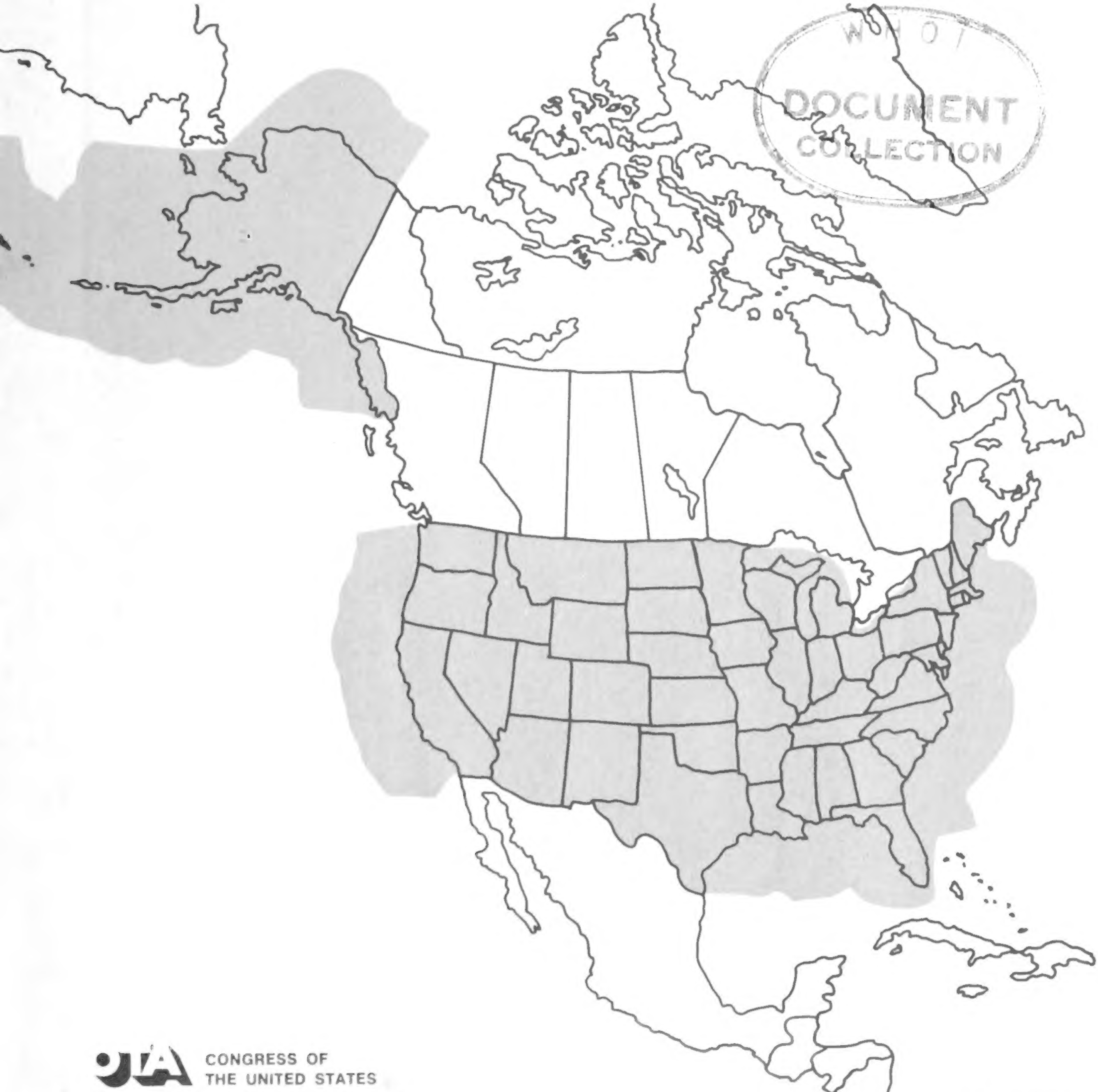
Working Papers

Establishing a 200-Mile Fisheries Zone

(Implementation of the Fishery Conservation and Management Act of 1976)



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Working Papers
Establishing a 200-Mile Fisheries Zone
(Implementation of the Fishery Conservation and Management Act of 1976)

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FOREWORD

The six working papers included in this document contain background data and detailed analysis prepared for the Office of Technology Assessment in the course of its study of problems and opportunities that may be encountered in establishing a 200-mile fisheries zone for the United States and implementing other provisions of the Fishery Conservation and Management Act of 1976.

These working papers do not represent a complete bibliography of materials used by the assessment staff during its study. Interviews and other published data were also used and these are cited in the footnotes to the Assessment Report. No attempt has been made here to reproduce such material, much of which is available through established information channels.

The OTA analysis found that most of the problems and opportunities of establishing a 200-mile fisheries zone relate to: 1) the need for new types of data which will be required to draw up and maintain fishery regulations and management programs, and 2) the need for new enforcement techniques and equipment to be used by agencies responsible for patrolling the zone.

These subjects are discussed in detail in the Assessment Report, a separate document which summarizes the OTA findings and recommendations. That document, entitled "Establishing a 200-Mile Fisheries Zone," is for sale for $2.45 through the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

A third document, containing classified portions of the discussions about remote sensing technology as an enforcement tool, has also been prepared.

List of Working Papers

Working Paper No. 1	Economic Data Needs in Fisheries Management Under Extended Jurisdiction by John M. Gates
Working Paper No. 2	Social Data Needs in Fisheries Management Under Extended Jurisdiction by James M. Acheson University of Maine
Working Paper No. 3	Marine Fisheries Stock Assessment: Issues and Needs by Development Sciences Inc.
Working Paper No. 4	A Short Analysis of Stock Enhancement Possibilities for Certain Commercially Important Marine Species by John Vernberg University of South Carolina
Working Paper No. 5	Survey of the Potential of Remote Sensing Technology to Support Enforcement of the 200-Mile Fishing Zone by Stanford Research Institute

Working Paper No. 1

ECONOMIC DATA NEEDS
IN
FISHERIES MANAGEMENT UNDER EXTENDED JURISDICTION

Prepared for OTA
by
J. M. Gates, Ph.D.

September, 1976

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ACKNOWLEDGMENTS

The author is indebted to the many individuals in Federal and State agencies who were most helpful in their suggestions for this report. Special thanks are due to R. Siegel and B.G. Thompson of the National Marine Fisheries Service, Washington, D.C. This report would not have been possible without the assistance of A. Holmsen, V. Norton, K. McConnell and W. Jensen who served as consultants.

LIST OF TABLES

INTRODUCTION

Working Paper No. 1 is a survey of the economic data which will be needed in order to implement The Fishery Management and Conservation Act of 1976.

The paper presents a broad background to the subject, including an analysis of the problem and the economic information implications of theAct as it applies to domestic commercial and recreational fisheries and foreign fisheries. It also looks at the existing information base compiled largely by the National Marine Fisheries Service of the U.S. Department of Commerce and analyzes how that data is deficient for new needs outlined in the Act.

(It should be noted that the National Marine Fisheries Service recently has made several organizational changes which are not specifically covered in this paper. These organizational changes have not, to date, however, effected the findings in this paper regarding deficiencies in the current fisheries information base.)

Also included in the paper are a series of data collection tasks and a rough estimation of the funds necessary to carry out such tasks. Excerpts from reviewers substantive comments are included at the end of the paper.

I. BACKGROUND

A. The Problem

The Fisheries Conservation and Management Act of 1976 is potentially the most significant institutional change in the history of U.S. fisheries management.[1] Under the provisions of the Act, regional management councils are created with broad authority to recommend fisheries management plans to the Secretary of Commerce for approval and implementation.

The Act specifies certain broad national standards and purposes, including fisheries development and management for "optimum sustainable yield" (OSY),* which are to be pursued. The exact meaning of OSY will presumably evolve over time through the decisions of Regional Councils; but is to reflect maximum sustainable yield as modified "by any relevant economic, social or ecological factor" (Section 3(18)). In conjunction with congressional testimony and statements of Congressional intent it is clear that Congress intended implementation of the Act to reflect economic factors. In order to do this it is imperative that certain minimal economic information requirements be defined and measures implemented to ensure that they are met as soon as is practicable. The objectives of this Report are:

1. to identify economic information requirements under the Act;
2. to describe the current economic data base;
3. to specify additional data needed to meet the requirements identified in objective 1;
4. to project program costs to acquire the data identified in objective 3.

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[1] 94th Congress, H.R. 200, Public Law 94-265, April 13, 1976. Hereafter, the Fisheries Conservation and Management Act of 1976 is referred to simply as "the Act."

*Throughout this paper, the author refers to "optimum sustainable yield" rather than the term "optimum yield" as used in the Act. This is to emphasize that allowable catch is to be taken without future depletion of parental stocks.

B. Scope of the Report

The scope of this Report is limited in several ways. First, it is restricted to economic information requirements; it does not consider biological, ecological or sociological information needs. Second, it does not attempt to specify all economic data needs; only those which can be directly related to the information requirements of the Act. Third, the Report focuses on the additional economic data needs of the New England and Pacific Regional Councils.[1] This geographic restriction was necessitated by available time and personnel.

The Report does not address conceptual or modeling issues. While very real issues do exist in these areas, a more pressing problem with fisheries is that the economic data base is inadequate to implement even the simplest models or to permit empirical tests of concepts and models.

Finally, the Report addresses long run issues and is not concerned with the immediate economic data needs for formulating Preliminary Management Plans (PMP). Thses plans must be completed in such a short time horizon that there is little that can be done to augment the existing data base in time for its inclusion in the Preliminary Management Plans.[2] Given the restricted scope of this Report, it should be recognized that it is not a comprehensive statement of economic data needs in U.S. fisheries policy.

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[1] In the interest of simplicity the terms "New England" and "Pacific" Fisheries will be used to denote fisheries under the New England and Pacific Regional Councils, respectively.

[2] Section 201(g) of the Act specifies that the Secretary of Commerce shall prepare Preliminary Management Plans for fisheries in which foreign participation has been requested and for which no fishery management plan will be prepared by the Regional Councils before March 1, 1977.

It is rather, one component of the Fisheries Technology Assessment Project of the Office of Technology Assessment, U.S. Congress.

C. Methods and Procedures

As indicated earlier, the Act requires that economic factors be reflected in fisheries development management and conservation. In order to include economic factors the Councils must have access to certain minimal economic information. This Report contains an interpretive analysis of the Act in terms of what these informational requirements are expected to include. The current economic data base is then described and compared with needs to identify data deficiencies and program needs. Visits were made to Washington, D.C., and Regional Offices of the National Marine Fisheries Service and to several State Capitals to obtain descriptions of current economic data bases through interviews with appropriate Federal and State personnel. In these interviews an attempt was made to elicit opinions with respect to the subject of data needs as well as descriptions of the status quo.[1]

D. Economic Information Implications of the Act

The discussion below attempts to define certain information implications of the Act in very general terms. More specific discussion of data needs is deferred to Section III of this report.

D.1. Commercial Fisheries

(a) Domestic

(i) Optimum Sustainable Yield (Section 2(b)(4))
(Section 3(18)(A) and (B))

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[1] A list of individuals and agencies contacted is contained in Appendix B of this Report.

These sections specify that among the purposes of the Act is the achievement of optimum sustainable yield (OSY) from each fishery. OSY is defined as: (1) the amount of fish which maximizes national benefits and (2) as maximum sustainable yield (MSY) as modified by relevant economic social or ecological factors.

The implication of these sections is that the information base available to the Councils must be adequate to permit determination of OSY. The required biological data would include sustainable yield relationships and the rate of stock replenishment in response to incremental surpluses of sustainable yield over catch. The economic data requirements would include cost and returns, price projections and regional employment considerations for a range of management options. Whenever management plans will cause variations in the quantities of fish which reach markets, these plans will have impacts on prices and hence on incomes of people employed in the various sectors of the fishing industry. These price effects can be projected through price and market structure analyses. The direct impacts of changes in landings and prices can also induce changes in expenditures and employment in other sectors of the economy; especially those with strong linkages to the fishing industry. These induced or secondary income and employment effects can be important; especially from a regional viewpoint.

(ii) National standards for fishery conservation and management

Section 301 specifies broad national standards for fishery conservation and management. Among these are consideration of economic concentration in the harvest sector if domestic allocation schemes are implemented, and promotion of efficiency. Consideration of efficiency requires a formal integration of biological and economic concepts and an adequate data base to express these concepts in quantitative terms. The economic data required include cost and earnings information by vessel and gear type, demand relationships and the potential non-fishing employment and earnings opportunities of fishermen.

(iii) Fisheries development

Sections 2(a)(7) and 2(b)(6) express the intent of Congress to encourage development of fisheries not utilized or underutilized by U.S. fishermen. Thus, the Act is concerned with fisheries development as well as with conservation and management of stocks on which established fisheries are based. The information implications of fisheries development differ in certain respects from those of fisheries management. For fisheries management, many decisions are repetitive and most information needs are therefore continuous to permit effective monitoring of economic variables. This implies a continuing program for periodic collection of economic statistics for established fisheries.

Fisheries development decisions are more discrete or "one shot" in nature and since creation of an industry is the issue at stake there is no established industry for which economic statistics can be collected. Both fisheries development and fisheries management plans must involve an intensive and integrated examination of all facets of a potential fishery; resource assessment, harvest and processing technologies and costs, market potentials and institutional factors including artificial barriers to trade. While there is much similarity in the types of economic data needed, the absence of an established industry in many cases will force reliance on special studies to collect data and project economic effects of development.[1]

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[1] The most probable procedure may, however, frequently entail extrapolation of economic data for harvesting and processing sectors in established fisheries.

These studies become part of the bench mark data for management if the fisheries development effort is successful.

Fisheries development efforts are best viewed as special purpose studies, the details of which must be dictated by the specific biological, technological, economic and institutional facts which exist at the time of the study. This is especially true when there is only a small number of fisheries with significant development potential. As will be discussed later, this is the case with U.S. fisheries. While the number of fisheries with significant development potential is not large, some of the underdeveloped fish stocks are quite large. For examples, the combined annual yields of the New England herring and mackerel stocks, Pacific hake and Alaskan pollock have been estimated at 5.6 billion pounds or 2.5 million metric tons.[1] To put these figures in perspective, note that the U.S. commercial catch of all species in 1975 was 2.2 million metric tons. Thus, at least in terms of physical or biological yields, the potentials of these stocks are quite significant; being of the same magnitude as total U.S. commercial landings of all species in 1975.

(b) Foreign

(i) Foreign allocation

Section 201(d) specifies that the foreign catch allocation of any fishery covered by the Act shall be that portion of OSY which will not be harvested by U.S. vessels. Thus, the foreign allocation is to be a residual after projection of domestic catches. Domestic catches depend, however, on new investments which are influenced by the economic returns of

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[1] The reader is cautioned that yield estimates are often very imprecise; especially for undeveloped fisheries where little data has been collected.

fishermen. These catches, therefore, cannot be reliably projected without a knowledge of the cost and revenue relationships of the U.S. fleets. In addition to the normal free-market forces which impinge on them, there are various domestic and foreign policies which affect cost and revenue relationships. Among these are vessel construction subsidies, marketing programs, fisheries development policies and trade barriers to U.S. exports.

(ii) Conditions of access for foreign vessels

Section 204(b) specifies the terms under which foreign fleets may fish in waters under U.S. jurisdiction, including mandatory information which must be supplied by such fleets and a residual clause covering "any other pertinent information and material which the Secretary may require."

Foreign fleets employ harvest technologies which differ in varying degrees from those employed by U.S. fishermen. Some of these differences include vessel construction, vessel size, and gear characteristics. Given the physical data collected for management purposes it may be possible to measure technical efficiency by analysis of variances in catch per unit effort. Indices of technical efficiency are, however, only one of the components which affect cost and earnings. For economic analyses, data would have to be compiled directly on major inputs and costs of foreign fleets. If this information is collected, it should be reported in a form which permits isolation of operating costs in transit to waters under U.S. jurisdiction vs. operating costs while in such waters. It should also include information on capital construction costs and foreign subsidies.

Economic information on foreign fleets is of importance where the fish harvested affect international trade of U.S. importers or exporters. On the import side fish may be caught in U.S. waters, processed in a foreign nation and exported to U.S. markets with obvious implications for domestic prices, employment and incomes. A more subtle import market effect may also take place. Let us assume that a foreign nation has inventories of fish products produced partly from fish caught in U.S. waters and partly from waters outside U.S. jurisdiction. Foreign suppliers could fill U.S. import demands with products produced from fish caught outside U.S. jurisdiction and satisfy their own domestic demands or other world markets with fish caught from U.S. waters. Note here, that identical species are not necessary for this type of market substitution. All that is required is that the fish be close substitutes in meeting final product demands.

Under these circumstances the foreign nation could claim, correctly, that the fish captured in U.S. waters are not entering U.S. markets. Note however that by using U.S. fish to satisfy its domestic and other world markets, the foreign nation is able to allocate other stocks to U.S. markets. The end effect in U.S. markets is the same as if the U.S.-caught fish had been directly exported to U.S. markets.

In terms of U.S. exports, domestic exporters must be able to deliver products at prices competitive with foreign producers. One of the factors affecting the competitive status of domestic exporters is the level of subsidies received by foreign fleets and/or processors. Thus, to assess the international trade aspects of U.S. fisheries, information on the economics of foreign fleets operating in U.S. waters may, in some cases, be necessary.

It is important to recognize that this is a very complex area because of the complex social accounting problems involved in sorting out costs and returns of foreign fleets. Government intervention and subsidization is widespread and in some cases buried among more general social welfare policies.

Despite the complexities, it is an area which may have to be addressed. In international trade negotiations for example, offsetting tariff schedules can be invoked where foreign subsidization can be shown. This issue has arisen in the past but the existence and levels of foreign subsidies must be established to invoke such tariffs.

D.2. Recreational Fisheries

Sections 2(b)(3), Section 3(2) and Section 3(18) express Congressional purpose or intent with respect to recreational fisheries. Although the Act is conspicuously vague on details, it is clear that recreational uses are to be considered. In particular, the definition of OSY is to include recreational opportunities. Section 3(18) defines OSY so as to provide "the greatest overall benefit to the Nation with particular reference to food production and recreation." There is a substantial literature on recreational benefits; a subset of which deals with recreational fishing benefits. In general there are substantial conceptual gaps in measurement techniques which need exploration before one can devise a rational, comprehensive economic data collection system for recreational fisheries.

E. Species and Fisheries Most Likely Affected by the Act

E.1. Species

The resources most immediately affected by the Act may be classified by species or type of gear and vessel used for its harvest. The species or species group classification is most relevant for biological data collection and research. Appendix Tables A.1 and A.2 list the species which are likely candidates for management plans under the New England and Pacific Councils, respectively. These species are candidates at least for preliminary management plans under Section 201(g) of the Act. It is assumed that the Councils will continue these plans, with modifications, and will, in all probability, add other species to the list.

E.2. Fisheries

In most cases it is not possible to define fisheries, in economically relevant terms, based on species. This is because multiple species fisheries are involved. Provided gear or vessel modifications are not prohibitively expensive, the same vessel can be employed in fishing for several species. Indeed, in many cases the same vessel catches several species simultaneously. Marginal adjustments in the species composition are possible by altering fishing strategies or timing. Fundamentally, however, one must for economic purposes classify many fisheries by type of vessel and gear. Appendix Table A.3 provides such a classification for the New England and Pacific fisheries. As indicated in this table, the number of fisheries under this classification is much less than under a species classification scheme. It may be noted that these fisheries generally consist of aggregations of the species listed in Appendix Tables A.1 and A.2.

II. THE CURRENT INFORMATION BASE

A. National Marine Fisheries Service, Washington, D.C.

The two divisions of the National Marine Fisheries Service (NMFS) primarily responsible for the collection of economic data are the Economics and Marketing Research Division and the Statistics and Market News Division. These two divisions differ in terms of functions. The Statistics and Market News Division (SNMD) is specifically charged with the collection of data and preparing periodic statistical reports, of which the principal series are discussed later.

The Economics and Marketing Research Division (EMRD) is, as its name implies, oriented toward economic research and analyses which may be based in part or in total on the data base available from the SNMD. In addition, the EMRD collects data of its own as needs may dictate. Various publications of the EMRD may reflect either or both data bases. For the purposes of this report the functional distinction between these two divisions can therefore be ignored and a common data base assumed. A recent decision to phase out the EMRD is worth noting at this juncture. In view of the new economic information requirements under the Act, this decision raises questions about the sources of data and analyses to meet these requirements.

The NMFS collects, either directly or from state agencies, data on the landings by species, value, area of capture, depth, fishing effort and days absent from port for each vessel trip in the New England offshore fisheries. These data are stored on computer tape and are available at the Northeast Fisheries Center, Woods Hole, Mass., and at the Washington, D.C., office of the SMND. This data series is used to compile the Maine, Massachusetts and Rhode Island Bulletins (see below). Similar data are collected on the Gulf of Mexico shrimp fishery and are stored on magnetic tape and used in preparing the two shrimp bulletins (see below).

The NMFS collects and publishes several series of direct interest for fisheries management. These include the following:

1. Commercial Fisheries Data

    a. Current Fishery Statistics (CFS) Series

        (1) Commercial Landings by States

        This series is issued for each state as a preliminary bulletin on commercial landings by species. They are issued monthly and annually for Atlantic and Gulf Coast states. They do not cover the Pacific Coast states or Alaska. The data reported include catch by species by month and landed value by species by month.

        (2) Regional Summaries

        These are sectional summary bulletins which are published later in Fishery Statistics of the U.S. (Statistical Digest) in somewhat more detail and with a text. The regions covered in this series are New England Fisheries, Middle Atlantic Fisheries, Chesapeake Fisheries, South Atlantic Fisheries, Gulf Fisheries, Hawaii Fisheries, Great Lakes Fisheries and Mississippi River Fisheries. The data contained in these bulletins are annual data on U.S. commercial landings, fishermen and operating unit data (catch by gear type), and production of processed products by States.

        (3) Processing Sector and Foreign Trade Bulletins

        This series includes various bulletins which report on a monthly, quarterly and/or annual basis such processing sector data as freezings and holdings, canned products, fish sticks and portion, imports and exports of fishery products and data such as employment and output by product in the processing sector.

        (4) Fisheries of the United States

        This series is published annually as a preliminary report on the fisheries of the U.S. It is designed to provide timely information; more complete information is contained in Fishery Statistics of the U.S. (see below). The latter publication is typically two years late in publication.

        (5) Fishery Statistics of the United States

        These annual reports contain reviews of fishery statistics including data on volume and value of landings of fishery products, employment, quantity of gear operated, number of fishing craft employed, volume and value of processed fishery products, freezing and cold storage holdings and foreign trade. Although published annually, there is a lag of about two years between data collection and publication.

b. Historical Statistics

This series is published sporadically to summarize historical data. The latest in this series is "Prices Received by Fishermen, 1939-74."

c. Current Economic Analysis Series

This series of publications contains analyses of prices for commercial fishery products. Included in this series are:

i. Shellfish Market Review and Outlook
ii. Food Fish Market Review and Outlook
iii. Industrial Fishery Products Market Review and Outlook

d. Basic Economic Indicators

This series of statistical reports contain demand analyses, domestic production employment, fishing effort, biological stock assessment, U.S. trade, etc., for certain species. These include American and Spiny Lobster, Atlantic and Pacific Groundfish, Blue Crab, Clams, Halibut, King and Dungeness Crabs, Menhaden, Oysters, Salmon, Scallops, Shrimp and Tuna. Their utility stems from the fact that they summarize a great deal of data on a species or fishery basis. These data are available elsewhere but assembling them on a species basis can be time-consuming and tedious.

e. Market News Report

This series gives current market intelligence data for selected cities in the U.S. The cities covered are Boston (Blue sheet), New York (Green sheet), New Orleans (Goldenrod sheet), and Seattle (Pink sheet). This series contains data on landings, market receipts cold storage holdings, ex-vessel prices, wholesale prices, foreign trade data, and current market developments. It is issued tri-weekly with a weekly summary on a subscription basis ($35 per year). This series at one time was summarized and monthly and annual summaries were published. Due to budget reductions, these summaries are no longer done and few users can devote the requisite time to prepare their own summaries. A few larger companies which have electronic data processing capabilities do prepare such summaries for their proprietary use.

f. Market News Message Centers

Recorded current market information is available around the clock at message centers in Boston, Chicago, Gloucester, Mass., New Bedford, Mass., Hampton, Va., and New York City.

2. Recreational Fisheries

a. Current Fishery Statistics (CFS) Series

(1) Marine Recreational Fishing Statistics

This series is published on an irregular basis. The information included in this series is numbers of participants in marine recreational fishing by state of residence and coastal area fished, marine recreational catch of finfish by species and region and expenditures by marine fishermen by year and by coast. The data series involved are several and the frequency rather erratic beginning in 1955 with the National Survey of Fishing and Hunting by the U.S. Department of the Interior. This series was updated with re-surveys in 1960, 1965 and 1970. In 1960, 1965 and 1970, the National Marine Fisheries Service (Commerce) and the Fish and Wildlife Service conducted salt water angling surveys. Excluded are recreational catches of crustaceans, mollusks and other invertebrates which are significant quantities in some coastal areas.

(2) Participation in Marine Recreational Fishing, Northeastern United States 1973-74: Current Fishery Statistics No. 6236

A more complete report of results from the survey on which this report was based is currently undergoing an internal editing process prior to its publication. A survey similar to the Northeast survey was conducted for the Southeastern and Gulf States and will probably be available about September 1976. Plans call for a similar Pacific Coast survey and a national sampling program in the future.

The published data series just described are in many cases likely to be of limited value to the Regional Councils because of the time lag between collection and publication. One of the most useful series on economic data would be the Basic Economic Indicators, if completed for each fishery to be managed, and maintained in an up-to-date status. Unfortunately the decision to eliminate the EMRD places the future of this series in limbo.

The NMFS collects more data than are reflected in the publications just described. In the discussion which follows some of these data are described briefly. Most of these data are accessible with varying degrees of ease. Some appear in the publications series and are readily available but with a lag. Others exist on computer tapes or on market report sheets and are not likely to be useful to the Regional Councils in that format. The data series collected are retail, wholesale and ex-vessel price data, production and cold storage holdings, import-export data, landings, and some foreign statistics. Retail price data for major products in New York are collected (Table 1). The frequency of these data on retail prices varies somewhat. Most are compiled on a monthly basis; some are compiled weekly. The base period for these data varies somewhat from 1949 for flounder fillets to 1973 for others.

Wholesale price data are also collected for selected fish products on a monthly basis, and for many products, on a weekly basis. The base period for the data series varies from 1947 for oysters to 1974 for canned King Crab (Table 2).

Ex-vessel price data are generally compiled on a monthly basis for base periods ranging from 1950, for Ocean Perch, to 1974 for certain shrimp series (Table 3).

Production and Cold Storage holdings for many fish products are compiled on a monthly basis for base periods which range from 1939 for scallop cold storage holdings to 1971 for certain crab species (Table 4).

Import-export data for various fish products are collected from the Bureau of Customs and are compiled on a monthly basis for base periods ranging from 1939 for Maine lobsters to 1965 for Anchovy (Table 6).

A limited amount of foreign statistics is available (Table 7). As indicated in this table, the series are limited to crustaceans (specifically lobsters and shrimp), scallops and Peruvian meal prices.

For many fish products current landings and imports are only partial market indicators because of changes in cold storage stocks. Because of this, series have been prepared on supply, utilization and stocks for selected fish products (Table 8). These series are compiled monthly and yearly for base years ranging from 1950 to 1965.

Table 1

Retail Price Data for Selected Fish Products

Product	Frequency		Base Period
	Weekly-	Monthly	
Cod Fish fillets N.Y.	x	x	1962
Cod Fish steaks N.Y.		x	1962
Crab, Blue		x	1949
Crab meat	x		1971
Flounders, drawn N.Y.	x	x	1950
Flounder fillets N.Y.	x	x	1949
Haddock		x	1960
Haddock fillets N.Y.		x	1953
Halibut steaks N.Y.	x	x	1960
Oysters	since 1968 x	x	1950
Salmon steaks N.Y.		x	1967
Scallops		x	1950
Shrimp		x	1960
Whiting H & G N.Y.	x	x	1951
Raw Frozen:			
Cod fillets	x		1973
Flounder fillets	x		1973
Haddock fillets	x		1973
Halibut steak	x		1973
Ocean Perch fillets	x		1973
Turbot fillets	x		1973
Whiting fillets	x		1973
Shrimp, peeled and deveined	x		1973
Shrimp, raw and headless	x		1973
King Crab meat	x		1973
Lobster tail	x		1973
Canned Fish:			
Salmon, series for Chum, Pink and Red	x		1973
Sardines, series for Maine and Norway	x		1973
Tuna, series for chunk light and solid white	x		1973
Canned Ham:	x		1973
Fresh Fish:			
Bass (rd)	x		1973
Butterfish (fl)	x		1973
Cod (fl)	x		1973
Croaker (fl)	x		1973
Flounder (fl)	x		1973
Grouper (fl)	x		1973
Haddock (fl)	x		1973
Mullet (rd)	x		1973
Ocean Perch (fl)	x		1973
Red Snapper (fl)	x		1973
Rockfish (fl)	x		1973
Salmon (sk)	x		1973
Shad (rd)	x		1973

Table 1 -- continued

Product	Frequency Weekly-Monthly	Base Period
Fresh Fish: con't.		
Smelt (rd)	x	1973
Sole (fl)	x	1973
Whiting (fl)	x	1973
Processed:		
Breaded Shrimp	x	1973
Fish portions	x	1973
Fish sticks	x	1973

Table 2

Wholesale Price Data for Selected Fish Products

Product	Frequency		Base Period
	Weekly-	Monthly	
Anchovy Oil		x	1970
Anchovy Oil (Peruvian)		x	1964
Clams: Hard Clams		x	1959
Soft Clams		x	1950
Cod blocks		x	1960
Cod fillets		x	1958
Cod fish portions		x	1959
Cod fish sticks	x	x	1960
Crab: Blue Crab	x	x	1962
King Crab	x	x	1966
King Crab, canned	x	x	1974
Snow Crab	x		1968
Snow Crab, canned	x	x	1974
Flounder blocks	x	x	1970
Flounder fillets, frozen		x	1962
Haddock blocks		x	1958
Haddock fish portions	x	x	1959
Haddock fish sticks	x	x	1959
Halibut steaks	x	x	1958
Lobster, American	x	x	1959
Lobster tails		x	1960
Menhaden meal	x	x	1959
Menhaden oil	x	x	1959
Menhaden solubles	x	x	1959
Oysters since 1965	x	x	1947
Ocean Perch blocks	x	x	1958
Peruvian fish meal	x	x	1959
Pollock blocks		x	1960
Pollock fillets		x	1961
Pollock portions		x	1960
Salmon, canned, series for Alaska Red, Pink, Chum, Chinook, Coho		x	1960
Scallop, sea		x	1953
Shrimp		x	1960
Tuna, canned		x	1961
Tuna, raw		x	1961
Tuna and Mackerel meal		x	1972
Tuna and Mackerel oil	x	x	1972
Whiting, H & G	x	x	1955
Whiting blocks		x	1955

Table 3

Ex-vessel Price Data for Selected Groups of Species

Product	Frequency		Base Period
	Weekly	Monthly	
Clam, hard		x	1954
Clam, soft		x	1959
Clam, surf		x	1956
Cod		x	1958
Crab, Blue (hard)	x	x	1960
Cusk		x	1966
Flounder, 6 species		x	1960
Haddock		x	1958
Halibut		x	1960
Lobster, American (northern)		x	1939
Lobster, Spiny		x	1962
Ocean Perch		x	1950
Oyster		x	1960
Pollock		x	1966
Salmon, King		x	1960
Sardines		x	1959
Scallop		x	1939
Shrimp		x	1960
Shrimp	x		1974
Tuna		x	1952

Table 4

Production and Cold Storage Holdings for Selected Fish Products

Product	Frequency		Base Period
	Monthly-	Yearly	
Production			
Fish blocks and slabs	x		1959
Fish meal	x		1959
Fish oil	x		1959
Fish portions	x		1958
Fish solubles	x		1959
Fish sticks	x		1958
Canned Pack:			
Salmon		x	1960
Shrimp	x		1950
Tuna	x		1960
Cold Storage Holdings			
Crab, all	x		1948
Crab, Dungeness	x		1971
Crab, King	x		1971
Crab, unclassified	x		1971
Lobster tails	x		1950
Oysters	x		1950
Scallops	x		1939
Shrimp	x		1957

Table 5

Import-Export Data for Selected Fish Products

Product	Frequency Monthly	Base Period
Imports		
Blocks and slabs	x	1955
Clam	x	1960
Cod	x	1956
Crab	x	1966
Fish meal	x	1958
Fish oil	x	1960
Fish solubles	x	1959
Fish sticks and portions	x	1965
Flounder blocks	x	1964
Flounder, fresh and frozen	x	1956
Fresh and frozen fillets	x	1956
Freshwater fish	x	1966
Haddock blocks	x	1958
Haddock, fresh and frozen	x	1958
Halibut	x	1960
Lobster, live	x	1960
Lobster tail (Rock) (total and by country of origin)	x	1960
Lobster tail (3 product type series & country of origin)	x	1960
Ocean Perch	x	1956
Oysters (country of origin)	x	1960
Pollock, Cusk, and Hake and other blocks	x	1967
Saltwater fish (total)	x	1962
Salmon, canned	x	1957
Salmon, fresh and frozen	x	1956
Sardines, canned	x	1957
Scallops (by state of origin)	x	1960
Shrimp	x	1960
Tuna, canned	x	1955
Tuna, fresh and frozen	x	1955
Exports		
Crab, King	x	1970
Fish meal	x	1971
Fish oil	x	1959
Groundfish, fresh and frozen	x	1965
Salmon, canned	x	1960
Salmon, fresh and frozen	x	1960
Sardines	x	1966
Shrimp	x	1957

Table 6

Landings Data for Selected Species

Species	Frequency Monthly	Base Period
Anchovy	x	1965
Clam Landings (all)	x	1960
Hard clam (by state and total)	x	1960
Soft clam (by state and total)	x	1960
Surf clam (by state and total)	x	1960
Cod	x	1960
Crab, Blue	x	1960
Crab, Blue, Hard	x	1960
Crab, Dungeness	x	1960
Crab, King	x	1964
Crab, Snow (Tanner)	x	1967
Flounder	x	1960
Halibut	x	1960
Haddock	x	1958
Herring	x	1959
Jack Mackerel (California)	x	1962
Lobster, American (Northern)	x	1960
Lobster, Maine	x	1939
Lobster, Spiny	x	1962
Menhaden	x	1959
Ocean Perch	x	1950
Oysters (by state)	x	1960
Pollock, Cusk	x	1966
Salmon (by species and by port)	x	1964
Shrimp	x	1960
Tuna	x	1960

Table 7

Foreign Statistics[a]

Product		Frequency Weekly	Frequency Monthly	Base Period
Canada Lobster	(landings)		x	1960
Canada Scallop	(landings & cold storage holdings + prices)		x	1954
Lobster Tail	(wholesale prices)	x	x	1960
Peruvian Meal	(prices)		x	1959
Peruvian Meal	(production exports and stocks)		x	1962
Shrimp		x	x	1970
United Kingdom	(landings & wholesale scallop prices)		x	1970

[a] Includes items maintained by NMFS. In addition, foreign nations collect statistics for which NMFS does not maintain series but which can be obtained from the respective nations if needed.

Table 8

Supply Utilization and Stocks

Product	Frequency Monthly	 Yearly	Base Period
Blocks and slabs	x	x	1955
Cod, fresh and frozen	x	x	1960
Fillets and steaks	x	x	1954
Flat fish, fresh and frozen	x	x	1950
Flat fish fillets, fresh and frozen	x	x	1950
Haddock, fresh and frozen	x	x	1950
Haddock fillets, fresh and frozen	x	x	1950
Halibut, fresh and frozen	x	x	1950
Halibut fillets and steaks, fresh and frozen	x	x	1950
Ocean Perch, fresh and frozen	x	x	1960
Ocean Perch fillets, fresh and frozen	x	x	1960
Lobster, Spiny	x	x	1965
Lobster, Tails	x	x	1950
Oysters	x	x	1960
Salmon, canned	x	x	1950
Sardines, canned		x	1950
Scallops	x	x	1951
Shrimp	x	x	1950
Sticks and portions	x	x	1958
Tuna, canned		x	1950

The data series referenced in Tables 1 through 8 are accessible. A problem is likely to exist, however, in terms of the ease of accessibility and the utility to Regional Councils, as opposed to researchers, of the information in its current format. The information should be assembled in a useful format and on a timely basis. An excellent medium for this would be the Basic Economic Indicators series referenced in Section IIA of this report. This series should be extended and maintained in an up-to-date status.

A limited number of costs and earnings studies exists. These studies have generally been based on special purpose or "one-shot" surveys or are not representative. For example, vessels constructed under the Federal Vessel Construction subsidy program are required to supply such data to NMFS. Such data cannot be presumed representative of whole fleets of rather heterogeneous vessels.

An additional dimension of the economic data base which must be thought through is the conditions of access which should be applied. Section 303 (d) of the Act specifically directs the Secretary of Commerce to prescribe regulations to preserve confidentiality. As long as the data made available are in such a form that individuals cannot be identified there is no problem. If NMFS or the Councils contract with a non-federal agency, such as a university, for research involving disaggregated data, the data could be made available but the contractor would be responsible for the data in much the same way as federal employees are under various federal statutes. It is the understanding of this writer that language to this end can be incorporated as part of the contract.

Other research may involve second or third parties. Suppose, for example, that a Sea Grant funded research project is proposed or a research project is requested by a Regional Council and is to be executed by a private firm or a university. If disaggregated data are necessary for the research they should be accessible subject to restrictions that the user maintain confidentiality. The author received conflicting opinions in this area and since it involves legal issues did not feel competent to pursue it further. It is an issue which requires clarification, however, because it is anticipated that such situations will arise. Unless it is clarified, federal employees may be reluctant to supply disaggregated data to researchers. This would not be conducive to effective functioning of the Act.

B. Regional Economic Data Base

1. New England Fisheries

Various economic studies have been done from time to time on New England Fisheries (Table 9). Most of these were done by universities. Some have been based on primary data; others are based on the Federal data base just described. No regional comprehensive, continuing economic data collection program exists which augments the Federal data base. The current regional economic information requirements must be constructed from the Federal data base and/or piecing together an assortment of ad hoc studies done in the region. The data in such studies are often not current by the time they are published. Table 9 contains a selected list of such studies. The criterion for selection was empirical originality. Various theoretical papers have deliberately been excluded.

2. Pacific Fisheries

Data on landings and landed value are collected by the respective states in the Pacific Region. From this information ex-vessel prices can

Table 9

Selected Economic Studies[a]

Bell, Frederick W. and Jared E. Hazelton. 1967. *Recent Developments in Fisheries Economics*. Dobbs Ferry, N.Y.: Oceana Publications, Inc.

Brown, William G., Ajmer Singh and E. N. Castle. 1965. "Net Economic Value of the Oregon Salmon-Steelhead Fishery," *Journal of Wildlife Management*, Vol. 29: 266-279.

Farrell, Joseph F. and Harlan C. Lampe. 1965a. "The New England Fishing Industry: Functional Markets for Finned Food Fish I," *Economics of Marine Resources*, No. 2, Bulletin 279, U.R.I. Agricultural Experiment Station, Kingston.

________. 1965b. "The New England Fishing Industry: Functional Markets for Finned Food Fish II," *Economics of Marine Resources*, No. 3, Bulletin 380, U.R.I. Agricultural Experiment Station, Kingston.

Gates, J. M. and J. M. D'Eugenio. 1976. "Costs and Returns of Fishermen in the Massachusetts Inshore Lobster Fishery," U.R.I. Sea Grant Marine Reprint No. 60, University of Rhode Island, Kingston.

Holmsen, Andreas. 1967. "Economics of Small Trawlers." *Recent Developments and Research in Fisheries Economics*. Edited by F. W. Bell and J. E. Hazelton. Dobbs Ferry, N.Y.: Oceana Publications, Inc.

________. 1970. "Economics of Offshore Lobster Trawling," *Economics of Marine Resources*, No. 10, Bulletin 406, U.R.I. Agricultural Experiment Station, Kingston.

________ and Hiram McAllister. 1974. "Technological and Economic Aspects of Red Crab Harvesting and Processing," University of Rhode Island Marine Technical Report No. 28, Kingston.

Johnston, Richard S. and W. Robert Wood. 1974. "A Demand Analysis for Canned Red Salmon at Wholesale: A Progress Report," Oregon State University Sea Grant Program Publication No. ORESU-T-74-001, Corvallis.

Liao, David S. and Joe B. Stevens. 1975. "Oregon's Commercial Fishermen: Characteristics, Projects and Incomes in 1972," Oregon State University Sea Grant Publication No. ORESU-T1-75-001. Agricultural Experiment Station circular of information 649, Corvallis.

________. 1975. "Oregon's Dungeness Crab Fishing: An Economic Analysis of Productivity Profitability," Oregon State University Sea Grant Publication No. ORESU-T-75-005. Agricultural Experiment Station Special Report No. 441, Corvallis.

Marchant, A. and A. Holmsen. 1975. "Harvesting Rock and Johnah Crabs in Rhode Island: Some Technical and Economical Aspects," Resource Economics/NOAA Sea Grant, University of Rhode Island, Marine Memorandum No. 35, Kingston.

Table 9 -- continued

Matthews, Stephen B. and Gardner M. Brown. 1970. "Economic Evaluation of the 1967 Sport Salmon Fisheries of Washington," Technical Report No. 2, Department of Fisheries, University of Washington, Seattle.

Noetzel, Bruno G. and Virgil J. Norton. 1969. "Costs and Earnings in the Boston Large Trawler Fleet," Bulletin 400, U.R.I. Agricultural Experiment Station, Kingston.

O'Rourke, A.D. and D. B. DeLoach. 1971. "The California Fresh and Frozen Fishery Trade," California Agricultural Experiment Station Bulletin No. 580, University of California, Davis.

Perrin, William F. and Bruno G. Noetzel. 1970. "Economic Study of the San Pedro Wetfish Boats," *Fishery Industry Research*, Vol. 6, No. 3, U.S. and Wildlife Service, *Bureau of Commercial Fisheries*.

Rettig, Bruce and Kenneth J. Roberts. 1971. "Commercial Seafood Industry of Oregon: A Comparison with Other Regions of the U.S.," *Studies in Marine Economics*, Oregon State University Sea Grant Special Report 331, Agricultural Experiment Station, Corvallis, Oregon.

Rock, Robert C. and Arthur O. Flechsig. n.d. "42 Ft. Swordfish Boat," *Marine Briefs*, No. 12, Extension Sea Grant, University of California, San Diego.

Smith, Frederick J. 1972. "Pricing and Marketing Oregon Seafoods," *Studies in Marine Economics*, Special Report 289, Agricultural Experiment Station, Oregon State University, Corvallis.

________. 1973. "Marine Economic Data Sheets," Extension Service, Marine Advisory Program, Oregon State University, Corvallis. Note: this series comprises some 50 data sheets covering costs and returns for various fisheries, gear types and vessel sizes.

MEDS-1	32-Foot Port Orford Troller and Crabber
MEDS-2	40-Foot Brookings Troller and Crabber
MEDS-3	28-Foot Astoria Salmon Gillnetter
MEDS-4	52-Foot Westport Troller and Crabber
MEDS-5	50-Foot Coos Bay Shrimper and Crabber
MEDS-6	50-Foot Eureka Troller and Crabber
MEDS-7	62-Foot Eureka Dragger
MEDS-8	48-Foot Bodega Bay Troller and Crabber
MEDS-9	74-Foot Seattle Dragger
MEDS-10	72-Foot Seattle Halibut Schooner
MEDS-11	66-Foot Seattle Dragger
MEDS-12	60-Foot Seattle Dragger
MEDS-13	68-Foot Seattle Dragger
MEDS-15	77-Foot California Tuna Bait Boat
MEDS-17	118-Foot California Tuna Seiner
MEDS-41	30-Foot Astoria Salmon Gillnetter
MEDS-42	60-Foot Rhode Island Dragger
MEDS-43	80-Foot Rhode Island Lobster Trawler
MEDS-49	150-Slip Connecticut Marina
MEDS-50	150-Boat Connecticut Boat Yard

Table 9 -- continued

Stevens, Joe B. 1966. "Angler Success as a Quality Determinant of Sport Fishery Recreation Values," *Transactions of the American Fisheries Society*, Vol. 95: 357-362.

U.S., Department of Commerce, National Marine Fisheries Service, Economics and Marketing Research Division. Working Paper Series. Washington, D.C. A listing for this rather large series of papers is obtainable from the above source.

U.S., Department of Commerce, National Marine Fisheries Service. 1973. *1970 Salt Water Angling Survey*. Current Fishery Statistics No. 6200.

———. 1974. *Marine Recreational Fishing in Northeastern United States 1973-1974*. Current Fishery Statistics No. 6236.

White, Donald J. 1954. *The New England Fishing Industry: A Study in Price and Wage Setting*. Cambridge: Harvard University Press.

"Economics of the Dungeness Crab Industry," Circular of Information 627, Agricultural Experiment Station, Oregon State University, Corvallis, December 1967.

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[a] The data base on which studies are based in typically one or more years older than the date of publication.

be calculated by simple division. A small number of economic studies exist (Table 9) which together with the above price data, constitute the existing economic data base. The basis for inclusion in the list is a significant contribution to an economic data base. Other studies exist which emphasize conceptual economic aspects of fisheries management. These have not been included in the above list. It is very important to recognize that even the studies which are listed in Table 9 may be deficient when viewed as part of a data base. They are by their nature unique or ad hoc studies. The retrievability and validity of the raw data on which the studies are based can be expected to decay over time because continuity is lacking and the institutional context of these studies generally favors research but is not favorable to maintaining continuing data bases. Because they are not current, most of the regional studies which have been done are of limited use to Councils. State (i.e., non-university) supported studies relating to economic data collection were found to be unknown to persons interviewed in both the New England and Pacific Regions.

III. DEFICIENCIES IN THE CURRENT INFORMATION BASE

A. General Considerations

To facilitate the reader in the discussions which follow, statements of some general considerations and perspectives are in order. The first of these is that many fisheries have both commercial and recreational user groups. Between fisheries with a mixture of user groups, one can anticipate that the relative catches of commercial and recreational users will vary greatly. Moreover, even within such a mixed fishery one can expect to find a continuum ranging from purely commercial users to purely recreational users. Consquently, while a commercial/recreational dichotomy is useful it is potentially misleading. The important point however is that the Act requires consideration of both commercial and recreational benefits in establishing OSY. For this reason, the discussion which follows is partitioned first of all into commercial vs. recreational uses of fisheries.

A second distinction is made between data needs for monitoring and management decisions, which are repetitive and continuous, versus data needs for various isolated problems which arise and which involve more or less unique, non-repetitive decisions. This distinction appears repeatedly in the discussions which follow.

B. Commercial Fisheries

1. Established Fisheries

(a) Vessel inventories and characteristics

Sample design for collecting data by vessel type presupposes a current inventory of vessels from which strata can be designed and samples drawn. It is imperative that such inventories be compiled and maintained current and accurate. To achieve this, vessels in offshore fisheries should be identified by a number which stays with the vessel even if name or ownership changes. The Coast Guard vessel documentation number is a logical choice for vessel identification.

The minimum data which should be a part of this vessel inventory are:

—documentation number
—fishery in which vessel is engaged (see Tables 1, 2 and 3)
—length
—gross tonnage
—horsepower
—construction (wood or steel)
—name and address of owner
—home port (particularly important if the skipper is not the owner)
—navigational equipment
—sonar devices
—year of construction
—refrigeration system

While a current vessel inventory is feasible and imperative for the offshore fisheries, such an inventory for the inshore fisheries is more difficult. The large number of vessels and small size of many individual operations would make a vessel inventory an expensive proposition. Survey samples can be drawn from a list of license holders instead of a vessel inventory list.

It should be noted that the "inshore"/"offshore" dichotomy can be defined in different ways. Many of the larger "offshore" vessels also fish inshore at least part of the year. The best criterion for classification is probably vessel length. Certain fisheries will be characterized by small vessels almost exclusively and can be considered inshore fisheries. A good example would be the New England lobster fishery. With the exception of Rhode Island landings, the lobster landings of New England are largely caught in inshore waters by boats not exceeding forty feet in length.

(b) Domestic capacity

As indicated earlier, determination of foreign allocations of stocks is ostensibly based on OSY less projected domestic catch. In some fisheries this residual may represent OSY minus domestic harvesting "capacity." In other fisheries the capacity bottleneck may lie in the processing sector in terms of seasonal plant capacity available or processing costs or market restrictions. For example, fisheries development may be predicated on export markets which are subject to tariffs or import quotas in the receiving nation. Current domestic/foreign shares in such cases may reflect neither technical or cost efficiency of the domestic fleet but international trade barriers. The economic data needed to evaluate such situations include relative cost structures of domestic and foreign fleets, foreign vessel subsidies, processing technology and costs, product transport costs, wholesale product prices in the importing nation, and trade barriers. It is worth noting, however, that this type of decision-making situation has a low recurrence frequency which implies that the economic data requirements are best handled via an international market statistics program plus special studies rather than as part of a continuing economic data base for OSY management. It does illustrate, however, the types of economic complexities inherent in implementation of the OSY concept.

For the major established fisheries, it is questionable whether one can anticipate major gains in productivity from extended jurisdiction in the immediate future. This is because the stocks in question are currently at low levels relative to historical levels and/or foreign fishing pressure is modest or even non-existent. Recovery of stocks will take time. There is, currently, considerable underutilization of capacity in harvest and processing sectors and hence capacity bottlenecks are not anticipated in the short run. As stocks recover the processing sector should have little difficulty in expanding. This is especially true since stock recovery can be predicted sometime in advance from relative year class strength data. This lag provides a partial cushion against bottlenecks in the processing sector.

In the harvesting sector some additional capacity may be necessary if stocks recover. The history of exploited fisheries suggests that such additional capacity will materialize through normal investment decisions. The problem is likely to be to avoid excessive investment in harvest capacity.

For fisheries with development potential (see Appendix Table A.3) the adequacy of harvesting and processing sector capacities is more problematic. Several factors are involved. First the vessels and/or gear are in some cases distinctly different from vessels and/or gear in established fisheries. Second, the stocks are large relative to the current domestic industry and third, the markets are very different and are not familiar. Thus, the capacity question is intimately connected with development of underutilized stocks; which is discussed later in this section.

(c) Cost and earnings data

The most general or pervasive need for additional economic data is that of costs and earnings data. Since fisheries management will be aimed at the OSY rather than at the MSY, the need for economic data on the performance of the U.S. fishing fleet is obvious. The need for relatively up-to-date cost and earnings records for vessels in different fisheries has existed for a long time, as demonstrated by the large number of requests received by government and universities for such information. The supply has been scarce, however, and one even finds reports published based on antiquated cost and earnings data collected a decade earlier by a university. It is a commentary on the data base that such reports can honestly cite the data as "the most recent data available." Not only is the need for such studies obvious but there are few studies of this type in existence and none is part of a continuing, comprehensive program.

The depreciation component of costs and earnings poses some problems. Basically, there is no non-arbitrary method of calculation. For example, does one use book value, market value or current replacement cost as the basis of asset valuation? The choice depends on the use to which the data is to be put. Ideally the data base would include all three bases. It is desirable, however, that the methods chosen be standardized.

The details of stratification frequency, etc., for cost and earnings surveys should be developed by the National Marine Fisheries Service on a regional basis but with some guiding principles to facilitate standardization of methods, procedures and results. It is possible, for example, that certain operating costs (e.g., fuel, ice) may eventually be collected and expressed in terms of physical units per trip as well as in dollar units.

To support the collection of annual cost and returns data on major components of the fishing fleet on a continuing basis is properly a function of government, and governments in a large number of countries have done so for a long time. The methods of collection, sampling analysis, etc., vary from country to country; however, to secure vessel owners' cooperation in supplying the information required they are generally given an incentive. In Canada, submission of cost and earnings records in the Maritime Provinces were required for all vessel owners receiving construction subsidies. Now, it is understood that cost and earnings records in Canada have to be submitted to receive the government fish price subsidy.

In Iceland submission of the data is required by law and since most of the fuel cost, insurance cost and food on board are paid by transfer funds from fish processors and exporters there is a strong incentive to comply. In Norway submission of cost and earnings records (for vessels over 40 feet in length) is voluntary, but the vessel owners are paid 300 Norwegian Crowns ($55 U.S.) for each usable record. This has resulted in a rate of response of about 40 percent.

It is not only in foreign nations that one finds collection of cost and returns data for an atomistic industry. In the U.S. and Canada there is a long history of public support for this activity in agriculture where collection of data was intimately connected with farm management research and extension programs of the U.S. Department of Agriculture (USDA) and Land Grant Colleges. These programs have evolved over time into computerized systems which furnish monthly summaries and comparative analyses for participating farmers.

Through these programs farmers benefitted from a built-in feedback of summaries and analyses. Public agencies, especially the USDA and Congress, have been able to make more informed decisions with respect to various agricultural programs. One possible drawback is that such a system may not provide a representative data base in that participation would probably be biased toward larger, full-time fishermen.

Therefore the Federal government may have to supplement such a program by mail survey questionnaire, standardized to suit all vessel categories. The U.S. has no built-in "carrots" in its fishery policy to secure cooperation. To argue that it is necessary for fishery management purposes, or by making it compulsory to submit the records, might for many be more of a disincentive than an incentive. However, to pay the vessel owner for his time and labor involved in filling in the questionnaire, would be an incentive and would be appropriate. A $100 payment, for example, for each usable record would be an inexpensive way to obtain cost and earnings data, and possibly a sufficient incentive to obtain the sample required. Payment of the fee could be conditional on the completed questionnaire being of acceptable quality. There are numerous possible ambiguities which can exist in the best of questionnaires. To discover these the program should include random personal interviews and analyses of business records. It should also include an extension education effort based on analyses of questionnaires so that respondents receive managerial assistance based on comparative analyses of business performance. In these ways a costs and earnings information program generates reciprocal benefits for the Regional Councils and for questionnaire respondents.

While the questionnaire with incentive approach to obtaining cost and earnings data has much merit there are disadvantages. For example, such a program may obtain good information from full time, commercial fishermen but a poor response from part timers and/or commercial fishermen who move between fisheries seasonally. For this reason, supplemental surveys of these fishermen may be necessary to obtain a valid description of the harvest sector. This problem of bias may be particularly severe for some of the smaller inshore fishermen.

(d) Vessel construction costs

In discussing costs and returns studies it was noted that asset valuation poses some problems and that ideally one should have book value, market value and replacement cost measures. It is desirable therefore to have a data series on capital cost construction for new vessels entering fisheries. With such information it would be possible to project economic returns for new vessels by meshing costs and returns information for recently constructed vessels with current capital construction costs for new vessels. Such returns can differ radically from average returns from samples for a fleet as a whole. It is these returns to new entrants which is most relevant for evaluating investment opportunities and various public policy measures.

(e) Price analysis data

For any given fisherman, the price received for his catch is typically unaffected by the magnitude of his catch. In the aggregate, however, fluctuations in aggregate catch, whether random or policy induced, will induce fluctuations in price. Measuring the relationships between aggregate catch and price is the objective of demand or price analysis. By incorporating such relationships in analysis of management alternatives, projecting the economic effects of management measures is made more realistic.

Demand relationships, especially those between landings and prices, have direct implications for net economic returns to fishermen. In addition, they provide the quantitative basis from which economic gains and losses to consumers of fish products can be measured. Much of the requisite data base for demand analyses already exists and is described in Section II-A of this report. There are areas, discussed below, where some improvements would be desirable.

An area of demand analysis which has received very little attention to date concerns the effects of qualitative attributes of the fish landed. A grading system to reflect quality is lacking in fisheries. This is in distinct contrast to agricultural products against which fish must compete. It is widely believed that a standards program would be beneficial to fishermen and to consumers. A first step in remedying this situation would be a statistically valid demonstration of the benefits, if any, which might be derived from a grading system.

Another determinant of prices to fishermen is the age class structure of the catch. Age class structure can be significantly influenced by certain management measures that rarely consider the price effects which may be induced. This is a qualitative dimension which has rarely been considered in demand analysis but which could be quite readily by an integrated analysis of biological and economic data.

Major determinants of domestic fish prices are the magnitudes and composition of fish imports. In the last two decades U.S. imports of fish have increased very rapidly. Approximately two-thirds of edible fish consumption in the U.S. is currently supplied by imports. The corresponding proportion in 1950 was only one-quarter. It would be naive to ignore the implications of jurisdictional extensions elsewhere and their potential impacts on U.S. markets. Demand analyses should therefore treat imports as endogenous and include an investigation of probable supply shifts in major fish exporting nations.

Another area of demand analysis in which the data base is quite poor is that of cross-sectional data on consumption patterns of households both at home and in restaurants. The existing time series data base is best suited to estimating short run demand relationships. It is not suitable for estimation and projection of long run demand relationships for reasons which are somewhat technical. For long run relationships, cross-section data are more suitable. Long run demand relationships are particularly critical in connection with product development, market expansion and changes in product form. It is probable that any substantial increases in supplies of fishery products would necessitate frozen product forms and development of new markets. The only comprehensive (national) survey data which could be used in this area was conducted by NMFS several years ago and was restricted to consumption patterns at home. A similar survey but more comprehensive should be conducted at five-year intervals as is done by the USDA for agricultural products.

(f) Employment opportunities and skills of the labor force

In applying the concept of OSY, cost and earnings studies are an inadequate indicator of the economic well-being of fishermen because one must have a reference point in judging how much is enough. An adequate income in one region of the country may be regarded as poverty in another. Moreover, fishing income may be only part of a fisherman's total annual income. The benchmark should be related to the non-fishing employment alternatives and incomes of fishermen.

In addition, if measures of economic efficiency are to be considered, the lay systems common in most fisheries may yield a biased indication of the social productivity of investments. If maximum economic efficiency (MEE) were the sole objective, management plans would seek to promote a rough parity between returns in fishing and non-fishing alternatives. Such a standard would be consistent with regional and seasonal adjustments to general plans because non-fishing employment opportunities vary regionally and seasonally. Since MEE will not be the sole objective in management, the above parity may rarely be achieved, but management decisions should be cognizant of any disparity and how the disparities respond over time to management plans. Consequently, to supplement cost and earnings studies for domestic fishermen, there should exist a continuing series on labor force characteristics and the non-fishing employment opportunities of fishermen. Such a series need not necessarily be an annual one and the most practical method for obtaining information would be periodic systematic samples.

(g) Fisheries development

In Section I of this report it was noted that the Secretary could require foreign vessels to supply certain information relevant for assessing the feasibility of technology transfers. In general, however, successful technology transfers tend to be highly specific and technical so that it is impossible to specify at this time what data, if any, should be collected. Given this high degree of specificity, such questions are best addressed by special purpose studies. There are, for example, specific studies which should be conducted in connection with developing herring and squid fisheries in New England. In general, fisheries development studies must be integrated. Aspects to be addressed may include the resource base, available harvest and processing technology, marketing and trade barriers (see subsequent discussion of fisheries development). In some fisheries, development efforts might begin by bilateral agreements for U.S. vessels to harvest fish and offload on foreign factory ships.

2. Underutilized Species and Fisheries Development

(a) New England species

The question of data needs to determine the potential domestic utilization of fish stocks currently harvested by foreign fleets, or to determine the residual which according to law has to be allocated to foreigners, do not differ in kind from the data needed for domestic management of traditional food fish species. However, the absence of an established fishery may force different methodologies and analyses as discussed earlier.

Extension of the United States fisheries limit to 200 miles, will have different impacts on the fishing industry in the various regions of the country. New England fishermen may be excluded from the eastern section of Georges Bank if this section becomes Canadian "territory," but will have exclusive access to most of the great resources of ICNAF-area 5, which in years past have been heavily exploited by foreign fleets.

Many of these fish stocks have been heavily overfished, however, and considerable time may be required for stocks to rebuild to previous levels.

Of traditional food fish species (such as haddock, pollock, cod, ocean perch and all flounders) the U.S. now has 85 percent of the total quota from Virginia north to Maine. These stocks should slowly improve under U.S. management, but exclusion of the foreign fleet may not result in an immediate significant increase in landings of traditional food-fish.

For fisheries development potential, the U.S. must examine the large fish stocks which the foreigners currently utilize, and determine whether these can be utilized by domestic fishermen, or what might be necessary to stimulate a domestic interest in these stocks. The stocks in question are the following five: squid, herring, mackerel, whiting, and red hake.

(i) Squid

Another factor which can be intimately connected with fisheries development and technology transfer is institutional barriers. A barrier to domestic development of the New England squid resources, for example, is a 30 percent tariff on imports to the Spanish market. The current squid quota in the Northeastern U.S. is 60 thousand metric tons (about 132 million lbs). The squid stocks are currently harvested by Spain, Japan, and the USSR; by the latter country particularly for export purposes. The squid resource consists of summer squid and winter squid which are distinct species. The United States does not have a directed fishery for squid in the Atlantic; what is landed is basically an incidental catch. The domestic market is rather small and price inelastic. Consequently, when landings are low the price is high while in early summer "the bottom falls out of" the market.

In the Mediterranean area, particularly in Spain and Italy, squid is a high priced species, and in most years this area could be an attractive export market. We do not know, however, what catch rates can be obtained by U.S. vessels, the cost of a directed fishery for squid, or the price which has to be received to be competitive with other fisheries. It is not certain even, which design of trawl nets would be best to catch this species. A large foreign market exists, but answers to the questions outlined above, and also efficient processing lines for squid would be necessary. These questions ought to be studied in some detail.

Initially one might suggest that it would be better if U.S. vessels fished for squid and unloaded the catch into a foreign factory vessel, as an alternative to allocating the bulk of the squid resource to foreign fishing vessels. Processing onboard foreign factory ships would reduce the cost of processing and also eliminate most of the import duty in the flag country. Spanish importers are very interested in such arrangements.

An alternative approach which deserves careful study is the feasibility of creating U.S. "freeports." A Spanish processing ship could be anchored in such a port to receive landings by U.S. vessels (landings by foreign vessels are prohibited by U.S. law). This might be necessary if offloading at sea is not practical. Since the processed squid would be Spanish produced, owned, and brought to Spain by Spanish vessels they would presumably be exempt from most of the above tariff. An advantage of such schemes is that they would result in accumulation of information about technologies, cost structures and markets under economic conditions more favorable than those which now exist. This example nicely illustrates the futility of "grab-bag" approaches to data collection for fisheries development or for technology transfers.

(ii) Herring

The Georges Bank herring stock under proper management might be expected to yield about 120 thousand metric tons annually. In the past the U.S. did not utilize this resource. With the deterioration of the Scando-Icelandic herring stock and North Sea herring stock the European market, particularly Germany, became attractive to U.S. exporters. However, due to the uncertainty regarding the U.S. herring quota and the over-fishing of this stock, investment in the processing sector has been slow. With low unit values and large volumes a capital intensive, rather specialized fishery is expected both in harvest and processing phases.

Currently 80 percent of the U.S. herring landings in the Northwest Atlantic are caught within the 12 mile limit, and due to water temperature and/or distance to port, refrigeration is not necessary. To utilize the herring resource, and particularly catch the fish in the fall when the fat content is the highest, fishing further offshore is necessary. Since icing is economically prohibitive when fishing on a 3 cent per pound fish, trawlers must have refrigerated seawater storage or offload catches into carrier vessels equipped with refrigerated seawater storage. Midwater trawling has proven to be the most efficient harvesting method for herring in New England waters. However, the U.S. fishermen are not advanced in this technology.

If the United States herring catch approached the current U.S. quota, the vessels would most likely be put on quotas due to lack of processing capacity. It would seem, however, that the herring industry could be a good investment market, and that the U.S. share of the resource, therefore, should rapidly increase.

(iii) Whiting and hake

Due to a decline in the North Atlantic groundfish stocks, the United States has increasingly turned to importation of fish blocks from Japan. The raw material for these is the Alaska pollock. Thus, whether there is a potential for utilizing the stocks of whiting (white hake) and red hake for blocks depends largely on decisions made regarding Japanese fishing for pollock in West Coast U.S. waters.

(iv) Mackerel

The biggest stock of food fish in ICNAF areas 5 and 6 is the mackerel stock, with a total allowable catch (T.A.C.) of 230,000 metric tons in 1976. This resource is almost exclusively utilized by foreign fleets, and possibly would be the most difficult to fully utilize by New England fishermen. However, fish meal prices fluctuate rather widely over time, depending on the climatic and other conditions in Peru. Whether it would be economical for U.S. fishermen to utilize the mackerel stock for fish meal is at least an interesting question. While lower in oil content than menhaden, they might be used in periods of high fishmeal prices and/or low menhaden abundance. One reason advanced for the failure to do so is state laws in the mid-Atlantic region which classify mackerel as a food fish and prohibit industrial uses of food fish. The vessels and gear required would be similar to those necessary to utilize the Georges Bank herring stock.

(b) Pacific species

In conversations with Pacific Coast officials (state and federal) and with industry no enthusiasm was expressed for development of underutilized stocks. Pacific hake was mentioned but was not judged to have much priority. These stocks might, however, be harvested by U.S. vessels and offloaded into foreign vessels. Alaskan groundfish, particularly pollock, were judged to have greater potential for development. Since these resources are not under the jurisdiction of the Pacific Council the potentials were not explored in much depth. It is worth noting, however, that a development study for Alaskan pollock was completed by the NMFS, Seattle, Washington, circa 1974. Unfortunately, its completion date was coincident with a collapse of prices which made immediate development economically unattractive. This collapse of fish prices was a world-wide phenomenon due probably to low meat prices and recession. Since that time the prices of fish substitutes (meat, poultry) have risen again and fish consumption and prices have generally resumed their upward trend. It is perhaps appropriate therefore that the study be updated.

C. Recreational Fisheries

In Sections I and II of this report it was noted that the Act contains provisions which require the inclusion of recreational or sport fishing benefits in the implementation of the OSY concept. It was also noted that while some surveys have been conducted in recent years, the data base is extremely fragmentary. Moreover there exist substantial gaps, both in conception and measurement of recreational fishing benefits.

Although most of the discussions surrounding the Act have dealt with commercial fishing, the Act empowers the Secretary of Commerce to manage marine recreational fisheries with the goal of OSY. The concept of OSY has received considerable attention in commercial fisheries, but relatively little attention in recreational fishing. Since OSY ostensibly maximizes direct net benefits (national benefits) subject to a sustainable level of fish stocks, it becomes necessary to determine what affects these benefits. We do not have good conceptual understanding of the relationship between (a) direct net benefit to the users and (b) population dynamics of the fishery. Hence the first need is for ad hoc studies of marine recreational fishing which develop the OSY concept; these studies should also attempt to substantiate conceptual models with empirical work. This initial phase would provide benchmark results and experience for subsequent, more comprehensive phase of work.

The current conceptual model of recreational fishing form suggests the following relations:

a) net benefits per user depend, <u>inter alia</u> on total fishing trips and average catch per trip; and

b) stock size in any year depends on stock size in the previous year, biological recruitment, and recreational harvest.

These basic relationships suggest that, at a minimum, the following data are needed for managing recreational fisheries according to the OSY concept:

1) data on the total number of fishermen;

2) data on the average number of fishing outings per participant;

3) data on the average catch per outing;

4) data which would permit estimation of per capita or per user demand functions, including distance travelled, average cost per trip, and number of trips to different sites;

5) socio-economic data on fishermen;

6) population dynamics data.

Information from items (1)-(5) could be used to estimate OSY for a particular species. However, given the nature of recreational fishing, such data are difficult and expensive to obtain. In contrast to the commercial fishery, sports fishing is an exceedingly diffuse undertaking, since the individual participants do not gather in a central place of exchange (markets in commercial fisheries) which facilitates data collection. Sports fishermen do not have a strong economic incentive to keep records, as do commercial fishermen, and thus data gathered from sports fishermen must rely on their ability to recall information. The accuracy of recall data is subject to the desire to catch fish. Another difficulty with gathering data items (1)-(6)

from sports fishermen is that OSY may refer to a particular species. However, experience suggests that many fishermen who fish for a variety of species cannot give items (1)-(4) for particular species (if, in fact, they can recall items (1)-(4) at all). Thus the nature of marine recreational fishing suggests that, while the general types of necessary data are known, gathering those data is difficult and expensive.

Basically there are two types of surveys which can be used to gather marine recreational fishing data: (1) the population-specific survey and (2) the site-specific survey. The population-specific survey requires that the general population be systematically sampled by phone, by mail, by door-to-door interviewers, or by some other systematic sampling methods. Within the population-specific survey, one can gather basic data on total participation (item (1) above) and perhaps crude data on catch and outings (items (2) and (3) above). The purpose of the site-specific survey is to develop a sample which is representative of marine recreational fishermen, or the individuals fishing for a particular speices. It involves contacting individuals in the field. From the site-specific survey, with data on catch per outing, average cost per outing, and total number of outings, by site and by species, can be gathered. Such data are necessary for the estimation of the per capita demand functions used in determining OSY. Of the two types of surveys, we can conclude that the population-specific survey is better at gathering participation data, while the site-specific survey is a superior source of data concerning catch, number of outings by species and by site, and cost data. Both methods need to be modified by techniques such as the wave approach used by SMND which reduce the period of time over which individuals must recall data.

Current systematic data gathering obtains little of the data needed to determine OSY for marine recreational fisheries. The main source of data has been the Statistics and Market News Division (SMND) of the National Marine Fisheries Service. This division (and its counterpart in the old Bureau of Sports Fisheries and Wildlife) has completed three national surveys of marine recreational fishing, 1960, 1965, and 1970, and is in the process of completing a fourth survey. These surveys are well known as the Salt Water Angling Surveys. The first three surveys were national in scope. The fourth survey will cover the whole nation, but in three separate, distinct surveys: the Northeast, the Southeast, and the Pacific area. These surveys in the past have gathered data, for each of seven regions, on the total number of participants by 79 species, the total number of fish caught and total weight of fish caught by species.

These data are also gathered, by species and region, for area of fishing (ocean vs. river, bay or sound) and by method of fishing (private boat, charter boat, bridge, pier or jetty, and beach or bank). Hence, the data gathered by SMND gives a good picture of item (1), the total number of fishermen. However, because no trip data have been gathered in the past, item (2) is missing and there is no feel for the total sports fishing effort.

The Salt Water Angling Surveys, through the numbers of fish caught and weight of fish caught, do give an approximation of the total catch, by species and region, for the survey years. Past Salt Water Angling Surveys have relied on the ability of anglers to recall their catch over the previous year as the principal method of estimating catch. Staff members of SMND have questioned the ability of anglers to recall accurately data more than two months old, and have redesigned the survey approach for the fourth survey to account for weak recall ability.

The data gathered by SMND is the only national data on marine recreational fishing which provides any detail by species. However, the National Hunting and Fishing Survey of 1970 does give data on the general category of marine recreational fishing. This survey was a population-specific survey conducted for the Bureau of Sports Fishing and Wildlife by the Bureau of the Census. It provides some data on expenditures per trip and number of trips for saltwater angling. However, because the data cannot be disaggregated to refer to individual regions or species, it is not likely to be of value in formulating national policy for the management of marine recreational fishing.

It is conceivable that state governments in New England would take an interest in gathering marine recreational fishing data, at least on an occasional basis. However, a survey of the appropriate agencies in New England and New York failed to locate any data on fishing participation by species, catch by species, or other data elements of the six items listed above as potentially important in determining OSY for recreational fisheries. However, in 1975, the state of Massachusetts conducted a massive site-specific survey, conducting about 12,000 interviews, of marine recreational fishing. The data from this survey have not yet been made public, but the survey approach was well planned, and it promises to provide considerable guidance to future site-specific surveys. The Massachusetts survey gathered data on the total number of participants, total number of days fished, total catch (by number) by species, and some detailed expenditure data. Hence, the Massachusetts survey gathers the data for items (1), (2), and (3) necessary for OSY. Although the Massachusetts survey gathers some information on expenditures, there is not enough data to permit estimation of demand curves. Such data might easily be gathered in a small supplementary survey.

In addition to the Federal and State efforts to gather marine recreational fishing data, numerous site-specific research projects carried on by universities and governments are studying particular problems and particular species on an ad hoc basis. These studies, which are somewhat hard to locate and catalogue, will be important in answering methodological questions concerning gathering marine recreational fishing data and defining the OSY concept in recreational fishing.

The data-gathering efforts for marine recreational fishing can be summarized as follows: the Statistics and Market News Division, through its Saltwater Angler Survey, provides the only data on catch and participants by species on a four to five year basis. Other federal government agencies gather data occasionally on marine recreational fishing outings. In New England, with the exception of Massachusetts, states have not attempted to gather any data. We thus have reasonable data on the total number of participants by species (item (1) above) at the intervals provided by SMND. There is no data which would give insight into number of outings by species (item (2) above). The Saltwater Angler Survey gives data on total catch by species, but there is no systematic data which would permit the estimation of average catch per outing by species (item (3) above). Some ad hoc studies have gathered data on the socio-economic characteristics of individual sports fishermen (item (5)) and estimated per capita demand functions (item (4)). However, in particular on the East Coast, there have been few empirical studies on the economic demand for marine recreational fishing.

Although the exact data needs implied by the Act have not been ascertained, it is possible to discuss (1) the types of studies which will develop the concept of OSY as applied to recreational fishing and (2) the data gaps which need to be filled in order to determine OSY. The following list provides a set of research topics or surveys which would help to provide the data base necessary to carry out the recreational management objectives of the Act.

A) Conceptual studies developing the concept of OSY as it pertains to marine recreational fishing.

B) Empirical tests of conceptual models. These empirical tests would involve work on the demand for sports fishing as a function of the traditional economic variables and some measure of the catch per outing. The catch per outing could be in pounds, numbers of fish, or maximum size or weight of the fish per outing. One of the objectives of the empirical work would be to ascertain what types of catch per outing variables are most important in the sports fishery demand functions. A second goal of the empirical work would be to determine the impact of the recreational take on selected species.

C) Pilot studies for testing different data gathering systems. Even if all the data needs for recreational fishing were known now, the state of the art of survey techniques is not sufficiently advanced to permit the data to be gathered. The errors created in catch data and trip data by faulty recall makes the ordinary phone or mail survey inadequate. Recall problems also occur with site-specific surveys, although better catch can be obtained through such surveys. The SMND has made significant developments in identifying methodological survey problems and devising techniques to overcome these problems. It would seem valuable to run a series of pilot surveys testing devices for gathering the kinds of data needed to determine OSY. The state of California has studied the various approaches (house-to-house, mail, telephone, etc.) but more experimental studies are needed.

D) Greater efforts at licensing. This issue causes significant controversy. Licensing is not a panacea for excellent data, because as much as 30 percent of the fishing individuals may be excluded.[1] However, a system of annual licensing would greatly enhance the ability of states to monitor changes in recreational fishing over time. Licensing per se would not provide the kinds of economic data which are crucial to determining OSY, but it would provide researchers with a ready list of sports fishermen.

E) Testing of techniques for monitoring catch data with site-specific surveys. The purpose of these tests would be to develop inexpensive methods for discerning trends and shifts in catch per outing of important species.

The most notable gap in recreational fisheries is the linkage between success ratios, which can be influenced by management decisions, and recreational benefits. Historically this connection has received little attention, in part because of the nature of the decisions which were to be addressed. The literature evolved primarily in the context of benefit-cost analyses for public water resource investments in which the question posed was an all or nothing decision. An assumption, often implicit, was that success ratios are exogenous to the immediate issue. Given the context in which the literature evolved, this assumption was tenable. It is not tenable in fisheries management which must consider both commercial and recreational benefits, and how each varies in response to management measures.

In general it seems reasonable to hypothesize that recreational fishing benefits would increase both with angler days and success ratios. Little is known about the relative importance of angler days and success ratios as

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[1] For examples; senior citizens, children, veterans, handicapped, etc., may be exempted from licensing requirements. This problem could be avoided by retaining universal licensing but providing exemptions from fees for such individuals.

determinants of recreational benefits. At the extreme, if success ratios have zero effect on recreational benefit measures then one need not consider recreational fishing in allocating fish stock between commercial fishing and sports fishing. Other issues need to be explored. For example, if sports fishing effort is determined in part by the maximum size of the fish rather than the average catch per outing, the OSY will be quite different. Similarly, it may well be that many sports anglers derive much more pleasure from catching the fish than keeping them. In the extreme, all fish caught by sports anglers could be thrown back in, suggesting that OSY could be determined purely on economic grounds, without regard to the population dynamics.

While this extreme case is probably not significant, it serves to illustrate the nature of the comparisons or trade-offs to be made and the conceptual difficulties which must be resolved in designing a data collection system. For this reason, it is suggested that studies be initiated through universities. The purpose of these studies would be to clarify some of the issues and to demonstrate valid measurement procedures covering conceptual issues, data specification, collection methodology and methods for analyzing the data obtained. If successful methodologies can be demonstrated, a comprehensive data collection system can be considered in the future.

D. Summary of Section III

Based on the discussions in Section III, there are seven areas in which additional economic data are needed. These areas are vessel inventories, costs and earnings data, vessel construction costs, demand analysis data, size, employment opportunities and skills of the labor force, fisheries development and recreational fishing benefits.

Not all of these areas require a continuing, annual data base. Those which do are the first three—vessel inventories, costs and earnings, vessel construction costs—and some components of demand analysis data. The residual areas, employment opportunities and skills of the labor force, fisheries development, recreational fishing and some components of demand analysis data, require either special purpose studies or periodic updating such as every five years. The following section consists of a series of task descriptions defining each of the data collection objectives, plan of action, end product, purpose and/or benefit, schedule and program cost.

IV. DATA COLLECTION TASKS

This section pulls together the deficiencies identified in Section III in the form of seven data collection tasks. For each task a statement is provided of objective(s), plan of action, end product, purpose and/or benefit, schedule and program cost. Table 10 summaries program costs for each year over the next decade. As indicated, program costs would range from $2.075 million to $3.4 million.* These increases represent substantial increases in the current combined budgets of the EMRD and SMRD; a fact that reflects the low funding priority accorded economic research in the past.

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*These estimates of cost are in 1975 dollars and are based on the personnel and computer costs which could normally be expected in the collection, analysis, and reporting of research information.

Task 1: Vessel Inventories

Objective:

To prepare and maintain in current status an inventory of vessels and their characteristics for each of the major fisheries listed in Section I.E of this report.

Plan of Action:

Work with appropriate state and federal agencies to develop and maintain vessel inventories for each of the major fisheries. The vessel characteristics to be included as part of the inventory are detailed in Section III.B.1(a) of this report.

End Product:

An up-to-date listing of economic units comprising the population of interest for cost and earnings surveys and for capacity determination.

Purpose/Benefit:

A prerequisite for economic studies is a current listing of the population(s) to be studied.

Schedule:

Annual—Initiation immediately

Budget:

$250,000 per year.

Task 2: Cost and Earnings Data

Objective:

Construct accurate, current statements of the numbers of fishermen and their economic status for each of the major fisheries.

Plan of Action:

Develop and field test a systematic survey program based on questionnaire methods with random personal interviews for validation purposes. Encourage the development of a companion program to review cost and earnings data with fishermen and to discuss their implications for the managerial decisions of fishermen. Such a program should be developed within existing Sea Grant/Marine Advisory Services rather than NMFS.

End Product:

Comprehensive current statements of the numbers of fishermen, their economic status and factors affecting economic performance. Provide economic, managerial information to fishermen, especially regarding the best vessel sizes for investment purposes.

Purpose/Benefit:

Enhance ability of Councils to include economic factors in their determinations of OSY for each fishery. Provide information on the economic effects of Council decisions over time. Provide fishermen with factual comparative analyses to aid in their decisions.

Schedule:

Annual—initiation immediately

Budget:

$1,000,000 per year.

Task 3: Vessel Construction Costs

Objective:

Compile and maintain series on the current cost of construction for each major type and size of vessel.

Plan of Action:

Survey of shipyards that build fishing vessels.

End Product:

Information which can be combined with cost and earnings data to project rates of return on new investments in the harvest sector.

Purpose/Benefit:

Complement cost and earnings data which will reflect historical construction costs in calculation of depreciation and rates of return.

Schedule:

Annual—initiation immediately

Budget:

$50,000 per year.

Task 4: Survey of Household Expenditure Patterns for Fish Products

Objective:

To determine household preferences for fisheries products.

Plan of Action:

Explore feasibility of survey with qualified agencies such as the U.S. Department of Agriculture which currently conducts similar surveys for agricultural products.

End Product:

Periodic data on expenditure patterns at home and away from home; by region, season and socio-economic status.

Benefit:

Improved ability to project economic impacts of fisheries development and management policies.

Schedule:

Periodic—five year frequency.

Budget:

$150,000 each 5 years, plus $50,000 each year.

Task 5: Labor Force Statistics

Objective:

To determine the size, composition, employment skills and occupational mobility of fishermen.

Plan of Action:

Explore feasibility of such a survey with qualified agencies such as the U.S. Departments of Agriculture and Labor.

End Product:

Improved knowledge of the labor force and the economic dependence of fishermen on fisheries resources.

Purpose/Benefit:

Improve ability of Councils to project magnitude and duration of dislocations resulting from alternative decisions or from scarcity of fishermen.

Schedule:

Periodic—five year frequency; initiation in 1980.

Budget:

$25,000 per year to 1980
$400,000 per year in 1980
$150,000 per year after 1980

Task 6: Fisheries Development

Objective:

To investigate feasibility of fisheries development for underutilized stocks of fish.

Plan of Action:

Phase 1: Survey.—For each region conduct periodic reviews of underutilized species to determine probable payoff from further in-depth investigations of feasibility.

Phase 2: Action.—For species where feasibility is plausible develop five year development programs covering all phases of the development process including harvest and processing technologies, market potential, trade barriers, etc.

End Product:

Systematic, continuing review of fisheries development potentials leading to in-depth development studies where appropriate.

Benefits:

Increased production and employment; reduced imports and/or increased exports.

Budget:

$500,000 per year.

Task 7: Measurement of Marine Recreational Fishing Benefits

Objective:

To determine feasible methods for measuring marine recreational fishing benefits and the sensitivity of such benefits to changes in the success ratio.

Plan of Action:

Phase 1.—Select one or two important recreational fisheries and solicit research proposals from qualified institutions.
Phase 2.—Comprehensive survey.
Phase 3.—Periodic re-surveys.

End Product:

Development and demonstration of methodologies for measurement of recreational benefits.

Purpose/Benefit:

Such measures are necessary if recreational benefits are to be reflected in determinations of OSY.

Schedule:

Two to five years; initiation immediately.

Budget:

$200,000 first 2 years (Phase 1).
$1,000,000 per year for 3 years (Phase 2).
$400,000 per year after 5 years (Phase 3).

Table 10

Summary of Projected Program Costs for Economic Data Collection

Task	Initiation Date	Schedule	Cost
1. Vessel Inventories	immediate	annual	$250,000
2. Cost and Earnings	immediate	annual	$1,000,000
3. Vessel Construction	immediate	annual	$50,000
4. Household Survey	FY 1978	5-year intervals	$150,000/5 years + $50,000/year
5. Employment Skills	immediate	5-year intervals	$25,000/year to 1980 $400,000/year in 1980 $150,000/year after 1980
6. Fisheries Development	immediate	annual	$500,000/year
7. Marine Recreation	immediate	periodic (5-year?)	$200,000/year first 2 years $1,000,000/year for years 3-5 $400,000/year for years 6+

Summary by Year

year	1	2	3	4	5	6	7	8	9	10
thousand $/year	2,225	2,075	2,875	2,875	3,400	2,400	2,400	2,400	2,750	2,750

V. SUMMARY AND CONCLUSIONS

This report (1) identifies economic information requirements under the Fisheries Conservation and Management Act of 1976; (2) describes the current economic data base; (3) identifies additional data required to fulfill the information requirements in (1); and (4) projects program costs to remove these gaps.[1]

It is concluded that substantial economic information requirements are implied under the Act and failure to satisfy these requirements could result in successful court challenges to management plans. The Sections of the Act which contain these informational implications are discussed in Section I.D. They are associated with (1) determination of optimum sustainable yield (OSY); (2) national standards for fishery conservation and management; (3) fisheries development; (4) foreign catch allocations; and (4) conditions of access for foreign vessels. Informational requirements identified include (1) cost and returns; (2) price and regional employment effects of management measures; and (3) institutional factors with economic implications including foreign fleet subsidies and international trade barriers.

The primary source of economic data and analysis at the present time and for the foreseeable future is the National Marine Fisheries Service (see Section II.A). Various ad hoc data collection and analyses are conducted by universities and/or Sea Grant. The respective states have no programs for collection of economic data other than landings and landed value statistics.

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[1] The reader is referred to Section I.B of this report for restrictions on its scope.

Substantial data gaps are identified and discussed under the headings of (1) vessel inventories and characteristics; (2) cost and earnings; (3) vessel construction costs; (4) price analysis data; (5) employment opportunities and skills of the labor force; (6) fisheries development; and (7) marine recreational fishing benefits.

The NMFS has historically been concerned primarily with biological data and research. Economic data needs have received relatively low funding priority. The area in which the economic data base is best is that of price data due to the activities of the Statistics and Market News Division of NMFS. The Economics and Marketing Research Division has been responsible for research and analysis of data and has collected some additional data. The recent decision within NMFS to eliminate this division raises questions about the capacity of NMFS to respond adequately to the requirements of the Act. While it is proposed that economics staff will be added to each of the Fisheries Research Centers it is questionable whether these regional staffs will have the time and direction to address issues from a national perspective. While the addition of economics staffs to the Regional Fisheries Centers is desirable it is not a substitute for a central economics research and planning staff.

A series of economic data collection tasks is specified in Section IV to remedy the data gaps identified. Program costs associated with these tasks are projected at $2.1-$3.4 million per year over the next decade.

It is assumed that the Agency responsible for these tasks is NMFS. Certain of the tasks can best be executed by contracting with other federal agencies such as the U.S. Department of Agriculture and are so indicated in the task description.

The current dearth of economic data reflects past funding within NMFS and also the general antipathy toward collection of such data which exists within the Bureau of the Budget. The response of the system has been to finance various ad hoc studies through universities and private firms. Fishermen often complain that they find the frequent surveys a nuisance. Their complaint is understandable, particularly since much overlap is inevitable, given the decentralized ad hoc nature of economic data collection for U.S. Fisheries. There is flavor of "Catch 22" here in that most of these ad hoc surveys would not have been necessary had support for a comprehensive national program existed in the first place.

VI. APPENDICES

Appendix A

Species and Fisheries Most Likely to be Affected by the Act[1]

Table A.1 Species which are likely candidates for management plans: New England Council.[a]

	1	2	3
Herring	*		
Mackerel	*		
Hakes	*		
Squids	*		
Cod		*	
Haddock		*	
Flounder		*	
Pollock		*	
Sea Scallops		*	
Lobster		*	
Northern Shrimp		*	
Surf Clams		*	
River Herring			*
Alewife - Blueback			*
Atlantic Salmon			*

Legend

Column #	Description
1	Species groups for which surpluses may be available for foreign allocation.
2	Species groups for which sufficient U.S. harvesting capacity exists.
3	Anadromous species.

[a] See Section I.E. of text for discussion.

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[1] This list of resources/fisheries is almost certain to change in the future.

Table A.2 Fisheries which are likely candidates for management plans: Pacific Council.[a]

	1	2	3
Pacific Hake	*		
Pacific Ocean Perch	*		
Other Rockfishes	*		
Dover Sole	*		
Other Flounders	*		
Sablefish	*		
Jack Mackerel	*		
High Seas Salmon		*	
Washington Troll Salmon Fishery			*

Legend

Column #	Description
1	Species groups for which surpluses may be available for foreign allocation.
2	Species groups for which sufficient U.S. harvesting capacity exists.
3	Anadromous species.

[a] See Section I.E. of text for discussion.

Table A.3 Distinct fisheries for which economic data will be needed.[a]

I. New England Fisheries (see Table A.1)

  A. Established Fisheries

    1. New England Groundfish Trawl Fishery
       Includes cod, haddock, pollock, flounder, shrimp
       (see Table A.1)
    2. Scallop Fishery
    3. Lobster Fisheries
    4. Anadromous Fisheries (sport fisheries)
       Includes river herring, alewife, Atlantic salmon

  B. Fisheries with Development Potential

    1. Pelagic Gear Fisheries
       Includes mackerel and herring
    2. Bottom Gear Fisheries
       Includes squid, whiting, red hake

II. Pacific Fisheries (see Table A.2)

  A. Established Fisheries

    1. California-Washington Trawl Fisheries
       Includes Pacific hake, Pacific ocean perch, other rockfishes, Dover sole, other flounders, sablefish, jack mackerel
    2. Salmon Fisheries

  B. Fisheries with Development Potential

    1. Alaskan Groundfish
    2. Pacific Hake

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[a] See Section I.E of text for discussion.

Appendix B

Individuals and Agencies Contacted

Individual	Location	Affiliation	Telephone
R. Siegel	D.C.	EMRD	202-634-7360
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Agency Acronyms

NMFS = National Marine Fisheries Service
EMRD = Economics and Marketing Research Division of NMFS
SMND = Statistics and Market News Division of NMFS
RO = Regional Office, NMFS
NWFC = Northwest Fisheries Center, NMFS
WFG = Washington Department of Fish & Game
IMS = Institute for Marine Studies, University of Washington
CFG = California Department of Fish & Game
PMFC = Pacific Marine Fisheries Commission
SWFC = South West Fisheries Center, NMFS

Comments from the Reviewers

"Concerning . . . economic data needs there is a serious value question as to whether the United States would receive a benefit commensurate with the efforts required to obtain the data. The report indicated two to three million dollars cost per year for only two regions, neither of which is particularly large in landed fish. I think a review of what the information will provide in the way of dollars in the GNP is in order. Further, one possible outcome of the analysis would be to indicate that the foreign fishing fleets are the most efficient harvesters of the available resources. If this were to be the answer, are we prepared to so state?"

--from P. J. Doody
Vice President, Production
Zapata Haynie Corporation
November 17, 1976

"Length may be the best criterion for determining cost of production but it may not be for effort. For example, in the Gulf of Mexico shrimp fishery horsepower and size of net are the most important variables to standardize days fished.

"(Also) in the Gulf of Mexico shrimp fishery all of the vessels which are 5 gross tons and larger are registered with the U.S. Coast Guard. They report for each vessel number, name, tonnage (net and gross), length, hull, when built, horsepower, owner, home port and rig. In addition, the NMFS also has a current list of vessels harvesting shrimp which they update the characteristics annually and add size of net."

--from Wade L. Griffin, Assistant Professor
Department of Agriçultural Economics
Texas A & A University
October 25, 1976

"The study was a good first cut at the problem of mass lack of regional economic fisheries data; however, much more needs to be done."

--from David J. Etzold, Sr. Research Assoc.
University of Southern Mississippi
November 5, 1976

"The only question I have is on (the) estimated costs for collecting the data he convincingly argues is necessary to achieve the objectives of the Act. I suspect he may be a bit optimistic and underestimates the cost associated with the systematic compilation of reliable data."

--from Lauriston R. King, Program Manager
Marine Science Affairs
National Science Foundation
November 9, 1976

"I would recommend an analysis of the task assignments and budgets between NMFS economics and agriculture economics. The domestic and foreign economic commercial production and analysis of fishery products could be greatly enhanced by some effort on behalf of the Agriculture Department. You will find that their structure, capabilities and output of fishery data exceed that of NMFS even though Agriculture does not have a direct interest in this area. The development of an aquatic products economic division or branch by Agriculture would be most helpful and could be funded with uncommitted S-K monies already in their hands."

--from William G. Mustard
Project Director
Atlantic States Fisheries Commission
October 13, 1976

Working Paper No. 2

THE ROLE OF THE SOCIAL SCIENCES IN FISHERIES MANAGEMENT UNDER EXTENDED JURISDICTION

Prepared for OTA
by
James M. Acheson

December 1976

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INTRODUCTION

Working Paper No. 2 discusses two problems which must be faced in implementing the optimum yield concept which is mandated by Congress as part of the Fishery Conservation and Management Act of 1976:

(1) The information from various academic areas is very uneven. The biological data and concepts are very sophisticated; the economic information is less so; and the social data on the fishermen and the communities in which they live are almost completely absent.

(2) Integrating the information from these areas poses very severe difficulties.

This paper contains a discussion of the general problems of data imbalance, integration of data, and the views of fisheries managers. It follows with information on existing studies and data needs, and concludes with an outline of some specific studies which are recommended by the author. Although these recommendations are represent the thinking of just one person, based on his experience and contact in the fishing industry, OTA presents them here as an example of the types of work which will be needed. These recommended studies will certainly generate both criticism and support, but it should be kept in mind that they were developed by the author simply as a starting point in a field where little substantive work has been done.

The paper also includes an extensive bibliography of works which are cited in the paper and a section containing some of the comments of reviewers who had substantive additions to make to the material presented in the paper.

Abstract

PL 94-265, the Fishery Conservation and Management Act of 1976, states that the fisheries of the United States will be managed for optimum sustainable yield, which means that social, economic and biological factors must be taken into account in promulgating regulations. The biological and economic information on U.S. fisheries is reasonably good; there is virtually no social or cultural information on U.S. fishing communities which would be of help to those charged with managing marine fisheries under PL 94-265. The object of this paper is to suggest the kinds of studies that need to be undertaken to obtain the socio-cultural data mandated by this law.

Of the thousands of types of socio-cultural information that could be obtained on all aspects of fishing, it is important to focus on the fishermen. It is the fishermen who are specifically affected by this legislation, and who have virtually blocked past attempts at effective management. Studies need to be undertaken to provide three kinds of information. 1. Base line data on demographic and social structural features of fishing communities. This data would be of primary use in the future when changes in fishing regulations are being considered. 2. Data on social

and cultural factors which will influence acceptance of various fisheries management plans. 3. Data on receptivity to technical and economic innovation. This information would be of primary use in predicting what impact PL 94-265 will have in the future. All of this information can be collected by a combination of survey research, in which a stratified sample of fishermen are interviewed, and 15 intensive community studies. All of the data could be collected and assembled in some 4 years from the inception of the project.

I Data Imbalance Problem

There are two reasons for the great imbalance in the data available. First, fisheries management has traditionally been the domain of the fisheries biologist. The administrators of Federal and State Agencies concerned with fisheries management have channeled funding towards biological research, and away from the social sciences. Second, among social scientists only the economists have built up a body of data and theory concerning the application of theory in their field to fisheries management problems. Even though economists have only been working with fisheries for some twenty-five years, their influence on PL. 94-265 has been enormous. If anything, they have had as much influence, if not more, than the biologists. However, they are not prepared to deal with the social and cultural aspects of management.

Other kinds of social scientists on the whole have not been interested in fisheries problems in the U.S. Political scientists tend to work with political institutions on a national and international level. Sociologists have concentrated most of their attention on problems in urban areas. Social psychologists have stuck to their laboratories where conditions can be carefully controlled and reactions observed. And anthropologists have tended to work in foreign cultures outside the Western world. Only recently have a few social scientists become interested in the modern fishing industry of the United States. Most are anthropologists, who I think have been attracted to fishing largely because of a growing interest within the profession in maritime communities, and because traditonal, rural fishing communities can be studied with the same sets of conceptual tools anthropologists have developed for studying small, traditional societies in other parts of the world. As a result, the little literature that exists on the socio-cultural systems of modern fishing communities in the U.S. and other industrialized nations has a strong anthropological cast to it. Hopefully, other kinds of behavioral scientists can be persuaded to take an interest in fisheries management. But in the meanwhile, only a small handful of anthropologists are interested, prepared, and trained to deal with the social, cultural, and historical dimension of fisheries management demanded by PL 94-265. The situation is not, in my opinion, as desperate as it might sound, because anthropologists are in position to gather most of the data and answer most of the questions concerning fishermen and fishing cultures which will be demanded by fisheries administrators.

It is critical to note that the problem cannot be corrected by merely collecting socio-cultural data. The information we wish to gather and the way we synthesize it depend very much on the kinds of ideas we have in mind about fishing communities and the ways they work. Data, after all, only make sense in terms of a theory. It is important to note that <u>we do not know</u> how fishing communities work. To phrase the problem in terms of a need for data assumes that the theoretical work has been done already. This simply is not true. In short, in order to give fisheries managers the kind of information they need, a lot of theoretical work needs to be done.

In this respect, the problems fisheries economists face are very different from those faced by other social scientists involved in fisheries research. They have a body of theory already, and many of their most acute problems at this stage do concern data collection.

Social scientists, of course, have hundreds of concepts and ideas which could be applied to understanding coastal communities and fisheries management. But it is critical to realize that very few of them have been applied as of yet. Under these conditions, the present ability of social scientists to aid in fisheries management efforts is minimal. There is no way to apply information we do not have. We cannot solve problems we do not understand.

This means that the most practical thing social scientists can do at this point is to gain an understanding of basic social and cultural features of fishing communities which are essential for understanding problems of fisheries management. We will discuss these features at length later in the paper.

II Integration Problems

Implicit in the concept of OSY is the idea that the economic, biological and socio-cultural data should be integrated and not treated as separate entities. Management plans based on the finest economic concepts will do little good if their implementation results in dangerous depletion of the fish stocks and massive social disruption with attendant political agitation. In the recent past, some attempts have been made to integrate biological and economic data to obtain a bio-economic model of fisheries. There has been virtually no attempt to bring in social or cultural factors. Indeed, this kind of synthesis poses many problems. For example, biological and economic variables can be expressed in terms of a continuous mathematical series. Many critical social and cultural factors can be expressed mathematically, if at all, only with some difficulty. This is particularly true of factors concerning social structure, values, symbolism, etc. It is no accident that when social and economic factors are modelled together the social factors show up as constants in the econometric equation. Moreover, the basic paradigms of these three academic fields are very different. Economics is strongly deductive; anthropology is inductive. Ultimately, social, economic and biological information will have to be synthesized if social scientists are going to present information of maximum use to agencies and units charged with managing the fisheries. However, there is no sense attempting such a synthesis at present. Our knowledge of the way in which these communities operate as systems is too inadequate at present. It is only after we have discovered what the critical social variables are that we can begin to think in terms of integrating social data with biological and economic information. Such an integration, is however, the ultimate end.

III The View of Fisheries Managers

Fisheries administrators themselves do not have a clear idea of the kind of information they need on fishing communities and the fishing industry. In the recent past, most assumed that they did not need any such information because, in their view, their job was "conservation of the fish resources," as if managing fisheries does not involve regulating the fishermen. Even administrators who are convinced that fisheries should be managed for "optimum yield" (as opposed to Maximum Sustained Yield) really do not know what information they need.

Some fisheries officials and involved academics are assuming that information should be collected only on catch and effort. Thus, they are assuming that the economic, social, cultural and historical information mentioned in Pl 94-265 will consist of collecting nothing more than statistical data on catches, income, boat size, horsepower of the engine, number of days at sea, etc. Certainly a fisheries manager needs such information, but such figures are scarcely the sum total of the data needed. There is little that is social, cultural, or historical about them.

Other officials of the National Marine Fisheries Service have been talking about the need to be able to measure "socio-economic impact" of fisheries management regulations. Measuring "impact" sounds very practical. It is interesting to note that the Office of Sea Grant, in its efforts to coordinate activities with the NMFS is planning to expend a good deal of money on studies concerning the "socio-economic impact" of extended jurisdiction. Most of these fisheries managers are surprised to learn that social scientists have not developed any neat set of concepts to measure "impact." Even after some discussion, most administrators have little conception of the difficulties involved.

Beyond catch and effort data, and a concern with "impact", those involved with fisheries management have few other suggestions for so called "social science input." They know that social, cultural and historical information is manadated under the law (Pl 94-265), but exactly what information should be involved and how it can be applied to solve problems of fisheries management is hazy in their minds. Two Federal and State officials have openly told me that they regard the whole OSY idea as a mistake. They have not used social and cultural data in the past, and they see no need to use it in the future. This viewpoint appears to be prevalent among State and Federal officials concerned with fisheries management. Under these conditions, it is safe to assume that the kinds of data and ideas about fishermen and fishing communities that will be necessary for the effective management of fisheries will have to be suggested by social scientists. Reasonable suggestions are not apparently going to come from fisheries managers.

Even though fisheries managers do not have a clear idea of what social science information they need, officials of the National Marine Fisheries Service have repeatedly stressed the need for social and cultural information on regions as a whole, since these are the units they must manage. Information on very small social units, such as one island, will do them a minimal amount of good. This point of view cannot be ignored. However, anthropologists ordinarily study very small units. They have learned through long experience that the most important social patterns and values of a given culture are rarely talked about. The people of that culture simply act in terms of them. These presupposition and sets of expectations can only be discovered through many months of participant observation, and repeated in-depth interviews with key informants (Pelto, 1970). Under these conditions, it is not surprising that anthropologists tend to study small communities, hamlets, sections of tribes, etc.

The problem, then, it to get the kind of in-depth information anthropologists know to be essential, and still cover a multi-state area--the kinds of units that will be taken into account by fisheries managers. This problem can be solved, I believe, by doing intensive studies of communities, in combination with broad surveys of whole regions using the information generated by these community studies.

NUMBER OF STUDIES AND SAMPLING PROBLEMS

The number of community studies that should be done is a problem. One is tempted to say that we should have a community study on at least one major community involved in every major fishery. That, of course, brings up the problem of what is a fishery? Biologists tend to talk about fisheries in terms of the species caught (e.g. the "lobster fishery," "shrimp," "tuna fishery," etc.). Such a classification makes no sense at all in discussing the people involved in fishing. After all, the same men who are involved in the lobster fishery in Maine during the spring, summer, and fall are catching shrimp in the winter months and may harpoon a few tuna in August. Clearly we need to focus on units that the people are involved in--namely "communities," whatever these units might be.

While it is not clear how many kinds of fishing communities exist in the U.S., I estimate that an adequate job could be done by obtaining detailed information on 10 to 15 communities in various parts of the United States whose inhabitants are engaged in a large number of different kinds of fishing operations. The East coast, for example, could probably be adequately covered by doing community studies on: a community in Maine where a lot of lobstering and inshore dragging is done; a large port in Massachusetts or Rhode Island which does a lot of off shore fishing; a community in the Chesapeake Bay area (oystering and crabbing); a community in the Carolinas or Georgia where a lot of shrimping is done; a community off the East Coast of Florida (inshore shrimping);

and perhaps 2 communities in the Gulf region where inshore and offshore shrimping are done. While I know very little about the West Coast, I would imagine that five or six more studies would be necessary there. Certainly one would be needed for a tuna fishing community and at least one on a salmon fishing community in Washington. We would probably need studies of two communities in Alaska since the fishing communities in the southern part of the state, dominated by Whites who produce fish for export, are very different from the Eskimo and Indian communities in the Western part of Alaska where fishing is primarily a subsistence activity. Once we understand a great deal about these communities, and know the appropriate questions to ask, survey research instruments could be prepared to pick up significant variations in these regions as a whole. Intensive studies of communities are absolutely mandatory. We cannot find out the relevant information by survey research techniques alone. At present, we do not know the important questions to ask and we cannot assume that what is critical to understand in one part of the country is critical for another. ¶ I am particularly worried about this estimate of the number of communities that should be studied. In the virtual absence of a solid body of information on the coastal regions of the U.S., I have nothing to go on but my experience in New England and my own imagination concerning the boundaries of major fisheries. I am sure that anthropologists familiar with other parts of the country would have some very different ideas about the units that need to be analyzed.

The number of survey research questionnaires that need to be administered in the U.S. as a whole poses other problems. As a general rule,a 15% stratified sample is adequate to ensure statistical reliability. The problem is in estimating the number of fisheries, and this is difficult because such a large number of people are involved on a seasonal or part-time basis. For example, in the Maine lobster industry, there are some 10,600 licenses issued by the state, but only approximately 2500-2800 of these can be counted as commercial fishermen. Many of these men earn part of their income in other fisheries or in other industries. The same is true in every other fishery in the U.S. In short, the line between commercial fishermen, part-time fishermen and sports fishermen is far from clear. No indication of relative numbers can be obtained from number of licenses issued by State Agencies--even though this is the usual method of obtaining such data.

For purposes of managing the marine fisheries of the United States under Pl 94-265 in the first few years, we need to concentrate on understanding the commerical fishing industry. The law is aimed parimarily at regulating the commercial fishermen; and most important, they are the interested players. The life of the sports fishermen will not be greatly affected by this legislation. The problem then is how to estimate the numbers of commerical fishermen--recognizing that some of these men may earn a good deal of money in other industries. Without going into all of the rule of thumb calculations I made, I estimate that we could obtain a 15% stratified sample of fishermen in the U.S. by interviewing approximately 6000 people.

I recognize that other social scientists working in other parts of the country may want to modify these estimates. However, everything that follows in this paper is predicated on the idea that we will be focusing on the commercial fishermen of the United States and will gather data by about 15 community studies and 6000 questionnaires.

OUTLINE OF SPECIFIC STUDIES

I believe three kinds of specific information would be of most use to fisheries managers, given the nature of Pl 94-265: I. baseline information on fishing communities in the United States, II. information on social and cultural factors influencing the acceptability of fisheries management proposals, III. information on factors influencing the responsiveness of the fishing industry to future changes in the economic environment. This last concern is closely related to the impact issue. The type of information needed to complete all these studies overlaps considerably. The reasons this information is important for fisheries managers and the specific data and concepts required for each study merit considerable comment.

I. Baseline Ethnographic Studies

In seeking baseline information, we are essentially concerned with obtaining a picture of the total way of life of fishermen and the "communities" these people live in. This may seem a mundane concern, but in the long run, the data and ideas generated will prove very valuable. In a few years, the eight

Regional Councils which are charged with managing the marine fisheries of the U.S. under Pl 94-265 will be faced with conflicting pressures to alter the bill in the face of changing conditions. In the absence of accurate baseline data, managers and politicians may have nothing on which to rely other than the vague recollections of interested parties. It may, in fact, be very difficult to reconstruct what the fishing communities were like before regulations went into effect. It is not only that observers will selectively recall events favorable to their case, but that observers in the same community will undoubtedly have different recollections about their communities, about fishing, and about the effects of the bill on them.

The future of the fishing industry is difficult to foresee. One thing is almost certain to happen. Somehow, the "impossible present" will be transformed into the "good old days"--a golden age when there was no Government regulation to foul everything up. When this occurs it may be very difficult to assess exactly what effects specific regulations have had.

Two kinds of baseline data need to be collected by different kinds of research techniques. First, we need quantitative demographic, social, and economic data on a large sample of fishermen and fishing ports. I suggest this data be obtained by; (1) administering a questionnaire to a representative sample of household heads of families in the fishing business to obtain data on family size, age and sex breakdown, range of occupations, consumption patterns, ethnicity, kinship ties, work experience, educational levels, alternative skills, political affilations, fishing gear used, annual round, species caught, income, associational involvement, and some kind of indirect indicators of commitment to the industry, political awareness, etc., (2) filling out a data sheet on every port in the U.S. to obtain information on transportation facilities, fish processing capabilities, size of community and size of fishing population, alternate employment opportunities, fisherman's organizations, fishing grounds and stocks, fishery statistics, fleet characteristics, marketing patterns, and facilities necessary for a fishing industry (e.g. hardware stores, repair facilities, docks, etc.).

Second, qualitative information needs to be obtained on the entire culture and social structure of "typical fishing communities" in 10 to 15 key areas of the coastal United States. Of special importance is information on the status and roles of people in fishing crews, cooperatives, etc., the organization of important kinds of groups in the communities, the values and goals of people in those communities, the kinds of problems people face, patterns of cooperation and conflict, etc. In short, we need a set of standard monographs on communities of the kind that anthropologists and sociologists have done in the past on primitive tribes, peasant communities, and ethnic groups in modern Western countries. Of course, these monographs would not attempt to cover every aspect of the life and culture of the total community, but would rather focus on the people and families directly involved in fishing.

II. Studies Concerning the Acceptability of Fisheries Management Plans

On the whole, efforts to manage marine fisheries have failed. The basic reason is that proposals to manage fisheries have been so massively opposed by the fishing industries of the United States that legislatures and other Federal and State agencies have not been able to enact viable management plans. This is true even though management would greatly benefit both the stocks of fish and the consumer. If the past is any indicator, fisheries management plans under Pl 94-265 must be made acceptable enough to the people in the industry that they will not invite such massive opposition that politicians are powerless to act.

One can, of course, simply ask people how they feel about specific management plans, but the results are not apt to be satisfactory. The answers one is apt to get will be entirely negative. No one likes regulations. Moreover, survey research techniques really tell very little about possible ways to amend proposed regulations. In Maine, we have had the experience of amending one fisheries management bill with the fishermen's comments in mind, only to have the new version opposed on still other grounds. The fact is that the reasons that people give for many of their actions are not the real reasons. Moreover, they may not be able to articulate what their real reasons are.

When people oppose projects concerning planned social change (in this case, fisheries management) there are usually two reasons: 1. the change is not economically profitable for them, 2. it is not congruent with existing social institutions (Linton, 1936:341). If this body of literature is correct, then we should strive to develop fisheries management regulations which benefit the fish resources, benefit the fishermen, and do not disturb key institutions and normative structures. In this best of all possible worlds, the fishing industry would gladly promote regulations which would maintain the fish stocks at optimal levels. Unfortunately, this utopian situation will probably never occur in reality.

A. Economic Costs and Benefits. The issue of economic benefits acruing from fisheries management is a thorny one and not well understood. Unfortunately, it is an important topic since many of the traditional problems in the management of marine fisheries stem from a lack of knowledge of aspects of benefits. The essence of the problem is that it is not at all clear who or what should benefit by management. It is not only that we have little knowledge of the subject, but that there is an apparent conflict of interest between those concerned with fisheries so that if one group benefits, others will not.

The facts are that it is in the fisherman's short-run benefit to catch all of the fish he can as quickly as possible, since the fish he conserves today will simply be caught by someone else tomorrow. It is not only that common property resources like fish are not conserved, but also that they are subjected to a kind of escalating exploitation as fishermen vie with each other to increase their share of the catch. As a number of economists have pointed out, the result is inefficiency, over-capitalization, higher prices for fish, over-exploitation of the fish resources, declining catches, and, where opportunity costs are high, the acceptance of low incomes (Crutchfield and Pontecorvo, 1969; Hardin, 1968).

Clearly, behavior which benefits individual fishermen does not benefit the fish. We have been aware of this for several years. Strangely enough, fisheries biologists tend to assume that the reverse is true--namely, that what is good for the fish is good for the fishermen. After all, they argue, if there were no fish, there would be no fishing industry. They are fully aware that fishermen rarely go along with their plans to manage fisheries, and sabotage them at every turn. The biologists and administrators usually interpret this behavior as evidence that fishermen are irrational, perhaps a little stupid, and certainly not capable of acting with their own enlightened self interest in mind. Usually, the biologists are quick to urge the kind of repressive measures and forced regulation of the industry that are common to countries with no democratic tradition. The results are political disaster. The idea that the basic axiom on which they are working might be completely untrue does not easily suggest itself.

In many fisheries (perhaps most fisheries) the idea that what benefits the fish benefits the fishermen is utterly false. The imposition of new fisheries management regulations is very likely to represent a loss of income to fishermen. There are several sets of factors involved. First, the results of fisheries management programs will probably not show up for years. This means that the costs of management (in terms of decreased catches) will be borne by the men currently in the fishery. The benefits will be gained by future generations of fishermen. Second, even if the benefits of management were to occur relatively quickly, the men currently in the fishery would bear the costs, but they would not be the only ones to gain. In the Maine lobster industry, for example, a substantial proportion of the licenses are held by men who are not active fishermen, but who would become active if the catches and potential revenues to be gained from the fishery increased. Full time Maine fishermen are not likely to take kindly to management schemes which put all the costs on them and benefit the hated "part-timer." I believe a similar situation exists in most other major fisheries in the country.

Third, management of fisheries will clearly pass on other kinds of costs to the people in the industry which reduces the utility they receive from management. One of the most important mangerial plans likely to be adopted under Pl 94-265 is limited entry. (This will solve many of the problems discussed above but not all of them. It certainly cuts down on fishing effort; and it solves the problem of inefficiency, since it removes from the fishery boats whose marginal productivity is zero.)

Limited entry will certainly affect employment.* It could easily operate to decrease the number of people employed in the fishing industry. Many of these people may be forced to move to new areas, and get retrained in some new field. For them, the monetary costs of limited entry may be very high.

Such plans might also affect the distribution of income by greatly increasing the income of those remaining in the fishery, and lowering that of people who are no longer allowed to fish. Most important, such management plans promise to disturb the basic cultural factors in ways that pass on the costs to fishermen (e.g. Acheson, 1976). In order to understand the benefits which accrue from fisheries management, we need solid information not only on the way management proposals will affect the costs and receipts of fishermen, but also information on institutional elements--the people who are supposed to benefit, those who are not, perceptions of benefits, etc.

Since the biological benefits of fisheries management cannot always be gained except at the expense of social and/or economic benefits, fisheries must be managed with multiple goals in mind. Instead of a clear cut single objective, the fisheries manager must deal in the hazy area of trade-offs. It is a world

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*Decreasing the number of boats may decrease the total number of people employed; on the other hand, a limited entry plan places a premium on efficiency, and could stimulate a boat building boom.

in which he can only protect the fish by incurring the wrath of the fishing industry; a world in which efforts to please the constitutency can mean biological disaster for a species. If this view of the problem is correct, then the fishery manager may be able to do little more than isolate all the managerial options that will help to solve the biological problems of the species, and pick the one which will cause the least social, political, and economic disruption. In other words, the information on benefits will do a manager little good unless it is treated in terms of some kind of multi-goal analysis. Many problems may be able to be handled via linear programming but I strongly suspect that the data on benefits can only be converted into optimal solutions for fisheries if some enormous econometric modeling problems are solved.

B. Cultural Compatability. In the past, many fisheries management plans have apparently been effectively opposed by the fishing industry because they threatened valued cultural patterns and existing institutions. Obviously, plans will succeed best in the political arena if they are compatable with existing institutional arrangements, or at least do not threaten traditional patterns any more than absolutely necessary.

This is not to say that fishermen are against all change, and that no fisheries management plan should change any traditional patterns. Fishermen may oppose certain changes, but they may be very happy to see other traditional features go. Of course, imposing regulations on an industry that has hitherto been unregulated is bound to cause a certain amount of disruption.

The aim of the manager should not be to avoid change, as much as avoid changes that will bring political opposition. I am not suggesting that managers attempt to manipulate the fishing industry. Quite the contrary, managers, where possible, should seek to ride the crest of social change, and take advantage of existing institutions. Above all else, they should avoid, where possible, proposing regulations which threaten key institutions and values. These are all basic axioms of applied anthropology. In the American fishing industry, however, it is far easier to talk in vague generalities than give specific examples of the way these principles can be applied to the management of specific fisheries. There are very few studies of U.S. fisheries that can serve as examples (e.g. Acheson, 1976).

The Canadian experience in Newfoundland provides us a case study of what can happen when these principles are ignored. The Government of Newfoundland decided to entice people from the small fishing outports to larger cities where schooling, medical services, and other Government services could be provided, and where modern piers and packing facilities for the fishing industry could be located conveniently. There is no question that the policy appeared rational on economic grounds, since it would allow the Government to provide additional services to a larger proportion of the people of Newfoundland at minimal costs. This migration to the larger cities, however, proved so disruptive to the traditional social institutions and culture that alcoholism, insanity, crime, and other social problems increased greatly.

The policy which allowed the Government to provide services made people live in a manner which removed much of the meaning from life (Brox, 1969). There is no way to compensate a man for a sickness of the soul.

The important points concerning the acceptability of mangement plans may be summarized as follows:

a. Plans which may be biologically beneficial may result in high economic and/or social costs. The opposite is also true; thus, management must necessarily involve some very difficult trade-offs.

b. It cannot be assumed that what appears to be in the short-run economic benefit of the fishermen will necessarily be favored by them. They may well be willing to trade off additional income for other social ends.

c. We need a lot of information on the social and cultural systems of coastal communities to identify key institutions and social features which managers might take advantage of or avoid disturbing.

d. Information on the compatability of management plans with institutional features of coastal communities can only be assessed after long study. One cannot obtain good information on key institutions, basic values, etc. by using survey research techniques, given the fact that no baseline information exists.

e. We can expect great regional variation. Management plans which might be perfectly compatable with the culture of fishing communities in one area might cause great problems in another.

f. Information on the acceptability of various management plans might not tell the eight Regional Councils how to manage the various fisheries in the respective areas, but it would give them valuable information on what to avoid (i.e. the kinds of managerial options which would raise a great deal of political opposition).

III. Innovation and Factors Affecting Impact

The concern with "impact" can hardly be ignored. Fishermen, processors, dealers, Governors, Congressmen and other politicians at all levels are going to want to know what the effect of Pl 94-265 is going to be. And the Fisheries Councils charged with managing the marine fisheries under Pl 94-265 will need similar information if they are going to make sensible alterations in fisheries regulations as conditions change in the future.

Two factors make it especially difficult to measure the so-called "impact" of a resource management bill. First, when we are talking about assessing the "impact" of extended jurisdiction, we are talking about predicting events in the future. The role of seer is always difficult. Second, the term "impact" refers to all the ramifying effects throughout the social system of a major change in fishing practices. These effects are apt to be far more extensive than anyone realizes. Extended jurisdiction will undoubtedly affect everything from fishing technology, crew size, catches, income levels, employment levels, migration rates, relative population of communities, to social problems such as the level of alcoholism, delinquency and crime.

¶ The task is made a little easier by the fact that there is no need to measure all possible effects of management bills. For example, if effective management of the U.S. fisheries becomes a reality, it is safe to assume that the quantity of fish landed will increase, and the price will decrease, which should bring about increased consumption. If the availability of fish increases, housewives in Kansas might well want to explore new ways of presenting fish to their famllies. Thus, changing recipes for fish products might ultimately be one of the effects of extended jurisdiction, but it is certainly far from critical.

It is important to measure some of the massive immediate effects of the bill. In my opinion the proper place to begin a study of these important effects (impacts) is if Pl 94-265 is to focus on innovative behavior of fishermen.

The relationship between "impact" and innovation is not at all clear and demands explanation. We will first discuss "impact"--a broad, if vague term--and then concentrate on one specific aspect of this topic, namely innovation.

The overall impact of extended jurisdiction will depend on a number of factors: a. the types of management plans being contemplated, b. the effect of the management plans on the economic environment of fisheries. c. the response of boat owners and captains to changes in the economic environemnt, d. the ways in which the decisions of boat owners will affect the communities in which they live, and e. the influence of cultural and social factors on the decision process. In short, in order to talk about the impact of the bill, we need to know a good deal about the bill itself, fishing practices, the structure of coastal communities, and the links between these factors.

It is important to note that Pl 94-265 does not specify any of the kinds of management plans to be imposed. But the bill does lay down certain guidelines within which fisheries management will take place. Four features of the bill are of interest: (1) A quota will be established for all species. (2) The foreign fleets will be allocated only that part of the quota which the small American fleets are incapable of catching (Pl 94-265: Sec. 101). It is expected that the American fleets will expand, so that, in time, foreign fishing efforts will decrease, and perhaps cease entirely. (3) As we have mentioned, fisheries will be managed for optimum sustainable yield, which means essentially that they will be managed not only with biological factors in mind, but social, economic and historical factors as well (Pl 94-265: Sec. 303). (4) Fisheries management schemes, wherever possible, will promote economic efficiency (Pl 94-265: Sec 301). Limited entry schemes will be given high priority.

All of these factors working in combination will undoubtedly bring about major changes in the fishing industry. Catches will most likely be larger. There is speculation that fishermen will have to purchase larger boats with more sophisticated equipment if they are to fully exploit the whole 200 mile zone. Such boats will presumably require a labor force with more sophisticated skills who will use different fishing strategies than are used at present.*

The larger, better equipped boats and larger catches will require larger piers, better maintenance facilities, larger processing plants, and better transportation facilities. In all probability, there will be a strong tendency to locate all of these facilities in a few central locations. If this occurs, the fishing industry will become increasingly centered around a few larger harbors. In addition, the United States may well become an exporter of many species not a part of the conventional U.S. diet (e.g. squid). In the New England areas, for example, this will probably mean that fish which are presently taken by the foreign fleets will be taken by American boats and exported to foreign countries. But all this is mere speculation, albeit speculation by some very expert observers.

Extended jurisdiction was certainly designed to lay the groundwork for the gradual expansion of the U.S. fishing industry. It is by no means a foolproof solution to the problems of the industry. As in all cases of economic development, there are a multiplicity of factors involved (Gill, 1963:7-20, Myint, 1971).

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*Such boats may not be gigantic, however, Cyrus Hamlin, a noted marine architect, states that the most efficient-sized boat to fish New England waters under extended jurisdiction will be no larger than 120 feet and will probably use equipment which has already been developed for use in other parts of the world.

Even with extended jurisdiction, the fishing industry may not revive if there are no markets for fish, if capital for new boats and technology is not available, if piers, transportation facilities, and other kinds of infrastructure do not change accordingly, and if New England fishermen will not or cannot catch and process the kinds of fish demanded (Wilson and Peters, 1976).*

While it is difficult to predict exactly what will happen in the American fishing fleet, it is reasonable to assume that the future will see increased economic opportunities in fishing. If this is true, then the impact of extended jurisdiction will ultimately depend, in large part, on the degree to which the people of coastal communities can take advantage of these opportunities.

Simply put, if large numbers of people are willing and able to invest in new boats and processing equipment embodying new technology, fish for new species, exploit new markets, etc., then the ramifying effects throughout the social and economic structure of coastal communities will be enormous. However, if fishermen cannot or will not respond, then it is reasonable to assume that the offshore fisheries of the U.S. will continue to be harvested by foreign vessels or there will be a radical shift to large corporate fishing enterprises. This may be true even

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*The people of the U.S. will have very little control over some of these factors. Their fate, to a large extent, will be tied up with such things as: the quota set by the Federal Government for foreign fleets, the tariff set for Canadian imports, the decision of large corporations to locate processing and maintenance facilities in the area, the prices of fish in the U.S. and abroad, etc.

though the actions of market forces, Government agencies, etc., present the people of coastal areas with substantial economic opportunities.

A central problem then--perhaps the key problem--is to understand the ability of the people of coastal communities to adapt to a new economic environment including the (highly probable) need to adopt new or unfamiliar fishing technologies. The ramifying effects of such changes throughout the rest of the social system cannot be reasonably assessed until this problem is solved.

Fishermen can respond to the new economic opportunities presented by extended jurisdiction; a. by adopting new boats and sophisticated fishing equipment, b. by adopting new fishing and marketing strategies. We fully expect fishermen to eventually use newer fishing gear and exploit new marketing mechanisms, etc., but it is possible for a person to do one and not the other. Both kinds of innovation are important to understand.

The social science literature on innovation and technical change is enormous. However, there are several themes in this literature that have special bearing on the problem at hand.

a. When new economic opportunities are presented to the people of a culture, the response to them is typically highly differential. Some people adopt the innovation; other do not. Neither communities as a whole nor groups accept innovations _en mass_ (e.g., Hagen, 1962: chaps. 6 & 7; Kunkel, 1970: 55 ff.; McClelland, 1961; Ryan, 1969: 91 ff.).

b. There is a marked difference between "early adopters" of an innovation and those who adopt innovations later in the cycle (Rogers and Shoemaker, 1971: 175-196). Usually, the "early adopters" are unusual individuals, sometimes even marginal or imperfectly integrated into the community. Typically these people repeatedly adopt innovations, despite the fact that they are inevitably sanctioned to one extent or another (Barnett, 1953; Merton, 1968: Chap. 10; Rogers and Burdge, 1972; Chap. 13; Ryan, 1969: Chaps 5 & 6). Only after the innovation is established and/or obviously profitable will it be accepted by the rest of the community. A few people adopt innovations long after everyone else, if they adopt them at all.

c. Many innovations are never accepted by the people of a given culture. Whether or not an innovation is accepted depends on a wide variety of social and economic factors (Wharton, 1972). However, several factors are mentioned repeatedly: a. profitability or utility of the innovation, b. compatability with existing norms (Linton, 1936: 341), c. where the innovation consists of new productive techniques, potential innovators must be able to obtain the minimum set of factors necessary for a viable business or production operation (Acheson, 1972a; Gold, Pierce and Rosseger, 1975; Kunkel, 1970: 262-274).

d. The speed with which the innovations are accepted again depends on a variety of factors: profitability (Mansfield, 1968: 4-5); social factors affecting the transmission of skills and technical information (Rogers and Shoemaker, 1971: 200 ff.); the degree to which the norms of the community are so-called "modern norms"; and the assessment of risks and anticipated results (Kunkel, 1976).

If this information is applicable to the United States we would expect some people to be able to adopt innovations in the form of larger boats and sophisticated fishing equipment, and to fish for new species to supply new markets. Others will not. The questions are: How many people will be able to adopt such innovations? Under which conditions? At what speed? The number of social, cultural and economic factors involved in answering such questions is enormous.

Since technical innovation involves some different issues than economic innovation (new markets, new species), we will discuss these issues separately.

A. Technical Innovation

In order to assess the ability of U.S. fishermen to adopt new technology in the form of new boats and fishing gear, we need to answer three questions especially.

First, what assets must men have to successfully adopt new fishing technology and larger boats?

Second, how many men in a particular area have the requirements for a successful large scale fishing operation?

Third, of the men who control all of the viability requirements for a successful large boat operation, or can easily acquire them, how many are actually interested and motivated in investing in modern equipment?

All of these questions pose serious problems.

Question 1. What assets must men have to successfully adopt new fishing technology and larger boats?

Capital. The ability to amass capital depends not only on the ability to save, and on having network ties to institutions granting large amounts of capital, but also on certain kinds of kinship ties. There is some suggestion that capital for new fishing enterprises is often amassed by forming partnerships with close agnates as fishermen do in other countries bordering the North Atlantic (Löfgren, 1972: 91; Nemec, 1972: 17 ff.); under other conditions, men are set up in the fishing business by affinal relatives.

Skills. There is a great deal of evidence to suggest that fishing and maintenance skills may be among the most critical factors influencing output of fishing boats and determining success in commercial fishing, but it is very difficult to define these skills and measure their effect on the production of fish. Recently headway has been made in solving these problems (Acheson, 1976).

Crew Organization. Larger boats which can remain on fishing grounds for days at a time require a very different kind of social organization of crew members than small boats which go day tripping or stay at sea for only two or three days (Anderson, 1969; Arbuckle, 1970). Crew organization is far more critical to a successful fishing operation than has been previously realized. Several large scale offshore fishing operations have foundered due to crew problems. The most famous cases are those of Sea Freeze Atlantic and Sea Freeze Pacific, two U.S. built factory ships that went out of business due to inability to organize crews, but the Russian and Polish offshore fleet has had many problems as well (Banaszkiewicz, 1964).

Social Ties. In many areas, not everyone is allowed to go fishing. The norms regulating entry into fisheries vary somewhat from area to area and from fishery to fishery. In the Maine lobster industry, for example, a person needs to become socially accepted as a member of a "harbor gang," and after he has gained membership, he can go fishing in that harbor's traditional territory (Acheson, 1972b; 1975a; 1975b; 1976; 1977). In southern New England, the social factors influencing recruitment into the fishing industry are very different, although kinship plays a key role here as well (Poggie and Gersuny, 1974). On the whole, the right to go fishing appears to be connected to membership in certain kinds of "communities", which in turn, is apparently affected by adherence to a large number of community values and accepted institutions. Among the most important factors are church membership, membership in certain voluntary organizations, family ties and history, a value placed on income equity, choice of residence, etc. In studying this aspect of social ties, men who were admitted to the fishing industry and those who were not should be compared. All of these factors will probably play a role in developing a viable offshore fishing business, and they therefore need to be understood in detail.

Question 2. How many men in a particular area have the requirements for a successful large scale fishing operation?

It is relatively easy to assess whether a man can or cannot effectively adopt fishing innovations at any given time. It is much more difficult to use this information to predict what he can do in the future. A man who might be so unskilled that he could not enter a large scale fishing operation at the present, might find himself in a very different position after several years experience in fishing. Some assessment of this situation could be gained by studying the strategies which men currently engaged in large scale fishing have used in getting assets necessary for adoption of better fishing technology.

Question 3. Of the men who control all of the viability requirements for a successful large boat operation, or can easily acquire them, how many men are interested and motivated to invest in modern equipment?

In the United States, many successful fishermen are highly innovative (Smith 1976:34). However, it cannot be assumed that everyone, or even a large number of men, who could possibly move into large-scale offshore fishing will do so immediately. People who exploit common property resources have such strong feelings about "sharing" and "equity" that strong social barriers are often erected against adopting any technological innovations which would give some men a competitive edge (Acheson 1976; Gersuny and Poggie 1974). If and when a set of "early adopters" does manage to adopt new offshore fishing technology, there is no reason to believe that a large number of other people will necessarily rapidly follow suit. Relationships between fishermen are usually marked by a situation of "competitive withdrawal" (Crutchfield and Pontecorvo 1969), secrecy, and an unwillingness to share information or transmit skills (Anderson 1972:120-120; Orbach 1975b). Under these conditions, men who have successfully adopted an innovation will not be likely to make it easy for others to emulate them. Social barriers will undoubtedly keep men with other characteristics from even attempting to enter fishing under extended jurisdiction (Acheson 1977).

In order to study patterns of adoption of new innovations, data should be gathered on owners of: 1. small boats, and 2. large boats. Particular emphasis should be placed on gathering data on: 1. the characteristics of men who were "early adopters" of innovations in the past, 2. the factors necessary for successful adoption of large boat technology--including capital, skills, crew organizing ability, etc., 3. the social, economic and cultural factors which in the very recent past have impinged on the decisions of men to innovate or not. Last, special focus should be placed on studying the men who control all of the viability requirements for the adoption of new boats and fishing technology, in an effort to discover which of them is likely to adopt or not adopt innovations. Some information on this topic can be obtained by direct questioning of fishermen about their plans for the future. In addition, two other kinds of information should be collected on these men to assess the probability of their adopting new fishing technology: 1. biographic information--especially information on their job experience and innovations they have adopted before. Men who adopted or refused to adopt innovations in the past are likely to do so in the future. 2. a test such as the Thematic Aperception Test (TAT Test) to measure "need achievement" (n-Ach) might be administered to all those who could possibly adopt new boats and fishing technology. The TAT test is a standard research instrument and relatively easy to interpret. It has been used with great success in predicting the motivations of entrepreneurs in the United States.

B. Economic Innovation

The future will undoubtedly see a larger number of American boats fishing off-shore areas than there are at present. Certainly this will mean that a large number of men will have to adopt larger boats than they have now, and probably they will equip them with more sophisticated gear than is presently in use in the antiquated American fleet. However, extended jurisdiction will undoubtedly create still other possible avenues for entrepreneurial activity--namely it will open new markets for species now caught as well as markets for species not caught at present. Here again, it is reasonable to assume that the response to these economic opportunities will be highly differential. Some of the factors influencing patterns of acceptance or rejection of these opportunities are similar to those affecting technical innovation. But there are some major differences as well. When we are studying the responsiveness of fishermen to new markets, we are essentially asking about their ability and willingness to catch new species and process them in ways that make them saleable. Two questions are paramount: 1. Under what conditions will fishermen exploit new species and markets? 2. How many fishermen will exploit a set of species under a given set of conditons?

Studying the conditions under which fishermen will exploit new species is greatly eased by the fact that fishermen now often exploit multiple species over the course of the year. Many species are over-exploited, and some species are greatly underutilized. But there are very few species which are not caught by someone, some place, at some time during the annual cycle off the American coast. At present, it appears that price is one of the primary factors influencing the decision of fishermen to exploit various species. That is, they often opt for the species which will give them the highest revenues relative to costs. If this is generally true, then we would expect that a change in the economic climate, especially changes in ex-vessel prices, would be one of the key factors influencing the responsiveness of fishermen to exploit new species.

However, social and cultural factors clearly play an important role as well. It has been noted, for example, that large numbers of fishermen strongly resist the idea of cleaning fish on board ship and undertaking certain procedures to reduce the bacteria count in fish holds. Their unwillingness to accept innovations such as these will certainly limit their ability to enter certain markets. Given the fact that structural and institutional features appear to block the responsiveness of some or all fishermen under certain conditions, it is to be expected that fishermen might have a strong preference for entering certain markets and an aversion to others. This may be true despite changes in prices brought about by the imposition of extended jurisdiction.

In order to study the social, cultural, and economic factors influencing the decisions of fishermen to enter certain markets at present, two kinds of studies are needed. First, data need to be gathered comparing fishing practices of boats which exploit a wide range of species over the annual cycle with those that do not. Emphasis needs to be placed on gathering data on such factors as the prices paid for fish, the catch of various species, the locations where fish are caught, etc. Interviews should be obtained with fishermen concerning their decision to enter a given market (i.e., exploit a given species requiring certain handling and processing procedures), and the social and cultural factors inhibiting them from entering others. Second, a set of questionnaires might be administered to a carefully selected sample of fishermen to obtain data on revealed preferences of captains concerning entry and exit from particular fisheries.

This kind of information is of particular importance for fisheries managers. A knowledge of the factors affecting entry and exit into different markets would allow managers to devise schemes influencing ex-vessel prices paid (e.g. taxes and subsidy) to influence the relative fishing pressure on various species. Such an approach to fisheries management has been suggested (Wilson and Olson 1975; Wilson and Anderson 1977).

AVAILABILITY OF INFORMATION

As we have pointed out, very little social science research of any kind has been done on fishing communities in the United States. As a result, almost none of the information is available to complete the three kinds of studies recommended here.

There are only a very few monographs on modern fishing communities (Bowles 1973; Grossinger 1975; Orbach 1975a; Poggie and Gersuny 1974).

No ¶ Few of these works are in published form as of yet. There are also a few books on ancillary topics such as organization of fishing crews (Arbuckle 1970); longshoremen (Pilcher 1972); fish marketing (Peterson 1974), and attitudes of mill workers and fishermen (Poggie, Bartee and Pollnac 1976). There is, however, good coverage on fishing communities of the North Atlantic--especially Newfoundland (Anderson and Wadel 1972; Brox 1972; Chiaramonte 1970; Dewitt 1969; Faris 1972; McKay 1975; Young 1975). A great many of the ideas and observations in this body of literature are almost certainly applicable at least to New England and perhaps other more distant areas as well. However, we do not have the kind of detailed studies of important fishing communities which will give the kind of background data and understanding of key institutions which fisheries managers need.

In the past few years several survey research studies have been done on fishing communities in the United States which supplement the data already available from the U.S. Census. Bill Mustard carried out a study of all the U.S. fishing industries under the auspices of the Eastland Resolution. Virgil Norton from the University of Rhode Island has run two surveys in New England, along with Smith and Peterson (Woods Hole Oceanographic Institute), and Wilson from the University of Maine. Most of the data collected in all of these cases concerns economic aspects of the New England fisheries. On the entire eastern sea board the only recent survey research work focusing on cultural and social aspects has been done by Peterson, who gathered data on the off shore New England trawler fleet, and myself. I have gathered some data on Maine lobstermen and their attitudes towards management, and I have spent some 3 weeks gathering data on shrimp fishermen in North Carolina, South Carolina, Georgia, and Florida (Acheson 1977). To the best of my knowledge my pilot study is the only survey research work that has been carried out in the south on the social science aspects of fisheries management. I am far less familiar with the work on the west coast, but some local surveys may well have been carried out in these parts of the country.

Of course, the National Marine Fisheries Service compiles a great deal of information on landing and fish prices. The Bureau of the Census has compiled general data on fishing as an occupation and on communities where fishing is done. Given the general absence of information on the U.S. fisheries, the data from these agencies is invaluable.

Unfortunately, none of these studies provide the detailed kind of basic demographic data needed. The U.S. Census data are very superficial and the data are aggregated in ways that give a picture of units no smaller than towns. The National Marine Fisheries Service collects only data on such items as species caught and a little data about the fleet. There is no information about fishing effort, or any other kind of data on social and political institutions or economic performance.

Most of the other studies mentioned above are oriented toward the collection of economic data--and most of the University studies have been restricted to New England. They do not give us socio-cultural data on the U.S. as a whole. More important, there is no way the information from these various studies could be conveniently synthesized. The raw data from one study could only be added to the data from another if all of the original interview sheets on the same person or boat were recoded and run through the computer again. This would not only be very time-consuming (assuming principal investigators would release the data), but it would scarcely be worthwhile given the fact that additional information needs to be collected. Rather than attempt to resynthesize existing data, etc., it would be far better and easier to do another survey containing questions on <u>all</u> the relevant social and economic factors in all coastal areas of the U.S.

In summary, virtually none of the baseline data (either survey research or in-depth studies) exist at present. The same is true for the data on social and cultural factors influencing reactions to management proposals. This information could be obtained at a reasonable cost in a short period of time. The existing survey research data and ethnography about fishing communities, though scanty, might speed up the process of obtaining such information.

In the case of the studies concerning technical innovation and the impact of extended jurisdiction, the situation is somewhat different. Little of the specific data needed exist (e.g. data on skills, capital, crew organization, etc.), but here there is an enormous body of theoretical literature to draw on. Where there are only a handful of studies dealing with support and opposition to management plans, there are literally hundreds of studies and hypotheses concerning diffusion and technical innovation (see Rogers and Shoemaker 1971). Since there is far more on which to build, it should be easier to pinpoint the kind of data needed, and results should come far more swiftly and surely.

Literally all of the data required for the three kinds of studies recommended in this paper have yet to be gathered. As one can see from the bibliography, social scientists have, as yet, paid very little attention to fisheries management. Social scientists, however, have done a good deal of work in areas which could quickly be applied to a study of fisheries--particularly in the area of social organization and technical innovation. The largest single problem we face is not gathering the information, but gaining an understanding of how fishing communities in various parts of the country work and synthesizing the social information with biological and economic information. A synthesis, however, can only be attempted after the tremendous imbalance in the kinds of data available has been corrected.

Timing

Three kinds of studies have been recommended in this paper: 1. baseline studies (community studies and survey questionnaires), 2. studies on factors influencing the acceptability of various management plans by the industry, and 3. studies of ability to innovate. The information needed for all three of these studies overlaps a great deal. That is, much of the information needed for the baseline studies will be useful in doing the other two. The baseline studies and the studies of factors influencing reaction to management are particularly close. I see no reason why the two could not be combined. Questions on management might be included in the baseline questionnaires; and the depth community studies could gather data on key institutions--the entities managers want to avoid disturbing if possible. (This is the question of cultural congruency of management plans). The kinds of questions concerning benefits of management alternatives would demand additional study. The same is true for studies of factors influencing technical innovation.

The first kinds of studies to complete are the depth studies of important fishing communities, since all the other studies can draw on the information generated to one degree or another. Anthropologists and sociologists usually spend about a year gathering data (if they have no language problems), and it usually takes another year for the data to be analyzed and written up in final form. Thus, if all ten to fifteen community studies were begun at the same time, it would be reasonable to expect that we could produce a set of monographs in about two to three years.

Second, a survey research project should be completed and include questions not only on the demographic issues, but also on attitudes towards management proposals and factors necessary to study technical innovation. The questions to be included in those questionnaires might very well depend on the part of the country being dealt with. Obviously, questions pertinent to the lobster industry (e.g. how many traps do you fish?) would not be applicable to the Eskimo areas of Alaska where one might want to ask about other things (e.g. How many "sticks" of fish do you feed to your dogs?).

The amount of time such a study would take depends greatly on the number of interviews needed to obtain statistical reliability. I have estimated that 6000 interviews would be necessary in the entire coastal region of the United States. If we assume that one man can do two good depth interviews per day (1 hour plus each), then some 3000 man-days would be involved. If a 20 man interviewing crew were put to work, all the survey data could be obtained in about 5 months, and it could be key punched, tabulated, and put in usable form in another 6 months.

Once this survey research information was available, the remaining studies could then be begun: the innovation studies, and completion of the studies concerning the acceptability of management alternatives. All of these would involve depth interviews in about 10 to 15 locations--perhaps the same locations where the community studies were done. In any location, these two kinds of studies would take 6 months each for the interviews and another 6 months to analyze the results and produce the final report. However, these two kinds of studies could not be done by the same person in any given area, since the kinds of people who have the analytical tools to analyze costs and benefits of various management alternatives would not be able to concentrate on the very different issues connected with studying technical innovation and impact at the same time. Thus, these final studies would demand two man crews in each of the 10 to 15 locations.

In summary, from the time of inception, all of these various cumulative projects could be completed in about 4 to 5 years. The result would be the very best social science coverage of fisheries in the world. The cost would not be low, but it would be very small in comparison with the millions of dollars spent on biological research every year by the State and Federal agencies concerned with the marine resource management. The major costs are salaries and computer time. Social science research is very inexpensive in comparison with research in the physical sciences where laboratories, ships and technicians by the dozens are required.

Warning: All of the ideas expressed in this paper are my own. They do not represent any kind of consensus on the part of social scientists experienced in fisheries. Moreover, all of these ideas have been strongly conditioned by my own field experiences--in Maine and the South Atlantic states. Other social scientists with experiences in other kinds of fishing communities will undoubtedly want to modify many of these ideas and perhaps make major alterations in concepts, etc.

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COMMENTS FROM REVIEWERS

"Speaking in terms of Northwest fisheries, management systems can be based on good knowledge of the economics of the industry. The matter of social consequences of alternative actions is going to be a problem for the Councils to deal with. It is obvious that these latter decisions are going to be based in many instances on political considerations so as to deal with the relevant social or ecological factors."

--from W. V. Yonker, Executive Vice-President
Association of Pacific Fisheries
September 14, 1976

"The type of socio-economic factors that I would consider pertinent would at a minimum include the entire seafood industry from catching to marketing and promotion and, on a broader scale, the balance of payments, and overall regional development that may be competitive or complimentary to the fishing industry, eg OCS oil production. As I've pointed out in earlier communications, any study related to fisheries has little other than academic meaning if stocks are not maintained at viable levels. The impact associated with the disappearance of a fishery will be no less severe even if we have gained 'an understanding of basic social and cultural features of fishing communities......'"

--from Robert M. Snyder
Snyder Oceanographic Services
November 11, 1976

"The community focus ... is one of anthropology's most developed methodologies and offers a significant contrast to the firm, county, and larger political unit focus of economists. The community studies ... would be informative and provide important baseline data. Two alternative approaches, however, might also be considered.

"One would be to adopt a conflict resolution focus and study existing and potential conflicts between resource users. Pacific northwest salmon allocation; recreation-commercial competition for albacore, bluefin, and swordfish; U. S. - Mexico shrimp relations; the impacts of resurgence of marine mammal populations; etc. are conflicts which could be the research focus of anthropologists and other social scientists. This would be a social issue, rather than a community study approach.

"A second alternative would be to take more of a systems view. Fishermen and fishing communities are one component in the harvest system composed of the biological system, and a social system which includes buyers, processors, wholesalers, market, and consumers. This fish harvest system is overseen by a number of regulatory agencies and cross-cuts a number of communities. What impacts do market relations, consumer patterns, environmental concerns have on the ways fish resources are used? A systems approach emphasizes factors external to local communities which may affect their opportunities and activities."

--from Courtland L. Smith, Assoc. Prof.
Department of Anthropology
Oregon State University
November 30, 1976

"It must be made clear ... that the information required on the social and economic aspects of the Act is not simply time series or head counts. Although demographic data is one important part, the more significant information must come from detailed, analytical community studies. These efforts take more time and cost more money than routine surveys, but are absolutely essential to understanding the effects of the Act on fishing communities."

--from Lauriston R. King, Program Manager
Marine Science Affairs
National Science Foundation
November 24, 1976

"The suggestion of 'standard monographs' has been tried with some success, e.g. Beatrice B. and John M. Whiting's six cultures study of child-rearing practices. Typically, however, anthropological monographs tend to be very diverse and reflect as much about the individual fieldworkers and their backgrounds as they do about the communities studied. Getting comparable monographs could be a problem. The study design would have to be carefully worked out in advance, and investigators would have to be in continual contact during the course of the study."

--from Courtland L. Smith, Assoc. Professor
Department of Anthropology
Oregon State University
November 30, 1976

"I disagree strongly with (the) discussion of baseline ethnographic studies. We do need quantitative demographic, social and economic data on a large sample of fishermen and fishing ports. Much of this can be collected by questionnaire, but first the qualitative information needs to be collected so that we have some idea of the importance of the quantitative material. Ten to fifteen community studies in the U.S. in NOT adequate. A small community study in Maine paired with a large port study in Massachusetts or Rhode Island wouldn't tell one anything useful from which generalizations could be made."

--from Susan B. Peterson, Research Assoc.
Woods Hole Oceanographic Institution
November 10, 1976

Working Paper No. 3

MARINE FISHERIES STOCK ASSESSMENT:
ISSUES AND NEEDS

Prepared for OTA
by
Development Sciences Incorporated

December 1976

TABLE OF CONTENTS

INTRODUCTION

This working paper was prepared for the Office of Technology Assessment as a part of its study of the background, methods and complexities of stock assessment and the role of such assessments in implementing the Fisheries Conservation and Management Act of 1976.

Passage of that law extended United States fisheries jurisdiction to 200 miles off the coast. Such action put one-fifth of the worldwide offshore groundfish resources under national management control. Management jurisdiction was extended in the spring of 1976, with initial management plans for selected species to enter into effect on March 1, 1977. Extension became necessary when it was realized that international management of offshore fishery resources had failed; the common-property nature of the fisheries prevented any individual or nation from assuming management control.

Stock assessment of fishery resources developed over time in response to the felt need that measures were necessary to predict species abundance and yield potentials according to different chosen priorities. Initially concentrating on single species, assessments sought to determine the abundance of year-classes, recruitment of individuals into the stock, the natural mortality of the stock, and the fishing mortality to be expected from man's harvesting activities.

Determination of stock abundance and size was accomplished through use of survey tows, size and age composition of individual fish, tagging experiments, and development of sophisticated models that were based on stratified random sampling techniques. Such sampling partly overcame the problem that it was impossible to observe fish populations directly.

As distant-water fleets developed during the 1950s and 1960s, assessments concentrated on providing information for the development of new fisheries in frontier areas. Such information required abundance estimates and assessments of potential yields. Consequently, great effort was expended to refine resource inventory methods.

At the same time, history had demonstrated that common-property fishery resources would eventually diminish under increasing fishing pressure. Ultimately, yields from those fisheries would exceed the capacity of stocks to replenish themselves.

Assessments, then, developed to predict the available yields under differing amounts of fishing pressure. Because it was impossible to observe a fish stock directly, the only means by which to gauge the short-term effects on the stock related to catch and effort: as long as increased effort produced yield increases, the stock was considered healthy. However, when increased effort produced the same yield or even yield reductions, the species was considered maximally utilized or depleted. Under these conditions, fishing mortality, combined with the assumed natural mortality*, exceeded the ability of the stock to reproduce itself through spawning and recruitment.

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* The need to assume natural mortality may be the greatest uncertainty in assessment theory; natural mortality must be assumed in any fish population because direct observation is impossible. Assessment theory attempts to determine yields through recommending a fishing harvest that, when combined with natural mortality, does not exceed the reproductive capacity of the stock. For example, assume that it is possible to remove 50 percent of a chosen stock on a yearly basis without reducing the capacity of that stock to reproduce itself to the same level the following year. If one assumes that 30 percent of that stock is lost to natural mortality, then a management goal would set an allowable harvest equivalent to the difference between the natural mortality and the assumed maximum allowable mortality. Clearly, if the natural mortality in fact is 45 percent, a fishing mortality based on the assumption of a 30 percent mortality will result in excessive removals from the stock. Thus, an incorrect assumption regarding natural mortality results in an incorrect yield strategy. Easily overlooked among the other complexities of assessment science, the fact that natural mortality must remain assumed indicates that yield estimates can only be general.

As it became clear that fishing fleet's technical ability to diminish stocks was growing, assessments sought to provide information upon which to make management decisions.

However, under International Commissions, management decisions were based upon political negotiations as well as biological considerations. While fisheries were expanding, the notion that the resources of the ocean were far from being overutilized was popular. Assessment science developed according to single-species indicators that were based upon the assumption that the effects of harvesting activity were relatively long term in nature; consequently, the science depended on complicated models that required extensive data and long periods of time to reach results.

Part I of this report describes existing assessment methodology. Information requirements are outlined, as are the necessary biological assumptions and the methods utilized. A discussion of the unavoidable complexities that drive research design of assessment methodology then follows, indicating a primary cause for the enormous data and time requirements that presently exist.

Fishing developments and activities have further complicated assessments. In the 1960s, particularly in the Northwest Atlantic, there occurred a sudden and massive introduction of factory-type vessels on grounds that had traditionally been very productive for small-boat, rural fisheries. Yields from popular banks more than doubled within three years. Species that had formerly remained underutilized were subjected to intensive-directed fisheries. As analysis of assessments for the Georges Bank haddock fishery indicates (Part II), many of the problems with assessments often had little to do with the scientific methodology itself. Indeed, the generation of data continued to be insufficient, the assessment community was forced to operate with little or no funding, and decisions determining possible yields were based on political and social factors rather than biological factors.

At the present moment, nearly all species of finfish in the Northwest Atlantic are overutilized. Estimates by the scientific community calculate that the total biomass of marine life found in the waters off New England has been reduced by approximately one-half. Recent development of multispecies fisheries often operated under lax enforcement or had no regulations at all. Yet the Northwest Atlantic has long been managed by the International Commission for the Northwest Atlantic Fisheries (ICNAF), an organization recognized by the world assessment community as practicing a high assessment state-of-the-art. However, within the space of a few short years, it became clear that the single-species orientation of assessments had to be broadened toward understanding of <u>all</u> species as well as their <u>interactions</u>. Part I of this report indicates that the development of comprehensive single-species understanding is itself an extremely demanding task, particularly today with the recent expansion of offshore fisheries toward species for which there previously existed no assessment information whatsoever.

The Georges Bank haddock example demonstrates that assessments have, since the late 1960s, been forced to operate in a "catch up" manner without a clear awareness of the validity of existing methods. Inadequate catch and effort data, constant technological changes in fleet activities, and improper feedback to the assessment community (due to the nonbiological basis of management decisions) all contribute to the shortcomings in assessment science.

Depletions have, in addition, placed pressures upon the scientific community to make yield estimates that are far more precise than the capacity of the science. A full understanding of the marine ecosystem the interactions that occur within it, and the effects upon that ecosystem of environmental conditions require studies based on years of observation. When combined with the rapid and significant changes introduced by fishing fleets (factory-type operations, stern trawlers, pair trawlers, improved electronics, and increased mobility), all of which accelerate the depletion of resources, it becomes clear that assessments have been forced to function within a highly variable situation that has placed enormous strains on the design of research programs.

In spite of such strains, however, assessments have achieved a relatively high level of accuracy. When determining species abundance--resource surveys--assessments are highly accurate; prediction of available yields based on fishing pressures, even given the present problems with catch and effort data, provide a degree of accuracy of roughly seventy percent. As outlined in Part III ("Assessment Capabilities and Needs"), data analysis through models and extensive programming appear to be sufficient, but two difficulties remain:

- <u>Problems concerning the accuracy of the data generated</u>;
- <u>Problems concerning the application of useful information within the short-term time requirements necessary to design management systems that will restore threatened stocks</u>.

Extended jurisdiction has invested tremendous responsibility in domestic assessment science. While international perturbations may well continue, it is now possible for management decisions to be based primarily upon biological considerations. However, existing fishing pressure continues to deplete offshore stocks at a rapid and devastating pace. The numbers of vessels in the distant-water fleets, combined with a growing worldwide need to harvest all potential stocks, force assessments to grapple with continued fishing efforts directed at severely reduced populations.

Thus, international pressure presently exists to take the last *available ton* from the ocean every year. At the same time, recent depletions argue for the imposition of *restoration strategies* such that the marine biomass returns to its former, more abundant level. Ideally, assessments should determine a specific yield for popular species such that the *maximum allowable catch is available within the constraints of a chosen restoration* goal. But as outlined in the following chapters, the data requirements to develop this comprehensive understanding are immense, as are the complexities, which include at least the following:

- Development of adequate catch and effort data;
- Adequate enforcement of management/biological decisions;
- Extension of surveys to inventory and assess all stocks;
- Design of models to predict the interactive nature of the marine ecosystem;
- Development of adequate biological assumptions upon which to base such interactive models;
- Full understanding of the environmental factors that influence potential yields;
- Full understanding of the effects of fishing activity on stocks in terms of the technology utilized;

- Awareness of the economic and social implications of various allowable yields, both domestically and internationally.

While this information, if developed, shall provide adequate data upon which to make yield decisions, the threatened status of many marine stocks argues that such information be useful for immediate short-term management decisions. Because the complexities outlined above have great impact upon the design of research programs, and because the immediate needs of stock assessment demand control of such complexities, the pressures to expand existing assessment methodology are great.

At the same time, however, assessment history has demonstrated that existing methods have not been properly validated, primarily due to inadequate data, even concerning those species of traditional value to domestic fishermen. Thus, while recognizing the need and pressure to expand present systems, the uncertain nature of such systems in terms of their accuracy speak compellingly for establishment of priorities within which future research programs be established.

At the same time, the status of stocks--and in fact the primary motivation for extension of jurisdiction--requires a reduction of fishing pressure to the extent possible, particularly distant-water operations, such that the marine biomass can recover.

Consequently, this report recommends (Part IV) the following program:

1. Test the validity of existing assessment methods during a chosen restoration period.

The major purpose of recent legislation is to promote the conservation and restoration of fisheries stocks. During this period, fishing pressure must be reduced drastically. Estimates of yields should be on the low side; if incorrect, the major consequences are that stocks will recover more rapidly while some economic opportunity is delayed.

During this restoration period, develop an harmonious time-series of data through accurate catch and effort figures gained via the use of observers on foreign fishing vessels. Develop a strict enforcement system. In addition, develop automatic plankton sorting and fish aging techniques, continue with design and development of hydroacoustics, and expand survey cruises to at least four times a year for several well-known stocks, not through the purchase of new research vessels, but rather through chartering commercial fishing vessels.

Stabilize technological changes in the fishing fleet such that the data generated is constant.

Assess the accuracy of existing assessment methods under this program and determine its degree of utility for management decisions.

2. While assessing existing methodology, establish research priorities for the future.

During the restoration period, establish the level of accuracy required for assessments under different management goals. For each chosen goal (for example, "last ton," "resource revitalization," "maximum yield for today." "maximum yield for the future," etc.), outline the key indicators that will be required to achieve the determined level of precision. Then, for each level of precision and those indicators that achieve that precision:

- Determine the probable cost
- Determine the time necessary to provide useful results
- Determine the relationship of each variable to assessment accuracy under the existing system (which is being validated through the above program).

The establishment of priorities and key indicators should directly involve working fishermen as participants, principally in essential working discussions testing existing assessment biological assumptions. In conjunction with increased surveys through chartering fishing vessels, the extensive expertise of direct producers shall be fully utilized.

3. Design a program strategy (regional Council)

As the existing accuracy of assessment is determined, and as differing management goals have been chosen with regard to required level of accuracy, cost, time needs, and level of increased utility with regard to existing methods, the following program strategy should be established:

- A listing of information needs, their utility, and their cost
- The precision of information necessary to achieve various management goals
- Based on the above analysis, choice of a cost-effective and useful assessment research program

PART I

STOCK ASSESSMENT BACKGROUND, METHODS, AND COMPLEXITIES

I. BACKGROUND

Stock assessment can be considered as the principal scientific tool utilized in fisheries management. As such, stock assessment attempts to develop an understanding of marine ecosystems and the effects of man's activities upon them. The mechanisms that drive marine ecosystems, as well as those that drive fishing activities, if understood, and if properly applied, serve as one means to predict the effects of future activities, and as such can and do contribute to fisheries management decisions.(1)*

Historically, stock assessment has studied individual populations of fish, and the biological basis for management has thus concentrated on the "single species" approach.(2,3) This approach has assessed the resource potential of one or another species of fish that has had commercial value to fishermen or that has promise of future value. For a very long time it was felt that the fishery resources of the ocean were inexhaustible and needed only to be found, harvested, and processed; stock assessment programs have often been designed with the objective of "...increasing the

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* By way of example, specific instances--drawn from the Georges Bank offshore groundfishery, the development of assessments for Georges Bank, and the history of the haddock fishery in particular--will be highlighted in Part II "The Georges Bank Groundfishery Example." Georges Bank demonstrates nearly all the issues that now face the assessment community under extended jurisdiction. An extremely productive fishing area, Georges is presently being severely overfished, yet has long served as the traditional harvesting area for the New England groundfishery. The value of Georges to domestic and foreign fleets has been reflected by more extensive assessment history and activity here than has any other area now falling under extended jurisdiction.

use of the living resources of the sea (Gulland, 1969)." (4)

Certainly the recent development of highly mobile distant-water fleets by many nations has required "...studies of the availability, distribution, abundance, and yield potentials of latent or little-used resources."(5) These studies continue at the present time (expressed, for example, in the National Marine Fisheries Service program to develop "underutilized species"), driven partly by a large existing infrastructure that has depleted many of the species of traditional commercial value.*

Assessments seek to develop information on what the maximum sustainable yield (MSY) of a fishery is; that is, fisheries are viewed as a renewable resource, dependent upon (1) the introduction of young fish into the population (recruitment); (2) their rate of growth; (3) their natural mortality; and (4) the mortality caused by fishing activities. The management goal is to not remove more from the population than can be replaced, thus allowing maintenance on a steady basis of an allowable surplus over and above the necessary parental stock to produce that surplus. The <u>principle</u> that catches should not exceed the level of MSY has found

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* Until the development of distant-water factory fleet operations in the 1950s, Georges Bank was harvested solely by American and Canadian vessels. During this era, the major species sought were haddock, cod, and yellow-tail flounder. Georges produced nearly one billion pounds a year of groundfish annually from the 1920s to 1960. In 1961, however, the Soviet fleet began to operate on Georges, and three years later over a dozen nations were heavily concentrated, fishing initially for species that had not been of commercial value to American fishermen: herring, mackerel, and silver hake. However, it soon became clear that species of value to domestic producers were being harvested also, and by the late 1960s Georges Bank was considered to have lost half of the formerly available biomass. By 1970, effort had increased seven times and landings three times from 1960--up to over one million metric tons from under five hundred thousand.

nearly universal acceptance in the international community.(6)*

Stock assessment, then, has traditionally served two purposes: provision of information and data for the development of new fisheries, and provision of information to maintain or restore depleted fisheries. These may be objectives with different consequences. They certainly serve to complicate a highly complicated matter. There exist a large number of uncertainties with existing stock assessment science: problems with the data <u>generated</u> by that science, as well as, more importantly, problems concerning the <u>use</u> of that data.**

Of paramount importance is the fact that offshore marine fisheries, particularly ground fish (demersal species), constitute populations that are nearly impossible to observe until harvested. As a result, assessment must depend upon inference, statistical probabilities, and the measures

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[*] In 1950 the International Commission for the Northwest Atlantic Fisheries (ICNAF) was created, with the express purpose of maintaining and enhancing the stocks of fish under its jurisdiction. With authority over international fisheries, ICNAF initially operated as a central clearing house for the development of new fisheries as distant-water fleets expanded. Funded by and large by American and Canadian money, ICNAF was forced in the mid-1960s to develop and attempt to enforce management regulations to preserve threatened stocks of fish. Needless to say, the pace of international negotiations was far behind the technological capacity of fleets to exhaust robust stocks. Thus, underfunded, undermanned, and depending on American assessment information that was itself vastly underfunded, ICNAF was caught playing "catch-up" assessments as one species after another declined.

[**] The sudden and massive introduction of increasingly efficient fishing technologies on Georges Bank during the 1960s only served to make more critical these uncertainties. Assessment scientists were forced to deal with a dynamic situation that constantly changed. The amount of data required was massive and yet often doubtful. Because threatened stocks were in international waters, enforcement of regulations was not possible, and consequently the feedback to the assessment community of decision results was difficult to analyze.

developed to understand the complicated and interrelated marine environment. As such, assessments depend upon the analysis of past information and trends to predict future fisheries developments.(7)

Fishing activities have continually changed as technologies have developed. These changes force adjustments in past data analysis to reflect future realities. Further, as fishing activities have varied, there exist environmental fluctuations and trends that are very long term in nature and are, as yet, poorly understood. This understanding is extremely difficult when technological changes continually perturb the time-stream of data.

Yet we have come to realize that, as awareness of the interrelatedness of marine species has grown, the biological foundation of marine ecosystems must be clearly understood.(8)*

Fisheries managers are pressured to treat stock assessment information with the same precision as other resource managers treat their data. However, while forest managers, for instance, can count the board feet of available timber, or while mineral assessments are based on the premise of a nonrenewable resource, fish populations cannot be counted. It is not enough merely to discover that they exist in commercial quantity. The concept

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* Whereas initial assessments concentrated on single species--for at that time single species were of major interest to harvesters--factory type operations were often unselective and essentially "clear cut" the marine biomass instead of "selective" fishing. While the implications of such efforts are difficult to understand, it has become clear, at least on Georges Bank through survey tows and other resource inventory methods, that mixed fisheries may have a synergistic effect, reducing the level of the biomass at a rate faster than one would assume. In 1972 ICNAF scientists began to argue for the study of interspecies relationships, clearly a far more complex undertaking than assessing one stock or another.

of <u>sustainable yield</u> places great demands on the science of assessments, demands that may require more precision from this probability science that it can be expected to deliver.

II. STOCK ASSESSMENT INFORMATION REQUIREMENTS(10,11,12,13)

In order to understand various fisheries populations, assessment science seeks to meet the following parameters:

1. <u>Determination of the Unit Stock</u>; i.e., the extent to which a fish population and the fishery based on it can be treated as a unit system (necessary for the purposes of calculation). This unit stock is determined by

- Distribution of the species
- Identification of spawning areas
- Age composition data
- Morphological and physiological characteristics (9)

2. <u>Population Parameters of that Unit</u>; i.e., the size and age composition of that unit stock.

- Rate of growth and source of food
- Food requirements
- Natural mortality
- Age of recruitment
- Basic productivity

3. <u>Effects of Environmental Factors on Stocks</u>

- Temperatures
- Bottom conditions
- Currents
- Seasonal changes
- Pollutants

4. <u>Effects of Human Activities on Stocks</u>

- Catch-effort coefficient, i.e., the amount of effort necessary to harvest a portion of the population

- Total amount of resource harvested in a given time span
- Degree of discards and by-catch, i.e., in a mixed demersal fishery utilizing nets--which are relatively unselective--species of no market value are usually discarded, and often other species of value are caught while directing a fishery at a particular species.

5. Interrelationships Among Species Information

- Identification of marine food chains and trophic levels
- Analysis of impacts of fishing activities on those interrelationships

The premise here is that awareness of the natural ecological system, combined with analysis of fishing activities in that system, will serve to predict an allowable harvest on a continuing basis. Thus, resource abundance studies are necessary, as well as data on the level of human harvesting effort, location, type of gear, and efficiency of gear.* Fishing mortality, when added to natural mortality, affects the size of the stock in that the degree of mortality is greater than that resulting from "natural" factors (not considering man), and may, if unregulated, so deplete the population that it cannot recover.

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* Georges Bank assessments are primarily carried out by NMFS personnel located at Woods Hole, Massachusetts. Until recently, such efforts were lacking in funding and consequently the comprehensiveness of the assessments was limited, concentrating on species of interest to American fishermen. In 1964, NMFS received a research vessel (Albatross IV) with which to perform survey tows, determination of unit stocks, population parameters of that unit, and environmental effects. Such surveys have been undertaken in the fall and the spring of the year, limited somewhat by budget and operating problems of the vessel. Effects of human activities on stocks have been gathered by ICNAF documentation, NMFS landing figures for the domestic industry, and some selected engineering studies. Broadly, the assessment community for Georges Bank has done an excellent job given the level of funding, international problems with foreign fishing data, and lack of enforcement for management decisions; extension of jurisdiction has for the first time instituted a formal national recognition of fisheries resources and the funding necessary to manage those resources.

III. BIOLOGICAL ASSUMPTIONS FOR MARINE RESOURCE ASSESSMENT*

Although there exist several biological assessment models, and although "...the methods used in fish population dynamics may differ (Schaeffer, Holt and Beverton, Rickert, all of whose methods have been refined and made more complex and exact by many specialists)..they are all fundamentally similar. They consist of a mathematical formulation systematically linking the main parameters of a fish population with the data that can be collected."(14)

These "parameters," however, cannot be interpreted without a clear awareness of the assumptions behind them, although in some cases the assumptions themselves are open to question, dispute, or doubt. Among the assumptions utilized are the following.

1. Basic Theory

$P = KI$

P - production
I - food intake of the prey
K - prey gross production efficiency

$Y = FB$

Y - yield to predator
B - average prey biomass
F - grazing/fishing coefficient

"...changes in predator numbers at different trophic levels lies in the fact that the yield to the predator is proportional to the average biomass of food particles present at a particular instant, and to the fact

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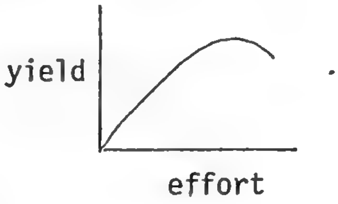
* Assessments for Georges Bank have been undertaken according to these assumptions, utilizing the methods outlined later in this report.

that each predator requires a certain 'economic' return from its searching efforts to maintain its metobolic 'economy' and to grow.

"It is from this point of view that analysis of the natural predator-prey system has special relevance to systems in which fishing vessels are the predators. The effect of heavy fishing on natural populations is to decrease the average size of the individual prey organisms, leading to an increase in the average production/average prey biomass (P/B) ratios of the exploited stocks. Under these conditions, increasing the yield by maintaining or increasing the ecological efficiency requires an increase in the grazing coefficient, F. Initially this may be accomplished by a simple increase in the numbers of fishing vessels. However, as the P/B ratios increase, the economic return to these large vessels drops sharply, limiting the possible increase in F."(15)

2. Identification of the yield-effort curve:

"When fishing is initiated an additional unit of effort produces a relatively large increase in yield. When fishing develops beyond its initial stages, larger increases in effort are required to produce the same increase in yield. Ultimately, more effort may even result in a decrease in yield...this diagram (below) is...the most fundamental element of the theory of conservation."(16)



3. Potential yield

"Within each resource the potential yield is determined by its absolute size (weight) as a function of the number of fish in the resource and the growth potential of the individual fish. In general, the larger the habitable area available to a stock, the bigger the stock is...
The number of fish in a resource is governed by the balance between recruitment (numbers of young fish entering the stock each year) and the death rate from fishing or natural causes... Experience to date is that within each resource--apart from a few severly depleted ones--recruitment fluctuates without trend; nor is there any evidence of trend in the rate of natural death. Given these parameters, the yield realized from the resource depends upon the rate of exploitation in relation to the growth potential of the fish concerned... As a very broad generalization, one may expect fast-growing fish to have a relatively shorter lifespan and vice versa."(17)

4. Basic productivity

Potential fisheries production from a region can be defined as the harvest which can be taken by man (as a predator) on a continuing basis operating at a given trophic level or combination thereof.(18)

5. Biological surplus

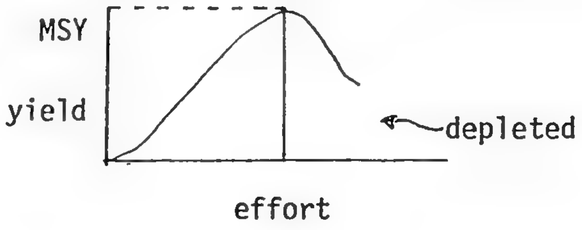
"A variety of models have been developed to quantify the surplus or growth potential of fisheries populations. Most assume that the surplus production will increase steadily until the population size reaches intermediate level, then will decline until the population comes into equilibrium with its environment. When at its maximum size, the population is said to have saturated the environment. At this point, additions to the populations from growth or recruitment are offset by natural losses. The dome-shaped surplus production and spawner-recruitment models...are examples of theories that assume the surplus production or recruitment is dependent on the size of the exploitable population..."(19)

6. Density dependent effects

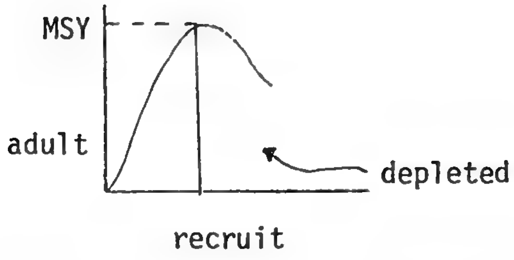
"If the stock increases, e.g., following a reduction in fishing, the likely effects are that natural mortality will increase, and the growth decrease, but that recruitment will increase. These effects act in opposite directions, the first two reducing the yield at high stock levels (i.e., at low fishing intensities, or with a large mesh size), but the last increasing the yield under these conditions of fishing."(20)

7. Depletion

A stock is considered to be depleted according to two possible definitions. In one, a fishery is considered to be depleted when the yield from that fishery is on the right-hand slope of the yield curve (Figure A).



A second definition relates depletion to the relationship between adults in the stock and recruitment: (Figure B)



For the purposes of fisheries management, both of these definitions have limited utility.(21)

8. Stability

Although environmental fluctuations are recognized as elements of marine ecosystem stability, they are extremely long-term in effect, difficult to predict and far exceeded in impact by the development of sophisticated marine fisheries.(22) Consequently, the ecosystem usually is treated as a stable system with regard to stock assessment.

9. Simulation Arrangements

"...Biological models are all static inasmuch as they convert yearly figures into long-term averages. The aim is to erase yearly fluctuations and to allow year-to-year comparisons so that the addition of all the successive yearly averages gives a systemmatic and dynamic picture of the long-term developments..."(23)

The general assumption here has been that interspecific trends as well as long-term developments would result from monitoring single species over time.(24)

10. Indirect methods for forecasting fisheries potentials

Although the actual techniques evolved have become extremely complex, it is generally assumed that the following methods serve to aid in forecasting fishery potentials:

- Estimates based on the general productivity of the oceans or areas of oceans
- Observations of eggs and larvae
- Inferences from stomach contents
- Direct observations of schools occupying the surface or deeper zones
- Systemmatic sampling with fishing gear
- Acoustic surveys
- Extrapolation from known areas.(25)

11. Fishing Effort

"As the abundance of the fish stock cannot be estimated by direct measurement, the changes in abundance are assumed to be parellel to the changes in catch rates of similar boats using the same techniques."(26)

There exist many other assumptions concerning assessment methodology itself; they are necessary when one must depend on sampling techniques to reach conclusions. However, in a very general sense the following factors must be assumed in order to undertake fisheries assessments:

- The biological system within which man operates is essentially stable
- Year-to-year data, when compiled, indicate long-term developments
- Existing sampling techniques serve to identify many of those developments
- Fish mortality as the result of man's harvesting activities can be determined through the relationship between fishing effort and yield

- There exists a reasonably identifiable sustainable yield that, properly controlled, ensures the renewability of the resource
- Increasing fishing effort tends to reduce the average size and age of the yield, although not necessarily the weight.

Based upon these biological assumptions, the information requirements outlined earlier are met in part through the following stock assessment methods. All survey techniques must be carried out through the use of a vessel, although catch and effort data are usually reported by the host governments of fishing fleets; in each case the accuracy of conclusions depends largely on the accuracy of the data, rather than the mathematical models that have been developed to analyze that data.

IV. STOCK ASSESSMENT - METHODS (27,28,29)

For assessment of fisheries populations (potential size, standing stock size, etc.), the following indirect methods are used.* For each method, following a brief description, the basic advantages and disadvantages are discussed. It should be noted that resource abundance surveys may be carried out with gear unlike that used by fishermen, although commercial surveys, to be of industry use, must use techniques and gear similar to that used by the fishermen.

1. General Productivity

General productivity of the marine area being surveyed can be determined by measuring active physiological processes or by evaluating standing stocks of phytoplankton. Various techniques seek to estimate: O_2 production, uptake of C-14 in the system, or figures based upon the standing stock of plankton.

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* For the Georges Bank area, the basis of most assessments has been data developed during the fall and spring survey cruises as well as foreign data from ICNAF. While the survey cruise data is relatively specific, to date the information from ICNAF--particularly for catch and effort data--has been uncertain, often false, and often is not available in time for management decisions that must be taken on a yearly basis. The mobility and harvesting capacity of distant water fleets is such that data time lags force management decisions to be made on the basis of information that is known to be incorrect. In the absence of changes brought about by man's fishing activities, such methods as outlined here would have by now generated considerably more precise information, but the perturbations resulting from man's activities have made historical data interpretation extremely difficult.

The procedure utilized is to estimate the flow of food through the food chain, based upon the amount of carbon fixed annually, the efficiency of material transfer up through the food chain, and choice of the trophic level at which to calculate fish yields.

Advantage: This form of survey is relatively inexpensive, carried out through plankton tows, lab analysis of samples of water, and compilation of records from many survey stations.

Disadvantage: Estimates based upon such information are extremely complex to perform and may vary from the correct figure by several orders of magnitude. Regarding, particularly, forecasts from zoo-plankton abundance, plankton nets are very selective (depending on mesh size) and no one net can yield a zoo-plankton sample in a manner that truly reflects the natural abundance of animals.

2. Egg and Larval Surveys

If the total number of eggs spawned in a season can be estimated and the mean fecundity determined, and if the percentage of females to males in the stock is known, the abundance of the mature stock can be calculated:

$$M = \frac{P}{KF}$$

M = mature abundance
P = total eggs
F = mean fecundity
K = proportion of females in stock

The estimation of the year-class for each stock (number of young fish entering the population) is critical, for the condition of the adult population ultimately depends on year-class populations.

Surveys are taken with small fine-meshed trawls in known or suspected spawning areas. Such surveys have proven useful for the purpose of forecasting subsequent stock size changes due to fluctuations in year-class strength. However, prior to an estimate of the population size, the following information is necessary:

- Whether the sampled spawn is from only the chosen species or from others as well;
- The extent of the spawning area and the period during which spawning occurs;
- The rate of development over the range of temperatures encountered in the survey area during the spawning season.

Advantage: Ease of collection.

Disadvantage: The distribution of eggs and larvae may have little relationship to the distribution of the adult stock during a large part of the year; consequently, this information alone is insufficient to plan a harvest strategy. It is also very hard to estimate future year-class abundance if the surveys do not cover the entire spawning area.

3. Examination of Stomachs

It has been found that examination of the stomachs of predatory fish (higher trophic levels) goes far toward determination of the availability of lower trophic forms. Such studies provide information concerning the food base upon which the larger forms subsist.

Advantage: Capture of such fish and examination of their stomachs is relatively cheap.

Disadvantage: As in the two previous production indices, any method that depends on existing sampling techniques is prone to bias.

4. Acoustic Surveys

Surveys conducted with sophisticated electronic fish-finding and sonar equipment hold great potential value for the future. Existing sounding techniques can spot and track schools of pelagic fish, determine the bottom type and configuration, and frequently can spot groundfish in the waters close to the bottom.

Advantage: Such surveys, charted continuously, deliver a continual visual record of the survey vessel's passage, are relatively cheap (once the equipment is purchased), and in some cases, particularly for schooling species, provide rough estimates of the size of the observed school.

Disadvantage: Acoustics are difficult to interpret, require fine tuning, do not appear suitable for biomass or stock abundance estimates, are not species selective, and are only useful, in any case, for the area immediately beneath the transducer--i.e., results will depend upon the course of the research vessel.

5. Oceanographic Conditions

Various methods have been developed to provide data on ocean temperature, salinity, currents, dissolved materials, and the geological characteristics of the bottom.

Advantage: The gathering of this data is relatively precise.

Disadvantage: Like all surveys, but particularly for this one, the data is often based on a single observation taken at several areas or several observations taken over time at the same area. Neither case gives a consistent record of oceanographic conditions, which are in constant flux and extremely difficult to generalize. The interrelationship between these factors and marine organisms appears to be critical, yet the data presently established may be too "spotty" to develop useful conclusions.

6. Survey Tows

As opposed to other sampling methods, this method, usually undertaken with gear similar to commercial gear and utilized in the same manner, seeks to determine the age and abundance of various groundfish or pelagic fisheries resources for commercial purposes. The method depends upon statistical models that have been developed for fish population dynamics.

Advantage: Such surveys can offer immediate indications to commercial fisheries of resource potential as well as year-class strength.

Disadvantage: The biases inherent in such a sampling scheme are numerous. Such survey tows determine the average weight, size, age, and sex of the species being studied, utilizing statistical formulations, and then go on to estimate the size of that species for commercial purposes.

7. Effort Data and Catch

The relationship between stock size and fish mortality becomes critical when utilizing assessment information to determine sustainable yield, and fishing mortality is determined by the weight of the catch and the effort needed to produce it. The assumption here is that when more effort produces less fish, the stock is in a depleted condition.

Catch data is determined through analysis of reported landings, skipper's logs, random surveys, estimates of species discarded, estimates of the round weight of fish (landed fish have usually been cleaned and are thus lighter than when caught), and reliance upon similar information as provided by other governments (in international waters this has been the only data available to scientists, and, particularly when reporting catch, notably slow in reaching a conclusion).(30)

<u>Effort data</u> is a determination of how much <u>fishing effort</u> was expended to land the estimated and reported catch. Fishing effort may be expressed by days fished, number of tows with a trawl, catch per hour or day, size of vessel, horsepower of vessel, numbers of vessels, number of trawls in use within the designated fishery, the area "swept" by a trawl during its tow; all of which must then be converted to a single standard (as, for example, the "British trawler ton-hour") and applied to all the vessels operating in the area over a specified period of time.(31,32,33,34)

<u>Advantage</u>: Such data is absolutely necessary to calculate fishing mortality. Many nations now require accurate reporting of such data by their skippers, under relatively stringent international regulations, although the variance among nations on this matter appears extensive.

<u>Disadvantage</u>: The major problem here is again the accuracy of the data, much of it reported and suspect, much of it tied closely to large necessary assumptions that seek to standardize the efforts of the international fleet, much of it gathered too late for useful application, and much of it not available at all.(35)

All of these methods attempt to provide the necessary data for application in highly sophisticated models. Many methods require extensive laboratory work, which is usually carried out on shore. All of the many models utilized are based upon the assumptions outlined earlier; assumptions that hopefully restrict the distortions that are likely to arise from selected observation of a highly variable ecosystem. The complexities of the marine ecosystem drive creation of highly complex models; some of the complexities are summarized in the next section. In addition, fishing activity--its technology, management, and historical pattern of development--adds further complexities to assessments, which also are discussed both on the following pages and in detail in Part II, "The Georges Bank Groundfishery Example." Before considering existing stock assessment capabilities and needs (Part III), it is important to recognize that the greatest need by far is achieving understanding of the system this science seeks to assess, both natural and human.

V. COMPLEXITIES

There are two immediate and significant complexities that must be addressed by stock assessment:

The ocean represents an integrated and dynamic ecosystem that operates according to little-understood variables.

Much of assessment must be based on analysis of fishing impacts on that ecosystem. Such impacts are difficult to calculate, particularly when their data are based on reported information.

These two complexities shall be treated in turn.

1. The Ocean

Easily overlooked in the face of rapid stock depletions there exist several problems implicit in a study of ocean resources.

First, the ocean within which fisheries resources are found is vast. Georges Bank alone represents several thousand square miles.

The marine ecosystem is distributed in three dimensions, not two as are most agricultural resources.

Within this vast area, or volume of water, exist the fish populations of the sea.

Such populations are of many different species and at least require:

- Food
- Breeding Areas
- Ability to occupy a certain volume of water

Plankton and phytoplankton, like plants on the land, require oxygen, carbon dioxide and light to survive. They thus concentrate in the lightpenetrated areas of the ocean.

They, too, must feed, often on each other, often on material that is organic and that washes into the sea from the land.

Consequently, the coastal, shallow waters of the ocean have the highest production of the material that forms the base of the food chain.

Upon this plankton feed small organisms, small fish, and so on, each predatory species requiring a certain volume of prey for survival.

Thus, the higher one rises on the food chain, the larger the individuals of the species. The total weight of the species, however, is less than that of the prey, primarily because all the weight of the prey is not converted into predator but is consumed through activity and then discharged.

Larger fish tend to grow slower and live longer. This food chain system operates in a fluid environment. Movements of marine water will have impacts on availability of food. So will the temperature of that water, the amount of light available, and the presence of prey.

The marine environment's conditions depend, in large degree, upon the following variables:

- Rotation of the earth (night and day)
- Currents - these are partly driven by the effects of rotation; Coriolis effect
- Season of the year
- Latitude and longitude
- Temperature of the waters
- Topography of the bottom
- Surface weather effects, both short-term and long-term

- Tides

Fish populations seek certain environmental conditions for certain activities: temperature that provides food, depths that provide food, currents that provide food or aid in spawning activity, certain kinds of bottom to feed and spawn, etc.

The fluid nature of the ocean may cause large environmental changes that can be daily, seasonal, or very long-term in trend. These changes in turn affect the conditions within which that ecosystem operates.

There do exist many constant aspects of the marine environment: the Gulf Stream flows north along the United States east coast, the surface waters get warmer in the summer, tides are regular and can be measured, marine currents have been observed and charted, certain kinds of weather produce certain environmental conditions; yet, as the kind of information sought grows ever more precise, the precision of the data--dependent as it is upon so many variables--most often does not follow.

Further, fish populations occupy certain favorable niches in that marine environment, niches determined by depth, salinity, temperature, and type of bottom. As those niches are not solely bottom-dependent, they move and so must the fish population.

Many species migrate, many more of the same species may not; spawning grounds, however, have been determined to be relatively area-precise. In general, populations of fish and even some shellfish move great distances according to the variables outlined above; those movements that depend upon seasonal fluctuations can be rather closely observed.

Fish, then, operate in an environment occupied by other species with similar or different needs. There is competition, sometimes new species entering a formerly occupied niche, sometimes different species seeking the same food, oftentimes among members of the same species.

Different species of fish often intermingle in the marine environment, particularly botton fish.

Fish tend to prefer specific sites for certain activities, but identification of the causes beyond first-order estimates is extremely difficult, made so by the great number of variables that must be measured.

In simple terms, the ocean is a big place and all aspects of it cannot be monitored. Even if it could be well monitored, the interpretation of feedback requires an understanding of the forces that operate ecosystems, and those forces themselves deliver complex, at times impossible to measure, feedback.

Until this information is known, the foundations of marine science must remain general. The demands on that science, clearly, cannot ask for more specificity than that science provides.

In addition, there exist complexities concerning the biological data that <u>is</u> received through survey activities. These complexities must be incorporated in any model so as to gauge bias. Some sources of bias are extremely difficult to erase:

- Any sampling method that is random or stratified in scope must, to be accurate, reflect the possible variations at each sampling station. Yet, these variations cannot always be judged. Determination of temperature, salinity, etc., during a tow is relatively straightforward, although the depth of the towed body, its swept area, and its position in relation to earlier tows may be somewhat in error.

- Any specific population analysis must first identify the chosen population unit. When such a population is scattered or widely spearated, data are inconclusive.

- The major difficulty lies in interpreting the results, weighing the biases, and reaching conclusions. Such interpretations are dependent upon a solid understanding of the marine ecosystem being sampled, and when that understanding is inconclusive so must the interpretations be inconclusive. Thus, identification of possible bias is critical, and the greater the bias, the less specific the conclusions.

- The biological tools for assessment of species interactions have only recently been developed. The pressure from industry to examine particular species, in part, drove the establishment of assessment. As general ecosystem studies are of limited utility to the short-term demands of industry, and as funding for assessment has occurred partly due to fishing activity impacts on stocks, it is not surprising that only recently have general ecosystem studies received any priority.

- Just as in industry, technological improvements in assessment tools (better electronics, use of transducers on the head-ropes of mid-water trawls, better ability to tow at a specified depth) have forced readjustment of data.

2. Human Activities

Man's impacts on the marine ecosystem must be measured when regulations to preserve that ecosystem are instituted.

The actual catch of commercial species must be measured. This information often depend on reported data that may be incorrect. This is particularly true when reporting nations are competing for limited common resources.

There is also an estimate necessary of the total catch as opposed to the landed catch. Nets are unselective, catching all fish of appropriate size in their path. As fish mingle in the ocean, species not of value are harvested and usually discarded by domestic vessels. These discards are almost always dead. Factory vessels on the other hand, reduce offal and undesired species to fishmeal.

In addition to discards, valuable fish of another species often are caught. These fish are kept and may not be reported.

Fishing effort must be measured, as well. How effort is expressed in international fisheries depends upon chosen catchability coefficients, which apply to all of the vessels in the fishery. Again, this tends to be reported information. There often are doubts about the number of vessels in a fishery--highly mobile trawlers can move rapidly and must be reported to be counted. Such coefficients do not respect the skill of the skipper, which can be critical, particularly with regard to extremely limited and hard-to-find stocks.

Both catch and effort calculations depend upon the monitoring of individual harvesting units, a task that could be determined with certainty only if every vessel were observed. Remote sensing or random searches as currently practiced are distorted by weather conditions (fog, for example, prevents observation overflights), limits on capability in terms of budget, and nighttime fishing.

Fishing effort calculations must make assumptions about the type of gear used, probable return in terms of weight, and relationship between the standard unit and likely harvest. As fleets have increased and return has dropped, there have been tremendous technological developments to improve the efficiency of the effort. Use of radar, loran, fishfinders, and information from survey tows has in each instance allowed the skipper to increasingly refine his fishing effort. As fish grow scarce, this is only logical, at least while allocation problems remain unsolved.

These developments have, in nearly all cases, forced readjustments of effort coefficients and have consequently distorted the validity of the historical data. Particularly within the past decade, fishing effort has changed considerably. It is now possible, for example, to use a fishfinder on a trawler, under favorable conditions, which can spot individual fish. Experience with interpreting the charted data has produced this result, but the implication in terms of effort is difficult to measure.

Fishing effort was initially related to the fishing time, the time actually spent towing. Searching time is difficult to include in the formula; if that searching time drops as the searching equipment improves, more fishing time is allowed; but with scarce fish, the harvest may be--with a good fishfinder--far better than with a random tow.

Developing complexities such as these into standard coefficients is extremely difficult.

Fishing effort and catch results data assume a particular type of gear, often described in management regulations as mesh size. In competitive fisheries, operating in an area often of zero visibility, the motivation is high to use illegal gear of smaller mesh size. The motivation is particularly high if tacitly supported by that fisherman's host government, which represents him in international negotiations.

In addition to the strong possibility of noncompliance, there exists a second problem: mesh regulations have been developed for different species and are of different size. The allowed mesh for a bottom trawl is not as small as that allowed for a pelagic, or midwater, trawl. Midwater trawling is directed at schooling pelagic species such as herring and, by regulation, must be "incapable" of fishing on the bottom. However, foreign fishermen report that recent technology allows this to occur. Consequently, it is possible to rig for herring and harvest groundfish. Such catches are called by-catch, and amount of by-catch becomes extremely important when such by-catches are of a depleted species. A recent estimate has suggested that 38 percent of the total biomass presently harvested on Georges Bank is achieved through by-catch.(36)

Distortions likely in assessment of fishing activities as they relate to stock sizes, the, result from the following variables:

- Rapid changes in harvesting technology
- Noncompliance with management regulations
- Intermittent and scattered gathering of necessary data
- Outright falsification of necessary data
- Problems with development of a catchability coefficient
- Great difficulties in monitoring fishing activities

It is within these variables that stock assessment science must operate. Recognition of these variables has created sophisticated and specialized probability forecasting models. In addition, political bargaining of common-property resources has increased the pressures on assessment science, demanding ever-more specific numbers as species have continually been depleted.

Assessments seek to quantify information from an ecosystem that is:

- Difficult to observe
- Highly variable
- Perturbed by fishing activities
- Managed according to political rather than biological decisions.

On the following pages the Georges Bank groundfishery in relation to assessment will be examined. While not a history of assessment in the area, examples shall be drawn from that history concerning the validity of such data, its use or nonuse, reasons for that use, and implications for assessments under extended jurisdiction.

PART II

THE GEORGES BANK GROUNDFISHERY EXAMPLE

I. HISTORICAL OVERVIEW

Stock assessment is essentially the study of marine fish populations in terms of their potential commercial yield, as well as the limits of that yield.(37,38) Assessment first sought to determine the potential yield from a specific fish population. Usually the population had existing or imminent commercial value. In many cases, assessments sought, located, and estimated the potential yield for populations located in remote or lightly fished areas (often populations of species having existing value elsewhere).(39)

It has long been clear that the resources of the ocean are not inexhaustible. Fishing pressures have traditionally intensified until depletion has occurred.

Fisheries resources of the high seas have never been owned by an individual or nation. Fresh water fisheries, forests, and most other resources have been located on land and have consequently been owned by someone, either an individual or nation. Fisheries resources are considered common property; that is, owned by no one and thus available to all.(40)

And just as no one individual has owned marine resources, no one has been entirely responsible for the management of such resources.

Most of the saltwater fisheries of the world, and particularly demersal fish (ground fish), are found along the coast and on continential shelves or banks. The deep ocean, that is, the ocean beyond the continential shelves, is not very productive. Plankton and the other small organisms that form the basis of all marine food chains drift in the water column while living and sink upon death. Over continential shelves, where the water is relatively shallow and considerable intermixing occurs as a result of tide and current, this abundant nutrient material is recycled. On the other hand, such material sinks below the zone of light penetration in deep water, is not recycled, and is consequently lost.

In very general terms, the history of marine fisheries has followed a similar pattern worldwide. Initially, coastal residents harvested fish from the beach or close to shore in small boats. Some areas were more productive than others, and consequently, some coastlines, and the nations that represented them, developed large fishing infrastructures.

The size of vessels grew, gear grew more sophisticated and, in time, coastal waters produced less fish due to the intense fishing effort. Trip fishing, as opposed to day fishing, commenced; larger vessels travelling long distances to new grounds and at first salting the catch.

This trend began remarkably early: English vessels are reported to have fished the waters off Iceland by 1300. There was activity on the Grand Banks by Portuguese vessels a century before the arrival of the Pilgrims.

Such trip fishing, initially using sailing vessels and handlines, then dories and line trawl or sailing vessels towing a beam trawl, was extremely difficult and dangerous. For centuries the technology man had developed was rarely sufficient to develop enough effort to endanger distant water stocks.

Near shore, the story was different. Coastal fisheries at times reduced stocks, and some management regulations began to be adopted. Stock assessment science developed, really a method of scientifically determining the available potential yield of a stock on a continuing basis. Management measures were adopted to regulate fishing activity, the one parameter of harvest under man's control.

Recall, however, that these coastal fisheries, by virtue of the internationally accepted three-mile (and later twelve-mile) limit, fell under the ownership of specific nations, and were thus within those nations' management jurisdictions. Yet, even here it became apparent that "fish have tails" and are prone to movement. The fishery resource that perhaps concentrated within a national limit during one season of the year often migrated to an offshore bank during a later season. When that population moved offshore, it became anyone's property and all one had to do was harvest it. All areas beyond the three-mile and, later, the twelve-mile limit were under no control whatsoever.

Before industrialization, fishery resource problems concentrated inshore. Offshore fishing remained risky and dangerous until the development of motorized vessels, sophisticated electronics, and adequate weather forecasts. All offshore areas were international fishing grounds, and the northern Atlantic Ocean was particularly productive.

Introduction of the otter trawl early in the 20th Century, in combination with the development of steam-driven trawlers, entirely changed the picture of offshore fisheries. Hook-and-line fisheries from sailing schooners rapidly declined. Sailing vessels were replaced by motor trawlers that had a larger hold capacity, speed in all weather, ability to fish in nearly all weather, radio and later other aids, and therefore the capability to range widely into previously unexplored regions.

At this point, the period between the two World Wars, international grounds in the northeast Atlantic, close to European nations, experienced some evidence of stock depletions. Initial international agreements were established.

Following the Second World War, worldwide fisheries again changed. The development of the stern trawler and on-board processing capability, availability of many of the war-developed electronic aids (radar, loran, sonar), huge increases in vessel size, and a vast increase in worldwide protein demand, all served to reinforce a trend established in all inshore fisheries: threats of stock depletion and an international acceptance of the need to manage the common-property resource.

Initially neglected by distant-water fleets, Georges Bank, located 50 to 200 miles due east of Cape Cod, had traditionally served as a mainstay of the New England fishery, producing nearly one-half million tons of a few selected species every year. To the foreign factory fleets constructed in the early 1960s, Georges Bank offered

> ...a number of fish stocks that had been neglected by New England offshore fishermen in their pursuit of traditionally more valued species such as yellow-tail flounder and haddock. Under-fished stocks of herring, mackerel, silver hake, and cod provided the large, seasonally concentrated schools of fish that were ideal for intensive fishing by large fleets. The entire fleet would be deployed to harvest a targeted species and when the catch rate of that species became unacceptable, the fleet would then be redeployed to search for another concentrated stock of fish. This strategy employed by the large vessel fleets is called pulse fishing.(41)

Soviet trawlers were first seen on Georges Bank in 1961, followed rapidly by vessels from at least fifteen nations. By 1965, an average of

200 - 300 foreign factory trawlers was operating off Cape Cod continually. Initially directing fisheries at species of little traditional domestic value, it was inevitable that a good year-class of a popular domestic species would attract a pulse fishing effort, as occurred in the haddock fishery in 1965.

Haddock had long served as a mainstay of the large Boston trawler fleet; for decades prior to 1965, New England fishermen had produced an average of fifty thousand tons a year.

> This total catch was considered by fishery researchers to approximate the maximum sustainable yield...Although extensive research by American scientists indicated that recruitment of juvenile haddock into an adult crop fluctuates widely from year to year, concern grew in the late 1950s and the early 1960s when a number of spawning failures were observed...In response to the spawning failures, the New England haddock fishery apparently reduced its harvest to a level approximating the annual recruitment of adult haddock.
>
> "When successful spawning seasons did occur in 1962 and 1963 they produced two large year-classes of haddock that would lead to a large natural increase in the adult crop of haddock three years later in 1965 and 1966 when the juveniles had matured. These year-classes might well have sustained the New England haddock fishery well into the 1970s and at the same time provided sufficient breeding stocks to proprogate future generations of haddock. But in anticipation of the large schools of haddock that their research vessels reported, the Soviet fleet, estimated to number as many as 300 vessels, deployed its vessels to catch haddock in 1965 and 1966."(42)

Landings leapt from sixty thousand tons in 1963 to one hundred fifty-five thousand tons in 1965 and one hundred twenty-six thousand tons in 1966, primarily due to the Soviet efforts. By 1969, only twenty-five thousand tons were landed; in 1974 landings were <u>one-eighteenth</u> the average catch prior to 1965. Today the New England haddock fishery hardly exists, for, in addition to the overfishing of 1965 and 1966, there occurred a series of year-class failures that virtually decimated the stock.

> "The case of haddock...(is) typical of the overfishing crisis which now affects nearly every fin fish on Georges Bank. According to research surveys by fishery biologists, cod, silver hake, red hake, and some flounders have declined in abundance by about 45 percent in the last 10 years. And sea herring, toward which much of the foreign effort has been directed, have reportedly suffered a 90 percent reduction in stock size."(43)

Thus, evidence now indicates that all the familiar species of the Northwest Atlantic are fully exploited.(44) Yet fishing effort continues to increase. Cuba, for instance, entered the Atlantic fishery less than a decade ago and now operates over 20 distant-water trawlers. The common-property aspect of the resource intensified competition among different fleets, driving technology development to increasingly refined levels in an effort to harvest scarce fish before others do.

Now the entire picture has once again shifted. Stock depletions, blamed by the coastal state on such distant-water activities (in some cases this is a false assumption), have resulted in the unilateral extension by some coastal states of fisheries mangement jurisdiction from 12 miles to 200 miles. The United States, Canada, Mexico, Iceland, Peru, and others have taken this step, arguing that international management of offshore fisheries has failed for a host of reasons, and that the coastal state will now take the management responsibilities.

The Law of the Sea Conference is slowly reaching a similar conclusion, but at the moment, this extension of jurisdiction is an <u>entirely unique concept</u> with relation to the long accepted definition of the "high seas." The basis of the American argument has been that existing fishing technology is more than adequate to rapidly deplete all stocks. Therefore, we cannot afford to wait for international consensus to avoid complete stock destruction. Consequently, we shall manage those resources within our limits for the benefit of all.

We extended jurisdiction April 13, 1976, and the outcome of this action is yet to be determined. Clearly, as this summary indicates, assessments have been forced to operate within a dynamic and always changing technological and institutional situation. As will be demonstrated in the following section, the historical record of assessments has reflected these many uncertainties.

II. HADDOCK ASSESSMENTS

In 1962 it had long been assumed by assessment scientists that the haddock stock for Georges Bank (ICNAF Subarea 5) was being utilized close to MSY. With the exception of reduced landings during the Second World War, annual yields from Subarea 5 had remained relatively constant, produced almost entirely by American vessels, since the 1920s. A report by the "Working Group of Scientists on Fishery Assessment in Relation to Regulation Problems" for ICNAF in 1962 indicates the preparedness of the assessment community to deal with the events that occured in 1965.(45)

As indicated in the foregoing summary of developments on Georges Bank, foreign governments had stated in the early 1960s that increased effort in Subarea 5 would concentrate on underutilized species. However, the assessment community stated in 1962 that little effort increase whatsoever was expected for Subarea 5:

> "As forecasts are lacking from a number of countries, no quantitative estimates of future changes in total fishing can be made, except for Subarea 5 (fished mainly by U.S.A.) where no substantial changes in effort are anticipated."(46)

As a summary chart of expected changes in fishing effort indicates, the expectations of the assessment community for the period 1960-1970 were incomplete and vastly underestimated.(47)

Table 11A

Summary of Expected Changes in Fishing Effort

Country	1958 landings (thousand of tons) for Subareas 1	2	3	4	5	Expected percentage increase over 1958 effort for the years 1961-70
Canada (M & Q)	-	3	28	355	13	+ 6 to + 24% in trawling in all areas, but no change for other gears
Canada (Nfld.)	-	13	194	28		+150% in Subarea 2, otherwise no change
Denmark (F)	44	-	4	-	-	No forecast
Denmark (G)	31	-	-	-	-	No forecast
France	24	18	35	42	-	No forecast
France (St.P&M)	-	-	9	-	-	No forecast
Germany (E)	1	2	1	-	-	No forecast
Germany	45	24	2	-	-	No forecast except that 1961 same as 1960
Iceland	14	33	44	-	-	Probably little change
Italy	1	-	1	1	-	No change
Norway	37	-	7	-	-	No forecast
Portugal	113	8	40	18	-	+120% in trawling and -50% in fishing by other gears in whole area
Spain	27	2	72	21	-	No forecast
U.S.S.R.	-	13	103	-	-	No forecast
U.K.	10	-	2	-	-	+10 to +40% in Subarea 1, +100 to +200% in Subarea 3, and little fishing in Subareas 2 and 4
U.S.A.	-	2	10	56	446	+25% in Subarea 2, -10 to -50% in Subarea 3, and -10% to no change in Subareas 4 and 5

During this period the primary emphasis was upon the effects of mesh size on fishing mortality. Mesh size was the earliest method of international fisheries regulation, and thus ICNAF scientists concentrated on this issue. It was not until later that season and area closures were instituted as it became clear that mesh size, while maintaining a stock, could not restore depleted stocks.(48)

However, ICNAF regulations regarding mesh size often failed to require a mesh size limit for new fisheries. As foreign fleets entered the Georges fishery, they were often able to operate on certain species--for example, redfish--with gear requiring no mesh size limits at all. Yet because groundfish species frequently mingle, a vessel harvesting redfish with unregulated gear often caught other species of value, such as cod and haddock. While directed cod fisheries required certain types of gear, a by-catch of immature cod would result from the smaller mesh size utilized in the refishery. In the late 1960s this was recognized as a serious problem, but in 1962 there was only passing mention of this issue throughout the assessment community.

The Working Group went on to predict future haddock yields given an increase in effort. The following table takes 1961 effort as "present" level of effort and predicts landings per unit effort resulting from total effort (as % of present level):(49)

Table 11C

Effort	50	75	100 (present)	200
Landings	86	95	100	102
Landings per unit effort	172	130	100	51

Thus, in 1962 the assessment community predicted that a doubling of effort would produce only a two percent increase in landings.

What actually occurred, however, was far different. In spite of expectations that effort would not increase greatly for Subarea 5, by 1965 total landings from Georges Bank had leaped from 446,000 tons (1958) to 890,000 tons.(50) All of this increase was due to the new fishing pressure of distant-water factory trawlers.

In addition, the 1962 and 1963 year-classes of haddock had been excellent, and in 1965 the stock of haddock scrod (young haddock) was exceptional. Both Canada and the Soviet Union directed fisheries to haddock. Haddock landings, by nation, were reported to ICNAF as follows for the period 1961-1974:(51)

Landings (000 tons)

	1961	1962	1963	1964
Landings:	52,190	59,000	60,000	70,000
U.S.	52,000	*	*	52,000
Canada	190	*	*	12,000
Russia	*	*	*	5,000
Other	*	*	*	*
T.A.C.	*	*	*	*

	1965	1966	1967	1968	1969
Landings:	155,000	126,000	57,000	44,000	25,000
U.S.	57,000	57,000	*	*	*
Canada	15,000	19,000	*	*	*
Russia	82,000	50,000	*	*	*
Other	*	*	*	*	*
T.A.C.	*	*	*	*	*

	1970	1971	1972	1973	1974
Landings:	12,852	12,214	6,330	5,265	*
U.S.	*	8,500	*	*	*
Canada	*	1,700	*	*	*
Russia	*	500	*	*	*
Other	*	*	*	*	*
T.A.C.	12,000	12,000	6,000	6,000	0

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* Figures not available or not relevant.

Although assessment theory had held that increases in effort would not greatly increase landings, the abundant year-class of 1963 as well as the use of small mesh nets by the Soviets had a critical effect on the stock:(52)

A Summary of the Trends from 1960 to 1965

	1960	1961	1962	1963	1964	1965
Annual landings (metric tons x 10^3)						
Actual	41	47	54	55	64	150
Equilibrium	44	44	45	42	40	-
Annual Days Fished						
Actual	7,700	7,200	8,600	12,400	12,100	26,700
3-year Average	8,300	8,100	7,700	9,400	11,000	17,100
Percent(a)	119	116	110	134	157	244
Landings per Day (metric tons)						
Actual	5.4	6.5	6.3	4.4	5.3	5.6
Equilibrium	5.4	5.5	5.8	4.5	3.6	-
Percent(a)	85	86	91	71	65	-

(a) Percent of maximum equilibrium yield level

A glance at landings in relation to effort (pounds per day fished) for the period 1940 - 1969 shows that, while the basis of the 1962 prediction might have been true over the long term, in fact the technological capacity of fleets distorted assessment expectations by demonstrating a harvesting capacity quite capable of continuing a high yield/effort ratio well into the depletion area of the traditional yield/effort curve:(53)

Haddock Catch - Pounds per Day Fished Average

1940	14,634	1950	16,558	1960	12,099
1941	18,946	1951	16,071	1961	13,493
1942	21,301	1952	16,080	1962	13,879
1943	20,914	1953	11,089	1963	9,628
1944	19,342	1954	17,617	1964	11,622
1945	18,234	1955	11,790	1965	12,413
1946	16,257	1956	16,092	1966	9,907
1947	14,593	1957	13,273	1967	8,096
1948	13,819	1958	12,589	1968	6,184
1949	13,053	1959	9,987	1969	6,881

When intensive foreign efforts began on Georges Bank in the 1960s, there existed no assessment information whatsoever on many of the stocks being sought. While such a lack of information had not appeared critical during the 1950s--when only a few species were harvested on Georges Bank--the sudden and spectacular inroads into the haddock stocks in 1965 and 1966 quickly placed demands on assessments that were nearly impossible to meet.

While it was recognized in 1966 that haddock had been decimated, it is clear that even the assessment community was unprepared for the sudden emergence of the crisis. In 1968, three years after the pulse fishing effort on haddock, the ICNAF assessment committee (STACRES) were still doubtful as to whether the failure of post-1963 year-classes was due to the heavy fishing pressure or environmental conditions.(54) The following year (1969) STACRES recommended "...no, or very little, fishing for a period of not less than 4-5 years, and until a moderate to strong year-class has been recruited and grown to maturity."(55)

It was not until 1970, five years after the haddock decimation, that ICNAF established a quota for haddock. The quota was 12,000 tons, despite the 1969 statement that there should be little or no fishing for haddock. In 1972, STACRES reported that bycatch may be greater than the annual surplus.(56) Despite United States efforts to ban directed fishing for haddock altogether, ICNAF negotiated a 6,000 ton allowable haddock quota for 1972.

Clearly a study of ICNAF documents indicates that while assessments on species abundance were quite good, the decisions finally made concerning allowable catches were entirely political. With ICNAF member nations competing over limited resources, quotas--finally established in 1970--were initially negotiated in excess of STACRES assessments. This further points to the issue of historical data, for regardless of whether assessments were correct, decisions on future yields only agreed with STACRES recommendations when it became clear to member nations that the stock in question was severely threatened.

III. LESSONS FROM THE HADDOCK EXAMPLE

Assessment methodology had developed during a period of expanding fisheries, single-species harvesting strategies, and still primitive fishing technologies. Initial ICNAF management regulations concerned mesh size only, although new fisheries were usually characterized by no mesh regulations at all. Assessments depended on scattered data for selected species and relatively incremental effects on stocks due to chosen fishing strategies. The science did not develop with a primary emphasis on key indicators required for rapid decisions, for until the 1960s, problems relating to individual stocks only arose slowly over a period of years.

In addition, further indicating the lack of crisis orientation of the science, funding remained very low, placing severe limits on scientific projects.

The Georges Bank haddock example indicates several important lessons with regard to assessments:

- The science was unprepared to analyze the possible outcomes resulting from the rapid and intense increases in fishing effort on all commercial stocks found on Georges;
- The time required to gather and analyze relevant data--from survey tows, catch and effort statistics, and environmental studies--was far greater than the time necessary for factory fleets to destroy stocks;
- Until recent extension of United State jurisdiction, management decisions were the outcome of international negotiations, which took years to develop and were impossible to enforce;
- Inclusion into assessment models of technological developments was difficult, delayed, and thus not consistent;

- Whereas species abundance estimates were accurate (the good year-class of haddock was well observed), yield estimates were not;
- Assessment theory had developed in a manner to require long-term analysis instead of the need to make short-term decisions.

Broadly, assessments have evolved to provide fishery managers with two types of information:(57)

1. Identification of new fishery resources, location, size, and potential yield. Often of species having value elsewhere, such surveys of fisheries resources have been a response to expanding worldwide demand, causing redirection of industry infrastructure efforts into new areas since those currently utilized have been overfished. Also, this effort has been partly the consequence of an attitude that, while ocean resources are limited, those limits, particularly in new areas, have not yet been reached.

2. Identification of the limits on yield to provide maximum sustainable yield (MSY). Although an intensive resource inventory might well provide this information, and ideally should provide this information, it has been separated for two reasons: First, the time sequence of fisheries, although recently much accelerated, must (a) determine the commercial potential of a population, (b) determine whether and when that potential is achieved, and (c) further identify the limits of that potential (there is thus a time lag); and second, that the MSY cannot be determined without, at the present time, an awareness of the fishing effort expended,

Operationally, expanding fisheries have driven an awareness of what resources there are in the ocean; as fleets have increased so has pressure to utilize them.

Expanding fisheries have also driven assessments of the limits on those resources; competition among nations for a common-property resource has often resulted in massive depletions. It is awareness of the limits that has resulted in the formation of national and international management regulations. These regulations have attempted to control fishing mortality to preserve stocks, and have, generally, been adopted in the following sequence:

- Mesh regulations--restrictions on mesh size to permit escape of young fish from each year-class in an effort to preserve the adult stock for spawning purposes;
- Size limits for the same reason;
- Area and season closures--it became clear early that mesh regulations alone did not serve the purpose of maintaining allowable surpluses; offshore fishing is conducted far from land and consequently far from enforcement powers;
- Limits on the allowable catch, usually in terms of weight;
- Limits on the allowed fishing effort.

It should be pointed out, then, that simple resource inventories are relatively straightforward and generally free from fishing-related complications; evaluations concerning how much is out there, where it is located, and the best fishing strategy are a science unencumbered by fishing activity. However, it is by no means a simple science: resource surveys cost money, take time, and are subject to every environmental fluctuation.

Once an inventory has been completed, however, information as to the effects of man's harvesting activity on that stock must be developed to produce assessments of the potential yield; presently an enormously difficult task:

- Because fishing activity seeks to take the last available ton of fish without diminishing the stock, and because it is impossible to count that stock, it is necessary to estimate the sustainable yield through a measurement of fishing effort in relation to yield. Measuring fishing effort is extremely difficult, especially when nations are competing for the same resources.(58)

- When such measurements have been made and assessments produced concerning available harvest, the means of monitoring and enforcing the allowed harvest must be considered. These means are generally expressed through management regulations. Enforcement is nearly impossible. Observation of every vessel's activity has not been possible, so compliance can be avoided if desired. In addition, competing nations in international waters, harvesting what are now seen to be highly limited resources, can only enforce management through International Commissions, which have traditionally served member nations' specific interests rather than the interests of the resources as a whole. Cooperation has usually come only when massive stock declines have occurred, for then all nations participating in the fishery suffer.(59)

- Whereas survey data can be developed in a consistent, planned manner, effort determination is extremely difficult to chart through time in the face of continual technological developments. Such developments have vastly complicated interpretation of effort data.(60)

Clearly, fisheries stock assessment is a science based on indirect data. Yet demands increase upon that science to provide specific, refined numbers in the process of making allocation decisions.(61) Such decisions must currently depend on assessments that have historically considered single species of fish rather than the total marine biomass.(62) While it is well understood that a knowledge of the marine ecosystem is of paramount importance, assessments cost money and that money has to come from industry or host governments. In both cases, the primary interest has been in fisheries of commercial value (individual species); assessments have, therefore, been funded by-and-large with the objective of determining information about a single species rather than the total marine biomass. This funding has been further specialized due to the depletions that have occurred in many groundfish species. Research has been funded more to emphasize development of new resources than to enhance recovery of depleted stocks. Although this past decade has seen a shift toward the biomass approach (responding to across-the-board depletions), this past decade has also witnessed intense and highly varied perturbations from fishing fleet activities. Definition of the natural system is extremely difficult when the feedback from that system is always changing. This situation directly impacts efforts to assess sustainable yield.

It is somewhat ironic that the two species with the best assessment information today for Georges Bank are haddock and yellow-tail flounder--the two species in gravest trouble.(63) Today, a decade after the haddock disaster, massive changes have occurred relating to extended jurisdiction, enforcement of quotas, and establishment of the quotas themselves. Today, ICNAF quotas are established according to the "two-tier" system, wherein the sum of the individual species quotas is lower than the sum of all quotas taken together. This system reflects interspecies relations that are as yet poorly understood; the assumption is that, over time, the two totals will grow closer.(64) The difference in totals reflects problems with by-catch, noncompliance with regulations, and efforts to restore stocks.

Importantly, however, radical changes in assessment methodology and techniques have not been made--today's efforts have largely become attempts to reflect all of the uncertainties and biases that are bound to occur in a fluid marine environment. Yet an historical study of assessments indicates that there never has been a period of adequate control over inputs so as to test the accuracy of assessment theories and biological assumptions. As the offshore fishery has intensified, and as fishing operations have become more complex, so has assessment methodology. Yet a science founded during an earlier era of harvesting strategy based on development of new fisheries must ask itself: is the existing method sufficient to understand the biological effects of pulse fishing, by-catch, "clear cutting" of the marine environment; and, more importantly, how important is such awareness likely to be in the future?

And here may be the critical lesson of the haddock example: whereas until 1965 assessments sought to maximize yield and determine potential yields of new fisheries, after 1965 assessments undertook a different and far more difficult task: determining yields to achieve a chosen level of species restoration while concurrently determining maximum allowable harvest to meet this level. Implicit in the earlier route was the long-term nature of harvesting effects on stocks; implicit in the situation today is the need to come to critical short-term decisions so that chosen stocks can survive. With extended jurisdiction now a United States law, the American assessment community has, for the first time, the chance of seeing management decisions made with primary respect to biological theory.

In conclusion, analysis of the Georges Bank haddock fishery indicates that assessments have traditionally suffered from (1) lack of funding; (2) political rather than biological management decisions; and (3) a sudden increase in data requirements that arose from the rapid introduction of foreign fisheries off the United States Coast.

Recent extension of jurisdiction by the United States to 200 miles carries hopes that assessments can now be developed according to controlled inputs, enforcement of management decisions, and adequate funding to undertake the necessary tasks. However, a thorough understanding of the marine ecosystem requires information that remains prone to bias, uncertainty, and error. Everchanging fishing technologies introduce a factor that further complicates an already complex natural system (Part I). The depressed economic nature of the domestic fishing industry, the presence of enormous foreign fishing infrastructures exerting pressure on the United States to continue their operations, and a clear awareness that the species found in the ocean are interrelated demonstrate that the costs to "count every fish in the ocean" may be prohibitive. Consequently, it is important to assess the present state-of-the art of assessments, future needs, and the time requirements to meet those needs. This latter area is critical, for while much of the necessary information may be developed given enough time (and free of man-induced perturbations through fishing activity), "...we don't have fifty years to get our fish back."(65)

Assessment scientists are faced with a dilemma: they must provide immediate short-term information that must be based on information that will require years to develop. While those years may have been available prior to foreign fishing pressures, recent events have shown that such pressures can have significant effects in the short term, forcing rapid and critical management decisions that, in the absence of sound scientific advice, may be incorrect.

A study of ICNAF history indicates that while allocation decisions were political, great pressure was exerted on the scientific community to provide a number to rationalize a decision.(62) The literature available on assessments indicates that assessment scientists have always been frank and honest concerning the validity of their data.(67) Many management decisions, particularly those concerning quota allocation and area closures, have been essentially social decisions: "We want this amount of fish because our national priority is for 'x' tons this year." Rather than accept such decisions as value judgments, however, managers have desired numbers to justify those decisions. The more refined the number, the easier the decision. One result of this attitude has been pressure on the assessment community to estimate to the last ton the available yield from a fishery. In fact, assessments provide information that is characterized by a degree of accuracy, although political pressures may demand even greater accuracy.

Under extended jurisdiction, such pressures are likely to continue; certainly the attitude that assessment science is close to full understanding of the marine ecosystem is a popular one.(68) Given limited financial resources for offshore fishery management, however, decisions will be required concerning budget allocation.

On the following pages assessment state-of-the-art will be examined with relation to development of information that is useful, not only to managers, but to the industry as well. The United States passed legislation extending fisheries jurisdiction to 200 miles in response to political pressure from fishermen, and clearly a major rationale for the legislation was development of management plans that serve to revitalize a moribund industry. As such revitalization depends entirely upon the health of fish stocks, at least initially, restoration strategies are critical. And, as the following section indicates, assessments are presently quite accurate, in spite of the problems--both concerning biological data and the effects of fishing activity decisons--outlined previously.

PART III

ASSESSMENT CAPABILITIES AND NEEDS

I. ASSESSMENT TOOLS

Tools Used on the Vessel

As assessments depend primarily upon observations of the marine ecosystem, the tools utilized to provide those observations must be examined.

As outlined in Part I of this report, survey information is developed through the use of selected survey tows with small-meshed nets, although abundance estimates for use by industry must be developed with gear utilized by industry (nets using regulated mesh sizes). Such tows are traditionally made on the basis of stratified random sampling, wherein several locations are sampled at different times of the year, with efforts made to remove as much bias as possible.

Samples from the tows are then examined, measured, weighed, and aged. Models predicting abundance on the basis of yield from such tows are well-developed and sophisticated, requiring extensive laboratory work and analysis before compilation.

Environmental evidence is developed through temperature and salinity sampling, using sounders that are dropped at selected areas and then retrieved. Studies of currents and weather patterns are also made.

All of these tools are utilized to develop data that is then analyzed through the use of models. Statistical theory is well-developed and, given good data, one can expect good results.

Almost all of this data, however, must be gained through use of a vessel. It should be noted that such data does not serve to predict man's effects on the marine environment--catch and effort figures provide the basis of such effects (following section).

Surveys that are based on stratified random samples depend greatly upon the control of biases. While the actual types of sampling gear vary and are subject to certain difficulties, these difficulties are well understood and adjustments are made. For example, plankton samples depend utterly upon the mesh size of the sampling net: a large mesh allows the small organisms to escape, thereby skewing the results toward selection of larger individuals than actually exists. However, such biases have long been recognized, and, through use of similar gear over time, are generally discounted.

The problem lies not with the taking of samples but with their analysis. There presently exists no automatic method of determining the species selection of plankton tows. Individuals must be counted by hand, a laborious and slow process that consumes time that might otherwise be used more productively.

A similar situation exists with regard the aging fish samples. While the measurement of fish size and weight is relatively straightforward, determination of age through analysis of scales or otoliths (ear bones)is still a slow process that is characterized by some as an "art."(69) There is a great deal of interest in designing a system that can estimate the age of fish rapidly and automatically. The present system is costly, requires highly-skilled analysts, and is subject to error. Yet age determination is critical, for upon such information the abundance of various year-classes is estimated.

Other forms of sampling (for example, temperature soundings) have been refined and are highly accurate. However, as in all such methods, their accuracy refers to a measurement made at a specific spot at a specific time. Efforts to compare measurements from different surveys are dependent upon assumptions concerning the conditions that may affect results. For much of the information gained, it is assumed that differing conditions of weather, currents, or temperatures will be reflected and understood over time, although it is clear that the more measurements, the better. Presently, sampling surveys are carried out on Georges Bank twice a year, in the spring and fall. Efforts are made to control biases as much as possible, to return to the same sampling station at the same date and the same time as on an earlier cruise. However, results from analysis must reflect the likelihood of errors, or "control" of biases. Twice-yearly cruises are clearly not as accurate as cruises taken four times a year. Unfortunately, the budget for assessments has not been sufficient to generate more complete data.

The actual procedures used on a research vessel, then, while well-developed and well-understood, particularly during the inventory portion of assessments, require precise and accurate data. There are essentially four needs that deserve special attention:

- Provision of funding to undertake surveys more often than twice a year;
- Use of this funding to charter domestic fishing vessels
- Development of automatic plankton sorting techniques (which can be used on such vessels).
- Development of automatic fish aging techniques (which can be used on such vessels).

Hydroacoustics

One recent and potentially valuable development in assessment work concerns hydroacoustics. Fishermen have now used such electronic aids as sonars and "fishfinders" for over a decade. While it remains impossible to determine the species of fish seen on the recording paper of such electronic aids, it is possible to see fish. Fishermen claim that they can, with a good fishfinder, spot individual fish at great depths. The basis of such a belief is experience: they see such targets, shoot their net, and retrieve some fish. Over time, they learn to read the recorder; this, just as aging fish, is considered to be an "art."

Hydroacoustics, properly developed, could be tremendously valuable for assessment work. Instead of requiring survey tows at selected areas, it might become possible to take a steady record of fish abundance as the vessel proceeds along a chosen course. Were it possible to determine the species of the target, abundance surveys could be undertaken far more rapidly and at far less cost than existing survey tows.

Presently, however, there is uncertainty as to the potential of hydroacoustics. Present technology limits hydroacoustics to schooling stocks, clear awareness of possible bias, and location in midwater depths. Such techniques can be used productively in known areas but not in frontier areas; it remains impossible to distinguish one species from another. Total biomass estimates from the use of such electronics may be off by five orders of magnitude.(70)

Clearly the following need is apparent:

Further development of the use of hydroacoustics in assessment methodology.

The Vessel as a Tool

For the New England Area, the National Marine Fisheries Service has two offshore research vessels--the Albatross IV and the Delaware II. NMFS has recently ordered another vessel for inshore work. In addition, cooperative programs with other governments have provided use of foreign research vessels on occasion for selected studies.

As all offshore survey work must be carried out at sea, the suitability of the existing vessels is critical, for an unsuitable vessel carries with it a host of problems. Research scientists require a stable platform upon which to carry out their work. Georges Bank is one of the roughest areas of the Northwest Atlantic. Personnel who spend much of their time in laboratories ashore are far more prone to seasickness than their fisherman counterparts.

Survey trips that are undertaken at certain specified times every year depend upon use of a vessel that is adequately maintained. Maintenance problems can force a vessel to remain in port or abort a trip when it should be carrying out offshore surveys.

At the present time, the existing survey vessels are called upon to provide time and space for other research needs, reducing available sea time for assessments. Combined with some serious maintenance problems--for instance, recently the Delaware II fell off the ways when being repaired--has been tendency for senior scientists to remain on land (often travelling abroad to provide advice for ICNAF proceedings) while new personnel are called upon to make cruises, take samples, and provide results for laboratory analysis. Often these new personnel are young fishery students who make one or two trips before moving to other positions. Needless to say, the quality of the data they develop may be open to question if they have been seasick during the cruise. In any case, the data provided must then be analyzed in the lab by senior personnel, requiring time and adjustment. There currently appears to be a dispute at NMFS concerning the suitability of the research vessels for their task. Personnel who do not make cruises very often tend to be satisfied with the existing vessels; those who do make cruises shake their heads.

Recent reorganization of the National Oceanic and Atmospheric Administration (parent agency of NMFS in the Commerce Department) placed the existing vessels under the authority of the National Ocean Survey. Formerly, they had been operated and controlled by NMFS, and during this period spent a great deal of time at sea, averaging well over two hundred days a year. The present situation can only be described as difficult, with those who man the vessels feeling somewhat separated from the organization they serve (NMFS). Budget constraints have intensified and further complicated the problem.

Ideally, a research vessel should meet the following criteria:

- It should be a stable platform;
- The vessel should have the necessary range for extended cruises;

- The vessel should have comfortable accommodations;
- The vessel must have space on the working deck to carry out sampling activities, unencumbered by machinery;
- The vessel should have well-maintained operations;
- The vessel should have adequate laboratory and analysis space.

Presently NMFS is budgeting nearly one million dollars on the refurbishment of the Albatross IV. This vessel, built in the early 1960s, is a medium-sized stern trawler that has long served as the basic mainstay of the Georges Bank assessment community. While the history of this vessel is a sad story of limited funding, the vessel itself has several limitations that, when combined with her age and condition, indicate a continuing series of operating difficulties.

Instead of a single engine, the Albatross has two smaller diesels that are used to drive a single shaft and wheel. While such engine duplication is necessary for tows at a very low speed, the engines have never been aligned properly, and consequently there have been a series of broken propellor shafts and subsequent need for repairs.

The steering system is of foreign manufacture and utilizes steering nozzles. Whenever this system breaks down, much time is wasted while awaiting replacement parts from abroad.

While the vessel does have extended range and comfortable accommodations, as well as a clear aft deck for working space, she is arranged in a manner that wastes space below and forces creation of laboratory structures well above the waterline. Although she is said to be a good "sea boat," the presence of working areas well above the waterline imply exaggerated motion for all analysis activities.

Thus, while NMFS is attempting to make the best of a presently bad situation, the future importance of good domestic assessments argue for the construction of new research vessels. It is interesting to note that, while the domestic fishing industry regards assessments with suspicion, personnel from that industry feel that NMFS should "spend more money now" for a new research vessel rather than upgrading present vessels.(71) Indications from personnel who man the crew of the Albatross consider her a "dog" that is "aptly named."(72) Personnel at NMFS in Woods Hole feel that assessments would be well served by the presence of at least two more vessels to undertake survey and other assessment work.(73)

In a general sense, problems with assessments at present are not related to the methods of analyzing data, which have come to depend on sophisticated computor modeling that is done ashore. Rather, the problems primarily concern the gathering of that data. As that data must be developed through the use of a vessel, the quality of that vessel becomes critical to good assessment work. As an adequate vessel is the primary tool of assessment work, the following need is apparent:

- Direction of effort to construct or purchase new or relatively new vessels for offshore survey work.

II. CATCH AND EFFORT STATISTICS

Assessments must address the potential yields available from selected fisheries on a year-to-year basis. Present theory holds that the health of a chosen stock can only be determined through analysis of catch and effort data; as long as effort increases produce yield increases, the stock is considered robust and underutilized.

As indicated in Part I of this report, sophisticated methods have been developed to convert the landed weight of dressed fish into "round" weight figures, as well as sophisticated estimates of fishing effort. Particularly in recent years, however, technological changes in fishing fleets have complicated effort calculations. Vessels from different nations must be standardized according to chosen effort coefficients. It has been extremely difficult to develop a basis for comparing, for example, the effort produced by an American seventy-foot side trawler with a Soviet Atlantik Class stern trawler.

Historically, ICNAF figures for both landings and effort have been reported to the Dartmouth headquarters in Nova Scotia on a piece-meal basis. Assessment had to be undertaken with a clear awareness that such figures were often inaccurate or missing. While landings of species from American vessels were gathered by NMFS with a high degree of accuracy, particularly for groundfish species,(74) figures for foreign fleets were often guesses.

Thus, while abundance surveys were relatively accurate, even with the limitations outlined previously, possible yield estimates in relation to potential effects on stocks were not. Theoretically, continual surveys taken within an area can serve to predict the health of stocks and possible yields. However, the time requirements to gather the necessary volumes of data are greater than the time necessary for a factory fleet to decimate a stock.

Figures concerning the number of vessels fishing in an area were extremely imprecise, depending on overflight information as well as reported information that was often three years out of date.(75) Such imprecision had three important effects on assessments:

- Only when stocks were recognized as threatened were scientists' recommendations adhered to;
- Calculation of catch/effort coefficients was based on information that was known to be incorrect.
- It became recognized that the time necessary to gather, collate, and analyze catch and effort data exceeded the demands on the part of managers to base their decisions on up-to-date information.

In addition, assessment theories and procedures were founded on a single-species approach that in and of itself was extremely complex. Introduction of hundreds of factory vessels into Subarea 5 in the 1960s drove assessments to consider entirely neglected species. Not only did information needs increase by several orders of magnitude, but it soon became apparent that fishing activities were having important effects on stocks that had to be included in catch and effort analyses.

Two examples serve to illustrate this point:

- As it became clear that factory vessels were catching and keeping quantities of species not being initially sought--bycatch--it was realized that effort coefficients had to reflect the bycatch potential of a chosen vessel.
- Improved electronics increased the searching capacity of vessels. Combined with skill of the skipper, it became very difficult to assess the effects of effort undertaken with such aids as compared to effort undertaken before such aids were developed.

It has generally been assumed that total catch from Georges Bank has tripled since the 1960s and effort has increased six times.(76) According to assessment theory, all stocks then must be in danger. Without precise estimates of effort and catch, however, the accuracy of the stock reduction estimate is only general.

Recognition that foreign vessels were harvesting all species in the path of their nets, added to the need to understand the biological foundation of all commercial species found on Georges Bank, created the requirement to understand interspecies interactions. Whereas previously American vessels concentrated on one or two species, the interspecies direction of foreign fisheries forced assessments to consider the interspecies interactions of the marine ecosystem. While the biological assumptions necessary to understand such interactions may yet be undeveloped, it has been assumed that monitoring single species over time would develop the necessary interactive information.(77)

However, much of this information depends on adequate catch and effort data. Historically, such data has been insufficient because ICNAF lacked adequate enforcement powers. Extension of jurisdiction now carries the potential for good enforcement, and through such enforcement the development of good reliable catch and effort data for the assessment community.

Consequently, the following needs should be considered:

- Provision of funding to enforce management decisions relating to allowable yields.
- Development of a system whereby catch statistics are provided on at least a monthly basis to the assessment community.
- In order to determine the degree of bycatch (as well as the yield of species that are then reduced to fishmeal), provision of funding to place observers on factory vessels offshore.

- Unless or until survey information can determine what catch/effort data does today, provision of funding to develop a system whereby effort statistics can be adequately applied to different types of vessels.

III. BIOLOGICAL ISSUES

The Assessment Community

Recent emphasis upon interspecies relationships has forced the assessment community to design systems and models that serve to analyze the total marine environment. Recognizing that budget limitations produce severe constraints on project design, and recognizing as well that many of the issues now under consideration are extremely time-consuming and expensive, several basic assumptions appear necessary in order to understand interrelationships.

1. The Relationship of Inshore Marine Ecosystems to Offshore Systems

Very little is presently known concerning the relationship of inshore marine ecosystems to offshore stocks. NMFS has budgeted a research vessel for this task; the vessel should be operating in 1977. The effects of estuary degradation on breeding grounds and lower trophic forms may have severe impacts on offshore species, particularly those that spend part of their life cycle in shallow nearshore waters.

2. Behavior Characteristics and Other Life Patterns Occurring in Midwater Depths

All fish spend a portion of their life cycle in pelagic form; that is, drifting or swimming in the midwater zone between the surface and the bottom. For groundfish, this period is short and occurs directly after the hatching of eggs. Pelagic species, such as herring, spend their entire life cycle in this zone. Although hydroacoustics can generally assess concentrations of midwater fish, adequate knowledge of this region has not been developed.

Clearly, design and enactment of projects to investigate this region is extremely difficult, for the variables and biases that are likely to be present are even more numerous than for bottom-dwelling species.

3. Interspecies Trophic Relationships

In order to understand interspecies relationships, the predator-prey coefficient among species within the marine environment should be understood. Although man acts as a predator on the marine ecosystem, there already exist abundant predatory situations in the natural environment. Species of fish depend on other species for survival. Thus, man's activities may effect the food supply of a particular species through removal of prey.

It has been assumed that an assessment of the rate of energy transfer in the marine ecosystem will develop these interspecies webs. Much work is presently being done by NMFS on precisely this issue.

The present ICNAF quota system is of a two-tier nature, assessing potential yields from individual species. However, the sum of these assessments is greater than an established Total Allowable Catch for the entire Subarea. This two-tier ICNAF system, wherein the Total Allowable Catch is less than the sum of the individual species quotas, reflects interspecific relationships and an acceptance that such relationships are not adequately understood.

Yet this system does not adequately assess the predator-prey relationship within the ocean. Consequently, efforts are underway to develop a new matrix into which the allowable quotas can then be measured and determined. The aim is to eventually take the results of this interspecies matrix and feed them back into the Total Allowable Catch and the individual quotas of the two-tier system, respecting the interdependent balance of all marine species.(78)

It has been assumed that over time the Total Allowable Catch will approach more closely the sum of individual quotas as these interspecies relationships are better understood.

These three issues appear to be of primary importance of the assessment community at present. It should be noted that development of information in these areas is long term in nature and must be developed while at the same time providing information for short-term management decisions. The present state-of-the-art, according to NMFS personnel, is about seventy percent effective; in other words, existing methods and funding develop information that will provide correct assessments seven times out of ten. It is felt that the degree of accuracy can be somewhat increased by the addition of two more vessels.

The Domestic Industry

Discussion with industry personnel revealed several other biological issues that may be of importance, particularly regarding interspecies relationships.(79) It should be noted that during the 1950s assessment scientists enjoyed relatively good rapport with members of the domestic fishing industry. However, the foreign pressure on Georges Bank had two critical effects on this rapport.

- Foreign incursions rapidly depleted species of value to the American fishermen, forcing him into economic difficulties, and all too rapidly creating the need to restrict domestic fisheries harvesting efforts.

- The foreign depletions of stocks created tremendous pressure on ICNAF, which, in turn, exerted pressure on the assessment community to primarily study species of no value to the domestic fisherman whatsoever.

Thus, whatever expertise working fishermen had concerning species abundance and behavior was either avoided or ignored by the assessment community. Certainly the indicators that fishermen use to harvest species are different than those chosen by assessment personnel to assess stocks. Fishermen rapidly refused to cooperate with the assessment community; tensions developed; and today the relationship between the personnel who depend on stocks for a living and those who assess those stocks is, at best, an adversary relationship. Fishermen feel, with much justification, that they are responsible for the legislation extending fisheries jurisdiction; they are concerned that their expertise and knowledge is not sought or utilized by those who undertake assessments.

Fishermen feel that assessments should serve them; that NMFS exists because the United States has a fishing industry and that assessments should respect their needs. While they recognize that much of the recent lack of communication is due to them, and that assessments must attempt to develop estimates of possible yields in a cost-effective manner, they remain concerned that studies have not been developed to investigate issues _they_ feel to be important. These issues fall into two categories: information regarding biological relationships; and information relating man's activity with respect to stock abundance. These shall be treated in turn.

Biological Relationships

1. _Fishermen have argued for years that foreign inroads into such species as herring and mackerel have had important effects on the yield potential_

of groundfish stocks. Their feeling is that herring serve as an important food source for cod and haddock; that herring depletions (presently 90% of former levels) have, in turn, caused reductions in cod and haddock abundance.

Their basis for such a belief is experience: in the late 1950s, during the herring spawning season, fishermen would seek the spawning beds so as to capture the cod and haddock that fed on those beds. At that time, they estimate that herring spawn lay on the bottom to a depth of several feet, which tended to clog nets although cod and haddock were found in abundance. Soviet surveys in the mid-1960s discovered herring spawning beds several miles square lying to a depth of one foot; in the late 1960s, following pulse fishing efforts on the herring, that spawn was only 5-7 centimeters thick.(80)

Presently, no specific studies of such a relationship have been carried out by the assessment community.

2. The experience of fishermen indicates to them that changes in the course of the Gulf Stream have important effects on the abundance of certain species. Admittedly a difficult project to carry out, the attention of NMFS to this issue has been cursory.

3. Similarly, fishermen depend upon experience with regard to yields on weather conditions. Certain types of weather appear to be beneficial to certain fisheries and harmful to others. In addition, the phase of the moon and tide conditions have been found to be critical factors. While fishermen may have opinions regarding such effects in relation to stock abundance, little work has been done in this area.

4. Difference over time in size of year-class individuals. Members of the domestic fishing industry feel that biomass reduction on Georges Bank may be

accompanied by trends concerning the size of fish, in that a three-year-old fish today may be smaller--due to lack of food--than a three-year-old fish of five years ago. Such information, and its degree of importance, has not been studied.

5. Fish behavior. Fishermen have many opinions concerning the behavior characteristics of fish. They feel that such characteristics are very important, particularly with relation to effort coefficients.

For example, domestic draggermen have found that yellow-tail flounder tend to scatter when a certain number of vessels concentrate in an area. Whereas one vessel can fish the same ground all day, the presence of several seem to cause the fish to scatter after a few tows. If this is true, fishermen feel that stock abundance may be incorrectly estimated according to effort calculations: increased effort may produce less yield, but not for reasons of depletion so much as behavior.

In addition, it has been found that certain species are attracted by bottom disturbance while others are repelled. During the last few years it was found that affixing a large chain to the bottom rope of a trawl attracted yellow-tail through stirring up the sand during the net's passage. With such a chain, then, the effort coefficient of a vessel would alter by increasing. Had such information been utilized, yellow-tail depletions might have been predicted earlier.

Although such issues may be of questionable importance in relation to overall assessments, the fact that behavior characteristics of fish populations have not been investigated through a coordinated program is disturbing to members of the fishing industry.

Effects of Man's Activity as a Predator on Yields:

While the assessment community has grappled with technological changes in relation to fishing effort and catch coefficients, virtually no work has been done investigating the effects of that technology on stocks. Although catches themselves serve to reduce stocks, the methods by which catches are made may also have effects on stock abundance.

- Effects of towing nets on the bottom: This is seen to be an absolutely critical issue by members of the domestic industry. The introduction of ever-larger nets on Georges Bank, sometimes towed by two vessels (pair trawling), may disturb the bottom in such a manner as to reduce food abundance, alter stock behavior, and reduce stock abundance. Although many areas of Georges Bank are flat bottom continually swept by strong tides, other areas, particularly those close to the edge of the shelf, contain abundant bottom communities that can be 'swept clean' by a net's passage. The effects of such 'sweeping' activities remain unknown.

- Relationship between a discard and no-discard fishery: American fishing efforts have been selective in nature, seeking valuable species while throwing others back over the side. Depending on the area fished, such discards can comprise up to sixty percent of the yield from a tow. Such discards are almost always dead. Fishermen recognize that discards are a wasteful method of operation, but feel that, however inefficient, such discards are returned to the marine food chain. In fact, a general rule of thumb in the hook-and-line longline fishery is to avoid throwing offal over the side if gear is to be later set on the same bottom. There are indications, in addition, that discards from shucking sea scallops (done at sea while towing a dredge) attract groundfish and, in fact, can even increase their abundance.(81)

  Foreign factory efforts, on the other hand, rarely produce any discards. Demersal fish are gutted and the offal thrown into a fishmeal plant. Whereas American fishing vessels are usually followed by flocks of seagulls, such is not the case with factory vessels.(82)

  Fishermen feel that such factory operations may have the same effects on the marine environment as does clear-cutting on tracts of forest. They feel that their fishery, although in some senses economically wasteful, is less biologically wasteful than fishmeal operations.

  Specific projects have not been designed to determine the yield implications of a discard as opposed to a no-discard fishery. It is interesting to note that Georges Bank produced nearly 500,000 tons a year from the 1920s to the 1960s. All of this production was a discard fishery. Clearly another several hundred thousand tons were caught and destroyed. Although assessment theory holds that the eventual tripling of yield on Georges reduced the biomass by up to 45 percent, it may be that the 'clear-cutting' nature of the fishery had equally important effects.

While the trophic model described earlier may include the energy value of discards in its matrix, no specific work in this area has been designed.

- The fishmeal "loophole": There presently exists no method of determining the species composition of fishmeal. Fishmeal is composed not only of offal from commercial species, but of whole fish that are of no value as fillets or frozen blocks. Assuming that reduced production from Subarea 5 increases the value of all species found, and assuming further that the value of any fish will increase in the future, it may well be that fishmeal production will become valuable in itself even though the species in that meal have value as fillets. This raises an enforcement problem: once the fish are reduced to meal, and unless they are seen on the deck before being reduced, there presently exists no method of determining whether, in fact, reported figures are accurate.

  Members of the domestic industry feel that efforts should be made to either observe all catches (observers) or design a method of determining fishmeal composition by species.

  Although this is not strictly a biological problem, until such information can be developed, accurate landing figures for Georges Bank (or any offshore region) will be subject to error.

Biological Issue Needs

The assessment community faces a difficult and demanding task. Development of predictive models to fully understand the interactions within the marine community requires initial assumptions, judgments, and choices of possible study options. As outlined throughout this report, the complexities of this science eclipse nearly any other resource management issue.

Such complexities force the choice of projects that will serve to provide the key indicators upon which management decisions are to be made. Confronted with offshore fisheries that stand threatened by overfishing, assessments must have utility in two areas:

- Short-term yield estimates that will maintain existing stocks;
- Longer-term strategies that will restore stocks to chosen management levels.

The information requirements now upon assessments are enormous, expensive, and critical. Present level of accuracy--the *existing* state-of-the-art--does not provide excessive precision for fishery managers. In addition, the existing science has little or no utility to industry. Lack of communication as well as a lack of site-specific orientation (assessments cannot predict yields from certain discreet areas at certain specific times) does little to increase the fishing efficiency of commercial fishermen, who argue in any case that they are more than capable of catching fish if there are fish to catch.

A study of ICNAF documents indicates the validity of a long-held opinion on the part of the domestic industry: *stock depletions and general biomass reduction of Georges Bank is solely the responsibility of foreign factory-type operations*. Prior to their arrival, the area produced fish on a steady and relatively stable basis for fifty years. Even today the one species that has long been of value to New England fishermen--sea scallops--remains essentially healthy, despite a lack of regulation and consequent maintenance of the common property nature of the resource. Interestingly, *sea scallops have never been the target of directed foreign fisheries*.

Although today it is true that domestic efforts are capable of depleting such devastated species as haddock and yellow-tail flounder, such devastations are the result of pulse fishing efforts; the domestic industry remains suspicious of assessments that continue to close areas to it while allowing foreign fisheries to continue. Fishermen throughout New England feel that each time they have cooperated with assessment scientists since 1968 they have had an area closed to them.(83)

Yet assessment scientists remain subject to the demands of international politics. They realize that foreign fisheries will continue on Georges Bank, that species will continue to be maximally utilized although efforts will now be made to reduce fishing effort. Further, they are driven by domestic and international economics to design models and systems that can predict variable yields to an absolutely precise level.

Such precision remains impossible. Funding to increase such precision may be a natural outcome of the recent history of modeling efforts, but the relative costs to gain that final thirty percent of accuracy may be excessive, particularly when the need for such accuracy remains undetermined.

Recognition that modeling has severe limits, particularly when applied to an environment as variable as the marine ecosystem, should be accompanied by a recognition that a major traditional problem with assessments has been enforcement of decisions and accuracy of data. By and large, the methods that have been developed to assess stocks are sophisticated, but they depend on data that continues to be suspect and often erroneous. Rather than attempting to design further models, therefore, that seek to incorporate economic effects with biological effects, the following needs are suggested:

- For short-term estimates of yields, continue with existing methods supplemented by more frequent abundance surveys.
- Recognize that a major problem has been enforcement in the past, as well as the validity of data; in the future, assessment requires development of better data gathering systems, particularly regarding catch and effort statistics, possibly through the placement of observers on foreign vessels.

- Because stocks are generally severely depleted, cease fishing to the extent possible, concentrating on factory-type operations that carry severe adverse biological potential through 'clear-cutting' harvesting strategy.

- Recognize that while stocks are restored, specificity of data is less important than continually underestimating available yields.

- During the restoration period, place controls on fishing technology developments such that an honest time-stream of data is developed. In this manner it will be possible, for the first time, to adequately assess existing assessment methods and models instead of further refining approaches that may not be correct.

- Immediately initiate a cooperative extension program with working fishermen so as to utilize their expertise.

- Immediately design and begin to implement an assessment strategy that seeks several factors:

  - Determination of level of accuracy required under differing national fisheries policies.

  - Determination of key indicators to provide that accuracy.

    . What is necessary for biological indicators?
    . What is necessary for catch/effort indicators?
    . For each indicator: Time required for application
    Cost required for application

  - Determine an implementation strategy.

PART IV

RECOMMENDATIONS FOR THE FUTURE

I. NEED

Ideally, assessment scientists desire the following information:

1. Understanding of species-stock biology;
2. Quantification of the commercial indices which allow trends in abundance to be followed. Estimation of such indices requires knowledge of the effects of changes in harvest technologies;
3. Survey information that demonstrates changes in total stock abundance and age composition;
4. Survey information giving prerecruit indices;
5. Accurate knowledge of species/stock abundance and area location. Such issues require knowledge concerning discards as well as unrecorded mixed fisheries (which often produce fishmeal);
6. Accurate age and size composition;
7. Historical catch-effort data;
8. Understanding of movements and migrations;
9. Knowledge of the sum of such factors as temperature;
10. Knowledge concerning the interrelatedness among species.

At the present time, no stock has adequate quantitative data on all these items.(84) Such information is necessary to develop estimates of maximum potential yields without reducing the parent stock. Such information requires the awareness of not only first-order effects but second-order effects as well. The time and budget needs to provide this data are enormous.

Yet while such information may well become necessary in the future, when stocks have been restored and when worldwide food demands have intensified, the immediate short-term needs of assessment are to design *restoration* strategies. And restoration of stocks is relatively simple: reduce the fishing pressure. Clearly it is easier to underestimate available yields than it is to estimate the maximum fishing mortality; and underestimation, while having economic implications, will only serve to restore a stock at a more rapid pace.

In fact recent legislation requires development of fisheries management plans to produce optimum yield, thereby formally recognizing the economic and social implications of differing allowable yields. Assessment science at NMFS is currently attempting to design models that serve to predict the economic as well as the biological implications of different management goals. Over one million dollars is being budgeted by NMFS for bioeconomic analysis for the coming year.

This effort, combined with the massive data requirements outlined earlier, indicate that efforts are underway to design systems that will develop a *high degree of accuracy*. The immediate need for such accuracy may be questionable given the need for stock restoration (and thus the need to reduce fishing pressure to the extent possible). In addition, the preceding sections of this report have shown that such accuracy carries cost implications that may be enormous; it may be far more cost-effective to choose key indicators upon which to make decisions, with all parties participating in those decisions aware that, in the end, yield judgments will remain *judgments*.

Given the uncertainties that such judgments must reflect, even with an elaborate and expensive research program, and given the changing needs upon assessments to now manage stocks for restoration, priorities should be established which reflect the management goals of extended jurisdiction. Many assessment needs may be satisfied initially by provision of better data for existing methods. Before substantial costs are incurred to improve on the current level of accuracy, a number of recommendations should be considered. Expansion of research programs would appear inevitable in the light of expanded management goals over time, but the form of that expansion and the interests it serves should be selected from the list of possibilities that result from the needs identified in this report.

The recommendations on the following pages are addressed to the newly-created Regional Councils, which were established as a means to decentralize fisheries management into regional authorities sensitive to specific issues unique to chosen regions. As this report has indicated stock assessment is highly dependent upon chosen goals. Too complex for universal application, always subject to error, and increasingly expensive, the wish to understand the entire marine ecosystem must be tempered by the need for rapid decisions concerning stock restoration and fleet revitalization.

II. RECOMMENDATIONS

1. Test the Validity of Existing Assessment Methods

Extension of jurisdiction provides the assessment community with an opportunity to develop an harmonious time-series of data upon which to predict yields. As demonstrated earlier in this report, resource abundance surveys are extremely reliable; problems arise with incorrect catch and effort data. United States jurisdiction over offshore waters; properly managed, provides a possible solution to these problems. Although assessments will continue to provide general information, the specificity of that information may increase considerably. Specific catch and effort information can be gained in the following manner:

- Requirement upon foreign nations fishing off the United States coast that observers be carried on offshore fishing vessels. Although the legal problems concerning such a requirement may be complex, the following information can be received and reported frequently:
    - Precise catch data by species and area;
    - Precise effort data in terms of number of tows;
    - Species composition of bycatch by area and season.
- Accurate compilation of domestic industry landing figures, discards, and areas fished through development of a cooperative extension program with the domestic fishing industry (see below).
- Under the recognition that observers would be expensive if placed on all foreign vessels when they entered the extended jurisdiction zone, several alternatives are suggested:
    - Catch figures compiled through landing reports of foreign nations, supplemented by an extensive inspection program and a clear awareness that noncompliance or inaccuracy will result in revocation of an operating license;

- Effort estimates developed through establishment of a system whereby different types of vessels can be compared. Present systems are complex and often inaccurate. It may well be that the energy required to construct, maintain, and operate a trawler is closely related to its likely harvest. If so, initial establishment of energy subsidies required for different vessels, once established, will provide effort estimates based on number of vessels and number of days seen on the grounds.

- Development of a system whereby the species composition of fishmeal can be determined during inspections. Without observers on vessels, such a system is absolutely necessary to estimate the yields from unrecorded mixed fisheries.

Concurrent with development of precise catch and effort figures, continuation of resource abundance surveys should be established in the following manner:

- Provision of a series of new research vessels for offshore survey work:

  - Rather than refurbishing existing vessels, construct or purchase new vessels that would be utilized entirely for survey work. In this manner, expand offshore surveys from twice a year to four times a year. Develop a survey system that is based upon well-maintained, dependable vessels rather than the present reliance on vessels likely to break down. If new vessels are not available, restrict operations on existing vessels for surveys only. Certainly the fact that the fishery resources now under United States jurisdiction comprise one-fifth of potential worldwide demersal yield argue for adequate survey tools.

    While the Jones Act presently restricts the purchase of foreign-built vessels, the fact remains that recent rises in operating costs have forced Canadian (and other) mid-size stern trawlers to be offered for sale. One American corporation has purchased such a vessel. The advantages with such vessels are clear:

    - Although used, they tend to be well-maintained and are relatively new;

    - Purchase price is very cheap when compared to a new American vessel;

    - Conversion would be rapid and efficient. Placement of laboratory space in the former fish hold will provide an environment that can be controlled, is large, and situated where there is least motion.

- An increase in survey cruises allows for abundance estimates of more species than at present. Such surveys will provide, over time,data that can be compiled on a controlled basis. This data, in conjunction with specific catch and effort data, will serve to identify the potential accuracy of existing stock assessment methodology, particularly in relation to the need for short-term decisions that must be made in order to revitalize stocks.

Because marine fishery resources must be restored, initial management plans will seek to reduce fishing effort to the extent possible so as to allow stocks to recover. Existing stock assessment methodology is sufficient to develop restoration yield estimates, particularly if it is recognized that in cases of doubt yields should be underestimated. Prior to maximal utilization of offshore fishery resources, those resources must be restored to potential levels. As such restoration demands a reduction of fishing effort, the precision of assessments during this interim period must only ensure stock recovery rather than maximum sustainable yields.

2. During the Initial Restoration Period, Determine the Future Level of Precision Required and the Key Indicators Needed to Provide that Level

- Analysis should immediately determine the differing levels of precision under different management goals. For example, management that seeks to continue the maximum yield from the presently depleted Georges Bank biomass requires extremely precise information--the technological capacity of fishing fleets exceeds the yield capacity of the resources. Consequently, under this management goal of continued yield, the last available ton must be predicted. While such a goal is a political decision, the stresses it places on existing assessment science are enormous.

  On the other hand, a management goal of resource restoration--under the assumption that the food value of the stocks will only increase in the future, that therefore the maximum stock must be available, and consequently short-term yields must provide for stock abundance increases--reflects both the present level of accuracy of assessments and the ability of assessments to presently determine possible restoration yields.

For existing programs that have been established to determine an understanding of marine ecosystems, the following subjects should be addressed:

- What is the expected level of accuracy for the program?
- What is the expected cost to achieve that level of accuracy?
- What are the time requirements to develop useful results?
- Are the cost and time implications justified?
- What is the expected accuracy of assessments given adequate catch and effort data (previous recommendation)?
  - What is the expected cost to achieve that level of accuracy?
  - What are the time requirements to develop useful results?
  - How do these cost and time implications compare to programs that seek to expand understanding of the marine ecosystems?
- Under different management goals, what is the required level of accuracy of assessments? Cost? Time needs for results? Utility?

- While stocks are restored (and while assessments can determine the validity of existing survey and abundance methodologies). efforts should be made to determine key indicators necessary to produce information that can be used for increasing understanding of the total marine ecosystem.

Rather than designing holistic systems models, it may in fact be far cheaper and more efficient to develop a series of program priorities that seek to determine indicators that lead to decisions that must be made. If in fact the utility of assessment information is only incrementally greater as a result of complex model design, if management decisions relating to yields remain somewhat general, it becomes difficult to justify the development of such models.

For development of key indicators, establishment of a cooperative extension service with the domestic industry is suggested. The expertise of fishermen in relation to stock location, yield, and abundance is recognized by many managers as extensive. However, such expertise has not traditionally been utilized by members of the assessment community. Particularly with relation to key indicators, issues that can later be developed into assumptions relating to the total marine ecosystem should be investigated.

- Extension programs will provide data to the assessment community that can then be incorporated into existing assessment theory;

  - Such programs will initiate and develop a cooperative relationship between assessment scientists and fishermen. Cooperation has now become critical with regard to compliance with management regulations as well as restoration strategies.

  - Initial consideration of the assumptions behind biological understanding of the marine ecosystem will clarify such assumptions, outline significant issues, and result in a more cost-effective program for future assessments.

3. Based Upon Choice as to Degree of Accuracy Required, Key Indicators, and Validity of Existing Assessments, Design A Program Strategy as Follows

- Immediate needs to enhance existing assessment methodology given better data
  - Increased survey work
  - Precise data through observers
  - Cost and accuracy implications of surveys and observers
- Proposed schedule of resource restoration
- Future level of accuracy required
  - Cost and time implications of chosen levels
  - Precision of such levels
  - Alternative methods using key indicators
- Choice of assessment program reflecting required accuracy, cost, time needs, and utility for management

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Comments from Reviewers

"It has been my experience that the determination of accurate numbers is a very expensive and impractical objective. The extension of operations from any one fishery or locality to other fisheries and localities is not reliable. Again, we need to consider in some detail what value is to be obtained by the United States fisherman from having this information."

--from P. J. Doody
Vice President, Production
Zapata Haynie Corporation
November 17, 1976

"What is required here (in stock assessment) is a broad-scale plan for scientific research ranging from ecosystem dynamics to mathematical modeling, and which can benefit by coordinating efforts with a wide range of agencies and research operations. More ships for surveys is a small part of the approach to coping with these issues."

--from Lauriston R. King
Program Manager, Marine Science Affairs
National Science Foundation
November 9, 1976

"An important point of any assessment is 'the fact that fishery resources must be restored. Without restoration of the stocks -- which requires the accumulation of a great deal of information, extension of our knowledge of fisheries and their interactions with the environment and with each other, and the periodic collection of accurate statistical data and enforcement -- studies involving community impact, processing, marketing, distribution, etc., will have little but academic meaning.

"Another point that...should be brought out...involves the alternative of developing indicators as opposed to holistic system models and the value of qualified judgments in making management decisions. These factors should be recognized during the early stages of developing management priorities so that possible indicators could be evaluated as the assessment data base develops.

"I would call accurate assessment of the maximum sustainable yield and whether or not it exists for a particular fishery a matter of importance in the management program (that) would be required for a fishery when in the management of that fisher. A different management program would be required for a fishery where stock assessment techniques are poorly developed as compared to a fishery where accurate stock assessment is routine. 'Relevant economic, social, or ecological factors' can be effectively applied only after a mature MSY technology has been developed. . . . I feel that a fishery by fishery assessment of the maturity of stock assessment and MSY technologies are paramount to the development of effective management systems. I would like to see an information flow diagram leading from discovery of a commercial species to accurate determination of the MSY for that species. Application of this diagram to each fishery would determine which management system to apply and what areas require research."

--from Robert M. Snyder
Snyder Oceanography Services
November 15, 1976

"In the Northeastern Pacific, it is our view that the stock assessment information is in fairly good shape. The work by National Marine Fisheries Service has been timely and of good quality. This assessment work is augmented by the State agencies of Oregon, Washington and Alaska as well as scientific and other data from foreign nationals using the resources of the area.

"The provisions of PL 94-265 are obviously going to vest the management levels of optimum sustainable yield and levels of national utilization with the Council as provided for in this law. One of the best tools to assess the practical levels of harvest of fishery resources is to permit a properly managed fishery.

"An increased level of effort on stock assessment is actually mandated by this 200-mile legislation. This information must be available to determine levels of harvest for U.S. citizens and for negotiations called for in legislation with foreign countries. The Congress did not consider taking into account the cost of this exercise but decreed that it would be done."

--from W. V. Yonker, Executive Vice-President
Association of Pacific Fisheries
September 14, 1976

Working Paper No. 4

A SHORT ANALYSIS OF STOCK ENHANCEMENT POSSIBILITIES FOR CERTAIN COMMERCIALLY IMPORTANT MARINE SPECIES

Prepared for OTA
by
John Vernberg

August 1976

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Introduction

This working paper is an abbreviated analysis of the possibilities of stock enhancement for certain commercially important marine species which may be impacted by the extension of the U.S. fishing zone jurisdiction to the 200-mile limit.

The paper discusses the rationale for stock enhancement--increasing the amount of edible product by increasing the number of fish and/or the size of the fish in the stock--and general techniques for stock enhancement. It also discusses briefly enhancement possibilities for a group of selected stocks, including cod, haddock, yellowtail and blackback flounder, ocean perch, pollock, Gulf shrimp, Pacific salmon, Alaska crab, Atlantic herring and Pacific pollock.

References for this work are included at the conclusion of the working paper along with excerpts from the comments of reviews who had substantive additions to make to the paper.

Stock Enhancement Techniques

Extended jurisdiction could be a stimulus for a comprehensive stock enhancement program. As has been documented in other parts of this broad study, certain of our fisheries, such as the New England ground fishes, have been over-exploited almost to the point of depletion. The National Marine Fisheries Service (NMFS) projected that a 100 percent increase in today's ground fish catch could be attained if depleted stocks were restored (1). It is probable that many of the other fisheries could be improved by a comprehensive stock enhancement program.

Stock enhancement is a complex subject, and in spite of erratic periods of intense interest by various private and governmental entities, detailed studies are not numerous. In general certain fisheries, such as salmon, are better understood in terms of stock enhancement than others. Various reasons can be given to explain this paucity of data, but one obvious major factor is the problem of control and recovery of stock by the government responsible for the enhancement activities. By extending jurisdiction to the 200 mile limit, the United States of America would have control over fisheries and its citizens or leasees could reap the harvest of a stocking program. It should be noted that certain fisheries might respond better to stock enhancement than others, and that new fisheries might emerge which would have better economic return and less ecological disruption than existing fisheries. A comprehensive policy of fisheries management by the United States Government is urgently needed to insure wise development and utilization of marine resources.

At the onset a description is needed of what constitutes a stock. Typically a stock is a population of a species which occupies a specific geographical location, especially at the time of reproduction. Hence within a commercially important species, a number of different stocks (populations) may exist. Because of such factors as potential genetic differences and differential effects of the environment, each of these geographically separated populations (stocks) may exhibit different morphological and/or functional characteristics. For example, different stocks of herring have been reported based on anatomical features, and, by analyses of blood factors different stocks of marine mammals are known. Stock enhancement programs dealing with one species must be aware and account for the possible effect of dealing with a complex of stocks and that a single stock may not be representative of a species.

Within a population (stock) of a given species, the size of the population is determined by a number of factors, especially natural mortality, recruitment, and growth. In the case of a commercially important species, man's fishing activities represent mortality to the population. Basically, stock enhancement involves procedures whereby the total amount of edible product (biomass) is increased by increasing the number of animals and/or the size of the animals in the population. A number of general techniques for stock enhancement have been proposed. These will be introduced now because of their general application, but specific suggestions will be made later when each species is discussed.

1) Control of harvest. If the amount of biomass removed from the stock is properly regulated, then the maximum sustainable yield (MSY) can be achieved. However, a depleted stock, such as haddock, might increase in biomass by natural processes if the amount of fishing is decreased. The levels of harvest are not always easily determined and must be evaluated constantly.

2) Recruitment. To assist a natural population in attaining a maximal size consistent with the marine ecosystem, additional individuals can be added to the population (stock). In hatcheries, many individuals can be reared under man-controlled conditions and released into the natural environment. One early attempt at stock enhancement was to culture fertilized eggs and young stages and to release them into the waters. This approach, however, does not insure adequate recruitment in all species because of high predation and environmental hazards encountered by very young stages. The release of individuals in more advanced stages of development normally increases their chances of reaching marketable size. Excellent examples of successful hatchery programs are those

related to Pacific Coast Salmon and many freshwater species, such as trout and bass. Unfortunately, many marine species have not been reared under hatchery conditions although some attempts have been made.

3) Development of new stocks. Utilizing standard breeding and genetic selection techniques, new stocks which have desirable traits, may be developed and introduced into marine waters or into confined waters for aquaculture purposes.

4) Habitat management and environmental quality. Some species spend a portion of their life cycle in estuaries, rivers, or near shore environments. Poor water quality will have a detrimental effect on the size of the stock either through a marked increase in mortality or sublethal effects such as stunted growth. Programs of pollution abatement will assist in stock enhancement. Some attempts at habitat manipulation may increase the availability of a suitable habitat for a species, such as artificial reefs or an increase in the level of nutrients by artificial upwelling. These nutrients stimulate the growth of phytoplankton, resulting in an enlarged food web base.

5) Aquaculture (mariculture). Animal husbandry of marine organisms has been extensively tried within the three mile limit (2); however, open sea mariculture experimentation is now underway (3). Typically aquacultural techniques are used with organisms that are confined to a specific area for harvesting as opposed to nursery programs where organisms are usually released to natural bodies of water.

With the continuing pressure for increased sources of protein and with the establishment of a 200 mile fishing zone by the United States Government, the need is apparent for the development and application of stock enhancement techniques (4).

The following is an analysis of stock enhancement possibilities for a selected group of commercially important species. They are: New England Ground Fish, including cod, haddock, yellowtail and blackback flounders, ocean perch, and pollock; Gulf Shrimp; Pacific Salmon; Alaska Crab; Atlantic Herring; and Pacific Pollock.

New England Ground Fish

Cod

Gadus morhua is a heavily fished species ranging in numbers from Labrador to south of Cape Cod, Massachusetts. Various stocks have been identified. In Newfoundland, the stock inhabits coastal waters during the summer and offshore waters in the winter. Another stock is always present on Georges Bank and apparently most individuals are there throughout their lives. A third stock spawns in more southern waters during mid-winter and then returns to Georges Bank. The female is prolific, laying millions of eggs which are pelagic as are the developing young (5).

Cod eggs were hatched in hatcheries and the fry released in coastal waters from the late 1800's until World War II. When no definite benefits were noted, this procedure was stopped. The International Commission for the Northwest Atlantic Fisheries (ICNAF) earlier stated that stock enhancement would only result when fishing intensity was reduced.

Future possibilities for stock enhancement in addition to catch restrictions are: 1) development of new genetic strains, i.e. southern populations grow and develop faster than northern stock; 2) application of the newer technology developed on the west coast for salmon might facilitate stock enhancement. The technology could be modified and applied, but economic feasibility studies should be conducted also; 3) the present level of sophistication of open sea mariculture appears to be too primitive to permit this technique to be actively considered as a viable procedure; and 4) water quality does not seem to be a sensitive factor in stock enhancement, but this factor should be actively monitored, possibly through the MARMAP program or by having the fisherman collect samples.

Haddock

Melanogrammus aeglefinus is listed as a "depleted" species by NMFS. Typically it is caught in greatest numbers on Georges Bank. Two distinct spawning stocks are reported; one on Georges Bank and another on Browns Bank. The haddock on Georges Bank reach marketable size two years earlier than those from Browns Bank. Spawning is of greatest intensity from late January to the end of May. Floating near the surface, the eggs hatch after 2-3 weeks. The larvae are pelagic. Both the eggs, the larvae, and the young up to six months of age are temperature sensitive. This may result in marked yearly fluctuations in population size, although other factors, such as availability of the right food at the right time might be as important (5).

Future possibilities for stock enhancement in addition to catch restrictions are: 1) since the eggs and young of this species are sensitive to environmental changes with the result that recruitment may fluctuate yearly, a hatchery program of rearing eggs to the juvenile stage and then releasing them seems feasible. However, in view of the previous disappointment with the cod hatchery program, a modest pilot program coupled to an economic feasibility study would seem a logical first step. One recurring problem in all hatchery investigations is developing the technology to rear marine organisms under laboratory conditions;

2) the development of new stocks which are less sensitive to environmental change would be one long-term project that could be considered; 3) open sea mariculture procedures are poorly known and at present would appear to be a low priority alternative; and 4) environmental deterioration does not seem to be a factor at present, but a monitoring program, especially following the spawning season would be indicated.

Yellowtail Flounder and Blackback (Winter) Flounder

Limanda ferruginea and *Pseudopleuronectes americanus* are both found in coastal waters and on offshore banks extending from Newfoundland to Cape Hatteras, North Carolina. The yellowtail flounder is listed as a depleted species as of August 1975 by NMFS (4). This species spawns in the spring in offshore waters. The eggs and larvae are pelagic. In contrast the winter flounder are quite different. They spawn in the winter and early spring, the eggs and larvae are demersal, and spawning occurs in estuaries.

Stock enhancement would best be accomplished by restricting the catch and also by a reevaluation of the mesh size of the nets used in the otter trawls, especially for the yellowtail flounder. In the case of the winter flounder, early attempts by the United States Bureau of Commercial Fisheries to hatch winter flounder eggs and release them to coastal waters appeared to have little effect on the size of the stock and the procedure was discontinued. Using newer technologies and by rearing both yellowtail and blackback flounders to later stages before release, stock enhancement could result. Coupled with a hatchery program, investigations are needed to develop new stocks using genetic techniques.

Although these approaches are initially expensive, a long-term potential for economical return exists. Land based agriculture has prospered by developing different strains (stocks) of corn, cotton, tobacco, cows, etc. which are disease resistant, faster growing, or exhibit some other economically desirable trait.

Habitat management is of particular value to any stock enhancement program for the winter flounder because part of its life cycle is spent in estuaries and shallow coastal waters. These habitats are particularly vulnerable to the harmful actions of human society. Increased pollution of estuaries has been well substantiated and the economic benefit resulting from improvements in the quality of coastal waters has been assessed by Bell and Canterbury (6).

Aquaculture of flatfish has been neglected for the most part in the United States (2). However in Great Britain a pilot scale project is in progress on commercially rearing the plaice and could provide valuable technological information for a project in the United States.

Ocean Perch

Sebastes marinus L., unlike the other fish species associated with the geographical area from Labrador to Georges Bank, lives at greater depths and has a different reproductive mechanism. The females retain the young within their bodies (live bearers) and the larvae escape from the female during the period from spring to early summer. Initially the young stages (fry) are found near the surface, but when they become about 5 months of age they migrate to the bottom. Of importance to stock enhancement is the observation that this species grows very slowly. Thus overfishing could have a long-term effect on the rate of recovery of this stock.

The principal immediate method of stock enhancement for this species is the regulation of fishing. A long-term program of selection for new stocks could have value to this fishery. Environmental monitoring should be part of any management program.

Pollock

Pollachius virens is a widely ranging species occurring latitudinally from the Gulf of St. Lawrence to New Jersey and vertically from the surface to the bottom. This schooling fish spawns in late autumn and early winter. In the Gulf of Maine it spawns at temperatures of 8.3 to 9.4°C and a salinity range of 32 - 35 o/oo. The young stages are all pelagic. A 1974 report by the National Marine Fisheries Service (1) suggests that this species is being underfished.

Since the maximum sustainable yield for this species is unknown and this species does not appear to be overfished, suggestions for a stock enhancement program do not seem warranted. An apparent need exists for more information on the biology of this species and a stock assessment.

Gulf Shrimp

The three most common species of shrimp caught in the Gulf of Mexico are: *Penaeus aztecus*, the brown shrimp; *P. setiferus*, the white shrimp; and *P. duorarum*, the pink shrimp. In the Gulf the brown shrimp is of major importance.

These species have life cycles which are closely associated with both estuaries and the open waters. Spawning occurs in open waters. Fertilized eggs hatch and the postlarval development stage migrate to estuaries where they become juveniles. After several months, they emigrate as pre-adults.

Unlike the previous species discussed in this report, shrimps are relatively short lived, probably about 2-3 years in duration. Management procedures have to differentially account for this phenomena as compared to other fisheries. Some doubt exists as to what is the maximum sustained yield for this fishery, according to NMFS (1) and R. G. Mauermann, Executive Director, Texas Shrimp Association and Shrimp Association of the Americas (7).

A stock enhancement program for this fishery must be based on better stock assessment procedures. Because of the importance of estuaries and open water environments to shrimp populations and the fact that each region is under a different level of governmental control, management procedures must be cooperatively developed between state and federal agencies.

Enhancement can result by governing fishing practices, such as mesh size regulation and closed seasons in certain areas. Proper habitat management and environmental control measures are especially important for that phase of the life cycle spent in estuaries. Dredging and filling operations in estuaries have reduced the total amount of habitat available for shrimps at the same time pollution and man-induced environmental perturbations, especially in estuaries, have had lethal and adverse sublethal effects on shrimp numbers.

In addition to increasing (or maintaining) the population size of wild stocks, shrimp mariculture has received active action by commercial comparison and government financed research. The Japanese were pioneers in this field and have developed a profitable business. However, in the United States commercial ventures have not been as successful for a variety of reasons. It has been suggested that shrimp farming in the United States will require "intensive" aquaculture techniques (rearing in man-made tanks or small enclosures) rather than "extensive aquaculture procedures (rearing in natural waters or large ponds with little environmental modification) (2).

Stock selection and improvement programs would have long range implications. However, with these species it will be necessary to develop the technology of being able to complete the entire life cycle in the laboratory and to control matings. One problem in studying shrimp genetics has been the necessity of obtaining ovigerous (egg-bearing) females from the field. This inability to cause females to produce eggs on demand and to fertilize these eggs with males of known genetic background has not only hampered stock selection programs, but also has dramatically curtailed the economic development in the United States of commercial shrimp farming.

The utilization of shrimp hatcheries for stock enhancement would require pilot studies both to develop the technology and to assess the economic feasibility of this procedure.

Pacific Salmon

Five species of salmon found in the Pacific have commercial value to the United States fishing industry. They are: *Oncorhynchus gorbuscha* (the pink or humpback); *O. keta* (chum or dog); *O. kisutch* (Coho or silver); *O. nerka* (red or sockeye); and *O. tschawytscha* (king or chinook).

Management and stock enhancement of salmon has reached a high state of technology relative to other fisheries. This technology is based on about a century's experience in research and development. Pacific salmon have certain behavior characteristics which have been capitalized on in developing the industry. All species exhibit a similar life history pattern in which the eggs are laid in freshwater streams or lakes. Upon emergence from the egg, the young (fry) either remain in fresh water from 1 to 4 years on their migration to the sea (Coho, sockeye, and king salmon) or migrate directly to the sea with little or no feeding (pink and chum salmon). Juvenile fish are found in coastal waters and make their way to the open sea. After about 1 to 4 years at sea (the time varies with species) the migration to home streams occurs for purposes of reproduction. The timing of this migration is fairly precise with little variance from year to year.

Various stock enhancement techniques have been used in the salmon fishery.

1. The level of fishing in international waters has been addressed by the International Pacific Salmon Fisheries Commission but not without continuing problems. The various states have regulations governing the salmon fishery located within their legal boundaries. These regulations not only pertain to fishing effort but also to environmental questions. Stock enhancement projects are obviously involved. For example, the recent court ruling that Indian tribes must be given the opportunity to catch half of the returning salmon has had a distinct effect on resource management of salmon.

2. The hatchery technology for salmon is well developed. The young can be reared to advanced development stages which are more resistant to environmental stresses before being released. For example the egg-to-fry survival has been estimated to be 80% or more in hatcheries as opposed to 20% or less in natural spawning beds. This procedure greatly increases the magnitude of recruitment to the natural populations. However, problems still exist as illustrated by the finding that over half of the young (smolts) released from hatcheries in the lower part of the Columbia River System never reach the sea. Another important feature of hatchery programs is that young can be reared and introduced into waters which are free of pollution or man-made obstructions that would inhibit the migration of the young to the sea. The longer the time developing organisms are kept in hatcheries the greater are the technological problems and the higher the costs. Although salmon hatchery technology is relatively well developed, not all of the technological problems have been solved and continuing programs of research and development are needed. For example, feeding of developing fish is a problem as is the spectre of disease. Since the private culture of salmon is legal in some western states, the salmon hatchery business could be encouraged to take over certain functions of the state or federal hatcheries and permit the government agencies to be more concerned with research and development.

3. Genetic research on salmon has been in progress and the long-range economic potential is great, but it was felt that this is not an urgent problem facing the industry (2). However, this type of study cannot easily be done on a "crash" basis since reproduction and growth of species have their own inherent biological timescale which is independent of legislative or industry mandate. A genetic or new stock development program is needed.

4. Habitat management has been recognized as an extremely important component of any stock enhancement program. Salmon inhabit streams, lakes, large river systems, and estuaries on their way to and from the sea. Each of these habitat types have been subjected to influence of man. River systems have been dammed and industries and towns have polluted the waters. Obvious conflicts have arisen between the salmon fishery and power companies and the private and public sector. Some solutions have solved specific problems, but not all. In attempting to create favorable habitats for salmon culture, the salmon fishery has had problems meeting existing environmental protection regulations. This is particularly obvious in the case of proposed construction of salmon aquaculture ponds.

5. Aquaculture of salmon is a reality and the production of pan-sized salmon in Washington and Oregon was 700,000 pounds during the 1974-1975 season (2). If the demand for salmon increases, as is projected, aquaculture could meet this need. On the other hand, if demand is not increased, the economic interplay between aquacultural based companies and the fisherman could be explosive. Stock enhancement programs would have to be aware of these potential economic problems.

In summary, the technology of the salmon industry is more highly evolved than other fisheries in many aspects of stock enhancement and can serve as a model for development. However, a complete transfer of technology is not possible because of differences in the biological characteristics of the species involved.

Alaska Crab

The king crab Paralithodes camtschatica is an important commercial species in Alaskan waters and is managed by the State of Alaska. Spawning takes place in the spring,and the female carries the eggs through the following winter with the larvae being released in the spring. The larvae are part of the zooplankton for about four months. The juvenile stages settle to the bottom where they spend the majority of their lives.

Stock enhancement procedures are poorly known for this species. Alaska controls the level of fishing in its waters. However, biologists have had difficulty in applying the usual concepts of maximum sustainable yield to this species (1). Detailed ecological studies of this crab would provide a broader basis for any proposed enhancement program.

The tanner crabs (genus Chionoecetes) have recently become of commercial importance. In general the comments about the king crab are pertinent to these crabs.

Atlantic Herring

The Atlantic Herring Clupea harengus harengus is widespread and in the western Atlantic it is distributed from Canada to Cape Hatteras, North Carolina with different stocks thought to exist. As of August 1975, NMFS listed this fish as a depleted species (4).

Although adults may enter estuaries, most of the early stages of the life cycle of this species are completed offshore. Spawning occurs in different seasons depending on the locality. In general spawning is earlier in the year at higher latitudes (5). Compared to other species, the female produces relatively few eggs which are heavier than sea water. These eggs sink and are attached to the bottom. After 12-18 days pelagic larvae emerge.

The control of catch levels is the primary stock enhancement procedure for this species. Habitat management is important to insure a high water quality, especially in estuaries and coastal waters. A hatchery program would have to be approached on a limited pilot basis coupled with economic studies. An analysis of the different existing stocks is needed to understand the basic biology of this wideranging important species.

Pacific Pollock

Theragra chalcogramma, the Pacific (walleye) Pollock, is one of the most heavily fished species in the world, chiefly by the Japanese and Russians. Relatively little is known of the stocks of this species. Japanese investigators predict that the size of the catches will be sharply reduced shortly as the three exceptionally large size classes are finished (1).

Without a basic understanding of the ecology and population dynamics of this species, recommendations on possible stock enhancement procedures would have to be very general. As is the case with many of the offshore fisheries, basic information is lacking which is needed to develop meaningful management and stock enhancement programs.

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Comments from Reviewers

"Since it is unlikely that we would be able to do it (enhancement) to or for everything, priorities would have to be set. Some (of the following) examples are useful to illustrate what considerations should be weighed:

1. Haddock and yellowtail flounders are important to U.S. fishermen, overfished, and valuable.
2. Alaska pollock are not presently important to U.S. fishermen--they are overfished, but the principal sufferers of the consequences are not U.S. fishermen. Nonetheless, under the Extended Jurisdiction Act, we will assume the responsibility to see that they are no longer overfished in our 200-mile economic zone.
3. One group of the Alaska crabs is presently underfished, i.e., it could yield considerably more than it does at present without anyone doing anything about it except fishing more.
4. Salmon is a particularly interesting case. Questions on the resource, its fisheries, regulations, aquaculture, etc., are extremely politically sensitive. What tends to get lost in the noise is that we now apparently produce more salmon than we can use--U.S. exports of salmon over the past few years have been 30-60 million pounds of products annually, equal to perhaps 40-70 million pounds of whole fish. Of course what drives the system here is economics, but this raises the question of whether we should enhance for economic reasons."

--from Albert K. Sparks
Acting Associate Director for Resource Research
National Marine Fisheries Service
October 8, 1976

"(In addition) I have a feeling that the estuarine ecosystem has great significance for even the totally pelagic species and we do have some control over these systems. It could be one of the few and very effective handles on our direct influence of fish stock. In addition to 'severe impacts' of 'estuary degradation', there is a very real possibility of actively improving the productivity of our estuarine areas by planned development which includes proper shoreline treatment, revegetation and habitat establishment, all of which can be compatible with coastal zone utilization. There is considerable backup for this point of view.

"Improving our fisheries by stock enhancement through increasing the productivity of our estuaries is "mature technology" (preventative technology) in its purest form and...will be less expensive and extremely effective compared with the 'don't touch it attitude' of well meaning but less-than-fully-informed preservationists."

--from Robert M. Snyder
Snyder Oceanography Services
November 15, 1976

Working Paper No. 5

SURVEY OF THE POTENTIAL OF REMOTE SENSING TECHNOLOGY TO SUPPORT ENFORCEMENT OF THE 200-MILE FISHING ZONE

Prepared for OTA
by
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Stanford Research Institute

October 1976

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TABLES

I. INTRODUCTION

This report provides the results of a survey of the potential of remote sensing technology to support enforcement of the 200-nautical-mile (nmi) fishing zone. The survey is part of an Office of Technology Assessment (OTA) overall assessment of fisheries technology that will provide information for Congressional consideration of other legislation which may be needed to implement the Fishery Conservation and Management Act of 1976 (Public Law 94-265).*

This survey of remote sensing technology was performed from 26 July to 7 October 1976, and represents approximately two man-months of professional research effort.

The scope of the survey was limited to the identification and establishment of performance bounds for feasible remote sensing techniques for detection and classification of vessels subject to regulation in the 200-nmi fishing zone established by Public Law 94-265. The effect of this limitation in scope can be seen by reference to Table 1, which lists the principal factors relevant to enforcement of the 200-nmi fishing zone. The list shows that the ultimate contribution of remote sensing

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* Superscript numbers refer to references listed at the end of the report.

Table 1

FACTORS RELEVANT TO FISHERY ZONE ENFORCEMENT

Enforcement Objectives
- Resource management
- Conservation
- Fishery stock allocation

Enforcement Functions
- Detection
- Surveillance
- Apprehension

Enforcement Roles
- U.S. Coast Guard (USCG) and National Marine Fisheries Service (NMFS) Division of Enforcement responsibility
- Other U.S. Executive Branch roles (e.g., State, Treasury, DoD)
- State and regional agency roles

Enforcement Elements
- Licenses/permits
- Inspection
- Reports
- Remote sensing

to fishery zone enforcement will depend on decisions on the specific enforcement objectives and strategies to be pursued, on the allocation of enforcement roles among interested agencies, and on the nature and effectiveness of the other elements of the enforcement systems that ultimately is implemented. Planning in all of these areas is just beginning. Accordingly, it was necessary to examine the potential of remote sensing technology to support enforcement in terms broad and general enough to permit using the results in the evaluation of a wide variety of enforcement approaches.

Despite this need for generality, however, it was necessary to establish a framework of "the enforcement problem" within which to compare the potential contribution of alternative remote sensing techniques.

Therefore, a portion of the survey effort was devoted to postulating the environment in which enforcement must be performed and to estimating the characteristics of vessels of interest to the enforcement process that affect their detection and classification by the remote sensing techniques that were considered. This necessary postulation of a framework for analysis involved some consideration of aspects of the enforcement problem that are outside the assigned scope of the survey. Information and comment in these areas are included, where appropriate, but it should be recognized that these are the result of a cursory and incidental examination of only parts of a very complex problem. They should not be interpreted as indicative of the way we believe enforcement will or should be performed.

Because a great deal of the available remote sensing technology has been developed for military purposes, it was necessary to use information through the DoD SECRET level to adequately portray the capabilities and limitations of various techniques. The main report, which is this volume, is Unclassified with references, where appropriate, to supporting information in a classified (SECRET) supplement, published as a separate volume. In addition, it is possible that data developed by certain military surveillance programs could contribute to enforcement of the 200-nmi fishing zone if appropriate access were available to the enforcing activities. Due to the sensitive nature of these programs and the high levels of security classification involved, consideration of this possibility is beyond the scope of this survey.

In general, except where indicated otherwise, the technological potential described in this report represents the present state of the art. In all of the areas described, improved capabilities can be expected in the future as the state of the art advances. This is particularly true in rapidly advancing technical areas, such as satellites and satellite-borne sensors. However, it is not possible to make specific predictions of future capabilities in a study of this kind because only a small amount of effort is being directed to the development of sensors designed specifically for fishing zone enforcements and because much of the development effort on remote sensing techniques is in support of highly classified national defense programs.

II SUMMARY AND CONCLUSIONS

A. Summary

The brief survey reported here involved approximately two man-months of professional effort in the examination of the potential of remote sensing technology to support enforcement of the 200-nmi fishing zone established by Public Law 94-265. The examination focused on determining performance bounds of the following remote-sensing techniques for the detection and classification of foreign fishing vessels:

- Microwave radar
- HF over-the-horizon radar
- Microwave radiometry
- Electrooptics
- Electromagnetic intercept
- Magnetic
- Acoustic.

Section IV of the report describes the selection of techniques for examination.

The enhancement of capability that could be obtained by requiring the use of beacons/transponders on vessels subject to enforcement was also examined, as were the benefits to be gained from combining information from several sensor systems in a multisource correlation facility.

The "design target" postulated to permit techniques to be compared is a steel hull vessel, 100 ft or longer, equipped with a power plant of 1000 hp or more, exhibiting a radar cross section of 500 m^2 or more at microwave frequencies, and equipped with both radio and radar equipment. An enforcement environment also was postulated to provide a frame of reference for the survey in the absence of any information on planned enforcement strategies or mandated levels of enforcement. The environment postulated included the necessity to conduct enforcement activities in any conditions of visibility and precipitation, and in sea states up to 5. A projected maritime traffic density and distribution model was described within which the foreign fishing vessels of interest from the enforcement standpoint are immersed. Section III of the report describes in more detail the survey framework and assumptions summarized above.

The selected remote sensing techniques were individually examined for their potential to support enforcement in the enforcement environment described in Section III. These analyses are presented in Section V and, for those involving classified information, in Volume Two of the report. Table 2 summarizes the principal survey findings.

In summary, the survey found that with the exception of magnetic techniques, all of the techniques selected for examination were capable of performing some functions related to pertinent enforcement activities to a degree that offers some potential for supporting enforcement. No single technique was found to be capable, alone and unaided, of performing all of the detection and classification functions that will probably be required, and some have very limited potential. The nature of the principal limitations are indicated in Table 2. In general, most of the techniques selected exhibited the capability to <u>detect</u> the design target in at least some circumstances, with microwave radar operation from aircraft being clearly the most capable and versatile in this regard. However, none of the techniques, except certain electrooptical techniques, exhibited any inherent capability to <u>classify</u> detected targets in a way that can contribute to enforcement. However, if the targets sought for detection (foreign fishing vessels) are equipped with beacons, all of the techniques gain some classification capability with the amount of capability depending mainly on the sophistication of the

Table 2

SUMMARY OF THE POTENTIAL OF REMOTE SENSING TECHNOLOGY TO SUPPORT ENFORCEMENT OF THE 200-nmi FISHING ZONE

Technology	Overall Potential	Detection of Design Target		Classification Capability					Costs versus Coverage	Related Capabilities
		Unaided	Beacon-Assisted	Fishing Vessel?	Foreign Fishing Vessel?	Fishing?	Permit?	Catch?		
Microwave radar	Excellent	Detection to 200 nmi from aircraft; some sea clutter limitations; position accuracy <5 nmi	Detection to >200 nmi from aircraft; no sea clutter limitations; position accuracy <2 nmi	Beacon required	Coded beacon required	Cooperative transponder required			Aircraft: $1M to $1.6M per year Radar: $250K to $500K per system Beacons: $500 to $2500 per vessel Coverage: >150K nmi^2 per hour per aircraft	Sea ice detection
HF over-the-horizon radar	Good	See Volume Two		Beacon required	Coded beacon required	Cooperative transponder required			See Volume Two	
Microwave radiometry	Limited	Detection to ∼10 kft; all weather except in extremely heavy rain; position accuracy, relative to platform, 1 to 10 ft	Beacon detection to line of sight	Beacon required	Coded beacon required	No capability	No capability	No capability	System cost: ∼$200K. When used in MRS aircraft can survey ∼600 nmi^2 /hr at total mission cost of $2.06 per nmi^2. Beacon costs: comparable to microwave radar.	Sensing sea state; inferred surface wind speed; sea ice detection; inferred rainfall rate; possible detection of oil spills.
Optics and electrooptics	Limited	Line of sight limited; subject to cloud and fog obscuration (day visual/night LWIR. Data subject to excessive clutter and ambiguity due to cloud and sea state; beacon assist gives only marginal improvement.		Good; requires low-to medium-altitude approach	Fair; requires very low-altitude approach	Good, with direct telephoto inspection	Cooperative transponder required	Fair, if catch visible on deck	Device cost: <<platform cost. Operating/processing cost not determined due to variability with overall enforcement mission; see Section V-B4.	Plankton survey Cloud cover survey Sea state survey
Electromagnetic intercept	Limited	Method inherently uses target transmissions as beacon. Detection limited only by propagation and interference conditions. Bearing accuracy ∼1°; position accuracy by triangulation limited by bearing accuracy and GDOP to errors ≥ a few miles.		Limited; requires target cooperation	Limited; requires target cooperation	Cooperative transmission required			Aircraft DF over 200 K nmi^2/hr at $0.005/nmi^2; ground HF DF cost: $12.59/hr per DF site if dedicated; $60K per site using existing nets.	None applicable
Magnetic	Negligible	Extremely short range	Not applicable	No capability	No capability	No capability	No capability	No capability	Not determined in view of negligible capability	None applicable
Acoustic	Limited	See Volume Two		Beacon required	Coded beacon required	Cooperative transmission required			See Volume Two	

beacon and the effectiveness with which it is operated. For operation with beacon-equipped targets, microwave radar, over-the-horizon radar, and acoustic techniques exhibit (in that order) the greatest classification potential.

Some examination was made of probable costs of implementing surveillance functions using various techniques. However, estimates of the cost of individual components of possible enforcement systems have very little meaning until a specific enforcement scheme and level of enforcement are specified. This is especially true when a component may have multiple uses; that is, when a component might be used to support search and rescue operations or pollution control activities as well as fishing zone enforcement, because it becomes impossible to determine how the component cost should be allocated among the missions supported. In certain cases, a technique may already be implemented in a military system and information useful for fishing zone enforcement may be available at purely nominal cost. Therefore, while Table 2 gives some cost data useful for comparing techniques, it was not possible to establish costs for different techniques with respect to comparable measures of performance. Accordingly, caution should be exercised in drawing conclusions on the basis of these cost data.

Some techniques have potential for functions unrelated to detection or classification of fishing activity but they nevertheless may be useful in overall enforcement planning or execution. Microwave radiometry, for example, has only limited detection capability, contrasted with radar, optical, or acoustic sensing, and has almost no potential for direct classification. However, radiometric methods have potential usefulness for sensing sea state, sea ice, and precipitation rates in situations in which few other usable techniques are known. These capabilities could conceivably warrant consideration of microwave radiometers in a fishing zone enforcement system despite their limited potential for fishing vessel detection and lack of classification capability. Table 2 identifies significant instances of auxiliary function capabilities of the kind described above.

B. Conclusions

The significant conclusions reached on the basis of this brief survey are itemized below. Because it was necessary to establish an enforcement environment framework within which to examine the potential of remote sensing techniques, some consideration had to be given to the overall problem of enforcing the 200-nmi fishing zone. From this part of the work, which involved survey of documentation and discussions with USCG, NMFS, and U.S. Navy personnel, certain conclusions were reached that address matters outside the nominal scope of the survey. These conclusions on the broader issues are included for the information of OTA. It should be recognized that they result from a brief examination of a complex problem arising from the passage of Public Law 94-265. Enforcement of this law will have an effect on many public and private interests. However, little study has yet been given to these possible effects and their ramifications in terms of the resources and procedures required to enforce the law. Until appropriate studies of the broad issues involved are completed, conclusions on an issue as narrow as the potential of remote sensing technology should be considered to be preliminary and should be used with caution.

1. A variety of remote sensing techniques are used now (primarily by the USCG) in fisheries law enforcement. Expansion and diversification of this use will be required to cope with the expanded fishing jurisdiction established by Public Law 95-265.
2. The kinds and amounts of additional remote sensing resources that will be required depend critically on decisions yet to be reached with respect to the overall strategy and level of enforcement to be implemented.

3. Providing the fishing vessel detection and classification capability needed to support enforcement of the 200-nmi fishing zone will require the combined use of a number of remote sensing techniques. It is probable that the needed capability can best be provided by combining data derived from some sensor/platform systems dedicated to fishing zone enforcement with data derived from sensor/platform operated (by the USCG or DoD) for other purposes. Therefore, the development of improved capabilities for multisource data correlation will be required.

4. With the exception of magnetic techniques, all of the remote sensing techniques considered in this survey have some potential to perform functions useful in fishing zone enforcement. However, no single technique is capable of performing all of the necessary detection and classification functions.

5. Microwave radar operated from aircraft has by far the greatest potential of all of the techniques examined for the performance, in the near term, of the large area surveillance required to detect fishing vessels of possible interest to the fishing zone enforcement process. This technique also has excellent potential for small area surveillance of specific vessels or groups of vessels and as a means to bring sensors capable of classification within usable range. However, unless it is coupled with the use of beacons on foreign fishing vessels, microwave radar has negligible classification potential.

6. In the medium to far term, i.e., 1985 and beyond, satellite-borne microwave radar has a potential to supplement or supplant airborne radar for broad area surveillance, but it suffers from the same lack of inherent classification capability.

7. In certain circumstances, HF over-the-horizon radar and acoustic techniques have potential to perform detection and classification functions (see Volume Two).

8. Electromagnetic intercept techniques (direction finding and communications content analysis) offer potential for wide area detection and limited classification functions. However, since these techniques rely on cooperative transmissions from vessels of interest in a dense environment of potentially masking emissions, they must be considered as supplementary rather than primary means of performing detection and classifications functions.

9. Microwave radiometry has potential for vessel detection at relatively short ranges but has no inherent classification potential. Accordingly, its overall potential is limited except under special circumstances when completely passive detection is required.

10. Optical and electrooptical techniques possess inherent classification potential coupled with fair to good detection potential under favorable conditions. Since these techniques are susceptible to degradation by clouds, fog, and sea state returns, they have low potential as primary detection and classification means. Beacons can provide marginal improvement.

11. Certain techniques examined have a potential to perform functions other than detection and classification that may be useful but not essential to fishery zone enforcement.

12. The USCG is examining many of the techniques included in this survey for their application to its fishing zone enforcement missions. However, the USCG assessment of the potential of various remote sensing techniques may differ from the assessment given here because USCG planning is constrained by present resources, presumed budget constraints, and the necessity to consider concurrent performance of other missions such as search and rescue and pollution control, none of which were considered in this survey. Nevertheless, on the basis of the results of this survey, we believe that USCG planning would benefit from increased consideration of the potential of over-the-horizon radar, acoustic techniques, and multisource correlation facilities. Data exchange with DoD and the operation of joint-use facilities also appear to have as yet unrealized potential for the support of USCG missions.

III SURVEY FRAMEWORK AND ASSUMPTIONS

A. The Enforcement Problem

The survey reported here is limited to examination of the potential of remote sensing technology to support enforcement of the 200-nmi fishing zone. Specifically, the statement of work states that the purpose of the survey is to identify and establish performance bounds for selected available remote sensing techniques for the detection and classification of vessels subject to regulation in the 200-nmi fishing zone. Moreover, in performing the survey, no specific enforcement scheme or mandated level of enforcement were assumed. However, because examination and comparison of alternative sensory approaches requires a common framework for analysis, it was agreed that assumptions would be made about the expected characteristics of vessels subject to regulation and about the environment in which enforcement will take place. This section of the report describes the setting within which fishery zone enforcement must be accomplished and provides an assumed "surveillance model" with respect to which the detection and classification potential of selected remote sensing techniques was examined.*

The basis for enforcement of a 200-nmi fishing zone is contained in Public Law 94-265 (Fishery Conservation and Management Act of 1976), enacted 13 April 1976, with enforcement to commence on 1 March 1977.

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*For this study, "surveillance" includes the detection of vessels potentially subject to enforcement action and their classification with respect to characteristics significant to planning and performing enforcement actions.

The pertinent provisions of the act that affect the kind of enforcement that will be required are summarized in Table 3.

Table 3

PERTINENT PROVISIONS OF PUBLIC LAW 94-265

- A Fishery Management Zone 200 nautical miles wide is established around all U.S. territory.
- Foreign fishing in the zone is subject to U.S. authorization and permit except for preexisting agreements.
- The USCG may require foreign fishing vessels to carry and operate appropriate position fixing and identification equipment.
- Enforcement is a joint responsibility of the United States Coast Guard and the National Marine Fisheries Services.

The enforcement problem posed by Public Law 94-265 can be described in terms of the provisions of the act. To begin with, a 200-nmi wide zone surrounding the United States and its possessions encompasses almost two and one quarter million square nautical miles.[*] The USCG estimates that approximately one fourth of the zone consists of primary fishery areas requiring concentrated enforcement efforts during at least certain time periods and that some level of enforcement activity may be required at some time in all parts of the zone. The distribution of enforcement activity was not specifically addressed in the survey. Rather, the

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[*] Other provisions of Public Law 94-265 and existing laws and treaties require some enforcement activities that extend outside the 200-nmi limit. Examples are provisions for U.S. control over anadromous fish stocks originating in U.S. waters and certain continental shelf fishing resources out to the edge of the continental shelf, and international agreements for the control of tuna fishing. These added areas were not specifically addressed in the survey.

detection and classification capability of remote sensing techniques were established with respect to selected measures of performance that relate to inherent capability. That is, the study establishes the potential of a given technique to perform certain detection and classification functions. This information can then be used in more detailed studies to establish the potential contribution of the technique to the performance of any desired enforcement mission.

A second significant characteristic of the enforcement problem is that the act provides for control of foreign fishing vessels.* Since fishing is only one of many maritime activities taking place within 200 nmi of U.S. shores, this means that not only must fishing vessels be identified within the mixture of all maritime traffic (merchant vessels, warships, recreational craft, etc.) but that foreign fishing vessels must be identified separately within the larger population of all fishing vessels. Moreover, since fishing is not, in general, to be prohibited to foreign vessels but is to be regulated under a permit system, foreign fishing vessels, once identified, must be classified with respect to their activity so that their observed activity can be compared with the activity permitted by a valid permit. Only when all of these detection and classification functions have been performed can it be determined what, if any, enforcement action is justified with respect to any particular vessel.

An important feature of the act that affects performance of the detection and classification functions described above is the provision that the U.S. government may require foreign fishing vessels to carry and operate appropriate position fixing and identification equipment.

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*The act also provides for the establishment of a National Fishery Management Program that may at some future date provide for some kind of regulation of U.S. fishing vessels in the 200-nmi zone. Until then, however, only foreign fishing is controlled by the act.

If properly designed and universally used, such equipment could vastly simplify performance of the detection and classification functions. Such equipment could, for example, provide a "tag" for any foreign fishing vessel that would immediately distinguish it from other classes of maritime traffic so that enforcement activity could be concentrated on (or if the system is foolproof, confined to) vessels known to be subject to the act. At the cost of additional engineering sophistication such a system of position fixing and identification equipment could provide information on other classification and status factors of interest to enforcement, such as permit number and provisions, status (fishing or not), catch (quantity, kind), etc.

However, the fact that the U.S. government can require such equipment does not mean that it will do so or, if it does, that it will be universally required. Even if it is universally required, there is no feasible, purely technical means of insuring compliance or of guaranteeing that the devices function properly under all circumstances including deliberate tampering. Therefore, while surveys such as this one can identify the technical potential of such devices it should not be inferred that achieving this potential is purely a technical matter.

Finally, enforcement is a joint responsibility of the USCG and the NMFS, which raises problems of allocation of enforcement functions and coordination of enforcement efforts. As a simple example of what this situation implies, consider the matter of on-board observers, which are permitted by the act. An observer with adequate communications on board a foreign fishing vessel or at the point where it lands its catch is the ultimate "remote sensor." If universally employed, the use of observers could reduce the rest of the enforcement problem to little more than supplying "muscle," on request, to carry out enforcement actions.

Complete reliance on observers is impractical for many reasons,[*] but the extent to which observers will be employed has not been determined, to our knowledge, so that the potential contribution of this kind of remote sensing technique cannot be assessed. The purpose of this discussion is to emphasize the point made in the Introduction with respect to Table 1, namely, that extreme care must be taken in considering remote sensing techniques out of the context of the overall enforcement problem.

The foregoing brief and oversimplified description of the enforcement problem provides a basis for constructing the analysis framework within which the remote sensing survey was conducted. This framework was used both to bound the analysis in terms of enforcement functions where remote sensing techniques appear to have a potential to contribute to performance and to provide a basis for devising performance measures suitable for comparing one technique with another. While it is clear that in the process of bounding the problem for analysis some potential remote sensing applications may fall outside the selected bounds and thus may fail to be considered, the amount of time and effort allocated to the survey required limitation of its scope. We believe that the framework selected permitted considering all of the most important potential applications of remote sensing as well as many of lesser importance. Furthermore if resources for a more thorough study of the enforcement problem become available, the survey presented here will provide a firm foundation from which to embark on a more comprehensive examination of remote sensing technology and its application to enforcement of the 200-nmi fishery zone.

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[*] Refusal to accept an observer, intimidation of observers, and the possibility of bribary or collusion are some of the more obvious drawbacks to widespread use of observers.

The selected framework is shown in Table 4 as a series of questions that must be answered in the process of planning and performing enforcement activities under the provisions of Public Law 94-265. The questions remain general in that they can apply to any desired enforcement area from the entire 200-nmi Fishery Management Zone to a small, localized fishery area of particular importance. The questions are also general in that they can be answered with respect to any desired strategy or level of enforcement by simple and obvious modification. For example, if it were desired to concentrate enforcement in a given area only on Japanese vessels catching salmon with purse seines, the question "any foreign fishing vessels?" becomes "any Japanese purse seiners?," and the question "are they fishing?" becomes "are they purse seining for salmon?."

Table 4

CRUCIAL QUESTIONS FOR ENFORCEMENT

With respect to any assigned enforcement area:

- Are there any vessels in the area?
- Any fishing vessels?
- Any foreign fishing vessels?
- Are they fishing?
- Do they have a permit?
- Is the vessel operating within the terms of the permit?

In performing the survey, each selected remote sensing technology (technique) was examined with respect to its potential to contribute to answering each question in Table 4. In accordance with the assigned purpose of the survey, the examination concentrated on the performance of detection and classification functions, but whenever it appeared that a capability for other useful functions existed this was noted also. Unclassified results of this examination are presented in Section V; classified results are presented in Volume II of the report. To the extent possible the results are presented in quantitative terms with respect to cost and performance measures that facilitate comparing the potential of one technique with that of another.

To permit quantitative assessment, it was necessary to postulate both the physical environment and the pertinent characteristics of vessels subject to enforcement. These postulations are described next.

B. Environment and Vessel Postulations

1. Postulated Enforcement Environment

The detection and classification of fishing activity subject to regulation takes place at sea within 200 nmi of U.S. shores. To be effective, at-sea enforcement activities must be performed under any environmental conditions that permit the fishing activity to take place. The nature of most fishing activity is such that both the fishing itself and the preparations for fishing and processing and transportation of the catch that precede and follow actual fishing operations--and are similarly subject to control--can take place twenty four hours a day under almost any weather conditions. Therefore, for this survey, it is postulated that enforcement must be possible under any of the following circumstances:

- Any visibility conditions
- Any precipitation conditions
- Wind and wave conditions up to sea state 5.

2. Postulated Fishing Vessel Characteristics

For the most part, foreign fishing vessels subject to Public Law 94-265 are large, seagoing vessels capable of overseas transit to the fishing grounds and able to store and process enough tonnage of fish to make this kind of operation economic. Both individual seagoing trawlers and very large factory ships accompanied by "capture fleets" are employed. The only notable exceptions to this general situation occur in the Gulf of Mexico and the extreme South Atlantic areas in which smaller vessels from Mexico and Cuba can economically be employed and in Alaskan and North Pacific waters where small- to moderate-sized Canadian vessels can economically fish close-in U.S. waters. However, available information suggests that these exceptions account for a relatively small part of the problem to which Public Law 94-265 is addressed. For this survey, therefore, we have selected as the "design target" of the enforcement system the typical transoceanic fishing vessel with the postulated characteristics listed below:[*]

- 100 ft or longer, steel hull
- Diesel powered, 1000 hp or larger
- Microwave radar cross section of 500 m^2 or larger
- Radio and radar equipped
- Visually distinctive gear deployed during fishing.

While no effort was expended to verify these characteristics, discussion with USCG personnel indicate that they are representative. In contrast to these characteristics, most U.S. fishing vessels that fish U.S. waters are significantly smaller. For example, a study some years ago by the U.S. Navy Pacific Missile Range[2] showed that with the

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[*] By "design target" is meant a vessel that is representative of the minimum detectability or identifying characteristics that must be controlled by the enforcement system.

exception of the largest tuna clippers and purse seiners few U.S. commercial fishing vessels exceed 80 ft in length and a substantial number are 60 ft or less. This does not guarantee that foreign fishing vessels can always be distinguished on the basis of size alone, but it does suggest that a detection technique designed to detect 100-ft and larger vessels will be able to detect virtually all foreign fishing vessels under any circumstances and will discriminate to some extent against detection of most U.S. fishing vessels under many circumstances.[*]

3. Vessel Traffic Density

A characteristic of the enforcement environment, which was mentioned earlier, is the existence of a relatively dense pattern of maritime traffic within which the fishing vessels of interest are immersed. No extensive investigation of this characteristic was made. However, Figure 1 is a plot of postulated ship traffic in 1980, which shows that, in general, the maritime traffic pattern can be expected to be dense along the coasts, i.e., in the vicinity of the 200-nmi fishing zone. The data plotted in Figure 1 are based on a distribution by trade routes and preferred operating regions of an at-sea vessel postulation given in Table 5.[†] Note that fishing vessels are the largest component of the forecast at-sea population. This information is included to underscore the fact that identification and classification functions will be important and challenging parts of the enforcement problem.

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[*] This discussion assumes that remote sensing "observables" are a function of vessel size. As it turns out, this was found to be true for the techniques found worth examination in this survey.

[†] Figure 1 and Table 5 are from Reference 3

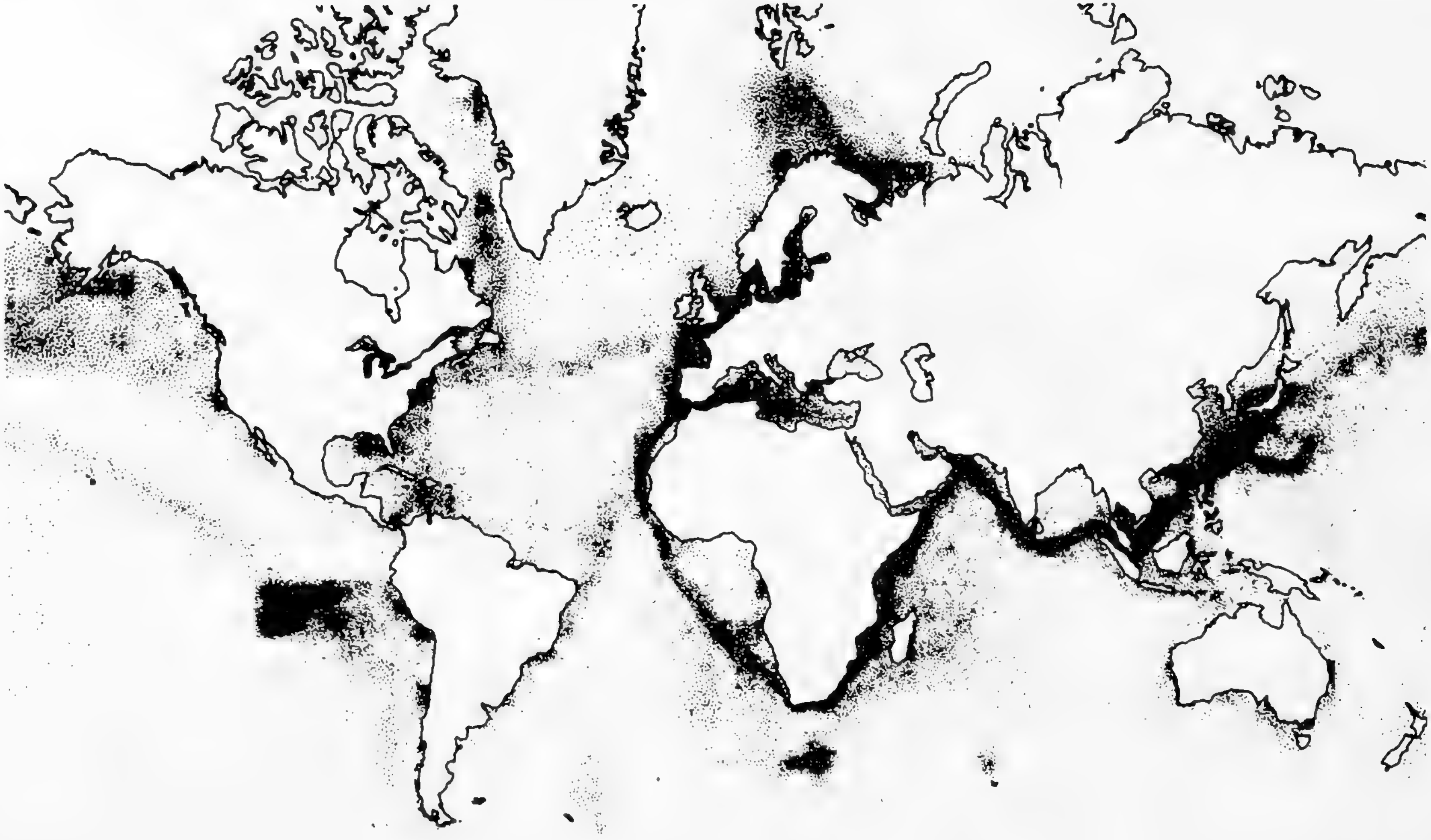

FIGURE 1 1980 SHIP DISTRIBUTION

Table 5

REVISED FORECAST SHIP POPULATION FOR 1980

Ship Types	Population	
	Total	At-Sea
Oil tankers	7,980	6,300
Ore and bulk carriers	4,115	2,715
Combination carriers	433	286
General cargo ships	13,320	3,330
Container ships	689	379
Passenger liners	101	21
Liquid gas carriers	934	467
Chemical carriers	990	495
Fishing vessels	17,900	13,950
Research vessels	348	174
Tugs and towboats	16,210	1,621
Ferries	296	29
Miscellaneous	6,700	670
Total	70,026	30,453

C. Enforcement System Characteristics

Although, as directed by the contract work statement, no assumptions were made about the nature of the regulations to be enforced or the mandated level of enforcement, certain gross characteristics of any likely enforcement system are pertinent to the methods used to assess candidate remote sensing techniques and to interpretation of the results. The most important of these characteristics are:

- Multiple sensor/platform types will continue to be used by the USCG in at-sea enforcement, including ship and aircraft types now in use. This implies that candidate remote sensor techniques should be examined in light of their compatibility with and potential to supplement or substitute for existing resources.
- Data from existing DoD remote sensor systems will be used by the USCG when it is feasible and economic to do so.
- Data from fishing permits and any required fishing activity reports will be available to the enforcement system for use in planning remote sensor use and in the correlation of remote sensing data.
- Although permitted by the act, mandatory use of position fixing and identification equipment on foreign fishing vessels will not be widespread in the near term. This implies that remote sensor techniques that require cooperative targets may have low potential for near-term application.

IV CANDIDATE SENSOR TECHNIQUES

A. Approach

By definition, remote sensing includes any method of obtaining information about an object from a distance without any physical connection to the object. Although in principle this definition permits considering a very wide range of techniques ranging from direct visual observation to extra sensory perception, in practice only a limited number of techniques have been found to have practical application. Feasible techniques are of two kinds, those that utilize some form of energy naturally emitted by the object to be sensed and those that utilize some form of energy transmitted to and reflected or reradiated by the object. Both kinds of techniques were considered in this survey.

The method used to establish a list of candidate remote sensing techniques for this survey was based largely on the judgment of the survey team. This team was composed of senior research professionals with broad knowledge and experience in remote sensing. On the basis of a review of recent work in the field and discussions with knowledgeable personnel in DoD and the USCG, a candidate listing of techniques was established. This list was reviewed with the OTA contract technical monitor and USCG representatives.

Although advances in the state of the art could at any time bring a scientific "breakthrough" that would add a new technique or drastically alter the potential applicability of existing techniques, we are confident that all of the techniques that have significant promise in meeting the short- and medium-term needs of fishing zone enforcement are included in the candidate list presented below. This statement is based on an assumption that the needs of fishing zone enforcement can be met by using state-of-the-art techniques and without resort to the kind of high-priority, high-cost, R&D programs used in defense and space exploration programs. Should the situation change and a need and justification for a high-priority research program appear, then a much more comprehensive and searching examination of remote sensing potential than this brief survey would be in order.

B. Candidate Techniques

Table 6 lists the candidate technologies for remote sensing that were examined in the survey, along with some of the characteristics that influence their applicability to functions useful for fishing zone enforcement. Included in the techniques are those based on electromagnetic, acoustic, and magnetic phenomena. Other theoretically usable phenomena, such as chemical analysis of air or waterborne effluents, gravitational anomalies, or changes in the oxygen content of seawater as a result of vessel or fishing activity were considered and rejected on the basis of lack of sufficient proof of feasibility, gross capability inadequacy, or obviously unacceptable cost.

Figure 2 shows the kinds of sensors that have been developed for remote sensing using electromagnetic energy and indicates the portions of the electromagnetic spectrum appropriate to the use of various sensor techniques. At the top of the figure is an inset showing the transmissibility of the earth's atmosphere in a portion of the visual and infrared spectrum.* This simply shows that in many portions of the spectrum low loss transmission of signals necessary for effective remote sensing is

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*Note that the scale of the inset is linear, while that of the main figure is logarithmic.

Table 6

PERTINENT CHARACTERISTICS OF CANDIDATE REMOTE SENSING TECHNIQUES

Technology Category	Implementation Technique	Principal Approach(es)	Candidate Sensor Platforms	Principal Target Observables	Principal Environmental Constraints
Electromagnetic	Microwave radar	Pulse, pulse Doppler, CW, synthetic aperture	Ground, floating, airborne, space	Radar cross section, Doppler	Sea clutter, atmospheric refraction and absorption
	HF over-the-horizon (OTH) radar	Skywave Surface wave	Ground	Radar cross section, Doppler	Sea clutter, atmospheric refraction and absorption
	Microwave radiometry	Scanning radiometers	Airborne, space	Spectral emissions and/or reflections	Natural background, atmospheric absorption
	Optical and electrooptical	Photography FLIR MSS	Airborne, space	Spectral emissions and/or reflections	Natural background, atmospheric absorption
	Electromagnetic intercept	Triangulation, signal analysis	Ground, floating, airborne, space	Electromagnetic emissions	Natural background, atmospheric refraction and absorption
Magnetic	Magnetic anomaly detection	Magnetic anomaly detectors	Floating, airborne	Magnetic field perturbations	Natural background
Acoustic	Active (sonar) passive array	Sonar, fixed or towed arrays	Fixed (sea bed), floating, towed	Acoustic emissions and/or reflections	Natural background, refraction, absorption, reverberation

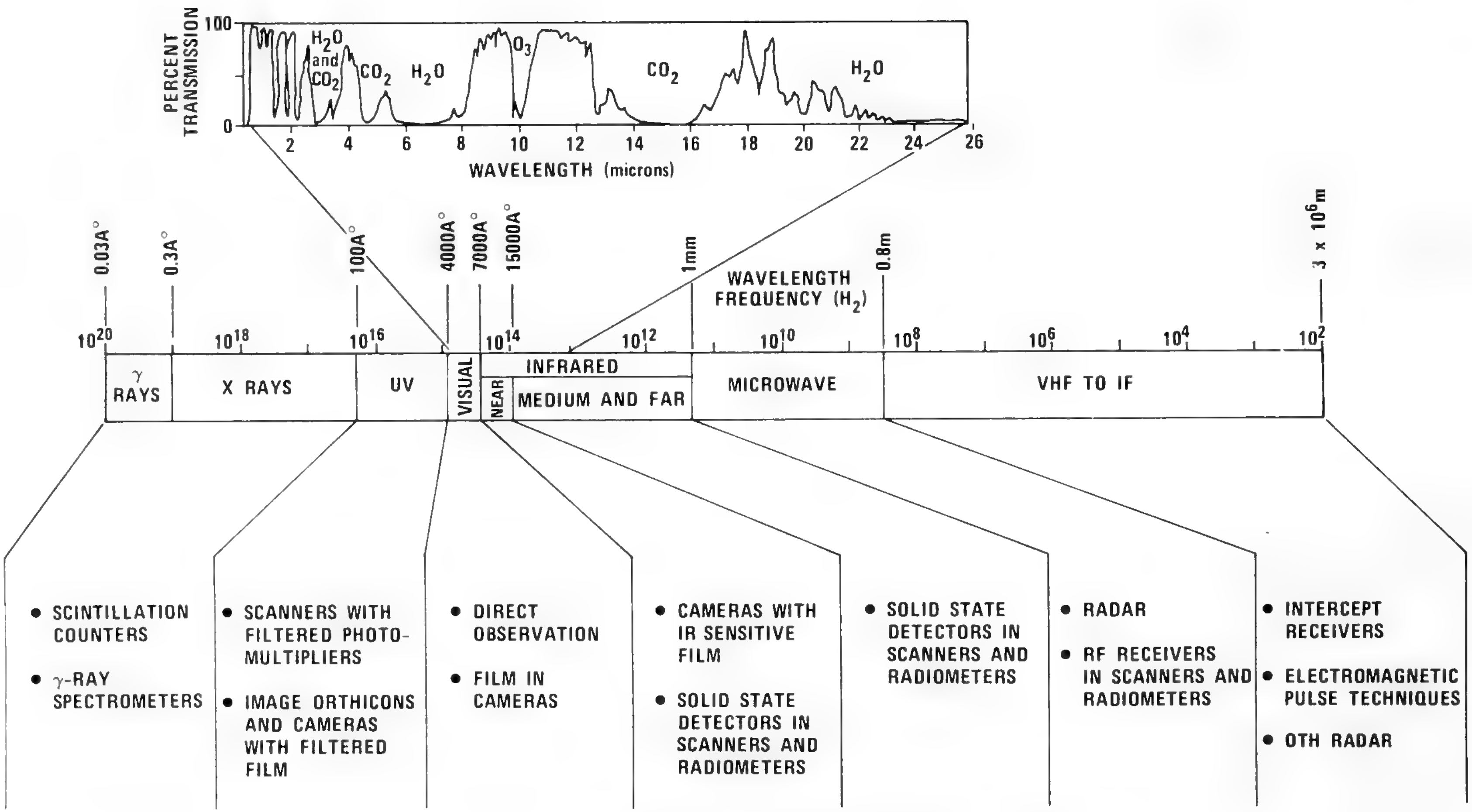

FIGURE 2 REMOTE SENSORS USING ELECTROMAGNETIC ENERGY

confined to restricted "windows," which often greatly complicates the development of practical operational remote sensing systems, even though the technique being employed is scientifically sound.

C. Methods to Enhance Sensor Capabilities

The performance of many remote sensor techniques can be improved significantly if the object to be sensed can be equipped with devices designed to enhance the target or supplement the signals normally used by the sensor. A simple example is the familiar corner reflector designed to concentrate and thereby enhance radar returns from a target equipped with the device. Such a device can increase the effective radar cross section of a target by an order of magnitude or more. Another device that can significantly enhance target detectability is an active beacon that responds to interrogation by transmitting energy at the interrogating frequency (or some other frequency) at levels up to a few orders of magnitude higher than the signal that would result from reflection of the incident signal alone. Active beacons of this kind are available for use with most radar and sonar equipment. Many of them can be coded so that the response not only aids detection but provides a limited amount of identification or status information. In theory, such beacons can be used with any remote sensor that operates on the principle of transmitting energy to a target and performing its sensory functions on the energy returned by the target.

At the cost of somewhat more engineering complexity, transponders can be built that respond to interrogation by a remote sensing device by transmitting a wide variety of identification and status information. The capability of such transponders is ultimately limited only by the ability of the target to provide power for their operation and by the ability to acquire and format target status and identification information for transmission in response to an interrogation.

In the survey reported here, an attempt has been made to identify the kinds of transponders potentially available to enhance the performance of various remote sensing techniques and to quantify the degree of enhancement that is feasible. However, it should be noted, that the state of the art in transponders and associated devices is advancing rapidly--largely in response to advances in digital storage and processing technology--so that the potential for improved performance from such devices is large.

From the standpoint of their contribution to the performance of functions important to fishing zone enforcement, the drawback of most transponding devices is that cooperation on the part of the target fitted with the transponder is required. That is, a transponder (beacon) that simply enhances detection or supplies a preprogrammed identification signal can operate independently of any input from the target. To supply additional information, such as activity status, intentions, etc., requires cooperative effort on the part of the target in the form of manual or automatic input of the information to be transponded. Thus, it is much easier to devise an "intelligent transponder" than to insure that it is reliably supplied with the information to be transponded.

In this survey, we have called attention to the functional enhancement that is technically possible through the use of various kinds of transponders. However, consideration of how to insure that appropriate information about the target is supplied to the transponder is beyond the scope of the survey.

D. Performance Enhancement Using Combinations of Sensors

Experience in performing the detection and classification functions associated with Navy and USCG ocean surveillance missions has shown that maintaining an adequate "picture" of vessel (and aircraft) activity in an ocean area requires inputs from a variety of sensors. For example, in performing its search and rescue and law enforcement missions, the USCG makes use of information from visual, radio, and radar sensors installed in cutters and in fixed and rotary wing aircraft. Additional information is obtained from the Automated Merchant Vessel Reporting (AMVER) system and various surveillance systems operated by DoD, supplemented by information about vessel identities and intended movements compiled by state and federal agencies. When it is properly correlated and analyzed, the information from all of these sources can be combined to provide an ocean surveillance "Picture" that is much more complete and of greater validity than could be provided by any one or a few sensor systems. The problem of 200-nmi fishing zone enforcement will also require the acquisition, correlation, and analysis of multisensor data.

The necessity to accept and correlate a large amount of sensory data from a wide variety of sources, in near real time, has led the military to develop specialized systems for the purpose that, generally, can be described as multisource correlation facilities. It seems likely that the USCG will need to develop similar capabilities to cope with the sensory data that will be required to enforce the 200-nmi fishing zone. Such a facility can also support other USCG missions, such as search and rescue, ocean pollution control, and so forth. Thus, a multisource correlation facility, while not strictly a remote sensing technique, will be an important means of obtaining maximum capability from available remote sensing resources. Accordingly, a description and general discussion of the potential of this area of technology is provided in Section V.

V PERFORMANCE AND COST ANALYSES

A. General

To the extent possible, the analyses of the techniques identified in Section IV with respect to the performance of functions that can support enforcement of the 200-nmi fishing zone addressed quantitative measures that can facilitate comparison of one technique with others in the performance of specific enforcement missions. However, because no information was obtained (or assumed) regarding the kinds of enforcement missions to be performed, the capabilities and limitations of the various remote sensor techniques analyzed are necessarily presented at a somewhat generalized level. Nevertheless, the information provided can be used to perform specific analyses of particular enforcement missions whenever these are established.

Examination of the overall enforcement problem and the environment in which it must be addressed, as described in Section III, suggests that remote sensing technology can make a contribution in three functional areas:

- Gross (large area) surveillance to detect and classify concentrations of fishing vessels of interest from the enforcement standpoint.
- Local (small area) surveillance to monitor fishing activity.
- Collection of position and identification information.

Accordingly, each technique is analyzed for its potential to support these functional areas. In addition, however, whenever a technique exhibits a potential to contribute to answering any of the questions listed in Table 4, this potential capability is also identified.

The potential contribution of each technique is described in terms of inherent technical performance capability, detection range and coverage for a single system, and cost for some defined system capability.

B. Technique Analysis

The following analyses of each of the candidate remote sensing techniques identified in Section IV are designed to emphasize those aspects of a given technique and its possible implementations that are most pertinent to its potential to contribute to solution of the enforcement problem described in Section III. For this reason, no attempt is made to describe all of the various other uses to which a technique could be (or has been) applied or to pursue the analysis of any technique or mechanization beyond the point at which its potential for this specific application can fairly be evaluated. Thus, some techniques are disposed of fairly quickly when fundamental limitations to potential usefulness exist. To the user of the survey, this simply means that for these techniques no proposed application to the fishing zone enforcement problem should seriously be considered unless it promises to overcome these fundamental limitations, which may include not only technical insufficiencies but expected costs that are grossly incommensurate with the performance capability provided.

For each technique, a brief description of the technique and its significant characteristics is followed by analysis of its probable performance capabilities in feasible mechanizations for the performance of functions related to the enforcement mission. Examples of existing or proposed systems with suitable or representative characteristics are cited where possible, and conceptual system characteristics are postulated where no suitable system exists. Costs are treated either by citing costs for representative existing systems or by providing engineering estimates of the cost to mechanize a given technique for a particular application. Finally, a comparative summary is presented that identifies the key performance and cost factors for each sensor technique analyzed.

1. Microwave Radar Techniques

a. Description

Microwave radars have been used for ocean surveillance in aircraft and ships for almost 40 years. The technology is highly developed and the design principles are so well known that it is possible to predict with high confidence the performance of any given design. The remote sensing principle involved is simplicity itself. Pulses of microwave energy are transmitted by a directional antenna and reflected by any material objects it encounters. The reflected energy is subsequently received and analyzed to determine the position and characteristics of the reflecting objects. The direction of objects thus detected are correlated with the antenna beam and their range determined by measuring the time delay from pulse transmission to reception. The design problems in building a radar for a particular purpose are to select a frequency, power output, and pulse characteristics suitable for the detection of desired objects at required distances and to determine optimal antenna beam patterns and scanning methods to enhance the detection of desired objects while minimizing interference by energy reflected from undesired objects (such as the background). Beyond these fundamental objectives, designers attempt to optimize designs in the cost-performance sense and to devise methods of extracting more information about the characteristics of detected objects and minimize the masking effects of background clutter through processing of their radar returns, manipulating the transmitted pulse characteristics, and optimizing antenna beam shapes.

The basic information provided by a microwave radar sensor relative to ocean surveillance is:

- The presence or absence of a vessel in a given area.
- The position of a detected ship at a point in time.
- Course and speed of a vessel when a continuity of position updates is available.
- Estimates of gross shape and size for some high resolution radars.

Microwave radar, by itself, has almost no potential to perform the classification function of vessel type, nationality, or operations since none of the information that can be obtained from analysis of radar returns from a vessel can be directly related to vessel characteristics that are unambiguous indications of its identity or status as a fishing vessel. Frequent or continuous surveillance of an area will permit tracking of vessels in the area, and it is often possible to identify fishing vessels engaged in fishing with reasonable certainty from their movement patterns. However, as a practical matter, unaided microwave radar in aircraft will continue to contribute to classification primarily through guiding the aircraft to a position where identification can be made by visual means.

The detection of targets in sea clutter with microwave radar can be greatly simplified if the target is equipped with a transponder or beacon that responds to interrogation by the radar with coded signals (often at a frequency other than the radar frequency). This not only facilitates target location but provides, by the use of appropriate coding of the beacon replies, other information about the target (identity, status, intentions, etc.). Transponder technology is also highly developed, and beacon design is well understood.

b. Performance Potential

Any modern commercial or military shipboard radar can easily detect fishing boats of the kind postulated for this survey to the radar horizon from the ship, typically 12 to 18 nmi. Similarly, modern ground-based surface search radars, such as the AN/FPS 114 sea surveillance radars developed for the Pacific Missile Test Center (PMTC) by the Navy Electronics Laboratory Center (NELC), can detect the design targets (i.e., 100-ft vessels) of this survey to horizon-limited ranges of 20 to 40 nmi from typical land-based sites. Thus, we assume that this land-based microwave radar potential is already being fully exploited by the USCG (although exploitation of the information-gathering potential of transponders in these applications is not yet complete).

Airborne and spaceborne platforms can employ two kinds of microwave radar that represent the state-of-the-art potential for sea surveillance. One is an optimization of existing airborne radar designs to increase the signal-to-clutter ratio (SCR) through improved pulse compression and signal processing specifically for sea surveillance. The second is the class of radars called synthetic aperture radar (SAR), which use pulse compression to increase the energy in the radar return while reducing the effective pulse length to reduce the range extent of the resolution cell, and reduce the azimuth extent of the resolution cell by synthetic aperture techniques that increase the effective antenna aperture.

The capabilities and limitations of microwave radar in general and the performance of these two major classes are summarized in the following subsections.

(1) Capabilities and Limitations

One of the most challenging microwave radar design problems is the detection of small objects (vessels) on the surface of the ocean in the presence of returns from the ocean itself, called sea clutter. A fundamental figure of merit for a radar designed for ocean surveillance is therefore the extent to which wanted returns (signal) can be made to exceed unwanted returns (clutter). This figure of merit is the signal-to-clutter ratio (SCR); a SCR somewhat greater than one in a given set of circumstances is required to give reliable detection and to avoid excessive false alarms, i.e., instances of identifying an unwanted clutter return as a target.

Factors that influence the detection of targets in sea clutter are generally related to the resolution cell size (i.e., the smallest area element of sea surface for which the radar returns can be processed independently). Signal processing compares the total reflected signal (the target reflection plus the sea surface reflection) in one resolution cell to the total signal in adjacent cells (sea surface only). If a cell containing a target produces a substantially greater return (~10 dB) than adjacent cells, then the target in the cell will be detected with a probability of about 50% for that transmitted pulse. Typical radars have pulse repetition rates sufficient to obtain about 10 to 12 hits on a given target each time an antenna beam scans the target location. The integration of multiple hits increases the cumulative detection probability to about 90%, depending on the signal to noise ratio (SNR) and the target scintillation characteristics.

Sea clutter effects exhibit a viewing angle dependence. For an elevated radar platform, such as from an aircraft, sea clutter limitations on target detection do not occur for grazing incidence angles when the radar beam is near the radar horizon. In this case, target detection is essentially radar system noise-limited, and performance can be improved by increasing the transmitted power that illuminates the target. At ranges closer to the radar platform, the antenna beam intersects the sea surface at larger incident angles and sea returns add to and eventually exceed the basic radar receiver noise, so that target detection becomes clutter limited. The onset of significant sea returns occurs at incidence angles equal to or greater than about 2° below the horizon and rapidly increases with increasing incidence angles (shorter ranges) to greatly degrade ship detection, despite the closer range, unless suitable design measures are taken.

Increasing transmitter power will not help in clutter-limited zones. Similarly, increasing the number of pulses that are integrated will not increase the target detection process because the physical structure of the sea surface changes very slowly (i.e., of the order of 30 s to 2 minutes decorrelation time), and therefore will not average out in short integration intervals.

The most effective measures employed to reduce the effects of sea clutter are those that decrease the resolution cell size. This is done in two ways: by increasing the range resolution (i.e., shorter effective pulse length), and by decreasing the angular sector width of the resolution cell (i.e., narrower azimuthal beamwidth). As a practical limit, however, SCRs will not be improved by reducing the resolution cell dimensions to values smaller than the size of the target (viz. ~ 100 ft). The limitations to shortening the effective radar pulse duration are of the order of 0.02 μs (i.e., ~ 3 m range) because: (1) the receiver video bandwidth must be of the order of the reciprocal of the pulse length so that 50 MHz (i.e., 1/0.02 μs) is about the practical limit of current receiver technology; (2) as the actual pulse transmitted becomes shorter, the power incident on the target diminishes, which produces insufficient signal to noise for reliable detection; (3) pulse compression techniques (which permit a long chirped pulse to be used to provide adequate transmitted power while preserving the resolution advantages of short pulses) are limited to compression ratios of ~ 100 to 1 and contribute significantly to system cost and complexity. Moreover, 15 m is already the order of the target's smallest dimensions so that no increase in SCR is provided for smaller pulse lengths. It should be noted that the above rationale is equally applicable to other indirect methods of decreasing the effective range cell length such as pulse compression or chirping techniques. Practical bounds on narrowing the antenna beamwidth (and thus the azimuthal dimension of the clutter cell) by increasing the antenna size are of the order of 1° beamwidths (corresponding to a 17-ft diameter antenna at C band) for airborne radars because of aerodynamic drag problems. Note that a 1° beamwidth would subtend a resolution cell dimension of over 5,000 ft at a slant range of 50 nmi, so that angular resolution remains the most significant contribution to sea clutter susceptability of conventional microwave radars.

An example of the state of the art in conventional airborne radar is a proposed modification of an AN/APS-116 radar to perform ocean surveillance from an aircraft flying at altitudes up to 70,000 ft. This proposal, by Texas Instruments, Inc. (TI),[4] predicts the SCR performance shown in Figure 3. This performance would provide detection of our 500-m^2 "design target" over an annular area underneath the aircraft with inner and outer radii of 15 and 320 nmi in sea state 3. The radar developed for the AWACS aircraft by Westinghouse Corporation is another example of a radar with at least comparable performance.

A more sophisticated radar system, the SAR, with complex signal processing techniques is available, which greatly reduces the effective resolution cell size for airborne or satellite borne radars. While providing the highest resolution (and sea clutter rejection) capability of any radar technique, the SAR systems are comparatively more complex and impose a significantly heavier data processing burden.

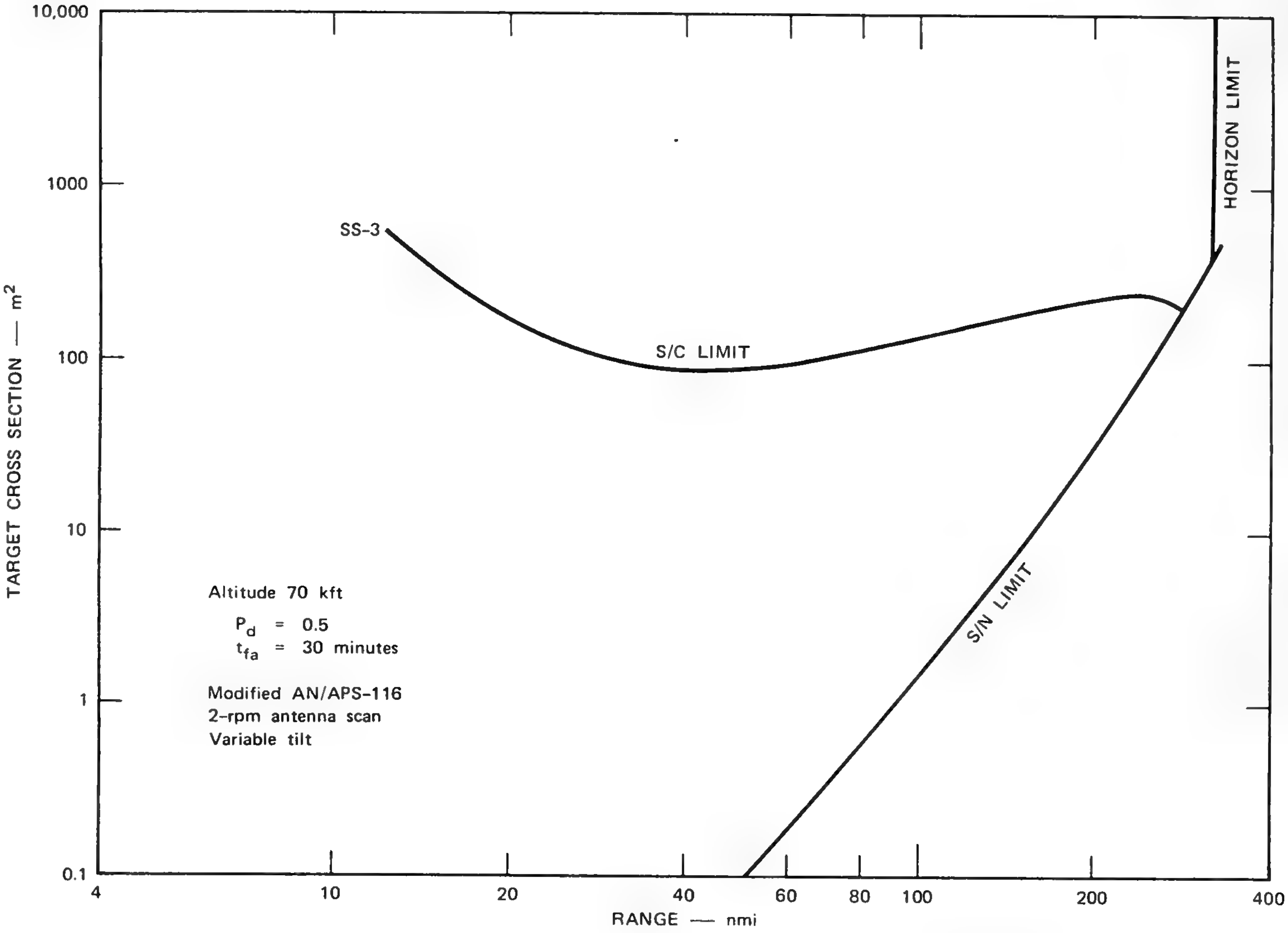

FIGURE 3 PREDICTED OCEAN SURVEILLANCE RADAR PERFORMANCE

In principle the SAR uses a relatively small transmitting/receiving antenna with a fairly broad beamwidth. The antenna beam is typically directed broadside, or skewed forward to the vehicle's flight path to function as a side-looking radar. Returns from radar pulse transmissions are recorded to preserve both amplitude and RF phase information as the vehicle moves along the flight path. These return signals can then be processed collectively as though they had all been transmitted and had been received from a single very long antenna aperture. The resulting effect is radar performance, with respect to resolution cell size and sea clutter rejection, that is much superior to conventional airborne radars with their attendant antenna size restrictions.

A disadvantage of SARs is the large amount of signal processing required to produce images from the raw data collected. Both optical and digital processing have been employed for SAR data. Conceptually, raw data can be downlinked from a satellite or airborne platform for ground processing. Obviously, the higher the number of resolution cells to be processed in a swath image, the greater the processing load. Although the resolution cell size is uniform over the SAR image, certain limitations of Doppler and range ambiguity limit the surveillance range to something less than conventional radars.

Current technology can support swath widths of the order of 100 km (62 nmi). Such a system is being developed by Jet Propulsion Laboratory (JPL) for the SEASAT satellite program. Fishing vessels of the order of 15 m have been detected during airborne tests of scaled down versions of the satellite hardware. The resolution cell size for the L-band SAR is 25 by 25 m. Performance projections for the satellite sensor are comparable to those exhibited by the sensor used in the captive flight tests.

Other SAR type radars have been built for reconnaissance and terrain-imaging from aircraft such as the AN/APQ-102. Optical processing techniques on the radar data produce images having the appearance of optical quality. Reference 5 provides a good summary of the state of SAR technology.

(2) Surveillance Coverage Capabilities

Conventional Radars--The area coverage of a conventional surveillance radar depends on the maximum altitude at which it can still detect the required target. For example, TI analysis of their proposed modified AN/APS-116 has shown that it could detect our 500-m^2 fishing vessel target out to 300 nmi. The aircraft platform altitude that will support this radar horizon distance is around 70 kft. The aircraft platform could be either a manned aircraft or remotely piloted vehicle (RPV). Assuming the maximum useful coverage is 200 nmi, an aircraft could fly along the coastline and search only the seaward sector. This surveillance geometry is seen in Figure 4.

The area covered in a radar sweep included by the radar maximum range and the 200-nmi boundary is approximately 104,000 nmi^2. Considering an eight hour mission period and an aircraft velocity of 250 kts, the total coast length passed over would be $8 \times 250 = 2000$ nmi. Considering this to be a 200-nmi swath, over 400,000 nmi^2 could be surveyed per eight-hour mission. Restating this, a single aircraft could patrol the west coast out to and beyond the 200-nmi limit every four hours. This average rate applies to detection of potential fishing vessels only. Classification to sort out actual foreign fishing vessels would require additional resources.

Synthetic Aperture Radars (SARS)--The coverage from a synthetic aperture radar is usually limited by the swath width it can

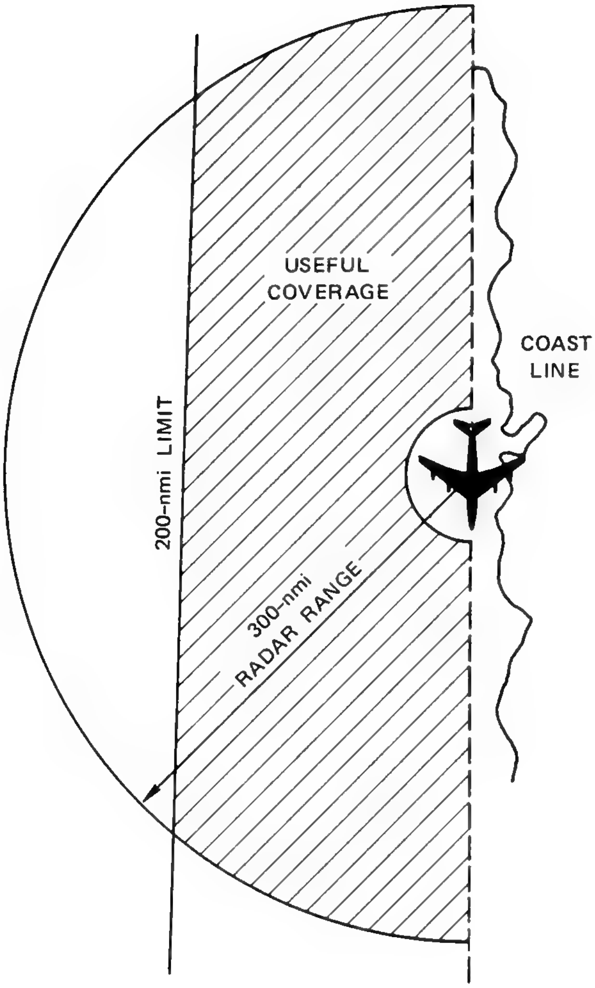

FIGURE 4 USEFUL SURVEILLANCE COVERAGE BY A STATE-OF-THE-ART MICROWAVE RADAR ON A 70-kft ALTITUDE AIRCRAFT

image. If the width of the swath is taken at 60 nmi (~100 km for the SEASAT L-band SAR) and a surface scan velocity of 6.8 km/s, the maximum usable coverage per orbit (~100 minutes) will be at best a 60-nmi swath along a north-south coastline (~1000 nmi assuming a polar orbit). This is equivalent to covering a path one degree wide on the earth's surface (i.e., 1° = 60 nmi).

NASA estimates of the performance of the Full Capability Operational SEASAT, planned for the late 1980s, indicate that eight satellites would be required to provide twice daily imaging of the U.S. 200-nmi fishing zone at a resolution of 25 × 25 m.[6]

(3) Beacon Aiding

Equipping targets with a transponder or beacon that responds to interrogation by a microwave radar with coded signals (often at a frequency other than the radar frequency) simplifies target detection in sea clutter. Not only can targets be located by this means but other information about the target (identify, status, intentions, etc.) can be provided by coding the beacon replies. The successful use of beacons obviously requires a cooperative vessel. Transponder beacons of various kinds exist that can respond to radar interrogation (on a selective basis in some cases) and that can be coded to provide identification and status information in addition to contributing to accurate position fixing. The Discrete Address Beacon System (DABS) program sponsored by FAA and the joint FAA-DoD AIMS program exemplify the capability of transponder beacon technology, although many other beacon developments have led to operational hardware that is in widespread use. The USCG is presently examining beacon approaches for application to the fisheries enforcement and search and rescue missions.

The benefits of radar-beacon operation range from unambiguous target identification and accurate position fixing, which are obtainable with simple and low-cost beacons, to quite elaborate status and intention reporting using more elaborate and expensive beacons.

For the classification requirements of fisheries law enforcement, these benefits can be most satisfactorily obtained if specialized beacons are used and if all of the vessels subject to enforcement, i.e., foreign fishing vessels, and only those vessels are equipped with beacons. The design of suitable beacons is a straightforward engineering development project, but establishing a mechanism to distribute the beacons, insure their reliable operation, and prevent illegal fishing by vessels that do not carry (or that disable) the beacons involves many questions that are not technical in nature and that were not addressed in this survey.

c. Cost Analysis

For comparison purposes, estimates were made of the costs of microwave radars and beacons and of representative costs of aircraft operation. No independent determination of aircraft related costs was made for the survey. Instead, the estimates made in Reference 7 were used. Table 7 summarizes the cost data.

2. HF Over-The-Horizon Radar (OTHR) Techniques

a. Description

Remote sensing using electromagnetic energy at microwave and higher frequencies is constrained by the essentially line-of-sight propagation in the atmosphere at these frequencies. Practically, this means that at the higher frequencies sensors must be elevated to achieve significant operating ranges.

However, as the frequency is lowered, atmospheric refraction increases until at very low frequencies (VLF) (a few tens of kilohertz) energy can propagate completely around the earth. In the high frequency (HF) region, roughly 3 to 30 MHz, energy propagates both in a ground wave mode that follows the curvature of the earth out to several hundred miles in a skywave mode in which the energy is refracted in the

Table 7

COST FACTORS FOR AIRBORNE RADAR TECHNIQUES

Aircraft Operation[*]	HC-130	MRS
Amortized investment[†] ($/hr)	$ 325	$ 120
Personnel ($/hr)	1,018	584
Fuel ($/hr)	218	78
Maintenance ($/hr)	441	315
Total ($/hr)	$ 2,002	$ 1,097
($/yr)	$1,601,600	$1,097,000

Radar Equipment	
Modified AN/APS-116, or equivalent	$250,000
Aircraft version of SEASAT-A radar	500,000

Beacon Equipment	
AIMS-type	$ 500
DABS-type	1,000
Specialized intelligent beacon	2,500

[*] Data obtained from Reference 6.

[†] Does not include additional cost of new radar.

ionosphere and follows a path that returns to earth at distances of from 500 to 2000 miles from its origin. These characteristics of HF propagation provide the basis for the development of radars that literally "look over the horizon," i.e., OTHR.

Because HF energy has been used for communications since the earliest days of radio, a well-developed technology exists for the generation, transmission, and reception of HF energy, and the effects of the atmosphere and ionosphere on HF propagation are well understood. Not as well known are the reflection characteristics of material objects at HF and means of concentrating and coding HF transmissions to enhance radar operation and the processing of radar returns to extract more information about objects detected.

Development of OTHR, primarily for military use, has been underway for several years and systems capable of performing a number of useful functions have been built. Two particular experimental OTHR that have been instrumental in exploring the capabilities and limitations of the technique are the SEA ECHO OTHR developed by the National Ocean and Atmospheric Agency (NOAA) and the Naval Research Laboratory (NRL), and the Wide Aperture Research Facility (WARF) developed for the Defense Advanced Research Projects Agency (ARPA) and the Office of Naval Research (ONR) by Stanford Research Institute (SRI).

b. Performance Potential

Use of OTH radar techniques would allow detection of fishing boats to much greater ranges and would allow coverage of much larger areas compared to those covered by microwave radar. For instance, a single skywave OTH radar located in Utah could provide surveillance coverage over the entire Pacific Coast of CONUS. While such a configuration may not be the most suitable, it demonstrates the wide area coverage that can be provided from a single site. Skywave OTHR takes advantage of the refractive property of the ionosphere, which causes the radar beam to curve back to earth at distances ranging from 500 to 2000 nmi.

Another OTHR technique, which uses frequencies in the 2- to 6-MHz region, employs surface-wave propagation in which radio energy travels along the curved earth surface. It is fortuitous that the attenuation of surface waves is much lower over water than it is over land, thus making possible the detection of ships at sea at distances beyond 200 nmi. Since the coverage of a surface-wave radar is limited to a region with a radius of a few hundred miles around the radar, the surveillance coverage is much less than for a skywave radar.

As a result, many such radars would be required along the coast, and such an approach would not ordinarily be recommended for complete surveillance of the 200-nmi fishing zone. On the other hand, there may be specific regions that require such coverage.

For detection, both surface-wave and skywave OTH radars make use of the velocity of the ship target relative to the radar location; or, with a ship dead in the water, such radars make use of the wave motion relative to the ship. Such considerations will need to be taken into account when a ship-detection radar is being designed for specific applications. Advantage should be taken of the fact that detection can be provided on a continuous basis, thus allowing full-time surveillance of very large areas so that the general population of foreign and domestic fishing boats can be monitored. When such radars become operational, performance of the system would be greatly enhanced if transponders were required on all foreign vessels.

If, for example, the United States required the use of a transponder as part of the licensing arrangement, and included the costs of furnishing, installing, and maintaining the transponders in the licensing fee, the entire program would be under U.S. control.

Because of the large number of vessels that would be transponder-equipped, it would be desirable, if not necessary, to provide selective interrogation. A number of benefits would result from this action.

- Vessels could be interrogated on the basis of type, size, or national origin.
- Within any chosen group, transponder responses could be coded to identify a particular vessel.
- Should a vessel discontinue responding, its activities would be suspect and an appropriate Coast Guard unit could be assigned to investigate. (Such an arrangement seems possible only if ownership of the transponders is vested in the United States).

- If USCG units were transponder-equipped, they could be vectored to disabled transponder-equipped vessels for rescue purposes.

The WARF has demonstrated the detection of ships including fishing trawlers at over-the-horizon distances using skywave HF radar. The detection of smaller vessels would most likely not be feasible with a skywave radar, but it would be possible with a surface-wave radar. Reference 8, the report of a study by SRI of surveillance requirements at PMTC that are similar in many respects to those associated with enforcement of the 200-nmi fishing zone, gives further information on the projected capabilities and costs of practical OTHR. Volume Two of this OTA survey report gives examples of the kind of performance that could be expected from OTHR used for fishery zone enforcement. While it is not intended to imply that OTHR will uniquely provide full coastal coverage out to 200 nmi, it is suggested that OTHR has good potential to support enforcement of the 200-nmi fishery zone.

3. Microwave Radiometry Technique

a. Description

Microwave radiometry is a completely passive detection technique that uses the microwave energy emitted and reflected by a surface as opposed to active techniques such as radar, which transmit a signal and then measure the backscattered signal. A microwave radiometer has no range-measuring capability and provides only a measurement of microwave brightness temperature as a function of look direction. The radiometer is simply a sensitive detector or receiver of microwaves in a selected band of frequencies. The microwave energy received by the radiometer from a particular direction consists of energy emitted from the sea surface and from the intervening atmosphere, and energy reflected by the sea surface. Detection of a ship is possible because the microwave brightness temperature of a ship is different than that of the surrrounding ocean.[*] (A wooden ship appears radiometrically warmer and a steel ship cooler than the ocean.)

An example of a simple airborne microwave radiometer detection system is shown in Figure 5. The system consists of an antenna capable of scanning the sea surface, a total power receiver, and a display device capable of showing the "sensed" radiometric map of the sea below.

(1) Apparent Microwave Brightness Temperature of Fishing Vessels and the Sea

The apparent temperature of the ocean at microwave frequencies depends on factors such as geographic location, salinity, sea state, angle of incidence, polarization, and the observing microwave frequency. An example of the variation of sea brightness temperature with some of these factors is shown in Figure 6. Brightness temperatures at other microwave frequencies in the 10- to 90-GHz range show generally similar behavior although the temperature ranges from approximately 100° K at about 100 GHz to slightly over 200° K at 90 GHz[9] for nadir viewing.

Fishing vessels are visible to a microwave radiometer because they have a different apparent microwave brightness temperature than the surrounding sea. Fishing vessels constructed of good conductors such as steel will be good reflectors and tend to reflect the very cold (at microwave frequencies) sky into the radiometer. Curve A in Figure 6 is an estimate of the apparent brightness temperature of a perfectly reflecting ship. Wooden fishing vessels will have a low reflectivity (i.e., good emissivity) and display a microwave temperature close to

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[*] Microwave brightness temperature is primarily a measure of RF emissivity rather than actual thermal temperature.

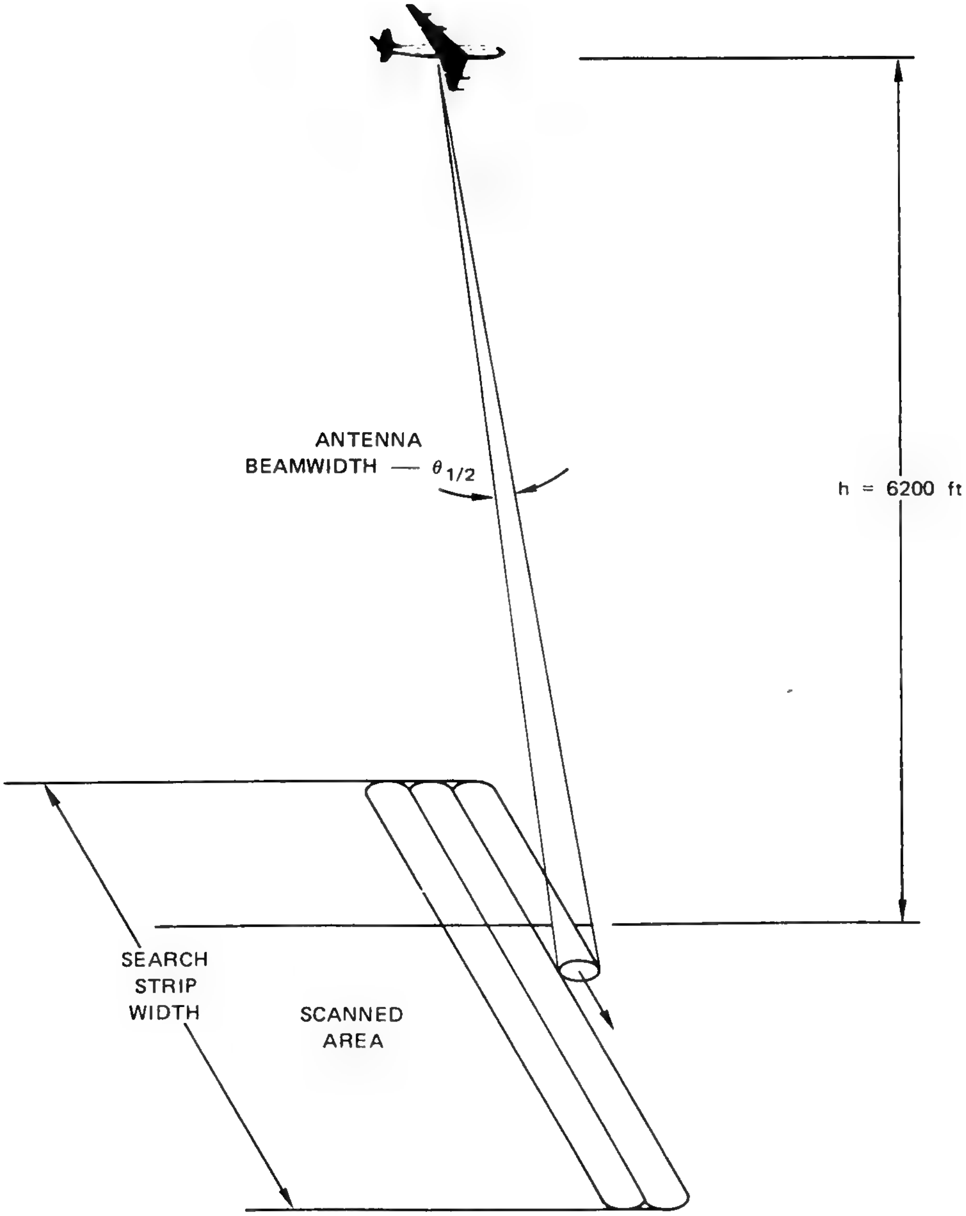


FIGURE 5 AIRBORNE SCANNING MICROWAVE RADIOMETER

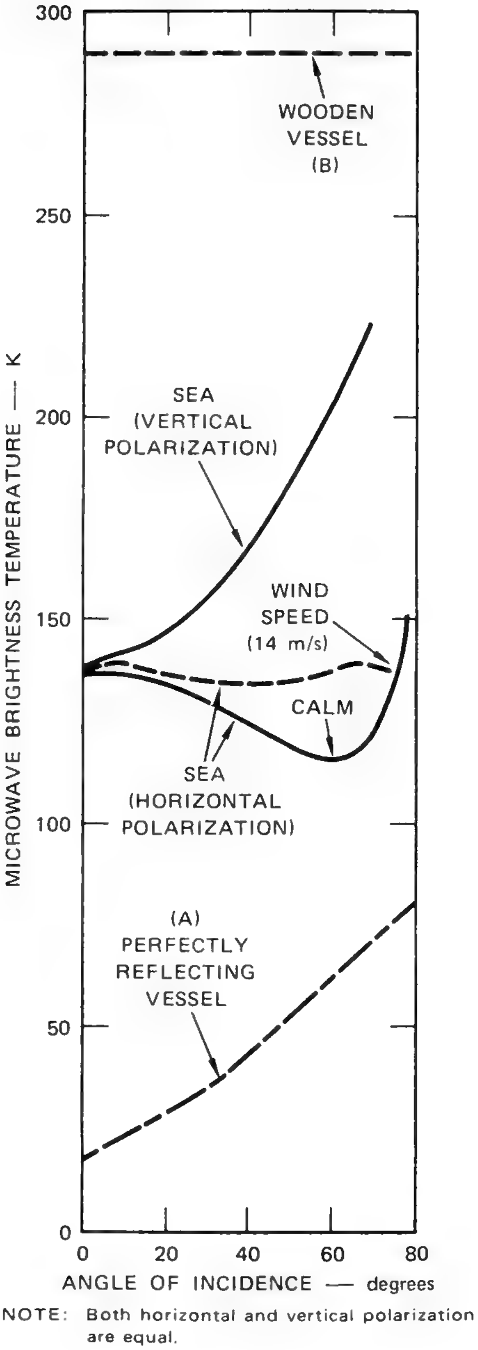


FIGURE 6 MICROWAVE BRIGHTNESS TEMPERATURE OF THE SEA COMPARED WITH A PERFECTLY REFLECTING VESSEL AND A PERFECTLY ABSORBING VESSEL AT 20 GHz (Sea Temperatures from Reference 10)

their true physical temperature (Curve B in Figure 6). In general, the apparent microwave temperature of an object depends more on its emissivity than on its actual physical temperature.

Most fishing vessels over 100 ft will be steel with some portions that are wood so that they will appear at microwave frequencies to be cooler than the ocean but warmer than the ideal perfect reflector (Curve A in Figure 6). Measurements at 90 GHz of the brightness temperatures of ocean water and ships at sea and at dockside reported by King et al.,[9] are summarized in Table 8. It can be seen that the ships are cooler than the ocean. King et al.[9] were also able to detect the wake of ships as a region of warmer water. Presumably, this results from the foam produced which is a better microwave emitter than the sea (higher emissivity) resulting in a higher apparent microwave brightness temperature. A similar mechanism is operative when the wind whips the sea and the effect is used to infer wind speed from the enhancement in apparent microwave brightness temperature resulting from the foam.

Table 8

ANTENNA TEMPERATURES OF SELECTED TARGETS AT 90 GHz

Targets	Temperature (°K)
Ocean water	207 ± 6
Ships at sea	159 ± 13*
Ships at dock	168 ± 12†

*Four ships, 425-ft to 708-ft long.

†Five ships, 250-ft to 750-ft long.

Source: Reference 9

(2) Available Technology

There do not appear to be any operational systems in use at present that are specifically designed for the detection of ships although from time to time such systems have been studied and prototypes have been tested. Studies demonstrated the capability of microwave radiometers operating at relatively low altitudes to detect and, in some cases, to image ships (e.g., Reference 9). There has been very little study of the classification of vessels by microwave radiometry, and microwave radiometry operating alone offers little promise as a technique for ship classification.

Microwave radiometers are used widely in various remote sensing applications from airborne and satellite platforms. Electrically scanning radiometers at 19.35 GHz aboard NIMBUS 5 and at 37 GHz aboard NIMBUS 6 have proved very successful. The characteristics of the NIMBUS 5 radiometer are tabulated in Table 9 to give an indication of available technology. A five-frequency microwave radiometer system covering the frequency range from 5 through 37 GHz has been developed for the NIMBUS 6 and SEASAT satellites and a microwave imaging system is under development for the SHUTTLE.

Primary areas in which microwave radiometers are finding application in remote sensing are the following:

- Remote sensing of ocean temperature and by inference sea state, wave conditions, and surface wind fields.
- Remote sensing and demarcation of areas of sea ice.
- Remote sensing of rainfall rates.
- Remote sensing of thickness and volume of oil spills.
- Radiometric-map terminal guidance aids for missiles.

In each of these areas, a well-developed technological base exists.

Table 9

SUMMARY OF NIMBUS 5 MICROWAVE
RADIOMETER CHARACTERISTICS

Antenna	
Antenna type	Phased array
Aperture size	83.3 cm x 85.5 cm
Half-power beamwidth	1.4° x 1.4° (at nadir)
Beam efficiency	90 to 92.7%
Beam scan angle	±50°
Antenna loss	1.7 dB
Polarization	Horizontal
Radiometer	
Center frequency	19.35 GHz
Predetection bandwidth	200 MHz
Mixer noise figure	6.5 dB
ΔT_{min} for 47-ms integration time	1.5°K
Absolute accuracy	2° K
Dynamic range	50° - 330°K
Calibration	
Reference load	338°K
Ambient load	Local ambient
Sky horn antenna	3°K

Microwave radiometers have been used routinely in the NIMBUS satellites to measure the temperature of the sea. Obtainable accuracy is in the range of 1 to 2°K.[11] Wind speed can be inferred from the enhancement of the apparent sea microwave brightness temperature above the prevailing background level. As described earlier, wind-driven foam and white caps are better emitters of microwave energy than the quiescent ocean surface, which results in a higher apparent brightness temperature. Nordberg et al.[12] demonstrated that a linear relationship between wind speed (>7 m s^{-1}) and enhanced brightness temperature exists. Sea surface winds of 20 m s^{-1} produce a 15° K increase in brightness temperature for nadir viewing. Preferred frequencies are 10 to 20 GHz and accuracy is estimated at 10%.[11]

Radiometers have also found wide application in the mapping of sea ice through persistent cloud cover from both airborne and satellite platforms. The ice is a much better emitter of microwave (emissivity 0.95 for first-year ice and 0.8 for multiyear ice)[13] than the ocean, thus appearing warmer than the surrounding sea. In addition to the ice surveillance capability, the ability to differentiate fresh ice from multiyear ice allows the ice boundaries to be detected and is useful for ship navigation.

Airborne or satellite-borne radiometer systems have also been very useful in mapping weather fronts and measuring rainfall.[14] The brightness temperature measured by the downward-looking radiometer increases with rainfall rate. A rainfall rate of 13 mm/hr produces an increase in apparent microwave brightness temperature of 100° K at 19.4 GHz according to Allison.[14]

Two additional areas of application of microwave radiometers that have received considerable attention are detection of oil spills and missile terminal guidance. Airborne radiometric measurements of oil spills have been made at several frequencies with limited success. Microwave radiometers have been frequently suggested for use in missile terminal guidance systems using map-matching techniques. Technology developed in the latter area is primarily concerned with continental terrain and will have limited impact on support of the 200-nmi zone.

In summary, existing technology in microwave radiometry is more than adequate for the detection of fishing vessels but it does not appear adequate to support classification of vessels. In addition, the several valuable remote-sensing capabilities of microwave radiometers suggest that microwave radiometers could provide, in addition to the ocean surveillance, information on sea state, ice packs, rainfall rate, and possibly oil spills.

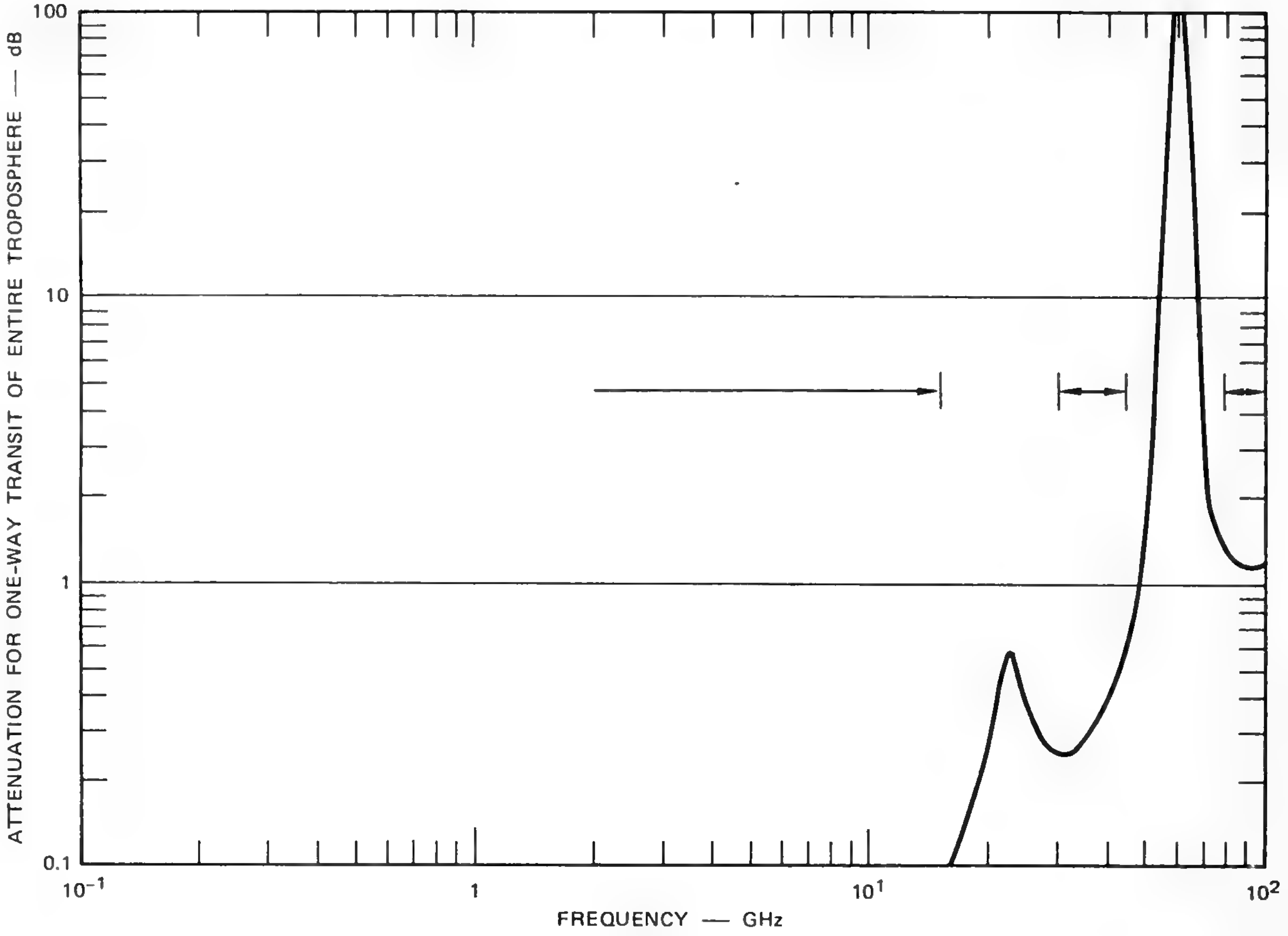
b. Performance Analysis

In this section we investigate the performance that can be expected from a microwave radiometer as a detector of fishing vessels. Specifically we are interested in the maximum detection range, since this determines cost, and in the range of environmental conditions under which detection will be possible. Two key constraints do much to determine the characteristics of a passive microwave sensor. The requirements of near all-weather capability constrains the frequency from going too high where attenuation from weather is excessive and the need to maximize angular resolution and sensitivity preclude use of the lower microwave frequencies because of the large beamwidths associated with antennas of practical size.

(1) Environmental Attenuation and Choice of Frequency

The tropospheric gases absorb and radiate microwaves primarily because of the presence of oxygen and water vapor. Inspection of an atmospheric transmission curve such as that computed by Blake[15] and shown in Figure 7 indicates that there are three windows in which microwave transmission is possible. These windows are summarized in Table 10.

In addition to the attenuation and radiation from the tropospheric gases that are always present, there will be attenuation and radiation from any rain droplets and fog. Attenuation from rain and fog increases as the square of the operating frequency as shown



NOTE: Arrows indicate the three microwave windows in the atmosphere.
SOURCE: Reference 15.

FIGURE 7 TOTAL ONE-WAY VERTICAL ATTENUATION FOR A TRANSIT OF THE ENTIRE TROPOSPHERE

Table 10

MICROWAVE WINDOWS IN THE ATMOSPHERE

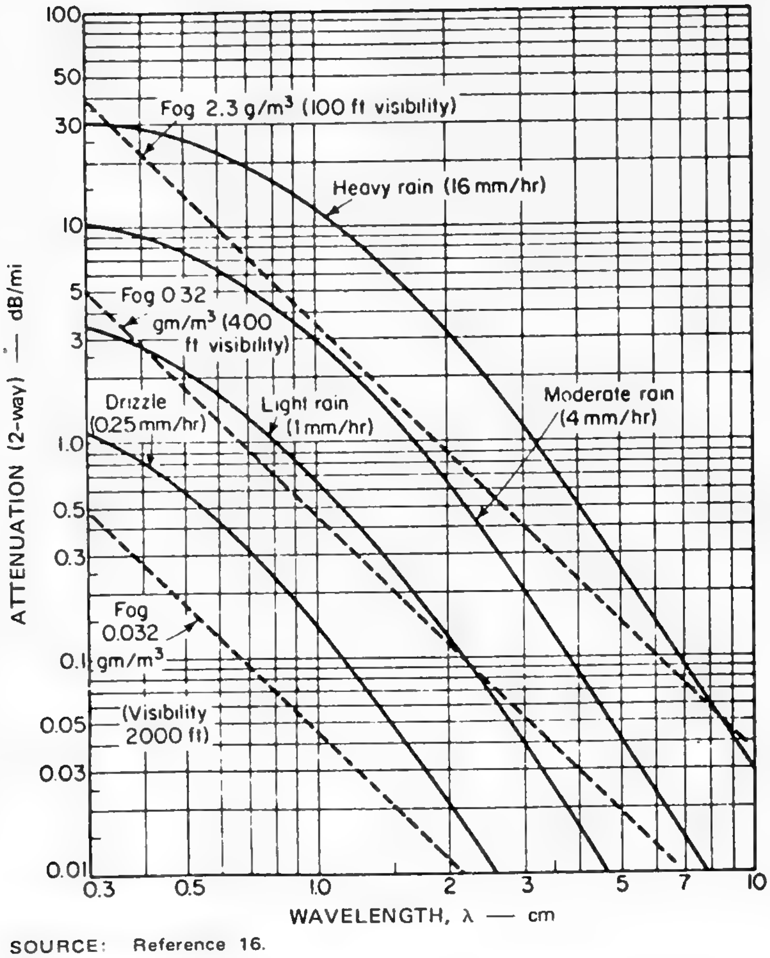
Frequency (GHz)	Wavelength (cm)	Window Designation
80 → 100	0.3 to 0.36	$O_2 \rightarrow H_2O$
45 → 30	0.7 to 1.0	$H_2O \rightarrow O_2$
15 → 1	2.0 to 30	$\rightarrow H_2O$

in Figure 8. It can be seen in Figure 8 that the 80- to 100-GHz window is subject to excessive attenuation from rain and fog. If a near all-weather capability is to be achieved, then the 30- to 45-GHz atmospheric window is the highest operating frequency that can be used.

The spatial resolution and sensitivity of a microwave radiometer increase with decreasing antenna beamwidth. A narrow beamwidth can only be obtained by use of an antenna of large size relative to the wavelength. Since antenna aperture size is limited on an airborne platform, it is essential to maximize frequency. Thus, to maximize resolution and sensitivity consistent with the need for all-weather capability, we adopt a frequency of 35 GHz for use in these performance estimates.

(2) Details of the Baseline System

To make specific performance predictions and cost estimates, a baseline system is postulated with the characteristics summarized in Table 11.



SOURCE: Reference 16.

FIGURE 8 ATTENUATION IN RAIN AND FOG

Table 11

BASELINE RADIOMETER SHIP DETECTION SYSTEM

Radiometer type	Dicke
Operating frequency	35 GHz
Equivalent noise bandwidth	200 MHz
Antenna type	Phased array
Antenna dimensions	1 m x 1 m
Beamwidth	0.6°
Wavelength	0.86 cm
Receiver temperature	500° K
Beam inclination	20° forward from vertical
Active scan angle across track	110° (side to side)

(3) Maximum Range for Detection and Platform Altitude

Maximum microwave sensor range is constrained by the fact that successful detection requires an adequate ratio between the solid angle subtended by the vessel and the antenna beam solid angle. Several different criteria are used to determine the maximum range at which detection can be effected. All of these criteria lead to about the same maximum range. We will adopt the criterion that the effective radiometric area of the vessel equals at least 10% of the area viewed by the antenna beam. The maximum allowable range, R, is then given by

$$R = \sqrt{\frac{4 A_e}{(0.1)\pi(0.01745\ \sigma_{1/2})^2}}$$

where

R = maximum range for detection, ft

A_e = effective radiometric area of vessel, ft^2

$\sigma_{1/2}$ = antenna beamwidth at 3-dB points, deg.

The relationship between beamwidth, aperture, and frequency is

$$\sigma_{1/2} = \frac{21}{fD}$$

where

D = antenna aperture diameter, m

f = radiometer operating frequency, GHz.

A reasonable estimate for the projected area of a 100-ft vessel viewed at an angle of incidence of 55° is 2×10^3 ft^2. We assume that approximately 50% of this area will be effective radiometrically as a target cooler than the ocean, which gives 1×10^3 ft^2 of effective radiometric area for our nominal fishing vessel. An airborne sensor with an antenna aperture diameter of 1 m would be capable of detecting our assumed vessel to a maximum range of 1.1×10^4 ft when operating at the assumed frequency of 35 GHz. If the side-to-side scan angle is 110°, then the maximum platform altitude is 6.2×10^3 ft.

With the platform height and side-to-side scan angle specified, one can calculate the ratio of the antenna temperature contrast, ΔT_A, caused by viewing the ship to the minimum detectable temperature difference that can be discerned with the radiometer system. The minimum detectable temperature difference, ΔT_{min}, is

$$\Delta T_{min} = \frac{T_{rec} + T_A}{\sqrt{B\tau}}$$

where

T_{rec} = receiver temperature, K

T_A = antenna temperature, K

B = equivalent noise bandwidth, Hz

τ = integration time, s.

The integration time, τ, is chosen to equal the time the target dwells within the scanning beam:

$$\tau = \frac{(\theta_{1/2})^2 \; h \; (0.01745)}{V\varphi}$$

where

V = platform velocity, ft s^{-1}

φ = scan width (side-to-side), deg.

Using a platform height of 6.2×10^3 ft, a receiver temperature of 500° K, an antenna temperature of 150° K, a platform speed of 200 kts, and the system characteristics of Table 11 gives ΔT_{min} = 1.66° K.

A temperature contrast of from 50° K to 80° K is expected between fishing vessels and the sea. For a beam filling factor of 10%, this produces a radiometer antenna temperature contrast between viewing and not viewing the vessel of 5° K to 8° K. The corresponding ratio of the antenna temperature contrast to the minimum detectable contrast of 1.7° K will be in the range of 3 to 5, which will be adequate for detection.

(4) Areal Mapping Rates

Areal mapping or surveillance rates depend on platform altitude, platform speed, and search strip or swath width. Considerations of detectability described earlier limit platform altitude to 6.2×10^3 ft, which precludes the use of satellites and severely restricts coverage. The maximum side-to-side scan angle is determined by the decreased contrast between vessel and sea at large angles of incidence. Areal mapping rates for the baseline system are tabulated in Table 12.

Table 12

AREAL SURVEILLANCE RATE FOR BASELINE SYSTEM

Airborne platform altitude	6.2×10^3 ft
Search strip width	1.76×10^4 ft (2.89 nmi)
Areal surveillance rate Platform speed = 200 kts	5.8×10^2 nmi^2/hr

(5) Location Accuracy

The microwave radiometer beamwidth of 0.6° permits the vessel to be located with respect to the platform with an accuracy of better than 100 ft--typically much more accurately than the position of the platform is known. Thus, vessel location accuracy will be determined by the accuracy with which the airborne platform can be located. For example, LORAN-C, the navigational system selected as standard for the Coastal Confluence Zone, gives position location to accuracies of one-quarter nautical mile under favorable conditions.

c. Cost Analysis

It is estimated that a 35-GHz radiometer using a phased array installed in the belly or bottom of the wing of a suitable aircraft could be built and installed for $200,000. It is estimated that if a quantity of ten or more units or installations were made, this cost could be reduced to approximately $100,000.

Surveillance cost per unit area of ocean patrolled depends on the type of aircraft used. We have adopted an operating cost of $\$1097/\text{hr}^{-1}$ for an aircraft capable of carrying a 1-m^2 antenna and of performing ocean patrols. This cost figure for the aircraft assumes that a MRS aircraft will be used; the hourly cost is extracted from page 38 of Reference 7. The total hourly cost comprises an operating cost of \$977 per hour and an investment cost of \$120 per hour.

Operating cost of the radiometers, data processing, and data interpretation is estimated at \$100/hr for a total cost of $\$1.2 \times 10^3/\text{hr}$. All costs are in FY 1975 dollars. This gives an operating cost, C, of

$$C = \frac{\$1.2 \times 10^3 \ \text{hr}^{-1}}{5.8 \times 10^2 \ \text{nmi}^2 \ \text{hr}^{-1}}$$

$$C = \$2.07 \ \text{nmi}^{-2}$$

d. Conclusions

The following conclusions have emerged from this study of the microwave radiometric detection of ships off the coast:

1. Detection of ships by microwave radiometric techniques is feasible and a suggested baseline system at 35 GHz utilizing a phased array is outlined.
2. Constraints on maximum frequency and detectability requirements severely restrict the height of the platform. A satellite platform is ruled out and an airborne platform is limited to altitudes of approximately 6×10^3 ft for the baseline system considered.
3. Detection of ships on the ocean surface is possible because metal ships appear cooler than the sea by virtue of reflecting the sky temperature,

and wooden ships appear warmer than the sea because of their high emissivity. A ship will be easily detectable at the platform heights considered with present state-of-the-art receiver and antenna systems.

4. Microwave radiometers operating alone offer very little promise as a means of identifying fishing vessels or their catch. If combined with a beacon system, then the combined system would have the capability to locate ships on a day/night, all-weather basis and then identify and classify the vessels by use of a beacon. Any beacon within line-of-sight of the airborne radiometer would be detectable.

5. Vessel location accuracy is determined by the accuracy with which platform position is known. This is estimated to be 2000 ft in range and 2° in bearing.

6. Main advantages of the radiometric technique appear to be the fact that (a) it is passive, offering the advantage of surveillance without radiation (the adversary does not know he is being observed); (b) detection by day or night and under almost all weather conditions is possible; and (c) the equipment can have a multipurpose capability providing information on sea state, sea ice, and rainfall rates, if properly designed.

7. Ice, fog, dense clouds, and even moderately heavy rainfall are not expected to seriously degrade performance of the system. However, heavy rainfall may degrade the system by reducing contrast between the vessel and the sea.

8. Equipment cost per platform equipped is estimated at $200,000 with the unit cost decreasing to approximately $100,000 in quantities of ten or more.

9. Approximately 5.8×10^2 nmi^2 can be searched per hour, at a cost of approximately $2.07 per nmi^2 FY 1975 dollars.

4. Optical and Electrooptical Techniques

a. Description

This category of sensors includes the traditional visual, aided visual, and photographic techniques, as well as the more sophisticated, recently developed methods of electrooptics typified by low-light-level television and infrared imaging systems. Here, the optical regime is construed not as the limited spectral range of the eye (i.e., visible light) but as the entire range from the long-wave infrared to the near ultraviolet (see Figure 2) from submillimeter wavelengths (less than 1000 μ) to about 0.25 μ (2500 Å). Longer wavelengths (in the millimeter range) are more properly considered microwave; shorter (UV) wavelengths are of little interest in the present context since such energy is absorbed by the atmosphere and is therefore not useful for long-range observation.

Extending the sensitivity of sensor systems beyond the visible can provide several advantages, well known to military reconnaisance specialists:

- Many surfaces exhibit very different reflectivities at nonvisible wavelengths than in the visible; thus, objects that would be difficult to distinguish from the visual background may become more readily detectable at near-infrared wavelengths.
- Sunlight (and moonlight/starlight) contains much near-IR energy; thus, a detection system that uses both visible and IR wavelengths obtains an improvement in illumination and, therefore, in sensitivity.
- While there is very little long-wave infrared (LWIR) energy in sunlight and starlight (e.g., in the range from 8 to 15 μ), objects at "room" temperature (~25° C, 75° F) and above emit self-radiation in proportion to their temperature, the so-called "thermal signature." Thus objects, such as ships, which are warmer than their surroundings (the sea) stand out in LWIR images, developed by TV-like scanning systems

commonly referred to as FLIR (forward looking infrared) sensors in military airborne reconnaisance.

Photographic film can be made sensitive to near-IR energy (i.e., less than 1 μ), and in a common reconnaisance and resources assessment application can provide "false color" images that reveal factors not apparent in visible-light pictures. LWIR observations are only possible with sophisticated electronic systems.

The arsenal of available optical detection and surveillance systems may be listed in ascending order of sophistication (and, therefore, cost):

- The human eye, directly and as aided by optical systems such as binoculars and telescopes.
- Electronically augmented viewing systems, such as the "starlight scopes" that came into prominence during the Southeast Asia conflict; these allow the extension of the visual image into the near IR part of the spectrum.
- Film cameras, including the use of special filters and false-color IR; these may be "single-shot" framing cameras or moving-film mapping/reconnaissance cameras that provide a strip chart of the area overflown by an aircraft.
- Low-light-level television systems (L^3TV), usually sensitive to visible and near-IR wavelengths and embodying an electronic image intensifier (i.e., light amplifier). This technology has progressed rapidly in recent years to the point that relatively clear images of a scene illuminated only by an overcast, moonless sky can be obtained.
- FLIR imaging systems (operating in the LWIR), providing a thermal "map," or picture, with resolution comparable to the best TV systems, which may be viewed on a screen or recorded on tape or film. These systems are not dependent on illumination and can reveal surface characteristic differences dramatically (as in the detection of oil slicks on the water surface). Since even minute temperature

differences are revealed in the image, vessel wakes are frequently detectable for several miles astern, due to the mixing of power plant cooling water and the frictional heat of the vessel's passage through the water.

Special note should be taken here of systems that operate in the visible but that utilize several narrow spectral channels (as opposed to the much broader "channels" of color images) to emphasize small differences in object reflectance and thereby discriminate between objects of materials of special interest (such as pollutants, or different types of fish). Such sensors, referred to as multispectral scanners (MSS) or multichannel ocean color sensors (MOCS), are usually electro-optical in nature, providing a signal similar to color TV, although direct recording of the images on film is possible by the use of narrow-band filters.

No discussion of optical sensors is complete without some consideration of the processing and handling of the raw data output. Photographic film requires chemical development, usually effected at the end of a reconnaissance mission (e.g., when the aircraft lands), although rapid-processing systems are in existence that can provide on-board output for examination or data transmission within seconds or minutes of the actual exposures. Typically, short-range (i.e., close-up) photography will allow for immediate interpretation, while long-range, wide-area surveillance images (from high-altitude aircraft or satellites) require more extensive and detailed examination, often requiring several hours or even days by expert photo-interpreters before useful, specific data are developed.

On the other hand, electrooptical systems provide real-time outputs capable of immediate display and examination and (since the output is in the form of electrical signals) are readily amenable to radio transmission to a remote (shore-based) facility. To immediate advantages accure:

- The data-collection (or surveillance) mission may be redirected in real time as the visual output is assimilated (either by the aircraft crew or at the shore-based command center) to improve data quality in required areas.
- The "longitudinal" (serial) nature of the electrical signal, as opposed to the parallel nature of a photograph (or, time distributed as opposed to space-distributed) makes digitization and computer use much easier. Thus, while real-time "coarse" images are available for instant review, computer image processing can proceed to provide, slightly later, refined images and data analysis.

The value of the latter characteristic would be hard to overemphasize; large-area surveillance photographs contain astronomical amounts of information, most of it superfluous (especially over the ocean). Manual (i.e., human) processing of all this information is tedious and inefficient; an electronic data processor can screen out most, if not all, of the image detail due to clouds and shadows, wind, waves, and sunglint on the water surface, and even uninteresting surface traffic. The "expurgated" image and data then provided to interpreters allow for much faster and more definitive analysis. When multiple, sequential images are being returned (as from an airborne or spaceborne TV, for example), the computer can also maintain a running record of the course and speed of all vessels of interest within the area. This information is of great value in the classification of vessels, and the determination of their activity (e.g., fishing).

The previous discussion has generally assumed aircraft platforms for the sensors; also candidate platforms, of course, are satellite and surface craft. The combination of timeliness of coverage and operational economics makes aircraft seem the most useful surveillance craft for the near future, with some data being derived from existing or projected satellites, and with final follow-up performed by surface vessel.

b. Performance Potential

Present optical technology permits the fabrication of a variety of optical and electrooptical sensors that can perform many useful functions in support of enforcement of the 200-nmi fishing zone. Sensor platforms include: high-altitude (quasi-synchronous) and low-altitude (100-400 nmi) satellites; high-altitude and long-duration patrol and reconnaissance aircraft; and low-altitude, high-performance reconnaissance aircraft. The apparent, most-appropriate sensor/platform combinations and corresponding preferred functions are shown in Table 13. The performance potential of these sensor/platform combinations are discussed below.

(1) Satelliteborne Sensors

Photographic Sensors--Although certain military reconnaissance functions are performed by high-resolution, film-type cameras in low-orbit satellites, the film return process, involving reentry packages and aerial retrieval systems, incur costs on the order of $100 million, for a continuous coverage capability. For this reason, and also because the instantaneous field of view of such systems is very small (a few square miles),[*] the only spaceborne systems considered here are TV and line-scan types in existing or presently envisaged NASA spacecraft.

Electrooptical Sensors--The primary NASA vehicles are the LANDSAT series (previously ERTS) and the upcoming SEASAT program; it is assumed that weather satellite data of value (for airborne patrol planning, as an example) are already available and in use.

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[*] Approximately an area of 5 × 5 nmi for film resolution of 5 × 5 ft.

Table 13

PREFERRED FUNCTIONS: OPTICAL AND ELECTROOPTICAL SENSORS

Platform	Sensor/Technique				
	Visual/Television	Line Scan	FLIR/LWIR	MSS	Photography
Aircraft	Identification and classification of vessels and their activity	No significant applications	Nighttime vessel surveillance for location and type classification	High-altitude surface plankton location	High-altitude surveillance for vessel location
				Low-altitude catch identification	Low-altitude vessel identification, activity, catch
Satellite	Surveillance for vessel location (marginal) Cloud cover update for aircraft planning	Surveillance for vessel location (marginal)	Nighttime vessel surveillance for locacation	Large area plankton survey to identify fishing areas	No significant application

LANDSAT vehicles carry two optical sensors of interest: a return-beam TV camera and a multispectral scanner (MSS) operating in the visible and near-infrared positions of the spectrum. The field-of-view of each of these is about 115 miles^2; the resolution would appear to be several hundred feet for high-contrast "targets." The orbits of the two vehicles presently active are sun-synchronous, and each satellite can survey essentially the entire earth every 18 days; their relative phasing allows coverage of any given point at 9-day intervals. To completely survey the CONUS-CZ would require about 9,000 images; Alaska-CZ coverage would add 5,000. Since the orbit planes are not optimized for U.S. coastal coverage, several days, and perhaps weeks, would be needed to cover all areas of interest; the average response time to a request for specific area coverage would be about 5 days.

These delays, considered in conjunction with the fairly low resolution provided and the limitations on surface access imposed by cloud and fog cover, render the satellite marginally useful in a fishing zone policing system.

The LANDSAT MSS (and a similar sensor to be included aboard SEASAT) can, however, provide useful information on the location and distribution of surface plankton flows. These, in turn, indicate the regions of commercial fishing activity (these data have been used to guide commercial fishing fleets), thereby narrowing the areas of significant interest to high-resolution, airborne reconnaissance sensors.

(2) Airborne Sensors

Photographic Sensors--Both high-altitude (wide area) and low-altitude reconnaissance can be performed with relatively inexpensive, highly developed camera systems used by the military and by civilian geodesic interests.

A typical system, carried at 50,000-ft altitude, can survey and record a surface "swath" 20-50 miles wide along the flight path with adequate resolution to categorize the size of surface vessels down to the 100-ft class (50-ft resolution cell).

The film may be returned to base for processing and analysis, or may be processed in flight and the images transmitted to a shore-based data center by microwave link. (The direct air-to-ground range would be about 250 miles; greater over-water ranges would imply relay, probably through communications satellites.)

Low-altitude reconnaissance by fairly high speed aircraft (Mach 0.9 up) would allow identification of specific vessels and determination of the nature of their activity. (Pilot/observer direct visual contact is, of course, valuable in developing the latter.) High-resolution (airspeed-compensated) color photographs of exposed-on-deck-fish catch can be used to determine the species being taken.

As opposed to "soft" data sensors, the "hard evidence" provided by photography may have significant value in establishing the credibility of fishing zone violation claims.

All photographic missions are constrained by weather, both from the point of view of flight safety and optical visibility. Unlike satellites, aircraft can usually fly below cloud cover (at the cost of reduced coverage as altitude is reduced) although surface fog would obviate results.

Electrooptical Sensors--Although they provide lower image resolution than photography, TV techniques can be used to provide a real-time readout (locally or at a remote control point) of shipping activities. Notice is taken here of the low-cost, TV-equipped remotely piloted vehicles currently under development for military reconnaissance. Applications of greater interest are the FLIR (forward looking infrared) imaging systems now used in many airborne applications. Operating in the 10- to 15-μ region (LWIR) these passive, line scan systems develop an image close to that obtainable with photographic resolution (e.g., 5-ft resolution from 50,000 ft) using the thermal ("blackbody") radiation from surface objects. Such systems can provide nighttime coverage equivalent to daylight airborne photo-reconnaissance. Although it is capable of penetrating light haze, FLIR is subject to essentially the same cloud cover/fog observation limitations as visual photography or TV.

(3) Special Electrooptical Means

If verification of licensing is of primary interest to a surveillance program, two categories of shipborne optical verification can be envisaged: passive and active.

A very inexpensive (~$100) optical retroreflector exhibiting spectral and/or polarization information coding could be carried at masthead and interrogated by an airborne (eye-safe) laser system "aimed" at the ship. The retroreflector does not require special positioning and it can be readily detected by current technology systems (in clear weather) at ranges of up to 50 miles. Coding could indicate nationality, nature of authorized catch, and other simple multivalued parameters. A somewhat more expensive (~$1000) coded reflector, requiring a small power input, could provide a vessel identification number and other more complex data.

The airborne interrogator (which could be fully automatic in acquisition) would represent a nominal payload and power drain (equivalent to, say, a surface search radar), would require some engineering development, but would be essentially similar to present target designators and trackers representing $100,000 to $200,000 unit cost. Operational maintenance costs would be somewhat higher than for airborne radio and radar equipment.

Alternatively, authorized vessels could be required to mount a coded (e.g., pulsed) optical beacon that radiated signals upwards that could be received by relatively simple airborne optical receiver/decoders. Such beacons, which might employ laser optical sources, would require ship-supplied power (of the order of 100-500 W) and would cost $1,000 to $5,000 per unit (if produced in quantity). The airborne receiver would be equivalent, in terms of size, weight, power, support requirements, and cost, to a radio-navigational avionics package such as a Distance Measuring Equipment (DME) or LORAN receiver/decoder.

No conclusions can be made within the scope of the present study on the acceptability of such devices or their vulnerability to counterfeit.

c. Cost Analysis

Three kinds of costs are involved in the use of optical and electrooptical sensors. First is the cost of the sensor systems themselves. These costs are estimated to range from a few hundred dollars for simple, hand-held cameras to several hundred thousand dollars for more complex devices such as FLIR systems. The significant thing about these costs is that they are much less than the cost of the platforms employed (aircraft or satellites).

The second kind of costs includes the costs of procuring and operating the sensor platforms. For satelliteborne systems these costs are huge, but as noted earlier the only satellite systems considered are those deployed and operated by NASA or the military for other purposes so that the only costs properly chargeable to fishing zone enforcement are those associated with acquiring the sensor outputs, which should be quite modest. For airborne sensors the cost per flight hour should be in the same range as those previously identified for microwave radar. However, it should be noted that, because of their more restricted field of view and the necessity to fly below or avoid cloud and fog cover, operating costs (and time) for covering a given surveillance area may be higher than for equivalent coverage by microwave radar. Data to determine the probable range of these increased costs were not obtained for the survey because they are so dependent on the enforcement scheme used and the weather conditions encountered.

The third cost category covers the processing required (usually on the ground) to extract information from the returned sensor data that are usable for enforcement. These costs will vary widely depending on whether the data are obtained from a NASA or DoD satellite or from a USCG aircraft and on how nearly "real time" the information output must be. Processing costs will also vary according to the kind of processing done. Photographic analysis, for example, is labor intensive (requiring highly skilled labor) but it requires relatively inexpensive equipment, while automatic processing of line-scanner outputs, for example, uses less labor but much more expensive processing equipment.

Considering both the wide variability of costs for various options and the critical dependence of option selection on enforcement strategy, and the fact that optical and electrooptical techniques are likely to play auxiliary or supporting roles, it was decided not to expend sparse project resources in trying to quantify costs.

5. Electromagnetic Intercept Techniques

a. Background

All ocean-going vessels are equipped with radio equipment, and a large percentage also carry radar for navigation. Radio frequencies are allocated for specific uses by international agreement and each radio-equipped vessel is assigned an international radio call sign for use in identifying its radio messages. Likewise, navigational radar frequencies are confined to specified bands and the kind of radar (and its characteristics) carried by a particular vessel can frequently be determined from official or semiofficial records, such as those maintained by the USCG for U.S. flag vessels or those maintained by Lloyds of London on a worldwide basis.

The foregoing circumstances raise the possibility of detecting and/or classifying foreign fishing vessels by intercepting and analyzing their radio or radar emissions. Two techniques are potentially applicable. One, based on direction finding, provides a means for determining the position of detected targets. The second involves the classification of a detected target on the basis of information derived from intercept of its radio transmissions. Both techniques can be combined in a single system.

The techniques can be enhanced by the use of radio or radar beacons. Moreover, the ultimate in technical simplicity and reliability in the use of these techniques would be a permit system for foreign fishing vessles that required mandatory, periodic communication to the USCG of location, status, and intentions. The political or administrative acceptability of such an approach and consideration of its susceptibility to evasion or deception are matters beyond the scope of this survey.

The technology for both the vessel radio and radar equipment and equipment for direction finding and communications interception and analysis is highly developed and numbers of systems have been developed both for military and civilian use. Direction finders and intercept/analysis equipment can be operated on shore or from floating, airborne, or spaceborne platforms.

The propagation range of radio and radar signals depends largely on the radio frequency. In general, radio frequencies above about 30 MHz are limited to line-of-sight. However, depending on ionosphere conditions, radio frequencies below 30 MHz, HF, may propagate by skywave well beyond line-of-sight and international boundaries. Because of extended range skywave propagation, HF direction frequency (DF) has the potential to cover large areas of earth. However, this area coverage is constrained by signal frequency, time of day, season of the year, latitude, and sunspot cycle. Thus, areas of immediate interest may not be accessible for hours, months, or years from a land-based DF station.

There are many users of the HF radio spectrum, and it is common for more than one user to time share a frequency. Furthermore, there are users that do not abide by international treaties and regulations. Thus, it is unusual to find a clear HF radio channel and to identify a signal source solely on the basis of frequency occupancy. Hence, call sign, language spoken, and other features of the signal become important parameters for identification of HF radio signals.

The line-of-sight range for signals above about 30 MHz requires that the direction finder be within line-of-sight for signal intercept and DF. This range can be extended by the use of airborne and space platforms. The mobility of these DF platforms have a further advantage in that the DF station may be moved to the geographical area of current interest. HF DF can also be accomplished from airborne platforms.*

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*Generally HF DF is not feasible from space platforms because the platform is above the ionosphere, which makes the propagation path frequency dependent.

b. Performance Potential

(1) Ground-Based HF DF Techniques

The technique for HF radio direction finding is highly developed and the United States currently operates several HF DF networks. A DF network consists of two or more DF stations, which are tied together via a communications system. The exchange of signal frequency, and signal bearing information between the DF stations, allows the location of the signal source to be determined by triangulation. The sophistication of the DF network ranges from one-man, manually operated, portable DF stations to highly automated, fixed site, DF stations each costing several millions of dollars. The size of the DF station is determined primarily by the work load (i.e., number of signal frequencies that must be monitored) and to a lesser extent by the DF accuracy required. Generally one large antenna, such as a 1000-ft-diameter Wullenweber array, is used. This one antenna has the capability to service many intercept and DF operators.

Historically, HF DF has been used for direction finding related to the navigation of aircraft and surface ships, and to the location of aircraft or surface ships in an emergency situation. Currently, HF DF is largely used for monitoring and surveillance. For example, the FCC* operates an HF DF network in the United States to locate illegal radio transmitters and sources of radio interference to authorized radio facilities. DoD operates several HF DF networks for surveillance and intelligence data collection. HF DF is seldom used for navigation because most navigation systems have greater position location accuracy.

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*Federal Communication Commission.

Figure 9 is a plot showing the general performance to be expected of ground-based HF DF as a function of distance. The areas of good, fair, and poor position location accuracy is approximately 1000 miles^2, 100,000 miles^2, and 10 million miles^2, respectively.[*]

(2) Airborne DF Techniques

DoD, Army, Navy, and Air Force have airborne HF, VHF, and microwave DF systems. Modern systems use on-board digital computers to tune radio receivers, make DF measurements, apply known corrections, and to exchange data between other airborne systems for real-time triangulation.

Assuming favorable geometric conditions for the intersection of the lines of bearing, a line-of-sight range of 200 nmi,[†] and a navigational accuracy of 2 nmi for the DF platform[‡] position, a CEP of the order of 5 nmi is possible. The mobility of the platform permits the CEP to be reduced to nearly the CEP of the platform navigation system by homing on the signal source.

As discussed in the previous section, the propagation ranges for HF signals is not limited to line-of-sight. However, the airborne HF DF accuracy will be best when the airborne platform is within line-of-sight of the signal source.

An airborne platform at 20,000 ft altitude will have a line-of-sight range of 175 nmi and will be able to receive radio signals from an area of 95,000 miles^2. With a platform speed of 300 kts it is

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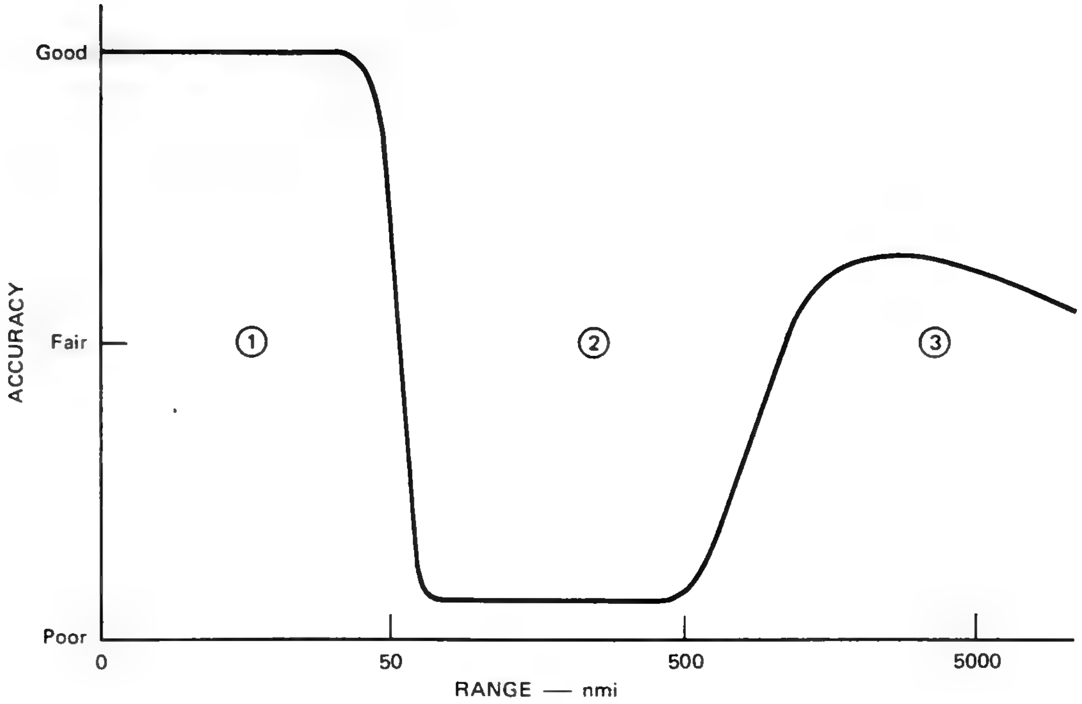
[*] Assuming favorable geometry for the intersections of the lines of bearing and a spacing between DF stations that is compatible with the distance shown in Figure 9.

[†] Platform altitude of 20,000 ft.

[‡] Typical for LORAN-C and OMEGA.



① Little dependence on time-of-day and signal frequency

② Depends on time-of-day, and signal frequency must be below 5-7 mHz

③ Most of path must be in daylight, and signal frequency must be above 5-7 mHz

GOOD: 1° accuracy, or better, on ground wave, CEP 0.9 nmi at 50 miles

FAIR: 3° accuracy, or better, with signal processing and large antennas; CEP 50 nmi to 1000 nmi

POOR: 5° accuracy, erratic and fading signal; CEP 25 nmi at 300 nmi

FIGURE 9 GROUND-BASED HF/DF PERFORMANCE

possible to have a line-of-sight access to 200,000 miles^2 of sea surface per hour.

Two or more airborne platforms can be used to decrease the time to intercept and locate an emitter. These aircraft can be flown at, say, 100-mile separation and can be coordinated in DF operation so that a near instantaneous triangulation may be made.

This type of operation requires an air-to-air data link between the aircraft. Preferably, one aircraft is the master interceptor and controls the receiver tuning and direction finder operation in the slave aircraft via a digital data link.

A single airborne platform may be used to take one, or more, DF cuts on the emitter as the aircraft flies a known path.

c. Cost Analysis

(1) Ground-Based HF DF Techniques

Use of Existing DoD Facilities--It is possible that some signal intercept information can be made available from the DoD files. However, most DoD operations are mission-oriented, and it is most unlikely that there is much time spent in tracking fishing fleets.

Because of the work load, it is reasonable to expect that the minimum cost would be at least that of the extra DF operator personnel required, which is estimated to be $60,000 per station per year.

Dedicated DF Stations--Assuming a low-cost HF DF system such as the Army AN/TRD-26, cost factors for a dedicated station are shown in Table 14.

Table 14

COST FACTORS FOR GROUND-BASED HF DR TECHNIQUES

AN/TRD-26 HF DF	$25,000	
Digitally tuned receiver	15,000	
Digital bearing readout	15,000	
Subtotal		$ 55,000
Land, 10 acres at $1,000/acre	$10,000	
Building	35,000	
Access road, underground power, etc.	25,000	
Subtotal		70,000
Total		$125,000
Personnel, 4 DF operators	$60,000	
1 Maintenance technician	16,000	
1 Supervisor	18,000	
Total		96,000
Power, telephone	$ 5,000	
Building maintenance	3,000	
Total		8,000
Assuming a 20-year life, $\frac{125,000}{20}$ = $6,250		6,250
Total annual cost		$110,250
or $12.59/hr per DF site		

In addition to the costs shown in Table 14, it is most likely that there would be additional cost for service provided (i.e, maintenance, heat, light, power, etc.). Depending on security interpretations, it may be necessary to physically separate the USCG operations from other areas in the DF site. Thus, there could be additional costs for building modifications.

(2) Airborne HF DF Techniques

Use of Existing DoD Facilities--Some signal intercept information from the DoD data files may be available to the USCG. However, most DoD operations are mission-oriented and DoD aircraft are flown in geographical areas of military interest. The feasibility of assigning aircraft equipped for electronic intercept to patrol the coastal areas of the CONUS would have to be explored with DoD since there are few aircraft of this type.

Unless there is an existing DoD mission in the geographical areas of interest to the USCG, it is reasonable to expect that the surveillance cost would be the full cost of operating the aircraft, or $1034/hr.

Dedicated Aircraft--Estimated costs for an airborne dedicated DF system are shown in Table 15.

Table 15

COST FACTORS FOR AIRBORNE HF DF TECHNIQUES

Airborne DF system		2000K
Aircraft		4000K
		6000K
Assuming a 20-year life, the annual cost is		$300K
Equipment cost per hour	34.25	
Estimated operating cost per hour	1000.00	
Estimated cost per hour per aircraft		$1034
Capable of providing good DF surveillance over 200,000 miles^2/hr. Cost per mile^2/hr		$0.005

6. Magnetic Techniques

a. Description

The structure and dynamic properties of the earth give rise to a static magnetic field whose characteristics are essentially fixed both geographically and temporally over reasonable time periods. Any object with magnetic properties placed in this magnetic field will influence its direction and strength in the immediate vicinity of the object. Such changes are called magnetic anomalies.

Well-developed techniques exist for detection of magnetic anomalies with magnetometers. Magnetic anomaly detector (MAD) systems have been built for such diverse purposes as detecting metallic ore bodies or submarines, and they can be used from surface vessel or aircraft platforms. Therefore, the theoretical possibility exists that MAD techniques could be used to detect the magnetic anomalies produced by steel-hulled fishing vessels.

The magnetic anomaly created by a steel-hulled vessel and its metallic contents (engine, propeller shaft, etc.) depends solely on the magnetic characteristics of the vessel. No method of enhancing this effect by a beacon or analogous device is known.

b. Performance Potential

MAD systems for the detection of submarines exist and there is no reason why they would not be equally effective in detecting fishing vessels. However, because of naturally occurring variations in the earth's magnetic field, which can only be mapped through extensive measurement programs, and perturbations in MAD outputs caused by instability in the movement of the vehicle carrying the MAD equipment, the technique is effective only at very short range, typically much less than radar or visual detection ranges. Moreover, no classification of objects detected is possible.

Magnetic techniques are evaluated as having neglegible potential to support enforcement of the 200-nmi fishing zone.

7. Acoustic Techniques

a. Description

Under favorable conditions, acoustic energy can propagate for relatively long distances in the atmosphere and in the ocean. Moreover, the technology for the generation, transmission, and reception of acoustic energy is well established and the characteristics that affect propagation in both the atmosphere and the oceans are well known. Accordingly, detection and classification of fishing vessels by use of acoustic techniques are possible and were examined in this survey.

Techniques based on the propagation of acoustic energy in the atmosphere were ruled out immediately since both the attenuation of the energy and the variability and unpredictability of sound propagation paths in the atmosphere make these techniques usable over only extremely short range and under extensively instrumented laboratory conditions.

Two generic kinds of techniques using acoustic energy propagated in seawater exist. The first involves sonar devices in which acoustic energy is transmitted, reflected from surrounding objects, and the returned (reflected) energy is processed to obtain position location and classification information. The process is almost completely analogous to radar, except that the characteristics of the transmission medium exert a much more profound influence on the transmission and reception of the acoustic signals and the nature and variability of naturally occurring background noise sources are quite different.

The second generic class of techniques employs only passive acoustic receivers, usually hydrophone arrays, to detect and process acoustic energy emitted by objects in the ocean surrounding the receivers.

Both kinds of techniques have been widely employed in military systems for submarine and antisubmarine warfare and in both military and commercial systems for navigation, communications, position fixing, oceanographic exploration, and a variety of scientific purposes.

The performance of both active and passive acoustic systems can be enhanced by the use of acoustic beacons mounted on objects to be detected. In addition to assisting in position fixing, beacons can be coded to provide a wide variety of status and intention data in the same way as for radar beacons.

With the exception of the possibilities described in Volume Two of this report, acoustic techniques were found to have little potential to support enforcement of the 200-nmi fishing zone. Qualitative reasons for the lack of potential are given below.

b. Performance Potential

Feasible approaches for using acoustic techniques in the detection and classification of fishing activity include active devices mounted on patrol vessels or installed on fixed platforms at various depths from the surface to the bottom of the ocean and passive devices mounted similarly. In addition, both active and passive devices can be towed by patrol vessels to better isolate them from noise generated by the patrol vessel. Each of these categories is briefly examined below.

Hull-Mounted Sonar Techniques--For steel-hulled surface craft the detection range and reliability of hull mounted sonar is significantly less than that routinely achieved by radar. The use of acoustic beacons on desired targets provides only marginal range improvement but can vastly improve both reliability of detection and availability of classification information. Overall potential low; technique not likely to become cost effective.

Hull-Mounted Passive Listening Techniques--These techniques are practically useless for detection since own-ship noise masks wanted signals. They may have some extremely limited potential for classification if fishing vessel signatures are distinctive; this capability can be significantly improved if beacons are used, but only if a patrol vessel stops and turns off noise sources when performing classification function. Overall potential low; technique not likely to become cost effective.

Towed Passive Listening Arrays--These arrays are only marginally better than hull-mounted arrays. Overall potential low; technique not likely to become cost effective.

Sea-Bottom-Mounted Passive Listening Arrays--See Volume Two of the report. Overall potential low except under special circumstances.

8. Multisource Correlation Facilities

a. Description

The multisource correlation facility in the context of fishery zone enforcement is to accept inputs of detection and classification information from a variety of sensor systems and information sources, correlate the information, and present it to analysts for use in planning and conducting enforcement functions. The correlation process includes the association of inputs to eliminate redundant target reports, the use of a stored data base and information from system inputs to identify and classify targets, and the processing of the resulting correlated target data for analysis and display. The trend in multisource correlation facilities is toward the use of modern data processing and interactive display equipment to automate the correlation process.

An example of the state of the art in multisource correlation capability is a system developed for the U.S. Navy by Lockheed Missiles and Space Company, called "Outlaw Hawk." The system was developed as an ocean traffic monitoring system for use by Navy task force commanders at sea and fleet command centers ashore. It uses a variety of input sources, many of them classified, and an extensive technical data base containing information on traffic that might be encountered in any area of interest. The sensitive nature of its data sources and performance capabilities prevents further description in this unclassified report.

Lockheed has proposed a system to the USCG based on Outlaw Hawk called Maritime Extended Range Interactive Terminal (MERIT). Figure 10 taken from a Lockheed briefing on MERIT, shows an overview of the system as it might be applied in supporting enforcement of fisheries regulations.* Figure 10 indicates how data routinely available to the USCG, including data from remote sensors like those examined in this

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*There are many approaches to the development of such multisource correlation capabilities, some of which are already used in operational systems, e.g., the Navy's Naval Ocean Surveillance Information Center (NOSIC). MERIT was selected as an example here only because an unclassified description of its application to USCG missions was readily available.

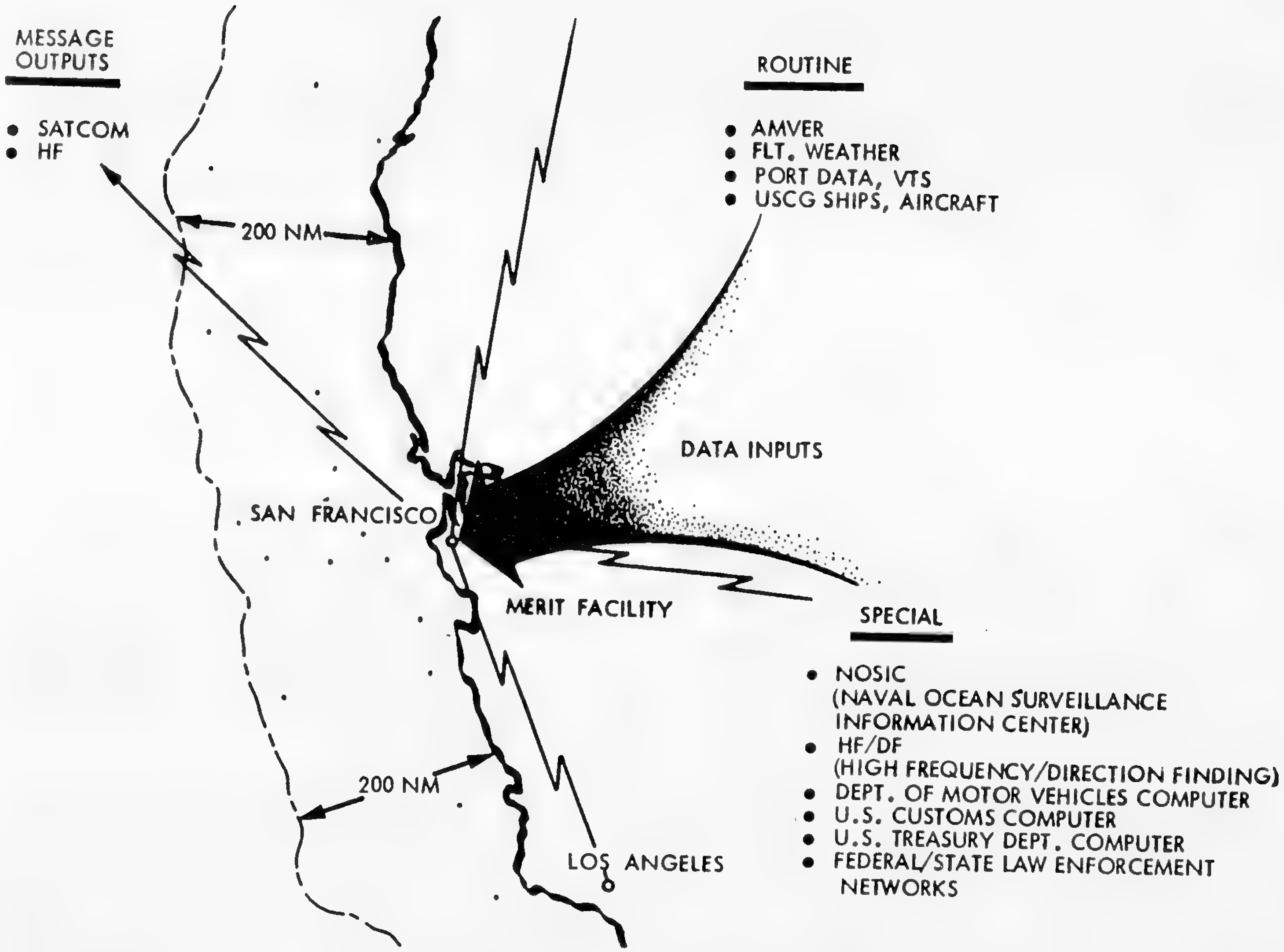

FIGURE 10 TYPICAL AREA OVERVIEW

survey, could be combined for correlation with data obtained from "special" sources not under USCG control, some of which are classified or require other forms of protection of the data. The principal output of the correlation process in MERIT would be a coordinated geographic display of all maritime activities along with the capability to selectively display activity of special interest, such as foreign fishing vessel activity, on interactive displays with facilities for accessing amplifying data stored in the computer on any particular target.

b. Cost Analysis

Estimated cost for a three-system MERIT network is of the order of $1.5 million with monthly computer lease and software support costs of approximately $14,000 for each system.

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GLOSSARY

AMVER	Automated Merchant Vessel Reporting
ARPA	Advanced Research Projects Agency
AWACS	Defense Advanced Research Projects Agency
DABS	Discrete Address Beacon System
DF	Direction Finding
DME	Distance Measuring Equipment
FAA	Federal Aviation Agency
FCC	Federal Communications Commission
FLIR	Forward Looking Radar
GDOP	Geometrical Dilution of Precision
JPL	Jet Propulsion Laboratory, Toluis Hopkins University
L^3TV	Low-Light-Level Television
MAD	Magnetic Anomaly Detector
MERIT	Maritime Extended Range Interactive Terminal
MOCS	Multichannel Ocean Color Sensors
MRS	Medium Range Surveillance (aircraft)
MSS	Multispectral Scanner
NELC	Naval Electronics Laboratory Center
NMFS	National Maritime Fisheries Services
NOAA	National Ocean and Atmospheric Agency
NRL	Naval Research Laboratory
ONR	Office of Naval Research
OTA	Office of Technology Assessment
OTHR	Over-The-Horizon Radar
PMTC	Pacific Missile Test Center

RF	Radio Frequency
RPV	Remotely Piloted Vehicle
SAR	Synthetic Aperture Radar
SCR	Signal-to-Clutter Ratio
SNR	Signal-to-Noise Ratio
USCG	U.S. Coast Guard
WARF	Wide Aperture Research Frequency

COMMENTS FROM REVIEWERS

This report was prepared in consultation with, and with the assistance of, the U.S. Coast Guard fisheries enforcement office. Since much of the new durveillance technology presented is based on military systems and hardware, OTA requested the U.S. Navy to review and comment on the contents of the report. OTA has received and discussed these comments with the knowledgeable Navy groups.

The overall comments reflected agreement with the report's conclusions except in the area of capabilities of specific radar and acoustic techniques. While many of these comments are classified and, therefore, not reproduced here, the following summarizes the key points:

1) Some new research conducted by the Navy in advanced microwave radar indicates that capabilities for detection and classification could be significantly improved from that discussed in this report. It would be desirable to further consider such newly developed military radar technology in future analysis of this subject.

2) Discussions in the report of acoustics systems for detection and classification do not reflect some of the Navy's experience with advanced systems or capabilities of acoustics experts working in Navy programs. The specific comments are classified but they suggest that a better knowledge of advanced acoustic system capabilities would modify some pessimistic conclusions about the usefulness of acoustics and added research may prove fruitful. Future analysis of this subject sould be in cooperation with Navy branches experienced in the field.

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OTA-O-46