A CONCEPTUAL FRAMEWORK FOR THE OPERATIONAL FISHERIES OCEANOGRAPHY COMMUNITY

JAMES J. SIMPSON
Marine Life Research Group
Scripps Institution of Oceanography
University of California, San Diego
9500 Gilman Drive
La Jolla, California 92093-0237

ABSTRACT

A conceptual framework is developed for interactions among the diverse groups involved in operational fisheries oceanography: fishing industry, basic and operational researchers, and tactical and strategic stock assessment managers. These interactions originate in a need for accurate and timely information, information so complex and diverse that no single sector of the community can efficiently and economically satisfy its own information requirements. Some methods of gathering and analyzing presently available remotely sensed data to provide such information are discussed.

RESUMEN

Se desarrolla un marco conceptual de las interacciones entre los grupos que participan en los aspectos operativos de la oceanografía pesquera: industria pesquera, investigadores "básicos" e investigadores enfocados en aspectos operativos, y administradores de la evaluación de los "stocks", tácticos y estratégicos. Las interacciones se originan de la necesidad de información precisa y oportuna; la información es tan compleja y diversa que ningún sector de la comunidad por separado puede satisfacer de manera eficiente y económica sus propios requerimientos (de información). Se discuten algunos de los métodos actuales de colectar y analizar los datos usados para proveer la susodicha información; los datos se obtuvieron de sensores remotos y se encuentran disponibles actualmente.

INTRODUCTION

Since about 1979, remote sensing has played an increasing role in both the management and utilization of marine fisheries. Remote-sensing products have been used to (1) assist both the commercial and sports fishing industries in harvesting fish from the sea (e.g., Svejkovsky 1989); (2) provide marine resource managers with information useful for assessing the survival of fish eggs and larvae to the juvenile stage within a given year class (e.g., Pelaez and McGowan 1986; Simpson 1987); and (3) indicate the onset of major interannual events (e.g., ENSO and associated mid-latitude warming events) that may threaten a local fishery (e.g., Fiedler 1984). Likewise, there has been an increased awareness of the importance of both remotely sensed and *in situ* environmental data for understanding the scientific basis of marine fisheries (e.g., Lasker 1975; Parrish *et al.* 1981; Leggett 1984; Simpson 1987), as well as for the intelligent management (e.g., Tillman 1968; Ushakov and Ozhigin 1987), and use (e.g., Laevastu and Bax 1989; Hogan and Clarke 1989) of the marine fisheries resource. Moreover, recent advances in data acquisition, digital mass storage of data and communications technologies, coupled with more powerful analysis methods, indicate that satellite and environmental oceanography will play a considerably expanded role over the next decade in all aspects of marine fisheries, especially in terms of near-real-time support of actual fishing activity. This paper presents some of the benefits to be gained from the increased use of remote sensing in operational fisheries oceanography.

AN INTERACTION MATRIX

In this section an attempt is made to describe some activities of the various sectors of the operational fisheries oceanography community (i.e., fishing industry, tactical and strategic stock assessment managers, and basic and operational researchers) and to identify common needs and linkages between these sectors.

Fishing Industry

The fishing industry's primary concern should be to harvest economically a given resource from the sea in such a way as to insure its continued, long-term use (figure 1). Thus, the fishing industry should constantly try to optimize catch per unit of effort without jeopardizing the fecundity of the stock. Unfortunately, this has not always been the case: in some circumstances (e.g., the California sardine fishery) the desire for short-term economic gain, coupled with inadequate resource management and an inability to properly observe and recognize early, major, interannual, environmental

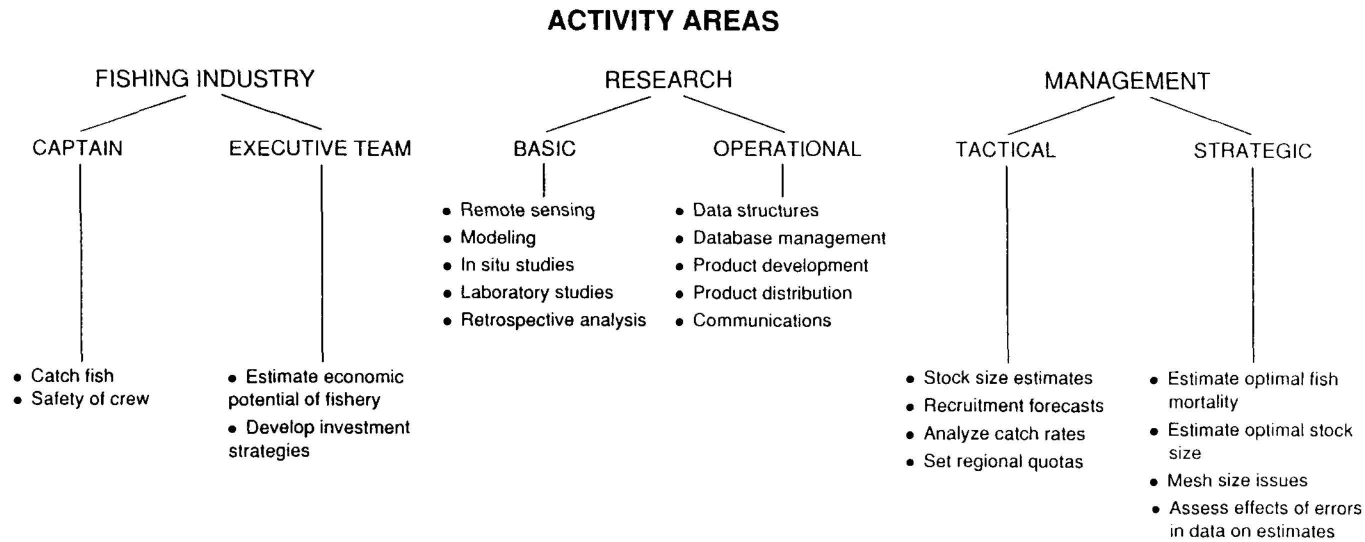

Figure 1. Conceptualization of the various sectors involved in operational fisheries oceanography and some of the functions performed by each.

changes in the fishery (e.g., the 1940–41 ENSO mid-latitude warming event), has led to the collapse of a fishery.

Most offshore fishing can be profitable only on aggregations such as shoals, or where the density of fish per unit area is high (Laevastu and Bax 1989). Fish aggregations may be purposeful (i.e., for spawning), or may be associated with feeding and migration. Major environmental factors that tend to produce aggregation are temperature, coastal and bathymetric boundaries, currents, and salinity. Thus, fish often aggregate near oceanic fronts; that is, at boundaries between water types and currents. Satellite data and modern methods of digital image analysis make it possible to accurately detect the near-surface expression of these boundaries, follow their evolution in space and time, and determine the velocity and current shears associated with them. Advances in communications technology make such information available in near-real time to help optimize fishing operations. Remotely sensed data also can be used to monitor storms and, in polar regions, to identify sea ice–ocean boundaries. These latter two analyses can lead to a safer fishing environment (e.g., in the North Atlantic cod fishery).

Most captains of fishing vessels do not have the time or training to obtain and analyze, in a state-of-the-art fashion, satellite or *in situ* oceanographic data. Moreover, the economics of fishing, of which the need for prorated capitalization (e.g., vessel, processing plant costs) is only one factor, should motivate commitment to conservation on the part of the fishing industry (figure 1). This commitment to conservation can be effective even if it is better expressed as a desire on the part of the fishing industry for good (i.e., technically sound and informed) counsel from stock assessment managers. Ultimately, the quality of such counsel is critically dependent upon the availability of reliable, near-real-time data on catch: data that can come only from the fishing industry. Thus the exchange of accurate information between members of the fishing industry and stock assessment managers represents the only practical way to insure a long-term, economically viable fishery. Efforts must be made to educate the fishing industry of the benefits to be obtained from such an exchange of information.

Fisheries Management

Fisheries management often consists of groups of fisheries biologists and stock assessment personnel who are required to monitor or predict fish stocks and recommend total allowable catch (TAC) on a species-by-species basis (figure 1). The basis for management of a given fishery usually involves an estimate or prediction of mortality and/or recruitment. (Recruitment is taken as a measure of variable year-class strength established by the time of the juvenile stage.) The ratio of the importance of the two measures (mortality vs. recruitment) is species dependent, with relative importance being determined largely by how long the fish lives. For squid, which live for only one year, recruitment is the key to management success; for rockfish, which live to 70 years and hence have many year classes in the fishery, recruitment data are tactically less important than mortality data for good management of the stock.

Accurate estimates of either mortality or recruitment are difficult to make because data are limited and the scientific basis for the tactical estimate is uncertain. For example, observationally based estimates of mortality are often determined empirically (e.g., Reed et al. 1989), depend upon assumed or measured patch size (McGurk 1986), and may have regional dependencies. Such estimates describe only observed change and do not distinguish between contributions from physical processes (e.g., advection, temperature) and mortality; thus a decrease in concentration can serve as an estimate of mortality only if one assumes no significant physical change (Reed et al. 1989). In general, however, such an assumption is not likely to be valid. For example, advection affects both mortality and recruitment because it can carry eggs and larvae into areas poor in food, rich in predators, or both. Conversely, water movement can carry eggs and larvae into areas rich in food, poor in predators, or both. The precise effects of water motion on a biological population depend upon the detailed phase relation (where and when) between the space-time history of the population and the environmental factors that form its habitat (Simpson 1987). English sole off Oregon (Kruse and Tyler 1989) and the cod fishery of Hecate Strait, British Columbia (Tyler and Westrheim 1986; Tyler and Crawford 1991) illustrate the importance of transport.

Spawner-recruitment models also have been used to estimate fish mortality between spawning and recruitment (e.g., Rothschild 1986). Wooster and Bailey (1989) point out that the most common models are those of Richer (1954) and Beverton and Holt (1957); both models contain density-dependent and density-independent terms. The density-dependent term, through compensatory mortality, has the effect of reducing recruitment with increasing stock size. Although compensatory mortality acts on new recruits in both models, the mechanism of interaction is interpreted differently. The Richer model emphasizes the role of predation (e.g., predators and cannibalism), whereas the Beverton and Holt model emphasizes starvation (i.e., pre-recruits increase with increasing spawner abundance, but the amount of available food per fish decreases). The underlying assumptions of such models, however, are far from universally accepted. Jones and Henderson (1985) conclude that, in general, little evidence exists for a significant relation between spawners and recruits in fish species. Other studies (e.g., Hollowed and Bailey 1989; MacCall 1990) find some density-dependent spawner-recruit relations but have difficulty separating these relations from density-independent effects. Thus the job of stock assessment managers to establish, on a species-by-species basis, realistic and profitable TACs to ensure resource fecundity is an unenviable task limited by both inadequate near-real-time observations and an inadequately developed scientific basis for management. Present and planned remote-sensing instrumentation, improved methods of digital image analysis, and the development of meaningful environmental/biological indices using satellite data (i.e., those that relate directly to stock assessment) provide a means of mitigating one of these handicaps; namely, the lack of adequate, near-real-time observations.

Mortality and recruitment data, however, are not solely related to the conservation side of stock management. In fact, accurate estimates of both mortality and recruitment can help insure more efficient harvesting of a given stock through improved estimates of abundance (e.g., Wooster and Bailey 1989). Stock assessment managers should use this latter relation to educate and encourage the fishing industry (i.e., it's in their own best interests) to provide accurate catch statistics for management use.

Finally, a distinction should be made between tactical and strategic management of a given fisheries resource (figure 1). Tactical management (e.g., Megrey and Wespestad 1990; Stocker and Leaman 1990; Anthony 1990) estimates stock size for the current year, forecasts recruitment, and analyzes catch rates and events in the fishery. This information is used to decide on quotas, establish allowable fishing areas, and determine the opening and closing times of the fishery. Strategic management (e.g., Cook and Copes 1987; Murphy et al. 1990; Zhang and Gunderson 1990) is concerned with mesh size, optimal fishing mortality given growth and natural mortality, optimal stock size for maximal recruitment, and how to handle errors in measured data and derived fishing indices. Clearly, a well-managed fishery is guided by closely coordinated tactical and strategic stock assessment decisions.

Research

Research activity can broadly be divided into basic and operations research. Both require environmental information and catch statistics that, in part, must be supplied by the fishing industry (figure 1).

Basic research addresses questions that can provide a better scientific basis for operational fisheries oceanography. Clearly, improved understanding of the environmental and biological processes that influence both recruitment and mortality is a central concern of basic fisheries research — a concern that relates directly to both the tactical and strategic needs of stock assessment (figure 1). For example, basic research must develop a theoretically sound means for determining the temporally and spatially varying relative importance of advection (e.g., Parrish et al. 1981; Simpson 1987) vs. starvation (e.g., Hjort 1914; Lasker 1975) vs. predation (e.g., Hunter 1981; Parsons et al. 1984) in the recruitment process of a given fishery. Also, methods need to be developed for separating the effects of density-dependent vs. density-independent factors in spawner-recruitment models used to estimate mortality. Basic research advances in these two areas alone will directly improve the ability of stock assessment personnel to develop better strategies and improved tactical indices for monitoring and managing a given fish stock.

The examples cited above are only two of the many fundamental environmental-biological questions that need to be studied if the complex interactions between fish and environment are to be clearly understood. Basic questions such as these, however, require a broad spectrum of research activity for proper resolution: (1) process-oriented experiments (e.g., Checkley et al. 1988; Rose and Leggett 1988); (2) laboratory studies (e.g., Theilacker 1986); (3) numerical models (e.g., Murdie and Hassell 1973; MacCall 1980); and (4) biogeographic and population dynamics studies (e.g., MacCall 1990). Remote-sensing analyses can provide real-time guidance for process-oriented experiments, some of the initial and boundary conditions needed by numerical models, data for validating the prognostic capabilities of such models, and data useful in biogeographical and population dynamics studies of marine fishes.

Operations research is concerned with the design of data structures that can provide an efficient and compact representation for environmental and biological data used in operational fisheries oceanography (figure 1). Such data structures are required to meet the ever-growing near-real-time support needs of a typical operational fishery, especially given the constraints and costs of present-day ship-to-shore communication networks. These data structures, in turn, are needed to build data bases to be used in developing and validating operational products useful to the community.

Operations research has many activity areas. This diversity is largely determined by the near-real-time needs of both the fishing industry and marine resource managers for data (e.g., catch statistics) or for operational products derived from data (e.g., sea-surface temperature charts) or models (e.g., wind-field analysis, marginal ice-zone analysis, fish mortality and recruitment analysis). Thus operations research activity includes, but is not limited to, real-time data acquisition (e.g., satellite data); archiving and distribution (including near-real time and ship-to-shore) of processed data sets to support fishing activity; and the design and implementation of computer-assisted decision-making tools to help prevent information overload to bridge personnel. Operations research also should provide the focal point (figure 2) for the collection of information from the fishing fleet (e.g., length of fish, gonad statistics, infestation data) and the subsequent distribution of this information to other sectors of the fisheries community (e.g., stock assessment personnel). Moreover, this information provides the basis for both the validation and refinement of operational products supplied to the fishing fleet and for the development and refinement of basic research concepts.

Community Interactions

The basis for interactions among the various sectors of the operational fisheries oceanography community is a need for accurate and timely information. The information is so diverse and complex that no single sector of the community can effectively and economically gather all of the information it needs. In a very real sense, the information imperative translates into a pragmatic necessity; the various sectors will hang together (i.e., communicate and share data) or hang separately (not meet their respective objectives). The vehicle for interaction is a communications network. Operations research, by virtue of its functions (figure 1) and its position within the framework of the entire community (figure 2), is the logical sector to develop and maintain the communications network. These are the premises under which the following matrix of interactions for an operational fishery was developed.

The fishing industry uses information at two primary levels: (1) the executive team and (2) the captain, or skipper-group (Hogan and Clarke 1989). The executive team (figure 1) uses information to formulate strategies, policies, capital investments, and other corporate decisions that affect the socioeconomic life of a fishing region (e.g., the Newfoundland cod fishery). These corporate decisions and actions are made within the framework of estimating the opportunities deemed to exist in the resource (i.e., the regional fish stocks) and the environmental factors governing their exploitation. Thus the fishing industry is critically dependent upon the stock assessment sector of the community to properly set TACs. A TAC that is set too high can result in an underutilized stock and probably economic hardship for the fishing region. Likewise, a

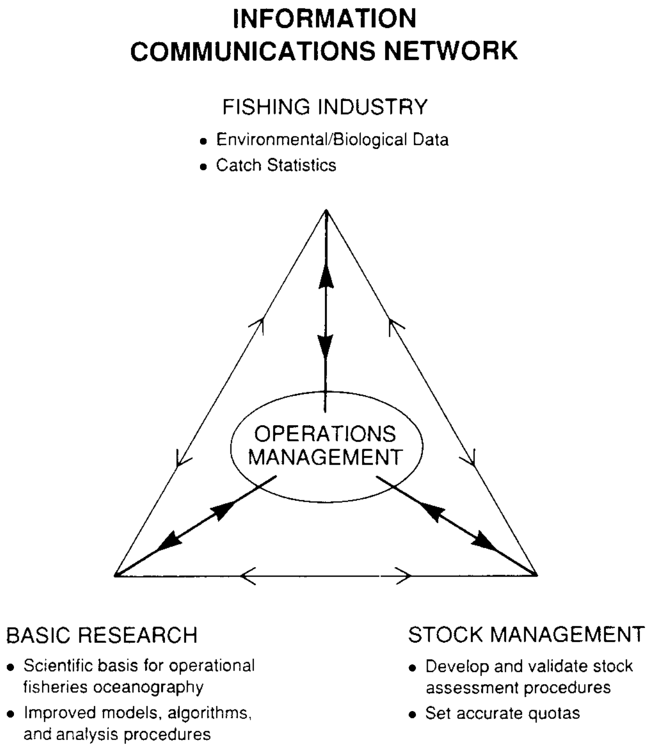

Figure 2. Conceptualization of the major types of communication linkages needed for a successful regional operational fisheries oceanography program. *Bold lines* indicate primary communications links via an operations research center. *Lighter lines* indicate secondary communications links.

TAC that is too low can result in an overutilized resource with potential long-term ecological and economic damage to the regional fishery. The captain, or skipper-group (figure 1) needs near-real-time information to make decisions and implement actions that affect the safety of crews and the efficiency of the fishing effort.

Traditionally, the fishing industry has been perceived as the "consumer" of information; the industry's potentially important role as a data source for the rest of the community has largely been ignored (figure 2). A fishing vessel, which is at sea for well over 200 days a year, is virtually a floating information-collection platform (Hogan and Clarke 1989). At the least, estimates of catch per unit of effort can be made from fishing industry data. But the prospects for additional information are more exciting. Consider the Newfoundland cod fishery, in which cod are normally eviscerated upon catch. Evisceration makes it possible to collect gonad statistics and to estimate predator-prey relations; for example, cod gut contents (redfish, capelin, or sand lance) can be determined, and fish preying on the cod are hauled in with the cod and can be counted. Infestation data, discards of other biota, sightings of cetaceans, the activity of foreign vessels in the regional fishery, and environmental data are additional types of information that other sectors of the fisheries oceanography community can glean from the fishing industry.

Both the strategic and tactical aspects of fisheries management need environmental and biological information. Strategic management issues (e.g., mesh size, estimation of optimal stock size, optimal fishing mortality, adult behavioral studies, and recruitment research) directly involve some aspect of operational fisheries oceanography. Tactical management issues—e.g., gathering indices of recruitment and mortality including ocean model predictions, survey design and covariates analysis, interpretation of events (varying catch rates) in the fishery caused by environmental factors (e.g., ENSO activity in the Northeast Pacific or severe winters in the Northwest Atlantic)—also require large amounts of high-quality environmental and biological data.

At present, the strategic side of fisheries management uses significantly more data than the tactical side. The tactical side of fisheries management, however, can reduce risk and uncertainty in a given fishery by more aggressively incorporating various oceanographic indices (developed in cooperation with basic fisheries research efforts) into assessment analyses. Remote sensing products developed within the context of operations research provide a basic source of information for such indices; planned instrumentation for the 1990s (e.g., SeaWiFS, MODIS) will expand this capability. The potentially diverse sets of fishing industry and historical data, collected and distributed via a communitywide communications network developed and maintained by operations research efforts, provide another source of data for developing and evaluating tactical fishing indices.

Two primary goals of basic fisheries oceanography research are (1) to provide a better scientific basis for both the use and management of an operational fishery; and (2) to develop improved algorithms and analyses for efficiently representing the state of a fishery from the large, diverse, and complex data sets needed to understand that fishery. Within this context the need for high-quality environmental and biological data is clear. Ultimately, the objective should be to translate advances in basic fisheries research into operational products that can improve both the use and management of the resource. Such products normally would be developed, evaluated, distributed, and maintained by operations researchers working in close collaboration with the fishing industry and stock assessment managers.

The communications network, complete with products, historical data bases, current data bases, satellite data, and geographical reference data, provides feedback mechanisms for the entire operational fisheries oceanography community (figure 2). Operations research centers, funded jointly by government and industry, must be created to develop and maintain the required data bases, operational products, and communications network. These concepts, together with an extensive set of examples using remotely sensed data, are discussed in Simpson 1992, MS[1] and the references contained therein.

ACKNOWLEDGMENTS

This work was sponsored by the Marine Life Research Group of the Scripps Institution of Oceanography, by a grant from the National Aeronautics and Space Administration, and by the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, under grant number NOAA NA89AA-D-SG138, project number 14-F-N and project number #R/OE-25 through the California Sea Grant College, and in part by the California State Resources Agency. The views expressed herein are those of the author and do not necessarily reflect the views of NOAA or any of its subagencies. The U.S. government is authorized to reproduce and distribute for governmental purposes. M. Wilke and D. Atkinson assisted with manuscript preparation. Fred Crowe and Guy Tapper prepared the final figures. Comments from Scott Akenhead and an anonymous reviewer are greatly acknowledged. Finally, special thanks are due to the late Reuben Lasker, who initially introduced the author to operational fisheries oceanography.

LITERATURE CITED

Anthony, V. C. 1990. The New England groundfish fishery after 10 years under the Magnuson Fishery Conservation and Management Act. N. Am. J. Fish. Mgmt. 10:175–184.

Beverton, R. J. H., and S. J. Holt. 1957. On the dynamics of exploited fish populations. U. K. Ministry of Agriculture and Fisheries, Fish. Invest. (Series 2), 533 pp.

Checkley, D. M., Jr., S. Raman, G. L. Maillet, and K. M. Mason. 1988. Winter storm effects on the spawning and larval drift of a pelagic fish. Nature 335:346–348.

Cook, B. A., and P. Copes. 1987. Optimal levels for Canada's Pacific halibut fishery. Mar. Res. Econ. 5:71–77.

Fiedler, P. C. 1984. Satellite observations of the 1982–1983 El Niño along the U.S. Pacific coast. Science 224:1251–1254.

Hjort, J. 1914. Fluctuations in the great fisheries of northern Europe viewed in light of biological research. Rapp. P.-V. Reun. Cons. Perm. Int. Explor. Mer 19:3–228.

Hogan, M., and H. M. Clarke. 1989. An ocean information network: a view from the commercial fisheries. International Symposium on Operational Fisheries Oceanography, St. Johns, Newfoundland.

Hollowed, A. B., and K. M. Bailey. 1989. New perspectives on the relationship between recruitment of Pacific hake (*Merluccius productus*) and the ocean environment. *In* Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models, R. J. Beamish and G. A. McFarlane, eds. Can. Spec. Publ. Fish. Aquat. Sci. 108:207–220.

Hunter, J. R. 1981. Feeding ecology and predation of marine fish larvae. *In* Marine fish larvae: morphology, ecology and relation to fisheries, R. Lasker, ed. Seattle: Univ. Wash. Press, pp. 34–77.

Jones, R., and E. W. Henderson. 1985. Population regulation and implications for the recruitment process in fish. Int. Council Explor. Sea, Demersal Fish Comm. CM 1985/G:21.

Kruse, G. H., and A. V. Tyler. 1989. Exploratory simulation of English sole recruitment mechanisms. Trans. Am. Fish. Soc. 118:101–118.

Laevastu, T., and N. Bax. 1989. Environment fish behavior interactions, numerical simulations and operational use (review of a dynamic system), International Symposium on Operational Fisheries Oceanography, St. Johns, Newfoundland.

Lasker, R. 1975. Field criteria for survival of anchovy larvae: the relation between inshore chlorophyll maximum layers and successful first feeding. Fish. Bull. U. S. 73:453–462.

Leggett, W. C. 1984. Fish migrations in coastal and estuarine environments: a call for new approaches to the study of an old problem. *In* Mechanisms of migration in fishes, J. D. McCleave, G. P. Arnold, J. J. Dodson, and W. H. Neill, eds. New York: Plenum Press, pp. 159–178.

MacCall, A. D. 1980. Population models for the northern anchovy (*Engraulis mordax*). Rapp. P.-V. Reun. Cons. Int. Explor. Mer 177: 292-306.

———. 1990. Dynamic geography of marine fish populations. Books in recruitment fisheries oceanography. Seattle: Univ. Wash. Press.

McGurk, M. D. 1986. Natural mortality of marine pelagic eggs and larvae: role of spatial patchiness. Mar. Ecol. Prog. Ser. 34:227–242.

Megrey, B. A., and V. G. Wespestad. 1990. Alaskan groundfish resources: 10 years of management under the Magnuson Fishery Conservation and Management Act. N. Am. J. Fish. Mgmt. 10:125–143.

Murdie, B., and M. P. Hassell. 1973. Food distribution, searching success, and predator-prey models. *In* The mathematical theory of the dynamics of biological populations, M. S. Bartlett and R. W. Hiorns, eds. London and New York: Academic Press, pp. 87–101.

Murphy, B. R., M. L. Brown, and T. A. Springer. 1990. Evaluation of the relative weight (W_r) index, with new applications to walleye. N. Am. J. Fish. Mgmt. 10:85–97.

Parrish, R. H., C. S. Nelson, and A. Bakun. 1981. Transport mechanisms and reproductive success of fishes in the California Current. Biol. Oceanogr. 1:175–203.

Parsons, T. R., M. Takahashi, and B. Hargrave. 1984. Biological oceanographic processes, 3rd ed. Oxford, England: Pergamon Press.

Pelaez, J., and J. A. McGowan. 1986. Phytoplankton pigment patterns in the California Current as determined by satellite. Limnol. Oceanogr. 31:927–950.

Reed, R. K., L. S. Incze, and J. D. Schumaker. 1989. Estimation of the effects of flow on dispersion of larval pollock, *Theragra chalcogramma*, in Shelikof Strait, Alaska. *In* Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models, R. J. Beamish and G. A. McFarlane, eds. Can. Spec. Publ. Fish. Aquat. Sci. 108:239–246.

Richer, W. E. 1954. Stock and recruitment. J. Fish. Res. Board Can. 11:559–623.

Rose, G. A., and W. C. Leggett. 1988. Atmosphere-ocean coupling and Atlantic cod migrations: effects of wind-forced variations in sea temperatures and currents on nearshore distributions and catch rates of *Gadus morhua*. Can. J. Fish. Aquat. Sci. 45:1234–1243.

Rothschild, B. J. 1986. Dynamics of marine fish populations. Cambridge: Harvard Univ. Press, 277 pp.

Simpson, J. J. 1987. Transport processes affecting the survival of pelagic fish stock in the California Current. Am. Fish. Soc. Symp. 2:39–60.

[1]Remote sensing in fisheries: a tool for better management in the utilization of a renewable resource. Can. J. Fish. Aquat. Sci. In revision.

———. 1992. Remote sensing and geographical information systems: their past, present and future use in global marine fisheries, Fish. Oceanogr. 1:3,238–280.

Stocker, M., and B. M. Leaman. 1990. Effects of extended jurisdiction on management and conservation of Canada's Pacific coast fisheries. N. Am. J. Fish. Mgmt. 10:144–153.

Svejkovsky, J. 1989. Fishfinding from space. Saltwater Sportsman 50:96–97f, 178–179.

Theilacker, G. H. 1986. Starvation-induced mortality of young sea-caught jack mackerel, *Trachurus symmetricus*, determined with historical and morphological methods. Fish. Bull. U. S. 84:1–17.

Tillman, M. F. 1968. Tentative recommendations for management of the coastal fishery of Pacific hake, based on a simulation study of the effects of fishing upon a virgin population. M. S. thesis, Univ. Wash., Seattle.

Tyler, A. V., and W. R. Crawford. 1991. Modelling recruitment patterns for Pacific cod in Hecate Strait, British Columbia. Can. J. Fish. Aquat. Sci. 48:2240–2249.

Tyler, A. V., and S. J. Westrheim. 1986. Effects of transport, temperature, and stock size on recruitment of Pacific cod (*Gadus macrocephalus*). Int. North Pac. Fish. Comm. Bull. 47:175–190.

Ushakov, N. G., and V. K. Ozhigin. 1987. The abundance of year classes of the Barents Sea capelin and peculiarities of the distribution of the young in relation to hydrographic conditions. *In* The effects of oceanographic conditions on distribution and population dynamics of commercial fish stocks in the Barents Sea, H. Loeng, ed. Inst. Mar. Res., Bergen, Norway, pp. 159–167.

Wooster, W. S., and K. M. Bailey. 1989. Recruitment of marine fisheries revisited. *In* Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models, R. J. Beamish and G. A. McFarlane, eds. Can. Spec. Publ. Fish. Aquat. Sci. 108:153–159.

Zhang, C. I., and D. R. Gunderson. 1990. Yield per recruit and management recommendations for Alaska plaice in the Eastern Bering Sea. N. Am. J. Fish. Mgmt. 10:1–9.