth(cm)	Total weight(g)	Market Value (US$/Indiv)	Profit margin
Summer[a]	10	10	1.00[b]	Baseline
Autumn	20	150	0.75	Negative
1 year	30	300	6.00	× 6
18 months	40	600	18.00	× 18
2 years	50	1300	52.00	× 52

[a] immediate
[b] hatching cost



Percentage of hatchery reared fish found in commercial catches of the coastal otter trawl

Figure 7. The number of hatchery reared Hirame flounder appearing in the commercial catch of coastal otter trawls in Fukushima prefecture, Japan.



	Spray on		Spray off		
No. mins on deck	No.	% Survival	No.	% Survival	Increase
0	43	100	50	98.0	2.0
20	44	100	49	71.4	28.6
40	44	90.9	56	22.0	68.9
60	44	86.4	51	2.0	84.4

Figure 8. The results of experiments to reduce mortality associated with human selection on board small coastal trawlers fishing for shrimp and flounder (Source: Inoue 1995).

60% when fish were sorted in a sea water bath and that spraying shrimp with sea water during sorting could reduce shrimp discard mortality from 90% to 30% when the sorting time was approximately 60 minutes (Fig. 8). This was calculated as being equivalent to a reduction in the number of dead fish and shrimp discarded annually by the Settu and Mitoyo trawl fleets of 1,800,00 fish and 7,560,000 shrimp (Inoue 1995).

Discussion

The Japanese fishing industry has taken a holistic approach toward conserving their coastal fishery resources for the purpose of maintaining food and income security. This approach has combined traditional catch control measures such as gear selectivity, spatial and temporal closure of fishing grounds, and regulating catch landings with new approaches such as reducing mortality of fish returned to the sea through improved human selection techniques and enhancing the natural stock with hatchery released fish. Most important, the approach toward conserving coastal resources is a partnership arrangement between fishers and government. This is made possible through a strong and well-organized work force spearheaded by the FCAs and NaFFCA. The custodial role adopted toward protecting their coastal marine resources has encouraged the movement of fishers into a wide variety of science and technologies such as fish rearing, fish release, and fisheries management, while at the same time maintaining their traditional skills as fish harvesters.

This type of cooperation between industry and government in the small coastal trawl fishery, mirrored in other coastal fisheries such as pot fisheries and hand collection of abalone is suggested as a necessary element of responsible fisheries management. How such a model might work in other countries will depend on the societal roles of fishers, the importance of fish in coastal and domestic economies, and the willingness of managers and fishers to accept and share responsibility. The Japanese example does show that fishers can take on this responsibility and be an integral part of the fisheries management process.

While much work has been accomplished to establish a sustainable base in Japanese coastal fisheries, there are still problems associated with offshore fishing grounds where several countries operate fishing fleets. A lack of communication between fishers and little or no multilateral R&D cooperation in commercial sea fisheries research are constraints to successful development of the fishery. The lack of a multinational forum for the exchange of scientific and technical information on commercial sea fisheries on a regular basis is a severe hindrance to rational development of fish resources.

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U.S. Diplomatic Involvement in Fisheries Bycatch Issues

William E. Dilday
Office of Marine Conservation, U.S. Department of State, Washington, DC 20520

Fisheries bycatch and discards of bycatch are an increasing global economic, environmental, and political concern. Attention to the issue of bycatch and discards grows every year, and addressing the matter is requiring steadily higher priority for those involved in fisheries conservation and management. Some believe that there is inadequate data to measure the various impacts—biological, economic, social, or other—of fisheries bycatch and discards, and therefore it is not possible to determine the extent of the problem. It is generally recognized, however, that the impacts of bycatch on at least some nontarget fish and nonfish species is significant, that the costs to business and industry of addressing bycatch and discards are far from trivial, and that the differences in attitudes and opinion on bycatch and discards result in disagreement and conflict. In this regard, governmental involvement in fisheries affairs and the bycatch and discards issue, at the local, national, and international level, has increased in recent years.

I would like to describe the current thinking of the Department of State on some of the international fisheries bycatch issues in which it is involved. Some of these issues are well known, such as large-scale driftnet fishing, bycatch of dolphins in the eastern tropical Pacific purse seine tuna fishery, and the incidental take of sea turtles in shrimp trawl fisheries. Other matters may be less well known, such as activities in the United Nations and the Food and Agriculture Organization, or action taken by international fishery organizations, or under other arrangements.

Tuna/Dolphin

Perhaps the most well-known international bycatch issue involves dolphins and the eastern tropical Pacific (ETP) purse seine tuna fishery. For unknown reasons, mature yellowfin tuna are frequently found in association with dolphins in this region. Following certain technological developments during the 1950s, fishing vessels adopted the practice of setting large purse seine nets around dolphins in order to catch schools of yellowfin tuna swimming beneath them. In the early 1970s, when the fishery was dominated by U.S. vessels, dolphin mortality due to fishing operations reportedly exceeded 300,000 individuals annually. As recently as 1986, U.S. and foreign fishing operations contributed to more than 100,000 dolphin deaths.

Concern over this bycatch problem contributed to the enactment of the Marine Mammal Protection Act (MMPA) in 1972. Under the MMPA, as later amended, a marine mammal take permit was required and permissible dolphin mortality rates were gradually reduced. Dolphin kill rates in the fishery dropped dramatically. The stringent conditions on dolphin bycatch, however, induced many U.S. vessels to leave the fishery in the mid-1980s. The fishery became dominated by foreign fishing vessels rather than U.S. vessels.

To ensure that yellowfin tuna harvested with purse seines in the ETP by vessels of other countries was caught in a manner consistent with the requirements set for U.S. fishermen, Congress required that imports of tuna caught in the ETP by these countries be embargoed unless the country adopted a dolphin bycatch regulatory program comparable to that of the United States. In addition, the average rate of dolphin mortality of the foreign vessels had to be comparable to the U.S. fleet. Congress later set specific comparability standards.

Embargoes were subsequently placed on a large number of countries, and continue today on Mexico, Venezuela, Colombia, Panama, and Vanuatu. Embargoes were also imposed on countries which did not fish in the ETP but which imported tuna from countries that fished in the ETP and also exported tuna to the United States. This included a number of countries and embargoes continue today on Japan, Italy, and Costa Rica.

The Inter-American Tropical Tuna Commission (IATTC) serves as the multilateral conservation and management body for tuna fisheries in the eastern tropical Pacific, including the ETP yellowfin tuna fishery. IATTC is actively addressing the dolphin bycatch issue.

The International Dolphin Conservation Program adopted in 1992 and implemented under IATTC has as its objective the reduction of dolphin mortalities to insignificant levels approaching zero with a goal of eliminating them entirely. It is an international program involving ten countries. Today, ahead of schedule, the number of dolphins killed in the ETP yellowfin tuna fishery has been reduced to about 4,000 individuals annually, while tuna catches have remained high. This represents approximately four-hundredths of one percent of the 9.5 million ETP dolphins whose populations are stable or increasing.

Yet, despite the progress of the IATTC dolphin mortality reduction program, the United States continues to embargo tuna from countries that do not meet the stricter requirements of the MMPA.

There is little doubt that the threat and imposition of U.S. trade embargoes were effective in securing agreement on the IATTC dolphin protection program. However, the factual situation on which the unilateral embargo standards were based no longer exists. Today, some of the countries that continue to be subject to the tuna embargoes are seriously re-evaluating their participation in that program and are considering forming an alternative international fishery conservation and management organization that could have a less restrictive dolphin protection regime.

In light of the progress made in reducing the bycatch and mortality of dolphins in the ETP yellowfin tuna purse seine fishery, the Department of State believes that U.S. fishermen should be allowed to return to the fishery on an equitable basis, and that the embargoes against countries complying with the internationally agreed upon IATTC dolphin mortality reduction program should be lifted. This would require amending the MMPA, which the Department of State has suggested to Congress. The progress achieved to date must be preserved for the future; otherwise, it may be in serious jeopardy.

Large-scale Driftnet Fishing

Another well-known international fisheries bycatch and discard issue concerns large-scale high seas pelagic driftnet fishing.

During the mid-1980s, nearly 1,000 vessels fished for salmon, squid, and tuna with large-scale driftnets in the North and South Pacific. Scientists saw rapid declines in the abundance of albacore tuna, and others held the conviction that the driftnet fisheries were taking large numbers of immature salmon.

The concern expressed about the impact these fisheries had on living marine resources prompted the Department of State to conclude agreements in 1987 with countries whose vessels fished with large-scale driftnets on the high seas of the North Pacific. The purpose of these agreements was to assess these fisheries and to restrict the fisheries to areas that minimized bycatch of U.S.-origin salmon.

Under these agreements, the United States annually deployed scientific observers on board Japanese, Korean, and Taiwanese driftnet fishing vessels from 1989 to 1992. The scientific information obtained from these cooperative monitoring programs substantiated concerns about the significant bycatch characteristics of large-scale pelagic driftnet fishing. The fisheries took, and subsequently discarded, huge quantities of individuals of different species. In 1990, for example, one of five North Pacific driftnet fisheries harvested 106 million neon flying squid, but also took as bycatch more than 41 million individuals of over 100 different species. This included more than 39 million fish, 700,000 blue sharks, 270,000 sea birds, and 141,000 salmon; nearly 25,000 other species of squid and 24,000 marine mammals; and 406 sea turtles. The cumulative effect of driftnet fishing was viewed to pose a significant threat to the marine ecosystem and to slow-reproducing species of target and nontarget fish, marine mammals, sea turtles, and seabirds, some of which were threatened or endangered.

In 1991 the United Nations General Assembly agreed by consensus to a global moratorium on all large-scale pelagic driftnet fishing on the high seas. The moratorium took effect in 1993 and implementation has generally been positive and successful.

The United States believed then, and believes today, that the enormous capacity of the large-scale driftnet fishing fleets to adversely affect large numbers of many fish and nonfish species necessitated the moratorium to ensure the protection of high seas living marine resources. The United States supported the United Nations call for the moratorium because of the wastefulness and potential negative impacts of large-scale pelagic driftnet fishing on the ecosystem. The Department of State was a primary sponsor of the moratorium and continues to call for, and support, its full and effective implementation.

The Department of State has ensured that implementation of the moratorium remains a priority of the United Nations. Since 1991, the United Nations has annually reported on and unanimously reaffirmed the need and importance of the global moratorium, and has encouraged members of the international community to fully implement and comply with it. We and the UN have urged greater enforcement, including sanctions, to ensure full compliance with the moratorium where there are reports of inconsistent conduct and activities.

Shrimp/Sea Turtles

Another well-known fisheries bycatch issue involves the incidental capture of sea turtles in commercial shrimp trawl operations.

Studies have shown that shrimp trawling has the greatest impact on sea turtle mortality. Turtle Excluder Devices (TEDs) are reported to be about 97% effective in releasing turtles from shrimp trawl nets. Since the late 1980s, U.S. domestic policy and regulations have required that commercial shrimp trawl vessels fishing in U.S. waters in certain areas of the Gulf of Mexico and Atlantic Ocean use TEDs to reduce the bycatch of sea turtles in trawl operations. At the same time, it was recognized that the use of TEDs by U.S. shrimp fishermen would be of limited effectiveness unless a similar level of use was in effect throughout the migratory range of the turtles across the Gulf of Mexico, the Caribbean Sea, and the western central Atlantic Ocean (the wider Caribbean area).

Therefore, in 1989 Congress mandated that shrimp harvested with technology that may adversely affect sea turtles, such as trawling, may not be imported into the United States from foreign nations unless the Department of State annually certifies to the Congress that such nations have conservation programs and bycatch rates comparable to those of the United States.

The evolution of efforts to reduce bycatch of sea turtles in international shrimp trawl operations has been remarkably swift and successful. When the Department of State made its first certification in 1991, we certified foreign countries on the basis of their commitment to adopt and implement a TED program within three years. Subsequent certifications were made on the basis of progress achieved in implementing a TED program, ensuring compliance with that program, and undertaking other efforts to reduce bycatch of sea turtles. Today, in order for an annual certification to be made, approved TEDs must be required and be in continual use on virtually all of the vessels in the commercial shrimp trawl fleet when fishing in the wider Caribbean area. Twelve of the 14 countries affected by the law, including all of the important shrimp producing countries, are currently certified as meeting the conservation and management requirements and may export shrimp to the United States. Suriname and French Guiana are currently not certified and shrimp imports from these two countries are prohibited, as they have been for a number of years.

The countries of the wider Caribbean have important and increasingly effective sea turtle protection programs to which they devote considerable resources. As in the case of the tuna/dolphin situation, the threat and imposition of U.S. embargoes have helped encourage some countries to devote greater attention to sea turtle protection in the wider Caribbean. However, the Department of State recognizes that this approach may not be viable over the long term. Therefore, we are currently engaged in discussions with other countries to establish a multilateral regional convention for the protection and conservation of sea turtles. An acceptable treaty would reduce the bycatch, injury, and mortality of sea turtles associated with commercial fisheries, in particular shrimp trawl fisheries.

The United Nations and the Food and Agriculture Organization

Last year in the United Nations General Assembly, the United States introduced a resolution on fisheries bycatch and discards. After considerable debate, the General Assembly adopted by consensus an amended resolution.

Among other things, the resolution registers the international community's belief that the issue of bycatch and discards in fishing operations warrants serious attention, and that a continued and effective response to the issue is necessary to ensure the long-term and sustainable development of fisheries. Toward this end, the General Assembly called on the United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks and the Food and Agriculture Organization (FAO) to address bycatch and discards in their respective work. The resolution also placed the bycatch and discard issue on the agenda of the General Assembly session to be held late in 1995.

The United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks concluded its work in August 1995. The United States was a key participant in the conference. After three years of negotiation, the conference adopted a treaty on the conservation and management of straddling fish stocks, such as Aleutian Basin pollock in the central Bering Sea, and highly migratory fish stocks, such as tunas and swordfish. The agreement contains a general obligation that, among other things, countries minimize bycatch of nontarget fish and nonfish species through measures including, to the extent practicable, the development and use of selective, environmentally safe, and cost effective fishing gear and techniques.

Since early 1994, the FAO has been drafting an International Code of Conduct for Responsible Fisheries. The United States is actively participating in discussions leading to the preparation of the code. The code will set out voluntary principles and global standards of behavior for responsible practices to conserve, manage, and develop fisheries. These will include guidelines for the conduct of fisheries conservation and management, fishing operations, aquaculture development, post-harvest practices, and research. Guidelines on fishing gear selectivity and practices, with the aim of reducing bycatch and discards, will be an important part of the code.

International Fisheries Agreements/Organizations and Bycatch

International fisheries agreements, such as the UN Fish Stocks Agreement or the proposed Western Hemisphere sea turtle convention described above, increasingly contain provisions on fisheries bycatch and discards.

Other examples include the Convention on the Conservation and Management of Pollock Resources in the Central Bering Sea concluded in February 1994. The parties to the convention, which include Japan, South Korea, China, Poland, Russia, and the United States, agreed to share data on anadromous species or other living marine resources incidentally caught by their vessels fishing for pollock in the central Bering Sea. Observers on board such vessels will monitor bycatch. These countries also share the view that they will prohibit their vessels from retaining anadromous species or herring that are taken as bycatch in the course of fishing operations for pollock.

The Convention for the Conservation of Anadromous Stocks in the North Pacific Ocean, which succeeded the International Convention for the High Seas Fisheries of the North Pacific Ocean in 1992, includes the provision that the incidental taking of anadromous fish by vessels fishing in the North Pacific should be minimized to the maximum extent practical. The convention further requires that vessels of the parties to the convention, which include Canada, Japan, Russia, and the United States, not retain any anadromous fish incidentally taken in a fishing activity directed at nonanadromous fish, and that any such anadromous fish be returned immediately to the sea. Fisheries for nonanadromous fish are to be conducted at times and in areas and manners that minimize the bycatch of anadromous fish to the maximum extent practicable to reduce such bycatch to insignificant levels.

The U.S.-South Pacific Fisheries Treaty, concluded in 1987, provides U.S. fishing vessels access to the zones of 16 South Pacific Island countries. Under the treaty, U.S. vessels are prohibited from fishing for species other than tunas, but the treaty also explicitly recognizes that other kinds of fish may be taken as incidental bycatch.

A final example of an international fisheries conservation and management organization addressing bycatch is the International Pacific Halibut Commission. Bycatch of halibut in U.S.

groundfish fisheries in the Gulf of Alaska and Bering Sea, as well as in Canadian fisheries off British Columbia, have affected the amount and division of halibut catch quotas between the two countries. The bycatch issue is not a biological conservation issue but rather an allocation issue between users of different gear types.

The United States has undertaken sustained efforts to control and reduce halibut bycatch in its groundfish fisheries. Strict halibut bycatch quotas on all gear types have been imposed and are monitored by an extensive observer program. Halibut bycatch in the United States was reduced 20% between 1991 and 1993. The costs of achieving this goal, however, were significant and totaled approximately $9 million in 1994. In addition, groundfish fisheries that were suspended to avoid halibut bycatch lost an estimated $14.6 million in foregone direct revenue in 1994. This figure does not include more than one million metric tons of available groundfish yield not allocated due to bycatch concerns. Yet, an indication of the difficulty of managing bycatch is reflected in the fact that halibut bycatch in U.S. groundfish fisheries increased 8% between 1993 and 1994. The United States and Canada continue, under the auspices of the International Pacific Halibut Commission, to address the halibut bycatch issue.

Conclusion

As noted at the beginning of this paper, fisheries bycatch is an increasing global concern in which government involvement at all levels has grown. The international community is giving more and more attention to the issue of fisheries bycatch.

Some suggest that because of the importance of fisheries to many nations, international bycatch policy should minimize social and economic conflict, be independent of ideological differences, and be based on sound conservation principles. In this way, they contend, acceptance of global bycatch and discard policies which are sensitive to social and cultural differences will be more feasible. They suggest that multilateral, negotiated approaches to fishery bycatch and discard issues are preferable to unilateral pronouncements. The Department of State is actively involved in a number of international fisheries bycatch issues, both bilateral and multilateral, in a wide array of forums. While our approach to addressing and finding solutions to bycatch issues must take into account a multitude of circumstances unique to each situation, our objective is firm and clear—to manage bycatch in the context of sustainable fisheries for today as well as tomorrow.

International Panel on Management Solutions: Discussion

Martin A. Hall, Moderator
Inter-American Tropical Tuna Commission, La Jolla Shores Dr.
La Jolla, CA 92037-8604

QUESTION: I'd like to compare the experiences of Norway and Japan with the experiences of other countries. Who originates the ideas that turn into experiments, and where is the source of funding for those experiments in both Japan and Norway?

OLSEN: In the case of Norway, it's partly the fishermen, partly the scientists. An example is the Nordmore grate. The original idea came from our fishermen. Last year 90-100% of the funding was public money.

QUESTION: Are the fishermen's ideas generally brought to some government office?

OLSEN: Often it's the fisherman who comes to one of the research institutions and presents the problem.

CHOPIN: The fishermen in Japan are very well educated, and much of the information that comes from the government is disseminated to the fishermen's organizations. They are free to choose some of these ideas, but they can also generate their own ideas.

QUESTION: Are the projects to be undertaken selected by the government, or by the co-ops themselves?

CHOPIN: Most of them are conducted by fishermen. If they need something, we can help them. However, there is no money available.

QUESTION: I want to ask the representative from the FAO (George Everett) to what extent we can expect a global report card at known intervals, so that we can actually get a grip on this problem, and on its progress from time to time.

EVERETT: I hope very much that we can continue the interest and further the work. As far as followup goes, I hesitate because our budget has not been approved for the next two years. But I would like to see FAO coordinating or being the catalyst. That does not necessarily cost a lot of money. I'll convey your wish back to appropriate people, and if others put forth the same request, I'm sure we would look favorably on this.

COMMENT: FAO and other global reports on the status of fisheries have been very helpful in trying to get some kind of perspective on whether overcapitalization is a worldwide or regional problem.

EVERETT: The "Alverson Report"[1] certainly contributed to the international community, and the United Nations specifically addressed the fishery bycatch issue. While last year's resolution was useful, I don't think there was enough time in the General Assembly to really consider the issue, but the General Assembly did take note of the seriousness of the bycatch problem. More important, it was put on the agenda for the next General Assembly session. While that may not sound as if it's a historic moment, it does indicate the seriousness they attach to this issue. Bycatch, and fisheries in general, is an issue that has received more and more attention every year.

QUESTION: I'm interested in the cultural implications Dr. Pauly mentioned in terms of the use of bycatch. The FAO representative mentioned

Africa in terms of the use of bycatch, and in conjunction with that, asked whether it's a conservation or cultural issue? If it's culturally acceptable to use the bycatch, maybe it's not really a bycatch issue but a conservation issue. Where we in the United States might call it waste and bycatch, and determine it be stopped, maybe in Southeast Asia it's not an issue of conservation, because it is actually turned into a food product.

PAULY: There is obviously a big conservation issue connected with Southeast Asian fisheries. Turtles are caught, marine mammals are caught as soon as they get close to the beaches, etc. But it is almost an intractable problem, because the governments and enforcement agencies have many problems tracking it and using the conventional management measures. The only thing I think will work is marine reserves. They make sense to lay people, and they make sense to fishermen once they can be convinced that the overall catch will not decline. In the long term, what will happen in many countries, including those in Southeast Asia, is that systems of marine reserves will be set up. In the Philippines it's one of the pioneering concepts that could be implemented, for the same reason that we have national parks.

QUESTION: Is it a conservation problem? Dr. Pauly answered in some respects. We have to remember that discarding bycatch is a part of a set of mortalities imposed by fishing activities. There is a certain advantage in the full-use concept that might develop more effectively in Asia as a result of the social structure that Daniel (Pauly) talked about. It is easier to document than sending a lot of people to sea to become observers on every boat. We have got to remember to put bycatch in perspective: is it impacting the population or the ecosystem, or is it a waste issue, which has different possibilities for solution?

CHOPIN: On the issue of full utilization in Japan, where most of the catch was traditionally utilized, there have been recent changes in the labor force. Young fishermen are not staying in the fishery. This has resulted in a change of the labor work force; 70% of the fishermen in Japan are over 49 years old. This creates a problem on the deck of the boat, where the older fishermen can't sort the catch like they used to. And although there is full utilization, if you haven't got the sorting work force anymore, you've got a problem. That is one issue which is driving the desire for use of some selective fishing gears. Another issue is cultivation and the release of fish into the wild. The fishermen involved in culturing are seeing that that their fish are being caught before they have a chance to grow to anticipated harvest size. This is another driving force behind the use of selective fishing gear.

QUESTION: The experience that I have in Latin America, which I think is similar to the that in Africa or Asia, is that sophisticated bycatch management teams cannot work in the local political structures. However, if gears could be developed with the right properties, which are not extremely expensive, they could be adopted. Looking for solutions that could be exported for use worldwide is really important. Perhaps it would make sense to develop initiatives to put together a year-long program internationally dedicated to a particular technology, and make a big push in a given direction (e.g., the year of the trawl); somewhat analogous to the Geophysical Year.

PAULY: It is clear that the bycatch problem has different solutions in different parts of the world. In some countries, it is meeting regulatory requirements for not catching this, and not catching that. In Southeast Asia it is really a utilization issue. I don't believe you would have a whole that would be more than the sum of its parts, if you did a global exercise on this.

I believe the other panel members would respond positively to your suggestion; but I would say no. This is a long-term work, and over-focusing won't bring you very far very soon. As mentioned, the problems are different in different parts of the world. It would be difficult to globally cast the real problems. Even if it's a question of catching the same fish, or avoiding catching the same small fish, we have different views as to the whole, and how technologies are applied.

QUESTION: I have a few comments that relate to the differences between problems that occur in Western fisheries and those that don't occur in many of the fisheries in Southeast Asia. One concept in Western fisheries is taking only some fish, leaving much of the remainder on site, while in Asian countries everything is taken, and only starfish and a few other critters are thrown back. That difference of ideas, of the whole history of development, becomes a problem when you have to develop general documents, such as the Code of Conduct for responsible fisheries. It seems to be a document developed on the philosophy associated with discarding and taking only one or two species, by a very good communications network. It's difficult to launch such a document in Asia, where 40% of the world's catch is taken, and where there is neither the communications network nor the same philosophy that governs how the fisheries have developed. That creates a problem. There are many ways to communicate and we now have the Internet to help overcome some of these problems, but as already mentioned, the research is lagging behind. Are there other ways to energize research internationally or nationally?

PAULY: The "Alverson Report" was very energizing. It put the problem in a new perspective. In the 1970s and 1980s, the bycatch issue was picked up only by some nations. At the time, the amount considered was 1-5 million tons. Since it was not clear how this value was arrived at, even its upper range failed to impress anybody. The total figures are staggering, as well as those for each of the FAO areas, and for each of the countries. In a sense, with that report your geophysical year has happened, and we are now using the fallout from that burst of energy. You can let the community work for the next four or five years under the influence of that event, before producing something at a global level.

ANSWER: That report definitely did bring greater attention to the bycatch problem, and one clear result is that the issue of bycatch and discards has taken on a very high profile both nationally and internationally. Now that we have identified this big problem, a lot of management solutions are being looked at, which can more easily be implemented in the short term. In many cases, the solutions you would really like to have as goals of fisheries management, such as maximizing production and employment, and securing the world food supply, require developing more selective gear and looking at problems more broadly. A year of selective fishing and gear development, even though it won't address all of the pertinent issues, might help to energize or mobilize research funding. Because these are long-term issues, we may need the decade of selective fishing gear developments.

I don't mean to ignore issues of survivability of fish that escape, and other issues, but research has been lagging behind the problem. I've been working on bycatch and gear research for years. Many times I started out looking at a problem before the industry or the Council identified it as a problem. It takes time to complete research, and sometimes management regulations come to the table and are put in place before the research is completed. We need to do something about that, we need to mobilize funding, we need a longer-term view, and the idea of global emphasis if a good one, but a year may not be long enough.

COMMENT: Sometimes there is a difference of attitude and commitment on the bycatch issue, depending on the nature of the investor. For instance, Japan's distant water fisheries show a different characteristic to discard than their local fisheries, which keep everything they catch and have very high utilization. Similar situations have developed in many other distant water fisheries, such as the high-tech shrimp fisheries. Because of the high value of shrimp, they can afford to maintain a fishery that targets on the shrimp and discards everything else. An issue worth considering at the international level is how to couple the bycatch problem with an acceptable joint venture arrangement.

Endnote

[1] D.L. Alverson, M.H. Freeberg, J.G. Pope, and S.A. Murawski. 1994. A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper No. 339. Rome, Italy. 233 pp.

Seabird Bycatch in Puget Sound Commercial Salmon Net Fisheries: Working Group Report

Keith Wolf
Washington Department of Fish and Wildlife, 600 Capitol Way North, Olympia, WA 98501-1091

John Grettenberger
United States Fish and Wildlife Service, 3704 Griffen Ln. SE #102, Olympia, WA 98501-2192

Ed Melvin
Washington Sea Grant College Program, 1801 Roeder Ave. #108, Bellingham, WA 98225

In 1993, many issues dealing with the marbled murrelet (*Brachyamphus marmoratus*), listed as threatened under the Endangered Species Act (ESA) were brought to the forefront. In 1994, both the Migratory Bird Treaty Act (MBTA) and ESA illuminated the prohibitions on the taking of seabirds in the Puget Sound commercial salmon net fisheries of Washington state. In particular, these regulatory statutes initiated a series of responses from the Washington Department of Fish and Wildlife (WDFW), the United States Fish and Wildlife Service (USFWS), and from the commercial salmon fishing industry in the form of observer programs aimed at estimating the rate of encounters of seabirds in net fisheries, in bycatch monitoring programs, and in net gear modification studies intending to reduce the number of seabirds entangled in net gear.

This working group was formed to provide a forum for discussion of seabird bycatch from a biological, regulatory, and scientific perspectives. Working group members were:

- Bruce Sanford (WDFW)
- Keith Wolf (WDFW)
- Jon Anderson (WDFW)
- John Grettenberger (USFWS)
- Julia Parish, University of Washington, Department of Zoology
- Ed Melvin, Washington Sea Grant College Program
- Glen Spain, Institute for Fisheries Resources

Twenty-five other participants from the Solving Bycatch Workshop joined the discussion.

WDFW Management Actions

In 1994, industry-led development of Conservation Action Plans began to build a framework for addressing the issue of bycatch in commercial salmon net fisheries in Puget Sound. These short term (1994) and longer term (5-year) plans outlined observer programs, gear modifications to reduce and/or minimize the impact on seabird populations, and Best Fishing Practices (a set of voluntary measures intended to increase awareness of bycatch issues within the industry, and foster communication among individual fishers).

Funding for an observer program aimed at estimating the rate of seabird encounters in commercial net fisheries was made available through the National Marine Fisheries Service (NMFS), with funding authorized under the Marine Mammal Protection Act. WDFW coordinated the program and hired over 40 temporary observers who were stationed aboard gillnet vessels in the area 7/7A (Fig. 1) sockeye fishery. Over 218 non-treaty gillnet boat trips were observed. The Northwest Indian Fisheries Commission and the Lummi Tribe also conducted observer programs in conjunction with the non-treaty component. The goal of the observer program was to determine the nature and extent of marine mammal and marbled murrelet interactions with commercial salmon gillnet fishing gear. Results indicated that 15 marbled murrelets (expanded from one entanglement) occurred in the sockeye fishery. In addition, 3,569 other seabirds were estimated to have been taken (expanded from 195).

The Puget Sound Vessel Owners Association funded a similar study in the purse seine fishery that was conducted by Natural Resources Consultants, Inc. with funding contributed by the Washington Sea Grant Program. This study observed no marbled murrelet entanglements, and estimated a total of 45 other seabirds taken.

In 1995, WDFW instituted a number of management actions to reduce the number of seabird entanglements in the 7/7A sockeye fishery. These included:

- Substantial portions of traditionally fished areas in the San Juan Islands (area 7/7A) were closed (Figs. 1 and 2) for all non-Indian commercial net fisheries this year to provide enhanced protection to marbled murrelets in identified occurrence areas.
- An important objective for minimizing seabird bycatch in the Fraser fishery (Pacific Salmon Commission control) this season was the achievement of a reduction from recent year "typical" levels in the number of open gillnet fishing hours. A linkage between total gillnet fishing hours and the level of seabird bycatch by the gear was assumed in pursuing this objective.
- Daily non-Indian gillnet openings in 1995 were reduced to 12 hours. Traditional practiced gillnet openings in years prior to 1995 were 15 hours in duration.
- Non-Indian gillnets fished a total of 78 hours for sockeye and pink salmon this season; a reduction of 58.7% in total hours fished when compared to 1994 (189 gillnet hours).
- Total gillnet hours open in 1995 were 56.9% of the most recent five-year average total gillnet open hours for this fishery (137 hours).
- It was desired pre-season that non-Indian gillnet fisheries be scheduled predominantly during daylight hours, and only during one "light-change" period per opening to reduce fishing time during periods when seabird activity, and potential bycatch risk, are enhanced.
- Standard, daily gillnet openings were set by WDFW and the fishing industry at 11 am to 11 pm (or 8 pm to 8 am as an alternate opening if treaty fishing schedules pre-empted this schedule) this season.
- Non-Indian gillnets fished 38 hours during daylight of the 78 total hours allowed for sockeye and pink fishing. Daytime gillnet fishing accounted for 49% of the total open hours allowed for this gear type.
- An alternative gillnet gear study was planned for implementation during the 1995 non-Indian sockeye and pink fishery to determine if seabird bycatch could be reduced in modified gillnet gear without significantly impairing sockeye or pink salmon harvest efficiency (allocation ramifications).

Washington Sea Grant Studies

Conclusions for 1994: Seabird entanglements were rare, occurring in 2.5% of experimental gillnet panel sets. Conclusive studies of the effect of different gear types on seabird entanglement rates require large sample sizes and should be focused in areas where seabird densities are high to maximize net encounters.

Monofilament gillnets with large (10-inch) opaque mesh in the upper portion of the net demonstrated the greatest potential as an alternative gear to traditional monofilament gillnets because they did not entangle seabirds or marine mammals, and caught sockeye at rates similar to monofilament during 1994 pilot studies.

Multifilament nets may not offer a viable alternative to traditional gillnets because they caught birds at similar rates to monofilament nets and entangled one harbor seal.

Monofilament nets with 5-inch opaque netting in the upper portion of the net do not appear to provide an acceptable alternative to traditional

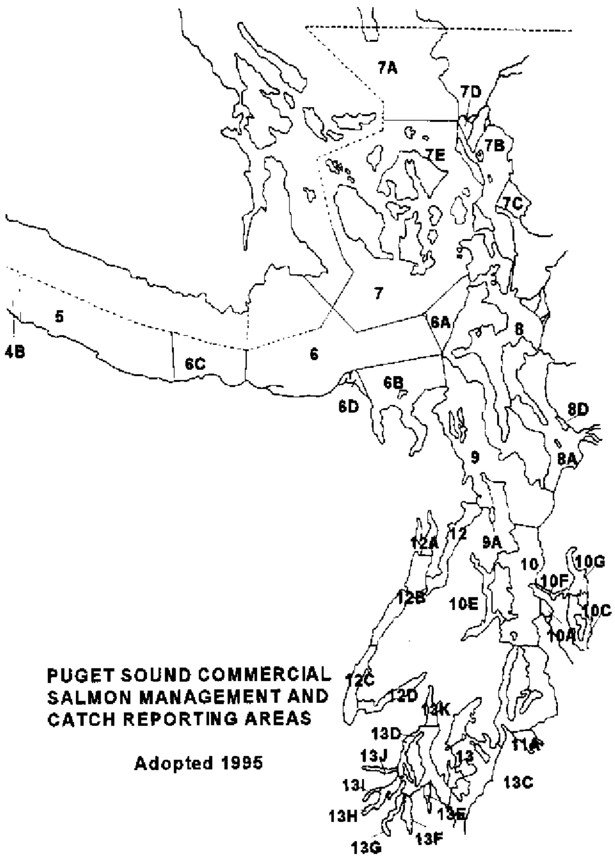

Figure 1. Puget Sound commercial salmon management and catch reporting areas. Adopted 1990.

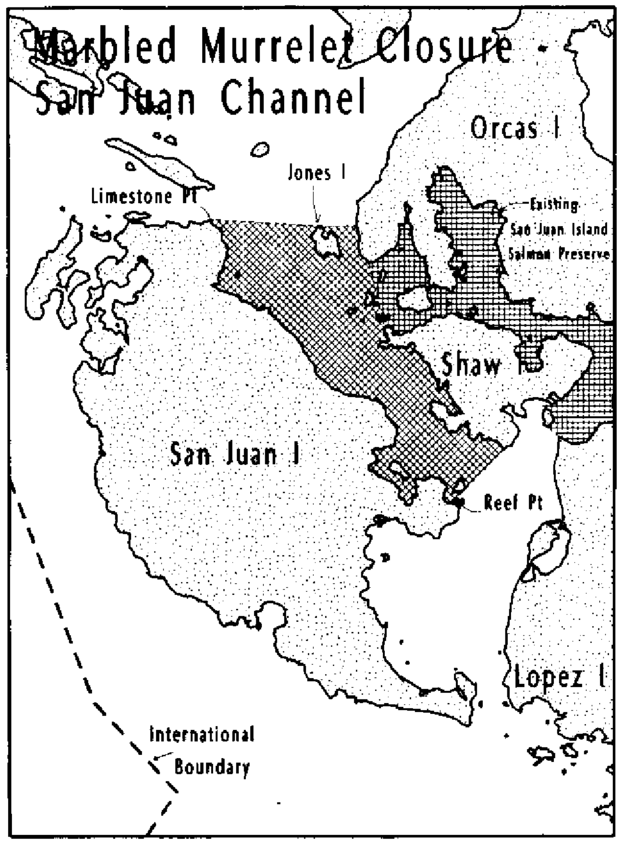

Figure 2a. Substantial portions of traditionally fished areas in the San Juan Islands (area 7/7A) closed to all non-Indian commercial net fisheries (Figs. 2a-2g). San Juan Channel.

monofilament nets. Although they did not entangle seabirds or marine mammals, they consistently caught fewer fish than the other gear types, they deployed poorly, and because of their bulk, they will not fit on net reels typically used in this fishery.

Monofilament nets with red corks do not appear to offer an alternative to monofilament gillnets with white corks because they entangled birds at similar rates, the corkline was difficult to see during fishing operations, and there was no behavioral evidence to support the contention that seabirds avoid red corks.

No conclusions were possible regarding differences in seabird entanglement rates between daytime and nighttime fishing, or between tidal states for the gear types tested.

Coho and chinook salmon were captured too infrequently to test their capture rates among the experimental gears tested.

In 1995, four test vessels using the 10-inch mesh in the upper portion of the net took part in a study similar to the 1994 study. Preliminary results are not available at the time of this report.

USFWS Perspectives

The USFWS has listed the marbled murrelet as threatened, under the ESA, primarily because of the loss of nesting habitat and extremely low numbers in the coastal waters of California, Oregon, and Washington. Because commercial salmon fisheries have been noted as a source of alcid mortality in other areas, and particularly in one specific fishery in Canada, the USFWS required consultation (Section 7 consultation) on biological assessments developed by federal agencies associated with the management of commercial salmon fisheries in Puget Sound to render a biological opinion. WDFW, the state fisheries management agency, was required to submit a biological assessment to the NMFS, by March 1995. NMFS conducted a review and forwarded the assess-

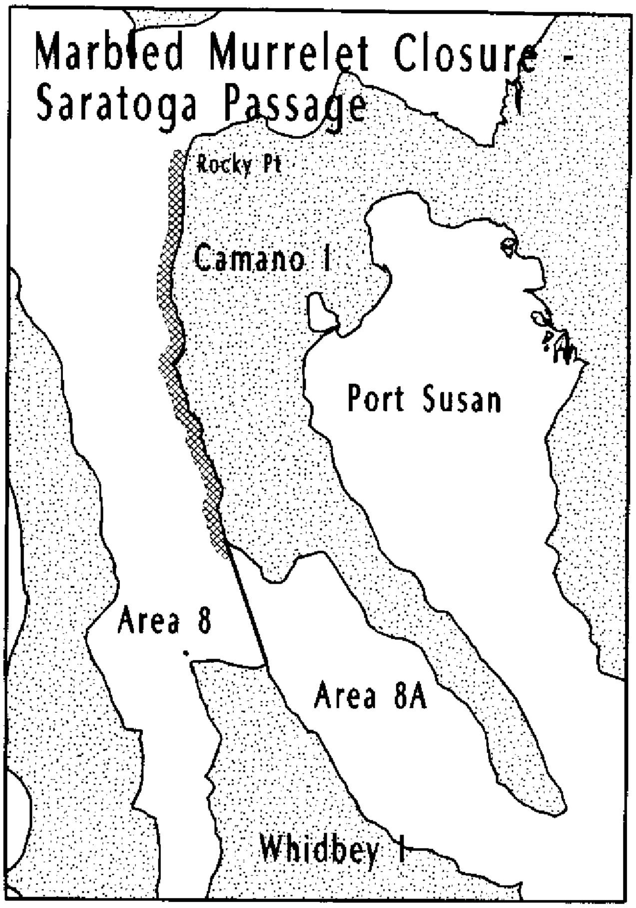

Figure 2b. Saratoga Passage.

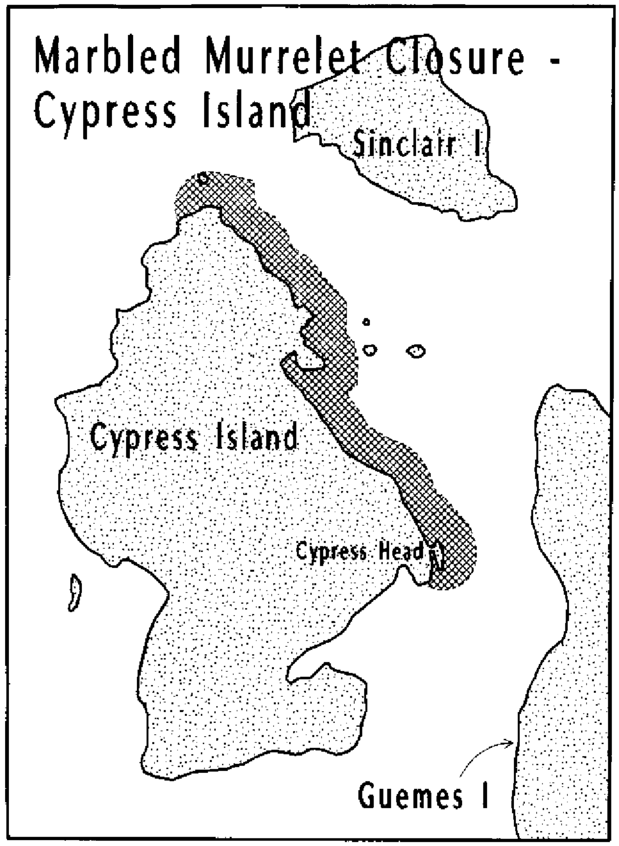

Figure 2d. Cypress Island.

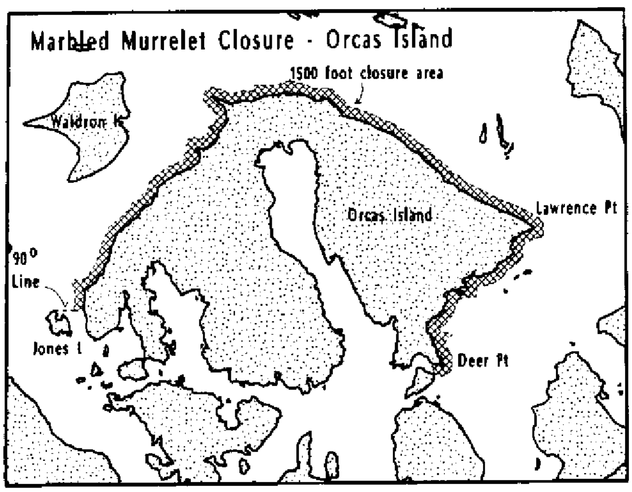

Figure 2c. Orcas Island.

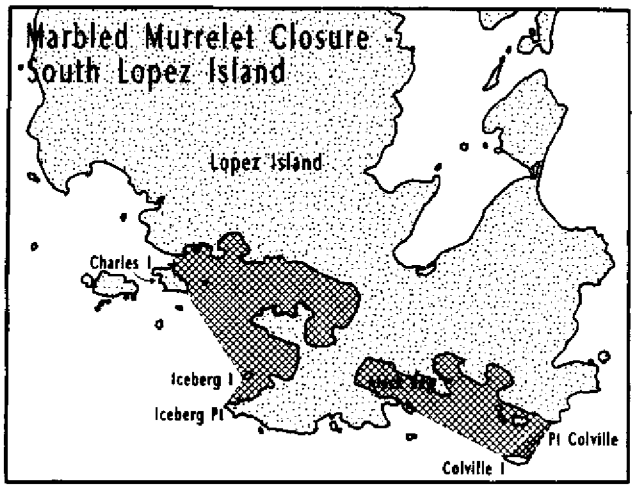

Figure 2e. South Lopez Island.

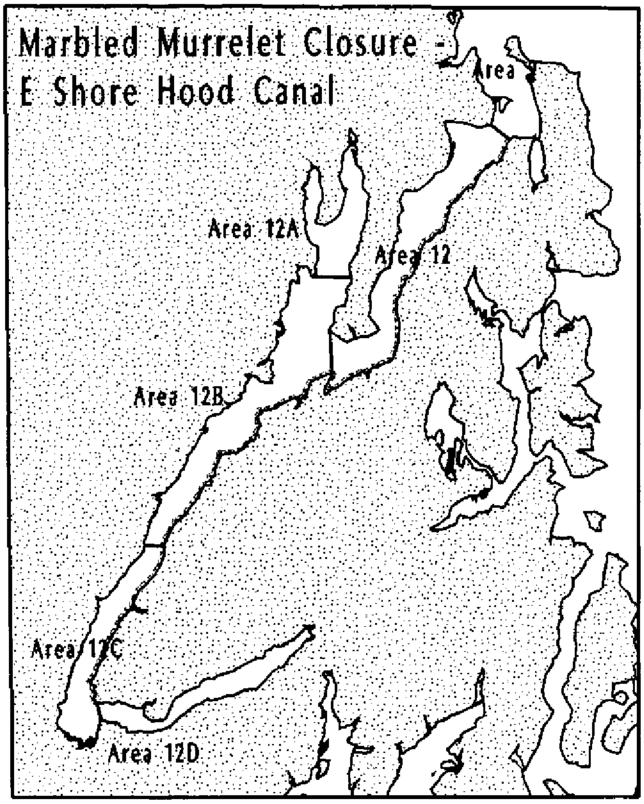

Figure 2f. East Shore Hood Canal.

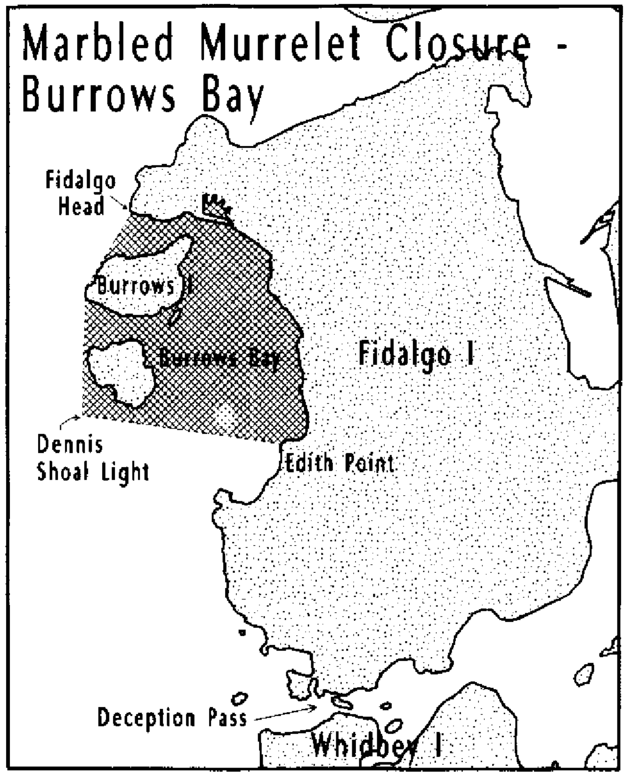

Figure 2g. Burrows Bay.

ment to USFWS, who in turn issued the biological opinion.

The USFWS has responsibilities for seabird resources as the manager of most of the major seabird colonies on the West Coast. It also has statutory responsibility because of its authorities under the MBTA and the ESA.

The Migratory Bird Treaty Act states, "... it is unlawful at any time, in any manner, to pursue, hunt, take, capture, kill (etc.) ... any migratory bird." Except for scientific purposes, the take of non-game migratory birds cannot be authorized.

The Endangered Species Act prohibits the take of any listed species (in this case the marbled murrelet). Take is defined broadly under ESA to include not only direct mortality but destruction of habitat and harassment. However, the take of a listed species can be authorized if it is occurring as a result of otherwise lawful activities and if it does not jeopardize the survival and recovery of the species. Through the Section 7 consultation process with the Bureau of Indian Affairs for the tribal fisheries and NMFS for the all-citizens fisheries, take has been authorized, but certain measures have been required that reduce the level of take.

The common murre is the seabird most commonly entangled in gillnets, with an estimate of 2,700 murres entangled in 1994 in the non-treaty sockeye fishery. Entanglement rates in the lower effort observer program in 1993 were higher than 1994, and were probably lower in 1995.

Murres are susceptible to gillnet entanglement because of the overlap of their distribution with the gillnet fishery, particularly south of the San Juan Islands (Figs. 1 and 2). Briefly, the concern for murres presently focuses on the population trends. The USFWS is presently conducting an evaluation of murre population trends on the west coast. The analysis has not been completed, but trends do not appear favorable. The Washington population crashed from around 30,000 in the early 1980s, and has never recovered. On the Oregon and California coast, populations are still in the hundreds of thousands, but numbers appear to have declined in the long term. While the El Niño conditions have undoubtedly contributed to these population trends and generally poor reproductive success in recent years, mortality from oil spills and net entanglement can significantly impair the ability of populations to rebound after these natural events.

The rhinoceros auklet is the other seabird that is frequently entangled in gillnets. Two of the three nesting colonies found in Washington are in Puget Sound at Protection and Smith islands, which are managed by the Fish and Wildlife Service.

An estimate of approximately 34,000 birds for these two colonies, or 60% of the Washington population was made in the mid-1970s, but burrow counts indicate that these numbers have declined 20-30%. The sockeye fishery is within the foraging area of these colonies, so the loss of birds that are entangled there directly affect these colonies. An estimated 787 auklets were killed by the non-treaty fleet in the 1994 sockeye fishery.

The marbled murrelet is federally listed as a threatened species. It was listed in 1992 as a result of a population that was low and declining, and the continued loss of its old growth nesting habitat. The loss of nesting habitat has not only directly reduced available habitat, but the murrelets nesting in remaining habitat fragments experience high predation rates and low juvenile survival.

Mortality from oil spills and gillnetting have been identified as secondary threats, particularly in Washington. The population in Washington has been estimated at 5,500, although there are no recent population estimates. Some of the most significant concentrations occur in the San Juan Islands and Hood Canal, which coincide with locations of major fisheries. A demographic model of the marbled murrelet population, based on juvenile:adult ratios, indicates that the population is declining at 4-7% annually, which is a cause for great concern.

The combined treaty and non-treaty observer programs in the 1994 sockeye season estimated, based on one observed murrelet entanglement, that 15 marbled murrelets were entangled in this fishery. However, because of the rarity of this type of event, the confidence interval was 2-59 murrelets. In applying these results, consideration was given to the possibility that mortality could be in the upper end of that range on some occasions, and that there was only one year's data. However, the implementation of the closed areas (Figs. 1 and 2) provides a basis that murrelet mortality is in the low end of the range.

Toward a National Bycatch Strategy: Working Group Report

Elizabeth A. Babcock
University of Washington, P.O. Box 357980, Seattle, WA 98195

There was general agreement that the national plan should not attempt to replace regional and local plans, but that there is a role for national government in ranking bycatch problems, promoting research, and other functions. The need for more work on the ecological effects of bycatch was acknowledged. There was strong support for individual vessel accountability, and solving the legal and logistical problems preventing vessel accountability programs.

Session moderator Brad Warren, of the National Fisheries Conservation Center and *National Fisherman*, opened the meeting. He said that the development of a national bycatch strategy had begun last year at the 1994 bycatch workshop at Fish Expo. At that meeting Rollie Schmitten of the National Marine Fisheries Service asked the participants to produce a document recommending a bycatch strategy to NMFS. In the past year meetings have been held throughout the country to develop the plan that is presented for comment here.

Chris Mitchell of the Alaska Fisheries Development Foundation reported that there have been two bycatch meetings in Alaska in the past month, one in Sitka and one in Kodiak. The meetings included all the participants in the Alaska fisheries, from "ocean to oven," including the environmental community, with the meetings run by a neutral facilitator. The panelists were skeptical at first, but in the end there was renewed enthusiasm. A methodology was developed for collaboration among the various stakeholders.

Krys Holmes, who was involved in the Alaska meetings, went on to discuss some of the results of the Sitka and Kodiak workshops. The meetings found 22 significant problems relating to bycatch in Alaska, determined what would constitute a solution to these problems, outlined possible steps to a solution, and listed some of the impediments to solutions. The bycatch problems in the North Pacific are not caused by high bycatch rates, but by the high volume of the fisheries. There are only a few biological problems with bycatch (king and Tanner crabs). For most bycatch species, the problems are economic and social. Concerns raised in the Alaska meetings included the need for individual vessel accountability for bycatch, lack of data on amounts of bycatch and the ecological effects of bycatch, and legal barriers to solutions. Some positive solutions were suggested, such as developing a mechanism for individual accountability with user fees, individual bycatch quotas, or posting lists of "clean" and "dirty" vessels. The NOAA General Council could help solve some of the legal problems with accountability.

Krys Holmes said that there was strong support at the Alaska meetings for industry-sponsored research on survival of released bycatch, and the ecological effect of bycatch. There is a need for better and more timely in-season data on bycatch rates. She concluded by saying that the Alaska meetings showed how much can be accomplished with an independent forum outside of the political process. There will be further meetings in western Alaska where the bycatch problems are mainly social and economic, and where reducing bycatch is a high priority. Community Development Quota (CDQ) vessels in western Alaska have had very low bycatch rates.

Steven Branstetter of the Gulf and South Atlantic Fisheries Development Foundation said that his organization has been involved in reducing bycatch in the shrimp fisheries since the late 1980s. Unlike Alaska, the Gulf and Atlantic states have strong pressure from recreational fishers as well as environmental concerns and allocation issues. The allocation issues include red snapper in the Gulf and weakfish in the Atlantic states. In 1990 a bycatch plan was adopted, with the priorities of documenting the fishery and finding gear and time/area closures that would reduce bycatch. The Foundation has been successful in gathering data on the fishery by working with fishing vessel associations. They have developed, tested, and used several bycatch reduction devices (BRDs). Finfish bycatch has been reduced by 30-40%, with a 50% reduction in the mortality of juvenile weakfish. There will be a workshop in Atlanta in October (1995) to discuss the bycatch problems in the region.

Lee Alverson, of Natural Resource Consultants, Seattle, said that the national bycatch plan should be designed to help the regions solve their own bycatch problems. He said that since the 1992 bycatch meeting in Newport there has been an increase in cooperation among fishers and other groups to reduce bycatch. Documenting bycatch, and acquiring data on bycatch in a timely manner are high priorities. The federal government could play a role in providing inseason bycatch data to the fleet. The national program should focus on fisheries that have a biological problem because of bycatch. Overfishing should be a higher priority than waste of fish that does not have an ecological impact. The federal program should rank bycatch problems.

Brad Warren distributed a preliminary version of the National Fisheries Conservation Center recommendations for a national bycatch plan. He went through the 10 main recommendations which were:

1. Scientific priority setting (bycatch problems should be ranked by biological urgency).
2. Management priority setting (instead of reacting to brushfires, management should have a planned response to bycatch problems).
3. Completing the knowledge base.
4. Placing responsibility on the individual vessel.
5. Cultivating home-grown solutions (involving stakeholders in the fishery in developing a bycatch solution).
6. Supporting long-term work.
7. Launching a global clearinghouse on bycatch reduction methods.
8. Continuing the focus on waste reduction—utilization may be a solution.
9. Reclaiming Saltonstall-Kennedy funds.
10. Scrutinizing regulatory roadblocks (regulations requiring discards should be reconsidered and a solution to the legal problems with vessel accountability should be found).

After Brad Warren read the list, the discussion became general. The audience was composed of fishermen from various regions, agency representatives, academic researchers, and environmentalists. One person asked the definition of bycatch, and Dr. Alverson answered that in this case bycatch was defined as discard, not secondary target species.

There was general agreement that all fisheries and regions have different problems and priorities, and that regional and local bycatch reduction programs would be the key to solving bycatch problems nationwide. No national entity can solve all bycatch problems in the same way, so the national plan should not dictate bycatch policies. It should help, and not hinder, the local and regional plans. Suggestions for the appropriate role of the federal government included setting performance measures or standards for the regional programs, promoting broadly applicable technical work, providing information and defusing misinformation in the bycatch debate, and ranking regional bycatch problems in terms of biological importance. Social and economic problems should be handled locally, while conservation problems are of national concern.

There was some discussion of the political roadblocks to bycatch reduction plans, and the need to get the management councils involved. The North Pacific Council has been involved in "penalty box" and other individual accountability programs. In Alaska the political problems are the greatest, and the bycatch problems cannot be solved until the allocation issues are resolved. Many speakers supported the idea of individual vessel accountability. Individual quotas on catch and bycatch were seen as a long-term solution to bycatch problems.

There was a range of opinions about the ecological effects of bycatch. In most fisheries the ecological effect of bycatch is not known. A bycatch species could be a predator or competitor that reduces the population of another commercially important species. Some said that this should be included in the determination of whether a bycatch situation is a problem. In the southeast, ecological models suggest that lowering finfish bycatch may reduce the shrimp populations. Increased utilization may be the answer, although there is opposition to utilization. However, the ecological effects of bycatch are poorly understood, and more research is necessary. There is no evidence that a very selective fishery is ecologically better than a "dirty" fishery.

The need for stable long-term funding for bycatch research was mentioned. There is also a need for cooperative research among academics, industry, and government. The following general points were also made. Regulatory discards are not inevitable, and should be reduced by the national plan. The national bycatch plan should acknowledge that all fisheries have bycatch. The consumer should be kept in mind. The social and economic effects of bycatch should also be studied, although biological problems have the highest priority.

Environmental Impacts of Fishing on Marine Communities: Working Group Report

Paul K. Dayton
Scripps Instituion of Oceanography, Mail Code 0201, La Jolla, CA 92093-0201

Good management of coastal resources and habitats involves maintaining viable populations. This involves protecting both the sources of larvae and the recruitment habitats (sinks or nurseries). It also involves protecting species made particularly vulnerable because of sensitive life history tactics.

Larval sources involve standing stocks of reproductive animals. Mammals, birds, reptiles, elasmobranchs, and others have very low reproductive rates and adult survivorship is critical to maintain healthy populations. These are the very species that are most seriously affected by bycatch, and it is critically important that adequate "brood stocks" be maintained in natural conditions. Another type of important limitation for many invertebrates is that they are broadcast spawners and to insure fertilization males and females must be surprisingly close together when they spawn (the distances are often in the order of 1-3 m) which implies a need for a high density of breeding animals; this is especially critical for sessile animals such as sponges, hydroids, bryozoa, tunicates, etc. Other invertebrates such as crabs and lobsters often undergo long migrations at which time they are particularly vulnerable to trawling disturbances.

Larval sinks are often thought of as larval nurseries which result from environmental heterogeneity that interrupts the boundary currents and allows larvae to settle and, most important, habitats that provide protection from predation for the small vulnerable larvae and juveniles. In most cases these nursery habitats are biotic; that is, they are composed of organisms such as seagrasses, algal turfs, and especially encrusting habitats of bryozoa, sponges, and tunicates. It is extremely important to protect these animals because most of them are very vulnerable to physical disturbances from trawling and dredging.

Another conservation problem is that the motile benthic animals such as crabs and bottom fishes are little studied from an ecological perspective as they are too deep for diving. Thus their study tends to depend upon fisheries that might in the process of collecting the animals be seriously altering the habitat. Such "Catch 22s" are common in fishery conservation.

Marine communities differ in their sensitivity to anthropogenic impacts. Some are much more vulnerable than others, and it is important to understand the more sensitive and important components of each community. It is important to understand that certain processes are vulnerable and from a management point of view it is important to maintain both larval sources and sinks.

1. Rocky intertidal communities are well known and well studied. The are naturally exposed to many types of disturbance, but the natural disturbances are patchy at small scales such that there is ample opportunity to recolonize and recover from the disturbances. Unfortunately they are vulnerable because they represent a thin, often broadly discontinuous band along some shores. Thus they are very rare and vulnerable to broad scale disturbances such as oil or human collecting. In some areas such as southern California, the anthropogenic disturbances are massive and continuous from fishing, poaching, and simply rolling the rocks to admire the biota. The effect is that in many areas there are practical-

ly no rocks unturned and previously common animals are becoming rare.

2. Rocky subtidal communities tend to be dominated by kelps or encrusting animals. Kelp communities are important habitats and nurseries for many types of animals; they are usually patchy and occupy rather limited areas. They too are naturally subject to many types of disturbances such as storms, nutrient stress, and sea urchin grazing. The kelp communities tend to be simple enough that many relationships are known. There are several types of nursery habitats ranging from algal turf to sea urchin spines. Under natural conditions dispersal is usually adequate and patches persist for years to decades. Because they occupy limited areas, many kelp habitats depend upon seeding from other habitats to maintain normal recruitment. Many kelp habitats have been grossly overfished and entire guilds of predators such as broomtail groupers, black and white sea bass, kelp and sand bass, sheepshead, lobsters, large crabs, etc., have largely disappeared, as have many types of invertebrates such as large urchins, most species of abalones, rock scallops, several species of whelks, sea cucumbers, etc. It often appears that just about anything that is alive has an Asian market and is being overexploited.

3. Rocky subtidal encrusting communities are different from many other marine communities in that they have very low rates of natural disturbances. These species include sponges, tunicates, bryozoa, and many types of cnidaria. They are often well protected by chemical defenses, but concurrent with their low rate of natural disturbance, they almost always have very poor dispersal and are extremely vulnerable to anthropogenic disturbances. These habitats are often considered to represent very important nurseries for many commercial fisheries, and they are being destroyed by trawling and dredging to even very deep depths.

4. Soft bottom subtidal habitats tend to be dominated by either filter feeders such as clams or by deposit feeders such as polychaete worms. Small scale usually predator related disturbances are common and some such as ray pits can be very important to the community. Small scale disturbances are recolonized very quickly. Natural large scale disturbances include river floods and slumping into canyons; recovery from large scale disturbances are slow. Longevity and resilience of the populations is variable; suspension feeders tend to be long lived and their recruitment tends to be unpredictable and episodic, but deposit feeders tend to be more ephemeral species with good dispersal and recruitment. Fishing effects tend to be large scale and for suspension feeding communities, recovery may be extremely slow.

5. Salt marshes and estuarine habitats are likewise considered critical nursery grounds for many species. Most of the salt marsh habitats in southern California have been destroyed by development while the intertidal components of the remaining habitats are exposed to heavy bait and sport fishing. An additional but little understood crisis is that of many exotic species introduced by ballast water and live fisheries such as oyster, mussel, salmon cultures. In the West Coast of the United States these are some of the most endangered habitats.

Another conservation issue that needs to be explicitly considered is that of having meaningful baseline or benchmark situations to enable us to evaluate cumulative impacts, long-term climate changes, and many other anthropogenic disturbances. Without representative natural habitats we have no yardstick to evaluate anthropogenic or natural change including fishing, oil impacts, sedimentation, pollution, habitat loss, as well as natural or man induced climate changes.

I propose that the most immediate steps that can be taken to offer general solutions to these many environmental crises are to establish meaningful marine sanctuaries or reserves. If such sanctuaries or reserves are properly designed and large enough, they can offer meaningful baselines as well as "seed stocks" for heavily exploited populations. They can help mitigate growth and recruitment overfishing, bycatch mortality, genetic overfishing, etc. In addition, they can furnish natural research areas for ecologists striving to understand how nature should work in the absence of human development.