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### *Northeast Fishery Management Task Force*

# Fishery Management Techniques, A Review

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## PREFACE

This document is the result of studies originating within the Northeast Fishery Management Task Force. The Task Force, organized in 1979 by the New England and Mid-Atlantic Fishery Management Councils and funded by the NMFS, seeks to promote discussion and dialogue on the major issues of fishery management and to explore the effects of various fishery management alternatives.

Composed of representatives from the fishing industry, Regional Fishery Management Councils, federal and state agencies, academic institutions, and general public, the Task Force will operate in three phases. The first phase will assemble background information for identifying and analyzing management options. The second phase will examine this background information to determine the data requirements, regulatory measures, administrative procedures, and enforcement methods associated with each management option. The third phase will critically review the various options for application to specific fisheries, particularly the Atlantic demersal finfish fishery.

This document is one of eight developed under Phase I operations, all of which are being issued in the *NOAA Technical Memorandum NMFS-F/NEC* series. This document and six others functionally serve as appendixes to the eighth and leading document for Phase I operations—“Overview Document of the Northeast Fishery Management Task Force, Phase I.”

Jon A. Gibson, Coordinator  
*NOAA Technical Memorandum NMFS-F/NEC* series

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## INTRODUCTION

There is a variety of methods available for the management of fisheries. In each case, the optimal set of fishery management techniques will depend on the objectives of management, the legal authority of the managers and the information base (scientific and otherwise) supporting management. Nevertheless, there are some inherent characteristics associated with each technique of fisheries management which are relevant to the application of the method in general. This paper is intended to stimulate discussion and consideration of these characteristics so that better-informed decisions will be made in the future.

It is often said that "fisheries managers manage fishermen not fish." While fisheries management is usually applied directly to harvesters in the form of regulations, there are forms of management which are applicable to other components of the socioeconomic sector; these may be non-regulatory in nature. Furthermore, while fishery managers cannot "regulate fish," there are some forms of fishery management which have a direct and predictable impact on fish populations, although the impact of some other forms is more closely related to the socioeconomic sector.

In the discussion that follows, fishery management techniques which are applied to harvesters and other components of the socioeconomic sector are considered. The expected biological and socioeconomic consequence of each technique is discussed. Several criteria for evaluating fishery management techniques are also proposed.

In addition to the methods of fisheries management discussed in this paper, there are other methods used to improve the condition of the resource independent of the fishery. Resource improvement methods include habitat protection and stocking. For some anadromous species of inshore fisheries, resource improvement methods may be vital to sustaining a viable fishery. For fisheries significantly affected by human activity other than fishing, such methods should be seriously considered.

## CRITERIA FOR EVALUATING FISHERY MANAGEMENT TECHNIQUES

Ultimately, fishery management techniques must be evaluated against the objectives of management. Comparison of benefits (short- and long-term) associated with the application of a management technique with benefits which would accrue without management is inherent in the evaluation process. There are several other

more specific criteria which are usually relevant to selection of a management technique.

**1) Relationship of the fishery management technique to the control of fishing mortality:** The linkage between the resource sector and socioeconomic sector of the fishery system is fishing mortality. This is the rate (proportion of the population per unit time) at which fish are removed as a result of fishing. Thus, man's ability to accomplish objectives related to the condition of the resource depends on controlling fishing mortality. Fishing and natural mortality (all causes of death other than fishing) act to reduce the size of the resource while growth and recruitment (rate at which young fish are added to the exploited component of the resource) act to increase it. The secondary impact of fishing mortality on growth, natural mortality, and recruitment as a result of its influence on the size and structure of the resource, is usually known only qualitatively. Nevertheless, the potential of these secondary impacts is of concern in the evaluation of fishery management decisions.

The linkage between the resource and the socioeconomic sector is described by the following equations:

$$F = qf \quad (1)$$

$$C = \frac{F}{Z} N(1 - e^{-Zt}) \quad (2)$$

where  $F$  is instantaneous fishing mortality rate,

$Z$  is instantaneous total (fishing and natural) mortality rate,

$N$  is population size in numbers,

$f$  is the rate of expenditure of standard units of fishing effort,

$q$  is a constant called the catchability coefficient,

$C$  is catch in numbers,

$t$  is time, and

$e$  the natural number 2.71828. . .

These are fundamental equations of fisheries science. The reader is referred to Ricker\* for a detailed discussion of their application. Equations (1) and (2) are introduced here to establish the direct relationship

\*Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Bd. Can. 119. 300 pp.

between fishing effort and fishing mortality, and catch and fishing mortality. Clearly, these equations are pertinent to the evaluation of the relationship between a fisheries management technique and its control of fishing mortality. Equations (1) and (2) will be discussed further when considering specific management techniques.

Fishing effort is a function of the amount of fishing gear and the amount of time the gear is used. If only one type of gear is used (all units of gear assumed to be of equal efficiency) and fishing practices are relatively standard, then fishing effort is equivalent to the total amount of time spent fishing. When a variety of types of fishing gear or fishing practices is used, then fishing effort is an additive combination of the amount of time spent fishing with each gear type or fishing practice. Coefficients for each term of this combination are used to account for differences in efficiency between types of fishing gear and fishing practices. Thus, the amount of time spent at one type of fishing is expressed in terms of the amount of time spent at another type of fishing (defined as the standard) which results in the same fishing mortality rate. Clearly, effort has many components: the amount of gear, the type of gear, how much it is fished, and how it is fished.

**2) Relationship of fisheries management techniques to other biological impacts:** Fisheries management actions may have more specific biological impacts than control of fishing mortality. Some fishery management techniques are effective in restricting the impact of fishing on specific components of the resource. For example, the techniques may be intended to protect small fish, spawning fish, or fish of a particular species. Such biological objectives are usually related to implicit socioeconomic objectives, for instance, the assumption that protecting small fish will increase yield per recruit (and revenues); the assumption that protecting spawning fish will increase the probability of a good recruitment and future productivity (and revenues); and the assumption that total benefits will be increased by protecting a particular species from one user group (foreign fishing for example) in favor of another (domestic fishery).

**3) Relationship of management action to the natural functioning of the fishery system:** The ability of fishery managers to influence the future state of the resource is limited. Total productivity of the system is ultimately determined by such factors as incident solar radiation and available nutrients, not by fisheries management. Fishery managers are more capable of influencing the structure (species and age distribution) of the system, but even this ability is limited. Thus, in evaluating fishery management techniques, the reasonableness of the goals that the techniques are intended to accomplish should be considered.

Fisheries management serves as an artificial form of control of system dynamics. There are other mechanisms which stabilize the system, such as the natural biological

processes which act to compensate for or buffer against perturbations, and the socioeconomic interrelationships between fishing activity (commercial or recreational) and the activities of related industries and markets. Fisheries management techniques should reinforce the functioning of these other mechanisms, not interfere with them.

**4) Relationship of fishery management techniques to harvesting efficiency:** There are many ways of expressing the efficiency of fishing activity. It may be expressed in terms of the proportion of total potential productivity of the resource (short- and/or long-term) actually utilized, the cost per unit of catch, the cost per unit of fishing mortality generated by fishing, the total income generated per unit of catch, or value of catch per unit of energy (fossil fuel) used, to give some examples. The specific measure of efficiency applicable to a particular fishery management plan depends on the objectives of the plan. However it is defined, the effect of a management technique on efficiency is an important criterion for evaluating that technique.

**5) Historical precedent for application of the fishery management technique:** In some cases, success of a fishery management plan will depend on its credibility with those managed and with society in general. Therefore, past perceived successes or failures of particular fishery management techniques should be considered. The lack of historical precedent for a particular approach is not necessarily a disadvantage when no popular alternatives are available.

**6) Relationship of the fishery management technique to cost of enforcement and administration:** The net benefit of fishery management (over that which would accrue in its absence) must include the cost of administering and enforcing the management programs. Some fisheries management techniques are inherently more difficult (and costly) to administer and enforce than others.

**7) The relationship of the fishery management technique to non-target components of the fishery system:** Biological, economic and social objectives of fishery management are often specific to particular components of the fishery system, e.g., a particular species, a particular user group or a particular processing segment of the industry. While a fisheries management technique may be appropriate for a set of specific objectives, the impact of its application on non-target components of the resource should be considered. In the case of species-specific biological objectives, the effect of management actions on the capacity of the harvesting, processing, or related sectors to redirect attention to other components of the resource is particularly important.

**8) Relationship of the fishery management technique to its scientific basis:** The specific application of a management technique is usually based on scientific consideration of the expected short- and/or long-term impact of the action. The cost and feasibility of

developing a scientific basis for the action varies, depending on the technique used and the acceptable level of risk that objectives will not be achieved. Furthermore, the *robustness* of the technique relative to its scientific basis also varies. To put this another way, given a vague or imprecise scientific basis for action, some techniques will nevertheless tend to serve the objectives of management while others might suffer in effectiveness.

## REGULATIONS APPLIED TO THE HARVESTING SECTOR ASSOCIATED WITH THE CONTROL OF FISHING MORTALITY AND OTHER BIOLOGICAL IMPACTS

Fishery management actions are usually in the form of regulations applied to the harvesting sector. These regulations are intended either to produce a direct biological impact on the resource or to influence the distribution of benefits between users or user groups. The former type of harvester regulation is discussed in this section.

As indicated by Equations (1) and (2) in Part 1 of the previous section, catch and fishing effort are directly related to fishing mortality. Thus, restrictions on catch and/or fishing effort are appropriate fishery management techniques for "active" or direct attempts at controlling fishing mortality (and accordingly, the short-term and potentially long-term dynamics of the resource). The relationship of active or direct fishery management techniques to fishing mortality is described by a simple function of socioeconomic variables specified in the regulation. Other common fishery management techniques which regulate the harvesting sector may be termed "passive" since these methods do not directly relate (by simple functions of socioeconomic variables specified in the regulation) to fishing mortality although they usually have some indirect effect. Spatial and temporal restrictions on fishing activity, restrictions on fishing gear, and restrictions on the nature of catch (as opposed to the amount) are examples of such passive (or indirect) management techniques. The effect of such techniques on fishing mortality cannot be explicitly estimated; where effort and catch are unregulated, fishing mortality remains theoretically unbounded.

Passive methods of regulation affect components of fishing effort (type of gear used, fishing practices) but other components are not controlled (the extent to which each type of fishing gear and practices may be used), thus the resulting mortality is not explicitly known. These two types of fishery management techniques regulating the activity of the harvesting sector are discussed below, with reference to the evaluation criteria proposed in the previous section.

**Active Regulation:** An overall restriction on total catch (during a specific time period) may be used to achieve a desired fishing mortality rate. In order to determine the appropriate restriction on total catch based on Equation

(2), population size must be estimated. Thus, the determination of the desired catch restriction is strongly dependent on the accuracy and precision of assessments of the status of the resource. Catch regulation is scientifically a very demanding form of fishery management. It is not robust with respect to its scientific basis. The following example should clarify this point.

Assume that the optimum fishing mortality rate is known, and that the fishing fleet is of an appropriate size to generate this amount of fishing mortality on a continuing basis. Suppose further that the fishery is managed by an overall annual catch quota and that the size of the resource is underestimated by 25%; it will become necessary to close the fishery for the last three months of the year. Such a closure might have a severe adverse social, economic, and political impact as well as resulting in a suboptimum fishing mortality rate. On the other hand, suppose that the stock is overestimated by 25%; this also will result in suboptimal fishing mortality and possibly in some long-term adverse social, economic and political impacts. In most cases, the precision of stock assessments is such that 25% errors in estimates of stock size will occur routinely.

Catch regulations designed to accomplish a specific fishing mortality rate not only require accurate and precise information on the size of the resource, but that this information and the regulations based on it be almost continuously updated. When the condition of the resource changes rapidly relative to the time required for collection and analysis of scientific data and revision of management regulations, it may be impractical to adjust regulations quickly enough to respond to the condition of the resource.

The application of catch regulations is further complicated for mixed fisheries (where more than one species is captured by a unit of fishing effort). It may be impossible to achieve the desired fishing mortality for one species without exceeding the desired mortality for another. For two species which are closely associated in trawl catches (cod and haddock on Georges Bank, for example), catch regulations which produce significantly different fishing mortalities for each species may result in early closure of fishing for one of them followed by wasteful discarding of catch which cannot be legally landed and sold. The mixed-fishery problem may in some cases be mitigated by gear and/or spatial-temporal regulations (discussed below). There are also analytical methods for designing an optimal set of species-specific catch regulations for a mixed fishery (linear programming for example), but the regulations may be suboptimal with respect to a subset of the species.

Catch regulations may also be applied passively (without direct consideration of the associated fishing mortality). For a developing fishery where data and analysis are minimal, the catch may be restricted as a precaution, to prevent fishing mortality from becoming excessive (this is referred to as a preemptive quota). This form of regulation is most acceptable for resources which are not in high demand. Thus, the potential short-term

loss of benefits associated with such a conservative strategy may be minor. Obviously, where demand for a resource is low, a more conservative strategy may be used to reduce the amount of stock assessment information necessary to support management decisions.

The relationship of catch restrictions to biological impacts other than fishing mortality is usually unknown. Where catch is restricted for a group of species about equally vulnerable to exploitation, the most valuable species is likely to be caught most; thus, the species composition of the resource may change. Catch restrictions which cause a change in the size and composition of the resource may indirectly affect recruitment, natural mortality, and growth, but usually such impacts can be foreseen only qualitatively.

In general, application of catch restrictions is compatible with the dynamics of the fishery system. Catch is usually reduced during periods of low productivity of the resource and increased when productivity is high, tending to stabilize the biological component of the system. Unfortunately, in some cases catch restrictions may work to destabilize the system in the short term. This occurs when the scientific basis of the regulation is in error. When the resource is larger than anticipated, catch is restricted to unnecessarily low levels and the resource increases. However, when the resource is smaller than anticipated, catch may in effect be unrestricted, resulting in a further decline in abundance.

There is substantial historical precedent for the application of catch restrictions, which have been used for the management of marine commercial fisheries throughout the world. In general, the success achieved through application of catch restrictions depends on the realism of the objectives they serve, and adequacy of the scientific basis for management action. In the case of New England groundfish, fishery management objectives have been unclear, and the level of precision of "state-of-the-art stock assessments" has been unsatisfactory to those managing this highly-valued resource. Therefore, application of catch restrictions for New England groundfish management under the auspices of FCMA has been controversial and generally unsatisfactory, establishing a poor precedent for the future.

Part of the difficulty associated with catch restrictions on New England groundfish has been in law enforcement. Special problems arise when specific regulations are applied to subunits of the resource, because catch sources are hard to identify and relate to subunit catch limits.

Desired fishing mortality rates are more directly achieved by regulation of fishing effort than by regulation of catch. Fishing effort (when standardized to appropriate units) is directly proportional to fishing mortality rate [see Equation (1)]. Therefore, once an appropriate level of fishing effort is determined, this level may be maintained without dependence on continuing stock assessment. Stock assessments, in such a case, would be used to monitor the response of the resource to

regulation, not as a basis for continuous updating of regulations. Furthermore, there is evidence that fishery resources during periods of low productivity are less susceptible to severe reductions in biomass when they are regulated by a constant fishing mortality (effort) strategy than by a constant catch strategy. Unfortunately, fishing effort (in units proportional to fishing mortality) is difficult to measure. It has many components. Furthermore, the relationship between nominal fishing effort (raw data before standardization) and fishing mortality changes when fishing practices and gear change. Therefore, an iterative approach to determine the appropriate fishing effort regulation might be necessary, possibly using historic data on fishing effort as a basis for selecting the starting point. Even a preliminary regulation should be adequate to prevent long-term damage to the resource without excessively sacrificing current benefits. Trends in fishing mortality of the resource must be monitored, but it would not be necessary to modify fishing effort regulations routinely as is the case with catch regulations. Furthermore, changes would be modest relative to those necessary with catch regulations. With catch management, changes in regulation are necessary in response to variability in production of the resource. With effort regulation, changes are usually related to the socioeconomic sector of the system which is less variable.

Fishing effort regulations are scientifically robust with respect to stock assessments. The fishing mortality associated with a particular effort regulation need not be known precisely so long as trends in abundance and productivity of the resource can be monitored. The condition of the resource at any particular moment is of little importance since catch will respond to stock size automatically, given constant effort.

Catch and effort regulations will encourage each individual harvester to maximize efficiency (catch per unit cost of harvesting) unless catch is limited during each time unit of harvest. There is a potential for overcapitalization where fisheries management is based on catch or effort regulations and marginal profits are adequate to attract more harvesters than necessary to utilize the available resource fully. Since effort regulation applies to harvesting units, not particular species (as is the case with catch regulations), harvesters are able to divert effort from one component of the resource to another, as they wish.

Effort regulation has been applied to marine commercial fisheries less extensively than catch regulation. The U.S.A. proposed effort regulations for the area off the northeastern U.S.A. to the International Commission for the Northwest Atlantic Fisheries (ICNAF) in the early 1970's, but the proposal was rejected. Since then, Canada has applied effort regulation to inshore fisheries along its coast. Effort regulation has been applied to the ocean quahog and surf clam fisheries in the Mid-Atlantic Region. It is too early to judge the success of these management actions. Fishing effort regulations are often associated with such forms of management as limited



entry or controlled access (these methods are discussed in greater detail later). In some regions, this may cause opposition to effort regulation. In fact, limited entry or controlled access may be intended to allocate resources among user groups, not necessarily to regulate fishing mortality. Limited entry could be used to allocate the resource to user groups within the framework of either effort or catch regulation.

**Passive Regulation:** Passive techniques of fishery management are usually related to specific biological impacts other than control of fishing mortality. Impact of these passive methods on fishing mortality cannot be analyzed by such functional relationships as those shown in Equations (1) and (2).

Spatial and temporal restrictions on fishing are usually imposed in order to protect a component of the resource, perhaps during a vulnerable period such as spawning. For example, spatial and temporal restrictions on fishing are in effect for the Georges Bank area in order to protect spawning haddock. Since fishing activity may disperse aggregations of fish necessary for breeding, spawning ground closures may increase the likelihood of successful reproduction. In some cases, spatial and temporal restrictions are intended to decrease by-catch of particular components of the resource or to minimize the likelihood of conflicts between user groups (i.e., gear types). Current restrictions on the allowable season and area for foreign fishing off the east coast of the United States serve both these purposes. Temporal and spatial restrictions on fishing may promote inefficiency, since they often result in fishing being carried out at times and places that yield a relatively low catch per unit of effort. Thus, some immediate cost is paid in the hope of future benefits (by protecting spawning aggregations, for example). In the case of spawning-ground closures, long term benefits are usually known only vaguely.

Spatial and temporal restrictions could be a means of reducing total fishing mortality for the resource. This could be accomplished by reducing the efficiency of each unit of fishing gear (fishing power) or the total number of fishing opportunities. The actual reduction in fishing mortality resulting from any set of spatial and temporal restrictions cannot be predicted explicitly, and it is for this reason that these regulations are classified as passive or indirect. The appropriate set of spatial and temporal restrictions for achieving some desired reduction in fishing mortality must be determined iteratively. Spatial and temporal restrictions alone cannot impose a ceiling on fishing mortality (except for the trivial special case where no fishing is allowed), since reduced efficiency due to spatial and temporal restrictions may be offset by improved technology or increased effort. The overall impact of fishing reflects both the intensity of fishing activity and its efficiency. Consequently, if temporal and spatial restrictions are the sole means of regulating

fishing mortality, these regulations will have to be "tuned" routinely to offset changes in fishing intensity and efficiency.

The scientific bases probably already exist for spatial and temporal restrictions on fishing aimed at protecting components of the resource during particularly vulnerable periods. For example, the areas and times of spawning of many of the fishery resource species off the northeastern U.S.A. are known within reasonable limits. Furthermore, the areas and seasons during which recruiting fish are particularly vulnerable are usually known too, from previous catch data and research survey data. Nevertheless, because of the mixed (multi-species) fisheries of the region, spatial and temporal closures of a fishing ground to protect one species may severely restrict fishing for other species. Further data on the spatial and temporal distribution of the resources may help to reduce any unnecessary impact of these restrictions on fishing, but the cost (perhaps a re-occurring cost) of gathering the additional information must be compared to the potential benefits.

Spatial and temporal restrictions on fishing are easily administered. Unless such restrictions apply on a fine scale, they are also easily enforced. Moreover, there is significant historical precedent for spatial and temporal restrictions as management tools for marine fisheries. The virtue of protecting particular components of the resource (such as spawning fish or young fish) is widely accepted by both managers and harvesters. Spatial and temporal restrictions on fishing activity are often widely supported by the fishing industry itself, notwithstanding the fact that the long-term potential benefits of such closures (particularly to protect spawning fish) are usually unknown.

Spatial and temporal restrictions reduce the flexibility of the harvesters. In some cases, such restrictions may preclude development of a fishery for some component of the resource not addressed in the fisheries management decision process. These regulations may also affect (intentionally or unintentionally) the distribution of benefits between user groups.

Gear regulations are also imposed in order to reduce fishing mortality on some particular components of the resource. But again, since these regulations are not directly tied to fishing mortality by explicit functional relationships (such as Equations (1) and (2)), gear regulations may be considered passive.

Mesh regulations are among the most common tools of marine fishery management. By increasing the size of the codend mesh of a trawl, the fishing mortality inflicted on young or small fish is reduced. Thus mesh regulations may be an effective means of advancing the age at which fish are recruited to commercial fisheries, resulting potentially in an increased yield per recruit and/or an increased proportion of individuals of each cohort that survives to spawn, for a given level of fishing effort.

Gear regulations may be used to reduce undesirable by-catch. For example, regulations which restrict the use



of bottom trawls in the foreign squid fishery reduce the by-catch of demersal fish.

Gear restrictions may also be used to reduce overall fishing mortality. In such cases, gear restrictions act to reduce the efficiency of fishing for some species or some size groups. To the extent that gear efficiency and the amount of fishing effort expended with the regulation in place can be compared with gear efficiency and effort without regulation, the effect of gear restriction on fishing mortality can be evaluated. However, as with temporal and spatial restrictions, the effect of gear restrictions on fishing mortality will usually only be known qualitatively. Gear restrictions in themselves are not capable of providing full control of fishing mortality. The appropriate set of gear restrictions for accomplishing a desired fishing mortality would have to be determined iteratively. Where fishing effort and efficiency have a significant potential for increase, tuning of the management system will require periodic assessment of the status of the resource.

There is considerable scientific knowledge about the effectiveness of mesh regulations in reducing fishing mortality as a function of fish length. It is clear that mesh selection is not very precise. That is, the mesh size which allows most fish smaller than a particular size to escape will allow many fish larger than that size to escape as well.

There are several appealing aspects of mesh regulations. They should be relatively easy to enforce except where multi-species fisheries require more than one codend on-board, as in New England. The optimal mesh regulation for protecting a component of the fishery resource is relatively insensitive to the current condition of the resource. Therefore, management by mesh regulations may reduce the need for ongoing stock assessments. In fact, if the minimum mesh size were established at a level that would allow "adequate opportunity to spawn" prior to becoming vulnerable to the fishing gear, no further regulation is likely to be necessary from a conservation standpoint. But there is usually no scientific basis for determining the amount and quality of spawning opportunity which is adequate. It is noteworthy that, for many fishery resources, postponing the age at first capture beyond the age of first spawning results in an increased yield per recruit. Unfortunately, mesh selection is species specific. Therefore, the optimal mesh size for a mixed species fishery will be based on compromise.

Restrictions on the nature of the catch are sometimes a means of accomplishing the same biological objectives toward which gear or spatial-temporal restrictions are directed. Gear restriction and spatial-temporal restrictions may be designed to prevent capture of small fish or fish of a particular species. As an alternative to these methods or in conjunction with them, the nature of the catch may be regulated directly (minimum size regulation or restriction on the taking or landing of specific species). When the nature of the catch is regulated without accompanying gear and spatial-temporal

restrictions, the harvester is responsible for avoiding specific components of the resource. Nevertheless, some unwanted fish may be caught and this catch may be discarded at sea with some accompanying mortality. Even when harvesters can avoid restricted components of the resource, some unwanted catch (and wasteful discarding) may occur because of the desire to catch other valuable components. For example, the capture of small haddock can be avoided by using larger-mesh trawl gear, but to do so may result in reduced catch rates of larger haddock and some other species.

The benefits associated with gear restrictions, spatial-temporal restrictions and restrictions on the nature of the catch tend to be species specific. Thus, it is necessary to consider the secondary impact of these fishery management actions on other species. For example, a mesh regulation or spawning ground closure appropriate for one species may eliminate a fishery for another.

## SOCIOECONOMIC METHODS FOR INFLUENCING FISHING EFFORT

In addition to active and passive methods for control of fishing mortality and the future state of the resource, management techniques directed at influencing the socioeconomic sector of the system may be considered. The distinction between socioeconomic controls and active and passive methods is found in the way in which they attempt to control mortality or related components. All three approaches affect the socioeconomic system. The socioeconomic methods attempt indirectly to control mortality by directly influencing the socioeconomic system toward a desired state of the fishery; the active and passive methods are more direct attempts at controlling mortality which indirectly influence the socioeconomic system.

Two techniques which can be used to influence fishing effort and mortality through the functioning of the socioeconomic sector are incentive-disincentive plans and price controls. These may be considered as variations of taxation depending upon how they are implemented. Both techniques influence the ex-vessel price, and thus revenues, in order to discourage or encourage the harvesting of a particular species.

Incentive-disincentive plans attempt to redirect vessels and harvesting from one species to another, making the price of the first species less attractive (the disincentive) than the price of the second (the incentive). The incentive is financed by a system of pooled landings fees. This approach has often been termed a landings fee scheme, a taxation scheme, or a subsidy program. Price controls also can function as an incentive-disincentive plan by establishing a regulated ceiling price on the more desired species and minimum prices on the less desired species. However, price controls, unlike the incentive-disincentive plan, do not include a mechanism whereby pooled funds can be used to make the prices of the underutilized species more attractive to harvesters. Moreover, price controls interfere

more directly in the market-established price because they directly affect not only the prices received by fishermen, but also the prices paid by processors/wholesalers to the harvester. The incentive-disincentive plan attempts to affect only the prices received ex-vessel, and thus higher market level prices should not be affected except by conventional market demand and supply phenomena.

Since the incentive-disincentive plan has actually been considered as a possible management approach for groundfish in the northeast and since price controls operate in a similar manner, a discussion of the economics and problems of the incentive-disincentive plan is presented for illustration. As already stated, this approach attempts to make the price of the overfished (however this is defined) species less attractive than the price of the underutilized species by directly influencing returns to fishermen by means of a pool of funds created by the landings fees. The relative difference in prices influences the harvesting activities by redirecting effort from the overfished species to the underutilized species.

The effectiveness of the incentive-disincentive plan is predicated on its acceptance by industry and by the ability of management to incorporate changes in the bioeconomic environment into the plan. That is, management must constantly monitor such changes in order for the incentive-disincentive components to be determined. This approach, like other regulatory or management techniques, must be established in accordance with a goal or set of objectives which explicitly or implicitly sets some desired level of catch and/or effort.

However, of far greater importance to the viability of the incentive-disincentive approach is the development of markets for the less desired species. It is often uncertain how such markets will be developed. Currently, most commercially-viable, underutilized species are either foreign-caught or exported by the United States. In order to sustain an expanded fishery for underutilized species, domestic and/or foreign markets must be developed, and the on-board quality-control, handling, and storage of the fish must be improved.

Initially, such a program will require funds for its establishment. Federal funds could be used for 'seed' money or an initial endowment. However, the long-term solvency of the fund is an important consideration in the development of such a plan. The cost and source of funds for market development must also be considered.

Almost all underutilized species are candidates for the incentive-disincentive program. However, the more common species with respect to the northeast and mid-Atlantic areas include silver hake, mackerel, squid, dogfish, and butterfish.

An incentive-disincentive plan presents certain problems. It requires an agency or group to administer it; it may lead to new entrants in the underutilized species fishery which may dissipate any gains in net benefits; such a plan requires management to adjust constantly the incentive-disincentive rates as either abundance or market conditions change; it also requires information

on harvesting costs which is not generally available, and extensive information on stocks. This approach would probably be costly in terms of monitoring and administration. However, the program, combined with other fishery management techniques, could be beneficial. It would save waste from discards. Technological innovation, often assumed to remain the same under many other regulatory approaches, would not be discouraged. Importantly, effort and therefore fishing mortality would be reduced on the overfished species.

As noted above, in principle, price controls work to influence fishing effort and fishing mortality in a manner similar to an incentive-disincentive program. However, price controls are potentially an alternative to species-specific catch or effort regulations where price is highly flexible. If price were held constant (independent of supply), then the incentive to harvest a resource would decrease as abundance decreased. Thus negative feedback between fishing effort and resource condition would be established or reinforced, tending toward stability in the system.

Price controls intended to influence fishing mortality via the functioning of the socioeconomic sector could be imposed at the harvester, processor, wholesaler, or retailer level. Price controls at higher market levels would affect the derived demand for fish and related products at all lower market levels, e.g., a price control at the retail level would affect not only the consumers demand at the retail level but also the retailer's demand from wholesalers and the wholesaler's/processor's demand from harvesters. The specific effects would, of course, depend also on other factors such as market substitutability, relative product prices, and export potential. However, price controls could benefit consumers in the form of reduced prices, though shortages (or black markets) for products in high demand could occur.

Agriculture has had a long history of price controls, and more especially, supports and/or loan programs. Most price support programs were based on the concept of parity, the parity price being pegged to the price of some other products and fluctuating from time to time with the price of those products. Such programs attempt to provide a standard of living or minimum income, while ensuring an adequate supply of agricultural commodities and preventing soil depletion. Many of the loan programs were actually price- or income-support programs termed "non-recourse" loans. They resulted in payments made to producers when market prices fell below a specified percent of parity price. However, it should be realized that these programs were all potentially directed at regulating the market price, and thereby, affecting the allocation of goods and services.

It is unclear how these programs could be used to help resolve the problems of managing the fisheries of the Northwest Atlantic. Fisheries problems are not the same as those in agriculture. Many of the agricultural problems resulted in the federal government buying and storing commodities; fish commodities are not as easily

stored. In addition, there are still the marketing problems for the underutilized species. Thus, further study is needed before serious consideration is given to using any of the above-mentioned programs as a form or part of fisheries management.

## METHODS OF ALLOCATING CATCH OR BENEFITS

In addition to influencing the future condition of the resource and the overall level of short- and long-term benefits, fisheries management also affects the allocation or distribution of benefits and income. The primary fisheries management techniques used to allocate benefits are trip limits, vessel allocations, and controlled-access schemes.

**Trip Limits.** These restrictions limit the catch of a particular species or group of species on a per-trip basis, usually expressed in the Northwest Atlantic fisheries as catch per-vessel-day or per-vessel-week. The purpose has been to distribute the total allowed catch over the period during which it was intended to be caught. However, the use of trip limits has seldom prevented a fishery from being closed. In fact, the perceived economic impacts of trip limits low enough to prevent closures (given the level of effort in the fishery) have often been so severe that it has been necessary for fishery managers to raise overall quotas in order to increase trip limits.

Trip limits may have an effect on the level and distribution of gross and net incomes. That is, if catches per trip are constrained, total revenues may also be constrained. However, trip limits not only affect the income or revenue component, they also may affect the cost component; this depends on how trip limits are implemented. If trip limits are used in accordance with an overall quota, and there are no constraints on the number of trips, fishermen will attempt to increase their number of trips in order to harvest as much as possible before the overall quota results in a closure. This increases the cost of harvesting on a per-unit harvest basis over time. The increased cost per unit harvested results in decreased net income or profit, and may eventually force the less efficient vessels (with respect to the trip limit) out of the fishery.

Trip limits are a method of allocation of income and benefits to harvesters and other user groups. If they are set in accordance with an overall quota, they may result not only in a decrease in revenue per vessel, they may also increase harvesting costs, thus causing net benefits to society to decrease. However, more profound are the potential impacts of trip limits and closed periods on local communities. They may severely disrupt the economy of small coastal communities by creating seasonal unemployment where there are few, if any, alternative seasonal forms of employment. Such impacts of management on local communities have sometimes been overlooked in implementing fishery plans.

Trip limits have another social impact which is difficult to quantify. They reduce the level of competition in the fishing profession. Without trip limits, the best harvesters (highliners) gain the largest share of the benefits. With trip limits, the advantage of being a highliner is reduced, and benefits are more evenly distributed. This may also prevent financial failures of some harvesting operations and act to maintain in the fishery some marginal units (vessels which are inefficient vessels in the absence of trip limits). This latter concept illustrates the type of trade-off decisions confronting management, forcing managers to choose among beneficiaries.

**Vessel Allocations.** Vessel allocations have certain effects similar to trip limits. Their primary purposes are to allocate catches in a manner that gives each vessel the chance at a sufficient income, and to avoid closures when used in conjunction with quotas. However, vessel allocations are different from trip limits in that they generally do not restrict catch per unit effort, and thus do not increase the minimum cost of catch per unit effort, provided additional vessels do not enter the fishery. It is important to note that vessel allocations do not necessarily restrict total harvest; they can be implemented without an overall catch quota for the primary purpose of distributing income. However, if vessels enter the fishery in anticipation of profits and allocations remain the same, gross and net incomes per vessel will fall as a result of lower catches per unit effort resulting from reduced stocks.

A major problem with vessel allocations is how to determine the allocation. The use of prior catches results in the same distribution of income as in the past, i.e., those with low incomes remain low while those with high incomes remain high. New entrants must be controlled or income per vessel will decrease either as a result of reduced stock size, or quotas used in conjunction with the allocation system.

In the fisheries of the Northwest Atlantic, the determination of allocations is made more difficult as a result of the multiple species nature of the groundfish fishery, in which the primary species sought are cod, haddock, and yellowtail flounder. In attempting to develop a strategy for vessel allocations in a mixed fishery, it is necessary to consider an allocation for each species in a directed fishery and the associated by-catch fisheries. This requires considerably more biological and economic information if the allocation system is designed to deal with the problems of income distribution. In addition, the implementation of a vessel allocation system would require a substantially greater cost to set up and enforce.

Vessel allocations, like many of the other methods already discussed, are dependent on biological data. It would be of little value to implement a vessel allocation system for the sole purpose of distributing income. Thus, it may be reasonably assumed that its consideration would also be predicated on goals of stock management and conservation; this would require data on stocks and

abundance. Given this objective, utilization of a vessel allocation system would have to be extremely flexible to adjust to changes in stock size and abundance as well as to changes in market conditions. In addition, a vessel allocation system, if based on 'reasonable' management criteria such as conservation, would in fact be a form of controlled access. Only those vessels with allocations would be allowed to exploit a particular species or species group.

**Controlled Access.** Limited entry, controlled entry, licensing, stock certificates, vessel allocations, and taxation are all forms of controlled access. All attempt to limit the level of effort either directly or indirectly, or when applied in conjunction with catch or effort regulations, to distribute benefits. Limited entry, licensing, and stock certificates grant property rights in the fishery and thus directly control effort. Taxation restricts effort by forcing out those vessels which are too inefficient to pay the tax, i.e., their harvesting costs approximate their revenues; thus, taxation is an indirect control on effort. Stock certificates are unusual in that they are direct allocations of potential income. All of the schemes are attempts to resolve the problems associated with common property resources, e.g., dissipation of rent, inefficient allocation of goods and services, etc. Their differences are based on the way they operate and whether or not they directly control productive input or output.

During the past decade, various controlled access schemes have been widely discussed. There has not been, however, a consensus on their applicability. This has been particularly true for the Northwest Atlantic fisheries. However, before devoting further attention to the various forms of limited entry, we will discuss the reasons why controlled access has been so often advocated.

It is well documented in the literature on fishery economics that the unregulated, open-access fishery results in an inefficient allocation of resources. More, or less, goods are produced than society requires, or alternatively, production is not at minimum cost. The question arises, whether the resources used in harvesting could be better employed in another industry or sector of the economy with either a corresponding increase in the aggregate production of goods and services, or a decrease in the existing overall costs of production.

In the case of fisheries, inefficiency of production and allocation are considered to follow from their common property nature, i.e., resources are commonly owned but individually exploited. This situation creates a potential for increasing the harvest (either by expanding fleet-size or effort) until the market price is equal to average cost; at this level, pure profit, rent, or producers' surplus (the difference between revenue and costs) becomes zero ("dissipation of rent"). The common property nature of the resource coupled with economic conditions can create an environment in which there exists a potential profit for anyone wishing to seek it. Prospective entrants

enter the fishery in an attempt to realize part or all of that profit. However, their entry may result in increasing the costs of production to the point where pure profit or rent is dissipated, and the number of vessels or units of effort coincide with the equilibrium between price and average cost. This is the open access equilibrium in which resources are misallocated, rent is zero, and net benefits to society are not maximized.

Since the open access fishery leads to the above problems, controls on entry or access have often been recommended to prevent the dissipation of rent and/or misallocation of resources by forcing some factor inputs into more productive alternatives. The primary gain to be expected from controlled entry is increased profit or other net benefits. It would be expected that any viable controlled access scheme considered for the groundfish resources of the Northwest Atlantic would be directed at preventing any new entrants and/or controlling the current levels of effort, allowing time to bring stock size and effort into an equilibrium; over time, changes in fleet strength, stocks, and economic conditions should improve the allocation of resources, and thus, economic efficiency. Working against this argument, however, is the fact that the current fleet appears capable of overfishing; as a result, possible gains by controlled access schemes may be difficult to realize. It also should be realized that the alleged misallocation of resources may not be the "beast" management needs to attack, since little is known about the size of economic magnitude of the inefficiencies in the groundfish fishery, and whether particular remedies are socially desirable. Nevertheless, controlled access schemes probably offer some potential for improving efficiency in terms of resource allocation, prevention of overfishing, and improvements in the general welfare of society.

A primary problem of most controlled access schemes is deciding which vessels and/or harvesters will be included or excluded. This is particularly true for licensing and stock-certificate programs. With stock certificates moreover, appropriate allocations must be determined and the problems potentially arising from transfer of certificates must be addressed. It may take several years before the benefits of controlled access schemes are realized unless vessels are forced out of the fishery. In addition, at its present strength, the fleet may be capable of overfishing in periods of low stock size.

Taxation, another potential management tool, presents certain problems: it requires legislation; it increases the need for flexibility in management because taxes have to be adjusted in response to market changes; finally, taxation requires an organization to appropriate and distribute tax revenues. However, taxation could result in a level of effort consonant with maximum net benefits.

Controlled access schemes, though they are not without problems, offer a viable approach to managing fisheries for maximum net benefits. Other types of effort regulations, which do not require limitations on entry,

are not, in general, directed at obtaining maximum net benefits for society; they are primarily directed at reducing fishing mortality rather than producing the best allocation of goods and services.

## SUMMARY

The optimal fisheries management technique depends on objectives of management, the legal authority of managers, and the information base supporting management. Fisheries management techniques should be evaluated with respect to their (1) effectiveness in controlling fishing mortality; (2) relationship to other biological impacts; (3) relationship to the natural functioning of the fisheries system; (4) relationship to harvesting efficiency; (5) historical precedent and public acceptance; (6) cost of enforcement and administration; (7) impact on fisheries for nontarget components of the resource; (8) impact on the distribution of benefits; and (9) scientific robustness (or how likely is it that the technique is appropriate given uncertainty in its scientific bases?).

Restrictions on catch and fishing effort are active methods of controlling fishing mortality by regulating harvesters. Catch restrictions are less robust scientifically than effort restrictions. Spatial-temporal restrictions, gear restrictions, and restrictions on the nature of the catch are passive with respect to fishing mortality, although they may be effective methods of protecting some components of the resource. Fishing mortality is theoretically unbounded when passive methods of fisheries management only are applied.

Fishing mortality may be controlled indirectly by management techniques which influence the socio-

economic sector of the system. Incentive-disincentive plans and price controls can be used to control fishing mortality indirectly. Neither method has been applied widely, but further analysis may indicate their usefulness for this purpose.

The allocation of benefits of exploitation is usually a secondary state of fisheries management, one which follows attempts to control fishing mortality. Trip limits, vessel allocations, and controlled access are typically used for allocation although in some cases they may be used as passive methods for controlling fishing mortality.

The primary method of controlling fishing mortality in the northeast has been catch restrictions. Trip limits have been used to spread catch over time; this affects the distribution of benefits. Effort regulation should be considered as an alternative method of active control of fishing mortality for the Northeast region. Effort regulations are more robust scientifically and require less frequent amendment than catch regulations. Trip limits promote inefficient harvesting and decrease competition among harvesters. Other methods of allocation should be considered in the future.

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