ECONOMIC CONSIDERATIONS OF MESH SIZE REGULATION IN THE WEST COAST GROUNDFISH FISHERY

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ABSTRACT

The Groundfish Management Plan of the Pacific Fishery Management Council (PFMC) outlines the historical use of fishnet mesh size as a groundfish management tool. Although minimum mesh sizes are in effect for various. groundfish fisheries on the West Coast, management has placed heavier reliance on numerical quotas to control fishing mortality.

In response to industry requests, the PFMC has encouraged the investigation of mesh selectivity in various groundfish (mixed-species) fisheries. This report assesses general economic aspects of mesh size regulation based on what is known about attributes of this type of regulation and about the structure of the West Coast fishery for groundfish. A discussion of mesh size regulation in New England fisheries is included to provide additional information on how a mesh-size regulation system works.

-‘Mesh size regulations will have both direct and indirect impacts. Some impacts may be evaluated based on our knowledge of fishery structure and some will require at-sea selectivity experiments under commercial fishing conditions. Still other impacts will remain unknown prior to an actual change in regulations.

The five sections of this paper focus on considerations related to the economic performance of mesh size regulations. The first section provides a general discussion of the costs and benefits of mesh size regulations in mixed-species fisheries. The second section describes the use of mesh size regulation in New England fisheries. The third section outlines the current use of mesh regulations in the West Coast fishery for groundfish. The fourth section describes the structure of fishing operations for West Coast groundfish. The final section discusses the potential for mesh size regulations in the context of West Coast fishery operations.

Four appendices provide background information on some technical aspects that arise in discussions of mesh size regulation: gear components, gear selectivity, eumetric fishing, and present value of income. A fifth appendix provides a bibliography of studies on gear selectivity and regulation.

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INTRODUCTION

The need to evaluate fishnet mesh size as a groundfish management tool is addressed in the Groundfish Management Plan of the Pacific Fishery Management Council (Pacific Fishery Management Council 1982). Although minimum mesh sizes are in effect for various groundfish fisheries on the West Coast, management has relied more heavily on numerical quotas to control fishing mortality and trip limits to control the timing of landings.

Many members of the fishing industry have expressed dissatisfaction with the current system of regulation and apprehension about the possible imposition of even more stringent fishing effort controls. In light of these concerns, fishing industry representatives have requested that a thorough investigation of. net selectivity on the mixed-species fisheries be undertaken. Studies should address the potential of mesh size regulation for reducing the management burden on the fishing industry while also meeting conservation goals.

In response to industry requests, the Pacific Fisheries Management Council (PFMC) has encouraged the investigation of mesh selectivity in various groundfish fisheries. As a first step, a group composed of fishermen, fishery biologists, and fishery economists was formed to design a mesh size study. Initial efforts of the group have concentrated on two areas: 1) modeling the effect of gear selectivity on yield; and 2) outlining the major economic considerations related to the use of mesh size regulations in the West Coast groundfish fishery. The results of gear selectivity modeling are summarized in Vaga (1987), and a discussion of the economic considerations of mesh size regulations is presented in the current paper.

This paper assesses economic aspects of mesh size regulation in general based on what is known about attributes of this type of regulation and the structure of the West Coast fishery for groundfish. A discussion of mesh size regulation in New England fisheries is included to provide additional information on how a mesh-size regulation system works.

Mesh size regulations, like any other regulation, will have both direct and indirect impacts. Some impacts may be evaluated based on our knowledge of fishery structure and some will require at-sea selectivity experiments under commercial fishing conditions. Still other impacts will remain unknown prior to an actual change in regulations. The central questions related to mesh size regulation will be based not only on how a net with a given size mesh determines species mix in a catch but also how fishermen will fish with mesh size regulations in place.

The following factors of mesh size regulation that remain unknown at the present time relate to multispecies selectivity and fisherman behavior:

Can mesh size regulations adequately protect the spawning potential to maintain standing stocks of commercially important species in a mixed-species fishery?

--How would the species composition of catches change with regulation?

--Would fishing patterns change with regulation?

--What would be the market (price) effects of any change in catch composition?

--Would mesh size regulations have unforeseen distributional effects favoring some fishermen at the expense of others?

--Would compliance and enforcement be adequate to ensure effective regulation?

Any regulation should satisfy criteria of maintaining resource productivity and promoting economic productivity and fairness. The following five sections of this paper focus on some considerations related to the economic performance of mesh size regulations. The first section provides a general discussion of the costs and benefits of mesh size regulations in mixed-species fisheries, the second section describes the use of mesh size regulation in New England fisheries, while the third section outlines the current use of mesh regulations in the West Coast fishery for groundfish. The fourth section describes the structure of fishing operations for West Coast groundfish and the last section discusses the potential for mesh size regulations in the context of the West Coast fishery operations.

Four appendices provide background information on some technical aspects that **arise in discussions of** mesh size regulation: gear components, gear selectivity, eumetric fishing, and present value of income. A fifth appendix provides a bibliography of studies on gear selectivity and regulation.

CODEND MESH REGULATION IN MIXED-SPECIES FISHERIES

Mesh size regulation raises two general questions. The first question relates to the effect of different sizes of mesh on what is caught. In a mixed-species fishery the size of the mesh affects not only the size of fish caught but also the species of fish caught. Applying a single mesh size to a mixed-species fishery will very likely result in the underharvest of some species and the overharvest of others. Related to mesh size regulations is a second, broader question: What is the economic effect on the total fishery, including the fleet, processors, management and enforcement.

Several economic considerations are related to both general questions. What are the costs of using mesh size regulations? What are the benefits? How is an optimum mesh size determined? What are the possible benefits or limitations of this type of regulation? These economic factors will be discussed in the general context of a multispecies fishery. It should be noted that a given economic effect may be perceived as either a cost or a benefit depending on the particular point of view. The applicability of these economic considerations to the specific context of the West Coast groundfish fishery will be discussed later.

Costs Associated With Mesh Size Regulations

The implementation of a larger codend mesh size carries with it costs of various types. Four general types will be discussed here: compliance costs to the industry, enforcement costs, management costs, and biological costs.

Compliance Costs

Different segments of the fishing industry bear different costs of complying with an increase in minimum mesh size.

Costs of changing gear--A new minimum mesh size requires gear replacement by fishermen and inventory replacement by marine suppliers. Replacement costs may be minimized by allowing a phase-in period long enough to approximate the normal gear-replacement time. A phase-in period also lessens the cost on marine suppliers of holding an obsolete inventory.

Operating costs--Operating costs to the fleet may either increase or decrease as a result of increased mesh size. If gear efficiency is impaired by the larger mesh size, that is if yields per unit of effort drop sharply, operating. costs may increase as fishermen spend more time fishing to maintain yields. An increase in mesh size also has the potential to lower operating costs. Larger mesh may mean less tow friction which will result in lower levels of fuel consumption. The selectivity of a larger mesh net decreases handling costs of sorting out undersized fish on deck.

Costs of yield loss--An increase in mesh size results in a potential loss of yield to fishermen in the short run as the net allows more fish to escape. The earnings foregone from these escaped fish represent an economic loss to both fishermen and processors. The expectation is that if a decrease in yields occurs this represents a short-run cost that will convert to a longer-run benefit as increased yields are realized in the future. However, if an individual fisherman faces uncertainty about the benefit from future increased yields or whether the increased future yields will be large enough to offset the short-run losses, the increase in mesh size represents a cost with no expectation-of future reward. The incentives remain to continue to fish with smaller mesh which will retain all marketable fish rather than use a larger net which allows escapement.

Enforcement Costs

The nature and extent of enforcement costs associated with mesh size regulations depend on several factors: the location of enforcement activities, the specification of regulation details, and the extent of industry compliance.

Location of enforcement activities--Monitoring compliance with gear regulations may take place either on shore or at sea. Enforcement costs are lower when monitoring takes place at the dock. However, on-shore enforcement may not be effective in detecting the use of liners, illegal chafing gear, lines to choke off the codend or other measures used at sea to decrease the effective meshsize.

Specification of regulation details--in general, the more clearly specified are the regulations the lower are the costs of enforcement. For example, a detailed specification of legal net rigging practices make a clear distinction between acceptable and unacceptable hanging of nets. Clear rules about the size and placement of chafing gear, about the accepted mesh measurement methods, and about the carrying of nets with smaller mesh on board all make the enforcement process more clearly defined and therefore less costly. In addition, enforcement costs may be eased by complementary regulations on minimum fish size which make it economically infeasible to target on small fish.

Extent of compliance--The extent to which the fishing industry accepts a new mesh size as a legitimate regulation will critically affect enforcement costs. Mesh size regulations that are accepted as beneficial and equitable to the industry overall will be enforceable at lower costs than regulations which are perceived by the industry to be unacceptably stringent. Industry attempts at evasion of the regulation through such means as net liners will require **a** higher level of at-sea enforcement.

Management Costs

The costs of using mesh size as a primary management tool depend on the complexity of the overall management system, the nature of the adjustment process used to modify rules, and the information required to make management decisions.

Complexity of regulations-If an increase in mesh size results in the elimination of other regulations, the resulting decrease in the overall complexity. of management rules leads to fewer costs of management. If new mesh size regulations are simply added on to the existing system of rules, management costs increase with the additional requirements on decision making.

Adjustments of regulations-In-season adjustments of regulations are expensive for both management and the industry. A mesh size regulation in place for more than an entire year may result in lower management costs if it replaces regulations such as trip limits which require in-season monitoring and adjustment.

Information-Information costs are a substantial cost of management, both for managers and for fishermen. The complexity of regulations and the frequency of changes in the regulations affect the costs of acquiring information for both management and business decisions. The management costs of information imposed by mesh size regulation relative to other regulations depend on whether the overall complexity of regulations is increased or decreased by setting a new minimum mesh size. Elimination of rules requiring fine-tuning adjustment will decrease overall information costs.

Biological Costs

The nature of the biological cost imposed on the resource by mesh size regulation depends on whether the fishery is single-species or multispecies.

Loss of production--When a single mesh size is used to fish assemblages of species, the fishery may exert higher levels of fishing mortality than is desirable on some species. Because species of different shapes and sizes are fished by a single mesh size, some species may be overfished and some may be underfished. This may result in a lower level of biological production than would be possible if all species were fished at optimal levels.

Economic cost of lower production--The economic consideration related to lower overall levels of biological production is not the absolute level of biological production (in weight) from the fishery but rather the value of that production. The value of yields for a given mesh size depends on three factors: 1) the relative prices of the species landed; 2) the value of a fish relative to its size; 3) the value to the fishery of the lost reproductive and growth potential of those fish incurring a higher than desirable level of fishing mortality.

Benefits Associated With Mesh Size Regulations

Codend mesh regulations are characterized by various benefits to management agencies and to the fishing industry. These include effects on the planning horizon, operating flexibility, landed value of the catch, fishing mortality and the integrity of landings data.

Planning Horizon

Heavier reliance on mesh size regulations as opposed to in-season adjustment type regulations increases the length of time over which both management agencies and the fishing industry can plan. Anything that increases the planning horizon carries with it the benefit of increased operating flexibility.. As the time period over which the rules are known increases, more stability is introduced into the planning environment. The potential for reducing in-season adjustments is a major benefit of mesh regulations.

Operating Flexibility

Mesh size regulations promote operating flexibility for a multispecies fishery to the extent that they do not impose severe modifications of existing patterns of operation. An often cited benefit of mesh regulation is that within the constraint of minimum mesh size, fishermen are free to choose when, where, and how long they will fish. Business decisions may be made according to individual strategies.

Landed Value of the Catch

A benefit of mesh size regulation is that after some initial adjustment period of decreased yields, yields are expected to increase in the long run. If an increase in mesh size is successful in reducing mortality of small fish, the eventual recruitment of those fish at a larger size results in increases in both yields of fish and in revenues earned by those yields. The exact nature of the increased revenues depends on the landed species mix, the relative prices of the species, and the effect of fish quantities and size on price. Empirical analysis of Dover sole data indicates that as fish size increases, filet yield also increases up to a point (Ueber 1986). For some species, large fish receive a higher ex-vessel price per pound than small fish. The increase in landed value resulting from an increase in mesh size represents a tradeoff between the loss of current value from decreased yields in the short run and the increased value of future yields in the long run (see Appendix 3).

Fishing Mortality

One aim of an increased mesh size is to protect a portion of the fish stock by reducing fishing mortality. The idea is to allow the escapement of undersized fish before they are landed, resulting in fewer discards and lower levels of discard mortality. The extent to which this benefit of an increased mesh size is realized depends on the selectivity of the net. Clean selectivity promotes maximum escapement of undersized fish. The economic benefits of reduced fishing mortality are realized by the potential increased future value of the yield.

Integrity of Landings Data

One undesirable side effect of numerical limits placed on catch (e.g., overall quotas and trip limits) is that they create incentives for catch to be underreported and species to be misrepresented. This deception leads to a degradation of the landings data which are essential for biological analyses, economic analyses, and management decisions. A likely benefit of stronger reliance on mesh size regulation to control catch is the removal of incentives to circumvent the regulation through misrepresentation of catch.

Determining an Optimum Mesh Size

Determining the optimum mesh size is like choosing the best of anything else; it depends on the objective. Common regulatory objectives underlying mesh size regulations include maximizing yields, either physical or monetary, protection of stocks, and minimizing regulatory intervention in the fishing industry.

Maximize Yields

Management of a fishery to achieve maximum yields may focus on either physical yields measured in weight of fish or economic yields measured in revenues earned from the sale of fish. The economic perspective is one of maximizing net earnings (revenues minus costs) from the fishery rather than weight of fish.

For a single species fishery, the choice of an optimum mesh size becomes a relatively simple matter of accounting for the growth rate, the price-size relation of the fish, and harvest costs; then adjusting the mesh size to select for the maximum-value size of fish.

Selecting the optimum mesh size in a multispecies fishery is far more complex because a single mesh size will have different selectivity properties for different species. The determination of the "best" mesh size involves tradeoffs in value between various species in the catch and between current and future income. For a given mesh-size, the tradeoff in value between species results from catching lower levels of one species and higher levels of another. The question then becomes: Is the value of the species lost to the gear through an increase in mesh size greater or smaller than the value of the increased catch of another species? The tradeoff between current and future income requires a determination of which carries a higher value: the income foregone in the. current time period through an increase in mesh size or the future income earned through increased yields. An important consideration in the tradeoff in value over time is how far in the future are the expected benefits of increased revenues. Also critical to the tradeoff over time is the question of whether the benefits of higher earnings accrue to the same group of people who bore the costs of decreased yields.

It is important to note that managing for maximum yields in a mixed-species fishery is always related to the yield of the complex as a whole. Because the optimal mesh size varies by species, achieving the maximum yield from each species in the mix is an impossible task.

Stock Protection

The choice of optimum mesh size on the basis of protecting stocks depends on whether protection is aimed at one species or at several. If maintaining strong biological diversity is a management goal the best mesh size is one for which a range of effort levels will maintain a group of species. An alternative management objective is to protect a single species at the expense of other species. In a mixed-species fishery this becomes a complex problem. If mesh size is manipulated for a single species, potential catch of other species is lost. If mesh size is adjusted for different species assemblages this may result in unacceptably complex regulations associating different mesh sizes with different depth ranges or fishing areas.

Minimize Regulatory Intervention

To achieve this management goal the choice of optimum mesh size is that size at which mesh regulation can replace other regulations in the fishery, such as trip limits. Implicitin the use of mesh size regulation is the replacement of direct catch controls (numerical quotas or trip limits) with the indirect catch control that results from increasing the selectivity of the gear. The best mesh size in this context is the size that at expected levels of effort results in yields not exceeding what are considered to be “safe” levels.

Once the management goal is determined and criteria are established for realizing that goal, the costs and benefits of mesh size regulations are evaluated in relation to the management goal. These include general costs and benefits of mesh regulations, specific costs and benefits of mesh regulation in the context of a particular fishery, and specific costs and benefits of various sizes mesh.

Possibilities and Limitations of Mesh Size **Regulations**

In summary, this discussion reviewed the possibilities and limitations of controlling mesh size to regulate multispecies fisheries.

The possibilities of a reliance on mesh size as a primary tool of regulation result from its potential benefits. These include the maintenance of operating flexibility for the industry, longer planning horizons, increased yields and value of the catch, decreased fishing mortality on juvenile fish, protection of spawning stocks, and protection of the landings data quality.

The major limitations of mesh size **as** a primary management tool stem from the costs of enforcement and from the need to control the overall level of fishing effort. Enforcement costs may be high if industry compliance is weak. In addition, although mesh size regulations may control the type of fishing effort, they do not control either the timing or the total amount of fishing effort. The “race for fish” will continue under mesh size regulations if quotas remain in effect. Mesh size regulations will not control the timing of landings to ensure a steady supply throughout the year. In a multispecies fishery, determining a single mesh size appropriate to the entire mix of species is a complex matter of compromise. Further, although it is expected that an increase in mesh size will increase future yields as growth exceeds natural mortality, there is no guarantee that higher yields will result. Biological variability introduces uncertainty about the causal relationship between mesh size and future yields.

MESH SIZE REGULATION IN THE NEW ENGLAND GROUNDFISH FISHERY

Information on specific regulations effective in New England was available in various documents of the New England Fishery Management Council. Insight into the development process of groundfish regulation was provided by conversations with the following people, each of whom offered a unique perspective on fishery management in New England:

Robin Alden, Publisher, Commercial Fisheries News;

Dick Allen, Vice President, Atlantic Offshore Fisherman's Association; Member, New England Fishery Management Council;

Cliff Goudey, Engineer, Center for Gear Technology Research, Massachusetts Institute of Technology Sea Grant Program;

Jim McCauley, President and General Manager, Point Judith Fisherman's Coop, Narragansett, Rhode Island;

Guy Marchesseault, Deputy Executive Director, New England Fishery Management

Jim Salisbury, General Manager, Portland Fish Exchange, Portland, Maine; Former member, New England Fishery Management Council;

Tim Smith, Branch Chief, Population Dynamics Branch, Northeast Fisheries Center, National Marine Fisheries Service, Woods Hole, Massachusetts;

Stanley Wang, Industry Economist, Northeast Regional Office, National Marine Fisheries Service, Gloucester, Massachusetts.

The New England groundfish fishery is a mixed-species fishery. Historically, the three most commercially important species are Atlantic cod (Gadus morhua), haddock (Melanoorammus aealefinus), and yellowtail flounder (Limanda ferruainea). Fishing for groundfish takes place over a large geographical area characterized by distinct fishing grounds (Fig. 1). Landed species mixes vary according to season and fishing location. There are also distinct differences in target fisheries among ports. Since fishing takes place on biological assemblages of mixed-species, landings are mixed. Fishermen may

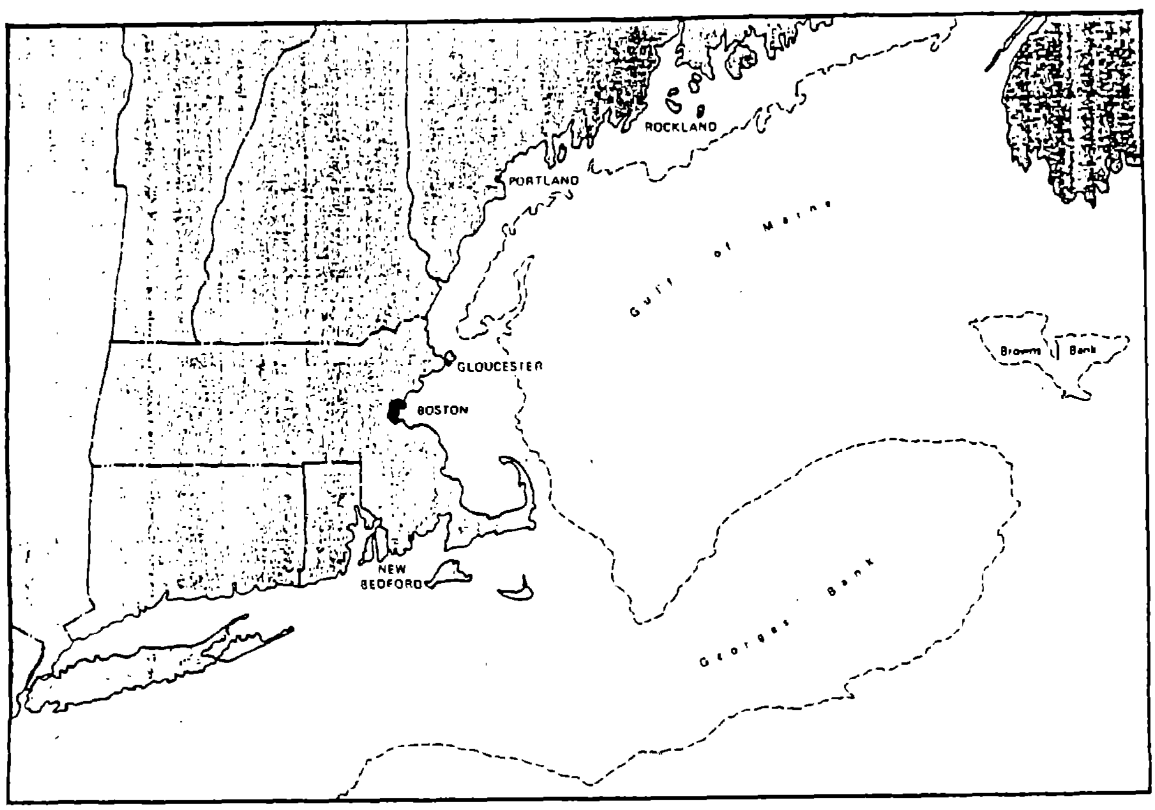

Figure 1. New England's principal fishing ports and fishing grounds.
Source: Dewar 1983.

target on **a** single species but catch several other species as well. In the haddock fishery or flat-fish fishery other species may comprise up to one-third or one-half of the mix.[1/] Exceptions to this are in the squid (Illex illecebrosus, Loligo pealei) and butterfish (Poronotus triacanthus) fishery where catches are relatively "pure." Throughout the fishery there is a general economic dependence on a wide variety of species.

The major species subject to regulation under the Northeast Multispecies Fishery Management Plan are cod, yellowtail flounder, haddock, winter flounder (blackback) (Pseudopleuronectes americanus), American plaice (dabs) (Hipooalossoides platessoides), pollock (Pollachius virens), redfish (Sebastes spp.), witch flounder (gray sole) (Glyptocephalus cynoglossus), white hake (Urophycis tenuis), and windowpane flounder (sand dab) (Lophopsetta masculata) (New England Fishery Management Council 1985).

History of Mesh Size Regulation in New England

Regulation of mesh size in the New England groundfish fishery began in 1953 with controls on the minimum mesh size allowed in the haddock fishery. At that time fishery management responsibilities were held by the International Commission for the Northwest Atlantic Fisheries (ICNAF). The ICNAF was formed in 1950 for the purpose of international cooperation and conservation in fisheries. Mesh size regulations were revised and expanded over time to protect haddock in nondirected as well as directed fisheries. Regulation proceeded primarily as a quota system in conjunction with a minimum mesh size and closure of spawning areas. By 1971 a minimum mesh size was set for yellowtail flounder

[1/] J. Salisbury, General Manager, Portland Fish Exchange, Marine Trade Center, 2 Portland Fish Pier, Portland, ME 04101. Pers. commun., August 1987.

as well as haddock. In 1972 per-nation quotas were set for the most important species (Dewar 1983).

Management and enforcement by ICNAF was insufficient to prevent overexploitation and depletion of fish stocks. From the point of view of the United States fishing industry, problems with the ICNAF management system stemmed from four sources: 1) enforcement; 2) incidental catch; 3) fishing by non-ICNAF nations; and 4) competitive advantages for foreign vessels. Poor or nonexistent enforcement of regulations resulted in established quotas having little bearing on actual harvested amounts. Further, the addition of incidental catch quotas allowed catches to exceed the quotas by large amounts. In addition, multilateral fishery agreements did not include all countries actually fishing in these waters. Quotas were seen as providing an unfair advantage to large distant-water vessels which could fish in more severe weather (Dewar 1983).

Concern for these resources led U.S. fishermen to seek U.S. jurisdiction over these fishing grounds and subsequent passage of the Fishery Conservation and Management Act (FCMA) in April 1976. This act provided the enabling legislation for the creation of Regional Management Councils. By the second year of New England Fishery Management Council (NEFMC) operation, management included quarterly quotas for cod, haddock, and yellowtail flounder as well as vessel size-class quotas, spawning area closures and minimum mesh size in certain areas (Dewar 1983). In some cases the single-species quotas were set at such a low level the entire quota could be caught as by-catch in nondirected fisheries. Once a quota had been caught, by-catch quotas were put in place. By-catch quotas were easily overshot and were unsuccessful in limiting fishing mortality. The difficulties in controlling by-catch quotas led to problems of discards, false reporting of landed species, and the invention of new species.

The quality of the landings database deteriorated. Large fines for violations further disaffected fishermen. Fish prices were low due to both market gluts and the weak selling position of fishermen selling illegal fish (see footnote 1).

In the interest of minimizing these negative side affects of numerical controls, the NEFMC moved toward a stronger reliance on the operational control of mesh size regulation. Quotas were replaced by nonnumerical optimal yields (OY). The nonnumerical OY was defined as whatever was caught using regulation gear. An interim management plan was written in which the choice of the minimum mesh size was made from past experience. The operating principle behind the choice of minimum mesh size was to select for the minimum size fish that had spawned at least once. For example, the goal for cod was to select for 50% escapement of 3-year-old fish.[2/]

The NEFMC opted for a general strategy of operational control in groundfish, sea scallops, and American lobster. Operational control methods are chosen to be consistent with fishery operations and to reduce the vulnerability of stocks. These methods include gear restrictions, area/time restrictions, and retention restrictions. There is no direct control of the size of the catch, the size of the fleet or fishing effort (New England Fishery Management Council 1985).

The primary concern is to protect or improve spawning stocks by controlling age-at-entry. Control methods include setting both a minimum size of fish and a minimum mesh size. A second concern is to limit by-catch fishing mortality. Control methods to limit discard mortality include area and time closures to protect both spawning stocks and juvenile fish.

[2/]G. Marchesseault, Deputy Executive Director, New England Fishery Management Council, 5 Broadway, Saugus, MA 01906. Pers. commun., October 1987.

The Council recognized that with mixed-species catches, maintaining the desired escapement levels for all species at the correct age was impossible. The mixed-species characteristic of the fishery dictated a tradeoff between species and between short-term and long-term considerations. The questions considered by the Council were: 1) How important was it to protect one species at the expense of others? and 2) How should the tradeoff between short-term gain and longer-term survival of stocks and of the fishery be weighed (see footnote 1).

The Goals and Objectives of Groundfish Management

The current Northeast Multispecies Fishery Management Plan, also called the Atlantic Demersal Finfish (ADF) Plan, became effective 1 October 1987. This plan reflects the NEFMC's experience with various types of regulations over the five year period that groundfish management has been in place. The Plan places an emphasis on minimizing economic dislocation of the fishing industry and maintaining freedom of choice for fishermen as long as species remain above minimum abundance levels (Commercial Fisheries News 1984).

The plan cites two major management goals for the groundfish fishery:

1) To minimize regulatory intervention in fishery operations.

2) To prevent stocks from reaching minimum abundance levels. Minimum abundance levels are defined as stock levels below which there is an unacceptable risk of recruitment failure.

One objective of the plan is to control fishing mortality. A second objective is to reduce fishing mortality on redfish and Georges Bank haddock to allow the rebuilding of stocks which are now of insufficient size to maintain a viable fishery. A third objective is to stabilize the cod and flounder fisheries (New England Fishery Management Council 1985).

Current Regulation

The NEFMC has adopted several operative measures to achieve the management objectives. Heavy reliance is placed on minimum mesh size combined with minimum fish size and area closures. These measures were chosen to minimize interference with operating flexibility and to build in incentives toward compliance. The idea is to replace the incentives to catch small fish with incentives to catch large ones (see footnote 1). In adopting the current groundfish plan the Council rejected suggestions by the NMFS that quotas, trip limits, or limited entry be evaluated as alternative management measures (Commercial Fisheries News **1986).**

Minimum Fish Size

Minimum fish size varies by species and will increase over a 3-year period for cod, haddock, and pollock. Fish smaller than the minimum size may not be possessed, landed, or imported. Minimum fish sizes also apply to the recreational fisheries but allowable sizes are smaller in the first 3 years.

Minimum Mesh Size

Mesh size regulations apply only to the cod end, defined as the trailing 75 meshes of the net. Mesh may be either of diamond or square configuration. Minimum mesh size varies by area (Fig. 2).

Gulf of Maine: Minimum mesh in trawl cod and bottom-tending gillnets is 5 1/2 inches.

Georges Bank: Minimum mesh in trawl codends and bottom-tending gillnets is 5 1/2 inches for years 1 and 2,6 inches for year 3 and after.

Southern New England: No minimum mesh size applies.

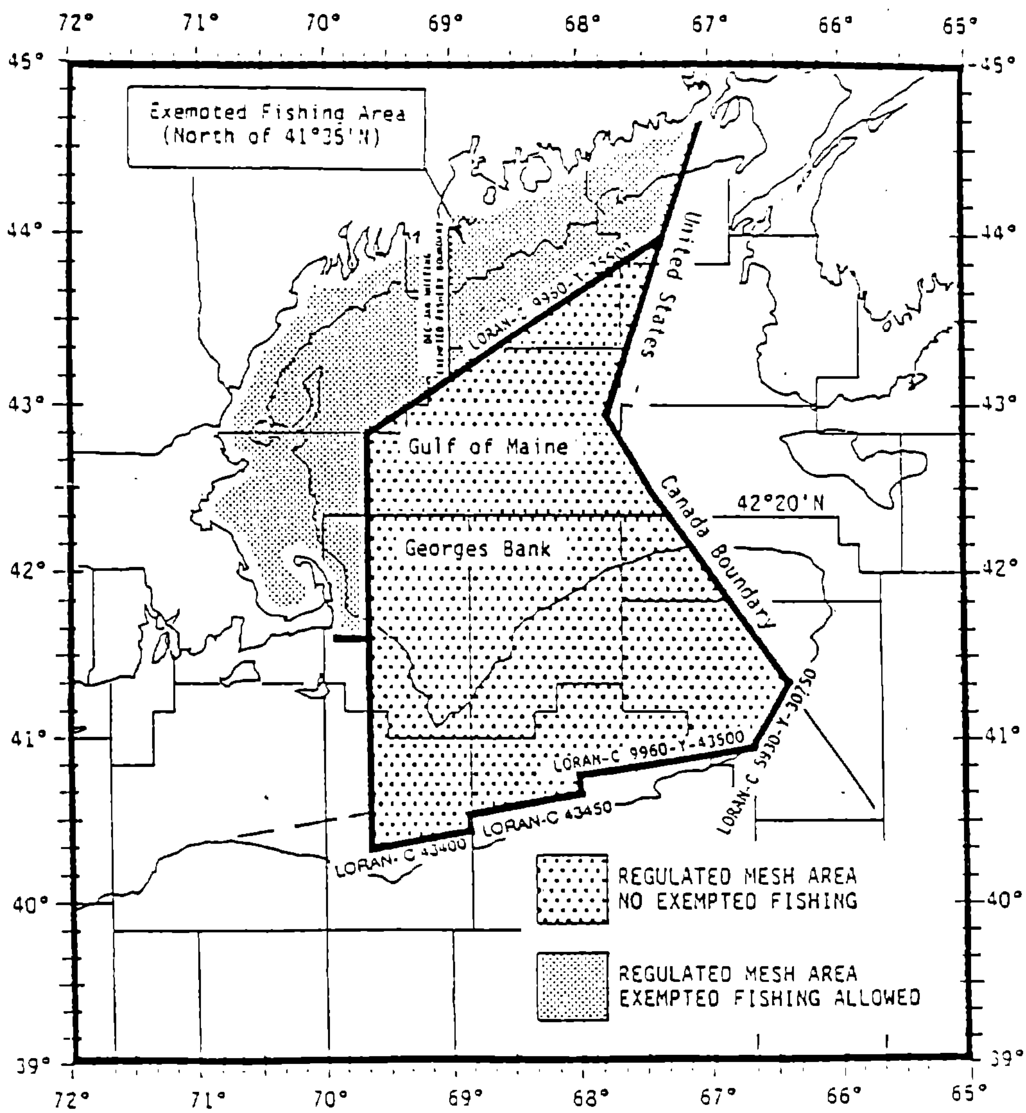

Figure 2.--New England regulated mesh areas and areas of exempted and non-exempted fishing. Source: New England Fishery Management Council 1987.

Seasonal and Area Exemptions from Minimum Mesh Size

In exempted seasons and areas, small mesh nets may be used (Fig. 2). Regulated species may not exceed **10% of** total landings of all species landed over the reporting period.

Area Closures

Seasonal closures of spawning areas for haddock are imposed, as well **as** seasonal area closures to limit mortality of yellowtail flounder.

Additional Options

If management objectives are jeopardized by the level of fishing mortality, the Council may consider additional measures according to the area.

1. Regulated mesh area: Change regulations, impose further time/area restrictions, increase minimum fish size, increase mesh size.

2. Nonregulated mesh area: Close areas, increase minimum fish size, set a minimum mesh size.

In addition to the above operative management measures, several administrative measures apply. These include gear marking, data reporting, and data monitoring (New England Fisheries Management Council 1985; 1986).

Enforcement

Enforcement of fishery regulations has remained a problem in New England. The main difficulties associated with mesh size as a regulation stem from the number of **ways** the regulation can be circumvented. These range from choking off the codend (to retain fish in the smaller-mesh portion of the net) to the use of liners to effectively reduce the mesh size. At-sea boardings by the U.S. Coast Guard to check for compliance have also been an ineffective control due to both the expense of the program and the advance warning of boardings received by fishermen. Primary enforcement efforts have been shore-based, aimed at ensuring that no undersized fish are landed.[3/]

The NEFMC has taken steps to increase the effectiveness of existing regulations and to improve compliance through the following measures.

Minimum Mesh Size

The regulated mesh size now applies to the trailing 75 meshes of the net: previous. mesh size regulations applied to the codend which was defined as that **part** of the net that holds the fish. The specification of the quantity of meshes to which the regulation applies is intended to both standardize the regulation and make it more difficult to tie off the net (see footnote 2).

Number of Nets on Board

Although nets of various mesh sizes are allowed on board in, **a** single trip, only a regulation-mesh net may be available for use in a regulated mesh area. Any net with a smaller mesh must be stowed until the vessel has entered an exempted fishing area.

Exempted Areas

Certain fishing areas at certain times are exempt from the minimum mesh-size regulation (Fig. 2). A myriad of species are fished in these areas, including shrimp (Pandalus borealis), squid, dogfish (Saualus acanthias), butterfish, and whiting. No minimum mesh size applies; however, landings must consist of at least 90% exempted species. The NEFMC is considering setting minimum mesh sizes for fishing in these areas.

[3/] D. ‘Allen, Vice President, Atlantic Offshore Fisherman’s Association, 221 Third Street, Newport, RI 02840. Pers. commun., June 1987.

Area Closures for Spawning

The NEFMC intends to remain flexible about the timing and duration of the closure period. The primary concern of the NEFMC is to remain responsible to changing conditions.

Minimum Fish Size

Minimum allowable fish size in the commercial fishery has been increased. Minimum size in the recreational fishery will increase next year. The appropriate minimum size remains an issue and the NEFMC is considering further increases (see footnote 2).

Gear Development Projects

Experiments with trawl gear are ongoing in New England. A coalition of gear technologists, fishermen, and net manufacturers meet annually to discuss trawl **gear** design. In 1987, the Massachusetts Institute of Technology Center for Gear Technology Research sponsored a conference on the use of gear selectivity as a fishery management tool (Goudey and Paterson 1987). Experiments with square mesh extension pieces in the butter-fish fishery have been conducted by **members of** the Pt. Judith Fisherman's Co-0p.[4/] Experiments with square-mesh codends for other groundfish species are being conducted by the Maine Department of Marine Resources. In addition, the NEFMC has received a grant to support fishing industry projects related to "conservation engineering," the use of developments in gear technology to achieve fishery conservation goals (see footnote 2).

[4/]J. McCauley, President and General Manager, Point Judith Fisherman's Co-op, Narragansett, RI 20882. Pers. commun., June 1987.

MESH SIZE REGULATION IN THE WEST COAST GROUNDFISH FISHERY

Regulation of codend mesh size has a history of use as a management tool in the West Coast fishery for groundfish. Trawl mesh sizes were first regulated in the California flatfish fishery in the early 1930s. Minimum marketable sizes of flatfish led to voluntary use of minimum mesh sizes between 1935-40. After 1940 minimum trawl mesh sizes were adopted by Washington, Oregon and California and these regulations continue to be in effect by state (Pacific Fishery Management Council 1982).

Mesh size regulations in federal waters were established by the Pacific Coast Groundfish Plan developed by the Pacific Fishery Management Council in 1982. Minimum trawl mesh sizes range from 3 inches to 4.5 inches according to trawl type and statistical area. These regulations are summarized in Table 1.

Table 1 .--Minimum mesh size (inches) by trawl type and statistical area as established by the Pacific Coast Groundfish Plan.

Trawl Type	INPFC Statistical Area				
	Vancouver	Columbia	Eureka	Monterey	Conception
Danish and Scottish seines	4.5	4.5	4.5	4.5	4.5
Pair trawls bottom	4.5	4.5	4.5	4.5	4.5
Pair trawls midwater	3.0	3.0	3.0	3.0	3.0
Flat-fish bottom trawl	4.5	4.5	4.5	4.5	4.5
Roller or bobbin trawl	3.0	3.0	3.0	4.5	4.5
Pelagic trawl	3.0	3.0	3.0	3.0	3.0

Source: Pacific Coast Groundfish Plan, Pacific Fishery Management Council 1982.

A 4.5-inch minimum mesh size is in effect for all bottom trawls used throughout most California waters (INPFC Statistical Areas Monterey and Conception, Fig. 3) but applies only to trawls which have continuous footrope contact with the

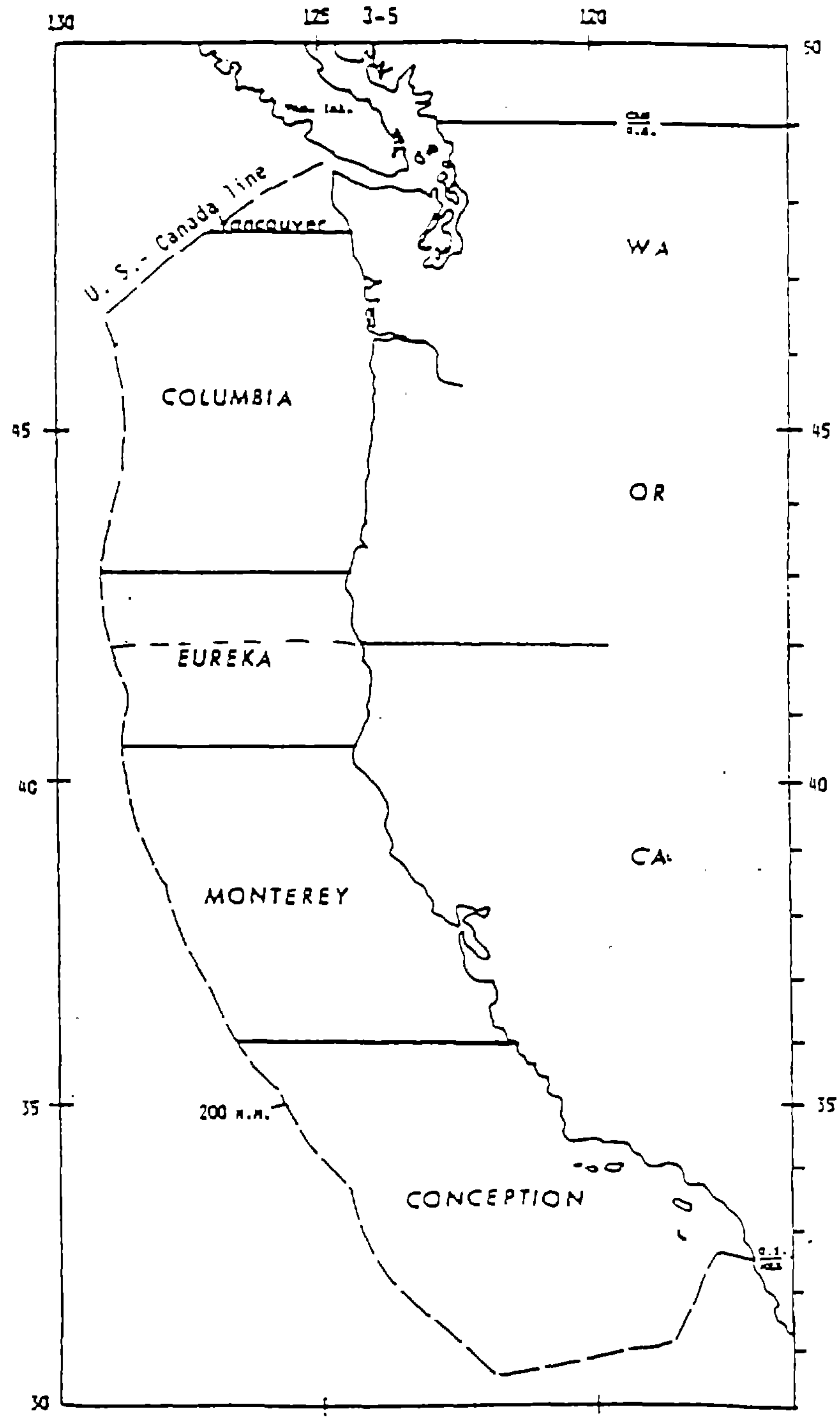

Figure 3.--INPFC statistical areas in the U.S. fishery conservation zone seaward of Washington, Oregon, and California. Source: Pacific Fishery Management Council 1982.

bottom (“mud gear” or “sole gear”) in waters off Oregon and Washington. The 4.5-inch minimum size was set to minimize fishing mortality on juvenile flatfish. Trawls with rollers at least 14 inches in diameter, used to fish in hard-bottom areas for rockfish, have a 3-inch minimum mesh size in Oregon and Washington (INPFC Statistical Areas Vancouver and Columbia, Fig. 3). The 3-inch minimum was set to prevent gilling of Pacific Ocean perch (Sebastes alutus), the most commercially important species during the early development of the rockfish fishery in the 1970s (West 1987).

Mesh size regulations apply to the terminal 50 meshes of the net. Regulations also control the use of codend chafing gear, restrict the use of double-walled codends, and describe the means by which mesh measurements are made.

Chafers are pieces of netting, leather, or canvas attached to the codend to prevent abrasion of the net (Jones 1984). Encircling chafing gear used on 4.5-inch nets must be of a mesh size at least 15 inches over the upper half of the codend. Chafing gear used on the upper half of 3.0-inch nets must be at least 6 inches in size. No chafing gear may be connected to the terminal end of the codend. This restriction is designed to promote escapement of small fish, which may be hindered by chafers.

Double-walled codends are allowed for 4.5-inch mesh nets only. A double codend is a codend constructed of two layers of netting. The concern over use of double-walled codends is that the layering of nets will reduce the effective mesh size below the legal minimum (Jones 1984).

Studies are currently being conducted to examine the selectivity characteristics of trawl codends of varying mesh sizes for the West Coast groundfish fishery. In 1985 the National Marine Fisheries Service conducted a selectivity experiment on mixed rockfish species off the coast of Washington and Oregon. Diamond mesh codends of 3-inch, 5-inch and 6-inch netting and a square mesh codend of 3-inch netting were evaluated. Preliminary results suggest that identifying a single codend mesh size that will meet conservation goals for all species and allow unrestricted fishing will not be possible (West 1987).

Further work in this area has begun by a mesh size modeling group. Models have been constructed to examine the potential biological and economic effects of different codend mesh regulations used in both the flatfish and rockfish fisheries. Modeling results suggest a potential for mesh size regulations in the fishery. Since results are found to be sensitive to the choice of selectivity parameter used in the model, there is considerable interest in performing at-sea selectivity experiments under production fishing conditions (Vaga and Pikitch 1987).

FISHING OPERATIONS IN THE WEST COAST GROUNDFISH FISHERY

This section summarizes the general pattern of fishing effort and groundfish landings on the West Coast. Information on the structure of fishing operations is necessary to any evaluation of the use of mesh size regulation as a primary management tool.

Fishing with relatively nonselective trawl gear takes place over different fishing areas. Different fishing areas are distinguished by depth, bottom characteristics, and species assemblages. Otter trawl gear includes bottom trawls pulled directly along sandy bottom surfaces, trawls with rollers used for rocky bottom surfaces, and pelagic or midwater trawls pulled through the water column with no contact with the bottom surface.

Other gear types used to land groundfish include gillnets, traps or pots, and longlines. Table 2 illustrates the portion of total groundfish landings by each gear type between 1981 and 1986 (Korson and Silverthorne 1987). Throughout this time period trawl gear accounted for between 75 and 88% of total landings.

Table 2.--West Coast groundfish shoreside landings (metric tons) by gear group, 1981-86.

Year	Trawl	Trap/Pot	Setline/Longline	Net	Other/Misc.*
1981	91,328	3,956	2,599	1,738	4,173
1982	103,297	6,530	2,504	2,028	4,542
1983	81,727	5,437	1,307	2,303	6,891
1984	72,694	3,854	1,351	2,212	9,744
1985	75,352	3,703	3,155	4,058	5,318
1986	61,252	2,208	3,541	4,232	11,014

*Includes set nets, troll, jig, commercial trawl, shrimp trawl, and uncoded gears.

Source: PacFIN, Groundfish Report Series (Korson and Silverthorne 1987).

Fishing different areas with various trawl gear results in mixes of several species landed together. For example, Figure **4** illustrates a mixed-species catch from trawl fishing activity at depths greater than 100 fathom (fm). This catch represents the proportions of the major species brought on board for 67 tows during October-December 1985 (Pikitch et al. 1985).

Landed catch for this same fishing activity and time period is shown in Figure 5. Landed catch differs from initial catch by the amount of fish discarded. Fish are discarded due to minimum fish size regulations, regulatory limits on incidental catch of prohibited species or because some species are not marketable. Discards from this particular catch mix consist of undersized sablefish, small flatfish, whiting, and “rough” fish.

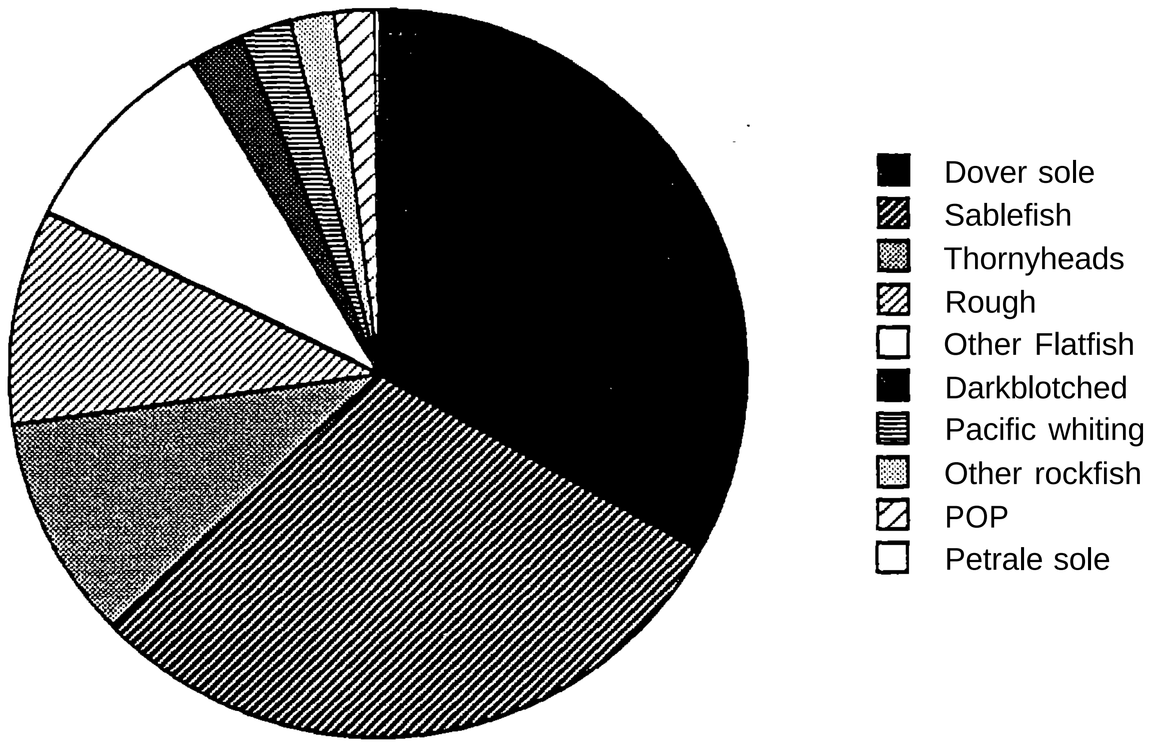

Figure 4.--Catch mix resulting from Oregon deep water (> 100 fms) fishing strategy using trawl gear, October-December 1985. (POP = Pacific ocean perch.) Source: Pikitch et al. 1987.

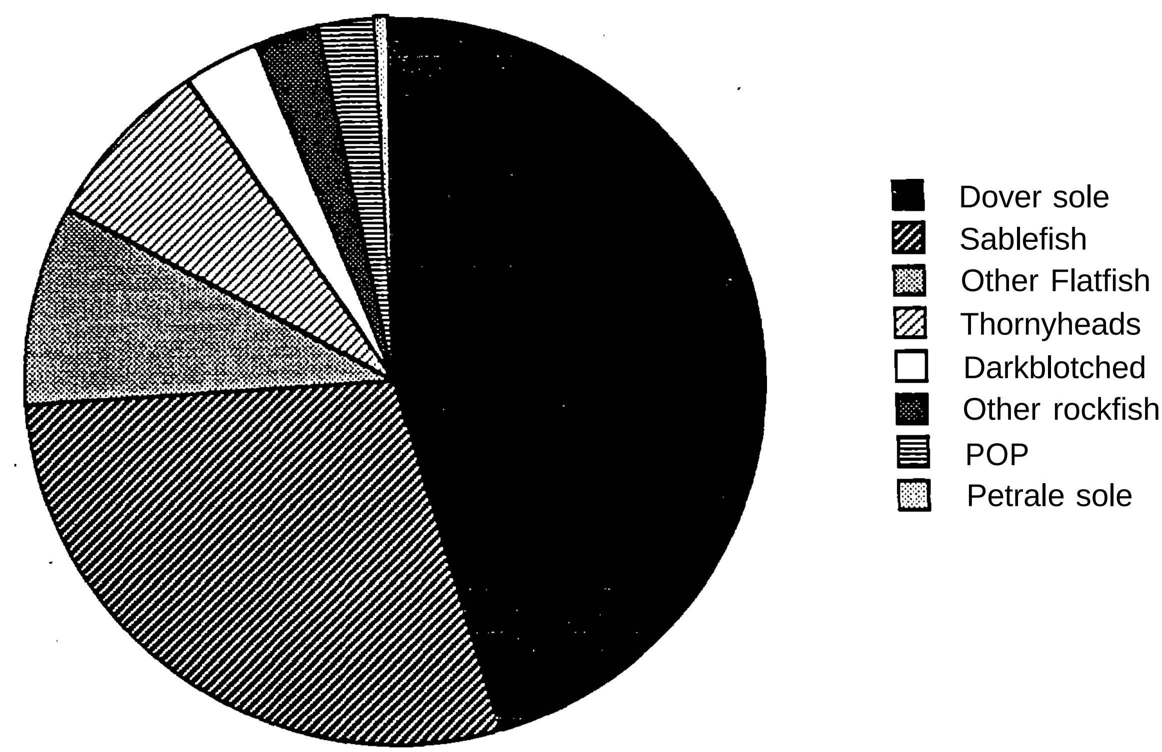

Figure 5.--Landed catch mix resulting from Oregon deep water (> 100 fms) fishing strategy using trawl gear, October-December 1985. (POP = Pacific ocean perch.) Source: Pikitch et al. 1987.

The importance of a particular catch mix to the fishery depends on its earning properties. Trawl fishermen fish for profit. The economic properties of a catch mix to the fisherman are illustrated in Figure 6. A revenue mix is calculated by multiplying the weight of each species in the mix by its ex-vessel price. The contribution of each species to the revenue mix is slightly different from its contribution to landed weight. For example, the relatively high ex-vessel price for sablefish means that sablefish makes a more important contribution to total earnings from catch than would be indicated by looking at its contribution to total weight.

In addition to the difference between weight and earnings shares for each species, catch mixes have another common characteristic. The contribution of any single species to the landed mix--either weight mix or revenue mix--is variable over time. A species contribution to total weight may vary widely for a given fishing strategy. For example, the proportion of rockfish (*Sebastes* complex) species in shallow-water trawl tows off Astoria, Oregon has varied between 20% and 79%. There is also a pronounced seasonality to species composition in a given area (Hanna 1987a).

Fishing takes place on assemblages of fish and results in catch mixes with variable species composition. A common economic adaptation to variability is diversification. Over the past 10 years the West Coast groundfishery has been characterized by diversification both in the number of different fishing activities pursued by each vessel and in the number of species landed (Hanna 1987b).

Diversification in order to reduce variability in earnings makes economic sense for fishermen. A key factor in the ability to diversify fishing activities is operating flexibility. Overall operating flexibility for vessels in multispecies

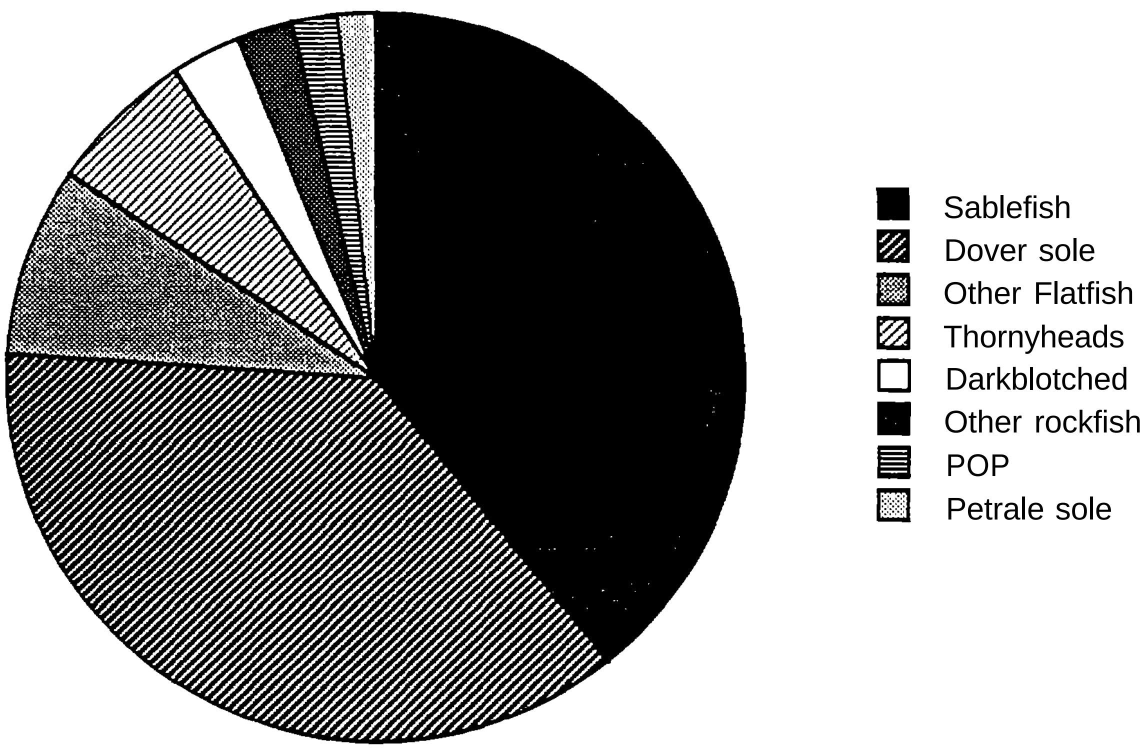

Figure 6.--Revenue mix resulting from Oregon deep water (> 100 fms) fishing strategy using trawl gear, October-December 1985. (POP = Pacific ocean perch.) Source: Pikitch et al. 1987.

fisheries includes flexibility in business planning, in fishing strategy, and in targeting and landing various mixes of fish.

APPLICATION OF MESH SIZE REGULATIONS TO THE WEST COAST TRAWL GROUNDFISH FISHERY

How well mesh size regulations can be applied as a primary management tool for West Coast groundfish depends in large part on their consistency with the structure of the fishery. In general, any regulation is more effective in achieving a desired management goal if it is consistent with the structure of fishing operations and if it is supported by the fishing industry.

As discussed previously, the West Coast trawl fishery for groundfish has several characteristics that will affect regulation success. These are multispecies targeting with relatively nonselective gear, discards, operating flexibility, stocks protected by quotas and an increasing complexity of regulations.

Multispecies Fishing

Given the mixed-species nature of the catch, setting a single mesh size for the groundfish fishery will certainly involve tradeoffs between species. For example, as Demory and Silverthorne (1983) note, "petrale sole would benefit substantially from a 6.0 inch mesh size but a 6.0 inch mesh would almost preclude a target fishery for Dover sole." Different mesh sizes will create different tradeoffs in species composition and in economic yield. Specification of these tradeoffs is impossible without at-sea trials of different mesh configurations. The determination of the multispecies selectivity of different mesh sizes will be most realistic if trials are conducted under operational fishing conditions (Demory and Silverthorne 1983).

Discards

The current system of regulation with numerical limits on incidental catch has lead to discarding of marketable fish. Discards carry costs. Two primary costs of discards are the loss of growth and reproductive potential from those fish suffering discard mortality, and the economic loss to the fishery of the nonsurviving marketable fish. In addition, other costs are associated with the practice of discarding fish. These include enforcement costs resulting from the close monitoring required by stringent incidental catch limits, handling costs of extra-sorting on deck, avoidance costs of changing fishing patterns to avoid illegal fish, and information costs imposed by the need to guess species weight composition with precision.

Mesh size regulation has the potential to reduce the discard costs imposed on the fishery if: 1) the selectivity properties of the net are such that a high proportion of undersized fish escape and survive; 2) mesh controls are effective enough at protecting prerecruits that numerical limits on incidental catch can be removed.

Operating Flexibility

Mesh size regulations, if they are effective at replacing alternative controls such as trip limits, will promote operating flexibility for fishermen and processors in the groundfish fishery. A major characteristic of mesh size controls is their passive nature. By controlling the selectivity of the gear, catch is limited in an indirect way that does not restrict a fisherman’s choice of when or where to fish. This is in contrast to direct controls such as trip limits which set limits on the timing of fishing as well as on the levels of catch.

Protection of Stocks

How nets of different size meshes would affect various stocks of fish is an open question. Actual net trials will yield information on the multispecies selectivity properties of different sizes of mesh. Estimates of long run impacts on spawning stocks may then be made from the retention characteristics of different size meshes. Theoretically, mesh size can be set to allow escapement of those species needing protection. Operationally, using a single mesh size in a multispecies may mean tradeoffs between species in resulting sizes of stocks. The likelihood of mesh size regulations used in place of numerical quotas for stock protection will depend on decisions made regarding the acceptability of these tradeoffs. Mesh regulation in a multispecies fishery implies acceptance of a multispecies complex view of management as opposed to single species management. The multispecies approach recognizes yield from the fishery as a whole with the understanding that yield from individual species in the complex may be lower than the desirable levels (see also Bainton et al. 1987).

Complexity of Regulations

Mesh size regulation has the potential to reduce the overall complexity of fishing regulations for groundfish by decreasing the number of direct control measures. For mesh regulations to replace other regulations and reduce the regulatory burden on fishermen several conditions would need to be met. First, a multispecies yield approach to management would replace **a** single species management concept. Although the groundfish fishery is recognized to be a multispecies fishery, regulation has proceeded on a species-by-species basis. Second, the number of mesh sizes set for the fishery would need to be limited. Attempts to adjust minimum mesh sizes for each fishing activity could result in regulations more complex than those currently in place. Third, unless mesh regulations are able to replace the numerical limits on incidental catch, a change in minimum mesh size may only increase the regulatory burden.

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APPENDIX 1
OTTER TRAWL GEAR

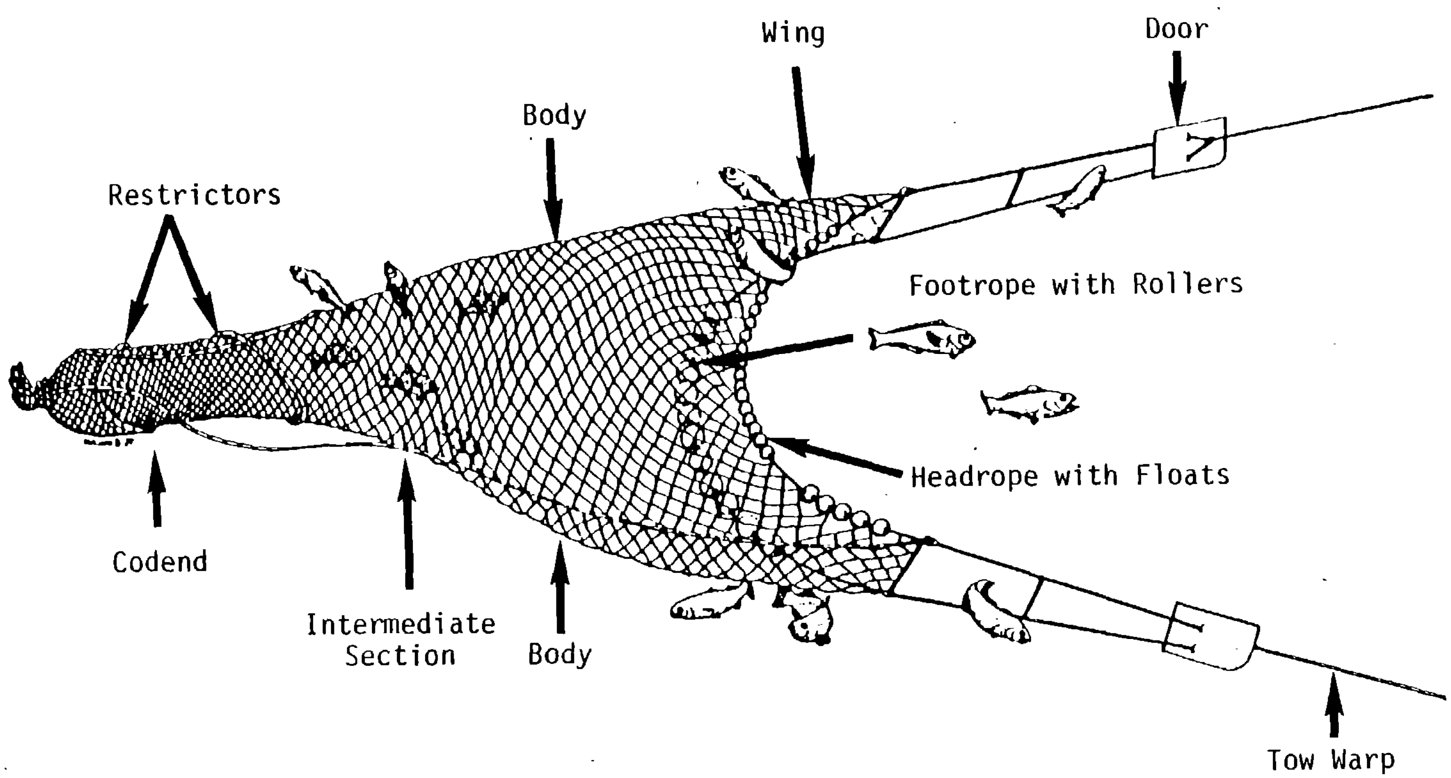

Illustration courtesy of Craig Rose, RACE Division, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, 7600 Sand Point Way NE, Seattle, WA 98115.

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APPENDIX 2
MESH SELECTIVITY

Mesh selectivity refers to the process of retaining a portion of an aggregation of fish as it comes in contact with trawl gear. All gears are selective to some extent and result in fish of certain sizes being caught more readily than others (Ricker 1975). The extent of gear selectivity will be determined by properties of the fish, properties of the gear, fishing method, and fishing area characteristics. Smolowitz (1983) discusses several factors affecting the selectivity of trawl gear which will be outlined below.

Selectivity of Trawl Nets

In general, discussions of the selectivity of trawl nets refer to the retention characteristics of the codend portion of the net. The codend is the trailing section of the net which retains the fish (see Appendix 1). Some selection also occurs in the forward portion of the net as fish escape during a tow.

It is common practice to look for the “50% length,” which is the length (or size) of fish at which 50% are retained by a codend of a given mesh size. Selection curves, or “selection ogives,” are drawn to express the size-capture relationship for different size meshes. A selection ogive represents the probability that a fish of a given size will be captured by the net in a single tow. Figure 2-1 shows selection curves generated from commercial fishery landings data for Dover sole using meshes of 3.5 inches and 5 inches (Natural Resource Consultants 1986).

The relation between mesh size and the “50% size” can be determined by looking at a number of selection curves for different mesh sizes. Selection curves for larger mesh sizes lie to the right of curves for smaller mesh sizes

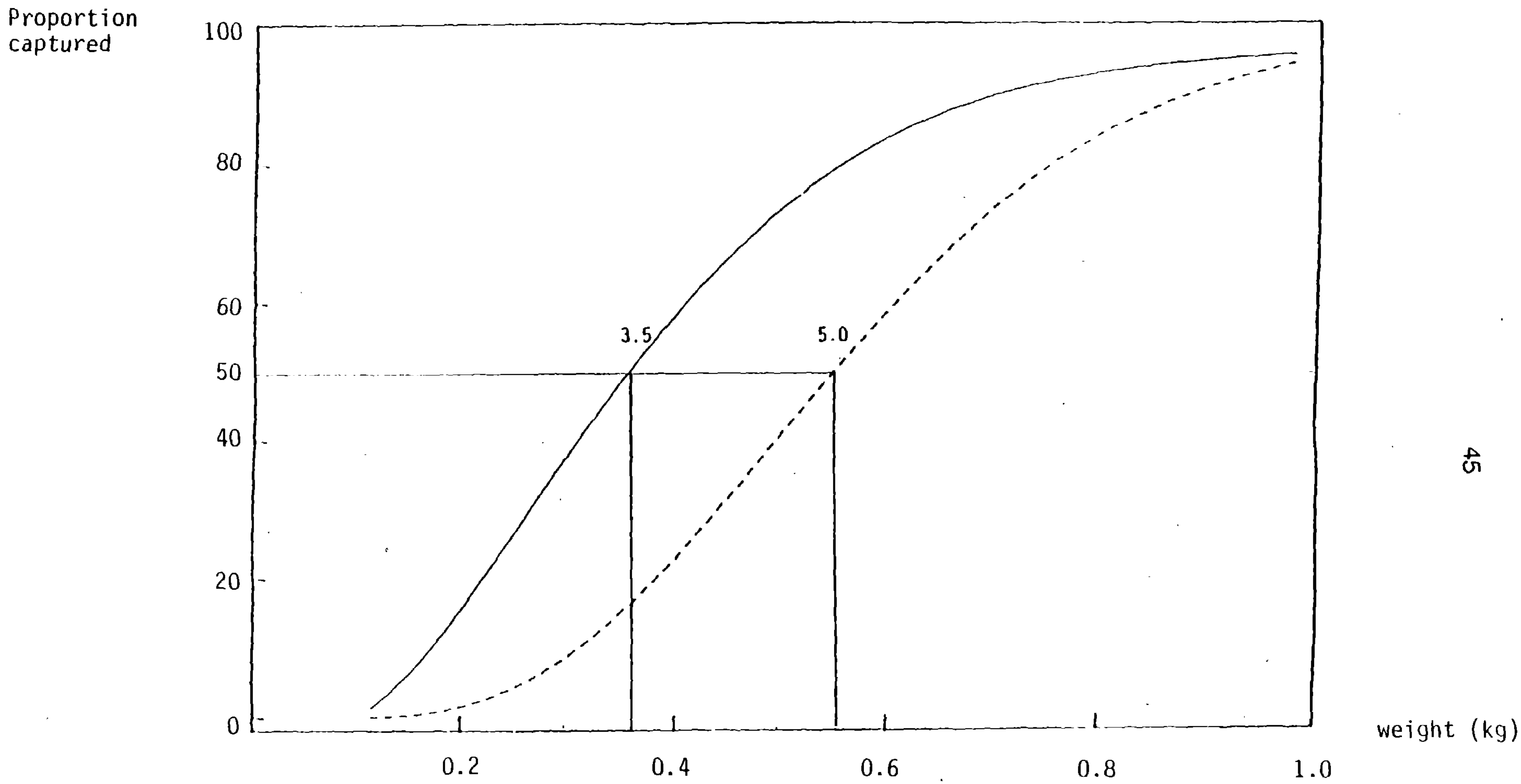

Figure 2-1 .--Dover sole size-capture relationships generated from data of Kimura (1978) for 3.5-inch and 5.0-inch mesh. Adapted from Natural Resource Consultants (1986).

because as mesh size is increased, the size of fish retained by the net increases. In Figure 2-1 the 50% size for Dover sole is 0.35 kg using a 3.5-inch mesh, 0.55 kg using a 5-inch mesh.

The “50% size” is a rule of thumb designed to ensure that at least half of the fish of a given size will survive to spawn. Without any known relationship between the size-of the spawning stock and recruitment, this rule is used as protection against the possibility of recruitment overfishing (New England Fishery Management Council 1985).

As selection ogives illustrate, the success of catching fish with a given net depends on the ratio of mesh size to fish size. This is called the selection factor of the net (Fridman 1973). More specifically, the selection factor is the relation between the 50% retention length (or size) and the inner length of the mesh (Smolowitz 1983).

A selection range includes the lengths (or sizes) of fish corresponding to between 25% and 75% retention (Fig. 2-2) (Blott, in Goudey and Paterson 1987). The smaller the selection range, the cleaner the selectivity of the net. The selection range varies with mesh size (Smolowitz 1983). Figure 2-2 shows a selection range for Dover sole of .25-.50 kg using a 3.5-inch mesh; .42-.72 kg using a 5-inch mesh. The larger mesh corresponds to a wider selection range.

Factors Affecting Selectivity

The factors affecting the selectivity of a given trawl net are many and varied. The results of experiments designed to determine the importance of various gear-related effects on the selection factor are summarized by Smolowitz (1983). Experimental results are sometimes mixed.

Smolowitz identifies experimental method as the most important determinant of selectivity. Two methods are commonly used: 1) a covered codend, in which

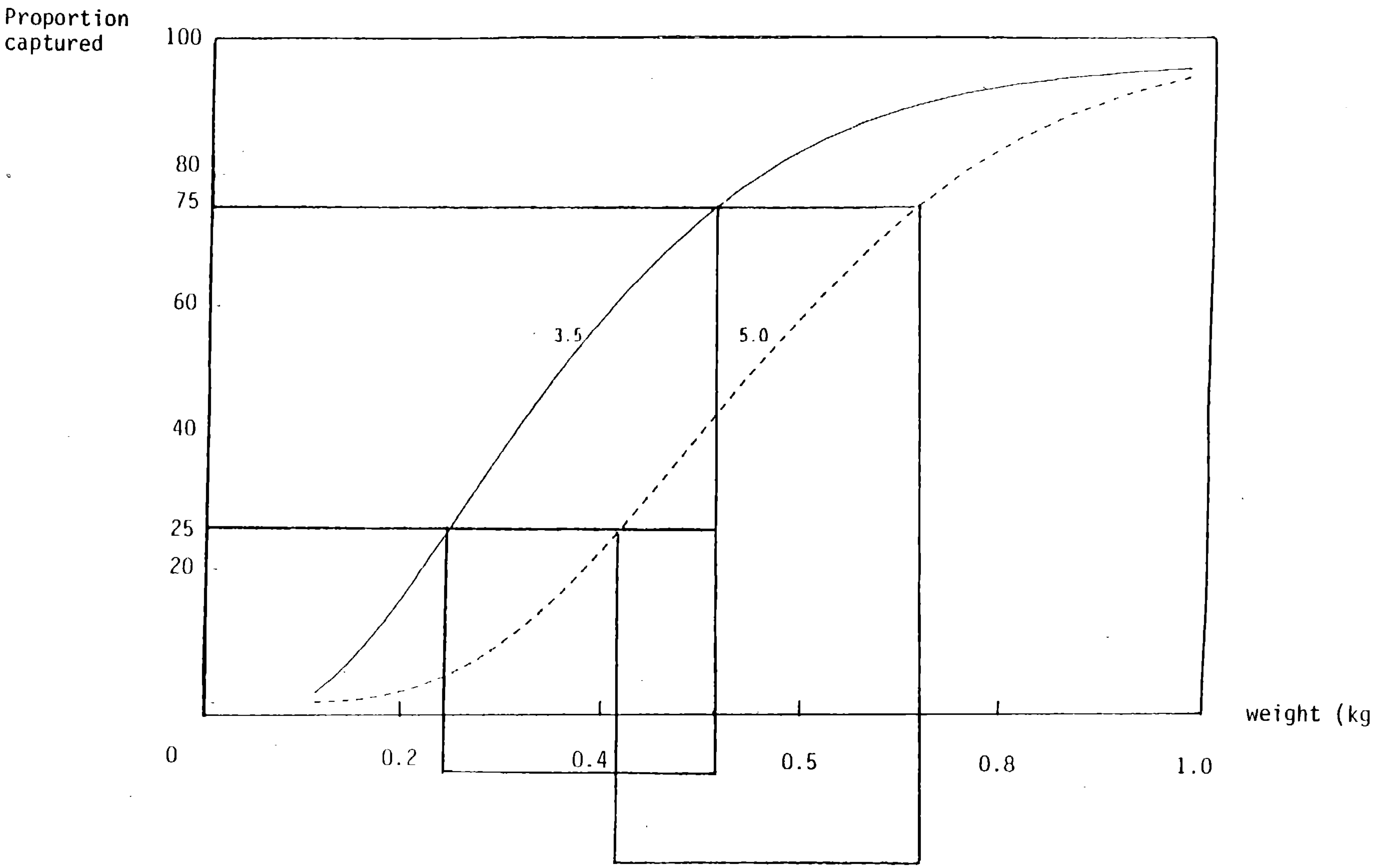

Figure 2-2.--Selection range for Dover sole by nets of 3.5-inch mesh and 5.0-inch mesh. Adapted from Kimura (1978) in Natural Resource Consultants (1986).

a small mesh cover is loosely placed over the codend to catch all fish escaping through the codend; and 2) parallel tows with small and large mesh codends (uncovered) to compare retention properties of both sizes. Parallel tows typically give higher selection factors than covered tows, probably due to the masking effects of covers which can prevent full escapement of fish from the codend.

Selectivity is also influenced by:

--Variations in measurement of net size due to different types of gauges, different gauge pressure, and different people employing the gauge.

--Escapement of fish from-sections of the net other than the codend.

--Net materials which differ in strength, flexibility, size, and configuration.

--Changes in the height of the headrope with changes in towing speed.

--Length of tow.

--Catch size.

--Length of the extension piece, the width of the codend, and the length of ground cables.

APPENDIX 3
EUMETRIC FISHING

The concept of eumetric fishing incorporates both mesh size and levels of fishing effort. Eumetric fishing consists of varying the mesh size as the level of fishing effort changes to select for a specified minimum size of fish. An increase in mesh size will increase the size of fish retained in the net. The immediate effect of varying mesh size is on yield. As mesh size increases, yield will decrease in the short run as the net becomes more selective. In the long run, however, yield is expected to increase with increased stock size as escaped fish are left to grow and spawn (Bell 1978).

The theory of eumetric fishing applies only to fish stocks with distinct year classes which grow at different rates over time. Individual fish grow first at an increasing rate, then at a decreasing rate as illustrated in Figure 3-1a. . Assuming the number of fish in each year class is constant, the total weight of the year class results from the net effect of the growth of individual fish and natural sources of mortality. As individual fish grow, natural mortality factors decrease the total weight of the year class. When the fish are young, the growth rate is expected to exceed the death rate leading to a net gain in weight for the total year class. Year class weight reaches its maximum at the "inflexion point" (a) of the individual growth curve, where growth changes from an increasing rate to a decreasing rate. As fish age, the death rate exceeds the growth rate and total year class weight falls (see Fig. 3-1b). According to the growth relationships illustrated in Figure 3-1 b, a mesh size set to select individual fish of size I, will result in the maximum physical yield (Y_2) from this year class over time (Anderson 1977).

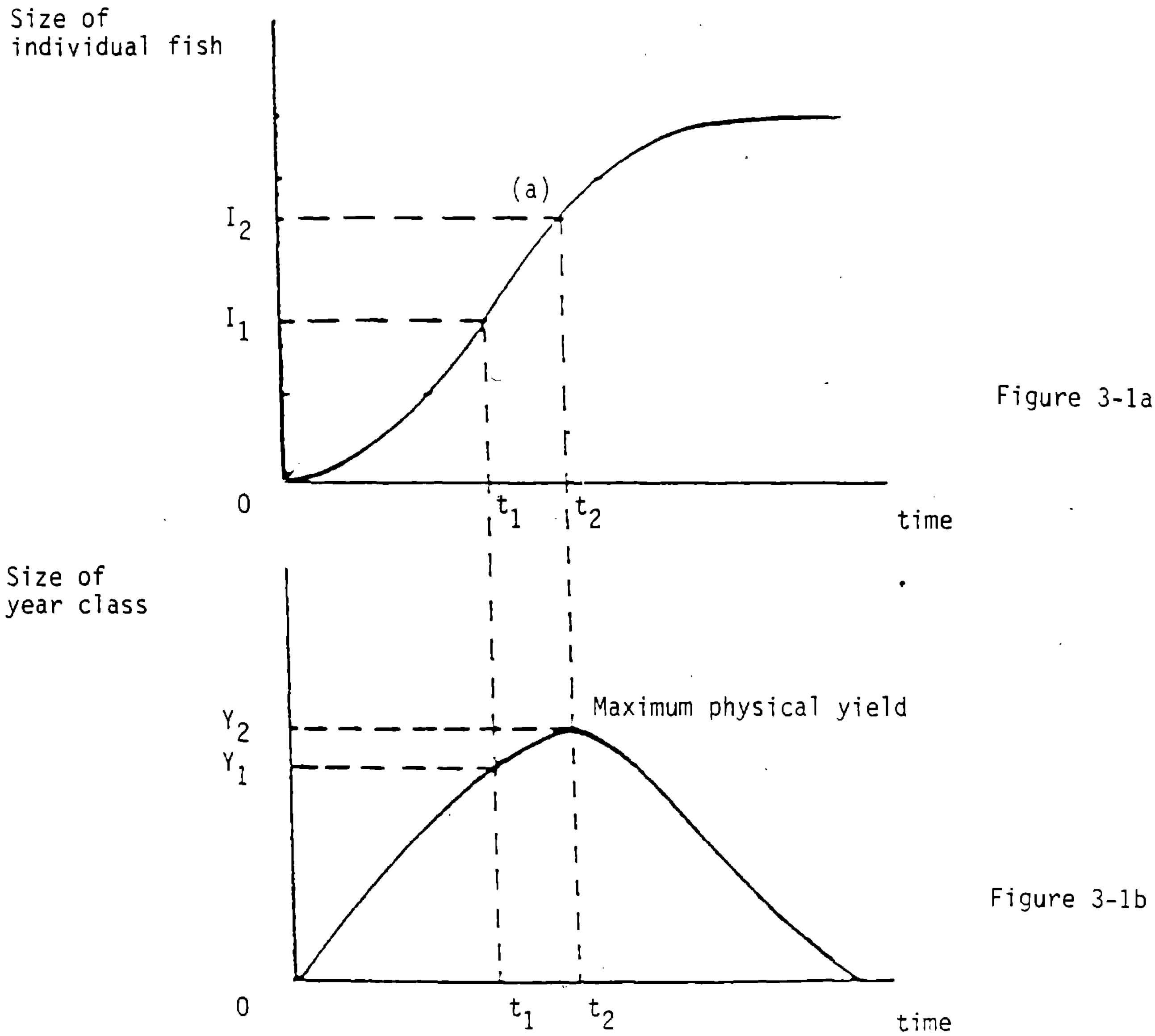

Figure 3-1 .--Growth curves for individual fish and a year class.
Source: Adapted from Anderson 1977.

(a) identifies the inflexion point.

Yield from the fishery also varies with the level of fishing effort. A separate sustained yield/effort relation is associated with each mesh size. Yield curves for various mesh sizes differ because of the different age of fish at recruitment (capture). As mesh size is increased, the age (size) of the fish selected also increases. As illustrated in Figure 3-1, if minimum mesh size is set so that fish smaller than I, escape, sustained yield from this year class can reach Y,. If mesh size is increased so that fish smaller than I, escape, sustained yield can reach level Y,. The increase in sustained yield from an increase in mesh size results from the increase in total year class weight as released fish mature. Growth rate is expected to exceed natural mortality for this size of fish (Anderson 1977).

An increase in mesh size can result in increased yields over some range of fishing effort. Figure 3-2 illustrates the relation between fishing effort and yield from all year classes using meshes of different sizes (Bell 1978). A separate yield curve is drawn for each mesh size, ranging from size 1 (smallest) to size 6 (largest).

For a given mesh size, a typical yield curve increases, reaches a maximum, and then decreases as effort increases. Figure 3-2 shows that for mesh size 1, yield decreases once effort levels exceed E,. If effort increases beyond level E,, yield will increase only if mesh size is increased. Yield is maximized for the fishery using a mesh of size 4 and effort level E_2. Increasing the mesh size above size 4 will not increase yields to the fishery above maximum sustained yield (Y_{MSY}). However, if effort is between levels E, and E,, increasing mesh to size 5 will result in higher yields than will be possible with a mesh of size 4. Similarly, for effort levels above E_4, mesh size 6 gives higher yields than mesh size 5.

Natural mortality factors such as disease or predation combine with fishing mortality to contribute to decreasing yields. In addition, as mesh size increases, at some point it becomes large enough to be ineffective at retaining catch (Beverton and Holt 1957).

As Figure 3-2 illustrates, if yields are below the maximum sustained yield, an increase in fishing effort results in corresponding increase in yields. Once effort has exceeded the level corresponding to maximum sustained yield, increases in mesh size will be necessary to maintain yields at a given level if fishing effort continues to increase.

Fishery management based on controlling the catch through adjustment of mesh size is called eumetric management. Eumetric management proceeds through the adjustment of two components of fishing activity: fishing mortality 4 and age of fish recruited (Beverton and Holt 1957). Adjustments are made to changing levels of fishing effort by changing the selectivity of the gear.

The yield of fish resulting from combinations of various mesh sizes and different levels of fishing effort is called the eumetric yield. The eumetric yield curve is the curve enveloping the maximum points of all the yield/effort curves, the dashed line in Figure 3-2. It represents optimal combinations of mesh size and fishing effort. The maximum of the eumetric yield curve is the maximum sustained yield for the fishery (Y_{MSY}). Eumetric yield generally refers to physical yield measured in weight of fish.

Economic yield is measured in net revenues (profits) to the fleet or the industry. Net revenues incorporate the costs of catching fish as well as the revenue earned from the sale of fish. Economic yield could also include benefits to consumers as well as producers. -The economic eumetric yield curve resulting from various mesh sizes will not necessarily take the same shape as the physical

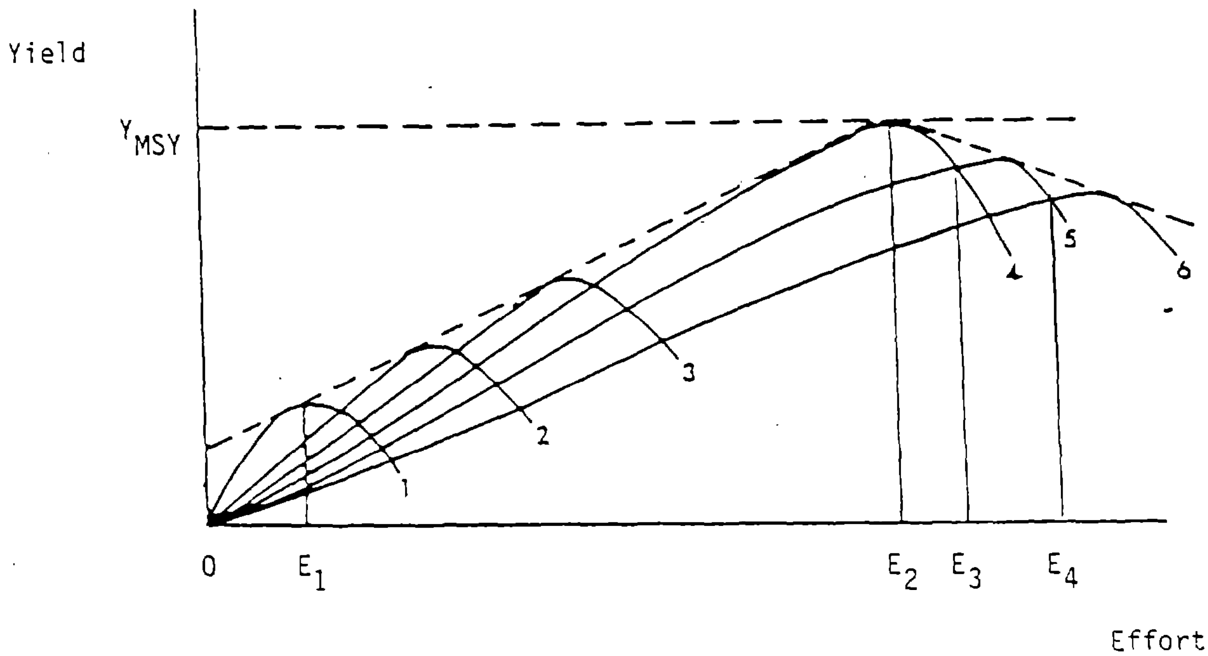

Figure 3-2.--Eumetric yield curve. Source: Adapted from Bell 1978.

yield curve. For a single-species fishery, the economic eumetric yield will depend on the relationship between fish size and fish price and the cost of effort. Preference for a particular size of fish may lead to a large difference in price between sizes (e.g., sablefish) which will mean that economic yield may not coincide with physical, yield. Differences in costs for various levels of effort may also lead to a divergence between physical and economic yield.

For a mixed-species fishery the situation is more complex. Species with different body types (e.g., round, flat) have different selectivities. Revenues earned by the mix of species and size of species retained by the gear will depend on both the size/price relationship of each species in the mix and the contribution of each species to the total mix. A strong preference for some species in the mix over others, reflected in large price differentials, will result in an economic yield curve that is distinct from the physical yield curve.

Whether eumetric management is based on physical or monetary yield depends on the management goal. If the management goal is to maximize sustained physical yield (MSY), eumetric management will consist of choosing a mesh size consistent with the level of fishing effort that will maximize the weight of each year class recruited (captured) into the fishery.

If the management goal is to maximize sustained economic yield (MEY), eumetric management will consist of choosing the mesh size consistent **with the** level of effort that will maximize the net revenues earned from each age class recruited into the fishery. If very large fish are preferred by consumers, eumetric management for MEY may require a larger mesh size than that consistent with MSY.

Using eumetric management to maximize earnings from the fishery involves a tradeoff over time. Management has a series of options related to the level of catch in any one time period. Simply put, the fishery can take more now and fewer later, or fewer now and more later.

Fish that escape from a net are expected to grow to maturity, spawn, and recruit into the fishery at a later time. For this tradeoff to make good economic sense for the fishery, the expected earnings from larger fish caught at some future date must exceed the earnings that could have resulted from the capture and sale of those fish in the current time period. More precisely, it is not just the future earnings from larger fish that must exceed the current earnings from smaller fish, but the present value of those future earnings as they are expressed in current dollars (see Appendix **4** for an explanation of present value of earnings).

Eumetric fishing has both economic and biological effects. Biological effects include the size of the spawning population and the size of the fishable stock. Economic effects include the different levels of revenues earned by different sizes or mixes of catch and the distribution of those revenues over time. The theory of eumetric management assumes that enough information is available concerning both biological and economic effects of different mesh sizes and levels of fishing effort to make reasonable management decisions.

APPENDIX 4
THE PRESENTVALUE OF INCOME

The idea of present value of money is a simple one: a dollar earned today is more valuable than a dollar to be earned in the future. A dollar earned today can' be invested, and can earn interest into the future. The present value of future earnings is the amount of earning discounted by the rate of interest that could be earned by that money if it were available now. If money can earn 5% per year then the value of future earnings is discounted by 5% per year to a present value.

When we talk about the discounted present value of a stock of fish, we are talking about expected future earnings from the stock. We are also implicitly talking about a tradeoff. The tradeoff is between fish caught now versus catch in some future period.

Take sablefish as an example. Say we can harvest 1,000 Ibs. of small sablefish now and earn $260 (1,000 Ibs. @ 0.26/lb.) in ex-vessel revenue. The alternative is to not harvest the small sablefish but to wait 3 years until they have reached large size and then harvest. Assume that we can expect the sablefish stock to increase at a net rate of 3% per year, allowing for the balance of the two effects of growth and natural mortality. At the end of the 3-year time period we can with fair certainty expect to harvest 1,093 Ibs. of large sablefish and earn $820 (1,093 Ibs. @ 0.75/lb.) in ex-vessel value.

If we had harvested the small sablefish and invested the money at 5% per year, at the end of 3 years we would have $301. The discounted present value of waiting to harvest large sablefish is the ex-vessel revenue earned by the large sablefish, $820, discounted by 5% per year, or $708. If our goal is to maximize earnings, the economic sense of harvesting small sablefish now or harvesting large sablefish later depends on the current value of the harvest of small sablefish compared to the discounted present value of the harvest of large sablefish. In this case, the future harvest of large sablefish has the greater present value.

Which harvesting strategy will have the larger present value will always depend on the relative magnitudes of the growth rate of the stock, the discount rate, the price differential by size if it exists, and the level of certainty about the future availability of fish left to grow.

The above discussion is presented to illustrate the concept of present value. Because it discusses sablefish in isolation from other species, it is an unrealistic example. In fact, sablefish is commonly caught by trawl gear in conjunction with Dover sole and thorneyhead rockfish (*Sebastolobus* spp.). Each species is an important component of revenues earned from the mix. A realistic calculation of the present value of future harvests would include all species caught together.

It is possible that given a relatively slow rate of growth in stock size, a relatively high interest rate on invested income, and small price differential by size the fish will be more valuable harvested in the present. The choice is, between investing monetary income and investing in fish.

A side note: the presence of extreme uncertainty about the future availability of a fish stock for harvest will increase the rate at which the value of future harvest is discounted. That is, expected future earnings are worth less relative to current earnings when there is uncertainty about their availability.

APPENDIX 5
SELECTED BIBLIOGRAPHY OF REFERENCES RELATED TO GEAR SELECTIVITY AND GEAR REGULATION

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