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Fisheries ecosystem studies off the Northeast Coast of the United States: summary of initial results[1]

by

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The fishery resources off the northeast coast of the United States support a fish-catching and processing industry contributing a billion dollars annually to the economy of the coastal states from Maine to North Carolina. These resources are now, under the terms of the recently passed Fisheries Management and Conservation Act[2], subject to management by the New England and Mid-Atlantic Regional Fisheries Management Councils. The Councils are required to develop management plans for the resources under their jurisdiction that ensure optimal sustained yields based on ecological, economic, and social considerations. Input for the ecological decisions are to be based on the "best scientific information available".

The best and most sought after scientific information from a fisheries management point of view is the accurate prediction of future stock sizes and the effects of different levels of fishing on the continued production of economically viable resource populations. This need has not changed since the early days of whaling, when the US Wilkes Expedition of 1838 was supported by Congress to improve our knowledge of Pacific whaling areas. Henry Bigelow was supported, in part, by Federal funds when in the 1920's he investigated the fish, plankton, and oceanography of the Gulf of Maine for the US Fish Commission with an end to improving the fishing industry. Subsequent studies on both sides of the Atlantic focused on the yields of single species, not from any lack of intellectual awareness of the interaction and inter-

[1] Extract from MARMAP Fisheries Ecosystem Study News, National Marine Fisheries Service, Northeast Fisheries Center, Narragansett Lab. Ref. 79-12, February 1979.

[2] Fisheries Conservation and Management Act of 1976, USA (FCMA) Public Law No. 94-265, 94th Congress H.R. 200, 13 April 1976.

dependence of species, but rather from the constraints of meager budgets provided to support fishery research organizations. Those days are passed. But the early orientation to single species assessments has not been easily shed. "Special" interests will continue to demand information on particular species, and we will need to continue providing single species estimates of abundance levels.

Under the FCMA some 2.2 million square miles of contiguous ocean water falls under the jurisdiction of the U. S. as a Fisheries Management Zone. At present only 150,000 square miles of the zone, most of which is off the northeast coast, is being systematically monitored for seasonal, areal, and annual changes in plankton, fish, benthos, and hydrography. There are no shortcuts to obtaining the comprehensive population and environmental information required to improve forecasts of fish abundance within the FMZ. A balanced approach is needed that allows for: (1) a time-series of observations in the form of routinized multispecies fish, plankton, benthos, and hydrographic monitoring surveys, (2) a systematic collection of fish-catch data, and (3) ancillary process oriented studies dealing with linkages among plankton production, benthos production, and the influence of the environment on the productivity of fish resources to ensure that the most critical spatial and temporal processes are, in fact, being monitored adequately for forecasting purposes. This kind of fisheries ecosystem program, called MARMAP for marine resources monitoring, assessment and prediction, is conducted by the National Marine Fishery Service on the continental shelf from the Gulf of Maine to Cape Hatteras. During the past decade this region of the continental shelf including the Gulf of Maine, Georges Bank, Southern New England, and the Mid-Atlantic Bight has been subjected to extreme fishing pressure. From 1968 to 1975 the biomass of the principal fish species declined approximately 50% (Fig. 1); much of the decrease in biomass correlates with increased fishing effort, indicating an overfishing condition (Clark and Brown, 1977). Environmental conditions, coastal pollution, inter- and intra-specific competition may also have contributed to the decline, but no quantitative estimate of this mortalit- is now available.

The full impact of the removal of several million metric tons of predators from the continental shelf ecosystem is now known. Significant questions remain unanswered. Does the reduction in the stocks of

important predator species - - herring, mackerel, cod, haddock, hake, and others - - release secondary production to be consumed by short-lived, fast growing, smaller, less desirable species? What are the probabilities associated with the return of over-exploited species to former abundance levels? Studies are now underway by the Northeast Fisheries Center (NEFC) to address these questions. They focus on the critical linkages among the principal food species of fish and the recruitment, survival, and productivity of the fish stocks on the continental shelf from the Gulf of Maine to Cape Hatteras.

Multispecies Assessments

Studies of single species alone do not provide the kind of assessment information required for effective management of multispecies fisheries operating at different trophic levels. While it is important to continue these studies, they are now being pursued within a broader matrix that measures interactions in changing abundances among the species in the ecosystem. Single-species yield models have recently been augmented with multispecies models that are ecologically sensitive (Regier and Henderson, 1973; Parrish, 1975; Laevastu, et al. 1976; Anderson and Ursin, 1977). These models deal with multispecies fishery interactions at different trophic levels. They are important approximations of the consequences of predator-prey dynamics based on fishery imposed selective mortality, and hold promise for providing a basis for the management of marine ecosystems. If ecosystem models are to assume an appropriate role in the management of marine resources, it will be necessary to overcome present deficiencies in: (1) understanding relationships between stock-size and recruitment, (2) identifying the linkages between primary, secondary, and fish production; and (3) quantifying predator-prey dynamics.

Predator-Prey Interactions

Predator-prey interactions are complex. They reflect a series of interrelationships that can change significantly the abundance of important fish stocks. A schematic representation of the predator-prey interactions for eight of the more abundant species of fish and squid off the northeast coast of the U. S. is given in Figure 2. It is presented as a qualitative example of the complexity of the known interactions between fish and their prey. In addition, the significant changes in the size of prey con-

sumed as a fish moves through larval, juvenile, and adult stages of development compound the difficulty in sorting out predator-prey relationships. The feeding habits of codfish illustrate the problem. Codfish larvae feed principally on microzooplanktonic copepods, crustacean eggs, pteropods, and larvae of meroplankton. As juveniles they feed on macrozooplankton including euphausids and amphipods, and as adults, fish become a principal food (Figure 3).

In stressed marine ecosystems it has recently been suggested that shifts in the abundances of predators can lead to significant changes in the species composition and size structure of the prey populations (Steele and Frost, 1977). The degree to which species shifts in abundance can result in changes to fish production of the continental shelf ecosystem is now the subject of an expanded research effort by the Northeast Fisheries Center. For example, it appears that the predatory consumption levels of a single species, the silver hake, is sufficient to consume 30% of all fish produced on the continental shelf of the northeast coast (Edwards and Bowman, 1978). Aspects of this research, including recent evidence of changes in abundance among ichthyoplankton and zooplankton species is given in the present report.

MARMAP Surveys

With the exception of relatively small groups of fishery scientists in the United States and elsewhere, particularly in Western Europe, society has not yet come to grips with the magnitude of the effort confronting the scientific community in its attempt to provide information on resource populations that can support management options within the fisheries management zones on both sides of the Atlantic. Fishery science is undergoing major changes in the approach to improving assessment of the abundance levels and forecasting potential yields of fish stocks inhabiting these zones. The new approach represents a balance between the more traditional studies of biological and physical processes as they relate to productivity of coastal waters and coastal populations, and the requirement for committing ships and personnel to fisheries-independent time-series surveys of annual changes in the productivity levels of plankton, fish, and benthos populations. Time-series surveys are dull, routinized, but absolutely necessary for measuring population, environmental, and pollution changes over time and space and sorting out

the causes of these changes with respect to fishing mortality, natural mortality, or mortality caused from the increasing introduction of pollutants into the continental shelf ecosystem. In addition to the surveys, carefully controlled ecosystem experiments are now being conducted in very large enclosures containing the smaller population components of the pelagic ecosystem. The best example of this effort is in the Controlled Ecosystem Experiments sponsored by the National Science Foundation. The CEPEX operation is conducted as a multidisciplinary study of the interactions of primary and secondary and tertiary trophic levels of a northwest temperate deep-water embayment in British Columbia under the effects of physical-chemical changes. Findings of this study will have application to our investigations of fishery ecosystems by providing more insight to the critical functions that need to be measured on the time-series surveys. Other technical advances in hydroacoustics, remote sensing, and electronic data processing when applied to the time-series approach will undoubtedly contribute singificantly to increased efficiencies and reduced costs of the MARMAP surveys.

In 1971 a systematic macroscale sampling of zooplankton and ichthyoplankton was initiated by the Northeast Fisheries Center, NMFS, in the Gulf of Maine, Georges Bank, Southern New England, and Mid-Atlantic Bight during bottom trawl surveys in autumn and spring. In 1976 the zooplankton-ichthyoplankton surveys were expanded to bimonthly coverage of the areas to examine the zooplankton-fish linkages including: (1) changes in the distributions, abundance, and growth of juvenile and adult fish, and (2) larval fish growth and mortality in relation to their planktonic prey and predators. MARMAP surveys are conducted systematically at stations selected from a stratified random design for fish, shellfish, benthos, phytoplankton, ichthyoplankton, and zooplankton. Bottom trawl surveys for fish are conducted in spring and autumn, and since 1977, in summer. Two shellfish surveys are made annually. Benthic sampling is limited, contingent on the analyses of 25 years of collections now being completed at the Woods Hole Laboratory of NEFC. Surveys of zooplankton-ichthyoplankton, phytoplankton, primary productivity, and hydrography are conducted on a bimonthly basis for a total of six surveys per year. The survey data is augmented with a comprehensive system for obtaining catch data at each of the major fishing ports from Cape Hatteras

to the Gulf of Maine. As required, special surveys are conducted to deal with specific problems (e.g. tagging, feeding, current meter deployment and retrieval, vertical distribution studies of ichthyoplankton, samplings for sharks and other large predators). Mesoscale studies of larval mortality have been done jointly with other countries for larval herring. Within the MARMAP survey matrix, microscale "patch studies" are conducted to study factors controlling larval survival from examination of larval predator-prey relationships within the water column. The area under investigation is extensive, requiring a heavy logistic commitment. The MARMAP studies are being conducted jointly with scientists and ships of the Federal Republic of Germany, German Democratic Republic, Poland, and the USSR.

II. Summary of Initial Results

Recognizing the broad scope of the problem at hand, much of our effort has been focused on those aspects of the problem for which we have significant data. We are directing considerable effort to testing the long-standing hypothesis that year-class success is determined during the first year of life between the hatching of larvae and their survival to the juvenile stage. An understanding of the biological and physical system controlling larval survival will allow for significant improvements of long-term forecasts in fish-stock abundance. This is one of our most important "process-oriented" studies. It is being conducted within the broader matrix of the MARMAP Program of the Center. Several documents have been prepared describing the results of this effort including advances in the modelling of larval fish survival recently completed by J. E. Beyer and G. C. Laurence (1978), and a brief description of a recently-completed multiship international "patch study", with larval herring as a target species prepared by G. Lough and submitted to ICNAF as Research Document 79/VI/116, Serial No. 5481.

We now have a reasonable level of ongoing MARMAP surveys (6x/yr) to provide basic plankton, fish, and environmental information for the area of the continental shelf extending from the Gulf of Maine to Cape Hatteras. Attempts are made to conduct at least four of these surveys (one each month) during spring in the Georges Bank-Southern New England areas when key species such as haddock, cod, yellowtail flounder, and mackerel are spawning, to monitor egg and larval production and observe major changes in larval growth

and mortality. Our research approach describing the utility of long-term monitoring surveys conducted in the MARMAP mode, and finer scale studies of important processes (e.g. recruitment, phytoplankton production, and predator-prey studies among principal fish and invertebrate species off the northeast coast) has been described in a number of key documents prepared by the staff during the past year. A listing of titles is found in the Appendix to this paper. We will be happy to send copies of these papers; just call or drop us a postcard listing the paper(s) of interest.

Development of Ecosystem Models

Prior to developing an ecosystem model, the first task was to organize the available data on the ecosystem off the northeast coast into a systematic framework.

To get on with this job, we first prepared an energy budget for Georges Bank. This was followed with critical reviews of the Laevastu-Favorite, Parrish, and Anderson-Ursin models of marine ecosystems.

In our view modelling is an essential tool for developing an understanding of how a marine ecosystem works, but the model itself should not become the principal goal in ecosystem studies. Further, no one model will answer all questions, nor will it be universally applicable to all ecosystems or suitable for all data bases. However there are certain basic similarities in all marine ecosystems and there are significant benefits to be derived from sharing ideas about basic processes and ways of measuring and simulating them.

During December a workshop on multispecies modelling was convened by Bill Bossert at Harvard University, sponsored by Harvard and the Northeast Regional Council. The models of Anderson-Ursin, and Laevastu-Favorite were discussed with respect to their potential as management tools. The workshop participants concluded that multispecies models could play an important role in fisheries management, but that neither of the models discussed was fully satisfactory for management purposes in their present mode. However, each model provided useful elements that will be seriously considered by the participants in the development of multispecies fishery models for use in the Northwest Atlantic.

An outline of the development of our multispecies model of fish production has been submitted to ICNAF as Research Document 79/VI/115, Serial No. 5480.

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Langton, W., and R. E. Bowman. 1977. An abridged account of predator-prey interactions for some Northwest Atlantic species of fish and squid. Northeast Fisheries Center, Woods Hole, Laboratory Reference Report No. 77-17.

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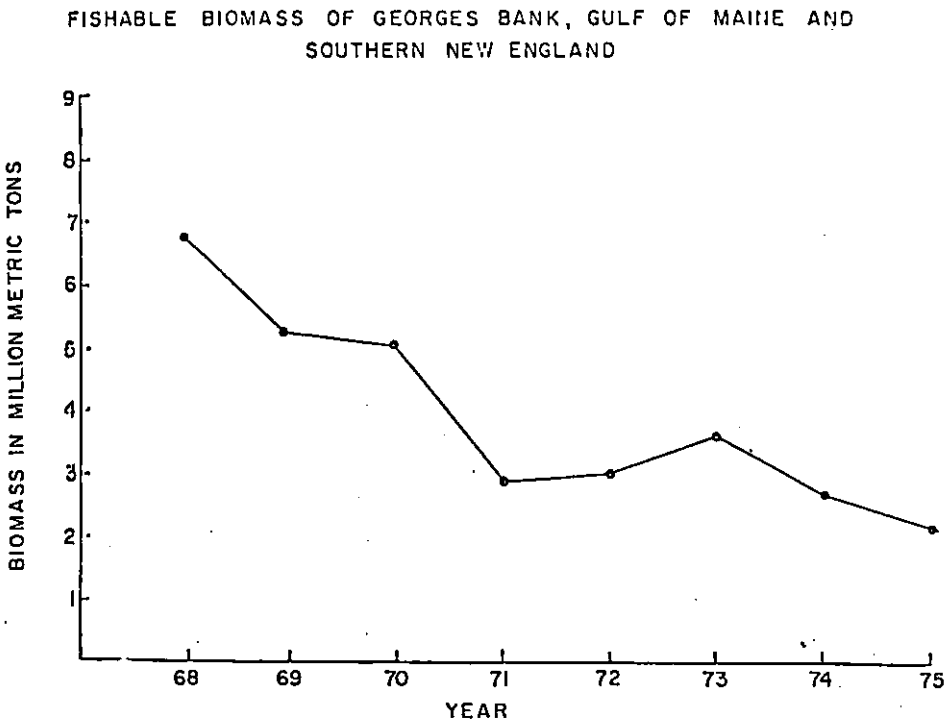

Fig. 1. Decline in the fishable biomass of Georges Bank, Gulf of Maine, and Southern New England, 1968-1975. Between 1968-1969 and 1974-1974, the biomass decreased 65%. Adapted from Clark and Brown (1977).

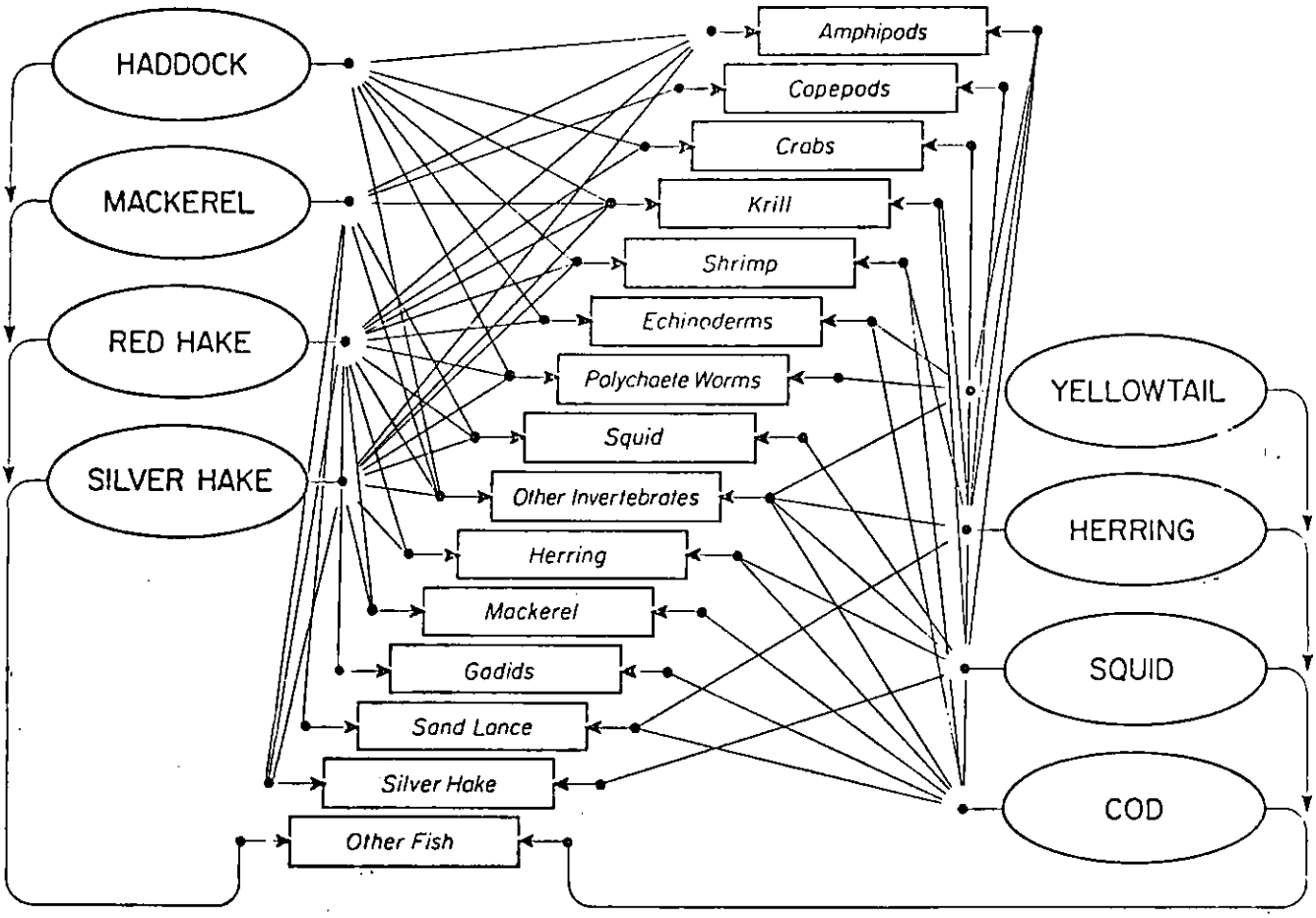

Fig. 2. Schematic presentation of predator-prey interactions for the more important species of fish and squid off the northeast coast of the USA. Predator names are enclosed in ovals; prey are shown in rectangles. From Langton and Bowman (1977).

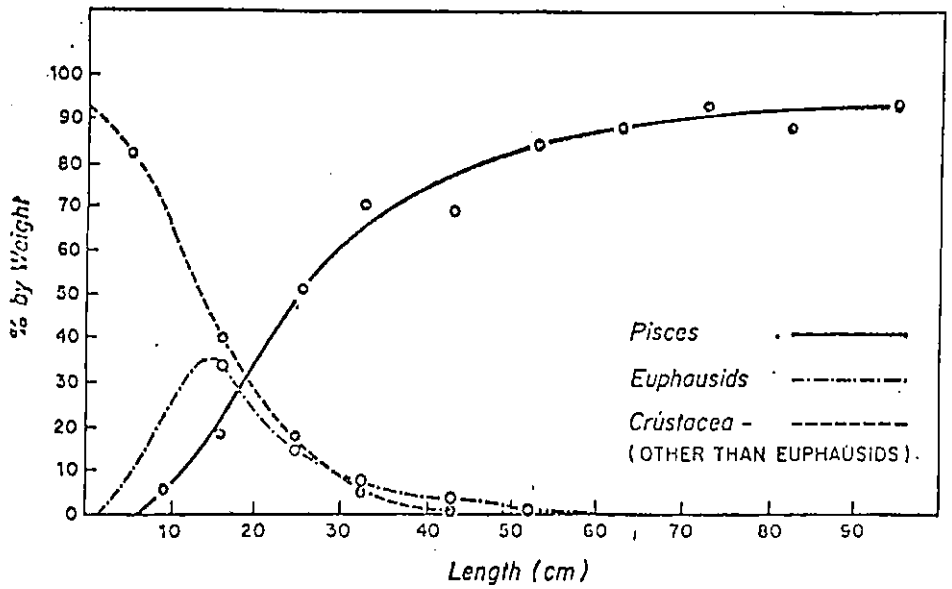

Fig. 3. Change in the composition of the prey of cod in the eastern Atlantic. From Edwards (1976).

APPENDIX

Listing of Pertinent MARMAP Reports, 1977-1979

Larval Fish Physiology, Apex Predators, and Plankton Ecology Investigations
Papers, Reports, Etc. 1977, 1978, and 1979

Buckley, L. 1977. Biochemical changes during ontogenesis of the winter flounder (Pseudopleuronectes americanus) and the effect of starvation. ICES C.M.1977/L:29.

Casey, J. 1977. The occurrence of large sharks off northeastern U. S.; results of monitoring an annual shark fishing tournament at Bay Shore, New York 1965-1977. ICES C.M.1977/H:42.

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Colton, J. B., Jr., and R. Byron. 1977. Gulf of Maine-Georges Bank ichthyoplankton collected on ICNAF larval herring surveys, September 1971-February 1975. NOAA Tech. Rep. NMFS SSRF-717. 35 p.

Colton, J. B., Jr., J. R. Green, R. R. Byron, and J. L. Frisella. 1977. Comparison of Bongo Net Retention Rates. NMFS, NEFC, Narragansett, RI, Lab. Ref. No. 77-11.

Green, J., J. B. Colton, Jr., and D. Bearse. 1977. Preliminary estimates of secondary production on Georges Bank. ICES C.M.1977/L:30.

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Beyer, J. and G. C. Laurence. 1978. A stochastic model of larval fish growth. ICES C.M.1978/L:28, Biological Oceanography Comm.

Buckley, L. 1978. Nitrogen utilization by larval summer flounder (Paralichthys dentatus). Fish. Bull., U. S. (In preparation).

Buckley, L. 1978. Relationship between RNA-DNA ratio, prey density and growth rate in cod (Gadus morhua L.) larvae. Fish Res. Board Can. (Submitted)

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Casey, J. 1978. Newsletter of the Cooperative Shark Tagging Program. NMFS, NEFC Narragansett, RI Lab. Ref. No. 78-03.

Casey, J. F. Mather, III, J. Mason, and J. Hoenig. 1978. Offshore fisheries of the Middle Atlantic Bight. pp. 107-129. In: Proceedings of the Second Annual Marine Recreation Fisheries Symposium, Norfolk, VA, March 29-30, 1978. Marine Recreational Fisheries 3, IGFA, NCMC, SFI, Wash., D. C.

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List of presentations at scientific meetings and publications during 1977 and 1978 Ichthyoplankton Investigation

In response to your recent request, I am submitting the following list of publications and scientific presentations by members of this investigation:

Papers at Scientific Meetings

Kendall, A. 1977. Annual Meeting of Ichthyologists and Herpetologists, Gainesville, Florida. Paper: "Relationships among American serranids".

Fahay, M. P. 1978. Annual Meeting of Ichthyologists and Herpetologists, Tempe. Arizona. Paper: "Distinguishing the postlarvae of two sympatric species of Merluccius in the western North Atlantic".

Publications

1977

Berrien, P., and D. Finan. 1977. Biological and fisheries data on king mackerel, Scomberomorus cavalla (Cuvier). NEFC, Sandy Hook Laboratory, Technical Series Rept. No. 8: 40 p.

Berrien, P., and D. Finan. 1977. Biological and fisheries data on Spanish mackerel, Scomberomorus maculatus (Mitchill). NEFC, Sandy Hook Laboratory, Technical Series Rept. 9: 52 p.

Kendall, A. W. 1977. Biological and fisheries data on black sea bass, Centropristis striata (Linnaeus). NEFC, Sandy Hook Laboratory, Technical Series Rept. No. 7: 29 p.

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