FINAL REPORT

Market-Based Incentives to Reduce Fisheries Bycatch

Submitted to

NATIONAL MARINE FISHERIES SERVICE

NOAA Contract No. 50-DGNF-5-00172

29 February 1996

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Executive Summary

This report represents a first step at considering the potential for the use of market-based incentives to aid in the resolution of fishery bycatch problems. Market-based incentives have several advantages over more traditional command-and-control approaches, including cost-effective allocations of environmental controls; incentives for firms to seek technological solutions; flexibility; returns to the public for the use of its resources; and lower administrative costs in some cases.

Notwithstanding these advantages and with several notable exceptions, market-based incentives are almost never employed in the management of fishery bycatch problems. There may be several reasons why this is the case, including significant distributional effects, high costs of monitoring and enforcement, difficulties in educating consumers about product attributes, administrative and transactions costs, or merely oversight.

We consider this report to be an "advanced outline" of the issues surrounding the consideration of market-based incentives. We begin first by developing in Section 2 a definition of bycatch, including a "typology" of bycatch types. Next, we compile available public information on bycatch in U.S. fisheries, as defined by target species, location, and gear type (Section 3 and Appendix 1). We then review, in Section 4, two potentially relevant strands of literature, the economic theory of multispecies fisheries and studies from other social sciences of how small-scale fisheries deal with problems of bycatch.

In Section 5, we describe, in general, the kinds of market-based policy instruments that may be of use in managing bycatch problems. Following this evaluation, we identify and discuss, as case studies, three priority fisheries: the northeastern groundfish fishery; the Gulf of Mexico shrimp fishery; and the eastern tropical Pacific yellowfin tuna fishery (Section 6).

Finally, in Section 7, we outline approaches to identifying appropriate policy instruments, including a qualitative comparison of market-based approaches, an examination of the effect of specific types of uncertainty on the choice between taxes and ITQs, and the development of a "proposal" for a bycatch management "policy package." This section concludes with a proposal for a set of priority market-based approaches to bycatch management in the three cases discussed in Section 6.

U.S. fisheries are quite diverse, and there are no panacea-type solutions to the multifarious bycatch problems that exist in almost every fishery. In general, each fishery and its biological, technological, economic, institutional, and distributional characteristics will need to be examined closely to evaluate the potential for the application of market-based approaches.

In light of the current state of many U.S. commercial fisheries, and in view of the rising significance of bycatch problems in the U.S. and worldwide, we believe that it is sensible to consider the full array of management options, including those, such as many of the market-based approaches, that have not been given full consideration to date.

Our most important conclusion is the need to define carefully, in the case of each specific fishery, the relevant bycatch problem, including the construction and parameterization of combined biological and economic multispecies models. The selective removal of fish or animals from one species in an ecosystem is not necessarily an optimal policy. Without such a definition, it is not possible to say with any degree of certainty whether or not the reduction of bycatch is either an economically or an environmentally sound objective of fisheries management.

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1. Introduction

This report represents a first step at considering the potential for the use of market-based incentives to aid in the resolution of fishery bycatch problems.

Figure 1 depicts the increasing scientific and policy interest in bycatch as a fisheries management problem during the last decade by showing, in the period since 1955, the time distribution of published studies on bycatch problems in U.S. fisheries, as reported in a recent worldwide study commissioned by the U.N. Food and Agriculture Organization (FAO) (Alverson et al. 1994). It is notable that, since 1990, none of the U.S. studies in the FAO database contain any specific data on either numbers or pounds of bycatch. Data of this type are only beginning to emerge for U.S. fisheries, and in this report we have initiated an effort to compile the most recent data from various sources (explained in more detail in Section 3 and displayed in Appendix 1).

While fisheries economists have always identified market-based incentives as potentially useful policy instruments (Copes 1986; Anderson 1986; Clark 1980), it is not until recently that fisheries scientists have begun to believe that incentive programs might be designed to "reward rather than penalize innovation and accountability of individuals" (Murawski 1994). Moreover, some portions of the fishing community have begun to call for the increased use of incentives, as opposed to "command-and control" regulation, to help mitigate some of the problems of fisheries bycatch (Hughes 1995). And legislative proposals have begun to emerge in the U.S. Congress to authorize regional fishing councils to impose "fees or other incentives to reduce bycatch" (Warren 1995).

Market-based incentives[1] are believed to have the following advantages in the management of environmental and natural resource problems generally (CRS 1994; OECD 1994a, 1994b, 1991; Hahn and Stavins 1991; Baumol and Oates 1988; Bohm and Russell 1985):

- they encourage the movement toward a cost-effective allocation of control of environmental damages;
- firms face incentives to seek innovative technological solutions to the environmental problem;

[1] We discuss the specific types of market-based incentives in greater depth in Section 4 below.

bycatches, is a real concern; and the costs of monitoring and enforcement can be steep. We examine other advantages and disadvantages in this report in order to gain a clearer understanding of the potential usefulness of market-based incentive approaches.

This report should be considered an "advanced outline" of the issues surrounding the consideration of market-based incentives. One of our most important tasks has been to identify the range of market-based approaches that might be utilized in managing bycatch and to begin to think carefully about the most appropriate applications of these approaches. Our analysis has led to a set of general recommendations for policy and the identification of areas for future research. The report is organized as follows.

In Section 2 we begin to develop a definition of bycatch, including a "typology" of bycatch types. This is followed in Section 3 with the results of an effort to organize the most recent data on bycatch in U.S. fisheries.

We review in Section 4 two potentially relevant strands of literature, the economic theory of multispecies fisheries and studies from other social sciences of how small-scale fisheries deal with problems of bycatch.

In Section 5, we describe, in general, the kinds of market-based policy instruments that may be of use in managing bycatch problems.

In Section 6, we identify and discuss three priority fisheries as case studies. These fisheries are (1) the New England and Mid-Atlantic groundfish fisheries; (2) the Gulf of Mexico shrimp fishery; and (3) the eastern tropical Pacific Ocean yellowfin tuna fishery. The case studies are organized as follows: we define the relevant fishery, including a description of the important bycatch problems; we provide a brief historical background, including a history of bycatch; we describe the current management regime, including a description of the current state of biological understanding; we review the published literature of solutions to bycatch in the fishery; and we suggest appropriate instruments for managing bycatch problems.

The management of all three of these fisheries has involved the application of at least one market-based incentive. These incentives may have had some influence on the level of nontarget stocks harvest or discard ("bycatch"). However, we did not identify these cases on the basis of the application of market-based incentives but rather on the basis of (1) the presumed importance

of bycatch problems (based upon attention in the academic literature and by the media) and (2) the potential in each case for the application of market-based incentives to help resolve bycatch problems.

We began this research with an hypothesis that the most appropriate policy instrument for bycatch management may be a function of the "type" of bycatch situation, as explored in Section 2, as well as other idiosyncratic factors. In Section 7, we outline some approaches to identifying appropriate policy instruments, and we summarize the results of the study and suggest some areas for future research in Section 8.

One final note about our approach to this study. We received several invaluable comments and suggestions from four reviewers of an early draft of this study. We have taken many of these comments into account in preparing this final report. Two of the reviewers felt that a study such as this would be improved through the development of bioeconomic models and simulation or empirical estimation of the models. Although this kind of analysis is beyond the scope of this study, we agree that it is an important next step. Moreover, we believe that such a step is made easier by the kind of analysis that we present in this report. Thus, we are hopeful that the report will be found useful by members of two broad groups: (1) policymakers, industry officials, interest groups, and the public, who must engage in the political process of choosing an appropriate set of policy instruments in any specific case, and (2) economic policy analysts, other social scientists, and fisheries scientists, who must continue to clarify our understanding of the problems of bycatch.

We welcome from the reader comments, criticisms, and suggestions for improving the usefulness of this report.

2. Defining Bycatch

Figure 2 describes the potential fate of fish from the moment they encounter fishing gear until they are landed. This figure gives an impression of what happens to fish that are captured, but it does not address an important distinction between target and nontarget stocks (or cohorts).[2] As explained in the next section, a fishery is defined, in part, by its target stocks. These target stocks are "catch"; they cannot, by definition, be "bycatch." For clarity, we refer only to "stocks," taking the term to include "cohorts" where relevant in any specific case.[3]

In published media accounts and in some of the academic literature, there appears to be some confusion about the precise definition of bycatch (Corey and Williams 1995). We define "bycatch" in a commercial or recreational marine fishery to be the capture of fish or animals from nontargeted stocks (cf. Lind and Terry 1995).[4] Bycatch may be kept as a byproduct, for sale or personal consumption, released alive, or discarded dead, but bycatch stocks are never targeted explicitly.[5] Bycatch problems are important in fishery resource management because of direct economic effects, direct biological effects resulting in indirect economic effects, or because of pre-existing legal requirements (Clark 1985).[6]

A more rigorous definition can be developed as follows. Ultimately, in a policy-relevant sense, we are concerned about bycatch because of its economic impact, irregardless of whether it can be expressed as losses in actual markets (foregone commercial sales) or because of "passive use" damages, such as the incidental "take" of marine mammals and endangered or

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[2] This definition applies as well to nontarget cohorts of one species or to combinations of nontarget cohorts of one stock and individuals from other stocks. For clarity, we will refer primarily to "stocks." In principle, bycatch can be defined to be any biological effect on a marine stock or set of stocks arising from the commercial or recreational harvest of another target stock or set of stocks. This definition is broad enough to encompass biological effects on stocks that are not even captured, such as the effect on a predator stock of the selective harvest of a prey stock. In this report, however, we will focus on stocks that are actually captured.

[3] "Highgrading" of smaller cohorts of a single species are by this definition a type of bycatch because the highgraded fish are nontarget cohorts.

[4] Lind and Terry (1995) present a very clear economic definition of the bycatch problem. We borrow some of their terminology and concepts here.

[5] We take the perspective of individual fishers in determining what is or is not bycatch. We assume that these fishers are aware of the relevant legal rules defining the set of potential target species. We argue below that, from a social perspective, the definition of target and nontarget stocks might differ. See the discussion below.

[6] Legal requirements may or may not be based upon economic or biological effects.

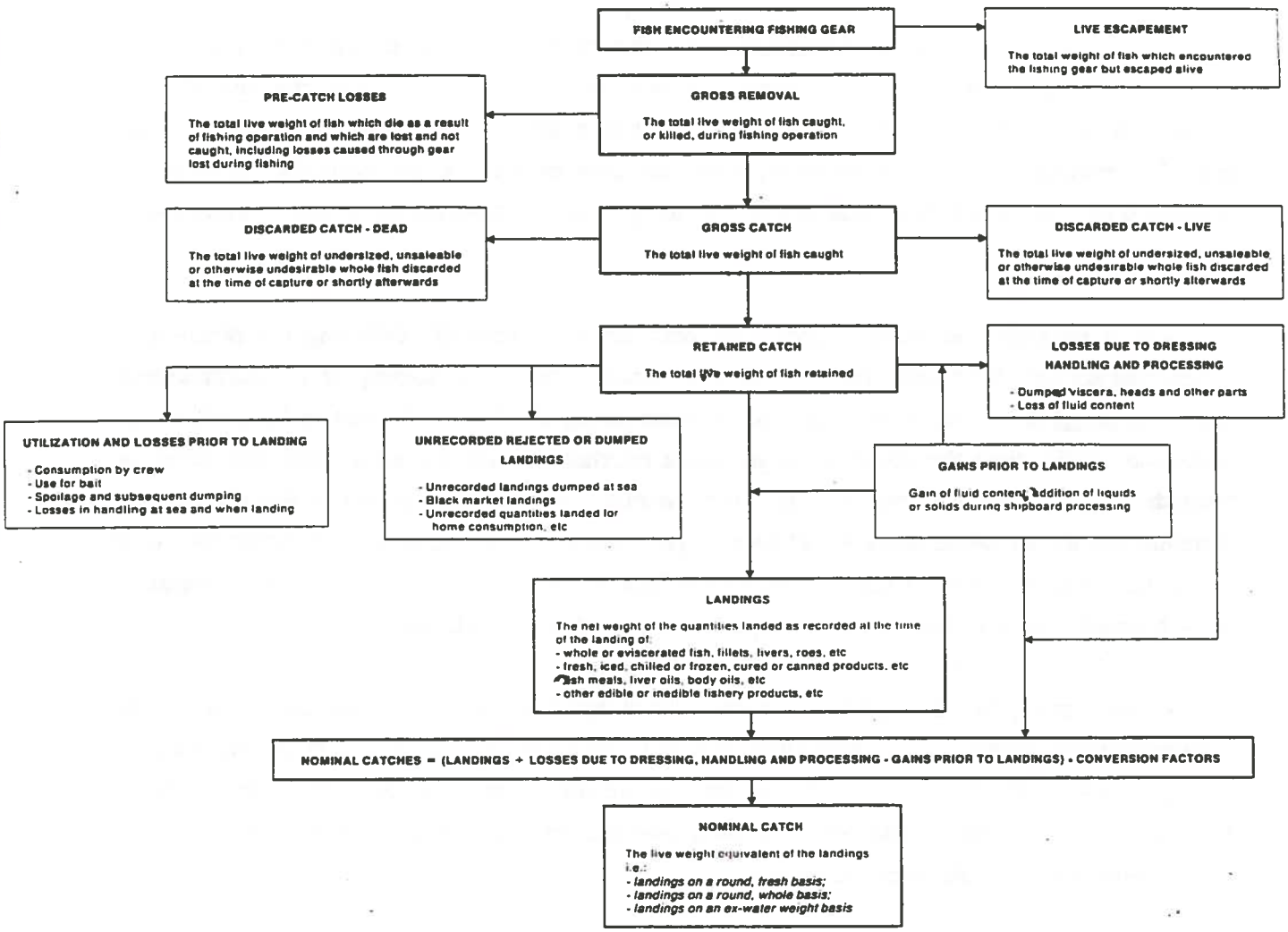

Figure 2: Diagrammatic representation of "catch concepts." Source: U.N. Food and Agriculture Organization.

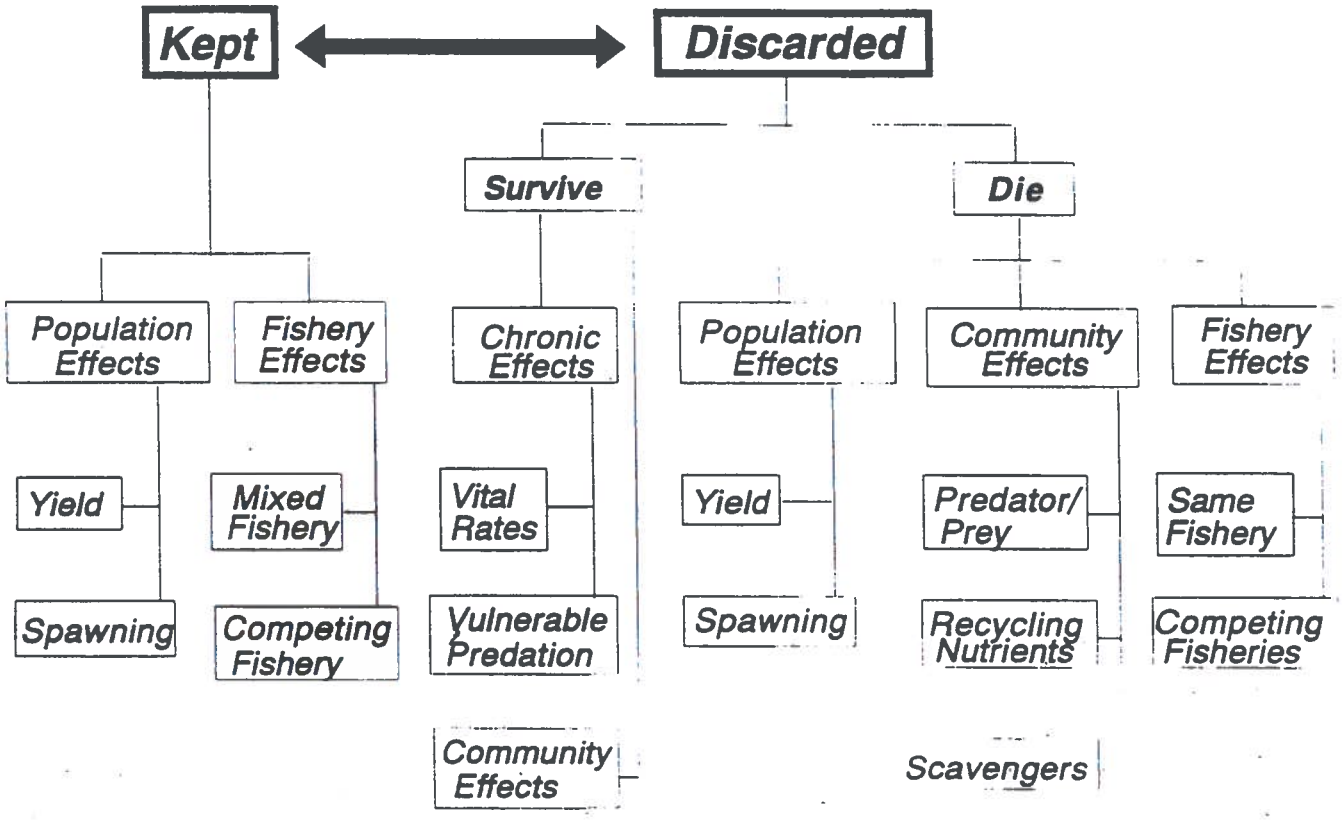

Figure 3: Biological implications of bycatch. Source: Murawski (1995b).

of these biological effects.

Depending upon the ecological relationships among stocks, biological effects can result in economic effects that can be either costly, beneficial, or insignificant, implying that bycatch can be bad, good, or inconsequential. The determination of the sign and size of the economic effects of bycatch requires the specification and estimation of a dynamic economic model *coupled to* the biological models mentioned above.[13]

Table 1 may help to clarify the definition of bycatch. Although we refer here to "stocks," the reader should keep in mind that the discussion could focus equally well on cohorts. The simplest possible theoretical example involves one stock, one owner, and one period. Even if this fishery is operated at the open access equilibrium yield (OA_1), instead of the economically efficient static yield (ST_1), no "own-bycatch" can occur, because there are no future periods. If we extend this case to two periods, then "own-bycatch" occurs if the fishery is not operated at the optimal sustainable yield (OSY_1), which accounts for the value of fish left in the sea that may grow and reproduce for harvest in the second period. In this situation, a "rational" owner would not operate the fishery at a level that incurs own-bycatch. As explained above, the latter example is the classic market failure in fisheries, and, for the remainder of this report, we do not consider it to be a type of bycatch.

In the case of two stocks with nonselective gear, the static case with one owner involves no economically relevant bycatch because the owner chooses to harvest that stock or combination of stocks to maximize the one-period economic value. The dynamic version of this case can involve own-bycatch in either or both stocks if fishing effort is applied at a level other than that required to achieve the multispecies optimal sustainable yield ($MOSY_{12}$), which we assume a rational single owner would not choose. An important lesson to be learned from this comparison is that one solution to bycatch as an externality may be to internalize the externality.

When we introduce another owner so that each stock [1,2] is owned by one of the two owners [1,2], then bycatch of stock 2 can occur, even if the owner of stock 1 maximizes his yield, in either the static or dynamic case.

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[13] The simple examples described in this section can easily become more complex and uncertain in the real world. For example, Berghahn and Rosner (1992) have studied the predation of discarded roundfish in the North Sea shrimp fishery and have found that between 68-90 percent of the discards are consumed by seabirds. Thus the effect of discarding may depend upon the value of the seabird population as well as ecologically related fish species.

Table 1: Bycatch Definition: Conceptual Matrix

BYCATCH DEFINITION	One Stock [1]	Two Stocks [1,2]; Nonselective Gear in 1	
	One Owner	One Owner	Two Owners
Static (One Period)	No bycatch	No bycatch	Bycatch at ST_1 or OA_1
Dynamic (Two Periods)	Bycatch at OA_1 or ST_1	Bycatch at MST_1 or MOA_1	Bycatch at OSY_1, ST_1, or OA_1

Key: OA = open access yield; ST = optimal static yield; OSY = optimal sustainable yield

A stylized economic model can be used to demonstrate the optimal level of bycatch reduction. In Figure 4, the top panel depicts hypothetical total benefits and total costs associated with a reduction in the level of bycatch. Total benefits include reductions in damages faced by other users of bycaught fish or animals and reductions in each fisher's costs of sorting and discarding. Total costs of bycatch reduction include each fisher's reduction of target catch, if any, lost revenues from bycatch that would have been landed, and increases in costs, if any, associated with the adoption of less efficient fishing technologies, such as the addition of "bycatch reduction devices." From an economic standpoint, the optimal level of bycatch is determined at the point where marginal benefits of bycatch reduction equate with marginal costs (Figure 4, panel b).[14]

Lind and Terry (1995) employ a variation of this model to demonstrate the divergence between the benefits and costs faced by individual fishers and those faced by society. These costs are indicated by dotted lines in Figure 4, panel b. These authors hypothesize that an individual fisher's marginal benefits of bycatch reduction are primarily those associated with lower sorting costs. As a result, the marginal benefits to society of bycatch reduction, which include the benefits to the fishers as well as reductions in damages to other users, exceed the marginal benefits of bycatch reduction to fishers.

Lind and Terry (1995) also hypothesize that, in an open access fishery, the marginal costs of bycatch reduction to fishers exceed those faced by society. The reason is that if bycatch reduction requires a reduction in a fisher's catch of the target species, then the resulting lost revenues are lost to the fisher, but not to society because, under open access, other fishers capture any fish not landed by others. These authors also suggest that the potential exists for fishers to adopt methods that are not cost-effective in reducing bycatch because of the open access market failure in the target fishery.

As we develop an understanding of bycatch in fisheries, it may be helpful to consider some specific examples:

- Adrokovitch and Stollery (1994) analyze the case of two distinct commercial fisheries concentrating on two distinct stocks (cod and haddock) and one fishery intercepts (bycatches) the other fishery's stock. This case is also analyzed by Ward (1994) in the

[14] In Section 7, below, we use this stylized model as an example to show how choices might be made between types of market-based incentives in the presence of uncertainty.

(a)

(b)

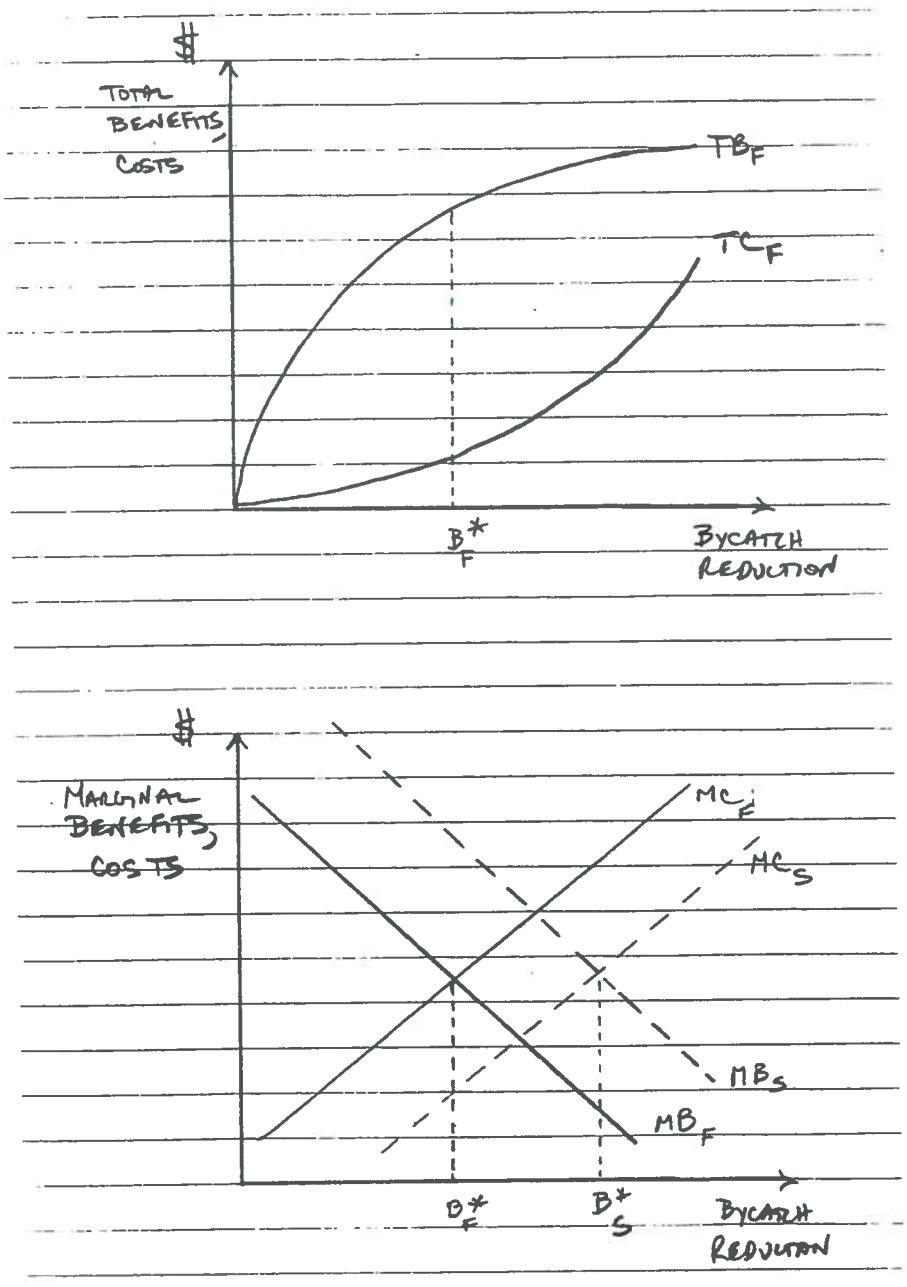

Figure 4: A stylized model of benefits and costs of bycatch reduction. Source: After Lind and Terry (1995).

specific context of bycatch in the Gulf of Mexico and South Atlantic shrimp fisheries. See also the case study in Section 6 below.

- Anderson (1994) examines the case of "highgrading" or the discarding of low valued cohorts due to constraints on hold capacity or due to individually tradeable quotas (ITQs). The act of discarding is costly.

- Arnason (1994) analyzes the case of a differentiated fishery with multiple grades of fish from a target stock. Each grade has a separate market, and the act of discarding is costly. All discards are removed from the biomass.

- Gordon (1992) and Clark, Major, and Mollett (1989) consider the case of New Zealand multispecies fisheries in which fish captured outside quota are considered bycatch. A "surrender" system has been established to utilize bycatch without encouraging fishers to target extra-quota fish. This system is described in greater detail below in Section 4D.

An understanding of the bioeconomic system is important to fisheries managers in determining management goals in the context of bycatch and in evaluating policy instruments that might be employed to achieve such goals. In an ideal world, we expect that the implementation of management goals, through laws or regulations, will be based upon a sound understanding of the bioeconomic system.[15]

In reality, however, legal requirements to reduce bycatch have been promulgated in many cases prior to the development of a complete understanding. A good example is the goal of 50 percent reduction of finfish bycatch in the Gulf of Mexico shrimp fishery. Thus bycatch may have a legal definition quite apart from notions of economic or biological effects. Indeed, because of the costs of developing bioeconomic models with good predictive power, "legally defined" bycatch may be the most common type of bycatch.

Alternatively, bycatch may result from the regulation of directed fisheries. A good example of this kind of legally defined bycatch arises through the implementation of an individual fishing quota (IFQ) system. When fishers reach their quota of the target species, they must discard any additional fish as bycatch. If more quota cannot be purchased on the market, for example through a tradeable quota system, then discards result. In addition, fishers may be

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[15] Clark (1985:204) is pessimistic about the possibility of such an ideal world, noting that "*operational* multispecies fishery models, capable of generating usable catch quotas derived from fishery or survey data, are not yet available. The quest to generate such models may well prove futile, owing to the irreducible complexity and uncertainty of marine systems. . . ."

likely to discard low valued fish (e.g., small sized fish) because of ITQ or hold capacity constraints (Anderson 1994).

In the presence of a legal definition of bycatch, managers may still be interested in cost-effective approaches to manage bycatch problems. We address specific issues surrounding legal definitions of bycatch in the case studies found in Section 6.

Finally, Figure 5 is a schematic diagram that combines all of the elements described above into a "typology" of bycatch. Assume, for clarity, that there is one target stock and one bycatch stock. Starting from the top of the diagram, there are three general types of biological or ecosystem effects of bycatch: competitive [-], independent [0], and mutualistic or commensalistic [+]. For each one of these branches, the bycatch stock can be valued (commercially, recreationally, or passively) or not valued at all.

Following a distinction higlighted by Bromley (1986), for those stocks that are valued, the nature of the use and the distribution of legal rights are such that there is either a producer-producer type of bycatch (target and bycatch are both distinct directed fisheries), a producer-consumer type of bycatch (the target is commercial and the bycatch is valued passively [e.g., an endangered species] or for recreational purposes), or a consumer-consumer type of bycatch (e.g., take of marine mammals in a recreational fishery). This distinction may be important because of the distributional effects associated with correcting any particular bycatch problem.

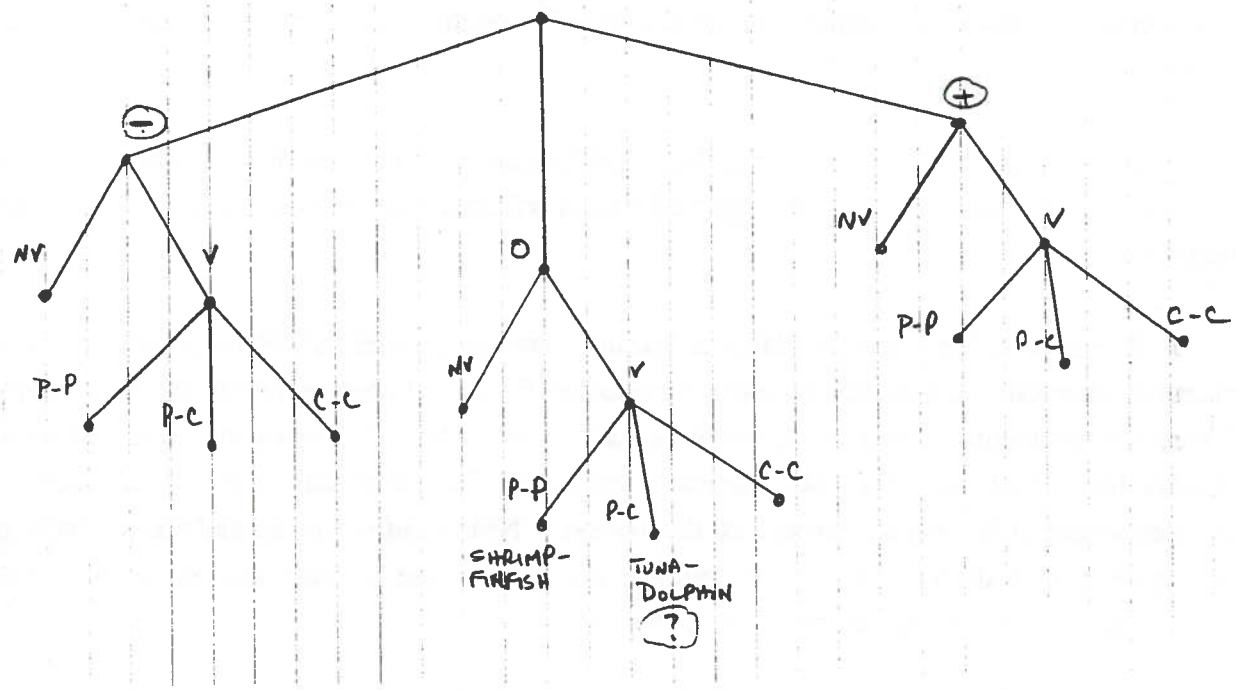

Figure 5: A possible bycatch "typology." Key: "+" represents a mutualistic or commensalistic biological relationship; "0" represents no biological relationship; "-" represents a competitive or predator-prey biological relationship; "NV" means no commercial, recreational, or passive use value for bycatch stock; "V" means commercial, recreational, or passive use value for bycatch stock; "P" represents a commercial fish producer; "C" means a consumer (recreational or passive use).

3. Bycatch in U.S. Fisheries

Our approach to the identification of the case studies involved the collection of data on bycatch in fisheries governed by federal fisheries management plans (FMPs). We have collected data on these fisheries and arranged the data into a table (Appendix 1). This table can be used to compare the levels of bycatch across federal fisheries.[16]

In Appendix 1, commercial fisheries are defined in the first three columns with the headings: Location, Target Species, and Gear Type. Target species are identified as "the catch of a species or species assemblage which is primarily sought in a fishery. . ." (Alverson et al. 1994).

In the fourth and fifth columns, the target species' Landings (in pounds) and Values (in U.S. dollars) are listed. In the Landings and Values columns, the most recent available data are presented.

The sixth column lists the National Marine Fisheries Service (NMFS) established marine mammal interaction categories for each commercial fishery. Category one is the documented "'frequent' incidental taking of marine mammals in the fishery." "Frequent" is described as "highly likely that more than one marine mammal will be incidentally taken by a randomly selected vessel in the fishery during a 20 day period." NMFS defines incidental take as "takings of marine mammals that result from, but are not the purpose of, carrying out an otherwise lawful commercial fishing operation" (NMFS 1995a).

Category two includes "documented information indicating an 'occasional' incidental taking of marine mammals in the fishery" and "in the absence of information indicating the frequency of incidental taking of marine mammals, other factors such as fishing techniques, gear used, methods used to deter marine mammals, target species, seasons and areas fished, and species and distribution of marine mammals in the area suggest there is a likelihood of at least an 'occasional' incidental taking in the fishery." NMFS specifies "occasional" to mean "that there is some likelihood that one marine mammal will be incidentally taken by a randomly

[16] Organization and compilation of the data in Appendix 1 was not an explicit task required of the investigators in this study. However, we feel that this kind of information is a necessary prerequisite to gaining a complete understanding of the scope of bycatch problems in the United States and of the potential for their resolution through market-based incentives.

selected vessel in the fishery during a 20 day period, but that there is little likelihood that more than one marine mammal will be incidentally taken" (NMFS 1995a).

Category three includes "information indicating no more than a 'remote likelihood' of an incidental taking of a marine mammal in the fishery" and "in the absence of information indicating the frequency of incidental taking of marine mammals, other factors such as fishing techniques, gear used, methods used to deter marine mammals, target species, seasons and areas fished, and species and distribution of marine mammals in the area suggest there is no more than a remote likelihood of an incidental take in the fishery." A "remote likelihood" is defined so that "it is highly unlikely that any marine mammal will be incidentally taken by a randomly selected vessel in the fishery during a 20-day period" (NMFS 1995a).

The seventh and eighth columns, on Incidental Catch, and the ninth column, Discard Catch, summarize the fish bycatch for each fishery. Fish bycatch is classified as "discarded catch plus incidental catch." Incidental catch is divided into the Landing Data (in pounds) and the Value (in U.S. dollars) for each incidentally caught species. In this commercial fisheries table, incidental catch is defined as the "retained catch of non-targeted species." Discarded catch is "that portion of the catch returned to the sea as a result of economic, legal, or personal considerations" (Alverson et al. 1995).

The tenth column, Marine Mammal Bycatch, lists the marine mammal incidental takes for each commercial fishery. The asterisks indicate that the marine mammal is a strategic stock. Strategic stocks are stocks that "have a level of human caused mortality likely to reduce or keep the stock below its optimum sustainable population" (NMFS 1995a). For certain marine mammals, several different stocks are listed (e.g., Steller's sea lion: Western U.S., Eastern U.S., etc.). The tenth column also includes, in parentheses, information on the biological significance of each marine mammal incidentally taken. Endangered, threatened and depleted species are listed. Also indicated is whether the Potential Biological Removal level has been exceeded for a species. Potential Biological Removal is "the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population." In order to determine the Potential Biological Removal level, several factors are considered: "(1) The minimum population estimate of the stock; (2) one-half the maximum theoretical or estimated net productivity rate of the stock at a small population size; and (3) a recovery factor of between 0.1 and 1.0."(NMFS 1995a). The Potential Biological Removal level is especially significant for those

species that are threatened or endangered.

The eleventh column, Sea Bird and Sea Turtle Bycatch, lists all the sea bird and sea turtle bycatch for U.S. commercial fisheries.

It is important to note that, because data on bycatch is not published widely and, in some cases, is not even collected, the table in Appendix 1 is incomplete. We believe that a coordinated effort to produce data of this kind at the national level will enable policymakers to gain a better understanding of the nature and extent of bycatch problems nationwide.

4. Literature Review

A. Economic Theory of Multispecies Fisheries

Fisheries bycatch involves complex problems. In developing market-based incentives to reduce bycatch in various fisheries, it is crucial to have a clear understanding of all major economic, biological, and technological factors associated with each specific case. Because of the many different types of bycatch and the many management instruments considered, a comprehensive review of fisheries economics literature is useful in three ways. First, as we will see below, existing literature includes many detailed studies of many different management instruments and their impacts on various aspects of different fisheries. These studies help us to realize important factors in different cases and the complexity of these cases. Second, some of the bioeconomic models reviewed below may be used by readers as bases for developing new quantitative models to examine specific bycatch problems. Finally, a up-to-date review of multispecies fisheries economic literature is of interest to researchers (e.g., economists and biologists) in both research and management communities. The review clearly indicates that further development of fisheries management requires close collaboration among industry experts, managers and social and natural scientists.

1. Basic Theory

A substantial literature on fisheries economics exists. A review of the principles of fisheries economics can be found in a number of texts (Anderson 1986; Clark 1980, 1976, and 1985; Wilen 1985; and Conrad and Clark 1987). The most important feature of fisheries economics is its emphasis on fish biology and marine ecology. While many general economic studies focus on market transactions and resource allocation, fisheries economics addresses the biological aspects as well. A typical fisheries economics model includes two major components capturing (i) market supply and demand and (ii) fish stock dynamics,[17] respectively. Plourde's (1970) paper is a classic example.

There are two primary reasons for modelling the dynamics of fish stocks. First, the fishery resource is renewable. In other words, the resource is subject to laws of natural growth

[17] There are a number of studies which employ only static analyses, focusing on steady-state equilibria in a dynamic system. For example, see Turvey (1964) and Anderson (1994).

that define a biological constraint on the activities of a fishing industry. Second, the resource and the activity of production from it form a stock-flow relationship. The new growth in the fish stock depends on the harvest rate relative to natural recruitment to the stock in each period. If, in any period, the harvest rate exceeds the recruitment rate, then the stock declines, and vice versa (Smith 1969).

One of the most important topics in bioeconomic studies is to examine the behavior of fishers under open access (Clark 1985, 1976; Gordon 1954) and to compare that with what is considered the socially optimal exploitation (Plourde 1970; Clark and Munro 1975). In these studies, individual fishers are modeled as profit maximizers, defined as revenue from fish sales minus cost associated with fishing operations. To explore the socially optimal solution, these studies view the fish stock as a type of capital asset that should be managed so as to maximize its value to society. In this case, the manager's objective is to maximize the net social benefit, defined as the social benefit (for example, in a simple case the benefit can be approximated as the area under the demand curve for fish) minus the total cost of the fishery. The total cost includes not only the fishing costs incurred by fishers but also the associated external costs, including, for example, the effects of fishing on the growth of the fish stock and on the ecosystem.

The most important conclusion of earlier studies is that open access resources will become overexploited, because the fishing effort under open access is greater than what is considered socially optimal (Gordon 1954). Another important conclusion is that MSY (maximum sustainable yield) may not be socially optimal. MSY is unstable and unsustainable in the long run. Further, specifying MSY for one species as a management objective does not make logical sense when two or more biologically or technologically interdependent species are being harvested. Finally, an MSY target ignores any nonmarket preservation values derived from nonconsumptive uses of the fish stock (Conrad and Clark 1987). A socially optimal harvest strategy should consider the long-run stock effect as well as other externalities.

2. Management and Regulation

Under open access, because fishers ignore the effect that their removals from a common stock have upon the future productivity of that stock, they always exert excessive levels of effort, relative to the social optimum. If, however, the cost of effort incurred by a fisher is

augmented by the amount of a "user cost," reflecting the stock externality, then the fisher will exert the optimal level of effort. In other words, a tax policy can, in theory, lead to social optimum. This is, in fact, a version of a theorem developed by the early welfare economist A.C. Pigou (Conrad and Clark 1987). Below, we refer to the optimal tax as a "pigovian tax."

Clark (1980) examines various methods of regulation: total catch quotas, vessel licenses, taxes on catch (or effort), and allocated catch (or effort) quotas. The results of his study indicate that (i) total catch quotas do not improve the economic performance of an open access fishery; (ii) limited entry results in a distortion of inputs unless every input is controlled; and (iii) taxes and allocated transferable catch quotas or individual transferable quotas (ITQs) are theoretically equivalent to one another in terms of economic efficiency, and both are, in principle, capable of optimizing exploitation of the common-property fishery.

Copes (1986) is cautious about the effectiveness of ITQs in some fisheries in spite of the favorable conclusions from theoretical studies of ITQs. He argues that the implementation of an ITQ system is not a new panacea because a nearly infinite variety of biological, economic, social, and political circumstances can plague fisheries and their management. Copes finds it difficult to be categorical about the merits of ITQs in relation to those of other fisheries management devices. For example, a discard problem may be so serious that an ITQ system must be ruled out as being too wasteful. We will have more to say about the potential for ITQs in dealing with bycatch below.

Many other studies have focused on different aspects of the management and regulation of fisheries. We summarize a few of the studies from this very rich literature here.

Karpoff (1987) addresses the discrepancy between theoretical advances in fisheries management and the persistence of suboptimal regulations. His study applies the "self-interest hypothesis" of regulation to a setting of heterogeneous fishers to explain why many traditional fishery regulatory techniques (e.g. season closures and capital constraints) have survived an onslaught of theory and data that demonstrate their suboptimality.

Turvey (1964) discusses the notions of optimization and suboptimization in fisheries management. The study shows that when externalities are involved both in the level of fishing effort and in the choice of mesh size, both of these variables need to be regulated in order to achieve the optimum. However, in practice, political and administrative considerations make

one or the other type of regulation impossible to introduce. Turvey argues that fishery regulation is one of those spheres of economic policy where what is the best thing to do depends on what can be done.

Several studies focus on fisheries enforcement. Anderson (1987) suggests that management agencies ought to consider a range of control variables rather than just one governing instrument (e.g., input controls, closed season, closed areas, or quotas). Specifically, he discusses the importance of two control variables: monitoring procedures and penalty structure. A fisheries management agency should select the optimal combination of these control variables. Sutinen and Andersen (1985) provide an economic analytical framework of fisheries law enforcement and compliance. These authors show that enforcement costs are a major determinant of regulatory policy for nonexclusive resources. Costly and imperfect enforcement of fisheries law significantly affects the behavior of fishers and optimal fisheries management policy. Crabbe and Long (1993) examine poaching fishery problems using game models. In their model, poachers make decisions in response to the home country's management strategy.

3. Uncertainty

As noted, fisheries economics has focused mainly on the optimal harvesting policy for a given deterministic function describing the dynamics of the natural growth of fish stocks. Specific issues include the existence and characteristics of steady-state equilibria for the optimally managed resources, the need for and design of regulations to prevent over-exploitation, and conditions under which the resource will be exploited to extinction.

However, the natural rate of growth of fish stock is in part stochastic. It is also very difficult to predict fluctuations in fish prices, factor prices, and actual harvests. Thus, it is necessary to develop analyses that capture these uncertainties. One of the objectives of developing stochastic bioeconomic models is to examine the impact of uncertainty of different types and sources on the results derived from corresponding deterministic bioeconomic models, and to develop relevant policy implications.

Generally, major sources of uncertainty include:

- Stock uncertainty: random variation in growth caused by changes in recruitment, growth and natural mortality.

- Harvest uncertainty: random variation in harvest caused by changes in environmental conditions, stock distribution, catchability.

- Price uncertainty: random variation in fish price and factor price caused by various stochastic market factors.

- Individual behavioral uncertainty: preference (utility) functions that vary randomly across a population.

Andersen and Sutinen (1984) provide a review of stochastic bioeconomic models. These authors conclude that, in some instances, the qualitative effects of incorporating uncertainty on the results of bioeconomic analysis differs little from the effects observed in deterministic models. However, they conclude also that the results of stochastic models are rarely unambiguous.

Pindyck (1984) examines the implications of uncertainty associated with the natural growth rate of a fish stock for the competitive equilibrium in a social planner's context. His study shows that stochastic fluctuations add a risk premium to the rate of return required to keep a unit of stock in situ. Also, harvest can increase, decrease or be left unchanged as the variance of the fluctuations increases, depending on the extent and speed of self-correction in the biological system and the characteristics of market demand.

Andersen (1982) extends deterministic bioeconomic models to include price uncertainty and risk aversion[18] among fishers. The study shows that in an open-access fishery, both the total fishing effort and the number of fishing vessels will decline as the variance of fish prices increase. The total fishing effort may be smaller in an open-access fishery than in an optimal fishery with either a high price variability or a high degree of risk aversion. Only a fixed producer price system can result in a true first-best optimum.[19] Andersen finds that a tax on revenue is more efficient than either a tax on catch or individual quotas--whether they are transferable or not.

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[18] In economic studies, attitudes toward uncertainty is categorized as risk neutrality, risk aversion and risk preference.

[19] If society is risk-neutral and has taken over all the risk.

Bockstael and Opaluch (1983) develop a discrete choice model of supply response under uncertainty and apply it to an analysis of New England fishing firms. Their study concludes that while fishers demonstrate a bias towards remaining within the same fishery, sufficient incentives, in terms of changes in expected returns and risk, are shown to elicit a response. Fishers exhibit a positive response to increases in expected returns and negative response to variability of returns, implying they are risk averse. The study argues that as long as behavior is not completely circumscribed by regulations, useful management models must take into account that manager's decisions are constrained by the responses of fishers.

Ward and Sutinen (1994) develop an entry-exit model of the Gulf of Mexico shrimp fishery. Their results support the findings in the Bockstael and Opaluch (1983) study. Ward and Sutinen also provide evidence of the existence of a stock externality that affects fishers' decisions to enter or exit a fishery. In addition, these authors find that a crowding externality exhibits a strong negative impact on the probability of entry.

Wilson et al. (1994) challenge the validity of the stock and recruitment relationships employed in bioeconomic models and their relevance to fisheries management. They argue that fisheries are complex and very likely to be chaotic.[20] These characteristics create a very difficult and costly information problem, which makes it virtually impossible to control the long term numerical abundance of individual species. Thus, feasible management must address the relatively stable parameters of fisheries systems, such as habitat and basic biological processes, and should rest on community based governance.

Duarte (1994) applies the basic principles of chaos theory to dynamic fisheries systems. Using simulation, the study shows that stationary steady-state is only one of many different possible outcomes of bioeconomic equilibrium. In unstable resource systems, the effects of some policy measures are very different from the ones from traditional analyses. Policies that induce a stabilizing effect on stock size generally provide greater welfare gains.

Ludwig and Walters (1982) examine optimal harvesting with imprecise parameter estimates for stock-recruitment relationships. Simple models for stock and recruitment ignore year-to-year fluctuations in recruitment. However, fisheries data suggest that such fluctuations may be quite large. In the Ludwig and Walters model, fluctuations in future spawners and

[20] Fogarty (1995) reports that there is currently little evidence to support the conclusion that fish populations are chaotic.

recruitment are explicitly addressed. Parameter estimates are updated over time. Spawner quotas are determined from year to year. The study shows that inclusion of uncertainty about recruitment model parameters can lead to striking changes in the estimated optimal escapement. When only a narrow range of spawning stocks has been observed, there is considerable uncertainty about how recruitment per spawner will decrease with increasing spawning stock. In this case, the optimal policy involves deliberate probing or experimentation with the spawning stock. The optimal number of spawners can be at least twice the number predicted by deterministic theory.

Generally, an optimal management strategy under uncertainty involves some kind of adaptive approach. The concept of adaptive management is illustrated nicely by Vukina and Anderson (1994) who develop an optimal marketing strategy for Alaskan salmon processors. A processor makes his decision in a year based on the most recent forecast of future prices and risk level. The price forecast is updated repeatedly over time with new market information. Opaluch (1984) discusses the optimal adjustment process for an effluent charge when the firm's response to the charge is uncertain. The optimal process exhibits the dual effects of caution and probing. Because of uncertainty, society should be cautious when setting the charge. However, because of the possibility of generating information for improving future control, this caution is balanced by the incentive to probe for additional information.

4. Age Structure and Multiple Species

For simplicity, most classical bioeconomic analyses consider one homogeneous species (e.g. Plourde 1970). Yet many fisheries involve several species, and for each species there are different cohorts. There have been a number of studies that extend basic bioeconomic analyses to consider the age structure of fish populations as well multiple species. Clark (1976) provides an introduction to studies on growth, aging, and multispecies problems.

The importance of considering the age structure is discussed in Turvey's (1964) study. The study assumes that both natural mortality and growth of the fish by weight and length are functions of age. The relationship between weight of catch and age of recruitment (mesh size) and fishing mortality rate (fishing effort) is examined in a simple model.

Conrad (1982) develops a reasonably general multiple cohort model (using a "Leslie

matrix") and derives conditions for optimal harvest and age structure based on a social planner's problem which maximizes the present value of net revenues subject to recruitment and spawning conditions. The model is applied to the hard clam resource in Great South Bay on Long Island, New York. The steady state optimum calls for exclusive harvesting of the younger and more valuable "littleneck" cohorts; leaving the older and less valuable "cherrystone" and "chowder" cohorts to specialize in the regeneration of littleneck stocks. If, however, the market price of littlenecks declines while cherrystones and chowders increase; positive harvest from all cohorts may be optimal. A system of landings taxes on equilibrium user cost or a system of transferable quotas may be used to guide the resource to the bioeconomic optimum and maintain it there.

Deacon (1989) presents another empirical study of a multiple-cohort fishery, the California abalone fishery. The study develops an econometric analysis of catch and effort data using an age-structured population model. The study concludes that it is unlikely that a single model of population dynamics will provide the best vehicle for analysis of catch and effort data in all cases. Because individual marine species differ in their biological attributes, variations in either the fishing technology or the regulations applied to their harvest can cause differences in the way fishing effort affects their populations.

A general multispecies model is described in Hannesson (1983). Hannesson models an "arbitrary number" of species, all of which have commercial value. The optimal condition requires that the rate of return on investing the rent of harvesting an additional fish equals the rate of return on leaving a unit of that fish in the sea for the purpose of reducing fishing costs and increasing steady-state catches. The rate of return on leaving a unit of a particular species in the sea is influenced by a sum of changes in the growth rate of all species resulting from augmenting the stock of that species.

The management of multispecies fisheries is discussed by May et al. (1979). The study focuses on the biological aspects of the problem and describes three models: a prey-predator model (krill and baleen whales), a model with one prey and two predators (krill, whales, and seals), and a model of three trophic levels (krill, cephalopods and sperm whales). The study concludes that for populations at the top of the trophic ladder, MSY will often be useful. For populations other than these, preservation of the ecosystem would require that stocks should not be significantly reduced. The slowest time scale, often set by the top predators, should be used in monitoring a harvesting regime. All estimates of population parameters are liable to fluctuate in response to environmental stochasticity, and harvest populations may be less able to recover

from external disturbances than are virgin stocks. If sustainable yields are the goal, harvesting levels should be set conservatively.

Most multiple-species bioeconomic models are in fact two-species model (see Mesterton-Gibbons 1987; Wilen and Brown 1986). Multispecies models are governed by systems of coupled and generally nonlinear differential population equations. Because of mathematical complexity, closed form solutions are often intractable and numerical experiments must be used, even with only two species. In some multispecies models, although optimal steady state values can be determined, exact solutions for the optimal path to the steady state are not known and may not exist for some problems (Clark 1976). Even in some two-species models, there are no strong, simple, qualitative results like those found in single-species models.

Wilen and Brown (1986) emphasize the importance of multispecies modeling. In reality, species are enmeshed biologically and many are connected economically as well. It is important to account for these interactions in developing management strategies. Also, multispecies models are the only conceptually defensible way to value prey which have no direct commercial or nonuse value. The value of these species is their marginal product in a predator-prey system.

Mesterton-Gibbons (1987) examines the optimal harvesting policy of two ecologically independent species. In this model, there is only one control variable, fishing effort. Fishing policy does not target any specific species. Both species have commercial value. The harvest of each species is determined by its catchability and its stock size. The study shows that there is a unique attainable equilibrium which yields positive revenue and to which the approach path satisfies conditions for maximizing the harvest present value. The survival of the less productive species depends on its initial stock level.

Gatto et al. (1982) also analyze a case with two biologically independent stocks, both having commercial value. In that model, there are two control variables, two separate fishing efforts for each species. However, the total fishing effort, sum of the two efforts, can not exceed a prespecified level. The study examines the optimal effort mix and the corresponding equilibrium population levels.

Hannesson (1983) considers the optimal exploitation of a two species predator-prey system. Both species have commercial value. The study shows that certain results from single-species fishery models are not applicable to multispecies models. Optimal regulation of a open

access fishery may call for subsidizing instead of taxing the harvest of predator species. Increasing the discount rate may lead to an increase in stock level, contrary to the result in the single-species case. A rising price may raise, not lower, the optimal stock level of the relevant species.

Beddington and Cooke (1982) examine the sustainability of yield from joint harvesting of predators and prey. Their study concludes that the position of system equilibrium in relation to the current situation is often not known with any precision, thus it is important to choose a yield for which the corresponding equilibrium is sufficiently globally stable to ensure that the system will reach the equilibrium from the suspected current state. It may be necessary to take a substantial fraction less than the MSY. Although harvesting of predators theoretically increases the MSY of prey, this MSY should not be increased greatly in practice due to ecosystem stability considerations.

Wilen and Brown (1986) study optimal recovery paths following perturbations (e.g. El Nino or an oil spill) in a predator-prey system. In this system, the harvested species also feeds upon a prey species. The prey has no commercial value. The study shows that in the event of a perturbation, it may be optimal to reduce a harvested population even further below its perturbed level, if, for example, an oil spill has also reduced the lower level population dramatically. This is to readjust the post-perturbation species levels in order to bring them into balance during the subsequent recovery phase.

McKelvey (1986) presents a model of heterogeneous multispecies and geographically dispersed fishery. In this framework, fishers are presumed to target on the most profitable pool. But this behavior may lead to the depletion of biologically valuable species, and consequent early closure of the entire fishery. Specifically, the study examines a case with two fish stock pools and within each pool there are two species with commercial values. The study considers a single fishing season. The results shows that those pools initially offering a larger return to fishing effort will be exploited more heavily at first. But, as the season proceeds, returns across the set of pools approach comparability and they come to be drawn down together.

In theory, the open-access fishery can be regulated to achieve a social optimum through temporally-and-spatially-varying landings taxes, or through establishing markets in temporally-and-spatially-allocated quotas. However, the optimal regulatory scheme may impose unrealistic information and enforcement requirements upon the management agency. Thus, it is appropriate

to examine operationally simpler, although suboptimal, regimes. If, however, fish prices are constant through the season, and in-season mortality is negligible, the fishery may be rationalized simply by limiting licenses (or seasonal quotas), to hold down effort, and by levying a constant landing tax on valuable species, to insure the proper effort distribution among pools (Mckelvey 1986).

Squires (1987) considers the management of a multispecies fishery as one of regulating the production of individual multiproduct firms. Using data from the New England otter trawl industry, he shows that public regulation of multispecies fishery may have been inappropriately designed. Traditional regulation involves the management of total industry catch and aggregate industry fishing effort. Multispecies fisheries management can be approached as a process of regulating the production of individual multiproduct firms. In New England, regulation consistent with this approach would directly regulate more than one input.

Finally, another important area of research is to examine multispecies fisheries within a game theoretic framework. Vincent and Gayek (1982) consider a two species fishery which is exploited by two different groups of fishers. Each group concentrates on a single species. The fishery is managed by an agency that sets the total quotas for the two species. The manager does not know how fishers will operate under these quotas. The manager's objective is to maximize the harvest for each species without having either of them become endangered by being driven to unacceptably low population levels. The study shows that, for constant harvests, there is a close connection between system stability and game theoretic optimization. Based on the premise that both harvesters would agree to a solution that would produce yields greater than or equal to their Nash yield, a compromise solution for maximizing harvesting limits can often be found which should satisfy both harvesters. However, the particular results are very model-dependent.

5. Bycatch

Copes (1986) discusses possible solutions for highgrading problems. For example, it may be feasible to reduce discarding to a tolerable level by fine-tuning regulations. Separate quotas might be given for different species or for different fish sizes that have different values per unit weight. If, at the same time, the trading of quotas among fishers are kept easy and are allowed to take place after the landing of surplus catches, much of the incentive to discard might be

removed. It might also be possible in some situations to devise value quotas, which could be filled by catches of any designated species or fish size according to landed value.

Squires and Kirkley (1991) present an empirical study of a Pacific coast trawl fishery. The study results indicate that firms' flexibility of product decision is tightly constrained by its technology and cost structure. Hence, as the stock of the regulated species, sablefish, declines and the trip quota tightens, firms cannot sufficiently reorganize their product mix to preclude increasingly large sablefish disposal, which defeats the purpose of the quota. The competitive multispecies firm's regulation-induced reorganizations of its optimum output bundle depend on the firm's technology and cost structure. Therefore, tailoring quota design to technology and costs anticipates many quota-induced economic responses and allows design of a more effective quota.

Anderson (1994) analyzes the economics of "highgrading" in terms of the operating decisions of individual vessels. The study compares the conditions under which highgrading will occur with ITQ and other harvest constraints (e.g., vessel hold capacity). The study shows that it can be socially optimal to highgrade with landing constraints that are costly to relax, however, ITQs can cause highgrading when it is not socially optimal. Highgrading occurs when the price differential between high and low valued fishes is greater then the cost of discarding and replacing the catch. The parameters which can lead to highgrading will likely differ for different vessels and for different types of trips and therefore policies must be developed which can cover as many conditions as possible.

Arnason (1994) develops a dynamic model that considers explicitly different grades of fishes to examine the catch discarding problem. The study shows that in a differentiated fishery discarding of catch may be socially optimal. Under certain conditions, individual firms in an open-access, competitive fishery employ the socially optimal discarding rule. By contrast, ITQs tend to generate an excessive incentive for discarding catch. If, however, ITQs are issued for each grade, the quota price for each grade will reflect the relevant economics of harvesting, processing, and marketing that grade. The quota prices will never induce excessive discarding of catch. The study concludes that given the intricacies of the discarding problem it appears unlikely that one general solution exists. In practice, it may be optimal to employ a mix of some or all of several management instruments (ITQs by grades, taxes and subsidies, and enforcement and sanctions).

Sampson (1994) develops a model for selection of fishing locations by a fisher faced with two species whose densities vary with distance from port. The model is used to determine the profit maximizing fishing strategy (locations and time spent at each location) and to explore the conditions that generate bycatch and discarding when one the species cannot be sold because it is unmarketable or because of trip quotas. The study shows that a fisherman will never fish at more than one location during a trip unless there are binding trip quotas or market limits. Trip quotas can be effective in protecting a species only when the two fish stocks are reasonably well separated. When the species regulated with trip quotas co-occur with unregulated species, bycatch and discard of the regulated species is unavoidable.

Androkovich and Stollery (1994) describe a stochastic dynamic programming model of fisheries bycatch control. Using the Nova Scotia cod and haddock fisheries as an example, the study compares the expected net economic benefits from optimal fishery regulation of both species with the regulation of each fishery separately, and with the open-access equilibrium. Their conclusions indicate that independent taxation requires significantly higher tax rates than the optimal coordinated taxation to control the stock externality associated with open access fisheries. Quotas are suboptimal relative to any taxation, because of their inflexibility in the presence of uncertainty, and because they can control bycatch only indirectly.

Boyce (1995) considers, within the context of a Clark single season model, two fisheries: one for a target species and one for a bycatch species. The bycatch rate is positively related to the harvest rate of the target species. The study shows that a competitive ITQ system is capable of maximizing social welfare, but there must exist quota markets for both target and bycatch species and if the bycatch species has no existence value. When both species have commercial value, a prohibition of fishers selling their bycatch reduces the bycatch, which benefits other fishers targeting the bycatch species. For the same reason, if the target fishery is allowed to sell the bycatch, the cost of bycatch declines, and fishers in the target fishery will tend to increase their harvest and thus incur a higher bycatch rate. Boyce finds that society as a whole would be better off if the target fishery is able to sell the bycatch.

6. Summary of Review

Our review indicates that bioeconomic modeling is a useful tool in assessing and developing market-based approaches to solve bycatch problems. However, in order to make

bioeconomic models relevant to specific bycatch management problems, we must have some knowledge of the certainty and uncertainty of biological systems. Specifically, for bycatch analyses, population dynamic modeling must focus on relevant species and cohorts. As a result, these models will, in general, be very complicated and will require close collaboration among fishing industry experts, managers, and social and natural scientists. Because of this complexity, models will need to be developed for each specific case.

B. Bycatch Management in Small-Scale Fishing Societies

1. Background

The purpose of this subsection is to review studies of small-scale or "traditional" fishing societies in order to determine whether or not lessons learned from the management of these fisheries might usefully be applied to bycatch problems in U.S. fisheries. This review is summarized in Table 2.

Other than the burgeoning economic literature described above, we have been unable to uncover a significant body of literature from other social science disciplines describing and analyzing problems of bycatch in either modern or traditional societies. Indeed, bycatch is barely touched upon in much of the social science literature.

We have found only two studies (Bishop et al. 1984; Gordon 1992) that actually use the term "bycatch." In some of the literature (Ruddle and Akimichi 1989; Davis 1989; Cohen 1989), bycatch, as we have defined it, is alluded to, but it is not discussed in detail. In these studies, bycatch is acknowledged as a problem, yet solutions have not been explored adequately. The problem of bycatch has been largely ignored or has gone unnoticed by analysts of fisheries management in small-scale fisheries.

We can make at least two hypotheses why little scholarly attention has been directed to issues of bycatch in these fisheries. First, small-scale fishing communities may be unable, from the standpoint of technological capacity, to deplete fish stocks. In this sense, "small-scale" refers not just to the size of the community relative to others but also relative to the fish stocks that are being exploited. In other words, technology, possibly in combination with population size or cultural norms, constrains fishing effort. As a result, there is little physical evidence of

Table 2: Comparison of Management Regimes in Small-Scale Fisheries

Community	Fishery	Management Regime	Regulations	Enforcing Institution	Bycatch	Source
Tlingit/ Haida (Southeast Alaska)	salmon (subsistence): lattice traps; weirs; stone traps; mobile gear	common property (internal)	Fishing area divided among clans; limited entry; territoriality; seasonal restrictions; area restrictions; gear restrictions; escapement rules	clan or house group chief	Escapement rules—lift lattice traps and weirs to let enough fish reach spanning grounds to sustain stocks	Langdon 1989
Tlingit/ Haida (Southeast Alaska)	salmon (commercial): traps; weirs; beach seines	common property (external)	Leased fishing rights from Natives; exploited fisheries for commercial use	Russian government	Initiated harmful harvesting practices	Langdon 1989
Tlingit/ Haida (Southeast Alaska)	salmon (commercial): purse seines; traps; weirs; beach seines	co-management (external/ internal)	Limited entry; gear restrictions	central government and local authorities		Langdon 1989
Japan* and Southwest Ryukus	multispecies: beach seines	1876: comanagement (external)	Individual fishermen allowed to use fishing grounds after paying a use tax to central government.: gear restrictions; area restrictions; size of catch restrictions; time limits; vessel restrictions; use of ocean resource coincides with ownership of land (i.e.,e sea tenure based upon land tenure)	central government allocates fishing rights to village groups; social pressure	conservation regulations: no piscicides, gear restrictions, seaweed harvesting monitored because certain eggs are laid in it; size restriction	Ruddle and Akimichi 1989
Japan* and Southwest Ryukus	multispecies: beach seines	1901: comanagement (internal)	limited access (based upon membership in community); licenses issued; gear and method restrictions; area restrictions, seasonal restrictions. FCAs administer fishing rights in coastal waters and engage in economic activities (including cooperative marketing)	government-acknowledged Fisheries Cooperative Associations (FCAs) monitor fishing grounds and allocate fishing rights to individuals; social pressure		Ruddle and Akimichi 1989
Northern Australian Aborigines	Multispecies (subsistence): spears; lines; traps	private property (by clan group); some areas common property (among clans) (internal)	limited access—outsiders wanting access must be introduced to ecosystem by member of community; no trespassing into sacred areas; closure of seas (when overexploited); territoriality based upon superstition and physical characteristics of land and sea areas you own; ownership of land contingent upon homage to decreased ancestors	religion; social pressure; aboriginal law; European law	No bycatch problem because everything utilized; even inedible parts are used because each has symbolic meaning	Davis 1989

Community	Fishery	Management Regime	Regulations	Enforcing Institution	Bycatch	Source
Takishima, Japan	multispecies (commercial): mackerel; butterfish; crab; herring; seabass; (subsistence): mullett; black porgy; rock cod; flounder; squid; clam	comanagement (internal/ external)	limited access: controlled by limited permits for motor boats; gear restrictions, area restrictions	prefectural government (Marine Products Department) based upon longstanding indigenous traditions	everything caught is sold or consumed	Norbeck 1954
Washington State Indians*	salmon (subsistence): traps; weirs	common property (internal)	territoriality; use rights to harvest fish; conservation rules: no pollution, no waste	local tribal authority	waste socially unacceptable; escapement devices in traps and weirs	Cohen 1989
Buen Hombre, Dominican Republic	multispecies (subsistence and commercial): spears	comanagement (internal/ external)	fishing groups cooperate to maximize catch; established Associations to increase market price; vary target species to avoid depletion of certain stocks; gear restrictions	village residents have legal right to monitor their fisheries; social pressure	size restrictions (small fish not as valuable)	Dyer and MCGoodwin 1994
Bahia, Brazil*	multispecies (subsistence with some commercial): purse seines; trot lines; hand lines; set nets; traps; corrals	open access by Brazilian law (ignored); common property; internal regulation	collective ownership based upon *respeito* (reciprocity); "favor" system; fishing areas allocated according to history and social status; territoriality; gear and vessel restriction	conflicts resolved by internal mediator; social pressure (*respeito*); gear sabotage and violence	small mesh seines used to catch shrimp viewed as damaging to other fisheries; gear restrictions	Cordell 1989
Florida west coast	shrimp (commercial): otter and roll trawls	open access; internal regulation	gear, season, size, area restrictions; informal area restrictions	social pressure; rumors, criticism, gear sabotage	mesh sizes; avoidance of shrimp nurseries; stone crab bycatch	Overbey 1989
Florida west coast	stone crab (commercial): stationary bottom traps	private property regime; internal regulation.	limited entry; claim area by setting traps; secrecy, deception, conservation; conservation measures: clean claw breaks; no "boxing" or "bulking"; no taking egg-bearing females; informal area restrictions	social pressure; rumors, criticism and gear sabotage	selective capture and careful claw-breaks to ensure survival; shrimp bycatch	Overbey 1989
Turkey: coastal fisheries	multispecies (commercial and subsistence): trammel nets; longlines; trawls; purse seines; beach seines	comanagement (internal regulation, external supervision)	trawlers not allowed within 3 miles of coast; no dynamiting; where they exist, cooperatives have jurisdiction over local fisheries	cooperatives established to police areas; government regulation		Berkes 1986
Turkey: Ayvalik-Haylazi	multispecies (commercial and subsistence): trammel nets; longlines; trawls; purse seines; beach seines	comanagement (internal cooperative, external oversight)	Limited access based upon residence in village; cooperative established	cooperative and central government		Berkes 1986
Turkey: Tasucu Bay	multispecies (commercial and subsistence): trammel nets; longlines; trawls; purse seines; beach seines	comanagement (internal cooperative, external oversight)	Cooperative established—open access, but compelling reasons to join cooperative (bank credit, year round seasonally adjusted fish prices, freezer/storage facility, discounted equipment, policies bay for illegal trawlers)	cooperative		Berkes 1986

Community	Fishery	Management Regime	Regulations	Enforcing Institution	Bycatch	Source
Turkey: Alanya	multispecies (commercial and subsistence): trammel nets; longlines; trawls; purse seines; beach seines	comanagement	Limited Access (informal) based upon knowledge of fishing area—participation restricted to those familiar with the fishery—limited fishing areas allocated to fishermen by request of specific site to local government. Lottery system based upon rotating schedule enables equal opportunity to fish at the most productive sites.	fishing community: social pressure or violence		Berkes 1986
Turkey: Bodrum	multispecies (commercial and subsistence): trammel nets; longlines; trawls; purse seines; beach seines	comanagement				Berkes 1986
Turkey: Bay of Izmir	multispecies (commercial and subsistence): trammel nets; longlines; trawls; purse seines; beach seines	comanagement	Cooperatives established for each sector (too many cooperatives with too many interests); first come first served allocation of fishing grounds.			Berkes 1986
Oceania*: Palau, Micronesia	multispecies: nets; traps; lines	Yes: common property regime; internal	Limited access (fishing permits); area restrictions; species restrictions (certain species off-limit to particular people); superstition/ religion; seasonal closings; gear restrictions; size restrictions; escapement	Clan or family group regulate their individual fishing area; social pressure; intervillage rule-breaking compensated by fees determined by regulating chief of controlling (local) village; religion	Regulations address bycatch: species restrictions; escapement devices, size restrictions; waste considered socially unacceptable	Johannes 1978
New Zealand	multispecies (commercial): longline; trawl; pot	Yes: common property regime (external)	Limited access (license system); ITQ system based upon Total Allowable Catch; mandatory reporting of discarding; rea closures once TAC has been reached; no dumping whole fish; gear, time and area restrictions; forfeit bycatch outside quota to state; monthly quota balancing	Central government	Bycatch is the focus of the study. No dumping whole fish; must report discards (which goes toward quota).	Gordon 1992
Fort Georges, James Bay: Cree Indians	multispecies, especially cisco and whitefish (subsistence): gillnet	common property regime (internal)	restrictions on size of catch; gear limits (mesh size); area restrictions	social pressure	waste socially unacceptable; "full utilization of catch" rule; net selectivity; no incentive to catch surplus	Berkes 1977
Lofoten, Norway	cod (commercial): handline; longline; gillnet; Danish seine	1816: private property (internal)	privatized fishing areas which led to transferable fishing rights, division among gear types	fishers report dissidents to superintendent		Jentoft and Kristofferson 1989
Lofoten, Norway	cod (commercial): handline; longline; gillnet; Danish seine	1857: open access (external)	government-organized; free access to fishing areas; division of Lofoten into districts which organized registration of boats; led to anarchy and neglect of small fishermen	government		Jentoft and Kristofferson 1989

Community	Fishery	Management Regime	Regulations	Enforcing Institution	Bycatch	Source
Lofoten, Norway	cod (commercial): handline; longline; gillnet; Danish seine	1897: comanagement (internal/ external)	government organized with local fisher participation; territorial borders established and gear restrictions; decentralization leads to flexibility	decisions and management by fishers as mandated by government		Jentoft and Kirstofferson 1989
Salango, Ecuador*	multispecies: beach seines first, replaced by purse seines	common property (internal)	limited access: only members of syndicate allowed to fish; coexistence of ordered sequence and shoal-sighting for net casting; conflicts resolved at syndicate meetings	locally organized "syndicate"; social pressure		Southon 1989
Maine	lobster (commercial): traps	open access regime (external)	size restriction; throw back law for egg-bearing females; no trap cutting	state government	laws (formal and informal) restricting take of egg-bearing females	Acheson 1987
Maine	lobster (commercial): traps	common property regime (internal)	limited entry; territoriality based upon social acceptance or ownership of land in the area; trap limits; seasonal closure	informal local "harbor gangs"; social sanctions and gear sabotage	laws (formal and informal) restricting take of egg-bearing females	Acheson 1987
Indonesia	multispecies (commercial and subsistence): trawls; seines; lift nets; gillnets; tidal traps; pole and line; longline; hand collection; handlines; purse seines; traps	open access (external)	catch limits; gear restrictions; area restrictions	limited government enforcement: Navy; Waterways Police; Ministry of Agriculture	Bycatch addressed. Shrimping bycatch solution: develop market for bycatch. Ban on dirty trawl fisheries; alterative shrimping methods (gear improvements). See discussion of case studies.	Bishop et al. 1984
Caye Caulker, Belize	multispecies, mostly lobster (commercial and subsistence): traps, handlines	open access (officially)	seasonal closures; conservation regulations: prohibition on taking of egg-bearing females, size restrictions; reciprocity among fishermen	local government (police enforcement)	size restrictions; prohibition on taking of egg-bearing females	Sutherland 1986
Caye Caulker, Belize	multispecies, mostly lobster (commercial and subsistence): traps, handlines	comanagement regime (internal/ external)	limited entry; use of facilities and loans for members; establishment of solid markets for members	cooperatives		Sutherland 1986
New York Bight (Gull Haven)	whiting (commercial): trawls	open access regime (external)	exclusion of foreign vessels	goverment		McCay 1989
New York Bight (Gull Haven)	whiting (commercial): trawls	common property regime (internal)	limited entry into cooperative; catch quotas among members to increase market price; use of facilities and equipment	cooperative		McCay 1989

*Overexploitation of fishery by external parties.

depletion effects on nontarget species.

Second, many cultures, especially those associated with subsistence societies, tend to utilize everything they catch, thereby eliminating the perception of waste. In other words, in some societies, everything is a target species, and bycatch, as defined, does not exist. This phenomenon may not be associated solely with small-scale fisheries. For example, a general rule in Japanese fisheries management is that all fish caught must be landed. If this hypothesis is true, then there may be an important lesson here for U.S. bycatch management in that the practice of landing all fish that are caught in effect internalizes a potential externality.[21]

Because of the dearth of studies on bycatch management in traditional fisheries, our review focuses to a greater extent on the general management regimes of traditional fishing societies than on the issue of bycatch. To conduct the review, we identified relevant case studies from bibliographies in published papers, through personal communications with several social scientists, and through a search of computerized databases. Table 2 summarizes some of the relevant cases from this review, and the following subsections describe the meaning of the headings in Table 2.

2. Property Regimes

There is some disagreement and confusion in the literature about definitions and categories of different resource management regimes. We adopt the categories and definitions proposed by Bromley and Cernea (1989) and Berkes et al. (1989), and we suggest an additional category. Therefore, in analyzing the traditional societies' fisheries management regimes, we have categorized each community as one or more of the following property rights regimes:

- An "open access regime" wherein property rights are lacking. Because open-access resources are essentially unowned, they cannot be considered to be property in a legal sense.

- A "common property regime" wherein the fishery is considered the "private property of a group." The group could be a fishery cooperative, a local political jurisdiction, such

[21] As explained in Section 3, above, a rule that requires landing all fish that are caught is not necessarily socially optimal. The reason is that such a rule considers neither the costs to fishers of landing fish that may be of little commercial value nor the impact of the nonselective withdrawal of fish from interacting stocks.

as a municipality, or a community of indigenous peoples, for example. Under such a regime, a well-defined group has the legally and socially sanctioned ability to exclude others and to regulate use of the resource.

- A "state property regime" wherein ownership and control over fishing rests in the hands of a regional or national political jurisdiction. Individuals and groups may be able to fish, but only with permission from the state.

- A "co-management regime" can be viewed as a combination of a state property regime and a private or common property regime. It can be defined as a "cooperative management arrangement between state and local organizations in which states assign group rights to specific resources, establish overall guidelines for inter-group interactions, and help to create more positive environments for the operation of local organizations" (Swallow and Bromley 1994).

- A "private property regime" wherein an individual or corporation has the right to exclude others from using the resource and to regulate its use.

3. Successful Management

Many fish stocks are good examples of "fugitive" resources. As a "public" attribute, fugitivity makes it costly for an owner or manager to exclude potential users. Even if ownership or regulatory jurisdiction is clearly established and user rights well-defined, it can be costly for the owner or regulator to control the behavior of individual licensed fishers in an optimal way.

A considerable body of social science research has developed around the potential for common property regimes to lower the relevant costs of enforcing a collection of rules for using fugitive resources, such as fisheries. One rough measure of the "success" of any management regime is whether or not the relevant fish stocks are able to regenerate themselves year after year. Several social scientists have offered examples of cultures that have been able to maintain their fish stocks indefinitely by using various forms of common property resource management (Langdon 1989; Ruddle & Akimichi 1989; Davis 1991; Overbey 1989; Berkes 1986).

A set of "design principles" that characterize successful common property resource institutions have been characterized by Ostrom (1990), who explains that each principle is "an essential element or condition that helps to account for the success of these institutions in sustaining the [resources] and gaining the compliance of generation after generation of appropriators to the rules in use." A list of Ostrom's design principles follows, modified to

refer to fishery management:

- Clearly defined boundaries. Individuals who have rights to harvest fish must be clearly defined. The geographical extent of the resource itself also must be clearly defined.

- Congruence between rules for fish harvesting and provision and local conditions. Rules restricting time, place, technology, or quantity of resource units ("harvesting rules") should be related to local conditions and to rules requiring labor, material, or money ("provision rules").

- Collective-choice arrangements. Individuals who are affected by the relevant fishery management rules can participate in modifying them.

- Monitoring. Those individuals or groups who actively monitor resource conditions and the behavior of fishers either are accountable to or actually are the fishers.

- Graduated sanctions. Fishers who violate rules are likely to be assessed graduated sanctions (depending on the seriousness and context of the offense) by other fishers, by managers accountable to the fishers, or by both.

- Conflict resolution mechanisms. Fishers and resource managers have rapid access to low cost local arenas to resolve conflicts among fishers or between fishers and managers.

- Minimal recognition of rights to organize. The rights of fishers to devise their own institutions are not challenged by authorities external to the regime.

- Nested enterprises. Harvesting, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises.

Fisheries "regulations," as listed in Table 2, can be formal, as with official governmental laws, or informal, as with social norms or unofficial conservation efforts.

4. Regulations

The success of a management regime may hinge also upon its ability to limit access to the resource. Entry can be limited through a variety of tools such as a licensing system or physical barriers to entry, such as limiting dock space to only a specific number of boats. Territoriality, or the ability of the participants in the fishery to establish boundaries, is another regulation commonly used to limit access to an area.

5. Enforcing Institutions

Enforcing institutions also vary in degree of formality. Formal institutions include local or federal governments. Informal institutions include social sanctions or religious beliefs and practices. In most of the cultures in the study, informal institutions may be at least as effective, if not more effective, than the formal institutions.

6. Reference to Bycatch

Conservation efforts interpreted to be a discussion of bycatch have been reported in Table 2. In our review of these studies, bycatch was often acknowledged as a problem, mostly due to the catch of juvenile target fish, yet few solutions or in-depth analyses were offered. The only solutions that were offered in these cases were gear, minimum size, and target species restrictions. Many societies, including those of the Australian Aborigines and the fishers of Takishima, Japan, do not have a perceived "bycatch" problem because they consume or sell everything that is landed. There is a strong ethic of conservation in these societies which forbids waste and respects the "inherent value" of marine life.

In a few of the studies we examined, bycatch was examined in some detail. Here we discuss and evaluate the bycatch problems and solutions in three specific cases involving societies in Indonesia, Oceania, and New Zealand.

7. Specific Cases

The Indonesian shrimp trawl fishery is the focus of Bishop et al. This is an extremely high-bycatch fishery in which approximately 80 percent of the catch is of nontarget species. Much of this bycatch is juvenile fish of species which are targeted by local, traditional fishers, who use selective gear. Bycatch in the shrimp trawl fishery is either discarded, with very high mortality rates, or sold in the market, posing two major problems for the traditional fishers. First, bycatch depletes the stocks of the traditional fishers' target species, and, second, the

markets for these species are flooded, driving the price of the fish down.[22]

Indonesia has taken a multi-pronged approach to solving this conflict. Allowing bycatch to be marketed reduces wasteful discarding, yet, it hurts the traditional fishers. Therefore, a law limiting shrimp trawlers' access to the inshore fisheries (until 10 miles from shore) was implemented. In addition to the area restrictions, research on modifying gear to include escapement devices was funded by the government (a market-based approach). The government also initiated a licensing program restricting the number of trawlers that could participate in the shrimp fishery.

Gordon's study (1992) of New Zealand pollock and groundfish fisheries offers some insight into the bycatch problem within an individual transferable quota (ITQ) system. In such a system, quotas are individually allocated to fishers, determining the maximum amount of fish each is allowed to catch.

Under an ITQ program, fishers have incentive to discard their bycatch, which includes marketable fish caught in excess of the quota. These discards are especially damaging because bycatch that is not reported cannot be counted against the total allowable catch (TAC) of the fish species determined by fisheries managers.

New Zealand implemented various regulations in order to decrease bycatch in their ITQ fishery. An electronic trading exchange was set up to provide a forum for fishers to buy and sell quota, including bycatch, depending upon whether they were under or over their quota limit for the month. Monthly quota balancing decreased bycatch because fish caught in excess of individual quotas had to be forfeited to the state. This system makes the discarding problem worse unless there is a way to ensure discards are reported.

In response to bad press received by the "dirty" pollock and groundfish fisheries in New Zealand, the fishing industry, scientists, and policy makers initiated "voluntary codes of practice." Voluntary codes of practice are general, informal regulations that were proposed to optimize efficient use of the resources, minimize bycatch and discarding, protect the fishing

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[22] Ben-Yami (1995) reports on a similar problem in a Central American country. There, finfish bycatch were required to be landed with shrimp. Shrimp fishers discarded small finfish (illegally) and trawled inshore, on the way back to port, catching and landing larger, more valuable finfish. Thus, the fishers landed with the "required" bycatch. It is not known if or how this problem has been addressed.

grounds (including habitat), and maintain the fish stocks for long-term harvesting purposes.

Pre-fishing briefings were provided by managers of the fisheries. These briefings included information on: waters available for fishing; quota limits; reports of fishing activities; catches and processing (logbooks); desirable fishing practices; processing requirements; waste disposal; trans-shipment schedules; and concerns over biomass stability. This program stressed the importance of reporting discards and encouraged the use of low-bycatch gear. It is consistent with Ostrom's second, third, fifth, sixth, and seventh design principles.

The case of Oceania fisheries outlined by Johannes (1978) is an example of social norms affecting fishing practices. A general conservation ethic of the cultures of Oceania discourages waste, resulting in less bycatch.

Various conservation rules are practiced by the cultures of Oceania. These fisheries were self-regulated by individual tribes, until European capitalists appeared. Regulations included allowing a portion of the catch to escape or deliberately not catching all readily available fish or turtles. The harvest of juvenile marine species was banned. Restrictions on taking seabirds and turtles and their eggs were established. Gear restrictions further supported conservation efforts.

Oceania's system is consistent with Ostrom's first, second, third, fourth, fifth, and seventh design principles. The entrance of newcomers into the fishery caused these sustainable practices to break down. They were replaced by exploitative practices focused on exporting as much as possible. Johannes assumes an anti-Western stance, blaming resource degradation on the introduction of capitalism.

8. Limits to the Transfer of Successful Approaches

It is difficult to draw lessons for large-scale fisheries management in the United States from these small-scale case studies because of some basic differences between types of societies. First, the communities in the studies tend to be small-scale, with fewer participants than the larger scale "industrial" U.S. fisheries with which we are mainly concerned (cf. Fogarty 1995).

Second, the communities in the case studies tend to have homogeneous populations. This

characteristic makes it easier to organize management regimes because the participants have relatively similar interests. Their religious beliefs and social norms, which, in many societies, have been important as a source of a conservation ethic, tend to be uniform. Notably, the fishers on the West Coast of Florida, at Buen Hombre, and in the New York Bight have successfully managed conflicting interests within their fisheries. These examples may serve as appropriate models for other fisheries in the United States.

Another characteristic that makes it difficult to compare small- and large-scale fisheries is ease of entry into and exit from a fishery. Many small-scale fisheries have fished certain areas for generations, and fishers find it very difficult to leave once the resources have been depleted. This situation stands in contrast to that of the commercial fishers that who participate in many of the U.S. fisheries and who may have less of an incentive to preserve particular stocks because of their mobility.

Despite the observed successes of small-scale, "traditional" fishing communities, movement toward stock depletion is almost invariably part of their evolution once external fishers or entrepreneurs attempt to enter a locally managed fishery. Blatant disregard of cultural norms in combination with external market motivations may lead to overexploitation of fish stocks. McNeely (1991) describes this eventuality as "the real tragedy of the commons" whereby "common property management systems that were effective for thousands of years become obsolete in a few decades, replaced by systems of exploitation which bring short-term profits for a few and longterm costs for many." One pattern is as follows: fishers from outside enter a local fishery, employ modern technology to fish the area to the point of overexploitation, and move on to another fishing ground. Meanwhile, the local fishers are left with depleted resources and economic hardship.

5. Comparison of Existing Market-Based Incentives

A. Introduction

Table 3 lists the types of policy instruments that are currently used or have been considered for use in fisheries management.[23] We compare these instruments at a general level in terms of their advantages and disadvantages, among other features.

Broadly speaking, any policy instrument can be described as "market-based" if it has some effect on a producer's or consumer's access to or behavior in relevant markets. However, we differentiate so-called "command-and-control" policy instruments, such as nontradeable quotas (standard-based) and gear, spatial, temporal, or fish size limitations (technology-based), from those policy instruments that provide financial or monetary incentives.

Market-based incentives often, but not always, involve the use of prices or fees to provide an incentive (or disincentive) for a particular activity. They may also involve the organization of a separate market, such as a market for individually tradeable quotas (ITQs), or they may involve the differentiation of a seafood product, such as through product labelling. Market-based incentives tend to be more decentralized than command-and-control policies so that, for example, fishers may have relatively greater flexibility in their choice of technology or fishing practices.

Our method of evaluation consists of a comparison of the subset of policy instruments which we identify in Table 3 as "market-based." Using the table, we examine the general effect of each instrument without regard to its specific application to the management of either a target species or a bycatch problem. In our discussion below, we evaluate market-based instruments in more detail using actual or hypothetical examples specifically of bycatch problems.

In the current political environment, NMFS may be interested in examining those market-based incentives that can be developed by industry without explicit government regulation or participation. Our comparison, therefore, identifies both the primary government action and the potential for industry to undertake the initiative to adopt the market-based approach independent of government intervention.

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[23] Good references include Anderson (1986).

Table 3: Some Policy Instruments for Fisheries Management

Policy Instrument	Market-based	Primary Government Action	Potential for Industry Initiative	Specific Purpose(s)	Advantage(s)	Disadvantage(s)	Distributional Issue(s)
Pigovian Tax	yes	set tax		efficient harvest; cost-effective reduction in effort	optimizes effort; raises revenue for the public	steep information costs	financial transfer from fisher to the public
Charges	yes	set charge		cost-effective reduction in effort	raises revenue for the public	suboptimal management	financial transfer from fisher to the public
Subsidy Program	yes	set/eliminate subsidies		encourage entry into underutilized fishery	encourage industrial growth; encourage optimal level of bycatch	adds to natural tendency for overcapitalization and potential overexploitation	financial transfer from public to fishers; potentially harmful to public resource
Compensation Program	yes	set compensation level		efficient reduction in effort	property owner (fisher) is compensated at fair market value	subsidy if public owns the resource	financial transfer from public to private fisher
Deposit-Refund	yes	set deposit; determine refund		efficient harvest; cost-effective reduction in effort	optimizes effort; raises revenue for the public	steep information costs	financial transfer from fisher to the public
Product Label	yes	set standard	potential	inform consumer about "quality" attribute(s); differentiate product	enhances efficiency if quality matters to consumer	potential for moral hazard; monitoring/enforcement costs	public bears cost of standard setting, enforcement;
Certification	yes	set standard	potential	inform consumer about "quality" attribute(s); differentiate product	enhances efficiency if quality matters to consumer	potential for moral hazard; monitoring/enforcement costs	public bears cost of standard, setting, enforcement
Consumer Information (Other)	yes	set standard	potential	inform consumer about "quality" attribute(s); differentiate product	enhances efficiency if quality matters to consumer	potential for moral hazard; monitoring/enforcement costs	public bears cost of standard setting, enforcement
Total Quota	no	set quota		regulate harvest	controls total allowable catch	encourages derby behavior; encourages discards; monitoring/enforcement costs	
Individual Fishing Quota	no	set quota; allocate shares		regulate harvest	controls total allowable catch	encourages discards; monitoring/enforcement costs	those lucky to obtain licenses gain, others lose
Individually Transferable Quota	yes	set quota; allocate shares		regulate harvest; promote efficiency	cost-effective level of effort; encourages innovation	encourages discards; potential for transactions costs; monitoring/enforcement costs	depends upon initial allocation: transfer from public to fishers if given away; transfer from fishers to public if auctioned
Individually Transferable Bycatch Quota	yes	set quota; allocate shares		regulate bycatch; promote efficiency	cost-effective level of effort; encourages innovation	potential for transactions costs; monitoring/enforcement costs	depends upon initial allocation: transfer from public to fishers if given away; transfer from fishers to public if auctioned
License Limitation	no	limit number of licenses issued		limit entry to fishery; reduces level of effort in short run	short-run reduction in harvests	increases cost of producing effort; encourages capital stuffing	those lucky to obtain licenses gain, others lose
Gear Restriction/ Mandated Technology	no	set standard; conduct R&D		reduce harvest in short-run	short-run reduction in harvests	increases cost of producing effort; encourages capital stuffing; technology testing requirements	fishers shoulder the cost of technology switch
Other Input Restriction	no	set standard		reduce level of effort in short-run	short-run reduction in harvests	increases cost of producing effort; encourages capital stuffing	fishers shoulder the cost of technology switch
Fish Size Limitation	no	set minimum (maximum) size		reduce level of effort on younger (older) year-classes	reduces harvest of younger (older) year-classes	can be ineffective depending upon migration patterns of year-classes; encourages discards	perceived as unfair if some fishers target regulated size
Area Closure	no	identify area		redirect effort away from critical area	eliminates harvest in critical area	can be ineffective depending upon spatial distribution of stock	
Season Closure	no	identify season		redirect effort away from critical period	eliminates harvest during critical period	can be ineffective depending upon temporal distribution of stock	
Harvest Priority System	no	split season; allocate entry into second season		encourage reduced bycatch by restricting entry to clean fishers in second period	provides incentive for reduced bycatch	bycatch reduction incentive reduced in second period; assumes bycatch is a function of fisher behavior; monitoring/enforcement costs	perceived as unfair if bycatch is random and not a function of fisher's actions

In general, we find that some form of government intervention usually is necessary, unless the public is willing to turn over ownership of the resource completely to private industry or to a cooperative.[24] Section 4, above, describes in greater detail institutional approaches, such as co-management or self-governance, which may permit autonomy on the part of an industry or a community in the development of market-based or other approaches to bycatch management.

One of the most effective forms of government intervention may be the issuance of a "credible threat" to regulate the industry in a way that would be more costly than if the industry itself adopted alternative market-based incentives. One example of this, which we admit is at least partially confounded by other events, was the adoption by U.S. tuna packers of the "dolphin safe" label prior to incorporation of a labelling requirement into U.S. law. The details relevant to this application of a market-based approach are summarized in the case study in Section 6.

In addition to advantages and disadvantages, we identify potential distributional issues. These issues pertain to the incidence of benefits and costs from the adoption of particular policy options. These issues may be of great importance in decisions to adopt policy instruments because of variations in the relative political power of gainers and losers.[25] As an example, although they are theoretically efficient, pigovian taxes are rarely employed to manage fishery resources because, at least in part, they involve a financial transfer from fishers to the government. If fishers are politically powerful, then they may be able to block the adoption of this kind of policy instrument.

We have found it useful to consider bycatch as analogous to a problem of environmental pollution (Section 2).[26] Using this analogy, bycatch of a nontarget species may involve the imposition of an external cost on other individuals or groups in society. There may be a role for government in correcting this externality through the use of one or more policy instruments, either alone or in combination.

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[24] Even if the locus of management is changed, the relevant decisionmaking body, whether it be a co-management institution, a fishing cooperative, or a corporation, still faces the same choice among market-based and command-and-control approaches.

[25] A recent extreme example is the seizure and occupation of Canadian federal fisheries offices in Nova Scotia to protest increases in the amount of lobster license fees.

[26] This analogy is made practically, but not conceptually, more complex because of nature of the growth of biological stocks and ecological relationships among stocks.

This analogy forces us to think carefully about the existing distribution of property rights. In other words, in considering appropriate measures to resolve bycatch problems, we need to identify "polluters" and "pollutees." "Pollutees" could be the public as owner of the resource or groups who have an "implied right" to use a nontarget stock (cf. Rettig 1994). The distribution of rights may not always be unambiguous, and, therefore, in any particular case, it may not be clear, a priori, whether or not claims of bycatch problems involve real external costs.

We should also be thinking in terms of an "optimal" level of bycatch at which the marginal costs of reductions in bycatch by fishers are equivalent to the marginal gains to other fishers or to the public in terms of reduced damages from lowered levels of bycatch. Using economic logic alone, the optimal level of bycatch is not necessarily zero. Those policies that prohibit bycatch or set as a policy goal an approach to a zero mortality rate, such as that for certain marine mammals, may be economically inefficient. In certain cases, such as those involving an endangered species, prohibitions may be warranted, even on economic grounds.

We should be clear at the outset that the harvest of wild fisheries may involve more than one kind of market failure. The most widely discussed market failure in a fishery is, of course, the tendency for overcapitalization because one of the inputs in the production of fishing "effort," the target species, is not priced.[27] A class of problems in environmental economics, known as "second-best" problems, focuses on the resolution of multiple market failures. One result from studies in this area is that the economically "efficient" solution to one market failure in the presence of another is not always identical to the efficient solution in the absence of the other market failure.

In our succeeding discussion, we assume that the target fishery is managed to achieve the economically optimal sustainable yield (there is no "own-bycatch"). The reader will recognize that, in reality, this is almost never the case. The problem becomes more difficult when less than optimal measures have been employed to manage target stocks such that the overcapitalization problem is inadequately addressed and multiple market failures remain. Nevertheless, it may be possible to suggest policies that move toward more efficient resource allocation, even if it is not possible to achieve a first-best outcome.

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[27] Other forms of market failure, such as the presence of monopoly in the harvesting sector or monopsony in the processing sector, may also exist.

B. Pigovian Taxes or Subsidies

This class of instruments involves first identifying the socially optimal level of harvest and bycatch in a fishery and "adjusting" the price of the target species through a tax on bycatch to achieve the social optimum. (We assume, for now, that there are no complicating factors such as cross-market effects between landed target and nontarget product "substitutes.") If there are damages associated with bycatch in a fishery, the "pigovian" or economically optimal tax is set to equal the amount of damages from bycatch that are incurred at the socially optimal level of output in the market for the target species.[28]

As a practical matter, the tax would be imposed on the level of bycatch. However, if there is a nonvarying relationship between catch and bycatch--a result that is unlikely to occur in reality--the tax on bycatch could be imposed in the target market. There may be difficulties in determining the level of damages which would occur at the social optimum (Baumol and Oates 1988) when empirical observations can be made only at the untaxed equilibrium. If this is the case, an iterative procedure may be employed to converge to the social optimum.

If legal requirements or issues of fairness dictate, the fishing industry could be encouraged to cut back or redirect its fishing effort through pigovian subsidies, which are defined analogously to the pigovian tax. When the subsidy is set at the correct level, the end result is theoretically identical to the effect of a tax. Special care must be taken when considering the application of a subsidy policy because of the risks that fishers will be led to exert too much fishing effort in an attempt to garner more subsidies.

Some of the problems associated with the imposition of a pigovian tax are discussed in the next subsection on bycatch charges.

[28] This level is not the market equilibrium level of output prior to the imposition of the tax but rather the market equilibrium level after the tax has been imposed. One reviewer has explained that the result of the tax will be to lower the level of target catch to less than the untaxed economic optimum in the target fishery. Thus extensive information about the markets as well as bycatch damage is necessary to set a pigovian tax. If bycatch is determined to be beneficial, instead of damaging, then vessels could be subsidized to increase their level of effort.

C. Bycatch Charges

It can be the case that the damages associated with bycatch are difficult to determine. A total quota on bycatch might be set to meet biological concerns or as the outcome of a political process. A bycatch charge or fee is exacted in an attempt to meet the quota, but it is recognized that this quota is not necessarily economically efficient. The bycatch charge is therefore a "cost-effective" policy instrument. As in the case of the pigovian tax, an iterative procedure may be necessary to reach the required reduction in bycatch.

Like the pigovian tax, a bycatch charge would involve a regulatory agency or a fisheries management council setting a fee per pound on, for example, bycatch hauled on board a fishing vessel, irregardless of whether it is landed as a byproduct or discarded. Vessels would have an incentive to reduce bycatch because they must pay the fee. The vessel compares its marginal cost of reducing bycatch with the size of the fee for each pound potentially hauled on board.[29] The vessel seeks to lower its bycatch until the marginal cost of reducing bycatch even further just equals the size of the fee.

Individual vessels may face different levels of cost associated with reductions in bycatch because of different levels of experience, gear differences, knowledge of the fishery, etc. A uniform charge ensures that the marginal costs of bycatch reduction across vessels will be equal. This is a cost-effective outcome, because there should be no way to reallocate costs among vessels to further minimize the total costs of bycatch reduction.

Heterogeneity in marginal bycatch reduction cost schedules across vessels implies, however, that each vessel will reduce different amounts of bycatch for any given charge. If the management council knows a priori what the marginal bycatch reduction cost schedules are for all vessels, then the council can first calculate the appropriate level of bycatch in the fishery, based upon biological or political criteria, and then calculate the appropriate fee to achieve that level.

Bycatch charges (and pigovian taxes) represent financial transfers from fishers to the government. This transfer may be attractive to government managers as it could be used to

[29] In practice, the marginal cost of reducing bycatch may be uncertain if the proportion of bycatch varies unpredictably due to uncontrollable environmental factors. The importance of uncontrollable factors in determining the bycatch proportion may vary across fisheries, times of year, areas, etc.

cover administrative costs. Charge receipts might also be used to fund research and development efforts on technological solutions to bycatch problems.

A bycatch charge may shift the supply curve for the target stock upward, as social costs are incorporated into the costs of production. If demand for the target fish is not perfectly elastic, then consumers of target fish will face a higher price. Less target fish will be demanded at this price, and so, in the short run at least, consumers will bear part of the burden of the bycatch charge. If this effect is clear and significant, the bycatch charge may face even greater political opposition.

In practice, information about bycatch reduction costs is likely to be difficult to obtain. Environmental economists have suggested an adaptive technique of setting a tax, observing the associated bycatch level, and then revising the tax up or down to converge to the desired level of bycatch. This kind of an approach is likely to be problematic in the presence of uncontrollable environmental factors.

Another major concern is observation of discards. Without onboard observers or electronic vessel monitoring systems (VMSs), regulatory authorities will have to rely upon estimates of bycatch rates or self-reporting by fishers. We expect that fishers will be extremely reluctant to report discard rates. Even with observers onboard, it may be difficult to measure the levels of bycatch. Thus there are likely to be steep monitoring and enforcement costs associated with bycatch charge systems.

One solution is to have fishers bear the burden of demonstrating conclusively their levels of bycatch. The bycatch charge might be set on the basis of historical estimated bycatch rates. Fishers might agree to carry certified observers on board in order to verify bycatch levels. The cost of onboard observers might be covered, in part, through collected bycatch charges.

Anderson (1994) examines the use of a tax to provide fishers with an incentive to stop highgrading. In his framework, highgrading potentially occurs under an individually transferable quota (ITQ) system, and its level depends upon the existence of a price differential between high- and low-valued fish, the cost of discarding, and the cost of extra effort to replace discarded fish. Anderson demonstrates the existence of a set of combinations of taxes on the landings of high-valued fish and subsidies on the landings of low-valued fish to ensure no highgrading (or lowgrading) will occur. A subset of these tax-subsidy combinations are "balanced budget"

combinations such that the vessels in the fishery, taken together, would breakeven over the course of a year. The set of possible tax-subsidy combinations will vary by vessel type, but it may be possible to find a subset of combinations that works for all vessel types in a fishery with minimal income effects.

D. Deposit-Refund Programs.

This class of policy instruments is very similar to the bycatch charge, except for the timing of payments. A simple deposit-refund system might work as follows: individual fishers pay into a trust fund an amount equal to the bycatch charge, as described above, or based upon an estimate of economic damages of bycatch. The size of the payment could be set with data from historical bycatch rates in the fishery for the relevant vessel class. At the end of the season, the actual bycatch is tallied and, if less than the expected amount, a pro-rated share of the deposit is refunded.

This kind of a system has an advantage in that fishers have an incentive to reduce bycatch to get their refund. It suffers the same kinds of information problems as the bycatch charge in the sense that it is difficult to demonstrate the occurrence of bycatch if fish are discarded at sea. Fishers may have an incentive to under-report discard if it means that they will get a refund for having reported lower levels of bycatch. Some of the most successful examples of deposit-refund systems, therefore, are those in which tangible things, such as bottles or batteries, can be submitted to obtain a refund. Further, there can be significant administrative costs associated with a deposit-refund system, but these costs are likely to be of the same order of magnitude as those associated with a bycatch charge system.

In New Zealand fisheries, a deposit-refund type of system has been suggested by Clark, Major and Mollett (1989). The New Zealand individual quota management system allows fishers to trade quota of a target stock for quota of a bycatch stock. However, the system is complicated, costly to use, and, in some cases, requires trading more valuable target quota for less valuable bycatch quota. Fishers can "surrender" their fish to the government for free; but many fishers prefer to discard bycatch instead. One solution is to develop "surrender" prices, analogous to the low-valued fish subsidy described by Anderson (1994), that encourage fishers to land their fish with a licensed "fish receiver." The surrender revenues earned by the fisher landing bycatch would be deposited in a trust account until, after the fact, the fisher purchased

quota from someone else or worked out an arrangement to fish for someone else. If this is accomplished before the end of the fishing season, then the surrender revenues are refunded to the fisher. If the fisher is unable to find a way to purchase quota, then the surrender revenues paid into the trust fund have acted like a bycatch charge.

Huppert (1989) describes some of the problems with the surrender price system. Notably, there is not likely to be one single surrender price that can be identified for a fleet of heterogeneous fishing vessels, for individual vessels at different points in time, or even for individual vessels at different times during one fishing trip. The most important issue concerns a trade-off in terms of identifying a surrender price that just encourages the landing of bycatch but does not encourage targeting bycatch species. Some of these problems have been addressed by Anderson (1994). The deposit-refund feature of the surrender price scheme does seem valuable in that it gives fishers the time to investigate quota trades after the fact.

E. Compensation Programs.

Compensation programs include the subsidies mentioned above as well as "buyout" programs. They have been discussed most extensively in relation to the management of target stocks. In their simplest form, buyouts represent policies to purchase vessels from existing fishers in order to reduce capacity in the target fishery. They must be used in conjunction with other limited access restrictions, such as restrictions on entry and, possibly, gear restrictions. To the extent that buyouts effectively reduce harvesting capacity on the target stocks, we can expect that bycatch may be reduced as well.

Buyouts often are implemented through programs using public monies, but one reviewer has reminded us that buyouts can be financed by industry itself. Indeed, a program of tradeable quotas can be interpreted as a form of industrial "buyouts" when quota is traded.

The effects of buyout programs on effort reduction depend critically on assumptions that fishing technologies are fixed and that there is no substitution among inputs to fishing effort that increase harvesting power among the vessels remaining in the fishery. Classic examples of violations of these assumptions include "boat-for-boat" rules in which larger vessels replace smaller ones or "ton-for-ton" rules in which economies of scale are exploited by combining small vessel tonnages into larger vessels, also known as "pyramiding" (Munro and Scott 1985).

If effort is not effectively controlled, then bycatch problems may persist. It can be difficult to determine the extent of the effect on bycatch when technologies are modified to circumvent limited access programs.

An option to control bycatch through compensation programs is to focus on buyouts of vessels or technologies with the highest bycatch rates.

Buyout programs represent a transfer from the public to the vessel owners. As a result, they may be politically popular with the vessel owners, particularly if the alternative is to be shut out of the fishery or to be forced to pay a bycatch charge. Buyout programs may also be favored by institutions, such as banks and other lenders, who hold vessel mortgages. Buyouts represent a transfer of financial resources from agency budgets, and, as a result, they may not be favored by government officials.

Buyouts are likely to involve significant administrative costs. An experimental, small-scale buyout program has been conducted to reduce effort in the groundfish fishery on Georges Bank. The success of the experimental program is likely to lead to a "comprehensive," $25 million buyout program for this fishery.

F. Research and Development Programs

Another important market-based approach involves investments in research and development (R&D) directed at fisheries bycatch problems. If the results of technological advances in, say, gear selectivity can be considered public goods, then an argument can be made for collective action, such as government sponsorship of research, to encourage R&D directed at such advances.

General policy instruments are in place to encourage R&D in basic and applied research. These include intellectual property protection, such as patents, R&D tax credits at the federal and state levels, as well as scientific research grants sponsored by the National Science Foundation, the National Sea Grant College Program, and the Small Business Innovation Research Program. R&D investments targeted specifically at fisheries bycatch, especially those designed to improve gear selectivity, have been funded through NMFS' Saltonstall-Kennedy grants program.

G. Product Labels and Consumer Information

The primary roles of product labelling are to provide information to potential consumers in cases where information is not adequately transmitted among market participants or to allow firms to take advantage of opportunities for product differentiation. The benefits of this approach have been recognized only rarely in fisheries management. A leading marine example is the "dolphin-safe" labelling of canned tuna sold in the United States. An emerging example is the "turtle-safe" labelling of boxes of shrimp.

Similar to the labelling policy, consumer information policies help to correct for information asymmetries which may have led to harmful levels of fishing effort. For example, as consumers become aware of the effect of certain fishing practices on sensitive biological stocks or marine ecosystems, they may rearrange their purchases to consume less of a product whose harvest involves environmental damages. Consumers may become informed through the actions of seafood producers, through government programs, through the publication of academic research, or through the actions of public interest groups or the media.

Wallstrom and Wessels (1994) report the results of a study of the effect of the "dolphin safe" label on U.S. consumer demand for canned tuna. Although the results are not completely unambiguous, there is some indication that both the adoption of the dolphin-safe label and measures of "media attention" to the issue were associated with a decline in the demand for tuna. This apparently counterintuitive result may be explained, in part, by the consumers' interpretation of the information presented by both the media and the label: namely that tuna fishing is damaging to dolphins. The authors believe that there may be a wider range of consumer reactions to information of this type than to information commonly found on labels regarding human health risks.

One of the drawbacks of the labelling approach is that, because of the complexity of bycatch problems in a particular case, it may be difficult to send an unambiguous message to the consumer. In the dolphin-safe case, there exists much confusion regarding the message of the label. This confusion has been exacerbated by a decade of boycotts, the lack of a unified promotional campaign by both the industry and conservation communities, recent concerns regarding the potential ecological effects of dolphin-safe fishing, and conflicting claims from various segments of the conservation community. We discuss this particular issue in greater depth in Section 6. One conclusion that we reach is that there may be an opportunity for

government or industry sponsorship of educational processes to mitigate the sources of confusion in any specific case.

H. Product Endorsements and Certification

Product labels enable seafood producers to differentiate their products and to capture a premium that consumers sometimes are willing to pay for products harvested according to "environmentally-sound" standards. Two primary policy issues concern (1) how these standards are determined and (2) what mechanisms exist to ensure that products meet these standards on a continuing basis.

Product certifications and endorsements are performed in the United States by independent organizations such as GreenSeal or Scientific Certification Systems (SCS). Generally, certifications are of two types: SCS certifies the producer's claims; GreenSeal certifies that a product meets a standard set by a independent outside group. Labelling standards also could be set by a regulatory agency or adopted by individual firms or groups of firms in a product market. Standards may need to be set for certifying organizations as well.

I. Individually Tradeable Quota Systems

In some fisheries, a regulatory agency sets a total quota or limit on annual harvest based upon biological or economic criteria. Fishers are allocated (or may purchase at an auction) portions (ITQs) of the total quota. Holders of ITQs are permitted to sell them (i.e., ITQs are "transferable"), making the instrument a potentially cost-effective way of handling environmental problems. Pearce and Walters (1992) see one of the main advantages of ITQ programs as a change in perception among fishers from competitors to joint-venturers.

The ITQ approach has been employed in several U.S. fisheries (Atlantic surf clam, ocean quahog, south Atlantic wreckfish, herring sac roe in Yaquina Bay and San Francisco Bay, and certain Wisconsin freshwater fisheries), but ITQs have not been used explicitly to help resolve environment-fishery conflicts in the United States. Several important studies focusing on fishery ITQ programs have been published recently. Two of the best are the National ITQ Study (Anderson 1992) and a study by Squires et al. (1995). We refer the reader to these studies for

detail on the advantages and disadvantages of fishery ITQ programs.

ITQ programs involving quotas in target stocks are likely to have an effect in reducing bycatch as target catches are reduced (Sutinen et al. 1992). However, as harvesting pressure is reduced on both target and nontarget stocks, biological relationships might change, and the potential for bycatch reduction will depend upon the specific characteristics of the fishery in question. As discussed above, New Zealand has developed an ITQ program through which bycatch can count against target species quota.

Another consideration is the biological interaction between species. If, for example, the bycatch is of a predator on the target species, then bycatch reduction might result in lower levels of the target species because of increased predation.

Significant levels of "highgrading" target species may result in unintended stock depletion or ecosystem effects. Anderson (1994) develops a model of highgrading in ITQs for the target stock. Unless bycatches of nontarget species are included in an ITQ program or otherwise regulated, it is likely that bycatches and discards will continue, though perhaps at reduced levels (Sutinen et al. 1992). Townsend (1995) has developed a concept called "transferable dynamic stock rights" to help mitigate the highgrading of younger cohorts by allocating "life-cycle" shares of each cohort.

An ITQ program also could focus specifically on bycatch species (Fraser 1995). A system of tradeable bycatch quotas is likely to be more cost-effective, in an economic sense, than a nontradeable quota system on bycatch for the following reason. Tradeable quotas result in an outcome in which those fishers who can most easily reduce bycatch bear the bulk of the bycatch reduction. Marginal costs of bycatch reduction will be equated across fishers, but each fisher will be reducing different amounts of bycatch. Marginal costs of bycatch reduction will include costs to the fishers of adopting technological solutions or reductions in target species output or both. This makes sense, and it is the analog of the pollution control case.

If nontradeable quotas were allocated to fishers, the same result would not obtain unless the managing agency had enough information to allocate quotas in amounts such that the marginal costs of bycatch reduction across fishers were equal. (Another--unlikely--possibility is that all fishers have identical capabilities for reducing bycatch, in which case the agency just gives each fisher the same quota.) There could also be the standard issues of transactions costs

with large numbers of market participants, thin markets with small numbers of participants, lags in market clearing, or uncertainties in marginal bycatch reduction costs (Stavins 1995).

This outcome is the main source of economic efficiency arguing in favor of tradeable permits. However, because a constraint is placed on the total level of bycatch, it is likely that fishing effort could be reduced on the target species as well.[30] If the target species is already overharvested because of an unregulated, open access situation, then bycatch quotas could, over time, result in lower levels of effort and increased levels of the target stock and increase the potential for higher yields in the target stock. This is a second source of efficiency.

As is the case with any policy instrument, including command-and-control instruments, the practical problems of implementing the instrument in the case of a multispecies fishery can be enormous. In theory, a bycatch ITQ might be developed for each stock. In practice, such a system may involve overwhelming administrative and transactions costs. Assuming perfect enforcement, Anderson (1989) examines a case in which ITQs are allocated for each of two species in a multispecies complex. He shows that for the species with the most constraining total allowable catch (TAC), ITQ prices will be positive and holders of ITQs for that stock will earn rents. Because the TAC on this stock constrains further effort to harvest the full quota on the other stock, the price of ITQs for the latter stock will equal zero. An interesting result is that, except in the rare case in which the TACs on both stocks are binding concomitantly, if positive prices are observed in the markets for both ITQs, then it is likely that the TAC is being violated for the stock with the more constraining TAC.

J. A Word About Design Standards

Bycatch management approaches, to date, have taken similar forms. In most cases, these approaches involve the implementation of "design standards," requiring the fishing vessels to employ specific gears or technologies that have been shown, usually through extensive testing, to result in lowered bycatch rates in the target fishery. A leading expert on bycatch in the United States observes that:

Unless species and size selectivity of fishing techniques are improved, tough new

[30] The actual effect may depend upon interactions between the existing management regime for the target species and the proposed regime for bycatch.

regulations may place additional requirements on existing fisheries or fisheries may be closed altogether (Murawski 1995).

There are two major economic benefits associated with technology-based approaches that improve the selectivity of fishing gear. The first benefit is that associated with the avoidance of catch reduction in the target fishery, and the second is the reduced damage (through bycatch). As we have noted already, in a directed fishery, the socially optimal level of harvest is generally lower than that in the open access case. In order to reduce bycatch, harvest may need to be cut back even further. If gear improvement is both technologically and economically feasible, then the bycatch problems are easier to solve.

Alternatively, a "direct control" system may be implemented. Under direct controls, either total or individual vessel quotas are set on the capture of fish or animals from nontarget stocks. Once the nontarget stock quotas are reached, harvest of the target species must be discontinued. Total quotas are used in the groundfish fisheries of the North Pacific, and individual quotas, also known as "possession limits," are used in conjunction with design standards in the New England groundfish fisheries.[31]

These traditional methods of bycatch management are classic examples of so-called "command-and-control" (CAC) approaches to environmental and natural resource management problems. Under ideal conditions, including good knowledge of economic and biological parameters and with low monitoring costs, it is well established that CAC approaches can result in economic inefficiencies.[32] The basic reason is that CAC approaches do not take advantage of differences in the inherent capabilities of fishers to control bycatch (cf. Baumol and Oates 1988). Even if we can reasonably assume that all fishers are identical, Anderson (1986) has shown that, ceteris paribus, design standards and direct controls are likely to achieve only second-best efficiencies.

Several authors have investigated the theoretical aspects of policy instruments designed to control bycatch (Arnason 1994; Androkovitch and Stollery 1993). For the most part, these authors have studied market-based policy instruments, ignoring CAC approaches.

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[31] Individual quotas are also used in longline fisheries targeting groundfish in Alaskan waters (Trumble 1995).

[32] A reviewer has pointed out that many CAC approaches, such as gear design standards, may tend to increase fishing effort if harvest efficiency is reduced through their implementation.

Nevertheless, it is not immediately apparent that CAC approaches are less efficient than other policy instruments for achieving bycatch control. Several conditions may affect the relative efficiency of individual policy instruments. These conditions relate to (1) the potential for threshold damages to fish or animal stocks or to the relevant marine "ecosystem"; (2) the relative costs of enforcement and other management techniques and practices; (3) costs of compliance and avoidance; (4) the net benefits of gear vetting programs; (5) the timing of policy implementation; among possibly others.[33] In their theoretical study of enforcement costs in fisheries management, Sutinen and Andersen (1985:394) conclude that:

> Since gear restrictions can increase the costs of production, they are typically viewed as inefficient regulatory measures (Crutchfield 1961). However, since gear restrictions may be less costly to enforce than other measures, gear restrictions could turn out to be the most efficient method of regulation when enforcement costs are taken into account.

If one or more of these conditions hold in the real world, then policymakers might legitimately promote the implementation of gear design standards as efficient instruments for bycatch management. If these conditions do not hold, then we may be observing yet another instance in which the use of CAC policies result in wasteful management.

[33] CAC approaches also may have important distributional characteristics that increase the likelihood that they will be selected among the set of all possible alternative instruments (cf., Karpoff 1987; Johnson and Libecap 1982).

6. Priority Case Studies

A. New England and Mid-Atlantic Groundfish

Since 1986, the New England groundfish fishery has been managed as a "multispecies complex" of thirteen species (Table 4: black dots). In some cases, special regulations have been instituted for haddock, juvenile cod, and yellowtail flounder. According to requirements under the Magnuson Act, all thirteen species are managed as a "unit" throughout their range.[34] Ten of these species are considered "large mesh" species for which minimum mesh sizes are required.

The multispecies complex exhibits nonuniform spatial and temporal distributions (NEFMC 1993), and certain species tend to occur together (Gabriel 1993). Fishers have traditionally utilized mainly nonselective gears including otter trawls and gill nets, although pots and set lines are also employed. Single vessel bottom trawls are used to harvest the majority of landings.[35] Fishers are thought to have a fairly well-developed understanding of the spatial and temporal distribution of the stocks. Fishers often target one or more species with some expectation that others in the complex may be caught and marketed as a byproduct.

In the early 1990s, the New England Fishery Management Council (NEFMC) attempted to identify all of the fisheries in the region. Based upon landings data, the Council identified an "incomplete" list of at least 40 different fisheries. Although further work along these lines has been suspended, it may be possible to identify literally hundreds of distinct fisheries based upon geographic locations in combination with gear types and target species (Haring, pers. comm., 1995).

There are several different types of bycatch in this fishery, but they are all primarily the result of regulation. One of the most important types involves the bycatch of juvenile groundfish of target species. These juveniles are now discarded because of size limits.[36] Minimum mesh sizes and the closure of nursery grounds have been established to help address the bycatch of juveniles. Nevertheless, the discard rate of undersized groundfish is unknown. A second

[34] The range extends beyond U.S. jurisdiction into Canada.

[35] Pair trawls were prohibited in 1994.

[36] Earlier, discards of juveniles may have occurred because of price differentials.

Year	L	V	P	L	V	P	L	V	P	L	V	P	L	V	P
	Am. Lobster			Sea Scallops			Blue Crab			Cod			Hard Clam		
1989	24.0	148.9	2.82	14.4	126.6	3.98	45.6	42.0	0.42	35.6	47.8	0.61	4.2	50.6	5.48
1990	27.6	151.0	2.48	17.2	147.4	3.88	43.9	43.2	0.45	43.6	61.4	0.64	4.6	46.9	4.63
1991	29.1	166.1	2.59	17.2	153.5	4.05	49.5	40.4	0.37	42.2	74.3	0.80	4.4	44.8	4.61
1992	26.0	166.5	2.91	14.2	153.7	4.89	30.1	34.7	0.52	27.9	52.2	0.85	4.3	40.7	4.30
1993	25.6	151.7	2.68	7.4	97.7	6.03	57.1	69.5	0.55	22.9	45.0	0.89	4.3	43.6	4.58
	Atlantic Salmon			Menhaden			Surfclam			Oyster			Squid *Loligo*		
1989	0.0	0.0	0.00	87.8	31.3	0.05	30.4	30.7	0.46	2.4	22.3	4.16	23.0	21.8	0.43
1990	2.1	16.1	3.50	36.1	37.2	0.05	32.6	32.4	0.45	3.3	40.1	5.54	15.0	14.0	0.43
1991	4.7	30.0	2.89	94.8	33.2	0.05	30.0	29.2	0.44	4.0	40.8	4.67	19.4	22.7	0.53
1992	5.8	45.3	3.52	85.9	31.6	0.05	33.2	34.7	0.47	4.6	55.7	5.44	18.2	23.3	0.58
1993	6.7	42.6	2.86	17.0	41.9	0.06	33.5	38.2	0.52	2.9	36.8	5.81	22.3	29.7	0.60
	Sea Urchins			Goosefish			Ocean Quahog			Bluefin tuna			Soft Clam		
1989	4.3	3.6	0.38	11.3	12.6	0.51	23.1	16.4	0.34	1.1	19.7	8.01	2.9	19.4	2.98
1990	6.1	6.1	0.45	10.1	13.1	0.59	21.2	16.3	0.35	1.0	21.2	9.26	2.4	20.8	3.88
1991	9.3	11.2	0.54	12.1	21.8	0.81	22.3	19.0	0.39	0.9	15.3	7.58	1.9	14.8	3.51
1992	12.0	15.2	0.57	15.8	20.7	0.60	23.0	20.1	0.40	0.9	14.5	7.23	1.9	17.8	4.23
1993	19.2	27.2	0.64	17.6	20.8	0.54	23.4	20.6	0.40	1.0	19.3	8.92	2.0	19.0	4.27
	Summer flounder			Winter flounder			Amer. Plaice			Silver Hake			Yellowtail Flounder		
1989	6.2	22.2	1.63	6.6	19.6	1.34	3.5	8.8	1.14	17.8	9.4	0.24	5.6	13.9	1.13
1990	3.0	12.0	1.84	7.0	17.1	1.11	2.5	5.6	1.03	20.0	11.1	0.25	14.4	28.1	0.89
1991	4.6	14.8	1.45	7.6	19.1	1.14	4.3	8.9	0.94	16.1	11.1	0.31	7.6	17.4	1.03
1992	6.4	19.6	1.39	6.5	16.2	1.14	6.6	13.9	0.95	16.2	10.9	0.30	5.7	14.0	1.12
1993	4.5	15.4	1.56	5.3	15.3	1.31	5.8	15.0	1.17	17.2	14.0	0.37	3.6	10.4	1.30
	Swordfish			Witch Flounder			Squid *Illex*			Pollock			White Hake		
1989	2.7	17.2	2.92	2.4	9.0	1.73	6.8	3.2	0.22	10.5	9.9	0.43	5.1	4.4	0.39
1990	2.3	15.1	2.92	1.5	5.8	1.78	11.3	6.5	0.26	9.6	10.6	0.50	4.9	4.3	0.39
1991	1.8	12.0	3.00	1.8	6.1	1.57	11.9	6.9	0.26	7.9	9.9	0.57	5.6	5.4	0.44
1992	1.7	10.8	2.90	2.2	7.0	1.41	17.8	9.7	0.25	7.2	10.5	0.66	8.4	8.0	0.43
1993	1.5	9.9	2.93	2.6	9.0	1.57	18.1	8.6	0.22	5.7	8.4	0.67	7.5	7.3	0.44
	Butterfish			Atlantic Herring			Bigeye Tuna			Scup			Northern Shrimp		
1989	3.0	3.9	0.60	40.7	5.0	0.06	0.4	2.7	3.18	3.5	6.1	0.78	3.6	7.8	0.98
1990	2.3	2.8	0.56	51.3	5.7	0.05	0.4	3.9	4.03	4.2	6.4	0.68	4.4	6.9	0.72
1991	2.1	2.7	0.59	48.5	6.3	0.06	0.7	6.2	3.93	6.8	7.8	0.52	3.4	6.8	0.91
1992	2.8	3.4	0.56	55.8	6.8	0.06	0.5	4.8	4.66	5.9	7.6	0.59	3.4	7.3	0.99
1993	4.5	6.8	0.69	49.7	6.5	0.06	0.8	5.8	3.48	4.3	5.5	0.58	2.3	5.2	1.03
	Tilefish			Spiny Dogfish			Black Sea Bass			Haddock			Yellowfin Tuna		
1989	0.5	2.0	1.81	4.4	0.8	0.09	1.0	2.7	1.20	1.7	4.5	1.19	0.5	1.6	1.33
1990	0.9	3.8	1.97	14.6	3.3	0.10	1.3	3.0	1.06	2.5	6.0	1.10	0.6	2.4	1.71
1991	1.2	4.2	1.61	11.5	2.4	0.09	1.2	3.1	1.20	1.8	4.6	1.13	2.0	3.5	0.80
1992	1.7	5.5	1.51	11.4	2.9	0.11	1.3	2.8	1.00	2.3	5.6	1.09	1.4	3.9	1.23
1993	1.8	5.0	1.23	15.5	4.5	0.13	1.3	2.9	0.98	0.9	2.7	1.38	0.6	2.7	2.15
	Striped Bass			Skates			Windowpane Flounder			Mussels			Weakfish		
1989	0.1	0.4	2.12	6.7	0.9	0.06	2.6	3.1	0.55	4.3	3.4	0.35	1.7	2.7	0.73
1990	0.3	1.0	1.48	11.4	2.0	0.08	2.0	1.7	0.38	3.9	2.9	0.34	1.4	2.2	0.69
1991	0.3	1.4	1.75	11.3	1.8	0.07	3.7	4.4	0.54	2.9	2.2	0.33	1.5	2.5	0.77
1992	0.6	2.4	1.73	12.5	2.5	0.09	2.1	3.0	0.64	4.1	3.0	0.34	1.1	1.9	0.79
1993	0.7	2.7	1.87	8.1	2.5	0.14	1.6	2.3	0.66	2.7	2.0	0.34	1.1	1.9	0.78
	Bluefish			Atlantic Mackerel			Red Hake			Redfish			Ocean Pout		
1989	2.7	1.3	0.22	8.1	3.2	0.18	1.6	0.6	0.17	0.6	0.9	0.66	1.3	0.3	0.10
1990	3.6	2.1	0.26	9.9	3.6	0.16	1.6	0.6	0.17	0.6	0.7	0.53	1.3	0.3	0.10
1991	3.5	1.7	0.22	16.5	5.4	0.15	1.6	0.8	0.22	0.5	0.5	0.46	1.4	0.3	0.10
1992	3.4	1.7	0.23	11.8	3.6	0.14	2.2	1.1	0.22	0.8	0.8	0.42	0.5	0.1	0.10
1993	3.0	1.8	0.27	4.6	1.3	0.13	1.7	0.9	0.24	0.8	0.8	0.46	0.2	0.1	0.10

Table 4: Important species landed or raised in the Northeast, their landings (L, 1000my), value (V, millions of dollars), and price (P, dollars per pound), 1989-1993. 1993 data is preliminary. Source: NOAA Tech. Memo. NMFS-F/NEC-101 (October 1993).

important type of bycatch is of the large-mesh species by trawls in the small-mesh and other peripheral fisheries. Under Amendment 5, which became effective in March 1994, possession limits were set for these latter fisheries of 500 pounds of protected groundfish per vessel per year. Under Framework Adjustment 9, which became effective in April 1995, small-mesh fisheries are disallowed unless they have been determined by the Regional Director to result in the bycatch of 5 percent by weight or less of regulated groundfish. Vessels can use small-mesh nets in two exempted subareas, but they cannot possess regulated groundfish. In addition, vessels can possess and retain longhorn sculpin, monkfish, and lobster as byproducts in these fisheries.[37] These small-mesh fisheries include those for butterfish, dogfish, herring, mackerel, ocean pout, scup, squid, silver hake, and red hake.

A third important type of bycatch is of harbor porpoise in the Gulf of Maine sink gillnet fishery. Restrictions on groundfish catch in this fishery were to await the results of studies determining the effectiveness of a technological solution ("pingers") to the incidental take of harbor porpoise.

Several good histories of the Georges Bank and Gulf of Maine groundfish fisheries have been written (Doeringer and Terkla 1995; Collins 1994; Anthony 1993; Serchuk and Wigley 1992) and will not be repeated here. The otter trawl was introduced at the turn of the century, changing the nature of the fishery dramatically. Murawski (1994) presents data demonstrating that the capture of juveniles of target species was the predominant form of bycatch. Between 1915 and 1940, cod was considered a bycatch in the directed fishery for haddock. Concern for depletion of groundfish stocks emerged as distant water fleets, mainly from Canada, the Soviet Union, Spain, Poland, and other nations, entered the fishery in the early 1960s. Anthony (1993) reports that these fleets, and U.S. fishers, moved from one target stock to another as each stock was depleted in turn. The predominant forms of bycatch were nontarget species, which were landed as byproducts, and juveniles of target species, which were discarded in some cases.

National catch quotas were instituted by the International Commission on North Atlantic Fisheries (ICNAF) in the early 1970s, and this approach was adopted by the NEFMC when it was established through the implementation of the Magnuson Act in 1977. NEFMC (1994) notes that this management practice led to increased entry and to derby behavior in the fishery. Replacement of the catch quota with individual trip limits occurred in 1980, but these limits were

[37] Possession and landings of the latter two species must be less than or equal to 10 percent of the total weight of all other species on board the vessel.

flouted because of NMFS' inability to monitor daily landings. In 1982, the quota system was replaced with minimum fish size and mesh size regulations.

Murawski (1994) reports that the predominant form of bycatch in the New England groundfish fisheries are now elasmobranchs, including skates and dogfish (Figure 6). However, stocks of these species have begun to dominate the ecosystem, occupying a niche that was formerly occupied by cod, haddock, flounders, and other groundfish. These species currently have limited market potential, and therefore discards of these species are not of paramount concern. Historical targeting of groundfish, with concomitant discards of juveniles or below minimum size groundfish, has led to the current situation in which there is increased concern for bycatch of groundfish.

The current management regime is described in Table 5 and is summarized in NMFS (1995, 1995). The table belies the extraordinary complexity of the management system, which is currently changing. Gear-oriented bycatch solutions include the use of nordmore grates in the Northern shrimp fishery in Gulf of Maine, pingers on gillnets, and time-of-day adjustments. Nordmore grates have been especially successful in the reduction of bycatch in the northern shrimp fishery (Figure 7).

The main objective of the proposed "Amendment 7" to the Northeast Multispecies Fishery Management Plan is to reduce the fishing mortality of Georges Bank cod, haddock and yellowtail flounder and Southern New England yellowtail flounder to as "close to zero as practicable." Although the management details of Amendment 7 are still to be decided upon, it is clear that the New England Fishery Management Council will permit some minimal fishing to occur while allowing roundfish and flatfish stocks to rebuild.

Current and proposed management involves the use of combined gear restrictions and size limitations, along with other controlled access rules. The most difficult bycatch problem relates to the discard of younger cohorts of groundfish because of the size limitations and the discard of groundfish of all sizes in the small mesh, scallop dredge (especially monkfish), and midwater trawl fisheries. In addition to the adverse effects on stock recruitment, discards of juveniles are thought to be economically wasteful. This problem is ubiquitous in groundfish fisheries worldwide.

The main policy issue is how to encourage landings of discards without encouraging

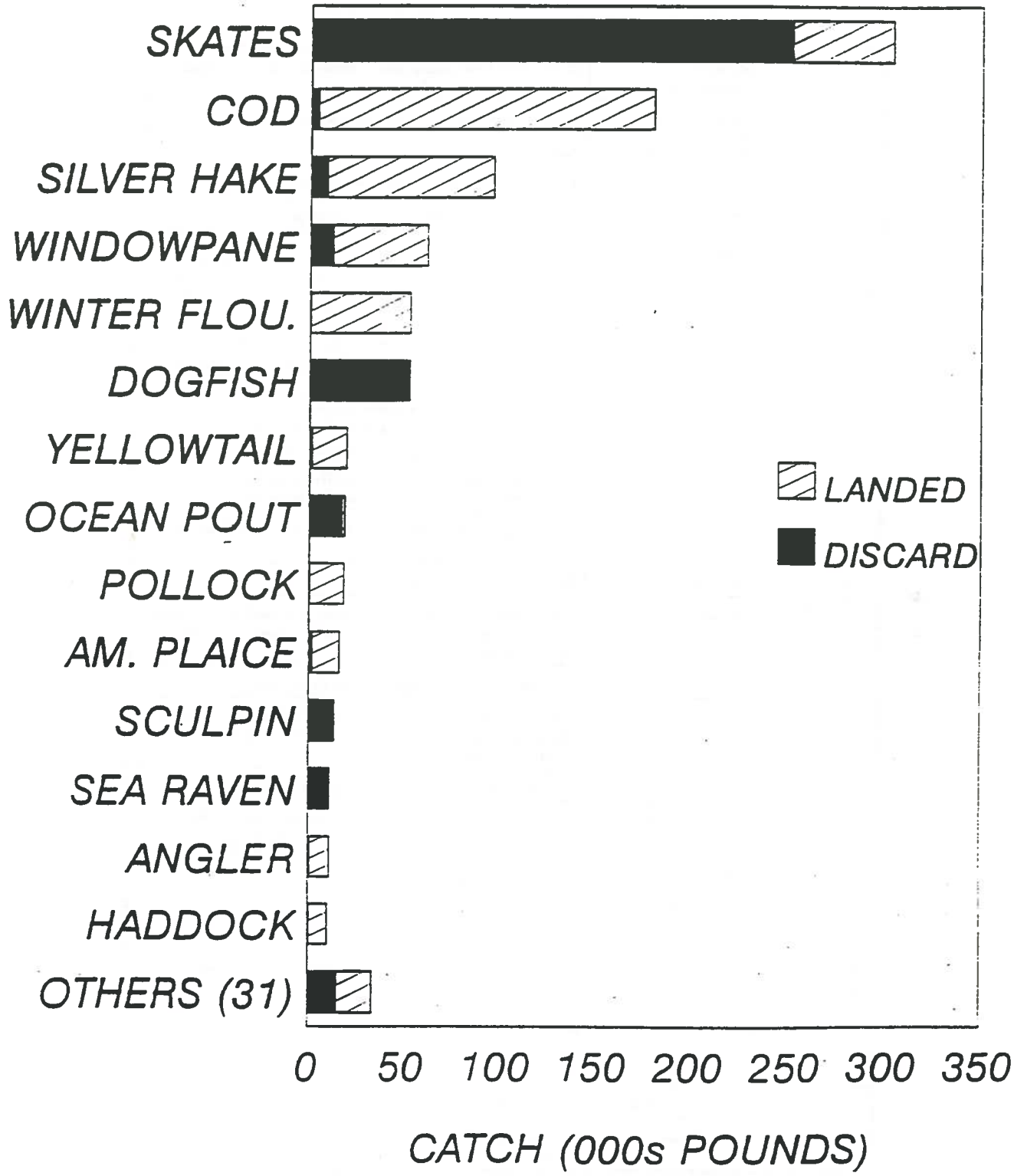

Figure 6: Distribution across species of the amount of bycatch in the Georges Bank groundfish trawl fishery in 1991. Bars represent the proportion of landed and discarded fish. Data are from the "Sea Sampling" observer program. Source: NOAA Tech. Memo. NMFS-NE-108.

Permits	Northeast Multispecies Vessel	Allocated to 1990 groundfishers; Renewable annually unless voluntarily relinquished
	Hook-gear Vessel	<4500 hooks (includes party and charter boats)
	Maximum-Possession Limit Vessel (<500 pounds of the ten large mesh species)	Non-groundfishers
		Scallop dredges (when fishing under scallop DAS)
		Multispecies permittees declared "out of groundfishing"
	Operator	Multispecies or possession-limit vessels
	Dealer	Person who receives groundfish by purchase, barter, or trade
Effort Controls	Multispecies permit moratorium	No new entry after 21 February 1991
	Vessel upgrade restrictions	<10% of length, GRT, net tonnage (limited to one upgrade)
		<20% of horsepower (limited to one upgrade)
	Time limits	Fleet-wide time "out of groundfishing" for trawls >45' in length, including 20 day period during March-May, or
		Individual allocation of days-at-sea (DAS) for trawls >45' in length, including 20 day period during March-May
		Sink gillnets must be "out of the water" for prespecified blocks of time each month
Gear Restrictions	Pair trawling	Prohibited in March 1994
	Minimum mesh size	5.5" diamond mesh or 6" square mesh in codend or 6" diamond or square mesh in entire net for all bottom trawls, depending upon location
		3" mesh in Cultivator Shoal whiting (silver hake) fishery
	Small-mesh fisheries	Subject to minimum possession limit (<500 pounds), includes purse seines and midwater trawls for herring, mackerel, and menhaden: area/time limits
	Finfish excluders	Nordmore grate required in northern shrimp fishery
Size Limits	Minimum fish sizes	Tied to mesh size restriction; length at which 25% of this size fish are retained by the relevant minimum mesh size
Area Closures	Haddock Area I	Closed all year, including scallopers
	Haddock Area II	Closed all year, including scallopers
	Nantucket Lightship	Closed all year, including scallopers
Possession Limits	Groundfish	<500 pound limit for possession-limit permittees, scallop dredges, and "out of groundfishing" multispecies permittees
	Haddock	<500 pound limit for all vessels
		Prohibition on landings or possession for scallop dredges during January-June
Other	Groundfish Transfers	Prohibited
	Data Reporting	Mandatory: landing reports, logbooks, VTS "call in" system, potential observer coverage

Table 5: The Northeast multispecies management system under Amendment 5. Many of the details of this system will change under the pending Amendment 7.

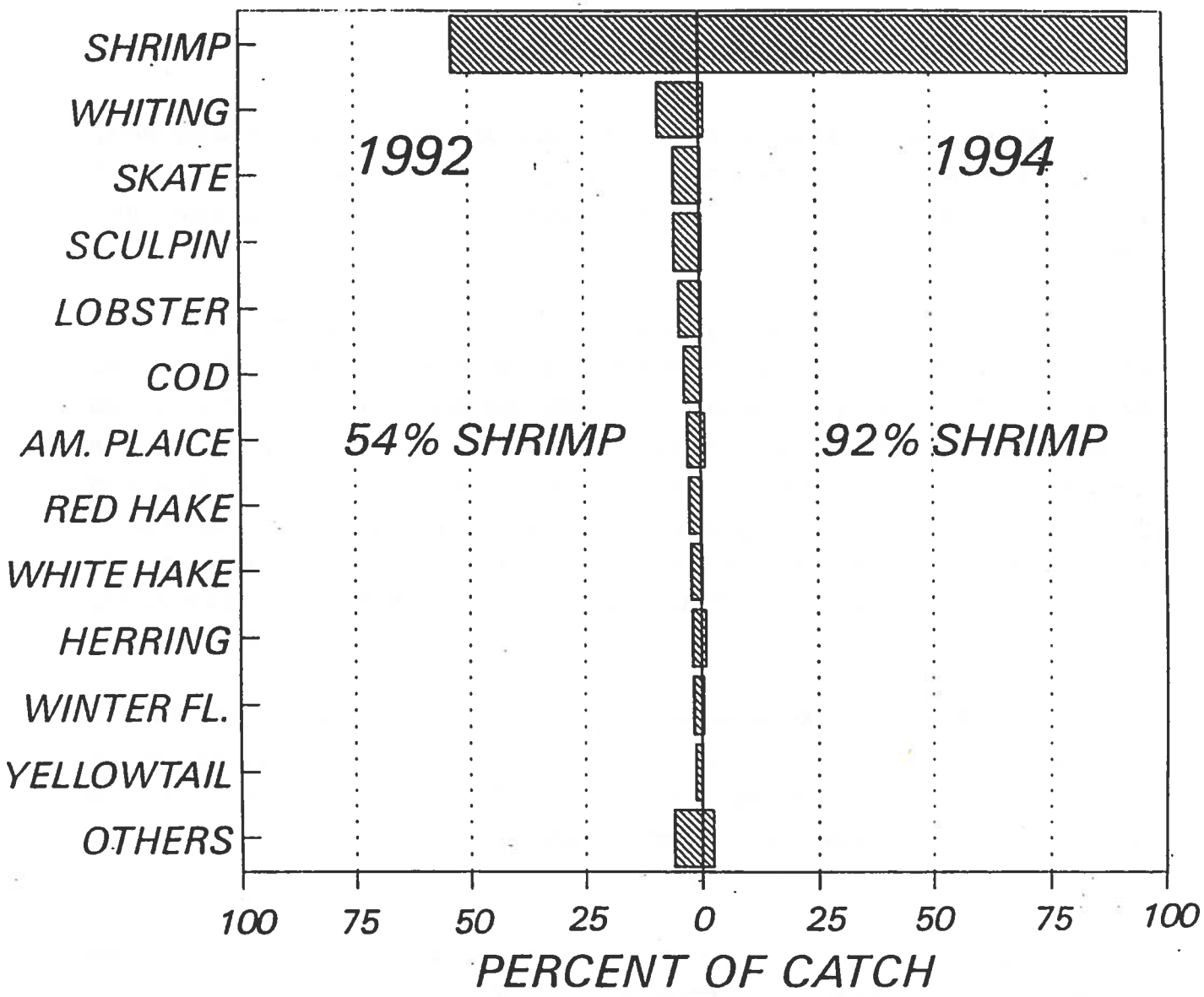

Figure 7: Change in the proportional species composition of catch in the northern shrimp fishery after the adoption of the "nordmore grate" finfish bycatch reduction device. (Note also that groundfish abundance decreased during the period.) Source: NOAA Tech. Memo. NMFS-NE-108.

fishers to target on these protected cohorts (Huppert 1989). One possibility is to design and implement a charge or an ITQ, or a combination of the two, to address this problem.

B. Gulf of Mexico Shrimp and Reef Fish

Two of the most important fisheries in the Gulf of Mexico (GOM) are those for shrimp and reef fish. These fisheries represent an interesting case because of the substantial bycatch of reef fish, a commercial species, in the shrimp trawl fishery. Thus this case represents a producer-producer bycatch problem.

There are three primary shrimp species: brown, white, and pink. In the EEZ, these species are covered by the GOM Shrimp Fishery Management Plan; the royal red shrimp will be covered in 1995. Shrimp are caught primarily with otter trawls and landed in all of the Gulf states. Spatial distributions of shrimp exist in the Gulf with brown shrimp off the coasts of Texas and Louisiana, white shrimp off the coast of Louisiana, and pink shrimp of the coast of Florida. Seasonal closures are employed in Florida Bay to ameliorate gear conflicts with the stone crab fishery. Bycatch of endangered sea turtles became an important issue during the 1980s (NRC 1990). Turtle excluder devices (TEDs) became mandatory on otter trawls during 1989-90.[38]

The GOM Reef Fish Management Plan governs the harvest of over 70 species of reef fish, but the primary species are red and vermillion snapper, and the red and nassau groupers. The primary gear types are handlines, bottom longlines, fish traps, and spearfishing. In terms of total landings, recreational catches of reef fish are nearly as large as commercial landings. Most reef fish are landed in Florida.

Significant levels of reef fish and other finfish are caught as bycatch in the shrimp trawl fishery (Table 6). Of particular concern is the bycatch of red snapper (Figure 8).

Shrimp have been covered under a federal fishery management plan since 1981. Federal

[38] Under a provision incorporated into the 1989 amendments to the U.S. Endangered Species Act, the United States is authorized to embargo imports of shrimp from nations that employ shrimp harvesting methods that could harm protected turtles. Although the application of this law has been limited to the Caribbean, a recent U.S. Court of International Trade ruling has interpreted the amendments to apply to all other nations exporting shrimp to the U.S. market.

Species	Millions of Fish
Atlantic Croaker	5600
Sea Trouts	1300
Longspine Porgy	1300
Spot	680
Gulf Butterfish	400
Atlantic Cutlassfish	130
Hardhead Catfish	112
Atlantic Bumper	110
Red Snapper	20
Spanish Mackerel	3.2
King Mackerel	1.3
Vermilion Snapper	0.9
Red Drum	0.2
Sharks	(5.6 m lbs)

Table 6: Estimate of 1989 Gulf Offshore shrimp fleet bycatch. Source: Nichols et al. 1990.

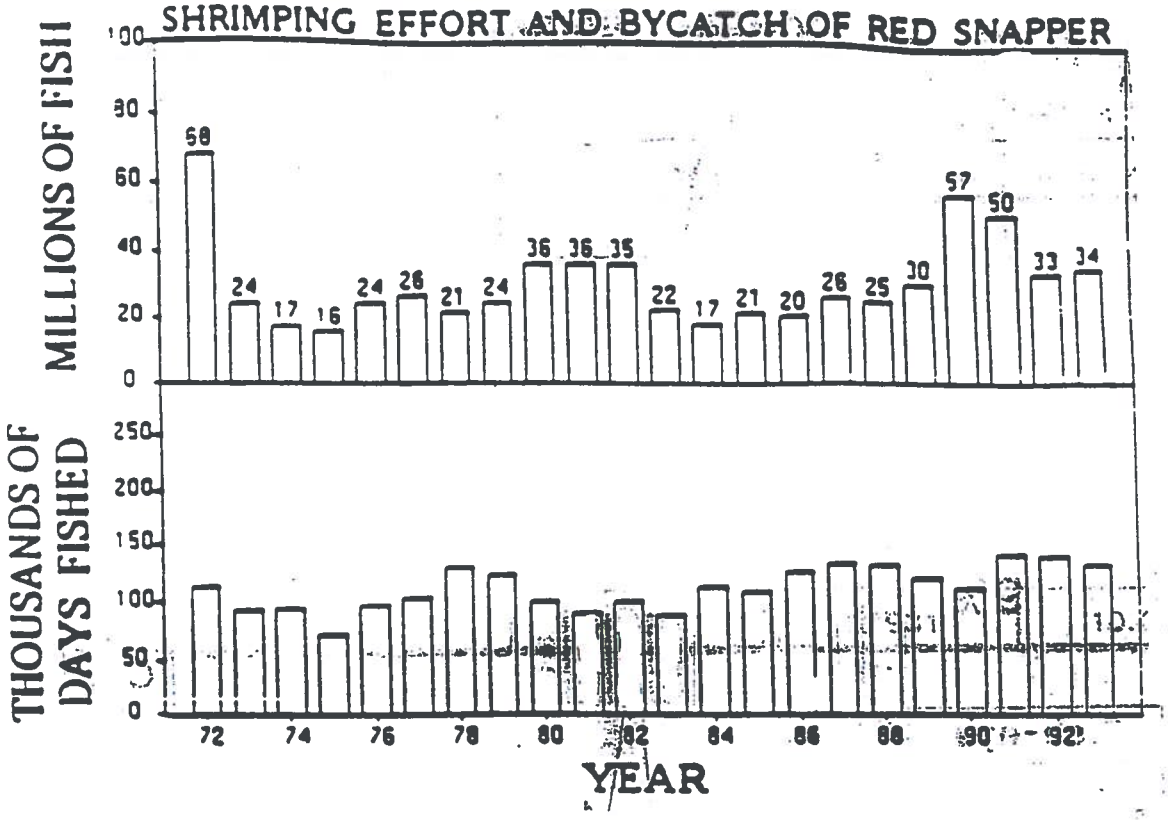

Figure 8: Estimates of the total annual number of red snapper discards as shrimp bycatch (top) and effort in the shrimp fishery (bottom). Source: Goodyear (1994).

management has focused historically on reducing effort on juvenile shrimp, including the establishment of the Tortugas Shrimp Sanctuary for pink shrimp and a seasonal closure off the coast of Texas to protect migrating juvenile brown shrimp. Overfishing has been defined for each of the covered species, but the shrimp fleet remains overcapitalized and overexploited.

Ward and Sutinen (1994) study the decisions of shrimpers to enter or exit the Gulf of Mexico shrimp fishery. These authors find, among other results, that the probability of entry responds negatively to fleet size, indicating that crowding externalities can occur, and positively to the abundance of shrimp. They conclude that tariffs[39] or quota restrictions on imports of shrimp, such as those that may result from embargoes of non-"turtle safe" shrimp, are likely to raise the price of shrimp, counteracting the effect of the crowding externality. As a result, the probability of entry into the fleet will increase, and overcapacity will be exacerbated.

A proposed Amendment 9 to the GOM shrimp FMP is directed at achieving a 50 percent reduction in the bycatch mortality of red snapper from the average bycatch level during 1984-1989. The objective of the Management Council is to reduce bycatch mortality to fish, mackerel, and groundfish stocks without adverse economic effects to the shrimp fishery. Studies have shown (Table 7) that gear modifications are both less costly and more effective than area closures as a method of reducing bycatch (Hendrickson and Griffin 1993).

Juvenile red snapper are particularly susceptible to bycatch in shrimp otter trawls. Studies have shown that only an estimated 25 percent of age 0-1 red snappers recruit to the commercial snapper fishery (SFSC 1993). Other juveniles are discarded by shrimp trawlers. TEDs are effective at removing larger reef fish and other finfish from the trawls (Graham 1995).

In 1990, the Management Council received a pledge of assistance from GOM shrimp fishers to reduce red snapper bycatch mortality by 50 percent by 1993. This assistance may have been prompted in part by federal amendments to the Magnuson Act calling for a three-year program to assess the impact of the incidental harvest of fishery resources by the shrimp trawl fishery. NMFS worked in conjunction with the Gulf and South Atlantic Fisheries Development Foundation to organize a 34-member Finfish Bycatch Steering Committee. The Committee developed and implemented a research plan (NMFS 1995).

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[39] Tariffs on imports of seafood are yet another market-based approach that we do not address in this report.

Management policy	Discards	Survivors[a]	Fish still subject to trawls
TED	8.338	8.460	11.51
By-catch reduction devices			
5% shrimp loss and 25% red snapper reduction	6.651 (−20.2)	9.828 (16.2)	12.88 (11.9)
5% shrimp loss and 50% red snapper reduction	4.960 (−40.5)	11.25 (33.0)	14.23 (23.6)
10% shrimp loss and 25% red snapper reduction	6.435 (−22.8)	10.01 (18.3)	13.03 (13.2)
10% shrimp loss and 50% red snapper reduction	4.798 (−42.5)	11.38 (34.5)	14.35 (24.7)
Closures			
May 1–Jul 15	8.166 (−2.1)	8.596 (1.6)	11.27 (−2.1)
May 1–Jul 31	7.888 (−5.4)	8.835 (4.4)	11.46 (−0.4)
Jan 1–Mar 31	7.738 (−7.2)	8.982 (6.2)	11.48 (−0.3)
Jan 1–Apr 30	7.518 (−9.8)	9.152 (8.2)	11.52 (0.1)
Dec 16–Apr 30	7.084 (−15.0)	9.509 (12.4)	11.97 (4.0)

[a] Fish large enough to no longer be vulnerable to shrimp trawls.

Table 7: Red snapper: numbers (in millions) of gulfwide discards, survivors, and fish still subject to trawls in year 10 for each management policy. Percent change is measured relative to a simulation for the TED policy (in parentheses). Source: Hendrickson and Griffin (1993).

Ward (1994) develops a multispecies model of the adoption of finfish bycatch reduction devices in the GOM shrimp trawl fishery. He finds that the adoption of this technology will have little impact on the equilibrium stock size of the bycatch species. The reason for this is that both the commercial and recreational fisheries directed at finfish will increase their efforts. Ward's model predicts that economic rents will be competed away in the finfish fisheries unless regulations are imposed to control effort in the finfish fishery.

Given the long experience with bycatch issues in the GOM shrimp fishery, it is surprising to find that market-based approaches have never been seriously considered to deal with the bycatch of finfish in the shrimp trawl fishery. NMFS (1995) states that the Steering Committee considered only bycatch reduction devices, season or area closures, time of day closures, explicit fishing effort limits, and onboard bycatch handling procedures. The "Shrimp Team" of the National ITQ Study considered ITQs for the gulf shrimp fishery (Anderson 1992). The Team recognized that although the size of the annual "crop" of shrimp did not seem to vary with harvest effort, the total effort in the fishery has been increasing causing catch per unit effort to drop. An ITQ program directed at the target shrimp fishery would reduce effort, causing a reduction in total bycatch of finfish and turtles, while leaving the total yield of shrimp unaffected.

Ward's (1994) findings suggest that a comprehensive bycatch management regime in the GOM should include effort restrictions on the commercial and recreational finfish fisheries. Anderson et al. (1992) suggest that an ITQ program might be feasible in this fishery, and the Gulf of Mexico Fishery Management Council has approved and ITQ program for the red snapper fishery to be implemented in 1996.

C. Eastern Tropical Pacific Yellowfin Tuna

The Eastern Tropical Pacific (ETP) is located from approximately 35 degrees north latitude to 20 degrees south latitude, and east of 160 degrees west longitude, to the mainland of the Americas (Figure 9).

Yellowfin tuna (Thunnas albacares) and skipjack tuna (Katsuwonus pelamis) are the two primary species targeted by ETP fishing fleets. The landings of both yellowfin and skipjack from the ETP constitute approximately 25 percent of the world's tuna catch (NRC 1992).

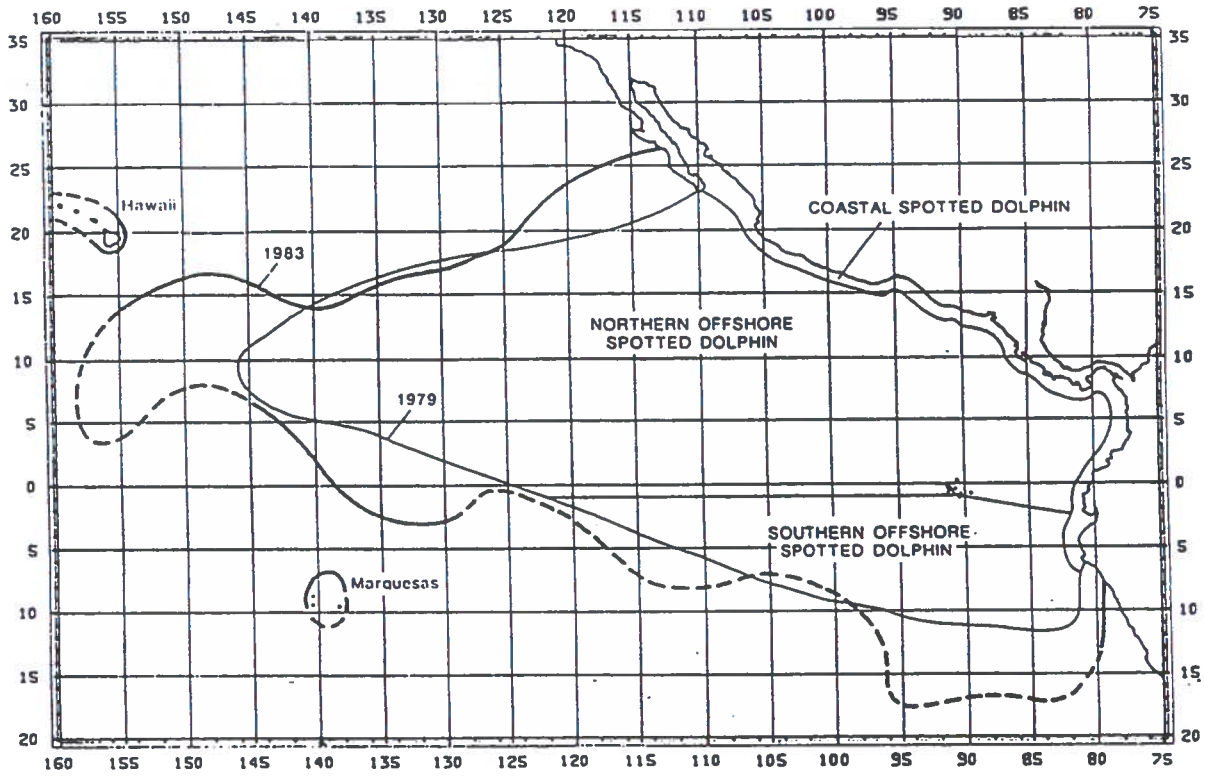

Figure 9: Distribution of dolphin species in the eastern tropical Pacific Ocean.

Purse seine fishing methods are employed in three ways to harvest tuna in the ETP: (1) "school fishing"--deploying nets around free-swimming schools of tuna; (2) "log or flotsam fishing"--deploying nets around schools of tuna as they aggregate beneath floating objects; and (3) "dolphin fishing"--deploying nets around schools of dolphins in order to capture the associating yellowfin tuna.

Bycatch in both school and flotsam fishing consists of: small tuna, mahi mahi, sharks, rays, wahoo, other small fish, billfish, yellowtail, trigger fish, other large fish and sea turtles which are captured but rarely killed or injured as a result of fishing (Hall 1995).

Bycatch in dolphin fishing include predominantly spinner, spotted and common dolphin, and small numbers of finfish, sharks, rays, and turtles (IATTC 1994). NMFS has estimated that more than 6.1 million dolphins have been killed in the ETP tuna fishery since 1959.[40] In 1993, NMFS determined that the two major stocks of marine mammals taken in the ETP tuna fishery are below their maximum net productivity levels. The stock of eastern spinner dolphin (Stenella longiriostris orientalis) was determined to be at 44% of its original, pre-exploited level. The major stock of dolphin--the northeastern offshore spotted dolphin (Stenella attenuata), which has been involved in more than ninety percent of dolphin sets for tuna--had been reduced to twenty-three percent of their pre-exploited population.

Sea turtles are rarely drowned in purse seine nets, as the nets are retrieved too quickly, however, they are caught and treated as catch by some crew members. The greatest danger to endangered species of turtles in the ETP fishery is not being killed in nets but injured by being dropped or eaten by the crew.

Background. Tuna fishing in the eastern Pacific Ocean began in the early 1920's. Most of the tuna was caught by hook, on longlines or by baitboats, until the late 1950's to early 1960's. During those early years, bait boats dominated the fishery, harvesting about 80 percent of the total landings. The bait boats fished within two hundred miles of the mainland and around offshore islands such as the Galapagos.

Fishermen have long understood that marine mammals and tuna share a strong associative bond that could be utilized to harvest yellowfin. By locating schools of dolphin, often by sighting birds overhead, fishermen found the tuna. Once close to the schools of marine

[40] Federal Register, Vol. 57, No. 117, p. 27010, June 17, 1992

mammals, fishermen chummed the water with live bait, creating a feeding frenzy, and then lowered hooks into the water. By using sonar capabilities, dolphins detected the metal hooks and bit only live bait while the tuna bit voraciously at anything shiny, even the unbaited hooks that the fishermen yanked from the water.

Early ETP fishermen took advantage of the tuna-dolphin association to harvest tuna without affecting schools of dolphin. The dolphins, in fact, were not harmed but were "rewarded" with live bait. Thus, there existed a symbiotic relationship between the fishermen and the marine mammals. Old-time fishermen have said that, instead having to seek out the schools of dolphin, dolphins would actually come to them.

During the late 1950's to early 1960's, new technological developments including nylon netting, hydraulics, and ammonia-cooled refrigeration systems changed the industry. From that time on, the efficiency of fishing for yellowfin tuna in the ETP was greatly increased.

One of the most important technological developments was the "Puretic" hydraulic power block, which allowed for the rapid recovery of large nets. Lighter woven nylon with greater tensile strength were adopted. Such nets permitted faster net sinkage along with decreased retrieval times. Nets up to a mile in length and greater than three hundred feet deep were used in combination with speedboats to chase, herd, and confine entire schools of dolphins, sometimes consisting of thousands of animals.

It is estimated that in 1959, 590 dolphin sets occurred. In 1960 the total shot up to 5400 (IATTC 1986). The highest recorded yellowfin tuna catch per standard day of fishing was also recorded in 1960 (Sheeley and Wilkinson 1988).

From this point on the nature of the fishery changed dramatically--tuna seiners capable of landing more than 1700 tons of fish were in demand, and bait boats became obsolete. Bait boats were quickly converted to purse seiners, and those that did not convert were forced to leave the fishery. On-board helicopters were introduced early in 1961 to spot dolphins, and the tuna fleet began to overcapitalize. So many extremely efficient large vessels were built that officials of the Inter-American Tropical Tuna Commission (IATTC) became concerned that the fishery could be overwhelmed (Sheeley and Wilkinson 1988).

The "backdown" procedure was developed and perfected by the U.S. fishing industry in

the early 1960's in an attempt to increase active fishing effort by reducing time wasted extracting dead dolphins from the nets. Backdown occurs when 1/2 to 2/3 of the net has been secured aboard the seiner and the engines are reversed. This causes an elongated narrow channel to form. Water flow forces the corklines to sink, thereby allowing dolphins to pass over the net and out into the open sea. Often stationed around the backdown area are manned rafts to further assist the dolphins. There are typically several stages of backdown, as care must be taken not to allow schooling tuna inside the net to escape with the dolphins.

The next major innovation developed to reduce the entanglement of dolphins in tuna nets was a fine mesh panel of netting called the "Medina panel." Medina panels dramatically reduce the entanglement of dolphin rostrums or flippers during backdown. Medina panels began replacing standard mesh in the backdown area of fishing nets in 1971.

A rapid expansion of the ETP tuna fleet took place from the late 1960's to the mid 1970's leading to further overcapitalization of the fishery. New vessels known as "super seiners" were built. These vessels, capable of remaining at sea for months harvesting and storing close to 2000 tons of tuna, replaced the converted bait boats and original seiners. From 1965 to 1980, total fleet capacity grew from 48,673 tons to 189,426 tons, exceeding the availability of the yellowfin resource. Catch per standard day of fishing decreased from eight tons in 1960 to two tons in 1980 (IATTC 1986).

With a recommended available harvest of 210,000 tons of yellowfin in 1980, the fishery could withstand on the average a little more than one fishing trip per vessel per year. At that time, purse seine vessels of one thousand tons or more capacity required at least two and a half trips a year in order to break even (Joseph and Greenough 1986).

El Nino events affect the ETP tuna stocks and fishing effort. Sheeley and Wilkinson (1988) report that:

> El Nino conditions prevailed in the ETP from late 1982 to early 1984. During an El Nino the thermocline is deepened and yellowfin become unavailable to the surface fishery. An exodus of vessels from the ETP to the Western Pacific began with 29 vessels leaving in 1982 and 62 leaving in 1983. The subsequent decreased fishing pressure allowed yellowfin stocks a respite and chance to rebound. . . . Vessels returning to the ETP in 1985 experienced the largest catch of yellowfin (240,000 short tons) since 1976. In 1986 the yellowfin catch of 296,000 tons was the highest ever recorded. Both the 1985 and 1986 catches

exceeded the IATTC recommended quotas.

Fishery management. As demand for yellowfin tuna grew in the 1980s, the less developed nations bordering the ETP increasingly insisted on the right to manage and exploit the resource. In light of a well equipped U.S. fleet capable of harvesting large amounts of fish throughout the ETP, competition for the resource increased.

The IATTC was established by treaty in 1949 as a research and management organization. Participating nations include Canada, Costa Rica, Ecuador, France, Japan, Mexico, Nicaragua, Panama and the United States. In 1976, realizing the importance of dolphin stocks in maintaining a viable fishery, the IATTC expanded its duties to address the tuna-dolphin association. Although the Commission cannot regulate or prevent the exploitation of dolphins by the tuna industry, it has assumed the task of monitoring the impact of the fishery on dolphin stocks with an eye toward reducing mortality through alternative methods and education. The IATTC also monitors the international fleet's kill levels and dolphin stock abundance levels, and instructs nations on mortality reducing gear, techniques and U.S. laws applicable for market access (Sheeley and Wilkinson 1988).

During the 1984 reauthorization of the U.S. Marine Mammal Protection Act (MMPA) a "foreign comparability" provision was included to help alleviate the rising dolphin mortality levels by the international fleet. Under this provision, if a foreign nation did not have a dolphin regulatory program comparable to that of the United States, the U.S. market would be effectively closed to exports of tuna. It was not until 22 March 1988, however, that NMFS issued interim final regulations--just prior to the 1988 reauthorization of the Act. So it was through the 1988 reauthorization of the MMPA that guidance in the form of specific Congressional parameters were mandated which made the well-publicized tuna embargoes a reality in 1990.

The 1988 amendments to the U.S. Marine Mammal Protection Act further required "intermediary countries" (those receiving tuna from another country), who wished to export tuna into the U.S., to show proof of comparable dolphin protection programs in keeping with the precautions required by United States law. The required provisions determined, among other things, that: intermediary nations be prohibited from importing tuna from countries embargoed by the United States for violations of comparability standards; importing nations have prohibitions against exploiting certain species of dolphins in pure schools; and nations refrain from exploiting dolphins in "sundown" sets or near dusk, when the majority of dolphin

mortalities take place.

In addition, foreign programs must be monitored with observer placement comparable to the U.S. through the IATTC, or another international program. Perhaps most critical are the qualitative requirements that triggered a 1990 embargo--that the average kill rate cannot be greater than two times that of the U.S. fleet during the same period by the end of the 1989 fishing season, and no greater than 1.25 times that of the U.S. fleet by the end of 1990 and on to subsequent fishing seasons.

On July 19, 1989, Congresswoman Barbara Boxer (D-CA) introduced the "Dolphin Protection Consumer Information Act" (DPCIA). In an effort to give consumers a chance to help protect dolphins, the bill called for the labeling of tuna products as to whether or not they involved the killing of dolphins. This initiative was in response to the still-growing public outcry of the continued killing of tens of thousands of dolphins annually in tuna purse seines. In late October 1990, Congress passed the "dolphin safe" tuna labeling law. This precedent setting legislation,[41] designed to reduce dolphin bycatch, was signed into law in November 1990 by President George Bush.

Bycatch Solutions. On April 12, 1990, in a bold move designed to preempt the building momentum of the dolphin safe tuna labeling initiative, H.J. Heinz, parent company of StarKist Seafoods, announced the adoption of a voluntary dolphin safe policy. Heinz said it would refuse to purchase or sell any tuna caught in ways that harmed dolphins. Within hours, Unicord, (parent company of Bumblebee) and Van Camp (parent company of Chicken of the Sea) announced similar policies. The tuna canners and the environmental community worked cooperatively for the remainder of the year to secure passage of the DPCIA in order to ensure consumer confidence.

The combined result of the tuna processors dolphin safe policy and passage of the DPCIA led to both a decrease in the number of U.S. fishing vessels encircling schools of dolphins for tuna and a decrease in the United States incidental dolphin mortality from 5,083 in 1990 to 812 in 1991, and to fewer than 500 in 1992 (MMC 1992).

Implementation of regulations by NMFS in September 1991 allowed observer coverage

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[41] The Dolphin Protection Consumer Information Act (DPCIA) was the first labeling law in the history of the United States to protect wildlife.

and a tracking and verification system to codify the voluntary measures taken by the tuna processors. Consumers should have confidence in dolphin safe claims, at least with regard to tuna harvested in the ETP.

International Agreements and U.S. Law. A 1990 embargo of Mexican yellowfin under the comparability provisions of the MMPA brought the tuna-dolphin controversy before a dispute panel convened by the General Agreement on Tariffs and Trade (GATT) in September 1991. The panel was sympathetic to Mexico's complaint of an unfair trade practice by the U.S. and supported Mexico in a preliminary report.

With the tuna embargoes mired in international controversy, Congress again took up the issue in 1992 with the "International Dolphin Conservation Act" (IDCA). The IDCA was an effort to blend a domestic legislative initiative with a multilateral conservation regime. Provisions in the IDCA include an international dolphin safe research program, prohibitions on the sale of dolphin unsafe tuna in the United States, and mandatory observer coverage on all vessels fishing in the ETP.

In 1992, amendments to the MMPA also dropped the 20,500 incidental take of dolphin quota for the U.S. fleet. The quota, which had been in place in the form of a general permit since 1978, was to be racheted down to 1,000 for 1992 and 800 for 1993 and early 1994. On March 1, 1994, the permit was to expire completely, yielding a zero quota. But there was a catch--at least some foreign countries had to enter into agreement establishing a moratorium. To date none have, and in the absence of a moratorium, the general permit will remain in place until 1999 subject to a decreasing annual quota.

In April 1992, about the same time that Congress was deliberating the IDCA, representatives of nations to the IATTC were meeting in La Jolla, California, to reach agreement on a program to reduce dolphin mortality over a seven-year period to "levels approaching zero." The plan that was finally agreed upon is known as the La Jolla Resolution (LJR).

The LJR permits the continued encirclement of dolphins but establishes a program that includes all the hallmarks of the U.S. dolphin protection program that resulted from the 1988 reauthorization of the MMPA (observers, maintaining high skipper performance standards, prohibition on sundown sets, prohibition on the use of explosives, etc.) including a commitment to rachet down the level of observable dolphin mortalities to levels approaching zero.

The LJR calls for all vessels with greater than 400 short tons carrying capacity fishing in the ETP to be assigned a Dolphin Mortality Limit (DML). Beginning in 1993 the figure of 19,500 was divided by the total number of active and qualified vessels with an adjusted limit. The DML is reduced each year, and any vessels reaching their DML are required to cease fishing in the ETP for the remainder of the year. The DMLs for each subsequent year are: 1994: 15,500 (later adjusted to 9,300); 1995: 12,000 (later adjusted to 9,300); 1996: 9,000; 1997: 7,500; 1998: 6,500; and 1999: <5,000. DMLs are certified through an observer program with 100 percent coverage on all vessels exceeding 400 short tons.

The LJR has been criticized on a number of grounds, including the fact that it may cede U.S. dolphin protection management authority to the IATTC, an institution with the primary mission of managing ETP tuna stocks, and the fact that decisionmaking under the LJR proceeds by consensus, giving every member veto power. Moreover, Mexico, the country with the largest fleet operating in the ETP, is not even a member of the IATTC.

The current LJR quota is not a binding constraint (the 1995 quota is 9,300, about twice the actual dolphin kills for 1994), providing little incentive for reducing the current level. Some environmental groups have become concerned that environmental standards are being undermined by trade agreements.

James Joseph, IATTC Director, has argued that as fishing effort shifts to a dolphin-safe fishing strategy, the ETP fishery itself will be damaged. ". . . If fishing effort shifts from catching large tuna associated with dolphins to the capture of small tuna with other modes of fishing, the abundance of yellowfin will decline, as will the resulting catch" (Joseph 1995).

Joseph also points to concerns about bycatch of other species (please see Figure 10). When exploiting dolphins for tuna the predominant bycatch are the dolphins themselves. But when school fishing, and especially log or flotsam fishing for tuna, the amount of discarded bycatch of other species is increased. ". . . The lowest discard rate is for dolphin-associated fish; the highest, for log fishing is several hundred times higher. Additionally, large numbers of small yellowfin of no commercial value are discarded: it is estimated that in 1993 and 1994 the fishery on logs discarded between 3.5 and 7.2 million small individuals of the species" (Joseph 1995).

An important policy issue in this fishery concerns the extent to which dolphin take at

	1993			1994		
	Dolphin sets	School sets	Log sets	Dolphin sets	School sets	Log sets
Dolphins	3,594	0	7	4,078	17	0
Billfishes	619	880	1,770	488	1,157	1,292
Large fishes	474	44,347	468,237	6,292	69,312	1,116,027
Small fishes	28,970	15,474	2,256,681	18,457	203,091	724,399
Sharks	12,646	14,632	47,355	2,570	16,357	27,418
Rays	1,075	6,433	177	711	4,160	173
Sea turtles	64	129	102	85	34	48
Unid./Othrs.	11	3	155	1,244	75	176
Invertebrates	305,472	177,467	8,202	621,552	224,942	151,751

Figure 10: Estimated total bycatch by species in the ETP yellowfin tuna fishery, 1993-94.

levels approaching a zero rate of mortality should be traded for increased bycatch of other stocks. A careful analysis of this tradeoff would consider the health of the populations in question, the relative reproductive potentials of the different stocks, and the impact of directed fishing on younger cohorts of tuna. This is an area for further research. Research might focus on gear types that minimize the impact on incidental marine species resulting from dolphin safe fishing methods involving flotsam and school fish.

Another factor that deserves further study is the extent of "cryptic" kills. Cryptic kills occur to animals which do not show signs of injury but later die from exhaustion or stress.

For many years the tuna industry has cited the percentage of dolphins "backed out" or released from nets relative to the number of dolphins captured as a way to demonstrate their dolphin rescue efficiency. In 1986, the tuna industry stated that 98.98% of the dolphins captured by the U.S. tuna fleet alone were released, indicating that more than two million dolphin were captured and a greater number were chased with helicopters, speedboats and the purse seine vessels in that one year alone (Sheeley and Wilkinson 1988).

It is a common practice for the various tuna fleets to work in code groups in order to maximize the efficiency of their fishing effort. Often when dolphins, along with the associating tuna, escape from one vessel, other vessels intercept the animals and continue the chase. It is also a common practice, once the net has been retrieved, for the same vessel to execute repeated chases on the portion of the school that previously evaded capture.

As a result, a single school of dolphin may be chased and encircled numerous times in a given day. This indirect form of bycatch is largely ignored today. It is important as a form of bycatch, and renewed attention should be directed at the impact of nonlethal encirclement on the relevant dolphin stocks.

In October 1995, U.S. fishing interests, members of five U.S.-based conservation groups, representatives of the "wise use" movement, the Clinton Administration, and representatives of the other IATTC member nations agreed to a revision of extant policy in a document known as the "Panama Declaration." The declaration calls for the lifting of the U.S. embargo on tuna caught "on dolphin." If the United States passes enabling legislation, the result will be an increased level of dolphin bycatch in the yellowfin tuna fishery. If the U.S. embargo is not lifted, Mexico and Venezuela have threatened to file a complaint against the United States under

the new procedures of the World Trade Organization.

Media Attention. What happens aboard tuna purse seine vessels was brought to the public's attention via Sam Labudde's video aboard a Panamanian seiner, and raised the level of the conservation debate at the inception of the 1988 MMPA reauthorization. Largely because of the public exposure of the video, the Act was reauthorized with strong provisions, including the foreign comparability provisions and the prohibition on sundown sets. With the processors announcement to buy only tuna that was not harvested in association with dolphins, and the passage of the DPCIA, which legislatively defined "dolphin safe" at the end of 1990, much of the U.S. fleet exited the ETP for the Western Pacific where the association of yellowfin with dolphins does not occur and a ready supply of dolphin safe tuna could be sold in the U.S. market.

Industry Initiatives and Sundown Sets. Backdown remains the only viable method for releasing dolphins from the nets. It is important to note that both the backdown procedure and the finer mesh Medina panel were developed and in use prior to passage of the MMPA in 1972. Both are currently the primary methods for reducing mortality when exploiting dolphins for tuna. Perhaps the single most important component leading to the dramatic decrease in dolphin mortalities beginning 1989 (Figure 11) was the prohibition on sundown sets mandated by the 1988 MMPA amendments.

Before 1989, the dolphin kill rate during sundown sets was three to four times greater than the average kill per set. As an example, in 1979 sundown sets accounted for only 10 percent of the total yellowfin catch, while causing 35.5 percent of the total dolphin mortality. Between 1977 and 1980 sundown sets only accounted for 8.2 percent of the tuna catch but 27.9 percent of the dolphin mortality (Sheeley and Wilkinson 1988).

As part of the 1988 amendments to the MMPA, the National Research Councils (NRC) was asked to perform an independent review of alternative methods to harvesting tuna in the ETP without encircling dolphins in purse seine nets. The NRC made recommendations in two parts: (1) developing methods and techniques to reduce dolphin mortalities by perfecting the existing purse seine method on schools of dolphins; and (2) researching and developing new methods independent of exploiting dolphins.

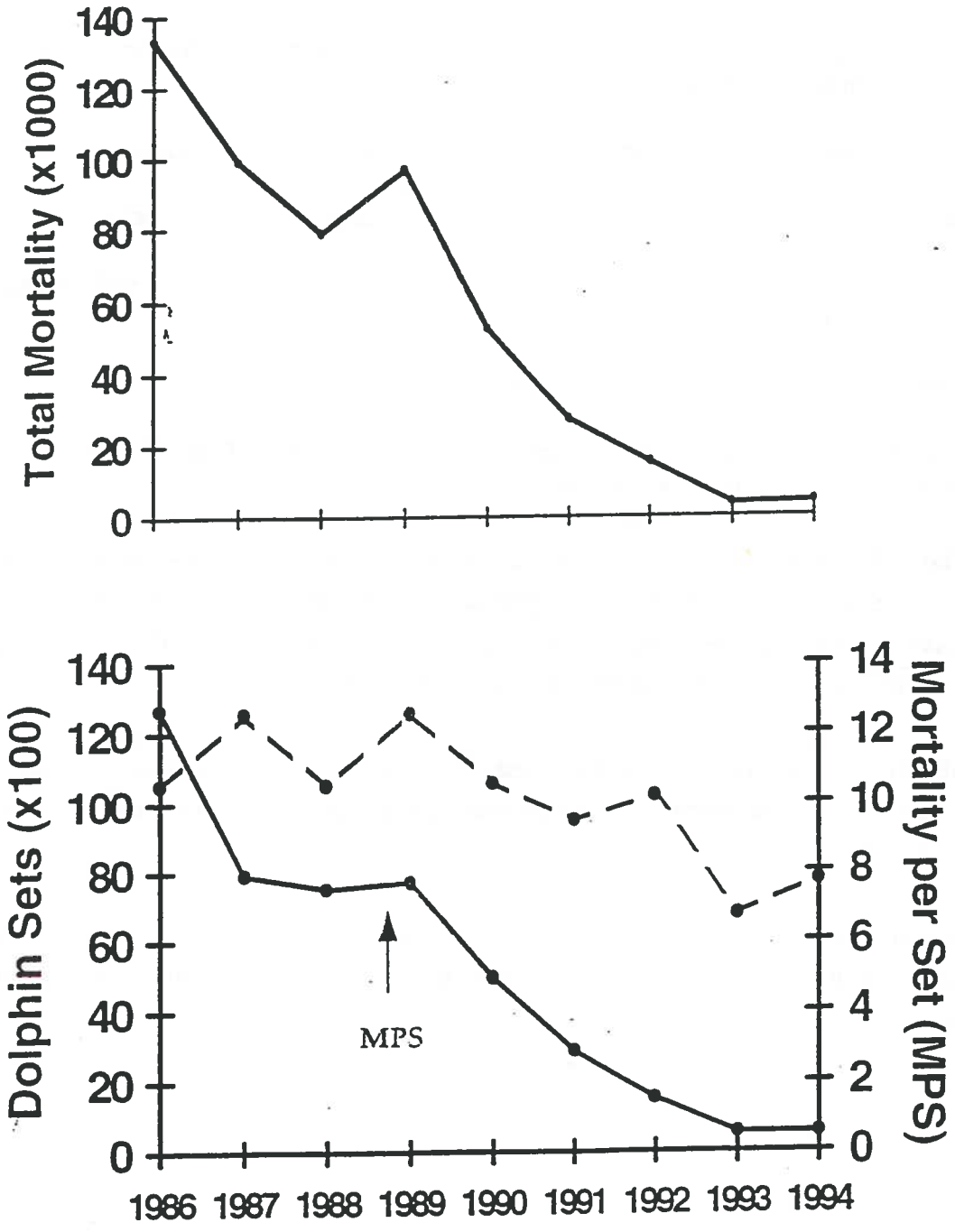

Figure 11: Total mortality, numbers of dolphin sets, and mortality per set (MPS) in the ETP yellowfin tuna fishery, 1986-1994.

The specific recommendations included:

(1) Development of an educational certification and monitoring protocol for all fishing captains in the international fleet;

(2) Research incentives to improve captain performance in limiting dolphin mortalities;

(3) Research into the behavior of tuna and dolphins, such as nocturnal behavior;

(4) Research on tracking flotsam-associated yellowfin, of log fish, and radio tagging and monitoring dolphins;

(5) Research the use of satellites to locate tuna aggregations; and

(6) Research assessment of the impact on tuna populations if purse seining for tuna associated with dolphin is discontinued.

The NRC research recommendations for developing new methods independent of exploiting dolphins have not been fully explored. Additional conservation measures for low reproductive species might be undertaken by member nations of the IATTC, both nationally at sea, and regionally by adopting binding resolutions through the IATTC.

Member nations to the IATTC might usefully focus on the bycatch of endangered species, including sea turtles. Monitoring and enforcement can be integrated into the existing observer program for dolphin.

A public education campaign could be designed with the cooperation of conservation groups and tuna processors, and coupled with the great appeal of dolphins, to provide funding for research.

7. Deciding Upon Appropriate Market-Based Incentives

A. Introduction

We turn now to the issue of determining what kinds of market-based incentives might be appropriate as approaches to the resolution of bycatch problems.

Whether or not bycatch is, in fact, a "problem" in any specific case requires the specification of a social objective for managing marine fisheries and their natural habitat. One such objective is to maximize the net present value from the relevant fisheries. In order to do this, the ecological characteristics of the target stock and its interactions with other stocks must be described (Wilen and Brown 1986; May et al. 1979). Without a serious attempt at constructing a model of the relevant fisheries that incorporates both ecological and economic components, we cannot say whether or not an objective of economic efficiency is likely to be achieved (Clark 1976; Plourde 1970).

In the discussion of Section 2 surrounding Table 1, we showed that economically suboptimal bycatch can occur when ownership is divided across stocks and at least one owner's fishing technology is nonselective. This definition hinges, of course, on the abilities of the owner(s) to calculate the relevant optimal sustainable yield in any specific case and to control fishing effort in their respective fisheries. The exercise of these abilities involves costs, particularly in terms of monitoring and enforcement activities (Anderson 1987; Sutinen and Andersen 1985).

We reiterate here that an important distinction must be made between the occurrence of bycatch at any level and the occurrence of an economically optimal level of bycatch (Arnason 1994). As in the case of environmental pollution problems, because of the costs involved with reducing bycatch, through modifications of gear design, reductions in or geographic displacement of fishing effort, or others, it is likely to be the case that an economically optimal level of bycatch involves the continuation of bycatch at some positive level.

In practice, multiple objectives may be sought simultaneously, complicating the process of managing bycatch. For example, economic efficiency may be one objective; minimizing economic impacts on identifiable interest groups might be another; and protecting ecological systems yet another. If these objectives are inconsistent in the sense that they cannot be fully

met simultaneously, then a process for trading off objectives must be utilized. This trade-off process might be made systematic, but, more often than not, it is likely to be political.[42]

An objective of achieving so-called "clean fisheries," or fisheries with low or zero levels of bycatch, is sometimes cited as an appropriate policy. However, if we disregard the ecological relationships among species, then one cannot say whether or not the selective removal of individuals from one stock in a clean fishery is better in an ecological sense than the removal, through bycatch, of individuals from several ecologically dependent stocks (Wilen and Brown 1986; Hannesson 1983; May et al. 1979). Similarly, if we ignore the economic costs of achieving a clean fishery, then lost opportunities may be incurred by devoting too much attention to the reduction of bycatch with relatively low economic or ecological significance.

In this section, we will focus on the use of market-based incentives to achieve cost-effective outcomes to meet pre-specified policy objectives. This focus will allow us to suggest appropriate policy instruments both in circumstances in which there is enough information to determine an economically optimal outcome and in circumstances in which a political decision has been reached about the most appropriate level of bycatch. We argue that it is appropriate to attempt to achieve the required level of bycatch reduction in the most efficient way, even if that level is determined by politics, not science.

B. A Qualitative Comparison of Instruments

In this subsection, we summarize the information from Section 5 that describes the economic attributes of market-based instruments (please see Table 8). This approach, while general in nature, mirrors that of Segerson (1995), Bohm and Russell (1985); and Marasco and Terry (1982).

We have made a series of qualitative judgements about the "usefulness" of the market-based policy instruments arrayed in Table 8. Each instrument can be described, in part, by its policy-relevant "features," which are listed in the leftmost column of the table. For each of the instruments, judgements about its policy-relevant features range from low to high. These features indicate each instrument's potential for (1) achieving economic efficiency (a score of

[42] We do not mean to imply that political decisionmaking proceeds in total ignorance of scientific inputs. However, fisheries management decisions often must be made in the absence of full information.

Table 8: Qualitative Comparison of Important Features of Market-Based Approaches to Bycatch Problems

Potential for:	Pigovian Tax	Charge	Pigovian Subsidy	Subsidy Removal	Buyout	Deposit-Refund	Product Label	ITBQ
Economic Efficiency[a]	high	moderate	high	high	moderate	high	high	high
Significant Enforcement Costs	high	high	moderate	low	low	high/ moderate	moderate	low
Management Information Costs	high	low	high	low	moderate	high	low	moderate
Entry	low	low	high	low	high	low	unknown	low
Surreptitious Discards	high[b]	high[b]	high[b]	unknown	low	high	high	high
Public Collection of Resource Rent	high	high[c]	low	moderate	low	low	low	high[d]
Industry Support for Instrument	low	low	high	low	moderate	moderate	low	moderate
Usefulness Overall	moderate	high	low	high	moderate	moderate	moderate	high

a/ Potential for efficiency exists, but may depend upon other instruments to correct other market failures.
b/ In the presence of inadequate enforcement.
c/ Only a proportion of the rent.
d/ If quotas are auctioned.

high is better); (2) incurring significant enforcement costs (low is better); (3) incurring management information costs (low is better); (4) encouraging entry into the fishery (low is better); (5) encouraging surreptitious discarding (low is better); (6) enhancing the public collection of resource rent (high is better); and (7) industry support for the implementation of the relevant instrument (high is better).

An overall usefulness assessment is made from the seven features for each instrument. This assessment is conducted, arguably somewhat arbitrarily, by weighting each feature equally. (Note that in assessing an overall score, we have made some judgements about whether or not a score of, say, "high" for any particular feature is good or bad. These judgements are indicated in parentheses after each feature in the previous paragraph.)

The results of the overall usefulness assessment suggest that bycatch charges, removal of existing subsidies, and tradeable bycatch quotas are among the most useful policy instruments. This conclusion must be qualified in each case. For example, bycatch charges may result in high levels of surreptitious discharges unless enforcement costs are incurred. Moreover, charges, as we have defined them, are not an "optimal" instrument; they merely act as incentives for fishers to move in the direction of reduced bycatch. The main advantage of charges over an optimal tax may be in the lower level of required information needed to set the charge (McKelvey 1986). A deposit-refund system could be implemented on the same basis as the charge system, making its ranking equivalent to the charge system ranking.

Subsidy removals can be highly useful because they are likely to lead to reduced effort in the target fishery. Although this may not change the proportion of bycatch at the vessel level, the total amount of bycatch for the fleet should decline (Anderson 1992; Wilen 1990).

Individually tradeable bycatch quotas also can be highly useful, if they are used in conjunction with effort controls in the target fishery. Because ITBQs are legally enforceable rights, there may be a higher likelihood of industry enforcement of fishing effort. A major impediment to the implementation of this instrument, however, may be the transactions costs associated with markets for multiple tradeable quota instruments.

We should warn the reader that this kind of comparison of instruments has its drawbacks. One of the most important is that it does not give a measure of the degree of importance of each of the features for each policy instrument. Notably, the degree of importance is likely to depend

upon the specific characteristics of the fishery for which they are being considered. Nevertheless, we feel that this comparison is a useful way of sorting out the policy-relevant features across instruments, and it helps to illustrate how a quantitative model might be designed to examine a specific case. And, with careful assumptions about the relative weights to assign to each of the features, this method may be generally useful in judging the usefulness of different market-based approaches in specific fisheries.

C. Effect of Uncertainty on the Choice of Instrument

In this section, we focus on uncertainty in the choice between market-based incentives. In particular, we examine two instruments that are believed to be equivalent under deterministic conditions: the pigovian tax and ITQs. This example helps to illustrate the need to examine the specific conditions of each case of bycatch before deciding upon the most appropriate instrument or combination of instruments.

We use, as an example, the impact of sink gillnet fishing in the Gulf of Maine on the harbor porpoise. We treat bycatch as the analog to a problem of environmental pollution, and we follow the analysis of Baumol and Oates (1988) to outline issues affecting instrument choice.

In the Gulf of Maine, gillnetters harvest many different types of fish stocks: cod, pollock, hake, angler, bluefish, dogfish, cusk, and mackerel. Gillnets are long stretches of net that are buoyed to the surface. Fish become entangled in the nets as they swim through. It has been estimated that from 2 to 5 percent of the Atlantic harbor porpoise stock is caught (or taken) "incidentally" in gillnets on an annual basis. Because the harbor porpoise is an air-breather, entrapment in a gillnet results in rapid mortality.

As is the case with other marine mammals, the harbor porpoise is protected under provisions of the U.S. Marine Mammal Protection Act (MMPA). Section 114 of the MMPA states that:

> . . . [I]t shall be the immediate goal that the incidental kill or serious injury of marine mammals permitted in the course of commercial fishing operations be reduced to insignificant levels approaching a zero mortality and serious injury rate.

An MMPA provision plan allows an exception to section 114 so that commercial fisheries which take certain categories of marine mammals can continue in operation.

Given a pre-established system of property rights under which resource ownership is incompletely defined[43], the incidental take of harbor porpoise by gillnetters is an example of rational fishers ignoring the social costs associated with the damage inflicted on individuals and groups in society who value the lives of porpoises.

A coasian solution may be precluded because of the potentially high transactions costs due to the large number of gillnetters, the large numbers of individuals who value porpoise lives, and the presence of the government as a third party, which is due to the legal requirements of the MMPA and the Magnuson Act. A total quota for harbor porpoise take is currently under consideration, but it is unclear at this time whether or not property rights to portions of the quota will be tradeable.

Under conditions of perfect certainty about both the value of damages caused by bycatch and the costs of bycatch control (abatement costs), a regulatory agency could just as easily set a total level of bycatch (tradeable quota) as it could set a pigovian tax (Baumol and Oates 1988). Either policy instrument would be capable of achieving the desired outcome. However, when uncertainty exists about the level and nature of damages and abatement costs, then one instrument may be superior to another.

A first step in choosing among instruments is to characterize the damages associated with incidental porpoise takes (accidental deaths). We examine a static model.[44] Figure 12a is a hypothetical depiction of the monetary value of damages. At zero take, damages are zero. Damages increase linearly (at rate "a") with the number of takes (each death imposes an

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[43] Part of the problem in this case is that property rights are defined only imperfectly. The multiple goals of the Marine Mammal Protection Act are conflicting in the sense that the Act seeks to achieve a level of zero mortality of marine mammals while maintaining the commercial viability of fisheries that cause incidental take. Therefore property rights are given to both polluter (fishermen) and pollutee (individuals who are harmed by porpoise deaths).

[44] Assume that the damages (and later abatement costs) are present values of flows of benefits (and abatement costs) at equilibrium levels of the harbor porpoise population. There are no adjustment lags to reach some designated level of take.

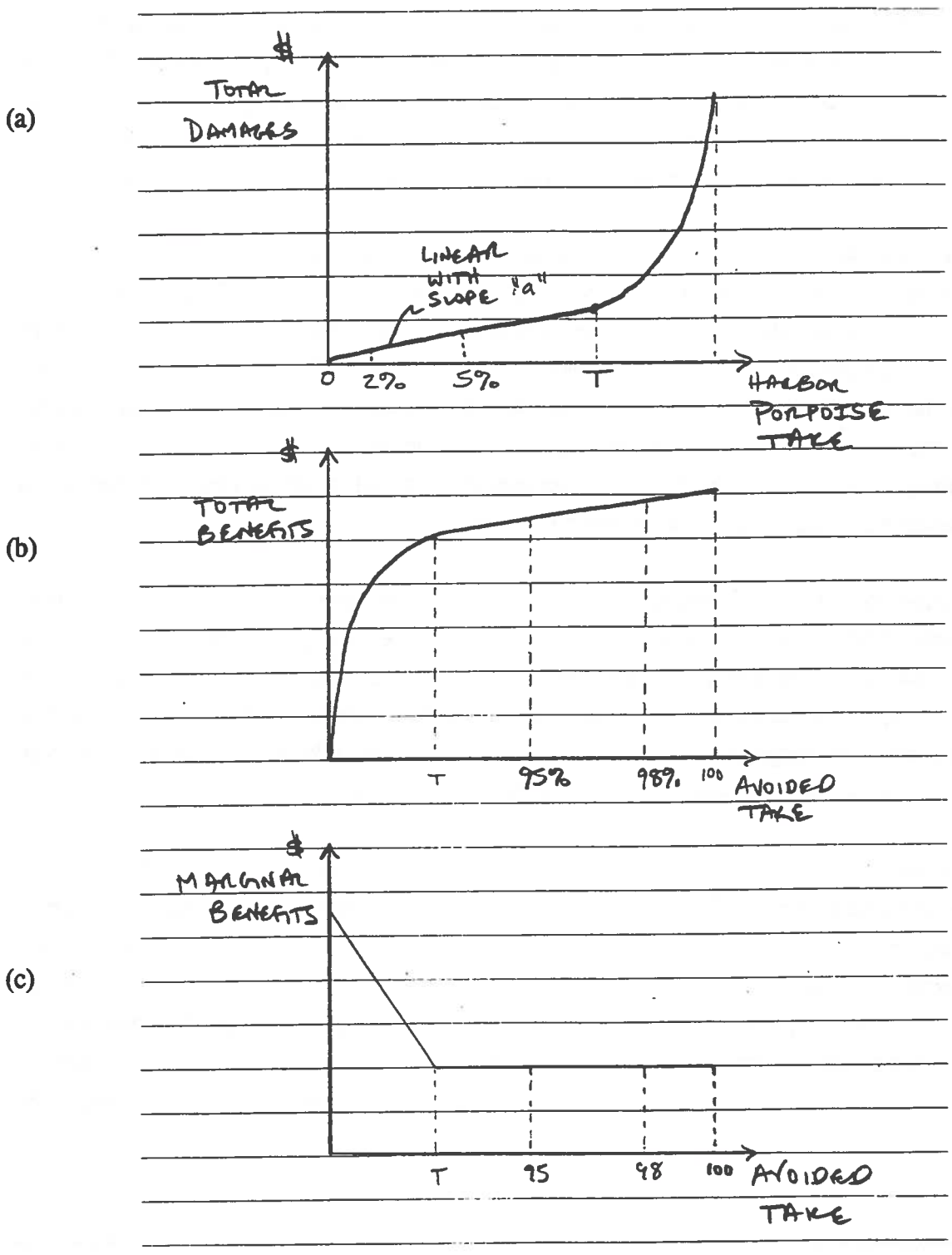

Figure 12: A stylized model of the benefits of avoided take of harbor porpoise

additional cost of, say, $X on those who value dolphin lives).[45] At some threshold level, T, the monetary value of damages per porpoise take increases sharply.[46] This threshold effect may be due to the fact that (1) takes are occurring at such a level that the population has become endangered (nearing extinction) or (2) perhaps at the threshold level the population serves as a proxy (like the spotted owl) for the rapid deterioration of the Gulf of Maine ecosystem.

The opposite of porpoise takes is porpoise lives saved (avoided porpoise takes [APTs]). The total benefits associated with avoided porpoise takes are represented in Figure 12b in terms of the percent of the population. If the entire population has been taken, then, at a level of zero APT, there are no benefits realized from avoiding porpoise takes. The total benefits curve rises rapidly as the percentage APT increases to the threshold level. Thereafter, the total benefits increase linearly with APT. It is theoretically possible to represent the entire total benefits curve, although we would normally not be too concerned about its shape beyond 5 percent of the population if no takes ever occur beyond that point.

A curve depicting the marginal benefits of avoided porpoise take (Figure 12c) can now be constructed from the total benefits curve. The marginal benefits curve exhibits a sharp kink at the threshold level, reflecting the shift from a quadratic to a linear total benefits curve. An important aspect of the marginal benefits curve for the harbor porpoise is that it is perfectly flat, at level "a," over the range at which current levels of incidental take are occurring, from 5 to 2 percent. This fact has important implications for the choice of instrument.

The next step is to examine the costs associated with avoiding porpoise takes. These costs arise from reductions in fishing effort, involving foregone revenues, or possibly a shift to different harvesting technologies that are more costly to purchase and operate but which result in lower incidental take (cf. Lind and Terry 1995). Figure 13a depicts a hypothetical shape for total costs of avoiding porpoise takes. For expositional purposes, consider that the costs of avoiding porpoise takes increase at an increasing rate. (The actual shape of the curve may be more complicated, reflecting the different ways in which different firms decide to reduce effort or shift technologies.)

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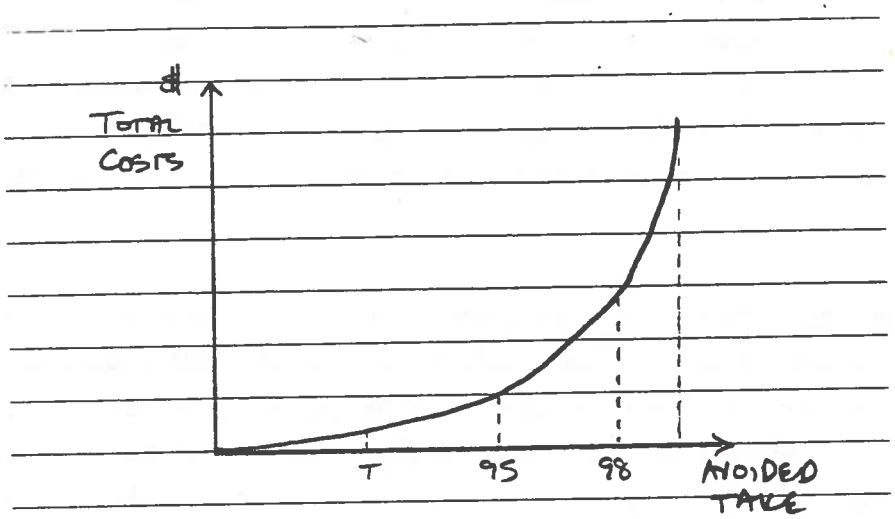
[45] In reality, there may be a step from zero up to the first porpoise take. This is because damages are inflicted in two ways: (1) there are damages associated with each porpoise take and (2) there are damages associated with the "principle" that any porpoises are taken. For clarity, we ignore the latter issue.

[46] For demonstration purposes, assume that the shape of the damage function is described by a quadratic curve. Thus marginal damages will be linear.

(a)



(b)

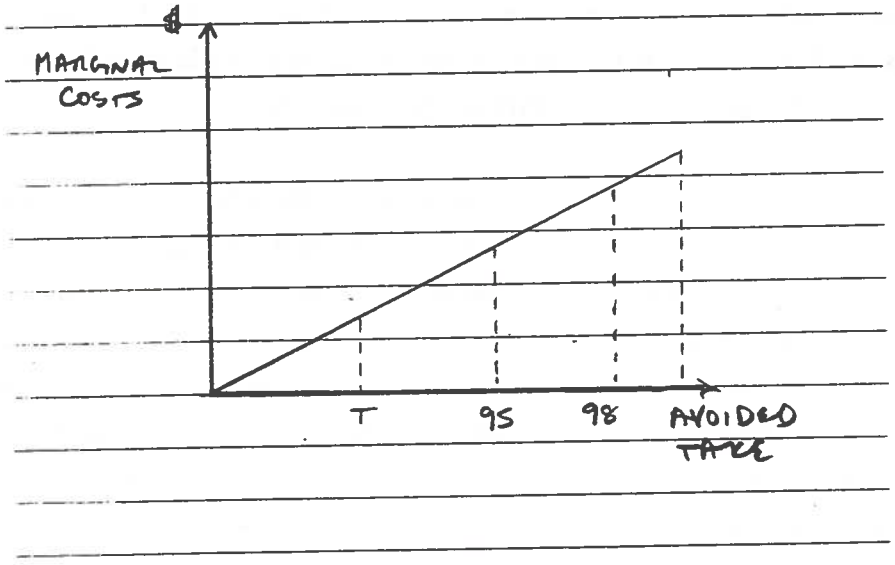


Figure 13: A stylized model of the costs of the avoided take of harbor porpoise.

The marginal costs of avoiding porpoise takes are depicted in Figure 13b. The curve is linear over its entire domain. Of special importance is that marginal costs are linear and increasing over the relevant range of avoided porpoise takes.

The marginal benefits and some hypothetical positions of the marginal costs of avoiding porpoise takes are depicted in Figure 14a. The figure shows the optimal level of incidental take under various assumptions about the position of the marginal cost function. If we consider that the unregulated level of incidental take is at ten percent of the population, then it would be socially suboptimal to regulate the gillnet fleet if the marginal costs of avoiding porpoise takes are represented by either MC_1 or MC_2. If costs are represented by MC_4, then it would make sense to set a goal of zero mortality of harbor porpoise (as has been incorporated into the MMPA).

Because there are no costs of avoiding porpoise takes at the present unregulated level and because we expect that the marginal costs of reducing take to zero will be quite large, for the rest of this section we will focus on marginal costs of the type MC_3 (within the range of 95 to 98 percent). The representative diagram is drawn in Figure 14b. When the shape and position of both marginal benefits and marginal costs are known with certainty, then it is a matter of indifference to the regulatory agency as to whether a total quota of Q* is established (for a tradeable permits market) or a tax per porpoise taken is imposed at a level of $a. Either choice will result in the socially optimal level of avoided porpoise take.

What happens if there is some uncertainty about the position of the marginal cost curve?[47] For example, say that MC is the "true" marginal abatement cost curve but the regulatory agency believes that MC" is the true curve. Assume that the damages are known with certainty. Now there is a difference between control instruments. If the agency picks a quota of Q", then the gillnet fleet will avoid too many porpoise takes, because the fleet will control its fishing effort according to its true marginal abatement costs. There will be an excess burden associated with the quota of the amount by which marginal abatement costs exceed benefits (area Y in Figure 14c). Analogously, if the agency believes MC' is the relevant curve, then gillnetters will take too many porpoises, leading to an excess burden of Z. However, if the agency sets a tax of "a", then, regardless of the position of the marginal cost curve, the

[47] There could also be uncertainty about the shape (slope) of the marginal cost curve. We will ignore this source of uncertainty, because it is likely to affect only the size of the potential excess burden.

(a)

(b)

(c)

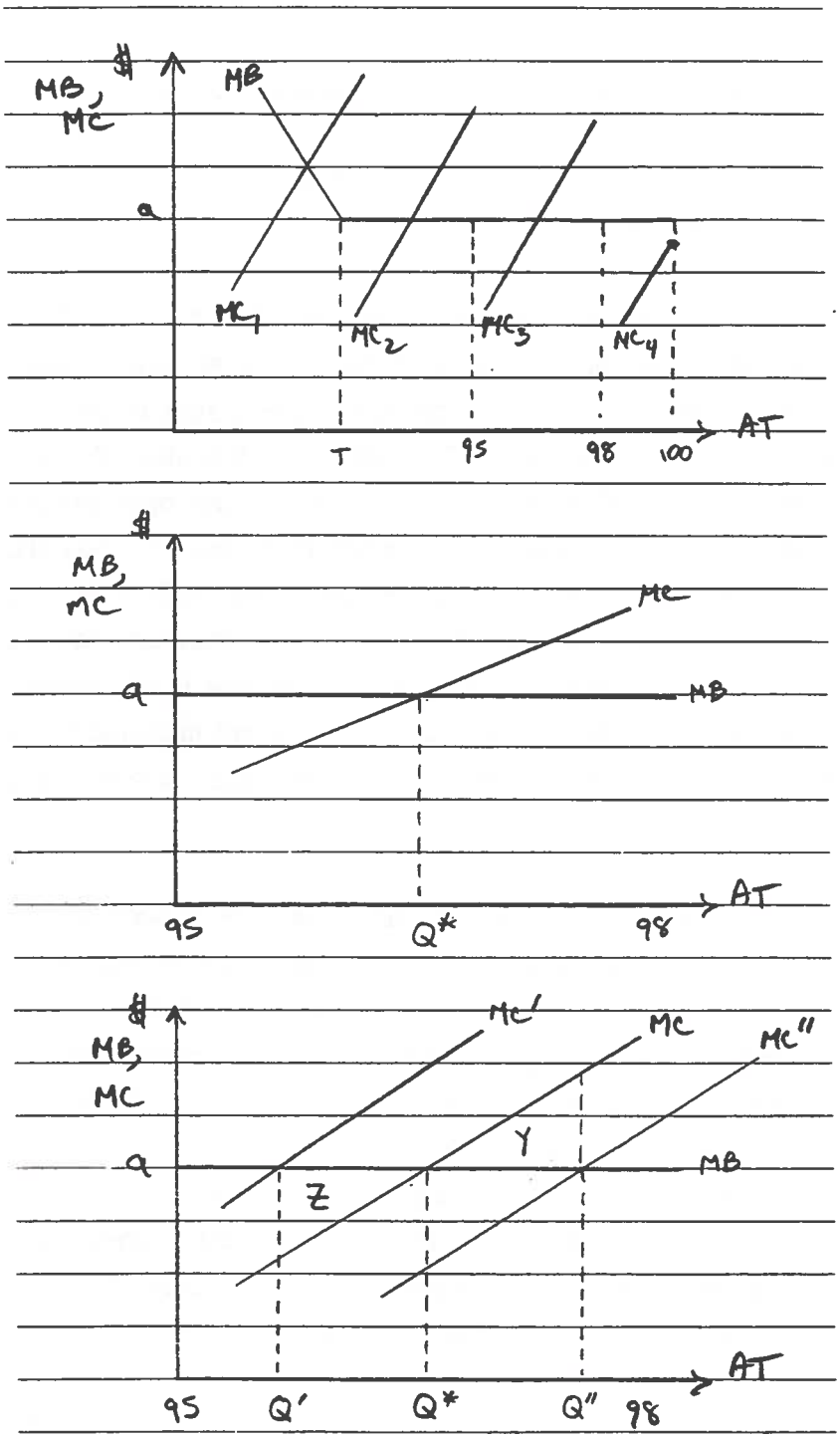


Figure 14: Uncertainty regarding the marginal costs of avoided harbor porpoise takes.

gillnetters will achieve the socially optimal amount of avoided porpoise takes.

To summarize, when the marginal benefits of avoided porpoise takes are constant across the relevant range and known with certainty, then the efficient regulatory instrument is a tax--not a tradeable permit system. The tradeable permit system is optimal only when the position of the marginal cost curve is known with certainty.

What happens if there is some uncertainty regarding the position of the marginal benefits of avoided porpoise takes? In the case of the harbor porpoise, the benefits associated with porpoise lives are likely to be difficult to determine. The reason is that benefits are almost completely nonmarket "existence" or "option" values. Thus it is likely that regulatory agencies might have a better estimate of abatement costs (lost fishing opportunities or technology switches) than of benefits. This situation is depicted in Figure 15. Say that the regulatory agency believes that MB" is the marginal benefits curve when MB is the true curve and that marginal abatement costs are known with certainty. If the agency sets either a pigovian tax of a" or a total quota of Q", then an excess burden equal to area B will result. (An analogous situation results if the agency believes that MB' is the relevant marginal benefits curve.) The conclusion in this case is that there is absolutely no difference in terms of efficiency in the choice of instrument.[48]

Finally, what happens if there exists uncertainty about both marginal benefits and marginal costs of avoiding porpoise takes? There are four situations that need to be considered. These are depicted in Figure 16. Let the "true" marginal benefits and marginal costs be represented by MB and MC. First, suppose that the regulatory agency overestimates marginal benefits and underestimates marginal costs and considers regulating at the intersection of MB" and MC". A quota set at Q" incurs an excess burden of the sum of areas 1, 2, 3, 4, and 10. A tax set at a" incurs an excess burden of the sum of only areas 1 and 10. Because 1 and 10 are contained within the excess burden of the quota, then the tax is preferred in this case. (An analogous situation occurs when marginal benefits are underestimated and marginal costs are overestimated: a tax of a' is socially preferred to a quota of Q'.)

Next, consider what happens when the regulatory agency overestimates both marginal benefits and marginal costs. The agency seeks to regulate at the intersection of MB" and MC'

[48] Note that the size of the excess burden depends upon the slope of the marginal cost curve: the more rapidly abatement costs increase, ceteris paribus, the smaller the excess burden (and vice versa).

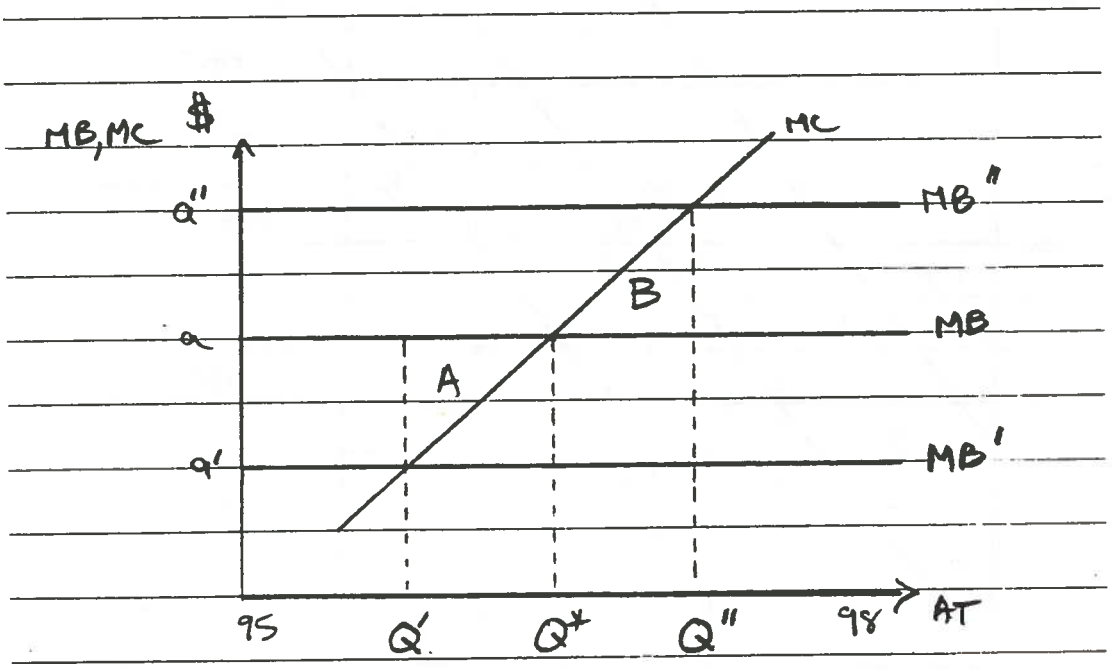


Figure 15: Uncertainty regarding the marginal benefits of avoided harbor porpoise take.

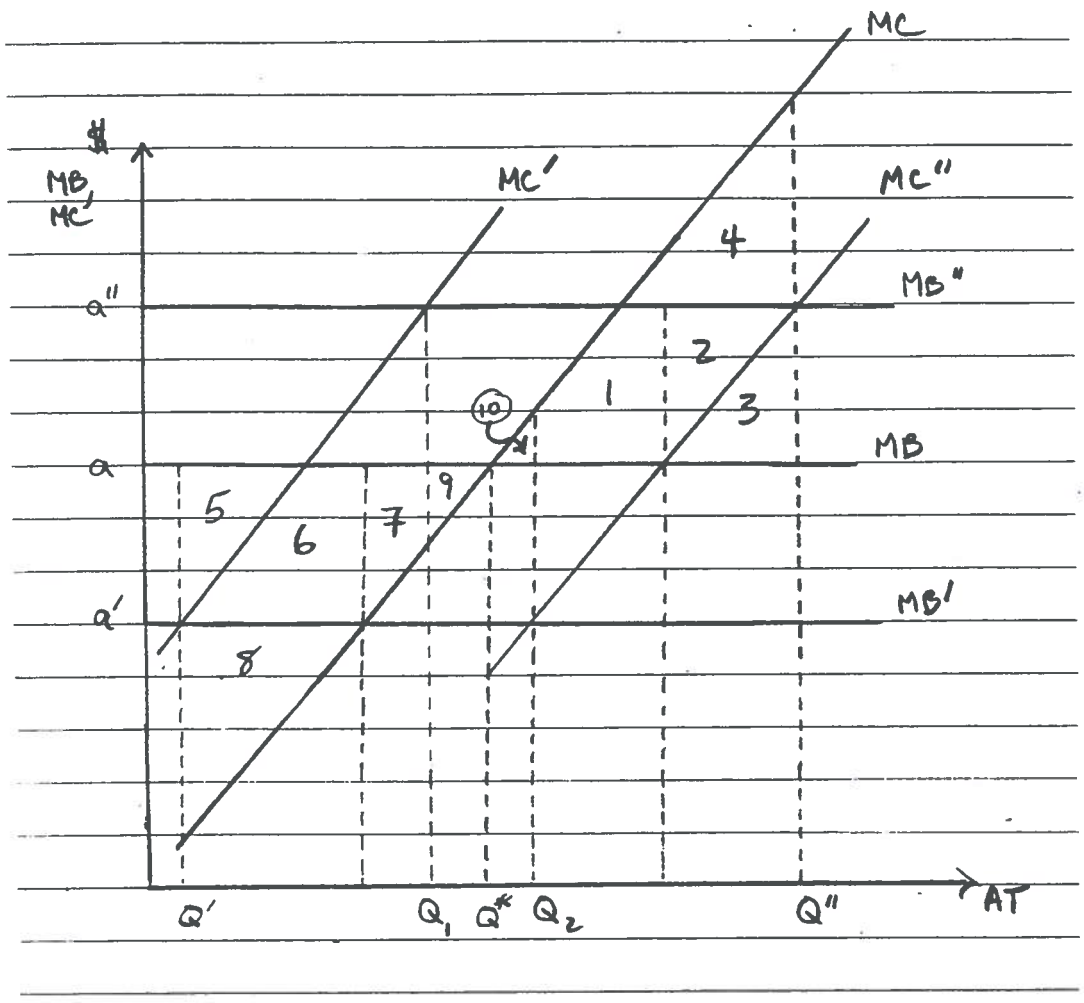


Figure 16: Uncertainty regarding both the marginal benefits and marginal costs of avoided porpoise takes.

by setting a tax of a" or a Quota of Q_1. The tax causes an excess burden of the sum of areas 1 and 10, but the quota causes an excess burden of only area 9. Because of the linearity of the marginal benefit and marginal cost curves, area 9 equals area 10, and therefore the quota is preferred in this situation. Note that this result occurs only because of the slope as drawn in Figure 16.[49] As the slope of the marginal cost curve increases, the excess burden due to the tax shrinks and the excess burden due to the quota enlarges. At some point the two become equal, and a further increase in the slope of marginal cost will result in a smaller excess burden due to the tax than the one due to the quota. (An analogous situation occurs when the regulatory agency underestimates both marginal benefits and marginal costs: a quota of Q_2 is preferred except when marginal costs are extremely steep.)

Table 9 presents the results of the analysis for the case of the harbor porpoise. Note that in most situations the pigovian tax is either preferred or indifferent to the choice of a quota. This result is a little misleading. It is most likely to be the case that a regulatory agency will have almost no information about damages and very little information about abatement costs. In such an environment, a quota is likely to be set on the basis of biological criteria (e.g., what level of take will minimize harm to the species in question--see Beddington and Cooke (1982)) or political feasibility (e.g., the zero mortality goal in the MMPA). If the quota takes the form of a program of tradeable permits, then at least a cost effective outcome will be reached--at some indeterminate level of excess burden. (Note that if the quota is set at zero takes, as called for under the MMPA, then it will not be possible to devise a tradeable permit program.[50])

An additional issue concerns the incidence effect. Assume that abatement costs are known with certainty but damages are uncertain (Figure 15). If the government believes that MB" is the relevant marginal benefits curve, then the excess burden associated with a tax of a" or a total quota of Q" is area B. This burden is borne (almost) completely by the gillnetters as they are forced to reduce fishing effort or switch technologies.[51] If MB' is believed to be the

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[49] Also, the result occurs because of the size of the error in estimating the position of the marginal benefits curve. Recall that when the marginal benefits curve is known with certainty, then the tax is always preferred.

[50] This is because it is not possible to reduce take below zero. But it might be possible to devise a tradeable program over time.

[51] Actually, the analysis of incidence is more complicated. Suppose the government is considering only a pigovian tax. A pigovian tax that is set too high is much like a per unit sales tax in the market for fish. (Likewise, a pigovian tax that is set too low is like a subsidy in the market for fish.) The incidence of the tax (or subsidy) will depend upon the relative elasticities of supply and demand for fish. For example, if supply is somewhat elastic then

Table 9: Instrument Choice for Avoiding Porpoise Takes

	COSTS	KNOWN	UNCERTAIN	UNCERTAIN
BENEFITS			OVERESTIMATE	UNDERESTIMATE
KNOWN		Tax or Quota	Tax	Tax
UNCERTAIN	OVERESTIMATE	Tax or Quota	Indeterminate	Tax
UNCERTAIN	UNDERESTIMATE	Tax or Quota	Tax	Indeterminate

fish consumers will bear a portion of the burden of a tax. To even further complicate matters, fish consumers can be fishers or the beneficiaries of avoided porpoise takes (or both).

relevant marginal benefits curve, then the burden falls upon those who value the lives of porpoises.[52] The incidence effect can have important political implications. Hence we see the "interim exemption" which permits the gillnet fleet to operate at a positive level of porpoise take.[53]

One final issue concerns regressivity. If most fishers (especially crewmembers) are low income individuals and the primary beneficiaries of avoided harbor porpoise takes are middle to upper class "elites," then a policy that overestimates benefits is regressive (and vice versa).

If the regulatory agency is able to obtain some information about damages (i.e., the value to individuals of avoiding a porpoise death) or at least some guess about whether marginal benefits or marginal costs are being over- or under-estimated, then it may be possible to make a more efficient choice between a pigovian tax and a tradeable quota.

D. Proposed Market-Based "Policy Packages"

In this subsection, we follow the approach of Segerson (1990) in making a "proposal" for the use of market-based incentives for bycatch management. In her study of agricultural water pollution, Segerson (1990) examines the case of a pollution problem involving multiple market failures. She explains that:

> [n]o single incentive mechanism (either ex-ante or ex-post) is capable of producing a first-best outcome. . . It is therefore likely that the best policy approach will involve use of several instruments . . . based on both incentives and regulation. Choice of the specific instruments to be used will require a balancing of multiple objectives, relating to efficiency, distributional implications, budgetary effects, and administrative ease (low transactions costs). A policy package that attempts to balance these concerns *will be imperfect in terms of any single criterion*, and it should not be judged in that way. Instead, it must be evaluated as a compromise solution to an environmental problem that defies easy solution (emphasis added).

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[52] Note that because the harbor porpoise is valued for its "existence", the individuals who bear the burden of too many porpoise takes do not bear a financial burden.

[53] This does not mean that the "interim exemption" exists because the regulated level of take is too low from a socially optimal standpoint. It is likely that any level of abatement is perceived as costly by the gillnet fishermen, and therefore political opposition is likely to develop.

Our proposal for a bycatch management "policy package" is made up of three basic elements: (1) control of effort in the target fishery; (2) encouraging research and development in three distinct areas; and (3) implementing market-based approaches to manage bycatch. The most appropriate combination of instruments may depend upon the idiosyncrasies of each fishery of interest. In Appendix 2, we have compiled a set of questions that should be asked as managers look to implement market-based approaches to manage bycatch problems.

Effort controls in the target fishery are important for at least two reasons. First, we cannot expect that much progress will be made on bycatch management if effort cannot at least be controlled in the target fishery. Second, if the fishing technology remains constant, then we might expect that the total amount of bycatch will decline as effort is cut back toward optimal levels in the target fishery. According to Alverson et al. (1994), "[t]he single action that will provide the greatest improvement to the bycatch-discard problem will be the reduction of . . . effort levels [in target fisheries]."

The nature of effort regulation will be important as well. In theory, market-based approaches are preferred to command-and-control approaches. Once again, enforcement costs may be significant determinants of the type of instrument adopted. If ITQs are implemented, attention should be paid to the potential for levels of highgrading and discarding that exceed unregulated levels of bycatch. Wilen (1990) suggests that, because an ITQ program in a target fishery removes the incentive to "race" for fish, the fishing season will tend to expand. As fish quality improves with its year-round availability, its value is likely to increase. As a result, fishers will have ". . . added incentive to move away from low quality, mass contact, mixed species methods (an attendant high bycatch) towards more direct methods."

An important part of effort reduction in the target fishery will be the removal of all subsidies, including guaranteed or low interest loans, vessel construction funds, and others. In addition, buyout programs should be employed to move fishers out of the fishery permanently. Both of these types of incentives are seeing increased use in target fisheries, such as the northeast multispecies fishery.

An important market-based approach involves the encouragement of research and development in three areas: improving the selectivity of gear types; bioeconomic modeling; and improving vessel monitoring systems (VMSs) to reduce the costs of enforcement. In principle, general methods of encouraging such research are in place. These methods include the patent

system, R&D income tax credits at the federal and state levels, and grants for basic scientific research.

Research on improving gear selectivity is already being sponsored through NMFS' Saltonstall-Kennedy program, NOAA's Sea Grant programs, and by the National Science Foundation. Research on bioeconomic modeling of bycatch problems is being funded through these same sources and by NMFS at its regional science centers, although we expect that this research could receive more attention. Research on VMS is minimal and funded primarily by private industry.

An important component of research on bioeconomic modeling will involve estimation of damages associated with bycatch. In the case of nonmarket species, such as marine mammals, this may require the use of specialized valuation techniques (Hoagland 1995).

The final element of the policy proposal involves the use of controls on bycatch. Again, we reiterate that only careful scientific research and bioeconomic modeling efforts will allow us to determine the appropriate level of bycatch. Where political decisions are reached to reduce bycatch in the absence of conclusive knowledge of ecological or economic effects, market based approaches might be employed to achieve cost-effective outcomes. Bycatch charges, deposit-refund systems, and individually tradeable bycatch quotas are among the most preferred instruments for accomplishing bycatch reductions.

Based upon our review of the three case studies in Section 6, we have developed proposed policy packages for each of the three fisheries. We have arranged in Table 10 lists of priorities for each fishery relating to (1) effort control in the target fishery; (2) research and development; and (3) bycatch control.

In the northeast multispecies fishery, simple solutions are unlikely to exist. Effort control in the target fishery is critical, including removal of any remaining subsidies at federal and state levels. The experience gained from the pilot scale buyout program appears positive, and the full-scale program should be implemented as soon as feasible. A critical aspect of the buyout program will be controls on effort remaining in the fishery. As explained in Section 6, effort is controlled already using multiple instruments. However, consideration might be given to the development of a system of multispecies ITQs, including quotas for different year classes. Research needs include the development of better monitoring capabilities and continued efforts

Table 10: Priorities for Market-Based Policy Packages: Proposals for Three Cases

	New England Groundfish	Gulf of Mexico Shrimp	ETP Yellowfin Tuna
Priorities for Effort Control in Target Fishery	1. subsidy removals 2. buyback program 3. multispecies ITQs	1. subsidy removals 2. shrimp ITQs	1. Subsidy removals (international) 2. ITQs on tuna harvest
Priorities for Research and Development	1. improving VMS 2. bioeconomic modeling 3. gear selectivity	1. gear selectivity (finfish BRDs)	1. product labelling in seafood markets 2. dolphin harassment effects
Priorities for Bycatch Control	1. interpret results of bioeconomic modeling 2. improve monitoring 3. charges, deposit/ refunds, or ITBQs	1. finfish ITQs 2. consumer education about "turtle safe" labelling	1. consumer education about "dolphin safe" labelling

at bioeconomic modelling. Research on gear selectivity, especially in the scallop fleet, is also a priority. Bycatch control should depend critically on the results of bioeconomic modelling efforts. Bycatch control will depend upon improved monitoring, such as with more advanced vessel monitoring systems, and control might be implemented with a system of charges or a deposit-refund program, if a multispecies ITQ program involves very high transactions costs.

In the Gulf of Mexico shrimp fishery, bycatch reduction has been at least partially successful through a program of improving gear selectivity, including TEDs and, now, finfish BRDs. There is still too much capacity in the fishery, and effort controls, such as might be achieved through the removal of subsidies and the implementation of a shrimp ITQ system, are critical to reducing this capacity. Research needs are now being focused, appropriately, on improving finfish BRDs. The implementation of finfish ITQs, such as that for the red snapper fishery, and increased attention to consumer education programs that help the public to understand the meaning of "turtle safe" labels are priorities.

In the ETP yellowfin tuna fishery, effort controls should involve the removal of subsidies in each of the nations involved in the fishery. This is a tall order, but a system on international ITQs can be a useful step. Because of the problem of dolphin takes, monitoring is already extensive, and this should enhance the potential for the application of market-based approaches. Research needs include those focused on the theoretical and empirical aspects of product differentiation through labelling in seafood markets. Such research might usefully enhance the application of product labelling to other fisheries. If the result of current international negotiations is to relax the movement toward the zero mortality of dolphin in the fishery, then further research on the effects of nonlethal harassment of dolphins appears justified. Increased attention to consumer education programs that help the public to understand the meaning of "dolphin safe" labels is a priority as well.

8. Conclusions and Research Recommendations

A. Study Conclusions

In order to better understand the scale of bycatch problems on a national level, there is a need to gather consistent, longterm data on bycatch by stock in individual fisheries. This data is necessary, but not sufficient, for developing an understanding of the economic and environmental effects of bycatch.

For each specific fishery, the relevant bycatch problem should be carefully defined. This will require the construction and parameterization of combined biological and economic multispecies models.

For each specific fishery, the economic effects of bycatch should be estimated. Bycatch occurs because, given existing stock distributions and technological and institutional constraints, there are net benefits to individual fishers from bycatch. Bycatch can involve "social costs" such as the direct costs of sorting, discarding, additional effort to replace discards, and adverse ecosystem effects. The latter type of cost may not be immediately apparent to fishers. Bycatch can be costly to other individuals or groups who value bycaught species. Damages from cases of "producer-consumer" or "consumer-consumer" bycatch may be more difficult to measure than either damages in cases of "producer-producer" bycatch or the direct costs of bycatch to fishers.

For each specific fishery, the ecological effects of bycatch should be estimated. This will require the development of an understanding of ecological relationships and their dynamics. Some purported cases of bycatch impacts may not be ecologically important. Other cases of bycatch could be ecologically beneficial. However, in some cases, such as those involving rare or endangered species or species assemblages, a level of "zero" bycatch or bycatch approaching a level of "zero mortality" can be optimal in both an ecological and an economic sense.

Bycatch "conflicts" can arise for several reasons. The most common reason may be catch constraints, such as those that arise with "total allowable catches." Such command-and-control methods may be good examples of inefficient methods for controlling fishing effort in the target fishery, and discards may, in part, be evidence of inefficiency. Conflicts can also arise due to property rights that are in dispute or inadequately specified. This suggests that there is a need to characterize property rights or to develop programs, such as ITQ programs, that

establish and clarify the distribution of property rights.

The current preferred method for handling bycatch problems involves command-and-control gear regulations. This approach fails to recognize that there can be benefits from fostering flexibility in the selection of technological or operational solutions to bycatch. Market-based incentives, such as bycatch charges, ITQs, deposit-return systems, or labelling and consumer information programs, are more likely than command-and-control approaches to foster this kind of flexibility. Indeed, market-based approaches can be used as incentives to encourage industry to undertake research and development to improve gear selectivity that reduces damaging levels of bycatch.

In most cases, it will be necessary for the government to participate in the design and implementation of market-based incentives. A good example of the type of effort needed can be found in the case of the Finfish Bycatch Steering Committee in the Gulf of Mexico. However, such an effort should include as part of its mandate the investigation of potential market-based incentives, used alone or in combination with other policy instruments, to manage bycatch.

Consumer education is an important component of product labelling approaches. There is evidence that consumers are willing to pay for "environmentally friendly" products. However, bycatch problems often are not well-defined, and consumers may be reluctant to pay a premium for a "green" seafood product that is difficult to differentiate from a "nongreen" product. There may be opportunities for government, nongovernmental organizations, and industry to work cooperatively in the development of consumer education programs that help to alleviate bycatch problems.

In some circumstances, a "credible threat" from the government to regulate bycatch in a manner that is more costly to the current fishers (such as a moratorium on fishing) can provide a stimulus for the industry to develop its own solutions to bycatch problems, including market-based incentives.

Where multiple bycatch-type externalities exist in a fishery, such as with most multispecies fisheries and in fisheries with nonselective gears, economic theory concludes that it is generally necessary to have multiple regulatory instruments to address each of the corresponding externalities so that the socially optimal ("first-best") solution can be achieved.

In reality it is often infeasible to design and implement regulatory measures for every externality due to political, social, and economic reasons. Only some of these instruments will be adopted, leading to a suboptimal outcome from an economic perspective.

In order to achieve a "second-best" solution, all major externalities in a subject fishery should be examined, and the feasibility and effectiveness of corresponding regulatory instruments, or combinations of instruments, should be assessed. Policy alternatives employing policy instruments either singly or in combination should be ranked in terms of net economic benefits. The most economically beneficial "policy package" should be chosen from among the alternatives. All such packages must involve effective mechanisms to control effort in the target fishery.

In some fisheries, this selection process may involve the selection of instruments to achieve a politically or biologically determined goal at least cost. At the minimum, consideration should be given to market-based approaches that are capable of achieving cost-effective outcomes without excessive information requirements. Where monitoring of bycatch is costly, market-based approaches might be used in combination with vessel monitoring systems.

Options to manage bycatch should rarely be considered permanent solutions. Following "adaptive management" techniques, regulatory policies should be re-evaluated on a continuous basis, and policies should be modified if results do not meet with expectations.

We have observed that market-based incentives are almost never adopted in fisheries management, much less in the management of bycatch problems. One exception to this observation is the growing interest in and application of ITQs to manage target stocks. There may be several reasons why market-based incentives have heretofore not been considered as solutions to bycatch problems. These reasons include oversight, significant distributional effects (especially in the case of charges or deposit-return systems), high costs of monitoring and enforcement, difficulties in educating consumers about product attributes, and administrative and transactions costs. All of these reasons, and others, should be evaluated in the context of any specific bycatch management case to see whether or not they impede the adoption and implementation of market-based incentives.

Given the great diversity in U.S. fisheries, it is difficult to identify panacea-type solutions

to bycatch problems. In general, each fishery and its biological, technological, economic, institutional, and distributional characteristics should be examined closely to evaluate the potential for the application of market-based approaches. In light of the current state of many U.S. commercial fisheries, and in view of the rising significance of bycatch problems in the U.S. and worldwide, we believe that it is sensible to consider the full array of management options, including those, such as many of the market-based approaches, that have not yet been given full consideration to date.

B. Recommendations for Research

We have identified the following general research needs relating to market-based incentives to reduce fisheries bycatch.

1. A national database on bycatch by stock in target fisheries (single or multispecies) should be developed. In order for the data to be useful for making comparisons at the national level and for setting priorities, the data should be reported in a consistent fashion across fisheries. Ideally, data should be collected over the longterm to detect trends.

2. Using data on biological interactions, effort levels, and catch and bycatch rates, "bioeconomic" multispecies models for each major fishery should be developed to estimate the economic effects of bycatch. We conclude that even very rough estimates of the economic effects of bycatch are more useful than the current situation in which no estimates are made and decisions are based upon political or other criteria.

3. A general analytical framework, akin to a risk assessment, should be developed to incorporate information on bycatch rates and economic effects. Such a framework would enable national decisionmakers to set priorities for focusing limited national resources in those fisheries with the most pressing bycatch problems.

4. Research on the nature and scope of fishing "institutions" should be conducted. Institutions, which include management regulations and actual or implied legal rights to fishing activities, can be important determinants of the existence and type of bycatch problem. Research should focus on the economic effects of existing and alternative institutional arrangements on contributing to or alleviating bycatch problems.

5. Research on legal constraints to the development of market-based and other approaches to bycatch should be conducted. Examples of such constraints include "due process" issues surrounding real-time monitoring and enforcement of quota management and antitrust issues arising out of industry proposals to control effort in fisheries. Other legal constraints should be identified, and means by which the constraints can be relaxed should be investigated.

6. Where bycatch reduction is warranted, the implementation of different kinds of policy instruments should be modelled and the net benefits of bycatch reduction should be compared across instruments. These comparative analyses should consider costs of monitoring and enforcement, the likelihood of individual vessel compliance and avoidance, and other relevant administrative costs. Individual instruments as well as combinations of instruments might usefully be analyzed to develop a feasible policy package.

7. The implementation of market-based approaches to bycatch problems may require the development and use of innovative technologies to reduce the costs of gathering information. As required by NMFS' national standards on vessel monitoring systems, benefit-cost analyses of the implementation of alternative monitoring techniques should be conducted. The development of a standardized benefit-cost model that can be used in any fishery is needed.

8. The elements required to develop a successful consumer education program to implement a product labelling approach to bycatch reduction should be identified and characterized. The characteristics of seafood markets that enable the successful implementation of "green" labels for bycatch problems, such as "turtle-safe" or "dolphin-safe," should be analyzed in detail. As the fundamental elements of such an approach are revealed, it is likely that the seafood industry may begin to implement product labelling to a greater extent.

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Appendix 1

U.S. Commercial Fisheries and Bycatch Database

Commercial Fisheries in the Atlantic Ocean, Gulf of Mexico, and Caribbean

Fisheries Description						Incidental Catch		Discard Catch	Bycatch Species	
Location	Target Species	Gear Type	Landings	Value	Category	Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
Atlantic Ocean /1 Gulf of Mexico/1 Caribbean/1	Swordfish/1 ----- Tuna /1 Albacore/9 Yellowfin/9 Bigeye/9 ----- Shark/1	Pair Trawl/1 (>20 inch mesh)/2	- 1993 Data - ----- Tuna: Albacore: 31,050 lbs/9 Yellowfin: 15,441 lbs/9 Bigeye: 21,334 lbs/9		1/1	- 1993 Data - Swordfish, M: 5,854 lbs/9	- 1993 Data -	- 1993 Data - Tuna: 271 lbs/9 Albacore: 271 lbs/9 Yellowfin: 303 lbs/9 Swordfish: 4,312 lbs/9 (quota on swordfish)	Risso's dolphin/1,2 Pilot whale (all stocks)2,9 Long-finned*/1 Short-finned*/1 Bottlenose dolphin /2,9 Mid-Atlantic offshore*/1 (Depleted >PBR/2) Common dolphin/2,9 Western North Atlantic*/1 (>PBR/2) Gray Grampus/9 Dolphin, unidentified/9 (extrapolated data)	Leatherback turtles, E: 1 observed in 1993/2 2 observed in 1993/9
Atlantic Ocean/1 Gulf of Mexico/1 Caribbean/1	Swordfish/1 Tuna/1 Shark/1	Drift gillnet/1 (22 inch stretched mesh)			1/1				Right whale*/2 Beaked whale*/2 Humpback whale: */2 Western North Atlantic*/1 (E) Blue Whale/1 Sperm whale: */2 (E) Western North Atlantic*/1 (>PBR/2) Risso's dolphin/1,2 Pilot whale: Long-finned*/1,2 Short-finned*/1,2 Atlantic white-sided dolphin/1,2 Common dolphin*/1,2 (>PBR/2) Striped dolphin/1,2 Spinner dolphin/1,2 Spotted dolphin*/2 (>PBR/2) Bottlenose dolphin: (Depleted stock) Mid-Atlantic off-shore*/1,2 Harbor porpoise: Gulf of Maine/Bay of Fundy*/2 Unidentified dolphin/2 (extrapolated data)	Estimated total take: 14 loggerhead turtles in 1990 /2 Estimated total annual take for 1989-1993: 11 unidentified shearwaters /2
New England/1 Gulf of Maine from the Lower Bay of Fundy to Cape Cod/2	Multispecies:/1 Cod/2,11 Haddock/2,11 Pollock/2,11 Yellowtail Flounder/2,11 Winter Flounder/2,11 Witch Flounder/2,11 American Plaice/2,11 Redfish/2,11 White Hake/2,11 Windowpane Flounder/2,11 Silver Hake/2,11 Red Hake/2,11 Ocean Pout/2,11 Misc. Other	Sink gillnet:/1	- 1991 Data - ----- 7,234.2 mt/11 81.5 mt/11 2,919.2 mt/11 123.3 mt/11 110.8 mt/11 18.3 mt/11 39.3 mt/11 53.8 mt/11 1,614.3 mt/11 0.9 mt/11 55.4 mt/11 30.2 mt/11 0.6 mt/11 1,278.2 mt/11 ----- 13,560.0 mt/11	- 1991 Data - ----- ----- $15.8 mil	1/1			Goosefish/10 ? Spiny Dogfish/10 ? Skate/10 ?	North Atlantic right whale: Western North Atlantic*/1 Humpback whale: Western North Atlantic*/1 Minke whale/1,2 Pilot whale: Long-finned*/1 Short-finned*/1 Atlantic white-sided dolphin/1,2 (>PBR/2) Harbor porpoise: Gulf of Maine/Bay of Fundy*/1,2 (>PBR/2) Harbor seal/1,2 Gray seal/1,2 Unidentified species/2 (extrapolated data)	Shearwaters Cormorants Loons Gulls Northern Gannets
Gulf of Maine/1	Small pelagics/1	Surface gillnet/1			1/1				Humpback whale (Western N A)*/1 (E) Minke whale/1 Atlantic white-sided dolphin/1 Harbor porpoise (Gulf of ME)*/1 Harbor seal (Western N A)/1 Gray seal (Northwest N A)/1	

Fisheries Description						Incidental Catch		Discard Catch	Bycatch Species	
Location	Target Species	Gear Type	Landings	Value	Category	Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
Atlantic Ocean Gulf of Mexico Caribbean	Tuna Shark Swordfish	Longline			1				Humpback whale (Western N.A.)*/1 Minke whale/1 Pilot whale: (all stocks)/2 (Exceeds PBR) Long-finned*/1 Short-finned*/1 Common dolphin*/1 Risso's dolphin/2	In 1992 and 1993, an estimate of 887 leatherback and 536 loggerhead turtles were captured. One leatherback died in 1992 and 2 loggerheads died in 1993, the remainer were captured and released/2
U.S. Mid-Atlantic (Coastal)	Perch (CT) Shad Black drum --- Weakfish	Gillnet	 --- Weakfish		2				Humpback whale (Western N.A.)*/1,2 Minke whale/1 Bottlenose dolphin: Mid-Atlantic off-shore*/1,2 Harbor porpoise (Gulf of ME)*/1,2	Overlaps occur in the peak number of turtle strandings and the timing of gillnet, trawl, pot, and pound net operations along the mid-Atlantic coast/2
U.S. South Atlantic	Black tip shark	Gillnet (18 inch mesh)			2				Bottlenose dolphin: Western N.A.*/1,2	No reports of sea turtle or sea bird takes/2
Gulf of Maine Mid-Atlantic	Menhaden	Purse seine			2				Minke whale/1,2 Bottlenose dolphin (Western N.A)*/1,2	No reports of sea turtle or sea bird takes/2
Atlantic	Mackerel/2 Atlantic Spanish King --- Squid/2 Loligo/14 Illex/14 --- Butterfish/14	Mid-water trawl	-1992 Data- 36,079,242 lbs 9,451 lbs 86 lbs --- 65,784,432 lbs 48,906,974 lbs --- 10,547,894 lbs	-1992 Data- $5,514,191 $5,877 $62 --- $39,918,056 $12,686,853 --- $6,569,056	2	Silver Hake: 21,796,292 lbs Summer Flounder: 4,385,301 lbs Angler: 2,733,355 lbs Winter Flounder: 2,107,138 lbs Skates (Unc): 1,427,336 lbs Black Sea Bass: 816,617 lbs Cod: 529,143 lbs Dogfish (NK): 303,962 lbs Tilefish: 411,525 lbs Tautog: 190,342 lbs Witch Flounder: 208,499 lbs Lobster: 166,438 lbs Scup: 9,345,744 lbs Butterfish: 10,547,894 lbs Red Hake: 2,636,000 lbs Bluefish: 2,271,306 lbs	 $9,208,360 $7,146,354 $1,839,033 $2,055,547 $141,856 $764,876 $499,020 $44,851 $231,683 $124,577 $263,979 $642,234 $6,560,430 $6,569,056 $720,668 $560,780	Swordfish ? Bluefish ?	Risso's dolphin/1 Common dolphin*/1 Pilot whale: (all stocks)/(m & s)2 Long-finned*/1 Short-finned*/1 Atlantic white-sided dolphin/1,(m)2 Unidentified small cetacean/(m)2	Overlaps occur in the peak number of turtle strandings and the timing of gillnet, trawl, pot, and pound net operations along the mid-Atlantic coast/2

Fisheries Description			Landings	Value	Category	Incidental Catch		Discard Catch	Bycatch Species	
Location	Target Species	Gear Type				Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
						Atlantic Herring: 5,715,176 lbs	$293,506			
						Yellowtail Flounder: 809,357 lbs	$843,156			
						Squetcague Weakfish: 735,287 lbs	$399,438			
						Conger Eel: 197,917 lbs	$41,853			
						White Hake: 143,582 lbs	$50,575			
						Ocean Pout: 110,477 lbs	$17,993			
						Black Whiting: 87,984 lbs	$23,915			
						Sea Robins: 75,530 lbs	$20,096			
						Sand-Dab Flounder: 42,095 lbs	$12,112			
						Spiny Dogfish: 168,033 lbs	$16,860			
						Pollock: 27,476 lbs	$14,043			
						Conchs: 19,669 lbs	$23,566			
						Am. Plaice Flounder: 16,083 lbs	$18,041			
						American Shad: 14,124 lbs	$5,227			
						Smooth Dogfish: 33,300 lbs	$6,931			
						Menhaden: 11,070 lbs	$708			
						John Dory: 10,554 lbs	$6,322			
						Haddock: 4,199 lbs	$1,393			
						Swordfish: 29,986 lbs	$90,398			
						Northern Puffer: 7,901 lbs	$3,686			
						Sea Scallop: 44,959 lbs	$227,949			
						Blue Back Herring: 428,961 lbs	$20,119			
						Atlantic Croaker: 52,583 lbs	$12,592			
						Sturgeons: 14,738 lbs	$17,444			
						Sandbar Shark: 10,436 lbs	$3,717			
						Squid (NS): 12,559 lbs	$6,386			
						King Whiting: 17,782 lbs	$4,672			
						Wolffishes: 7,480 lbs	$4,573			
						Bonito: 4,318 lbs	$1,400			
						Herring (NK): 1,506 lbs	$240			
						Other fish: 56,571 lbs	$8,618			
						Shark (NK):				

Fisheries Description			Landings	Value	Category	Incidental Catch		Discard Catch	Bycatch Species	
Location	Target Species	Gear Type				Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
						4,202 lbs	$3,824			
						Thresher Shark:				
						4,949 lbs	$2,994			
						Redfish:				
						1,453 lbs	$847			
						Cunner:				
						1,413 lbs	$110			
						Dusky Shark:				
						1,339 lbs	$194			
						Jonah Crab:				
						3,534 lbs	$1,697			
						Spot:				
						18,538 lbs	$2,732			
						Triggerfish:				
						302 lbs	$139			
						Fourspot Flounder:				
						204 lbs	$38			
						Horseshoe Crab:				
						92,261 lbs	$9,253			
						Alewife:				
						31 lbs	$2			
						Atlantic Halibut:				
						158 lbs	$257			
						Albacore Tuna:				
						9 lbs	$4			
						Cusk:				
						6 lbs	$2			
						Channeled Whelk:				
						920 lbs	$823			
						Striped Bass:				
						5,516 lbs	$8,059			
						Black Tip Shark:				
						666 lbs	$120			
						Cobia:				
						311 lbs	$405			
						Rock Crab:				
						236 lbs	$233			
						Porbeagle Shark:				
						1,983 lbs	$589			
						Flounders (NK):				
						88 lbs	$87			
						Mako Shortfin Shark:				
						15 lbs	$46			
						Knobbed Whelk:				
						933 lbs	$340			
						Thresher Bigeye Shark:				
						2,155 lbs	$310			
						Mullets:				
						519 lbs	$78			
						Tiger Shark:				
						321 lbs	$69			
						Spotted Weakfish:				
						165 lbs	$113			
						Sheepshead:				
						16 lbs	$5			
North Carolina (Shore)/12	Croaker/12 Spot/12 Harvest fish/19 Bluefish/12 Weakfish/19 Misc. Other/12	Haul Seine			2	Red Drum:		Angel Shark/12 Blowfish or Puffers/19 Menhaden/19	Bottlenose dolphin (Western N A)*/1 Harbor porpoise (Gulf of ME)*/1	
						11 lbs	$2			

Fisheries Description			Landings	Value	Category	Incidental Catch		Discard Catch	Bycatch Species	
Location	Target Species	Gear Type				Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
North Carolina/1	Roe Mullet	Stop net			2				Bottlenose dolphin (Western N A)*/1	
North Atlantic/1 ----- [Mid-Atlantic/2]	Atlantic cod/2 Pollock/2 Hake/2 ----- Flounder/2 Scup/2 Goosefish/2	Bottom trawl			3				Pilot whale (all stocks)/2 Long-finned*/1 Short-finned*/1 Atlantic white-sided dolphin/1,2 Striped dolphin/1,2 Bottlenose dolphin Western North Atlantic*/1 Mid-Atlantic coast*/2	From 1989-1993, this fishery takes an average of 30 loggerhead turtles annually./2
Mid-Atlantic U.S. South Atlantic Gulf of Mexico	Shrimp Finfish Shellfish	Trawl Aquaculture Aquaculture			3 3 3			Commercial finfish: Juvenile Coastal sharks Juvenile shrimp	Bottlenose dolphin: GOM OCS/1 GOM CS Edge & Slope/1 Western GOM Coastal/1 Northern GOM Coastal/1 Eastern GOM Coastal/1 GOM Bay & Sound/1 U.S. Mid-Atlantic Coastal*/2 Harbor seal (Western N A)/1 Gray seal (Northwest N A.)/1 None documented	Green turtles (225) Leatherback turtles (160) Loggerhead (5,000-50,000) Hawksbill Kemp's ridley
Rhode Island Southern Massachusetts New York Bight (Inshore)	Winter flounder/15 Tautog (Black fish)/15 Monkfish/15 Bluefish/15 Striped bass/15 Bonita/15 Weakfish/15 Winter flounder/16 Cod/16 Bluefish/17 Striped bass/17 False albacore/17 Spanish mackerel/17 Weakfish/17 Monkfish/17	Gillnet			3				Humpback whale (Western N A.)*/1 (E) Minke whale/1 Bottlenose dolphin (Western N A)*/1 Harbor porpoise (Gulf of ME)*/1	
Long Island Sound (Inshore) (Summer fishery)	Bluefish/17 Striped bass/17 Bonita/17 Spanish mackerel/17 Menhaden/17 Atlantic herring/17	Gillnet			3			Striped Bass (quota)/17	Humpback whale (Western N A.)*/1 (E) Minke whale/1 Bottlenose dolphin (Western N A)*/1 Harbor porpoise (Gulf of ME)*/1	
Delaware Bay (Inshore)	White Perch/13 ----- American Shad/13 ----- Weakfish/13	Gillnets: Steaked Gillnet Drift Gillnet			3			Striped Bass ----- Summer flounder	Humpback whale (Western N A.)*/1 (E) Minke whale/1 Bottlenose dolphin (Western N A)*/1 Harbor porpoise (Gulf of ME)*/1	
North Carolina (Inshore)	Dogfish/19 Croaker/19 Weakfish/19 Bluefish/19 Summer flounder (in sound)/19	Gillnet	-1994-95 Data- 8.2 million lbs/19 1.6 million lbs/19 1.4 million lbs/19 1.6 million lbs/19 * 3-5 miles out/19	-1994-95 Data- $1.435 million/19 $1.35 million/19 $1.35 million/19 $400,000/19	3			Menhaden/19	Humpback whale (Western N A.)*/1 (E) Minke whale/1 Bottlenose dolphin (Western N A)*/1 Harbor porpoise (Gulf of ME)*/1	

Fisheries Description			Landings	Value	Category	Incidental Catch		Discard Catch	Bycatch Species	
Location	Target Species	Gear Type				Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
Gulf of Mexico/1 (Inshore)/1	Black drum/1 Sheepshead/1	Gillnet/1			3				None documented	
(Offshore)	Monkfish	Bottom gillnet			3				None documented	
Gulf of Maine/1	Northern shrimp/1	Trawl/1 Otter trawl, bottom/11 (small mesh)	-1991 Data- ----- 3,040 mt/11	-1991 Data- ----- $5.8 mil/11	3			American Plaice/10 Silver hake/10 Witch flounder/10	None documented	
Gulf of Maine	Mackerel	Trawl			3				None documented	
Gulf of Maine/1 Mid-Atlantic/1	Sea scallop/1	Trawl/1 Otter Trawl/11	-1991 Data- ----- 870 mt/11	-1991 Data- ----- $6.2 mil/11	3/1			[Goosefish/6 Summer flounder/6 Witch flounder/6 Loligo squid/6 Black sea bass/6 Scup/6 Silver hake/6 Conch/6 American lobster/6 Shark/6 King whiting/6 Puffer/6 Red hake/6 Sea robin/6 White hake/6 Bluefish/6 Atlantic mackerel/6 Dogfish/6 Jonah crab/6]	None documented/1	
Gulf of Maine/1 Southern North Atlantic/1 Gulf of Mexico/1 (Coastal)/1	Herring/1	Trawl/1			3				Atlantic spotted dolphin/1 Pantropical spotted dolphin/1 [Common dolphin Pilot whale]	
Mid-Atlantic	Mixed species	Trawl			3				None Documented	
Gulf of Mexico	Butterfish	Trawl			3				Atlantic Spotted Dolphin/1 Pantropical Spotted Dolphin/1	
Georgia South Carolina Maryland	Whelk Calico scallops/1	Trawl Trawl/1			3 3/1				None Documented None Documented/1	
	Bluefish/1 Croaker/1 Flounder/1	Trawl/1			3/1				None Documented/1	
	Crab/1	Trawl/1			3/1				None Documented/1	
Gulf of Maine/1	Atlantic herring/1	Purse seine/1	-1991 Data- ----- 18,870 mt/11	-1991 Data- ----- $1.9 mil/11	3/1				Harbor porpoise Gulf of ME/Bay of Fundy*/1 Harbor seal/1 Gray seal/1	
Gulf of Mexico	Menhaden	Purse seine			3				Bottlenose dolphin Western Gulf of Mexico/1 Northern Gulf of Mexico/1 Eastern Gulf of Mexico Gulf of Mexico Bay & Sound/1	

Location	Fisheries Description		Landings	Value	Category	Incidental Catch		Discard Catch	Bycatch Species	
	Target Species	Gear Type				Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
U.S. South Atlantic	Menhaden	Purse seine			3				Bottlenose dolphin (Western N A)*/1	
Florida West Coast	Sardine	Purse seine			3				Bottlenose Dolphin: Western Gulf of Mexico/1	
U.S. Mid-Atlantic		Hand seine			3				None Documented	
Gulf of Maine/1	Groundfish: White hake/18 Pollock/18 Cod/18	Tub trawl/1 Bottom longline/1 Hook-and-line/1			3/1			Atlantic halibut/18	Harbor seal/1 Gray seal/1	
U.S. South Atlantic Gulf of Mexico	Snapper:/1 Red snapper/8 Vermilion snapper/8 Silk snapper/8 Grouper:/1 Yellowedge grouper/8 Warsaw grouper/8 Other [reef] fish:/1 King mackerel/cero/8 Greater amberjack/8 Yellowfin tuna/8 Triggerfishes/8 Scamp/8	Bottom Longline Hook-and-line			3				None Documented	
U.S. South Atlantic Gulf of Mexico	Shark	Bottom Longline and Hook-and-line			3				None Documented	
Gulf of Maine/1 U.S. Mid-Atlantic/1	Tuna/1 Shark/1 Swordfish/1	Hook-and-line/1 Harpoon/1			3/1				None documented/1	
U.S. South Atlantic Gulf of Mexico U.S. Mid-Atlantic	Pelagic	Hook-and-line and Harpoon			3				None Documented	
Gulf of Maine/1 U.S. South Atlantic/1 (Coastal)/1	Shad/1 Sturgeon/1	Gillnet/1			3/1				Minke whale/1 Harbor porpoise: Gulf of ME/Bay of Fundy*/1	
U.S. South Atlantic Gulf of Mexico	Finfish: Robyn Angliss/NM Black Drum Red Drum Snappers	Gillnet			3				Bottlenose dolphin: Western Gulf of Mexico/1 Northern Gulf of Mexico/1 Eastern Gulf of Mexico/1	
Florida East Coast Gulf of Mexico	Pelagics king Spanish Mackerel	Gillnet			3				Bottlenose dolphin: GOM Outer Continental Shelf/1 GOM Outer Continental Shelf edge and slope/1 Western Gulf of Mexico/1 Northern Gulf of Mexico/1 Eastern Gulf of Mexico/1	
Florida	Mullet	Gillnet			3				None Documented	
Gulf of Maine/1 U.S. Mid-Atlantic/1	Mixed species: Mackerel/18	Trap/pot/1			3/1				[North Atlantic right whale]*/1 Humpback whale: Western North Atlantic*/1 (E) Minke whale/1 Harbor porpoise: Gulf of Maine/Bay of Fundy*/1 Harbor seal/1 Gray seal/1	

Location	Fisheries Description		Landings	Value	Category	Incidental Catch		Discard Catch	Bycatch Species	
	Target Species	Gear Type				Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
U.S. Mid-Atlantic	Black sea bass	Trap/pot			3				None Documented	
U.S. Mid-Atlantic	Eel	Trap/pot			3				None Documented	
Gulf of Maine/1 U.S. Mid-Atlantic/1 (Inshore)/1	Lobster/1	Traps/1 Pots/1	-1991 Data- --- 4,200 mt/11	-1991 Data- --- $22.6 mil/11	3/1			Cod/18 Cusk/18 Ocean wolf fish/18	North Atlantic right whale: Western North Atlantic*/1 Humpback whale: Western North Atlantic*/1 (E) Minke whale/1 Atlantic white-sided dolphin/1 Harbor seal/1 [Blue whale Fin whale Sperm whale]	[Leatherback turtle Logerhead turtle]
(Offshore)/1									None documented/1	
Atlantic Ocean/1 Gulf of Mexico/1	Blue crab/1	Trap/pot/1			3/1				[North Atlantic right whale]*/1 Bottlenose dolphin: Western Gulf of Mexico/1 Northern Gulf of Mexico/1 Eastern Gulf of Mexico/1 Florida manatee*/1 (E)	
U.S. South Atlantic Gulf of Mexico Caribbean --- South Florida --- Puerto Rico & U.S. Virgin Islands	Spiny Lobster	Trap/pot Dive/Hand			3				[North Atlantic right whale]*/1 Bottlenose dolphin: Western Gulf of Mexico/1 Northern Gulf of Mexico/1 Eastern Gulf of Mexico/1 [Florida manatee]/1	Anecdotal information indicates some unknown level of sea turtle mortality/4
Gulf of Maine/1 --- Atlantic/1	Herring/1 --- Mackerel/1	Stop seine/1 Weir/1			3/1				North Atlantic right whale: Western North Atlantic*/1 Humpback whale: Western North Atlantic*/1 Minke whale/1 Harbor porpoise: Gulf of Maine/Bay of Fundy*/1 Harbor seal/1 Gray seal/1	
U.S. Mid-Atlantic	Mixed Species: Coastal fish: Robyn Mullet Menhaden	Stop seine Weir			3				None Documented	
U.S. Mid-Atlantic	Crab	Stop seine Weir			3				None Documented	
Gulf of Maine U.S. Mid-Atlantic	Sea scallop	Dredge	-1991 Data- --- 19,060 mt/11	-1991 Data- --- $149.3 mil/11	3			[Goosefish/6 Yellowtail flounder/6 Winter flounder/6 Windowpane flounder/6 Summer flounder/6 Cod/6 Skate/6 American Plaice/6 Witch flounder/6 Haddock/6 Redfish/6 Halibut/6 Silver hake/6 Cusk/6 Pollack/6 Red hake/6 Scup/6 White hake/6 Wolffish/6	Humpback whale: Western North Atlantic*/1	

Fisheries Description						Incidental Catch		Discard Catch	Bycatch Species	
Location	Target Species	Gear Type	Landings	Value	Category	Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
								Bluefish/6 Butterfish/6 Black sea bass/6 Conch/6 Loligo squid/6 Illex squid/6 Jonah crab/6]		
U.S. Mid-Atlantic (Offshore)	Surf Clam Quahog	Dredge	-1991 Data- 49,240 mt/11	-1991 Data- $44 6 mil/11	3				None Documented	
Gulf of Maine/1	Mussel/1				3/1				None documented/1	
U.S. Mid-Atlantic Gulf of Mexico	Oyster				3				None Documented	
U.S. South Atlantic Caribbean	Jacks/20 Grunts/20 Snappers/20 Groupers/20 Snook/20 Members of Drum family/20	Haul seine (mechanical)/20			3			Juvenile reef fish /20 Snappers, Groupers, etc.	None Documented	
Caribbean	Jacks/20 Grunts/20 Snappers/20 Groupers/20 Snook/20 Members of Drum family/20	Beach seine (by hand)/20			3			Juvenile reef fish /20 Snappers, Groupers, etc.	Florida manatee/1 (E)	
Gulf of Maine/1	Urchin/1	Dive, hand/1 Mechanical collection/1			3/1				None documented/1	
Atlantic Ocean/1 Gulf of Mexico/1 Caribbean:/1	Shellfish/1	Dive, hand/1 Mechanical collection/1			3/1				None documented/1	
Puerto Rico /3 U.S. Virgin Islands/3	---- Conch:/3 Queen Conch Milk Conch W.I. Fighting Conch Rooster Tail Conch Hawkwing Conch FL Horse Conch Ture Tulip Atlantic Triton's Trumpet Flame Helmet Cameo Helmet Caribbean Helmet Whelk Green Star Shell		----- - 1992 - 90,947/3	----- - 1992 - $200,993						
Caribbean:/5 Puerto Rico U. S. Virgin Islands (shallow water)	Reef Fish:/5 Grunts Hogfish Trunkfish Squirrelfish Parrotfish Grouper Mojarra Lane Snapper Yellowtail Snapper Silk Snapper Mutton Snapper Other Snapper Triggerfish Porgy Goatfish		P.R. 1990 1,879,606 lbs ----- U.S. V.I. 1989 1,583,613 lbs ----- St. Croix 1989 587,353 lbs ----- St. Thomas/ St. John 1989 996,260							

Fisheries Description						Incidental Catch		Discard Catch	Bycatch Species	
Location	Target Species	Gear Type	Landings	Value	Category	Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
Florida/7 West Coast South/East Coast	Live Rock	Buckets	West Coast 1993 323,564 lbs South/East 1993 630,007	West Coast 1993 $402,228 South/East 1993 $658,100						

/1 Federal Register/Vol. 60, No 116/ Friday 16 June, 1995/Proposed Rules
/2 Environmental Assessment of Proposed Regulations to Govern Interactions between Marine Mammals and Commercial Fishing Operations, Under Section 118 of the Marine Mammal Protection Act, June 1995
/3 Draft Fishery Management Plan/RIR/EIS for the Queen Conch Resources of Puerto Rico and the U.S. Virgin Islands, January 1995
/4 Amendment 4 to the FMP for Spiney Lobster in the GOM and South Atlantic including the RIR and EA, December 1994
/5 Amendment 2 to the Fishery Management Plan for the Shallow-Water Reef Fish Fishery of Puerto Rico and the U.S. Virgin Islands, May 1993
/6 Amendment 4 and Supplemental Environmental Impact Statement to the Sea Scallop Fishery Management Plan, July 1993
/7 Amendment 3 to the Fishery Management Plan for Coral and Coral Reefs of the Gulf of Mexico including an ES/RIR and Initial Regulatory Flexibility Analysis, February 1995
/8 Draft Amendment 8 and Environmental Assessment (Effort Management Amendment) to the Reef Fish Fishery Management Plan for the Reef Fish Resources of the Gulf of Mexico, May 1995
/9 Section 7 Consultation on Fishing Conducted under Authorization of an Experimental Pair Trawl Fishery for Atlantic Tunas, August 1994
/10 Status of Fishery Resources off the Northeastern United States for 1993
/11 Amendment 5 to the Northeast Multispecies Fishery Management Plan incorporatin ghe Supplemental Environmental Impact Statement, 1993
/12 Personal communication, Ben Blalock, NMFS
/13 Personal communication, Desmond Kahn, Delaware Fish and Wildlife
/14 Draft Environmental Impact Statement for Amendment 5 to the Fishery Management Plan for the Atlantic Mackerel, Squid, and Butterfish Fisheries, October 1995
/15 Perso sonal communication, noushian, NMFS, RI port agent
/16 Personal communication, David McCarron, State of MA
/17 Personal communication, Erik Braun, NMFS, NY port agent
/18 Personal communication, Pete Marckoon, NMFS, ME port agent
/19 Personal Communication, Glenn Montgomery, NMFS, NC port agent
/20 Perso al communication, Miguel Colon, CFMC

Commercial Fisheries in the Pacific Ocean

Fisheries Description						Incidental Catch			Bycatch Species	
Location	Target Species	Gear Type	Landings	Value	Category	Landing Data	Value	Discard Catch	Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
CA	Angel shark/22,23 Halibut/22,23 Soupfin shark/23 Yellowtail/23 White sea bass/23	Set gill net (3.5 mesh)			1				Harbor porpise*/22,23 Common dolphin (all stocks) /23 Short-beaked/22 Long-beaked/22 CA Sea lion/22,23 Harbor seal (CA)/22,23 Northern elephant seal/22,23 Unidentified cetacean/23	
CA/OR/WA	Thresher shark/22,23 Swordfish/22,23 Blue shark (OR only)/22,23	Drift gillnet 120 ft. deep 6000 ft. long			1				Steller sea lion (E U.S.)*/22,23 (T) Sperm whale*/22,23 (E, exceeds PBR) Dall's porpoise/22,23 Pacific white-sided dolphin/22,23 Risso's dolphin/22,23 Bottlenose dolphin/22,23 Common dolphin (all stocks)*/23 Short-beaked/22 (exceeds PBR) Long-beaked/22 Northern right whale dolphin/22,23 Pilot whale*/23 Short-finned/22 Pygmy sperm whale*/22,23 Northern elephant seal/22,23 Beaked whale*/23 (exceeds PBR) CA sea lion/23 Unidentified cetacean/23	
WA, Northern coastal areas (4 and 4a)	Salmon/23	Set gillnet			1				Gray whale/23 Harbor porpoise (OR/WA coast)/23 Harbor seal (OR/WA coast)/23 Sea otter/23	
AK, Prince William Sound Copper River Bering River	Salmon/22,23	Drift gillnet			2				Steller sea lion: Western U.S.*/22 (T) Eastern U.S.*/23 (T) Harbor porpoise/22,23 Harbor seal (Gulf of AK)/22,23 Unidentified small cetacean/23	Murrelets: marbled/23 kittlitz/23 unidentified/23 Loons: common/23 red-throated/23 Sooty shearwaters/23 Murres: common/23 unidentified/23 Unidentified alcids/23 1990: 1468 birds taken/23 1991: 993 birds taken/23
AK, Peninsula Aleutians	Salmon/22,23	Drift gillnet			2				Northern fur seal*/22,23 (D) Harbor seal: Gulf of AK/22,23 Bering Sea/22,23 Spotted seal/22,23 Harbor porpoise/22,23 Dall's porpoise/22,23 Walrus/22,23 Unidentified small cetacean/23 Unidentified species/23	Murres: common/23 unidentified/23 Shearwaters: sooty/23 short-tailed/23 Puffin: horned/23 tufted/23 Marbled murrelets/23 Unidentified birds/23 1990: 337 birds taken/23
AK, Southeast	Salmon/22,23	Drift gillnet			2				Steller sea lion(E U.S.)*/22,23 (T) Harbor seal/22,23 Pacific white-sided dolphin/22 Harbor porpoise/22,23 Dall's porpoise/22,23 Unidentified small cetacean/23 Unidentified pinniped/23. Unidentified species/23	Most likely: Common murres/23 Marbled murrelets/23
AK, Cook Inlet	Salmon/22,23	Drift gillnet			2				Steller sea lion (W U.S.)*/22 (T) Harbor seal/22 Harbor porpoise/22	Most likely: Common murres/23 Marbled murrelets/23

Fisheries Description			Landings	Value	Category	Incidental Catch		Discard Catch	Bycatch Species	
Location	Target Species	Gear Type				Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
AK, Yakutat	Salmon/22,23	Set gillnet			2				Dall's porpoise/22,23 Unidentified small cetacean/23 Harbor seal: SE AK/22 Gulf of AK/23 Spotted seal/22,23	Most likely: Common murres/23 Marbled murrelets/23
AK, Cook Inlet	Salmon/22,23	Set gillnet			2				Steller sea lion (W.U.S.)*/22 (T) Harbor seal (Gulf of AK)/22,23 Harbor porpoise/22 Dall's porpoise/22	
AK, Peninsula/ Aleutian Island	Salmon/22,23	Set gillnet			2				Steller sea lion (W. U.S.)*/22,23 (T) Harbor porpoise/22,23 Unidentified pinniped/23	Shearwaters: sooty/23 short-tailed/23 Puffin: tufted/23 horned/23 Marbled murrelets/23 Murres: common/23 unidentified/23 Unidentified birds/23 Total est. take: 337 birds/23
AK, Kodiak	Salmon/22,23	Set gillnet			2				Harbor seal (Gulf of AK) /22,23 Harbor porpoise/22,23 Sea Otter/23 Unidentified small cetacean/23 Unidentified species/23	Most likely: Common murres/23
AK, Bristol Bay	Salmon/23	Drift gillnet			2				Steller sea lion (W.U.S.)*/22,23 (T) Northern fur seal*/22,23 (D) Harbor seal (Bering Sea)/22,23 Spotted seal/22,23 Bearded seal*/22,23 Beluga/22 Pacific white-sided dolphin/22 Gray whale/22 Unidentified small cetacean/23 Unidentified pinniped/23 Unidentified species/23	
AK, Bristol Bay	Salmon/23	Set gillnet			2				Harbor seal (Bering Sea)/22,23 Beluga/22,23 Unidentified small cetacean/23	
AK, Metlakatla/ Annette Island	Salmon/22,23	Drift gillnet 200 fm length			2				Harbor seal/22,23 Harbor porpoise/22,23	Most likely: Common murres/23 Possibly: Marbled murrelets/23
AK	(Except salmon or herring)/23	Gillnet			2				Unidentified pinniped/23 Unidentified species/23	
WA, (Puget Sound Region) Strait of Juan de Fuca — Nooksack-Samish — Skagit — Hood Canal	 Chinook salmon/25 Coho salmon/25 Pink salmon/25 — Chinook salmon/25 Coho salmon/25 Pink salmon/25 — Chinook salmon/25 Coho salmon/25 Pink salmon/25 — Chinook salmon/25 Coho salmon/25 Pink salmon/25	Drift gillnet Troll			2				Steller sea lion (E.U.S.)*/22,23 (T) Dall's porpoise/22 Harbor porpoise/22 CA Sea lion/22,23 Harbor seal: OR/WA coast/22 WA inland waters/23 Unidentified pinniped/23 Unidentified marine mammal/23	Sea Birds: Common murres/23 Loons: common/23 yellow-billed/23 Pigeon guillemots/23 Rhinoceros auklets/23

Fisheries Description						Incidental Catch			Bycatch Species	
Location	Target Species	Gear Type	Landings	Value	Category	Landing Data	Value	Discard Catch	Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
Stillaguamish-Snohomish --- South Puget Sound	Chinook salmon/25 Coho salmon/25 Pink salmon/25 --- Chinook salmon/25 Coho salmon/25 Pink salmon/25									
WA, (Coastal river) Quinault River --- Queets River --- Hoh River --- Quillayute River	 Chinook salmon (S/S)/25 Chinook salmon (F)/25 Chum salmon/25 Sockeye salmon/25 Coho salmon/25 --- Chinook salmon (S/S)/25 Chinook salmon (F)/25 Coho salmon/25 --- Chinook salmon (S/S)/25 Chinook salmon (F)/25 Coho salmon/25 --- Chinook salmon (S/S)/25 Chinook salmon (F)/25 Coho salmon (S)/25 Coho salmon (F)/25	Set gillnet			2				None documented/23	
CA, Klamath River	Chinook salmon/25	Gillnet			2				None documented/23	
CA	Non-salmonid /23 Herring/roe/23	Gillnet			2				Unknown/23	
CA	Mackerel: Jack/26 Pacific/26 Northern anchovy/22 Tuna/22	Purse seine	-1994 Data- 2,648 mt/26 9,750 mt/26 1,924 mt/26		2				Bottlenose dolphin/22,23 CA Sea lion/22,23 Harbor seal/22,23	
AK, Southeast	Salmon/22,23	Purse seine			2				Humpback whale*/22,23 (E) Harbor porpoise/22	
AK, Peninsula	Salmon/23	Purse seine			2				None documented/23	
AK, Bering Sea and Aleutian Islands	Walleye pollock/27,28 Pacific cod/27,28 Yellowfin sole/27,28 Greenland turbot/27,28 Arrowtooth flounder/27,28 Rock sole/27,28 Other flatfish/27,28 Sablefish/27,28 Pacific ocean perch/27,28 Other rockfish/27,28 Atka mackerel/27,28 Other fish/27,28	Trawl	-1994 Totals- 1,278,456.62 98,695.82 144,344.82 6,443.43 12,505.18 60,071.19 18,638.79 535.74 12,814.98 77.23 69,468.57 13,445.97	-1994 Data-	2	-1994 Data Totals- Flathead Sole:/28 5,802.02 mt Dover Sole:/28 37.68 mt Rex Sole:/28 292.76 mt Butter Sole:/28 24.71 mt Starry Flounder:/28 245.55 mt Sand Sole:/28 .08 mt AK Plaice Flounder:/28 4,102.88 mt Northern Rockfish:/28 2,131.93 mt Copper Rockfish:/28 34.52 mt Thornyhead Rockfish:/28 39.41 mt Yelloweye Rockfish:/28 .06 mt Rosethorn Rockfish:/28	-1994 Data	-1994 Data- Walleye Pollock: 104,694.66 mt /28 Pacific cod: 29,628.41 mt /28 Yellowfin sole: 36,721.41 mt /28 Greenland turbot: 865.19 mt /28 Arrowtooth Flounder: 12,092.42 m Rock Sole: 39,236.41 mt /28 Other Flatfish: 12,041.10 mt /28 Sablefish: 84.86 mt /28 Pacific Ocean Perch: 1,864.54 mt / Other Rockfish: 28.01 mt /28 Atka Mackerel: 10,232.68 mt /28 Other Fish: 13,111.19 mt /28 Flathead Sole: 2,730.93 mt /28 Rock Sole: 39,236.41 mt /28 Dover Sole: 37.44 mt /28 Rex Sole: 33.42 mt /28 Butter Sole: 24.30 mt /28 Yellowfin Sole: 36,721.41 mt /28 Starry Flounder: 227.94 mt /28 Sand Sole: .07 mt /28 AK Plaice Flounder: 3,276.11 mt /28 Northern Rockfish: 2037.20 mt /28 Copper Rockfish: 32.33 mt /28	Steller sea lion: Western U.S.*/22,23 (T) Eastern U.S.*/22 (T) Northern fur seal*/22,23 (D) Killer whale: Transient/22,23 Resident/23 Pacific white-sided dolphin/22 Harbor porpoise/22 Harbor seal (Bering Sea)/22,23 Spotted seal/22 Bearded seal/22,23 Ringed seal/22,23 Ribbon seal/22,23 Dall's porpoise/22,23 Northern elephant seal/22 Northern AK sea otter/22 Walrus/23	

Fisheries Description						Incidental Catch			Bycatch Species	
Location	Target Species	Gear Type	Landings	Value	Category	Landing Data	Value	Discard Catch	Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
						.01 mt Rougheye Rockfish (GOA):/28 .45 mt Shortraker Rockfish (GOA):/28 1.55 mt Redbanded Rockfish:/28 .02 mt Dusky Rockfish:/28 1.02 mt Redstripe Rockfish:/28 .01 mt Sharpchin Rockfish:/28 .09 mt Squid:/28 534.21 nmt Pelagic Shelf Rockfish:/28 13.08 mt Shortraker Rockfish (BS):/28 814.29 mt Rougheye Rockfish (BS):/28 2,960.34 mt		Thornyhead Rockfish: 15.21 mt /28 Rosethorn Rockfish: .01 mt /28 Rougheye Rockfish: .04 mt /28 Shortraker Rockfish: .92 mt /28 Redbanded Rockfish: .02 mt /28 Dusky Rockfish: .33 mt /28 Redstripe Rockfish: .01 mt /28 Squid: 272.18 mt /28 Petrale Sole: .09 mt /28 Pelagic Shelf Rockfish: 8.29 mt /28 Shortraker Rockfish (BS): 204.30 mt /28 Rougheye Rockfish (BS): 2,258.98 mt /28		
AK	Cod/23	Pair trawl			2				Harbor seal: Gulf of AK/22 Bering Sea/22 Pacific white-sided dolphin/22 Dall's porpoise/22	
AK, Prince William Sound	Sablefish/23	Longline/setline			2/3				None documented/23	
AK, Southern Bering Sea Aleutian Islands and Western Gulf of AK	Sablefish/22,28	Longline/set line [Fed. Regulated waters]	-1994 Data- Sablefish: 1,638.38 mt/28	-1994 Data-	2	-1994 Data Totals- Other Fish:/28 135.84 mt Pacific Cod:/28 21.26 mt Rock Sole:/28 1.05 mt Greenland Turbot:/28 2,321.61 mt Other Rockfish:/28 61.43 mt Pacific Ocean Perch:/28 2.15 mt Thornyhead Rockfish:/28 139.56 mt Yelloweye Rockfish:/28 2.35 mt Rougheye Rockfish (GOA):/28 .96 mt Shortraker Rockfish (GOA):/28 .07 mt Other Rockfish:/28 .39 mt Shortraker Rockfish (BS):/28 47.56 mt	-1994 Data	-1994 Data- Other Fish: 135.74 mt /28 Pacific Cod: 10.98 mt /28 Miscellaneous Flatfish: .59 mt /28 Flathead Sole: .30 mt /28 Dover Sole: .10 mt /28 Yellowfin Sole: .13 mt /28 Greenland Turbot: 2,128.97 mt /28 Other Rockfish: 12.20 mt /28 Pacific Ocean Perch: .18 mt /28 Thornyhead Rockfish: 1 mt /28 [Other Rockfish]: .01 mt /28 Shortraker Rockfish (BS): 15.74 mt /28 Pollock: .19 mt /28 Sablefish: 22.65 mt /28	Killer whale/22 Northern elephant seal/22,23	Northern fulmars/23 Laysan albatross/23
OR	Swordfish/22 Blue Shark/22	Surface longline			2				Unknown/22	
AK, Prince William Sound	Salmon/29	Set gillnet			3				Steller sea lion: Western U.S./22 (T) Eastern U.S.*/23 (T) Harbor porpoise/22	
AK, Kuskokwim, Yukon, Norton Sound, Kotzebue	Salmon/22,23	Gillnet			3				Spotted seal/22,23 Beluga: (All stocks)/23 E Chukchi Sea/22 Norton Sound/22 Bristol Bay/22 Harbor porpoise/22,23	

Fisheries Description			Landings	Value	Category	Incidental Catch		Discard Catch	Bycatch Species	
Location	Target Species	Gear Type				Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
AK	Roe herring/22 Food/Bait Herring/22	Gillnet			3				Harbor porpoise/22 Harbor seal: SE AK/22 Gulf of AK/22 Bering Sea/22	
WA/OR	Herring/22 Shad/22 Mullet/22 Smelt/22 Sturgeon/22 Perch/22 Sablefish/27 Pacific whiting/27 Dover sole/27 English sole/27 Petrale sole/27 Thornyheads/27 Widow rockfish/27 Bocaccio/27 Canary rockfish/27 Chilipepper rockfish/27 Shortbelly rockfish/27 Yellowtail rockfish/27 Other rockfish/27 Lingcod/27 Pacific cod/27	Gillnet			3				CA Sea lion/22 Harbor seal: WA Inland waters/22 OR/WA coast/22	
WA/OR	Shad/23 Smelt/23	Gillnet			3				None documented/23	
WA, Willpa Bay	Chinook salmon/25 Coho salmon/25	Drift gillnet			3				Steller sea lion (E. U.S.)*/22 (T) CA Sea lion/22 Harbor seal (OR/WA coast)/22,23 Northern elephant seal/22	
WA, Grays Harbor	Chinook salmon/25 Coho salmon/25	Drift gillnet			3				Steller sea lion (E. U.S.)*/22 (T) CA Sea lion/22 Harbor seal (OR/WA coast)/22,23	
WA/OR, Lower Columbia Ri	Salmon/25,29	Drift gillnet			3				Steller sea lion (E. U.S.)*/22 (T) CA Sea lion/22,23 Harbor seal: WA/Inland waters/22 OR/WA coast/22,23	
CA	White Croaker/23 Bonito/23 Flying fish/23 Herring/23 Smelt/23 Shad/23 Sturgeon/23 Mullet/23 Pacific Ocean perch/27 Canary rockfish/27 Chilipepper rockfish/27 Widow rockfish/27 Shortbelly rockfish/27 Yellowtail rockfish/27 Other rockfish/27 Sablefish/27 Dover sole/27 English sole/27 Petrale sole/27 Pacific whiting/27 Thornyheads /27 Bocaccio /27 Lingcod/27 Pacific cod/27 Other fish/27	Set and drift gillnet stretched mesh (<3 5 in)			3				Steller sea lion (E. U.S.)*/22 (T) Gray whale/22 Harbor porpoise: Central CA/22 Northern CA/22 Dall's porpoise/22 Common dolphin: Short-beaked/22 Long-beaked/22 Harbor seal/22	

Fisheries Description			Landings	Value	Category	Incidental Catch		Discard Catch	Bycatch Species	
Location	Target Species	Gear Type				Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
AK	Whitefish/24 Arctic char/24 Dolly Varden/24 (ocean-going trout) Inconnu (sheefish)/24 Grayling/24 Pike/24 Sturgeon/24 Trouts/24 Smelt/24 Sardine/24 Misc. Tuna/24 Sculpin/24 Lamprey/24	Set gillnet			3				Steller sea lion: Western U.S.*/22 (T) (Eastern U.S. = T) Harbor porpoise/22 Harbor seal: SE AK/22 Gulf of AK/22 Bering Sea/22	
HI	Anything that can be caught, mullet and reef fish/30	Primarily inshore small mesh set gillnets/30			3				Hawaiian monk seal*/22 (E)	
AK (Except SE AK)	Salmon/22,23	Purse seine			3				Steller sea lion: Western U.S.*/22 (T) Eastern U.S.*/22 (T) Northern fur seal/22 (D) Harbor porpoise/22 Northern AK sea otter/22	
AK	Salmon/22,23	Beach seine			3				Steller sea lion: Western U.S.*/22 (T) Eastern U.S.*/22 (T) Harbor seal: SE AK/22 Gulf of AK/22 Bering Sea/22 Harbor porpoise/22	
AK	Roe herring/22,23 Food/bait herring/22	Purse seine			3				Steller sea lion: Western U.S.*/22 (T) Eastern U.S.*/22 (T) Harbor seal: SE AK/22 Gulf of AK/22 Bering Sea/22 Harbor porpoise/22	
AK	Roe herring/22,23 Food/bait herring/22	Beach seine			3				Steller sea lion: Western U.S.*/22 (T) Eastern U.S.*/22 (T) Harbor seal: SE AK/22 Gulf of AK/22 Bering Sea/22 Harbor porpoise/22	
AK	Octopus/22 Squid/22	Purse seine			3				Steller sea lion: Western U.S.*/22 (T) Eastern U.S.*/22 (T) Harbor seal: SE AK/22 Gulf of AK/22 Bering Sea/22 Harbor porpoise/22	
CA	Herring/22,23	Purse seine			3				Bottlenose dolphin/22,23 CA Sea lion/22,23	
CA	Pacific sardine/22,23,26	Purse seine	-1994 Data- 11,354 mt /26		3				CA Sea lion/22	

Fisheries Description						Incidental Catch			Bycatch Species	
Location	Target Species	Gear Type	Landings	Value	Category	Landing Data	Value	Discard Catch	Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
CA	Squid/22,23,26	Purse seine	-1994 Data- 55,770 mt /26		3				Risso's dolphin/22,23 Pilot whale, short-finned/22.23 CA Sea lion/22.23	
CA	Squid/22	Dip net			3				Pilot whale, short-finned/22 CA Sea lion/22	
WA/OR	Salmon/22	Net pens			3				Steller sea lion (E U S)*/22 (T) CA Sea lion/22,23 Harbor seal: WA Inland waters/22,23 OR/WA coast/22	
OR	Salmon/22	Ranch			3				CA Sea lion/22 Harbor seal/22	
AK	Salmon/22,23	Troll			3				Steller sea lion: Western U S */22 (T) Eastern U S */22,23 (T) Northern fur seal*/22 (D) Harbor seal: Gulf of AK/22 Bering Sea/22 Humpback whale*/22 (E) Unidentified small cetacean/23 Unidentified species/23	
CA Chinook salmon/25 Coho salmon/25 Pink salmon/25 ---------- OR Chinook salmon/25 Coho salmon/25 Pink salmon/25 ---------- WA Chinook salmon/25 Coho salmon/25 Pink salmon/25		Troll			3				Steller sea lion (E U S)*/22,23 (T) CA Sea lion/22,23 Harbor seal: California/22,23 WA Inland waters/22 OR/WA coast/23 Dall's porpoise/23 Sea otter (CA)/23 Sperm whale */23 Unidentified pinniped/23 Unidentified species/23	
AK North Pacific Halibut/22 Walleye pollock/27 Pacific cod/24,27 Yellowfin sole/27 Greenland turbot/24,27 Arrowtooth flounder/24,27 Rock sole/27 Other flatfish/27 Sablefish/27 Pacific ocean perch/27 Other rockfish/27 Atka mackerel/27 Other fish/27 Ling cod/24 Greenling/24 ----- WA/OR/CA Albacore/22 Pacific Ocean perch/27 Canary rockfish/27 Chilipepper rockfish/27 Widow rockfish/27 Shortbelly rockfish/27 Yellowtail rockfish/27 Other rockfish/27 Sablefish/27 Dover sole/27 English sole/27 Petrale sole/27 Pacific whiting/27 Thornyheads /27 Bocaccio /27 Lingcod/22		Non-salmonid troll			3				Harbor seal: SE AK/22 Gulf of AK/22 Bering Sea/22 California/22 WA Inland waters/22 OR/WA coast/22	

Fisheries Description			Landings	Value	Category	Incidental Catch		Discard Catch	Bycatch Species	
Location	Target Species	Gear Type				Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
CA	Pacific cod/27 Other fish/27 --- Halibut/22									
HI	All pelagics/29 (Bigeye scad)/30 (Yellowfin tuna)/30 (Billfish)/29,30 (Wahoo)/30 (Sharks)/30	Trolling, Rod and Reel			3				False killer whale/22 Rough-toothed dolphin/22 Bottlenose dolphin/22	
Guam	Skipjack tuna/23,31 Yellowfin Tuna/31	Troll	-1993 Data- 135,163 lbs/31 76,285 lbs/31		3				None Documented/22,23	
Commonwealth of the Northern Marina Islands	Skipjack tuna/23,31 Yellowfin Tuna/31	Troll			3				None Documented/22,23	
American Samoa	Skipjack tuna/23,31 Yellowfin Tuna/31	Troll			3				None Documented/22,23	
AK	Whitefish/24 Arctic char/24 Dolly Varden/24 (ocean-going trout) Inconnu (sheefish)/24 Grayling/24 Pike/24 Sturgeon/24 Trouts/24 Smelt/24 Sardine/24 Misc. Tuna/24 Sculpin/24 Lampray/24	Purse seine			3				Steller sea lion: Western U.S.*/22 (T) Eastern U.S.*/22 (T) Harbor seal: SE AK/22 Gulf of AK/22 Bering Sea/22 Harbor porpoise/22	
AK	Whitefish/24 Arctic char/24 Dolly Varden/24 (ocean-going trout) Inconnu (sheefish)/24 Grayling/24 Pike/24 Sturgeon/24 Trouts/24 Smelt/24 Sardine/24 Misc. Tuna/24 Sculpin/24 Lampray/24	Beach seine			3				Steller sea lion: Western U.S.*/22 (T) Eastern U.S.*/22 (T) Harbor seal: SE AK/22 Gulf of AK/22 Bering Sea/22 Harbor porpoise/22	
WA	Salmon/22	Purse seine			3				Dall's porpoise/22 Harbor seal: WA Inland waters/22 OR/WA coast/22	

Location	Fisheries Description		Landings	Value	Category	Incidental Catch		Discard Catch	Bycatch Species	
	Target Species	Gear Type				Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
WA	Salmon/22	Reef net			3				Harbor seal: WA Inland waters/22 OR/WA coast/22	
WA/OR	Herring/22 Smelt/22 Squid/22	Purse seine or lampara			3				CA Sea lion/22 Harbor seal: WA Inland waters/22 OR/WA coast/22	
WA	All species/22	Beach or drag seine			3				None Documented/22	
HI	Bigeyed scad (Akule)/30 Mackerel scad (Opelu)/30	Purse seine			3				None Documented/22	
HI	Bigeyed scad (Akule) Mackerel scad (Opelu) Mullet/30	Small mesh surround net manually deployed in shallow waters/30			3				None Documented/22	
HI	Anything that can be caught primarily recreation and subsistance i.e. mullet/30	Throw net/ Cast net			3				None Documented/22	
HI	Catch all/30	Net Unclassified			3				None Documented/22	
AK, State waters	Sablefish/22	Longline/setline			3				Harbor seal: Gulf of AK/22 Bering Sea/22 Killer whale/22 Northern elephant seal/22	
AK, Bering Sea and Gulf of AK	Whitefish/24 Arctic char/24 Dolly Varden/24 (ocean-going trout) Inconnu (sheefish)/24 Grayling/24 Pike/24 Sturgeon/24 Trouts/24 Smelt/24 Sardine/24 Misc. Tuna/24 Sculpin/24 Lampray/24 Walleye pollock/27 Pacific cod/27 Yellowfin sole/27 Greenland turbot/27 Arrowtooth flounder/27 Rock sole/27 Other flatfish/27 Sablefish/27 Pacific ocean perch/27 Other rockfish/27 Atka mackerel/27 Other fish/27	Longline/Set line			3				Harbor seal: Gulf of AK/22,23 Bering Sea/22,23 Northern elephant seal/22,23 Steller sea lion (E.U.S.)*/23 (T)	Bering Sea: 1990-1992: 7351 avg. rate of birds caught in yr. 1993: Northern fulmars Unidentified birds Unidentified gulls Laysan albatross Unidentified albatross -------- Gulf of AK: 1990-1992: 879 avg. rate of birds caught in yr. 1993: Northern fulmars Laysan albatross Unidentified shearwater/ petrels Unidentified birds
HI	Swordfish (offshore)/22,30 Tuna (inshore)/22,30 Billfish/22 Mahi Mahi/22 Wahoo/22 Oceanic sharks/22	Longline/setline			3				False killer whale/22 Rough-toothed dolphin/22 Pygmy killer whale/23 (Finning a problem in this fishery/30)	83.04166667 Green turtle/23 Leatherback turtle/23 Loggerhead turtle/23
WA/OR	North Pacific Halibut/22	Longline/Setline			3				Killer whale/22 Sperm whale*/22 (E)	
AK	Halibut/22	Longline/Setline [State and Fed. waters]			3				Steller sea lion: Western U.S.*/22 (E) Eastern U.S.*/22 (E) Harbor seal (Gulf of AK)/22	

Fisheries Description			Landings	Value	Category	Incidental Catch		Discard Catch	Bycatch Species	
Location	Target Species	Gear Type				Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
									Gulf of AK/22 Bering Sea/22 Humpback whale: W.N. Pacific/22 C N. Pacific/22 Northern elephant seal/22	
WA/OR/CA	Pacific whiting/27 Sablefish/27 Dover sole/27 English sole/27 Petrale sole/27 Thornyheads /27 Widow rockfish/27 Bocaccio/27 Canary rockfish/27 Chilipepper rockfish/27 Pacific ocean perch/27 Shortbelly rockfish/27 Yellowtail rockfish/27 Other rockfish/27 Ling cod/27 Pacific cod/27 Other fish/27	Longline/Setline			3				Steller sea lion (E U.S.)*/22 (T) Pacific white-sided dolphin/22 CA Sea lion/22 Harbor seal: California/22 OR/WA coast/22	
AK	Octopus/22 Squid/22	Longline			3				None Documented/22	
CA	Shark/22 Bonito/22	Longline/Setline			3				CA Sea lion/22	
WA/OR/CA	Shrimp/22	Trawl			3				None Documented/22	
AK	Shrimp/22	Otter Trawl and Beam Trawl (statewide and Cook Islet)			3				None Documented/22	
AK, Gulf of AK *****	Pollock	Trawl	-1994 Data- 110,793.87 mt	-1994 Data-	3	-1994 Totals- Other Fish: 2,090.16 mt Pacific Cod: 31,913.98 mt Misc. Flatfish: 69.32 mt Arrowtooth Flounder: 22,673.67 mt Flathead Sole: 2,578.10 mt Rock Sole: 3,011.12 mt Dover Sole: 2,595.95 mt Rex Sole: 3,673.67 mt Butter Sole: 241.63 mt Yellowfin Sole: 82.84 mt English Sole: 8.05 mt Starry Flounder: 56.26 mt Petrale Sole: .12 mt Sand Sole: 16.37 mt AK Plaice Flounder: 5.88 mt Greenland Turbot: .03 mt	-1994 Tota	-1994 Data- Pollock: 6,389.23 mt Other fish: 2,045.41 mt Pacific Cod: 2,770.87 mt Misc. Flatfish: 46.69 mt Arrowtooth Flounder: 22,238.73 mt Flathead Sole: 830.50 mt Rock Sole: 569.58 mt Dover Sole: 530.62 mt Rex Sole: 369.54 mt Butter Sole: 18.97 mt Yellowfin Sole: 37.76 mt English Sole: 3.56 mt Starry Flounder: 8.59 mt Sand Sole: 13.18 mt AK Plaice Flounder: .36 mt Northern Rockfish: 1,054.92 mt Pacific Ocean Perch: 1,117.12 mt Black Rockfish: .20 mt Thornyhead Rockfish: 221.96 mt Quillback Rockfish: .01 mt Rougheye Rockfish (GOA): 1.07 mt Shortraker Rockfish (GOA): .19 mt Redbanded Rockfish (GOA): .01 mt Dusky Rockfish: 4.79 mt Redstripe Rockfish: 4.28 mt Sharpchin Rockfish: 164.79 mt Other Rockfish: 28.74 mt Pelagic Shelf Rockfish: 275.32 mt Shortraker Rockfish (BS): 185.16 mt Atka Mackerel: 275.81 mt Pollock: 6,389.23 mt Sablefish: 543.81 mt	Steller sea lion: Western U.S.*/22. (T) Eastern U.S.*/22,23 (T) Northern fur seal*/22 (E) Harbor seal (Gulf of AK)/22,23 Spotted seal/22 Bearded seal/22 Ringed seal/22 Ribbon seal/22 Killer whale: Resident/22 Transient/22 Dall's porpoise/22,23 Northern elephant seal/22,23 Unidentified pinniped/23	1993: 24 observed unidentified shearwater/ petrels were caught. Total estimated take: 65 birds

Fisheries Description						Incidental Catch			Bycatch Species	
Location	Target Species	Gear Type	Landings	Value	Category	Landing Data	Value	Discard Catch	Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
						Northern Rockfish: 5,964.03 mt Bocaccia Rockfish: .27 mt Pacific Ocean Perch: 1,850.85 mt Black Rockfish: 1.13 mt Thornyhead Rockfish: 714.90 mt Yelloweye Rockfish: .12 mt Quillback Rockfish: .02 mt Rougheye Rockfish (GOA): 40.20 mt Shortraker Rockfish: 20.46 mt Dusky Rockfish: 30.58 mt Widow Rockfish: .01 mt Silvergray Rockfish: .61 mt Redstripe Rockfish: 23.82 mt Sharpchin Rockfish: 191.15 mt Other Rockfish: 54.04 mt Pelagic Shelf Rockfish: 2,573.96 mt Shortraker Rockfish (BS): 891.39 mt Harlequin Rockfish: .02 mt Splitnose Rockfish: .10 mt Atka Mackerel: 3,537.58 mt Sablefish: 2,426.97 mt Squid: 10.28 mt		Squid 9.51 mt		
AK, Bering Sea	Pollock/23	Trawl			3				Bearded seal/23 Dall's porpoise/23 Harbor seal (Bering Sea)/23 Killer whale: Transient/23 Resident/23 Northern fur seal*/23 Ribbon seal/23 Ringed seal/23 Steller sea lion (W.U.S.)*/23 Walrus/23 Unidentified pinniped/23 Unidentified cetacean/23	Unidentified shearwater/petrel/23 Unidentified murrelet/auklet/23 Unidentified bird/23 Unid. procellariliformes/23 1989-1992 avg. ann. rate: 1070 birds per yr./23 1993: 261 birds/23
AK State-managed waters of: Cook Inlet/Kachemak Bay --- Prince William Sound --- SE AK	Walleye pollock/27 Pacific cod/27 Yellowfin sole/27 Greenland turbot/27 Arrowtooth flounder/27 Rock sole/27 Other flatfish/27 Sablefish/27 Pacific ocean perch/27 Other rockfish/27 Atka mackerel/27 Other fish/27	Trawl			3				Dall's porpoise/22	

Fisheries Description			Landings	Value	Category	Incidental Catch		Discard Catch	Bycatch Species	
Location	Target Species	Gear Type				Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
AK	Whitefish/24 Arctic char/24 Dolly Varden/24 (ocean-going trout) Inconnu (sheefish)/24 Grayling/24 Pike/24 Sturgeon/24 Trouts/24 Smelt/24 Sardine/24 Misc. Tuna/24 Sculpin/24 Lampray/24	Otter or Beam Trawl			3				None Documented/22	
AK	Food/bait Herring/22,23	Trawl			3				None Documented/22	
WA/OR/CA	Pacific whiting/27 Sablefish/27 Dover sole/27 English sole/27 Petrale sole/27 Thornyheads/27 Widow rockfish/27 Bocaccio/27 Canary rockfish/27 Chilipepper rockfish/27 Pacific ocean perch/27 Shortbelly rockfish/27 Yellowtail rockfish/27 Other rockfish/27 Ling cod/27 Pacific cod/27 Other fish/27	Trawl			3				Steller sea lion (W U.S.)*/22 (T) Northern fur seal*/22 Pacific white-sided dolphin/22 Dall's porpoise/22,23 CA Sea lion/22 Harbor seal: California/22 OR/WA coast/22 Unidentified pinniped/23	Between 1990 - 1993: average annual take is 0.5 unidentified birds/2
AK	Shrimp/29 King crab/29 Tanner crab/29	Pot			3				None Documented/22	
AK, Bering Sea --- Gulf of AK	Finfish (for cod)/29	Pot			3				Harbor seal: Gulf of AK/22,23 Bering Sea/22,23 Northern AK sea otter/22,23	Total avg. annual take: 1989-1993 is 10.25 birds/23
WA/OR/CA	Sablefish/22	Pot			3				Harbor seal: California/22 WA Inland waters/22 OR/WA coast/22	
WA/OR/CA	Crab/22	Pot			3				Gray whale/22 Fin whale/22 Harbor seal: California/22 WA Inland waters/22 OR/WA coast/22	
WA/OR	Shrimp/22	Pot and Trap			3				None Documented/22	
CA	Lobster/22 Prawn/22 Shrimp/22 Rock Crab/22 Fish/22	Pot			3				None Documented/22	
OR/CA	Hagfish/22	Pot or Trap			3				None Documented/22	
HI	Lobster/22	Trap			3				Hawaiian Monk seal*/22 (E)	
HI	Crab/22	Trap			3				None Documented/22	

Fisheries Description			Landings	Value	Category	Incidental Catch		Discard Catch	Bycatch Species	
Location	Target Species	Gear Type				Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
HI	Jacks/30 Snappers/30 Groupers/30 Other reef fish/30	Trap			3				None Documented/22	
HI	Shrimp/22	Trap			3				None Documented/22	
AK	North Pacific Halibut/22	Handline and Mechanical Jig			3				None Documented/22	
AK	Whitefish/24 Arctic char/24 Dolly Varden/24 (ocean-going trout) Inconnu (sheefish)/24 Grayling/24 Pike/24 Sturgeon/24 Trouts/24 Smelt/24 Sardine/24 Misc. Tuna/24 Sculpin/24 Lampray/24	Handline and Mechanical Jig			3				None Documented/22	
AK	Octopus/22 Squid/22	Handline			3				None Documented/22	
WA	Pacific whiting/27 Sablefish/27 Dover sole/27 English sole/27 Petrale sole/27 Thornyheads /27 Widow rockfish/27 Bocaccio /27 Canary rockfish/27 Chilipepper rockfish/27 Pacific ocean perch/27 Shortbelly rockfish/27 Yellowtail rockfish/27 Other rockfish/27 Ling cod/27 Pacific cod/27 Other fish/27	Jig			3				Steller sea lion (E U S)*/22 (T) CA Sea lion/22 Harbor seal: WA Inland waters/22 OR/WA coast/22	
HI	Aku/22	Boat, pole and line			3				None Documented/22	
HI	Mackerel scad (Opelu)/30	Inshore handline			3				Bottlenose dolphin/22	
HI	Snappers/30 Groupers/30 Opakapaka/30 Ehu/30 Onaga/30 Ulua/30 Jacks/30	Typically handline/30			3				Bottlenose dolphin/22 Hawaiian monk seal*/22 (E)	
HI	Tuna, mostly yellowfin Bigeye tuna/30	Handline			3				Rough-Toothed dolphin/22 Bottlenose dolphin/22 Hawaiian monk seal*/22 (E)	
Guam	Grouper/32 Jacks/32 Lehi/32 Uku/32 Ehu/32 Onaga/32 Teapot/32		-1993 Data- 3569 lbs /32 2082 lbs /32 6939 lbs /32 10056 lbs /32 2007 lbs /32 8172 lbs /32 1146 lbs /32		3				None Documented/22	

Fisheries Description						Incidental Catch			Bycatch Species	
Location	Target Species	Gear Type	Landings	Value	Category	Landing Data	Value	Discard Catch	Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
	Yellowtail kalekale/32 Opakapaka/32 Yelloweye opakapaka/32 Kalekale/32 Gindai/32 Emperor/32 Amberjack/32		4809 lbs /32 611 lbs /32 522 lbs /32 317 lbs /32 3715 lbs /32 3712 lbs /32 0 lbs /32							
Commonwealth of the Northern Mariana Islands	 Misc. Bottomfish/32 Jacks/32 Gindai/32 Grouper/32 Onaga/32 Opakapaka/32 Emperor/32		-1993 Data- 5644 lbs /32 363 lbs /32 186 lbs /32 917 lbs /32 474 lbs /32 718 lbs /32 6467 lbs /32	-1993 Data- $15,345 /32 $923 /32 $731 /32 $2,601 /32 $2,077 /32 $2,127 /32 $13,506 /32	3				None Documented/22	
American Samoa	 Redgill Emperor/32 Ambon Emperor/32 Longnose Emperor/32 Misc. Emperor/32 Tomato Grouper/32 Giant Grouper/32 Flagtail Grouper/32 Yellowspotted Grouper/32 Peacock Grouper/32 Lyretail Grouper/32 Misc. Grouper/32 Oilfish/32 Bluelined Snapper/32 Gindai/32 Jobfish/32 Onaga/32 Ehu/32 Humpback Snapper/32 Red Snapper/32 Yelloweye Opakapaka/32 Pink Opakapaka/32 Etelis sp./32 Yellowtail Kalekale/32 Lehi/32 Bluelined Gindai/32 Black Trevally/32 Misc. Jacks/32 Misc. Bottomfish/32		-1993 Data- 229 lbs /32 935 lbs /32 119 lbs /32 2220 lbs /32 294 lbs /32 276 lbs /32 7 lbs /32 104 lbs /32 165 lbs /32 744 lbs /32 641 lbs /32 202 lbs /32 2015 lbs /32 229 lbs /32 2269 lbs /32 1518 lbs /32 1111 lbs /32 910 lbs /32 145 lbs /32 116 lbs /32 526 lbs /32 94 lbs /32 68 lbs /32 443 lbs /32 28 lbs /32 339 lbs /32 564 lbs /32 473 lbs /32		3				None Documented/22	
WA/OR	Smelt/22 Herring/22	Dip net			3				None Documented/22	
CA	Swordfish/22	Harpoon			3				None Documented/22	
AK, Southeast AK	Food/bait Herring/22	Pound net			3				None Documented/22	
WA	Herring brush/22	Pound net ?			3				None Documented/22	
WA -----	Ghost shrimp/23 -----	Bait pens			3				Gray whale/22,23 Harbor seal/22	
CA	"small bait"/29									
Coastwide	Scallop/22	Dredge			3				None Documented/22	
AK	Abalone/22	Hand			3				None Documented/22	
AK	Dungeness Crab/22	Hand			3				None Documented/22	
AK	Herring spawn-on-kelp/22	Hand			3				Steller sea lion*/22 (T)	
AK	Urchin/22				3				None Documented/22	

Fisheries Description			Landings	Value	Category	Incidental Catch		Discard Catch	Bycatch Species	
Location	Target Species	Gear Type				Landing Data	Value		Marine Mammals (and Biological Significance)	Sea Birds and Sea Turtles
	Sea cucumbers/29 Mussels/29 Clams/29									
AK	Clam/22	Hand Shovel			3				None Documented	
AK	Clam	Mechanical/Hydraulic			3				None Documented	
WA	Herring spawn-on-kelp	Hand			3				None Documented	
WA/OR	Sea Urchin Other Clam Octopus Oyster Sea Cucumber Scallop Ghost Shrimp	Hand, dive or mechanical collection			3				None Documented	
CA	Abalone	Hand			3				None Documented	
CA	Sea Urchin	Hand			3				None Documented	
HI	Squid	Spear and Hand			3				None Documented	
HI	Lobster	Diving			3				None Documented	
HI	Coral	Diving			3				None Documented	
HI	Octopus/22 Lobster/22 Snails, etc./22	Handpick			3				None Documented	
WA	Shellfish	[Aquaculture]			3				None Documented	
WA/CA	Kelp				3				None Documented	
HI	Mullet/22 Opelu/22 Reef fish/22	[Pond]			3				None Documented	
AK/WA/OR/CA	Salmon	[Commercial Passenger Fishing Vessel]			3				Harbor seal: SE AK/1 Gulf of AK/1 Bering Sea/1 CA sea lion/1,2 Harbor seal: California/1 WA Inland waters/1 OR/WA coast/1	
AK	Octopus/Squid	[other]			3				None Documented	
HI	Anything that can be caught/22	Shore longline (Kaka) near steep drop-offs/22			3				None Documented	
AK, Metlakatla	Salmon	Purse seine			3				Harbor seal/1 Harbor porpoise/1	
CA	Rockfish Cabazon Scorpionfish Shrimp	Live trap/hook-and-line			3				None Documented	
CA	Salmon	[enhancement rearing pen]			3				None Documented CA sea lion/2	

\22 Federal Register, Proposed Rules Vol. 60, No. 116, NMFS, Department of Commerce, June 16, 1995
\23 Environmental Assessment of Proposed Regulations to Govern Interactions bewteen Marine Mammals and Commercial Fishing Operations, Under Section 118 of the Marine Mammal Protection Act, NMFS, Department of Commerce, June 1995
\24 Personal communication, Nancy Sloan, State of Alaska Commercial Fisheries Entry Commission
\25 Review of 1994 Ocean Salmon Fisheries, Pacific Fishery Management Council, February 1995
\26 Jacobson, Larry D., Lo N.C.H. and Samuel F. Herrick, Jr. Spawning Biomass of the Northern Anchovy in 1995 and Status of the Coastal Pelagic Fishery During 1994, June 20, 1995
\27 Our Living Oceans, NOAA Technical Memo. NMFS-F/SPO-15, December 1993
\28 Personal Communication with Mary Firuness, NMFS, Juno, AK
\29 Personal Communication with Robyn Angliss, NMFS, Silver Spring, MD
\30 Personal Communication with Eugene Nitta, NMFS, HI
\31 Pelagic Fisheries of the Western Pacific Region 1993 Annual Report, Western Pacific Regional Fishery Management Council, August 1994
\32 Bottomfish and Seamount Groundfish Fisheries of the Western Pacific Region 1993 Annual Report, Western Pacific Regional Fishery Management Fishery Council, August 1994

Appendix 2. Some Important Issues to be Examined in Deciding Upon an Appropriate Bycatch Policy

I. Introduction

The implementation of market-based approaches to the resolution of bycatch problems requires economic and scientific information. Ideally, for any particular fishery, we would like to have the following kinds of information: (1) biological information; (2) technological information; (3) the structure and performance of relevant markets; (4) the existing institutional setting; and (5) the distributional effects of potential policy options.

In this Appendix, we have identified a list of questions that we hope will help government decisionmakers, industry officials, and the public begin to gain a better understanding of specific bycatch problems. Further, we expect that the development of the information necessary to answer these questions will make more clear the kinds of policy instruments that will be useful in any specific setting.

II. Biological Information

A central issue relates to our understanding of the effects of bycatch on the health of nontarget stocks. Numbers of discarded fish or animals are necessary for developing an understanding of a bycatch problem (Appendix), but these numbers are not sufficient to understand the full effects. Take, for example, the case of a producer-producer bycatch problem. For any particular nontarget species, effects can be of two types: (1) the loss through bycatch of (growing) individuals that would otherwise be harvested in another fishery during the current or future periods[1] and (2) the loss through bycatch of the reproductive potential of individuals that would not otherwise be harvested.

In some cases, there may be important biological relationships between species in an ecosystem, such as competition, mutualism or predator-prey relationships. The effect of bycatch may depend not only upon what happens to the nontarget stock but also upon this relationship. It is for this reason that positive levels of bycatch may be beneficial, even if the nontarget

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[1] There is no loss if property rights to the nontarget species are clear and compensation is made to the fishers of the nontarget species.

species is discarded. For example, the bycatch of a predator may improve the growth of biomass of a targeted prey species and thus be economically beneficial. Whether or not bycatch has ecosystemic effects, either positive or negative in an economic sense, requires the development and estimation of a biological model of the ecosystem. Without this understanding, we cannot say whether bycatch is good or bad.

Once we have an understanding of the biological effects of bycatch, we can begin to develop information on the size, in economic terms, of the damages (or benefits) associated with bycatch. For example, bycatch in one fishery of another fishery's target species will result in a loss to the latter fishery that can be quantified in dollar terms. Likewise, bycatch of a noncommercial species, such as a marine mammal, will result in a loss that may be felt by those individuals who value the lives of marine mammals.[2]

We may be uncertain about the size of economic damages (benefits) from bycatch. This uncertainty may derive from either biological or economic sources. If we lack information about individual species growth or about ecosystemic relationships, we may be uncertain about the economic effects of bycatch, even if we have good sources of information about potential economic damages (benefits). Alternatively, we may have a good understanding of stock dynamics and ecological relationships but lack information about potential economic damages (benefits). Finally, we may be uncertain about both biological and economic aspects. In order to suggest appropriate management measures, it will be important to pinpoint the sources of uncertainty and to estimate their magnitudes.

Table A2.1 summarizes these points with six questions that should be asked to help determine the nature of the bycatch problem.

III. Technological Information

A second basic issue concerns our level of understanding about the harvesting technology. We know already through our examination of biological information whether or not the harvesting gear is "selective." If bycatch occurs, then the gear is nonselective to some degree.

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[2] It is likely to be more difficult to value the loss associated with the bycatch of a marine mammal precisely because it is a noncommercial species.

Table A2.1: Biological Information Needs

ISSUE	QUESTION	
Biological Information	What are the levels of catch of target species and bycatch of nontarget species?	
	Have biological models of population growth been developed?	
	Do these biological models involve interspecies relationships?	
	What is the biological effect of the level of harvest and bycatch on:	Current and future harvests of nontarget species?
		Future reproductive potential of the nontarget species?
		Future harvests and reproductive potential of the target species?
	What is the economic effect of bycatch:	Sign?
		Size?
	What are the sources and estimated magnitudes of uncertainty:	Biological?
		Economic?

This nonselectivity is costly to fishers because they must spend time and effort sorting and discarding bycaught fish and replacing the bycatch with target species. Moreover, if bycatch is determined to be damaging to other producers or consumers, then some aspects of the harvesting method may need to be modified to reduce the level of damage.

The fact that bycatch is costly to fishers provides a natural incentive to reduce bycatch. This is the case unless there are rules and regulations that restrict fishers to particular technologies.

The traditional way in which bycatch problems are reduced or controlled is through mandated technological modifications. In general, a gear modification that reduces the level of bycatch is introduced into the fishery. Good examples include turtle excluder devices, the nordmore grate, and the medina panel. Ex ante, there may be substantial uncertainty about the effectiveness of bycatch reduction technologies. This approach requires testing and approval of the technology, imposing a "command-and-control" regulation on fishers, and monitoring and enforcement to ensure that the technology is being used.

Nontradeable quotas are sometimes set to regulate bycatch. This kind of instrument was employed in the 1970s and 1980s to regulate the level of dolphin takes in the ETP purse seine fishery for yellowfin tuna. A total quota on bycatch may cause derby behavior in fisheries, as fishers hurry to catch target species before the bycatch quota kicks-in. If experimentation results in a good estimate of the level of bycatch associated with the use of a specific gear type, then mandating this gear is much like setting a nontradeable, per-vessel quota on the level of bycatch.

There can be significant costs associated with a policy to increase gear selectivity through command-and-control methods. These costs include research and development (R&D), delays in the introduction of the technology because of the technology approval process, administrative costs of technology approval, increased costs of fishing effort with the new technology,[3] and potential increased bycatch of other stocks. If the existing gear is nonmalleable, then, in the short-run, fishers may be unable to raise the capital necessary to replace it with bycatch reduction gear.

Market-based incentives can obviate the need for mandated technological adaptations and allow fishers the flexibility to decide how to modify their harvesting technique or technology to

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[3] In some cases, fishers find that increasing gear selectivity increases the efficiency of fishing through saved costs of sorting and discarding.

reduce bycatch. This might involve redirecting effort at different times of the day, during different seasons, modifying gear, changing fishing locations, among other changes. It could also involve monitoring and enforcement to ensure that the level of bycatch is being reduced sufficiently. An important question for further analysis concerns the relative costs of monitoring and enforcement of bycatch under mandated technology versus market-based incentives (Table A2.2).

IV. Market Structure

A major criticism of ITQ programs is a concern that quota shares might become concentrated in the hands of a few, usually large, fishers or vertically integrated fishing operations. Although this criticism is relevant, whether or not it is valid will depend upon the circumstances of individual fisheries. Market concentration is not confined to an ITQ system. It can occur under other forms of market structure, including fishery cooperatives. Table A2.3 presents a summary set of considerations.

Managers need to be aware of the potential for different policy instruments to contribute to the potential for market concentration. The first concern is to develop an adequate definition of the relevant product market. One issue of concern is the extent to which an instrument that has been adopted to help reduce bycatch causes a barrier to entry into the fishery. Although each fishery should be evaluated independently, as a general rule we believe that management of the target stocks is more likely to affect the structure and performance of markets than bycatch management.

There may be net benefits that arise from the implementation of market-based incentives even if a situation is created in which market power is expressed by market participants. The important tradeoff appears in the relationship between the increased benefits of reduced bycatch damage and the increased costs of lost consumer surplus due to reduced output to the market.

V. Institutional Structure

It is important to understand the existing management regime for at least two reasons. First, we would like to know whether or not it is feasible to include a market-based instrument in an existing management regime to help reduce bycatch. In order to accomplish this we need

Table A2.2: Technological Information Needs

ISSUE	QUESTION	
Technological Information	Is the gear that is commonly employed in the fishery selective?	
	Is there substantial uncertainty about the selectivity of the existing gear?	
	Are there institutional constraints on gear types?	
	From an engineering standpoint, can the gear or its application be changed in some way to increase its selectivity by:	Modifying the use of the gear?
		Modifying the current gear?
		Substituting with alternative gear?
	What are the costs of increasing gear selectivity:	Research and development?
		Technology approval lags and administrative costs?
		Increased cost of fishing effort?
		Increased bycatch of other stocks?
		Nonmalleability of existing gear?
	What are the requirements for monitoring and enforcement of modified gear types?	
	Do monitoring and enforcement costs depend upon the policy instrument employed to mandate or encourage increased gear selectivity?	
	How to the costs of proposed modifications compare to the benefits of increased selectivity?	

Table A2.3: Market Structure Information Needs

ISSUE	QUESTION	
Market Structure	What is the relevant product market?	
	Is there the potential for fishers in this fishery to exert market power in the relevant product market?	Are there institutional barriers to entry, such as limited entry rules?
		Are there technological barriers to entry, such as scale economies?
		Are there cultural barriers to entry, such as fishing communities?
	What are the kinds of policy instruments that might be used to help resolve bycatch:	Limited-access restrictions?
		Charges or Deposit-Return?
		Tradeable quotas?
		Produce labelling or consumer information?
	Do these policy instruments contribute to the potential for market concentration in the relevant product market?	

to consider the extent to which a market-based incentive might either complement or contradict existing policies. Second, a proposed market-based instrument might substitute for existing command-and-control policies. If so, then we would like to understand the costs of switching from the existing regime to one that incorporates a market based approach.

Table A2.4 lists a few of the important questions that should be asked in making a determination of the appropriateness of a market-based approach. An important concern is whether or not the target and nontarget species are covered under the same regime.

VI. Distributional Concerns

In terms of the feasibility of adopting a policy to control bycatch, distributional concerns can be very important. An initial consideration is whether or not benefits and costs of a policy can be identified easily. If they can be identified, it may be relatively easy to determine the identity of gainers and losers from the implementation of a market-based policy instrument. The identification of these individuals or groups in combination with an analysis of their relative political power within the existing management regime will reveal the likelihood that a market-based approach to bycatch control can be adopted. Table A2.5 lists some of the relevant questions.

One of the most important types of market-based approaches might involve the compensation of losers by winners in order to implement a bycatch control policy. Thus buy-back programs through which the general public compensates fishers for leaving the fishery may make sense.

In understanding the extent to which potential losers from the adoption of a policy are able to exert political power, it is important to understand the setting in which decisionmaking for a fishery must take place. Even if losers are unable to exert political power directly, laws and rules may incorporate "fairness" provisions, explicitly or implicitly, that can affect the adoption of a policy instrument.

More commonly, it likely to be the case that benefits and costs are uncertain, and, in particular, the distribution of these benefits and costs are uncertain. Thus there may be tendencies for a continuation of the status quo management system or, possibly, an extension of traditional command-and-control techniques to manage the bycatch problem (cf., Dewees 1983). For example, although section 110(c) of the 1990 amendments [P.L. 101-627] to the Magnuson

Table A2.4: Institutional Information Needs

ISSUE	QUESTION	
Institutional Structure	What is the existing management regime?	Open-Access (activities limited)?
		Controlled-Access (numbers of participants and activities limited)?
	What are the administrative costs of the existing management regime?	
	Is there an onboard fishery observer program or a vessel monitoring system (VMS) in operation?	
	Are nontarget species a focus of the management regime:	Multispecies management?
		Conflicts between distinct management regimes?
	How is bycatch managed?	
	What are the costs of implementing market-based policies to control bycatch:	Costs of switching from existing system?
		Incremental costs of adding bycatch rules to existing system?

Table A2.5: Distributional Concerns

ISSUE	QUESTION	
Distributional Concerns	What is the policy instrument under consideration?	
	Is it possible to characterize the benefits and costs of the implementation of the policy instrument?	
	What is the degree of uncertainty surrounding these benefits and costs?	
	Are there differences across fishers:	In technological capability or experience?
		In ability to modify or react to new policy?
	Who are the gainers and losers from the implementation of the policy?	
	What is the setting within which decisionmaking must take place?	
	Is ti possible for the gainers to compensate the losers, for example, through public compensation programs?	

Act mandated that "nongear" and tactical approaches to bycatch be examined for solutions to finfish bycatch in the Gulf of Mexico and South Atlantic finfish fisheries, none of the approaches considered involved market-based incentives explicitly.