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An Analysis and Evaluation of Ichthyoplankton Survey Data from the Northeast Continental Shelf Ecosystem

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Center
Woods Hole, Massachusetts

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An Analysis and Evaluation of Ichthyoplankton Survey Data from the Northeast Continental Shelf Ecosystem

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EXECUTIVE SUMMARY

The Northeast Fisheries Center has conducted standardized ichthyoplankton surveys of the Northeast Continental Shelf ecosystem for about a decade. This report describes an evaluation of the surveys to determine their usefulness, the uniqueness of the information they provide, and the relationship between the quality of results and the survey effort.

Broadscale, long-term, fishery-independent surveys are needed to monitor large marine ecosystems. The abundance, distribution, and species composition of the finfish community are very dynamic. Changes in the finfish community may be caused by fluctuations in the natural environment and pollution, or they may be biologically regulated (e.g., predation, including fishing). Ichthyoplankton surveys are a useful means of monitoring these changes. Since environmental variables and indices of production at lower trophic levels are monitored simultaneously, these surveys help to distinguish between the potential causes of population change.

Ichthyoplankton surveys sample virtually all of the finfish (exceptions are sharks and skates) that spawn on the continental shelf. Lists of the dominant species collected during ichthyoplankton surveys are compared to analogous lists from trawl surveys. These lists are uncorrelated, which implies that the two sources of information are complementary. Several species of economic (e.g., Atlantic herring, *Clupea harengus*, and Atlantic mackerel, *Scomber scombrus*) and ecological (e.g., sand eel, *Ammodytes* spp., and Gulf Stream flounder, *Citharichthys arctifrons*) importance are better represented in ichthyoplankton surveys than trawl surveys.

In order to use ichthyoplankton abundance to estimate spawning biomass, several biological parameters must be estimated. These include larval growth rate and an annual mortality rate per unit time. But, an index which is proportional to spawning biomass can be calculated using an estimate of mortality rate per unit length pooled over several years. The index can be calculated for most of the species collected during ichthyoplankton surveys. The index is given for haddock (*Melanogrammus aeglefinus*), Atlantic herring, Atlantic cod (*Gadus morhua*), silver hake (*Merluccius bilinearis*), hakes of the genus *Urophycis*, and anchovies (Engraulidae). The pooled mortality rates per unit length are given for 15 additional species.

Ichthyoplankton data are used to estimate total finfish biomass. Total finfish biomass estimates are ecologically important in order to quantify total energy flow which relates to the role predation and competition play in regulating recruitment and multispecies production potential. A time series of total finfish biomass estimates will allow testing of the hypothesis that fishing affects species composition, but that total biomass is relatively robust to exploitation. Methods of estimating total biomass from trawl surveys are reasonably good for the principal demersal species, but they are suspect for pelagics and lightly exploited species.

Ichthyoplankton estimates of total finfish spawning biomass are based on a model that assumes that: (a) the number of eggs spawned is proportional to biomass of mature fish; (b) egg development time is a function of temperature; (c) egg mortality rate is 10% per day (the results are robust to this assumption); and (d) samples of egg abundance can be treated as random in time and space. A simple cohort model is developed in order to estimate the ratio of spawning biomass to immature biomass. Biomass estimates for species that do not have pelagic eggs or larvae (e.g., sharks, skates) are based on trawl surveys.

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Total finfish biomass estimates from ichthyoplankton surveys are compared with bottom trawl survey estimates. The former are consistently higher (up to a factor of two) and are generally more stable over the short time series (1979-1984) available for comparison. The recent ichthyoplankton estimates are comparable to estimates from bottom trawl surveys that applied about two decades ago. One interpretation of these results is that total finfish biomass is relatively stable although species composition is highly variable.

The most important control variables that determine the quality of ichthyoplankton survey data are: (1) the sample size within surveys, and (2) the frequency of surveys. In order to examine the importance of sample size, plots of the log of variance versus log of the mean were prepared for 20 species. The plots are well described by a linear relationship with slope of approximately two for all species. This means that the coefficient of variation (cv) is independent of the mean. For a sample size of 50 per subarea, which is typical of the current sample size, the cv ranged from 33.2% to 54.6% with a mean of 40.7% for the 20 species. If sample size were doubled, the average cv would decrease to 28.8%; if it were halved, the cv would increase to 57.6%.

A Monte Carlo simulation model is used to examine the combined effect of sample size within surveys and survey frequency on the accuracy and precision of spawning biomass estimates. The importance of biological parameters (e.g., growth rate, duration of spawning season) and various assumptions (e.g., constant mortality rate, normally distributed spawning probability function) are also examined.

The model simulates spawning, egg and larval growth, and mortality, sampling of larvae, and the calculations that are made to estimate spawning biomass. Several components of the model incorporate realistic random effects (e.g., timing of surveys, sampling error, random variations in mortality, and growth rates) which led to uncertainty in simulated estimates of spawning biomass. By repeating the simulations numerous times and comparing the simulated spawning biomass to the simulated estimates of spawning biomass, accuracy and precision are assessed.

The model was applied to three representative species: haddock which is a spring spawner, silver hake which is a summer spawner, and sand eel which spawns in winter and has an extended larval period.

The results indicate that spawning biomass estimates are about equally sensitive to sample size within surveys and frequency of surveys. Both are minimally adequate. Spawning biomass estimates are generally unbiased, but their cv's are over 100%. This means that only changes in spawning biomass of greater than a factor of two can be detected from a single year's data; i.e., there is about a one-third probability that a factor-of-two difference is due to estimation error. The implication is that spawning biomass estimates are most useful for monitoring trends in abundance which persist over several years.

The simulation shows the relative importance of certain biological parameters and assumptions of the method. For example, the duration of the spawning season is a more important parameter than the duration of the larval period. The simulation model is a powerful tool. It will continue to be used to improve estimates derived from ichthyoplankton data.

Planktonic egg surveys and bottom trawl surveys both provide unique and valuable measures of abundance and composition of fishery resources. Egg surveys can provide estimates of absolute abundance of adults; trawl surveys produce relative measures of abundance. The final paper in the set uses egg data for yellowtail flounder to illustrate a tech-

nique for estimating a proportionality constant that can be used to convert trawl survey indices from relative to absolute measures of abundance. If we can demonstrate from several years of trawl and egg surveys that the proportionality constants are consistent over time, the mean coefficient can be used for calculating changes in absolute abundance for NEFC's entire trawl survey time series.

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INTRODUCTION

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The Northeast Fisheries Center (NEFC) conducts plankton surveys of the northeast continental shelf, between Cape Hatteras and Nova Scotia, approximately 6-8 times per year. A standard survey design and method have been used since 1977. These are described in detail by Sibunka and Silverman (1984) and outlined in this volume by Smith and Goulet. During the autumn of 1985, the Fisheries Ecology Division initiated a rigorous quantitative analysis of the ichthyoplankton data collected during these surveys. The goals of the analysis were: (a) to examine the usefulness of ichthyoplankton survey data as a fishing independent measure of resource abundance, (b) determine to what extent the data provides unique information, and (c) determine the relationship between the quality of survey results (i.e., accuracy and precision of spawning biomass estimates) and level of survey effort (i.e., sample size within surveys and survey frequency). The results of these analyses are reported herein.

In order to meet the objective of the study, a multifaceted approach was applied. The facets are described in individual papers in this document. The first paper in the set establishes the need for a fishery-independent means of surveying large marine ecosystems. It outlines the strategy in place in NEFC for monitoring the finfishes as well as the biological and physical variables that almost certainly influence abundance, distribution, and species composition of the finfish community off the northeastern United States.

The next paper reviews NEFC's ichthyoplankton sampling methods and how survey data are processed. This short paper is followed by a comparison of catches from ichthyoplankton and trawl surveys, two alternative fisheries-independent methods used by the NEFC to measure long-term shifts within the finfish community and short-term changes and abundance levels of economically/ecologically important species. Since no single method monitors all species with uniform accuracy and precision, it is important to know if the two survey methods provide complementary or redundant information.

Ichthyoplankton survey data are used to estimate spawning biomass which requires an estimate of mortality rate. For many species larval mortality rate per unit time cannot be estimated annually. The next paper introduces an index of abundance that is appropriate for these species. It uses a pooled (over several years) estimate of mortality per unit length which can be derived for most species.

One of the most important reasons for monitoring the biomass of the entire finfish community is to determine how variable it is relative to individual species. There are ecological reasons to hypothesize that total biomass is more stable. The hypothesis has important fisheries management implications. The fifth paper introduces a new method for estimating total finfish biomass based primarily on egg abundance.

Of course, one of the major controllable (i.e., set by the survey design) variables that determines the precision of ichthyoplankton survey data is sample size. The sixth

paper examines the relationship for the twenty most abundant species of larvae. The other important control variable is the frequency of surveys. The following paper describes a simulation model that was designed to evaluate the sensitivity of back-calculations of spawning biomass from larval abundance to: (a) sample size within surveys, (b) survey frequency, (c) several biological characteristics of the fish populations, and (d) certain assumptions of the method. The simulation model is a powerful tool that will continue to be used to refine survey design and estimation procedures.

For many species of marine fishes, surveys of spawning products provide the only fishery independent means to estimate the absolute abundance of adults. The final paper illustrates a procedure for converting trawl survey indices from relative to absolute measures of abundance by using egg survey data to estimate a proportionality constant relating the trawl survey index and the actual abundance of fish.

ICHTHYOPLANKTON SURVEYS: A STRATEGY FOR MONITORING FISHERIES CHANGE IN A LARGE MARINE ECOSYSTEM

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Large marine ecosystems are extensive areas of the globe, encompassing approximately 200,000 km^2, or more, within the Exclusive Economic Zones of coastal nations in which biological communities have evolved together in response to unique bathymetry, hydrography, and circulation (Sherman and Alexander, 1986). The biomass of fish stocks inhabiting large marine ecosystems (LME's) in the North Atlantic have been altered significantly, particularly since the 1960's, resulting in negative economic impact to fishing interests on both sides of the Atlantic. The fluctuations in fish biomass within LME's have been of sufficient magnitude to result in species "flips" from positions of dominance to subordinate positions, in less than a decade, within several ecosystems around the rim of the Atlantic Ocean. A biomass flip occurs when the population of a dominant species rapidly drops to a very low level and is replaced by another species. In the North Sea ecosystem, where Atlantic herring (*Clupea harengus*) was a major component of the fisheries yield, the catch fluctuated between 600,000-800,000 metric tons (mt) from the 1920's through the early 1960's. Atlantic herring catches reached a peak of one million tons in 1965 followed by a biomass flip to a subordinate position in the North Sea ecosystem between 1965 and 1970. Catches in 1975 were less than 50,000 mt, and the North Sea herring fishery was closed in 1977. It took 5 years (until 1982) for the stock to rebuild to a level where a small quota could be allowed. A similar decline occurred in Atlantic mackerel (*Scomber scombrus*). By 1980, the catch of Atlantic herring and Atlantic mackerel contributed only a fraction of their long-term average yield. During the period of pelagic decline, the biomass of bottom fish flipped upward, including haddock (*Melanogrammus aeglefinus*) and Atlantic cod (*Gadus morhua*), along with the catch of small, fast-growing industrial fish such as sand eel (*Ammodytes* spp.), Norway pout (*Trisopterus esmarkii*), and sprat (*Clupea sprattus*) (Fig. 1).

Off the northeast coast of the United States, a similar biomass flip has been observed. Between the mid 1960's and 1970's, the biomass of the fishable stocks of cod, haddock, flounders, Atlantic herring, and mackerel all declined by just over 50%, from a level of approximately 8 million metric tons (mmt) to less than 4 mmt (Fig. 2). During this period, the population of sand eel exploded from less than a few hundred thousand tons to over 1 mmt, constituting a large-scale biomass flip in the Northwest Atlantic. The spawning stock biomass for Atlantic herring on Georges Bank reached a peak of approximately 1.2 mmt in 1967 and plummeted over the next 10 years to a complete collapse of the commercial fishery in 1977. During the years 1972 to 1981 surveys of ichthyoplankton on Georges Bank revealed a decline from $2{,}000 \times 10^9$ Atlantic herring larvae to fewer than 5×10^9 Atlantic herring larvae on the Bank.

Sand eel, Atlantic herring, and Atlantic mackerel inhabit, at least for part of the year, the same areas on Georges Bank and the Southern New England continental shelf. Evidence of Atlantic herring predation on sand eel and mackerel predation on the early developmental stages of both Atlantic herring and sand eel has been observed within the Northeast Continental Shelf ecosystem (Maurer, 1976). It is hypothesized that, in the ab-

sence of any prolonged environmental change, the decline in both Atlantic herring and Atlantic mackerel stocks during the mid 1970's released predation pressure on sand eel and allowed the population to explode (Sherman et al., 1981). Fishing mortality has been reduced on Atlantic herring and Atlantic mackerel stocks since the mid 1970's. No fishery exists for sand eel. It appears that the reduction of fishing mortality on Atlantic mackerel and Atlantic herring has allowed the stocks to begin a recovery trend. Atlantic mackerel has increased to approximately 1.2 mmt based on recent estimates (Anderson, 1985). Significant numbers of herring from the 1983 year class have appeared in trawl surveys and commercial catches on Georges Bank in 1987 (M. Fogarty, personnel communication) suggesting the possibility that some level of spawning stock recovery may be imminent on the Bank.

In these examples of biomass flips, commercially valuable species (e.g., Atlantic herring, Atlantic mackerel) appear to have been replaced for a period of several years by species of lesser economic value (e.g., sand eel). At present, it appears that following the reduction of fishing effort by foreign vessels in the mid 1970's, the fishing power of the U.S. fleet operating within the Northeast Continental Shelf ecosystem has grown to the level sufficient to depress spawning potential below the level necessary for populations to replenish themselves through recruitment (Sissenwine and Sheperd, 1987). Conversely, through prudent management and conservation it is possible to allow for the recovery of heavily exploited populations to levels that will support a sustainable yield. To provide a scientific basis for measuring changes in species abundance levels and the design of rational conservation strategies, the Northeast Fisheries Center conducts systematic surveys of fish stocks and their environments over the entire 260,000 km^2 of the Northeast Continental Shelf ecosystem from the Gulf of Maine to Cape Hatteras. Since 1963 bottom trawl surveys have been conducted in spring and autumn, and since 1977 surveys of fish eggs and larvae (ichthyoplankton) have been made at approximately bimonthly intervals. The ichthyoplankton provides an independent measure of spawning biomass of important pelagic and demersal fish populations. The survey effort is part of the NMFS Marine Resource Monitoring, Assessment, and Prediction (MARMAP) program.

The MARMAP ichthyoplankton surveys of the NEFC are designed to measure long-term (decadal) trends in species abundance, including recovery of depleted stocks, and estimate short-term changes in the abundance levels of the spawning biomass of important species for which other reliable abundance indices are unavailable, are questionable, or are incomplete (e.g., silver hake, *Merluccius bilinearis*; sand eel; Atlantic herring; Atlantic mackerel; and yellowtail flounder, *Limanda ferruginea*, in some areas). Estimates of the status of biomass of these fish stocks are especially important if NMFS is to provide the best scientific information available, setting appropriate limits on fishing within the Northeast Shelf Ecosystem.

Ichthyoplankton surveys provide information on the entire finfish biomass, except for a few species which do not have pelagic eggs or larvae. Preliminary analysis suggests that the total finfish biomass may be significantly higher than presently estimated from commercial catch and bottom trawl survey data. One of the papers in this volume (Berrien and Sissenwine) estimates a biomass of about 7.3 mmt which could probably sustain a yield double the present level, but only if the catch consists of a greater number of species than are presently utilized. Ichthyoplankton survey results suggest that species that are relatively abundant such as sand eel, searobins, *Prionotus* spp.; bay anchovy, *Anchoa mitchilli*; flatfishes, including smallmouth flounders, *Etropus microstomus*; and Gulf Stream flounder, *Citharichthys arctifrons*, represent the potential for supporting expanding fisheries for commutated or minced seafood products. The surveys also provide information on changes in spawning times and places. They are an important means for: (1) measuring present

trends and forecasting future trends in species abundance, independent of the catchability biases of the bottom trawl survey for pelagic species, and (2) providing information on yield statistics with fisheries-independent estimates of abundance. This advantage has been recognized widely and has led to the use of ichthyoplankton surveys as means of estimating mackerel abundance on the northeast shelf (Berrien et al., 1981), Atlantic herring and Atlantic mackerel abundance in the North Sea, the entire multispecies fish community of the Norwegian Sea and of selected species, in other large marine ecosystems, including estimates of sardine and anchovy in the California Current ecosystem, the Oyashio and Kuroshio Current ecosystems, the Benguela Current ecosystem, the Humboldt Current ecosystem, and the Iberian Coastal ecosystem (Sherman and Alexander, in press).

Data resulting from the surveys are used to measure variability of the ichthyoplankton prey field, primary productivity, secondary productivity, and hydrography of the Northeast Shelf ecosystem. These measurements are useful for providing cause and effect information on the anthropogenically, or naturally-induced, biomass flips that have occurred within the ecosystem in the past and are likely to occur in the future. The surveys, in addition to providing information on the status of fishery resources, are also used to monitor the state of natural productivity of the Northeast Shelf ecosystem. This information is relevant to studies of global ocean flux conducted by NSF, NASA, and NOAA (McCarthy et al., 1986) in relation to possible impacts on the fisheries of global heating that may result from ozone depletion (Cicerone, 1987) and the greenhouse effect (NAS, 1979).

Based on our analyses of the NEFC plankton time-series data, we have concluded that the natural environmental variability of the Northeast Shelf ecosystem is less than in the California Current upwelling ecosystem where interannual levels of primary productivity and zooplankton levels (Colebrook, 1977; Smith and Richardson, 1977) can vary two to three-fold, and where the temperature signal has shown a marked change over the past two decades (MacCall, 1986). Large-scale environmental signals, particularly those associated with temperature changes, can also be significant causes of changes in species dominance for continental shelf areas at the northern boundaries of distributions of both pelagic and demersal species, including the Arcto-Norwegian cod of the Barents and Norwegian Seas (ICES, 1987) and the North Icelandic herring (Jakobsson, 1980). No evidence of changes in long-term trends in zooplankton biomass of the northeast shelf ecosystem or species composition has, as yet, been detected (Sherman et al., 1983) although changes have been detected in the zooplankton field of the Northeast Atlantic based on analyses of long time-series of continuous plankton recorder sampling of the region (Colebrook, 1972, 1978).

The NEFC ichthyoplankton surveys measure bioenvironmental changes that could have a primary influence on recruitment success. Of particular concern are the fish species that have evolved a gyre-related spawning strategy at their southern limit of distribution, including cod and haddock on Georges Bank (Sherman et al., 1984). From the studies of Laurence and Lough (1984), we have concluded that "on the average" prey densities do not limit survival of cod and haddock larvae on Georges Bank. It is important, however, to maintain a monitoring program of prey availability and abundance since oceanographic phenomena and anomalies may effect the concentration of prey or effect fish eggs and larvae directly. Therefore, we have designed the NEFC mesoscale MARMAP surveys to monitor large-scale events dealing with: 1) primary production--by monitoring the phytoplankton field with underway fluorometry, 2) secondary production--by monitoring the zooplankton field as sampled simultaneously with ichthyoplankton, and 3) the hydrographic field--by monitoring water column stability, water mass variability.

LITERATURE CITED

Anderson, E. D. 1985. Status of the Northwest Atlantic mackerel stock--1984. Nat. Mar. Fish. Serv., Northeast Fish. Ctr., Woods Hole Lab. Ref. Doc. No. 85-03. 46 pp.

Berrien, P. L., N. A. Naplin, and M. R. Pennington. 1981. Atlantic mackerel, *Scomber scombrus*, egg production and spawning population estimates for 1977 in the Gulf of Maine, Georges Bank, and Middle Atlantic Bight. Rapp. P.-v. Reun. Cons. int. Explor. Mer 178:279-288.

Berrien, P., and M. Sissenwine. This volume. Total finfish biomass in shelf waters off the northeastern United States, 1979-1984, based on fish egg abundances in plankton.

Cicerone, R. J. 1987. Changes in stratospheric ozone. Science 237:35-42.

Clark, S. H., and B. E. Brown. 1977. Changes of biomass of finfishes and squids from the Gulf of Maine to Cape Hatteras, 1963-74, as determined from research vessel survey data. Fish. Bull., U.S. 75:1-21.

Colebrook, J. M. 1972. Changes in the distribution and abundance of zooplankton in the North Sea 1948-1969. Symp. Zool. Soc. London 29:203-212.

Colebrook, J. M. 1977. Annual fluctuations in biomass of taxonomic groups of zooplankton in the California Current, 1955-59. Fish. Bull., U.S. 75:357-368.

Colebrook, J. M. 1978. Continuous plankton records: zooplankton and environment, North-East Atlantic and North Sea, 1948-1975. Oceanologica Acta 1(1):9-23.

International Council for the Exploration of the Sea (ICES). 1987. Report of the Working Group on Larval Fish Ecology to the Biological Oceanography Committee of ICES. C.M. 1987/L:28.

Jakobsson, J. 1980. The North Icelandic herring fishery and environmental conditions 1960-1968. Rapp. P.-v. Reun. Cons. int. Explor. Mer 177:460-465.

Laurence, G. C., and R. G. Lough. 1984. Growth and survival of larval fishes in relation to the trophodynamics of Georges Bank cod and haddock. NOAA Tech. Mem. NMFS-F/NEC-31. 150 pp.

MacCall, A. D. 1986. Changes in the biomass of the California Current ecosystem. pp. 33-54. *In* K. Sherman and L. M. Alexander (Eds.) Variability and management of large marine ecosystems. AAAS Selected Symposium 99, Westview Press, Boulder, CO. 319 pp.

McCarthy, J. J., Brewer, P. G., and G. Feldman. 1986. Global ocean flux. Oceanus 29(4):16-26.

Maurer, R. 1976. 1976. A preliminary analysis of interspecific trophic relationships between the sea herring and the Atlantic mackerel. ICNAF Res. Doc. No. 121, Ser. 3967, 22 pp.

National Academy of Sciences [NAS]. 1979. Carbon dioxide and climate: A scientific assessment. Climate Research Board, Nat. Acad. Sci., Washington, D.C. 496 pp.

Sherman, K., and L. M. Alexander (Editors). 1986. Variability and management of large marine ecosystems. AAAS Selected Symposium 99, Westview Press, Boulder, CO. 319 pp.

Sherman, K., and L. M. Alexander (Editors). In press. Biomass and geography of Large Marine Ecosystems. AAAS Selected Series. Westview Press, Boulder Colorado.

Sherman, K., J. R. Green, J. R. Goulet, and L. Ejsymont. 1983. Coherence in zooplankton of a large Northwest Atlantic ecosystem. Fish. Bull., U.S. 81:855-862.

Sherman, K., C. Jones, L. Sullivan, W. Smith, P. Berrien, and L. Ejsymont. 1981. Congruent shifts in sand eel abundance in western and eastern North Atlantic ecosystems. Nature 291(5815):486-489.

Sherman, K., W. Smith, W. Morse, M. Berman, J. Green, and L. Ejsymont. 1984. Spawning strategies of fishes in relation to circulation, phytoplankton production, and pulses in zooplankton off the northeastern United States. Mar. Ecol. Progr. Ser. 18:1-19.

Sissenwine, M. P., and J. G. Sheperd. 1987. An alternative perspective on recruitment overfishing and biological reference points. Can. J. Fish. Aquat. Sci. 44:913-918.

Smith, P. E., and S. L. Richardson. 1977. Standard techniques for pelagic fish egg and larvae surveys. FAO Fish. Tech. Paper 175, Rome.

Ursin, E. 1977. Multispecies fish stock assessment for the North Sea. ICES C.M. 1977/F:42. 19 pp.

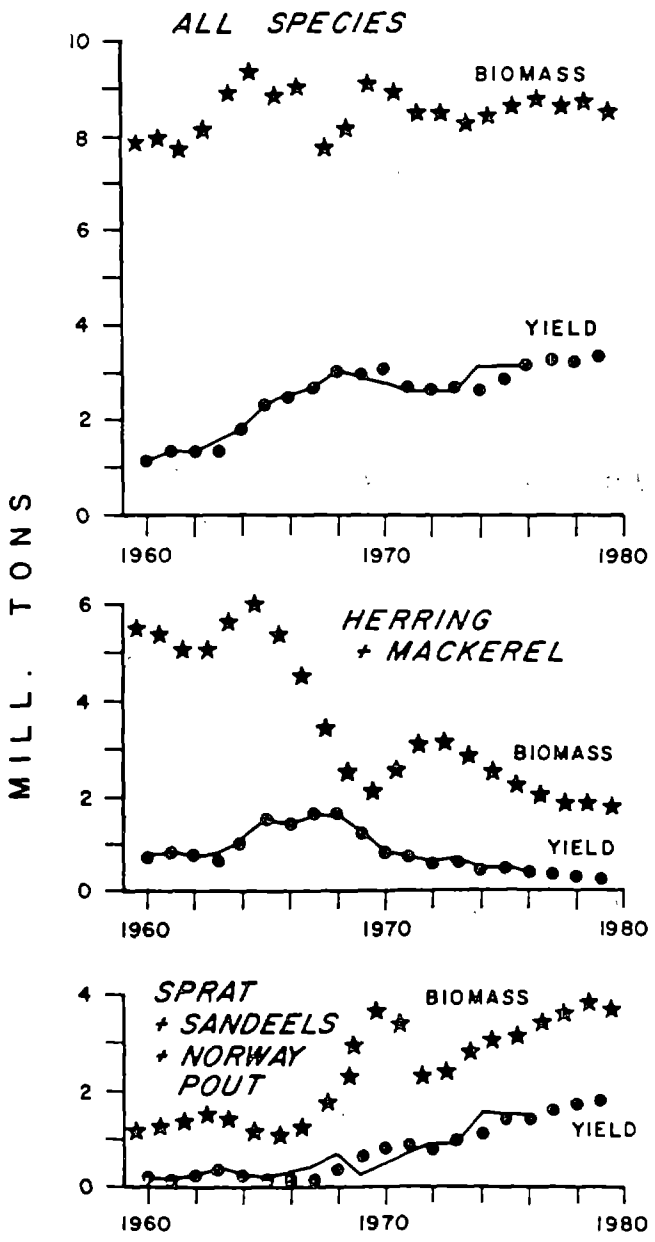

Fig. 1. Estimated changes in the biomass of fishes in the North Sea, 1960-1976, with simulated yield and biomass projections to 1980. The 1.0 million metric ton decline in Atlantic mackerel and Atlantic herring stocks from 1968-1976 from excessive fishing mortality is thought to be compensated for in the North Sea Ecosystem by replacement with small, fast-growing, opportunistic species (i.e., sprat, sand eel, Norway pout). (Adopted from Ursin, 1977.)

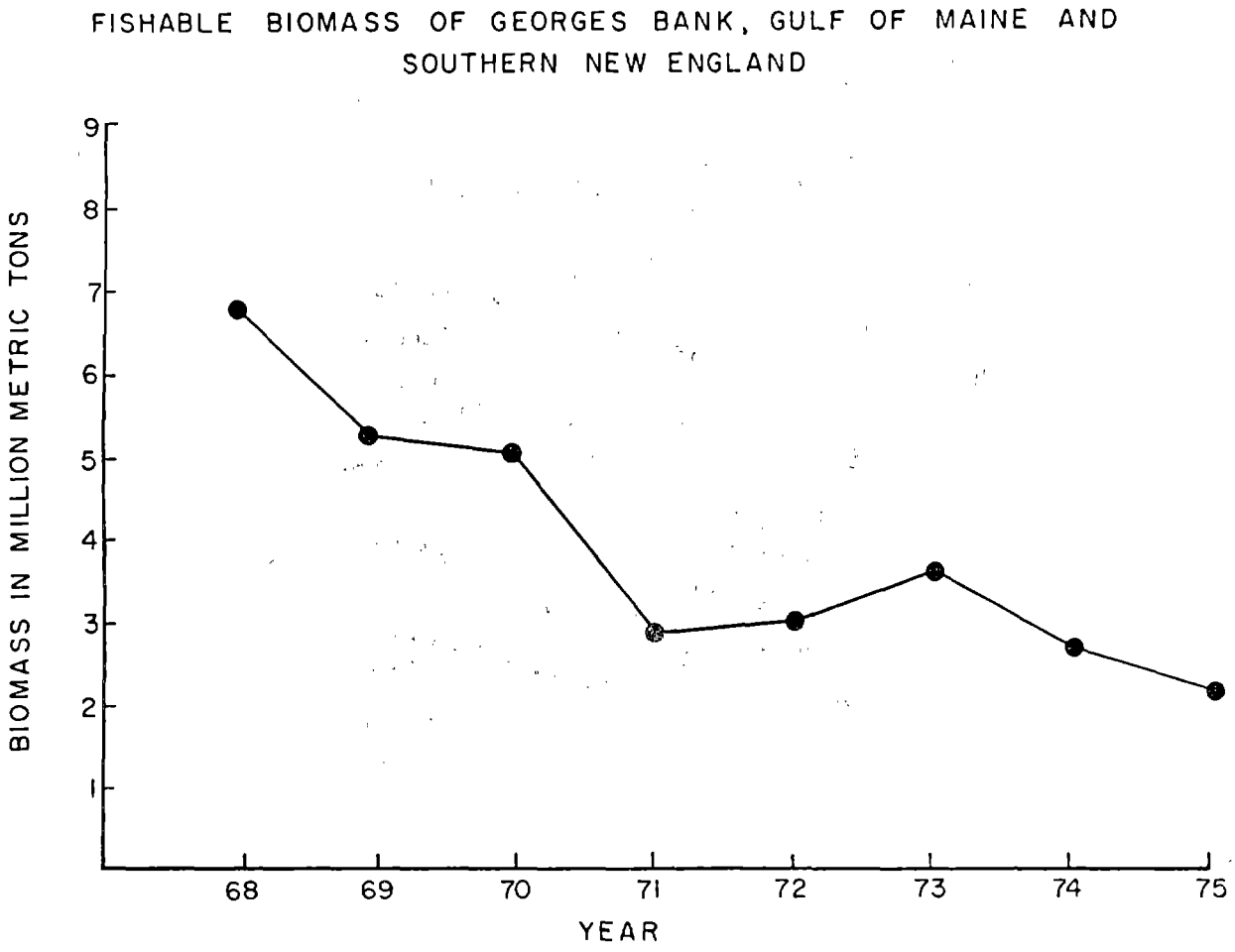

Fig. 2. Decline in the fishable biomass of Georges Bank, Gulf of Maine, and Southern New England between 1968 and 1975. (Adapted from Clark and Brown, 1977.)

MARMAP ICHTHYOPLANKTON SURVEYS: AN OVERVIEW OF METHODS AND DATA BASE MANAGEMENT

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ABSTRACT

Sampling methods and the data processing system designed to archive and retrieve information are outlined for a decadal time series of ichthyoplankton surveys conducted in coastal waters off the northeastern United States. These surveys, part of a broad-based fishery ecology study at the Northeast Fisheries Center, produced 25,000 plankton samples for ichthyoplankton/zooplankton analysis from 1977 through 1987.

INTRODUCTION

The Northeast Fisheries Center (NEFC) recently completed the 11th consecutive year of plankton survey in coastal waters off the northeastern United States as part of a comprehensive fisheries ecosystem study designed to monitor changes in community structure within marine ecosystems (Sherman, this volume) and investigate recruitment mechanisms (Sherman, 1986). Surveys are conducted at monthly-to-bimonthly intervals and cover the entire continental shelf from Cape Hatteras, North Carolina, to Cape Sable, Nova Scotia--an area of some 260,000 km^2. They provide a description of the interannual variability in temporal and spatial patterns of mesoscale distribution, abundance, production, and mortality of fish eggs and larvae along with measurements and/or collections of neuston, zooplankton, phytoplankton, chlorophyll *a*, temperature, and salinity. Seabird and mammal census data are collected by personnel from Manomet Bird Observatory, Manomet, Massachusetts. In addition to their contribution to NEFC's recruitment initiative, ichthyoplankton data are used to derive fishery-independent estimates of adult spawning biomass (Berrien et al., 1984; Berrien and Sissenwine, this volume). During the 11-year period from 1977 through 1987 these surveys provided 25,000 bongo samples for ichthyoplankton/zooplankton analysis (Table 1).

SURVEY METHODS

Fish eggs and larvae are collected on two types of cruises: those dedicated to broadscale plankton surveys; and those with a primary mission of assessing the distribution and abundance of fish and mollusc populations using trawls, or dredges, respectively. Station plans on plankton surveys remain largely unchanged between cruises. Sampling sites are spaced at 8 to 18-km intervals along seven transects. Others are uniformly distributed over the shelf at 25 to 35-km intervals. The survey area is sectioned into four subareas for analytical purposes (Fig. 1). Ichthyoplankton stations on trawl and dredge surveys are selected from stratified random station plans and change with each survey (Grosslein, 1969). Sampling intensity on these cooperative cruises in later winter/early spring, summer, and early autumn is similar to that on plankton surveys.

Collecting methods for all facets of the MARMAP surveys from 1977 through 1983 are described in detail by Sibunka and Silverman (1984). This report outlines only the ichthyoplankton sampling operation which involves double oblique tows with a 61-cm bongo. The net is lowered to within a few meters of the bottom, or to a maximum depth of 200 m at 50 $m \cdot min^{-1}$, and retrieved at 20 $m \cdot min^{-1}$. Ship speed varies between 1 and 2 kt to maintain a 45° wire angle during the tow. One side of the bongo is fitted with a 0.505-mm mesh net for ichthyoplankton studies, the other with a 0.333-mm mesh net for zooplankton monitoring. A flow meter is suspended at the mouth on each side of the bongo to record the amount of water filtered. To eliminate flow meter windmilling when setting the gear, disposable beverage cups are placed over the fins on the meter before setting the bongo. The cups are washed into the nets upon impact with surface water and retrieved after the tow when the net's contents are removed. A mechanical time-depth recorder is attached to the towing wire just above the bongo to record tow profile and maximum sampling depth.

Initial processing of the plankton samples is completed at the Sea Fisheries Institute, Szczecin, Poland. Larvae are sorted, identified, measured, and counted at the institute, then returned to NEFC's Sandy Hook Laboratory, along with appropriate logs and fish eggs. Quality control procedures are completed at Sandy Hook, and data are subsequently entered into the computer (VAX). Fish eggs of some 50 taxa, used largely for assessment purposes, are identified and staged at Sandy Hook with results then archived in the VAX.

DATA STORAGE AND MANAGEMENT

The MARMAP Ecosystem Data Base and Information Management (MEDBIM) System consists of a Data Base, a Quality Control Processing System, a Data Dictionary-Documentation System and a Query and Report System.

The Query and Report system is provided by the S1032, the DBMS used to implement MEDBIM. A library of record formats and procedures will contain commonly used procedures and output formats.

The Data Dictionary-Documentation system completely defines MEDBIM, including record formats, data set structures, software logic, file references, data locator, legal codes, taxonomic numbers, etc. It is also implemented in S1032.

The Quality Control Processing system consists of software modules, associated data structures, and processing instructions. The software modules are grouped into pathways each providing for the processing needed to move data, along one path, from input records to the master data base. There is at least one path for each of the master data sets. Sometimes there are several, as input record formats are changed or data are received from a new source. Over 50 pathways have been defined, of which approximately 15 are active. Another 20 software paths defining system utilities (e.g., data management) or user access procedures have been built. The Quality Control Processing software has been implemented in both S1032 and in DBASE III.

The MEDBIM data base was originally designed as shown in Fig. 2, with each data set containing only elements which truly belonged to the primary key shown. At each level, the key presumes the keys at higher level. Thus the primary key for Larvae includes the primary keys for Net, Experiment, Station and Cruise. Not all data types pertaining to FED are included in this design. It is, however, open-ended and new data sets can be added as long as the proper linking keys are included.

time, and a thorough quality control review of all data, 1977 through the present, was initiated. As each data set was implemented, compromises were made to accommodate limitations imposed by the PDP, or to reduce the complexity of the user interface. Fig. 3 shows the actual design and the links between the currently implemented data sets (bold). The actual design (Fig. 3) differs from the conceptual design (Fig. 2) in that some data sets have been composited to reduce linking complexity at the expense of data redundancy, and some data sets have been split apart for storage efficiency.

LITERATURE CITED

Berrien, P., and M. Sissenwine. This volume. Use of egg data to estimate total finfish biomass for the Northeast Continental Shelf ecosystem.

Berrien, P., W. Morse, and M. Pennington. 1984. Recent estimates of adult spawning stock biomass off northeastern United States from MARMAP Ichthyoplankton Surveys. NOAA Tech. Mem. NMFS/F-NEC-30. 111 pp.

Sherman, K. 1986. Measurement strategies for monitoring and forecasting variability in large marine ecosystems. pp. 203-321. *In* K. Sherman and L. M. Alexander (Eds.) Variability and management of large marine ecosystems. AAAS Selected Symposium 99, Westview Press, Boulder, CO. 319 pp.

Sherman, K. This volume. Ichthyoplankton surveys: A strategy for monitoring change in a large marine ecosystem.

Sibunka, J. D., and M. J. Silverman. 1984. MARMAP survey of the continental shelf from Cape Hatteras, North Carolina, to Cape Sable, Nova Scotia (1977-1983). Atlas No. 1, Summary of Operations. NOAA Tech. Mem. NMFS-F/NEC-33. 306 pp.

Table 1. Summary of MARMAP I survey activities, 1977-1987.

Vessel	Cruise	Date	Vessel Days	No. Sta.	PLANKTON SAMPLES 0.61-m bongo 0.505	0.333	Other	0.20-m bongo 0.253	0.165	0.165	0.053	Other	Neuston	XBT	WATER BOTTLES No. Casts	No. Bottles	Temp. (°C)	°/oo	^{18}O	D.O.	Cl	Phyto.	Nut.	^{14}C	Secchi	Weather
Delaware II	77-03	3/19-4/8	21	69	69	69	-	-	-	-	-	-	69	69	67	269	69	269	-	269	-	-	-	-	-	69
Goerlitz	77-01	3/3-4/7	36	109	109	109	-	29	29	-	-	-	94	-	-	-	109	-	-	-	-	-	-	-	-	109
Delaware II	77-04	4/12-4/29	18	151	151	151	-	-	-	-	-	-	151	151	151	822	151	822	-	426	-	-	-	-	-	151
Albatross IV	77-02	4/13-5/16	34	123	122	122	-	2	-	-	-	-	120	122	113	702	123	702	-	-	-	-	-	-	-	123
Delaware II	77-05	5/3-5/27	22	192	183	183	-	-	-	-	-	-	177	192	190	864	192	864	-	486	523	121	395	-	-	192
Rogliki	77-02	5/22-6/6	16	95	95	95	-	95	95	-	-	-	95	95	95	185[1]	285[1]	280[1]	-	-	-	-	-	-	39	95
Delaware II	77-07	6/9-6/30	20	133	133	133	-	-	-	-	-	-	133	132	132	828	133	828	-	445	665	-	-	-	-	133
Delaware II	77-09	7/27-8/6	11	15	15	15	-	-	-	-	-	-	15	15	15	15	30	30	-	15	-	-	-	-	-	15
Yubileiniy	77-09	7/30-9/3	35	190	169	169	-	43	43	-	-	31	169	169	190	1210	1210	1188	-	1038	762	-	605	-	101	190
Argus	77-01	10/15-11/11	28	142	144	144	-	24	24	-	-	-	140	142	142	1226	1224	1366	-	226	850	-	-	-	16	142
Mt. Mitchell	77-11	11/12-11/19	8	37	37	37	-	17	17	-	-	-	36	37	37	382	382	382	-	180	297	-	-	-	11	37
G.B. Kelez	77-11	11/25-12/13	18	58	57	57	-	12	12	-	-	-	26	54	54	510	444	564	-	147	405	-	-	-	16	58
TOTALS			267	1314	1284	1284	-	222	220	-	-	31	1225	1178	1186	7013	4352	7295	-	3232	3502	121	1000	-	183	1314
Delaware II	78-02	2/14-3/17	33	132	132	132	2	26	26	-	-	-	132	134	132	1264	590	1380	-	218	1106	-	-	-	64	132
Argus	78-04	4/13-6/24	42	149	149	149	-	29	29	-	-	38	148	154	150	1346	1346	1489	-	1311	1288	-	970	28	78	154
Albatross IV	78-04	4/26-5/16	21	40	39	39	-	20	20	-	-	-	39	40	-	-	40	40	-	-	-	-	-	-	-	40
Aliot	78-01	6/20-7/31	42	137	137	137	-	47	47	-	-	-	137	137	-	-	137	137	-	-	-	-	-	-	-	137
Albatross IV	78-07	6/22-7/17	26	149	149	149	3	29	29	-	-	-	149	149	149	1439	1223	1439	-	1233	1260	98	-	-	78	149
Belogorsk	78-01	8/9-9/6	28	154	154	154	-	29	29	-	-	52	154	156	154	1612	1612	1612	-	1612	1370	-	264	44	77	156
Belogorsk	78-03	10/5-11/2	29	130	126	126	6	31	31	-	-	40	125	49	131	1379	1379	1379	-	640	1196	324	264	42	61	30
Delaware II	78-06	10/24-11/25	20	14	14	14	-	-	-	-	-	-	14	14	-	-	14	14	-	-	-	-	-	-	-	14
Belogorsk	78-04	11/15-11/30	16	78	74	74	-	20	20	24	24	-	63	35	78	910	910	910	-	434	727	182	148	24	30	78
TOTALS			257	983	974	974	11	231	231	24	24	130	961	868	794	7950	7251	8400	-	5448	6947	604	1646	138	388	890
Delaware II	79-03	2/23-3/15	21	111	102	102	8	19	24	-	-	-	102	41	111	924	770	924	-	261	862	51	23	-	48	111
Albatross IV	79-03	3/31-5/12	34	52	52	52	-	21	21	-	-	-	52	52	-	-	52	52	-	-	-	-	-	-	-	52
Delaware II	79-04	4/11-4/30	20	53	53	53	-	-	-	-	-	-	-	53	-	-	53	53	-	-	-	-	-	-	-	53
Eisbar	79-01	4/24-5/7	14	58	58	58	-	-	-	-	-	-	42	58	-	-	-	-	-	-	-	-	-	-	-	58
Delaware II	79-05	5/4-5/29	26	175	170	170	4	33	33	30	30	-	170	60	175	1591	1166	1591	-	693	1479	79	566	36	91	175
Albatross IV	79-06	6/12-7/14	33	130	125	125	-	25	25	26	26	-	125	47	130	-	710	1171	-	1010	1138	64	499	29	74	130
Belogorsk	79-01	8/9-9/13	26	151	146	146	-	30	30	15	15	44	146	61	151	1151	1159	1151	-	644	1366	72	579	40	95	151
Belogorsk	79-03	9/10-10/10	31	52	59	59	-	59	59	51	51	-	60	108	52	582	573	582	-	477	495	51	313	31	36	52
Albatross IV	79-11	10/1-10/29	29	166	161	161	-	31	31	69	69	-	159	62	166	1127	1456	1683	-	720	1364	301	563	39	78	166
Viscano	79-03	11/13-11/28	9	33	33	33	-	-	6	-	-	-	33	33	33	66	66	66	-	66	-	-	-	-	-	33
Albatross IV	79-13	11/14-12/21	38	88	76	76	-	15	15	16	16	-	74	44	82	955	947	955	-	433	798	36	291	18	33	88
Belogorsk	79-05	11/21-11/28	8	16	15	15	-	15	15	15	14	-	16	16	16	179	174	179	-	179	154	33	138	11	-	16
TOTALS			289	1085	1050	1050	12	248	259	222	221	44	979	635	916	6575	7126	8407	-	4483	7656	687	2972	204	455	1085
Viscano	80-02	2/18-3/11	23	92	80	80	-	30	30	-	-	-	60	48	87	949	617	617	-	617	808	60	-	-	26	92
Albatross IV	80-02	2/27-3/5	34	158	148	148	-	25	25	37	37	-	145	65	156	1618	1590	1618	-	608	1428	120	532	42	79	158
Evrika	80-01	4/15-5/15	33	164	164	164	-	28	28	61	61	-	150	57	155	1661	1560	1573	-	882	2918	144	565	51	91	164
Albatross IV	80-03	4/24-5/2	9	11	11	11	-	-	-	-	-	-	11	-	-	-	-	11	-	11	-	-	-	-	-	11
Delaware II	80-02	4/30-5/8	9	12	12	12	-	-	-	-	-	-	12	-	-	-	-	12	-	12	-	-	-	-	-	12
Delaware II	80-03	5/21-6/13	21	121	120	120	-	13	13	30	30	-	120	36	121	1174	1091	1173	-	1172	1073	105	409	31	61	121
Evrika	80-04	6/24-6/30	7	28	28	28	-	4	4	10	10	-	28	16	28	334	332	334	-	334	275	18	94	10	16	28
Evrika	80-06	7/14-8/11	27	160	157	157	-	29	29	44	44	-	158	56	160	1700	1613	1646	-	1187	2917	194	607	44	88	160
Delaware II	80-05	7/28-8/8	12	1	1	1	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1
Albatross IV	80-10	9/24-10/30	32	175	174	174	-	31	31	34	34	5	174	61	175	1824	1720	1741	-	718	1601	226	613	44	74	175
Albatross IV	80-12	11/17-12/23	30	138	137	137	-	28	28	29	29	-	138	25	138	1351	1260	1351	-	577	1213	117	491	30	47	138
TOTALS			237	1060	1032	1032	-	188	188	245	245	5	997	364	1020	10611	9783	10076	-	6118	12233	984	3311	252	482	1060

Table 1 (continued).

Vessel	Cruise	Date	Vessel Days	No. Sta.	PLANKTON SAMPLES 0.61-m bongo 0.505	0.333	Other	0.20-m bongo 0.253	0.165	0.165	0.053	Other	Neuston	XBT	WATER BOTTLES No. Casts	No. Bottles	Temp. (°C)	°/oo	^{18}O	D.O.	Cl	Phyto.	Nut.	^{14}C	Secchi	Weather
Albatross IV	81-01	2/17-3/26	33	153	153	153	-	25	25	39	39	5	152	21	150	1590	1528	1577	-	655	1393	194	564	39	63	153
Delaware II	81-02	3/17-5/14	50	147	147	147	-	-	-	-	-	-	-	147	-	-	147	147	-	-	-	-	-	-	-	147
G.B. Kelez	81-03	3/18-4/9	19	99	99	99	-	16	16	28	28	-	98	25	97	918	836	909	-	419	769	78	366	25	41	97
Delaware II	81-03	5/20-6/18	27	147	145	145	-	16	16	24	24	5	145	57	147	1584	1495	1603	-	433	1441	206	407	25	83	147
Delaware II	81-04	6/27-7/2	18	78	78	78	-	-	-	-	-	-	-	78	-	-	149	149	-	-	-	-	-	-	-	78
Albatross IV	81-07	7/7-7/21	15	17	17	17	-	-	-	-	-	-	-	17	-	-	-	-	-	-	-	-	-	-	-	17
Delaware II	81-05	8/3-8/21	19	72	72	72	-	-	-	-	-	-	-	72	-	-	72	72	-	-	-	-	-	-	-	72
Albatross IV	81-10	8/26-9/4	10	24	24	24	-	-	-	-	-	-	-	24	-	-	-	-	-	-	-	-	-	-	-	24
Delaware II	81-06	9/15-11/13	54	167	167	167	-	-	-	-	-	-	-	167	-	-	167	167	-	-	-	-	-	-	-	167
Albatross IV	81-13	11/2-11/13	26	26	26	26	-	-	-	-	-	-	-	26	-	-	26	26	-	-	-	-	-	-	-	26
Albatross IV	81-14	11/16-12/22	31	96	97	97	-	21	21	34	34	4	89	31	89	1051	994	1049	1049	524	922	63	306	29	31	96
TOTALS			302	1026	1025	1025	-	78	78	125	125	14	484	665	483	5143	5414	5699	1049	2031	4525	541	1643	118	218	1024
Albatross IV	82-02	2/16-3/25	32	146	146	146	-	29	29	35	35	5	144	39	145	1518	1415	1509	1481	673	1364	126	516	36	43	146
Delaware II	82-02	3/8-5/8	43	166	166	166	-	-	-	-	-	-	-	166	-	-	166	166	-	-	-	-	-	-	-	166
Delaware II	82-03	5/17-6/11	23	110	102	102	-	22	22	27	27	27	5	102	111	1238	1182	1235	1235	511	1104	90	360	28	59	110
Albatross IV	82-06	6/1-6/11	11	38	38	38	-	-	-	-	-	-	-	38	-	-	38	38	-	-	-	-	-	-	-	38
Albatross IV	82-08	7/12-8/6	24	89	89	89	-	-	-	-	-	-	-	89	-	-	89	89	-	-	-	-	-	-	-	89
Delaware II	82-05	7/26-8/12	19	51	51	51	-	-	-	-	-	-	-	51	-	-	51	51	-	-	-	-	-	-	-	51
Albatross IV	82-11	9/13-11/12	55	156	155	156	-	-	-	-	-	-	-	156	-	-	156	156	-	-	-	-	-	-	-	156
Delaware II	82-09	11/15-12/22	32	161	151	152	-	28	28	36	36	-	152	47	162	1765	1660	1645	1645	789	1562	138	-	36	49	161
TOTALS			239	917	898	900	-	79	79	98	98	32	301	688	418	4521	4757	4889	4361	1973	4030	354	876	100	151	917
Delaware II	83-01	1/17-2/4	24	105	102	102	-	15	15	22	22	-	102	18	105	1210	1160	1210	1210	441	1040	60	327	25	39	105
Delaware II	83-02	2/14-2/24	11	39	39	39	-	8	8	-	-	-	-	39	-	-	39	39	-	-	-	-	-	-	-	39
Albatross IV	83-01	2/25-3/3	8	16	16	16	-	6	6	-	-	-	16	16	-	-	-	16	-	-	-	-	-	-	-	16
Albatross IV	83-02	3/7-5/6	55	140	140	140	-	-	-	-	-	-	-	140	-	-	140	140	-	-	-	-	-	-	-	140
Albatross IV	83-04	5/23-6/22	29	177	176	176	-	31	31	41	41	-	176	46	176	1852	1732	1812	1852	712	1639	138	-	42	102	177
Albatross IV	83-07	7/26-9/2	33	118	118	118	-	-	-	-	-	-	-	118	-	-	118	118	-	-	-	-	-	-	-	118
Delaware II	83-07	8/15-9/7	23	62	62	62	-	-	-	-	-	-	-	62	-	-	62	62	-	-	-	-	-	-	-	62
Albatross IV	83-08	9/12-11/10	54	165	165	165	-	-	-	-	-	-	-	165	-	-	165	165	-	-	-	-	-	-	-	165
Delaware II	83-09	11/14-12/21	31	152	151	151	-	29	29	38	38	-	151	40	152	1556	1453	1554	1554	656	1387	151	-	35	58	152
TOTALS			268	974	969	969	-	89	89	101	101	-	445	644	433	4618	4869	5116	4616	1809	4066	349	327	102	199	974
Delaware II	84-01	1/9-2/10	31	161	160	160	-	31	31	40	40	-	159	39	161	1684	1578	1683	1683	213	1492	158	654	38	67	161
Albatross IV	84-02	2/29-4/27	52	155	155	155	-	-	-	-	-	-	-	155	-	-	155	155	-	-	-	-	-	-	-	155
Albatross IV	84-03	5/7-6/3	26	181	178	178	-	30	30	36	36	-	178	42	181	1905	1795	1905	1904	704	1687	173	-	38	80	181
Delaware II	84-05	5/17-6/24	39	41	41	41	-	-	-	-	-	-	-	41	-	-	41	-	-	-	-	-	-	-	-	41
Albatross IV	84-06	7/2-7/19	18	70	70	70	-	-	-	-	-	-	-	70	-	-	70	-	-	-	-	-	-	-	-	70
Delaware II	84-06	7/9-8/1	24	107	107	107	-	-	-	-	-	-	-	107	-	-	107	107	-	-	-	-	-	-	-	107
Albatross IV	84-07	7/24-8/31	34	119	119	119	-	-	-	-	-	-	-	119	-	-	119	119	-	-	-	-	-	-	-	119
Albatross IV	84-08	9/10-11/9	52	158	158	158	-	-	-	-	-	-	-	158	-	-	158	158	-	-	-	-	-	-	-	158
Delaware II	84-09	10/29-12/7	32	146	144	144	-	25	25	32	32	-	144	32	142	1422	1313	1422	1421	509	1278	140	-	30	60	146
TOTALS			308	1138	1132	1132	-	86	86	108	108	-	481	763	484	5011	5336	5549	5008	1426	4457	471	654	106	207	1138
Delaware II	85-01	1/7-2/8	30	132	131	131	-	30	30	24	24	-	129	27	132	1334	1231	1332	1332	451	1188	131	-	24	57	132
Albatross IV	85-02	2/25-4/13	44	140	140	140	-	-	-	-	-	-	-	140	-	-	140	140	-	-	-	-	-	-	-	140
Delaware II	85-03	4/1-5/2	30	191	190	190	-	24	24	-	-	-	190	28	191	1848	1706	1848	1848	254	-	189	-	-	-	191
Oregon II	85-01[2]	4/23-5/28	36	158	158	158	-	-	-	-	-	-	158	5	153	-	-	348	-	151	87	-	-	-	58	158
Albatross IV	85-04	5/8-6/6	29	173	168	168	-	23	23	33	33	-	163	16	173	1660	1558	1660	1659	439	1410	162	-	37	83	173
Gyre	85-07	7/16-7/25	9	22	22	22	-	-	-	-	-	-	-	-	21	-	-	-	-	-	-	-	-	-	-	22
Albatross IV	85-07	7/22-8/31	30	126	126	126	-	-	-	-	-	-	-	126	-	126	126	-	-	-	-	-	-	-	-	126
Delaware II	85-07	8/26-9/22	26	193	192	192	-	31	31	-	-	-	187	13	193	2016	1893	1964	1946	279	-	189	-	-	-	193
Albatross IV	85-08	9/9-11/16	18	58	58	58	-	-	-	-	-	-	-	58	-	-	58	58	-	-	-	-	-	-	-	58
Delaware II	85-08	9/30-11/26	24	78	78	78	-	-	-	-	-	-	-	78	-	-	78	78	-	-	-	-	-	-	-	78
Delaware II	85-10	11/5-12/12	30	180	179	179	-	31	31	-	-	-	179	2	180	1880	1767	1878	1878	-	339[3]	-	-	-	-	180
TOTALS			306	1451	1442	1442	-	139	139	57	57	-	1006	493	1043	8864	8557	9306	8663	1574	3024	671	-	61	198	1451

Table 1 (continued).

Vessel	Cruise	Date	Vessel Days	No. Sta.	PLANKTON SAMPLES 0.61-m bongo 0.505	0.61-m bongo 0.333	0.61-m bongo Other	0.20-m bongo 0.253	0.20-m bongo 0.165	0.20-m bongo 0.165	0.20-m bongo 0.053	0.20-m bongo Other	Neuston	XBT	WATER BOTTLES No.[5] Casts	No. Bottles	Temp. (°C)	°/oo	^{18}O	D.O.	Cl	Phyto.	Nut.	^{14}C	Secchi	Weather
Delaware II	86-01	1/7-2/12	31	174	173	175	-	32	32	-	-	-	173	15	174	1823	174	1822	1823	-	312[3]	95	-	-	-	174
Albatross IV	86-02	3/3-4/27	46	150	150	150	-	-	-	-	-	-	-	149	-	-	150	148	148	-	-	-	-	-	-	150
Delaware II	86-03	5/6-6/7	30	223	160	160	20	29	29	-	-	-	180	42	167	1791	1636	1740	-	60	290[3]	164	46	-	-	164
Delaware II	86-04	6/17-7/18	22	105	105	105	-	-	-	-	-	-	-	103	-	-	104	80	-	-	-	-	-	-	-	105
Albatross IV	86-04	7/29-8/29	25	116	116	116	-	-	-	-	-	-	-	109	-	-	116	116	-	-	-	-	-	-	-	116
Delaware II	86-07	8/25-9/24	26	174	155	155	-	26	26	-	-	-	155	-	174	1617	1492	1617	1597	26	283[3]	156	-	-	-	174
Albatross IV	86-05	9/13-9/23	11	36	36	36	-	-	-	-	-	-	-	36	-	-	36	36	-	-	-	-	-	-	-	36
Delaware II	86-08	9/30-10-/10	11	41	41	41	-	-	-	-	-	-	-	41	-	-	41	-	-	-	-	-	-	-	-	41
Albatross IV	86-05	10/14-11/6	22	70	70	70	-	-	-	-	-	-	-	70	-	-	69	-	-	-	-	-	-	-	-	70
Delaware II	86-10	11/5-12/11	32	161	159	159	-	28	28	-	-	-	159	-	161	1624	1516	1624	1623	-	257[3]	158	-	-	-	161
TOTALS			256	1250	1165	1167	20	115	115	-	-	-	667	565	676	6855	5334	7183	5191	86	1142	573	46	-	-	1191
Delaware II	87-01	1/7-2/8	29	134	133	133	-	24	24	-	-	-	133	-	134	1307	1194	1261	-	-	191[3]	67	-	-	-	134
Albatross IV	87-01	3/24-4/28	44	123	123	123	-	-	-	-	-	-	-	123	-	-	122	-	-	-	-	-	-	-	-	123
Delaware II	87-03	4/21-4/28	10	32	32	32	-	-	-	-	-	-	-	31	-	-	27	-	-	-	-	-	-	-	-	32
Arctic Hawk	87-04	4/13-4/22	27	91	91	91	-	-	-	-	-	182[4]	-	46	-	-	91	-	-	-	-	-	-	-	-	91
Delaware II	87-04	5/4-6/8	33	253	253	253	-	11	11	-	-	354[4]	173	-	229	801	840	672	-	-	-	-	-	-	-	253
Wiesmo	87-01,I	5/30-6/14	14	107	107	107	-	-	-	-	-	213[4]	-	53	-	-	107	-	-	-	-	-	-	-	-	107
	87-01,II	6/17-7/1	15	98	98	98	-	-	-	-	-	196[4]	49	49	-	-	98	-	-	-	-	-	-	-	-	98
	87-01,III	7/3-7/6	14	86	85	86	-	-	-	-	-	172[4]	43	57	-	-	86	-	-	-	-	-	-	-	-	86
Prince	87-01	6/17-7/2	16	132	-	-	-	-	-	-	-	264[4]	--	--	132	-	-	-	-	-	-	-	-	-	-	132
Albatross IV	87-05	7/6-8/11	33	109	109	109	-	-	-	-	-	-	--	109	-	-	109	-	-	-	-	-	-	-	-	109
Delaware II	87-08	8/19-9/20	29	180	179	179	24	31	31	-	-	-	179	4	179	1674	180	456	180	36	1548	-	-	-	-	180
Albatross IV	87-07	9/11-11/6	50	144	144	144	-	-	-	-	-	-	-	144	-	-	144	-	-	-	-	-	-	-	-	144
Delaware II	87-10	11/2-12/11	29	125	124	124	-	21	21	-	-	-	124	1	125	1196	125	246	125	-	1188	-	-	-	24	125
TOTALS			343	1614	1478	1479	24	87	87	-	-	1381[4]	701	617	799	4978	3123	2635	305	36	2927	67	-	-	24	1614

[1]Includes surface measurements and samples.

[2]Staffed by SEFC personnel. Area coverage is from off Palm Beach, Fla., to off Chesapeake Bay, Va.

[3]Number of samples taken to calibrate the continuous underway fluorometry system.

[4]20-m bongo 0.505-mm and 0.333-mm mesh net for BIOMAC.

[5]Beginning with cruise DL87-04 no. casts includes CTD and bottle casts.

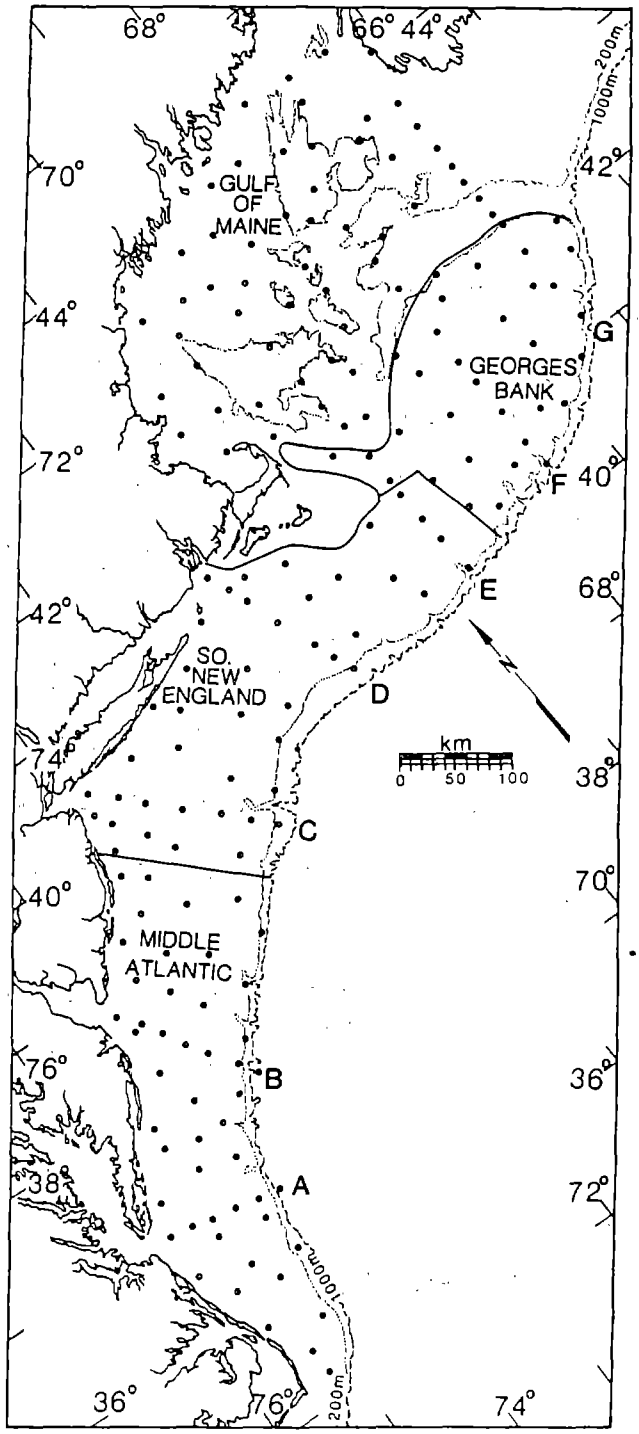

Fig. 1. Standard station plan and four subareas for NEFC ichthyoplankton surveys.

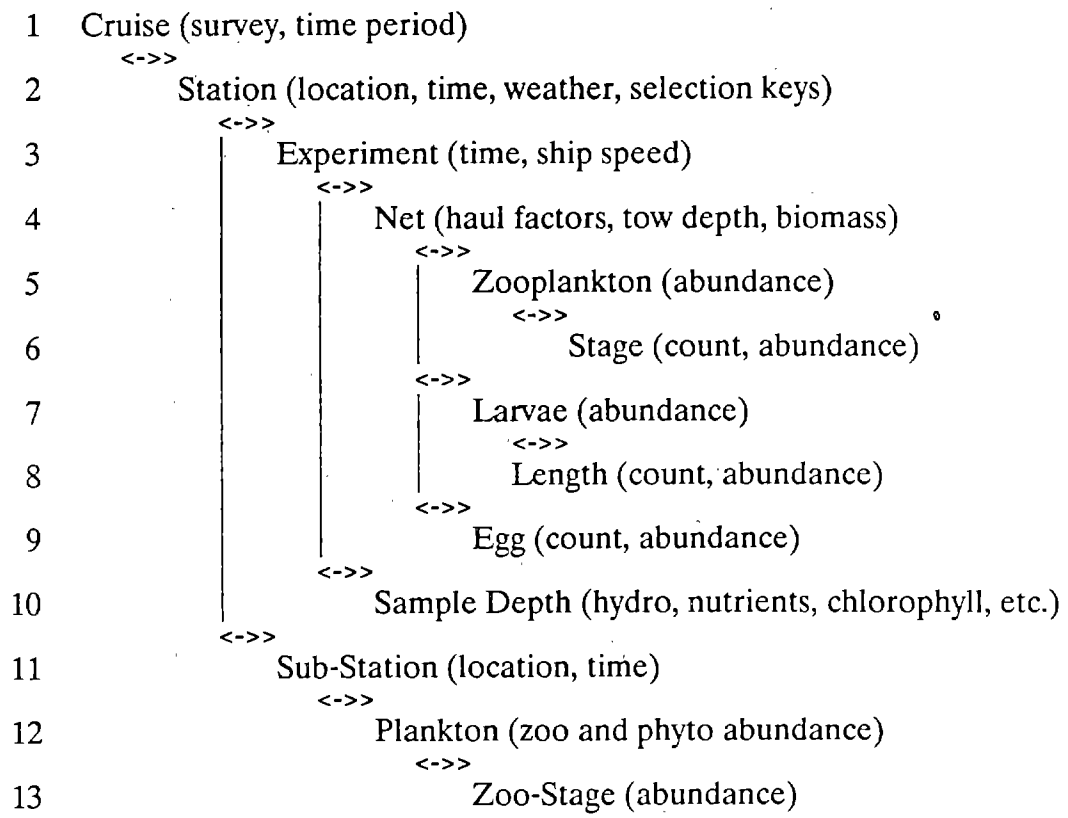

Fig. 2. Conceptual data base design for MEDBIM. Each data set (Cruise, Station, etc.) contains only variables that are specific to that data type.

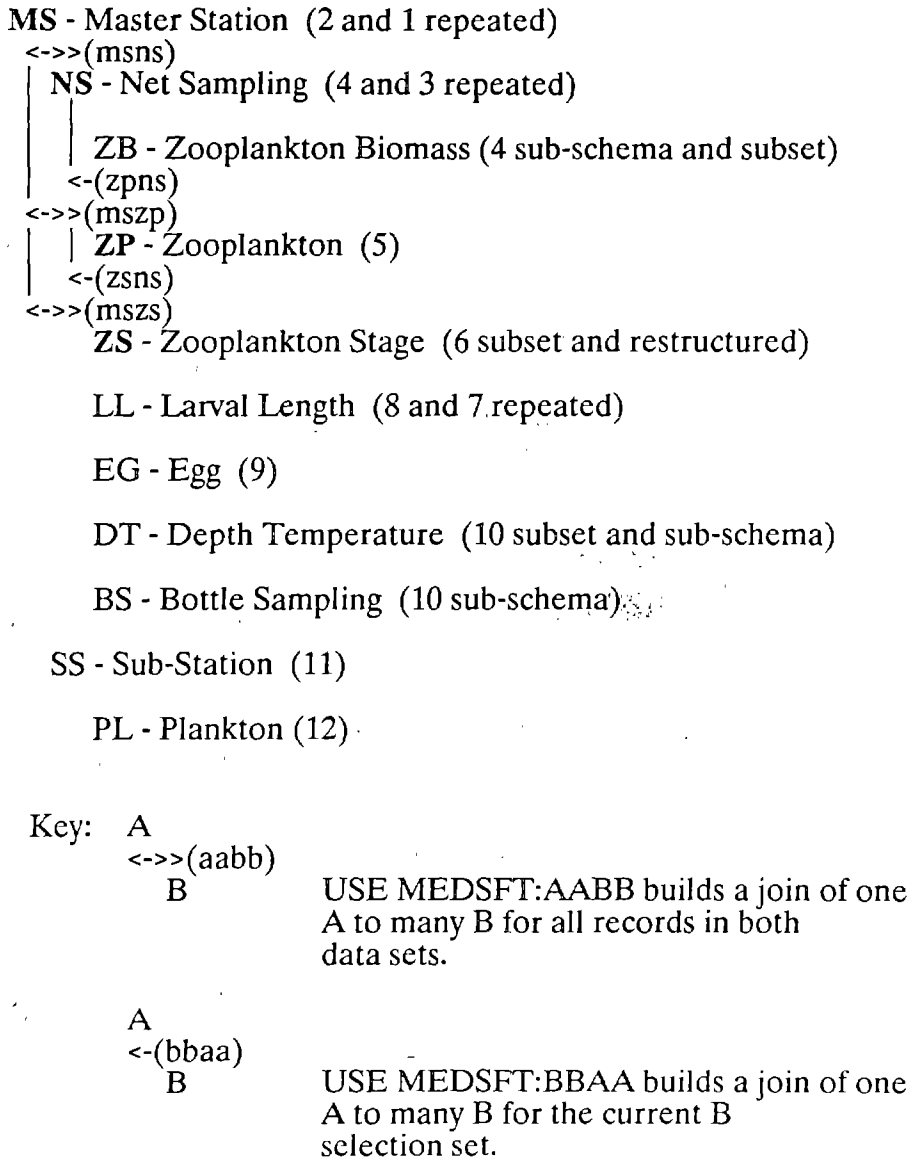

Fig. 3. Actual data base design for MEDBIM. The bold face indicates data sets that are currently implemented. The conceptual design has been modified for ease of user access.

A COMPARISON OF INFORMATION CONTENT FROM TRAWL AND ICHTHYOPLANKTON SURVEYS

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ABSTRACT

Spearman's Rank Correlation Test was used to determine whether finfish community information collected on trawl and ichthyoplankton surveys of shelf waters from Cape Hatteras, N.C., to Cape Sable, N.S., is complementary or redundant. Results show that the two data sets are complementary. There was no positive correlation between trawl listings of stratified mean weight tow^{-1} or stratified mean number tow^{-1} and an ichthyoplankton listing of mean number of larvae 10 m^{-2} surface area. Combining results of trawl and ichthyoplankton surveys provides a more comprehensive approach for monitoring finfish community structure than utilizing information from only one of the sampling strategies.

INTRODUCTION

Decadal time series of biological and oceanographic observations are needed to monitor changes and formulate and test hypotheses that will provide an understanding of the interactive processes that regulate fish production in the sea. To that end, coastal trawl surveys of groundfish populations were initiated by the Northeast Fisheries Center (NEFC) in 1948 with objectives to: (1) monitor fluctuations in structure and size of fish populations; (2) assess fish production potential; (3) determine environmental factors controlling fish distribution and abundance; and (4) provide ecological data to understand interrelationships between fish and their environment (Grosslein, 1969). Trawl surveys were standardized in 1963. A few years later (1953) surveys of fish eggs and larvae of varying scope, intensity and purpose were initiated and continued thereafter into the 1970's. Some targeted a single species and were areally limited, others were more extensive in both coverage and objectives (Marak and Colton, 1961; Boyar et al., 1973; Lough et al., 1985). Beginning in 1977, NEFC scientists initiated a standardized survey of fish eggs and larvae off northeastern United States that is part of the Center's ongoing Marine Resources Monitoring, Assessment, and Prediction (MARMAP) Program (Sherman et al., 1983). The objective of this paper is to compare the principal taxa collected on NEFC's two major survey efforts from the late 1970's through the early 1980's and determine whether they are complementary or redundant.

METHODS

Trawl survey methods are reviewed by Azarovitz (1981); ichthyoplankton survey methods by Smith and Goulet (this volume). For a detailed description of ichthyoplankton survey procedures, see Sibunka and Silverman (1984). Trawl surveys are conducted twice annually, in late winter/early spring and in autumn; ichthyoplankton surveys are carried out

For purposes of this report, ichthyoplankton listings of larval abundance for the 1977-1983 time period were compared with combined spring and autumn trawl survey results from 1977-1984. Spearman's Rank Correlation, a nonparametric test for association (see Sokal and Rohlf, 1981), was used to calculate a coefficient of rank correlation for the top 20 taxa from the two data sets in the Middle Atlantic, Southern New England, Georges Bank and Gulf of Maine subareas (Fig. 1). A nonsignificant or zero, rank correlation is interpreted as meaning the data sets are complementary, i.e., they provide information about different components of the finfish community. On the other hand, a positive correlation would not necessarily indicate that the data sets are redundant as the analysis only considers mean abundance. The top 20 taxa account for 76-99% of the total stratified mean catch by weight and 87-95% of total stratified mean number in the trawl survey data base for the 8-year-period, and 78-89% of the mean larval abundance for the 7-year ichthyoplankton data set.

RESULTS

Results of the ranking test show that the two data bases were not correlated, or had negative correlations, indicating that they were complementary. The principal taxa on the trawl listing are different, or occur in significantly different order than those taxa represented as larvae in the ichthyoplankton list. Whereas dogfish (*Squalus acanthias*) and skates (Rajidae), taxa of known high biomass, occur on trawl listings for all four subareas, they do not occur in the ichthyoplankton data set simply because of their reproductive strategies. Conversely, economically and ecologically important species such as bluefish (*Pomatomus saltatrix*) and anchovies (Engraulidae) rank high on the ichthyoplankton listings for the Southern New England and Middle Atlantic subareas, respectively, but they do not appear on the trawl listing for either subarea. Finally, the sand eel (*Ammodytes* spp.), a species with an estimated spawning biomass of about 1 million metric tons (mmt) (Morse, 1982), and the dominant taxon on the ichthyoplankton data set for three of the four subareas, occurs near the end of the trawl listing for only the Middle Atlantic subarea. In point of fact, half, or less, of the 20 principal taxa are common to both listings in each subarea (Table 1). Given these differences, the non-parametric ranking test produced the expected results. It showed no positive correlations between trawl listings of stratified mean weight tow^{-1} and ichthyoplankton listings of mean number of larvae 10 m^{-2} surface area in any of the four subareas (Fig. 2). Comparison of stratified mean numbers of fish tow^{-1} from the trawl surveys and larval abundance estimates produced like results. Conversely, correlations from comparison of spring and autumn trawl surveys (stratified mean weight tow^{-1}) for the 8-year time period are significant to highly significant in 3 of the 4 subareas. Only in the Middle Atlantic subarea are the twice-yearly survey results uncorrelated. Within-year comparison of stratified mean number tow^{-1} from the trawl produced significant positive correlations in the Gulf of Maine and on Georges Bank but not in the Southern New England and Middle Atlantic subareas.

DISCUSSION

Emphasis in fisheries recruitment research has shifted from studies of single species to a community approach which considers ecosystems and multispecies interactions that affect fish production at different trophic levels (Sherman et al., 1983). The NEFC trawl and ichthyoplankton surveys provide the foundation for this new approach in coastal waters off the northeastern United States.

Surveys of fish eggs and larvae have been shown to represent an effective sampling strategy for estimating interannual variability in multispecies fish communities (Pennington and Berrien, 1982; Stauffer and Charter, 1982). The NEFC trawl surveys, through their

historic nature and quantitative sampling methods, represent an important strategy for monitoring trends in abundance and mortality, and for estimating fish stock inventories (Clark, 1979). This evaluation demonstrates the complementary nature of the trawl and ichthyoplankton data sets. Trawl surveys are better suited for assessing sharks, skates and rays, none of which produce young stages vulnerable to plankton nets, while ichthyoplankton surveys provide more meaningful information on pelagic species and small fishes of little or no economic significance. Together, the two surveys provide a comprehensive strategy for monitoring and assessing changes in the community structure of fishery resources off the northeastern United States.

LITERATURE CITED

Azarovitz, T. R. 1981. A brief historical review of the Woods Hole Laboratory trawl survey time series. pp. 62-67. *In* W. G. Doubleday and D. Rivard (Eds.). Bottom trawl surveys. Can. Spec. Publ. Fish. Aquat. Sci. 58:273 pp.

Boyar, H. C., R. R. Marak, F. E. Perkins, and R. A. Clifford. 1973. Seasonal distribution and growth of larval herring (*Clupea harengus* L.) in the Georges Bank-Gulf of Maine area from 1962 to 1970. J. du Cons. 35:36-51.

Clark, S. H. 1979. Application of bottom-trawl survey data to fish stock assessment. Fisheries 4(3):9-15.

Grosslein, M. D. 1969. Groundfish survey program of BCF Woods Hole. Comm. Fish. Rev. 31(8-9):22-35.

Lough, R. G., G. R. Bolz, M. Pennington, and M. D. Grosslein. 1985. Larval abundance and mortality of Atlantic herring (*Clupea harengus* L.) spawned in the Georges Bank and Nantucket Shoals areas, 1971-78 seasons, in relation to spawning stock size. J. Northw. Atl. Fish. Soc. 6:21-35.

Marak, R. R., and J. B. Colton, Jr. 1961. Distribution of fish eggs and larvae, temperature, and salinity in the Georges Bank--Gulf of Maine area, 1953. NOAA Tech. Rep. NMFS Spec. Sci. Rep.-Fish. 398:1-61.

Morse, W. 1982. Spawning stock biomass estimates of sand lance, *Ammodytes* sp., off northeastern United States, determined from MARMAP surveys, 1974-80. ICES C.M. 1982/G:59.

Pennington, M., and P. Berrien. 1982. Measuring the effect of the variability of egg densities over space and time on egg abundance estimates. pp. 127-141. *In* Report of the Working Group on Larval Fish Ecology. Lowestoft, England 3-6 July 1981. ICES C. M. 1982/L:3.

Sherman, K., R. Lasker, W. Richards, and A. Kendall. 1983. Ichthyoplankton and fish recruitment studies in large marine ecosystems. Mar. Fish. Rev. 45(10-12):1-25.

Sibunka, J., and M. Silverman. 1984. MARMAP surveys of the continental shelf from Cape Hatteras, North Carolina to Cape Sable, Nova Scotia (1977-1983). Atlas No. 1. Summary of Operations. NOAA Tech. Mem. NMFS-F/NEC-33. 306 pp.

Smith, W. G., and J. Goulet. This volume. MARMAP ichthyoplankton surveys: An overview of methods and data base management.

Sokal, R. R., and F. J. Rohlf. 1981. The Principles and Practice of Statistics in Biological Research. 2nd Edition. W. H. Freeman and Co., N.Y. 859 pp.

Stauffer, G. D., and R. L. Charter. 1982. The northern anchovy spawning biomass for the 1981-82 California fishing season. Calif. Coop. Oceanic Fish. Invest. Rep. 23: 15-19.

MARMAP Contribution FED/NEC 87-01

Table 1. Comparison of 20 principal taxa from combined spring and fall NEFC trawl surveys (weighted mean weight/tow (kg) 1977-1984) and ichthyoplankton surveys (mean number larvae 10 m^2 surface area 1977-1983). Shrimp, scallops, and lobsters deleted from trawl listing.

GULF OF MAINE

TRAWL SURVEYS		ICHTHYOPLANKTON SURVEYS	
Taxa	Mean	Taxa	Mean
Spiny dogfish	15.9	Sand eel	32.8
Redfish	14.9	Atlantic herring	20.0
Haddock	13.3	Atlantic mackerel	11.4
Witch flounder	10.0	Cunner	6.5
Atlantic cod	8.4	Redfish	6.0
White hake	7.4	Silver hake	5.2
American plaice	5.6	Hake	4.4
Pollock	5.6	Haddock	2.8
Thorny skate	3.9	Fourbeard rockling	2.4
Silver hake	2.9	Snailfish	2.3
Goosefish	2.7	Witch flounder	1.6
Red hake	1.8	Butterfish	1.6
Cusk	1.7	Pollock	1.6
Shortfin squid	1.6	American plaice	1.3
Winter flounder	1.0	Offshore hake	1.2
Sea raven	0.7	Yellowtail flounder	1.1
Atlantic argentine	0.5	Radiated shanny	1.0
Yellowtail flounder	0.5	Rock gunnel	1.0
Alewife	0.3	Atlantic cod	0.9
Ocean pout	0.3	Sculpin	0.8

GEORGES BANK

TRAWL SURVEYS		ICHTHYOPLANKTON SURVEYS	
Taxa	Mean	Taxa	Mean
Spiny dogfish	35.8	Silver hake	99.1
Winter skate	21.9	Hake	65.9
Atlantic cod	16.2	Sand eel	43.8
Haddock	14.7	Haddock	31.8
Little skate	11.6	Yellowtail flounder	25.4
Silver hake	5.1	Atlantic cod	21.9
Shortfin squid	2.9	Offshore hake	9.5
Winter flounder	2.6	Windowpane	9.4
Longhorn sculpin	2.4	American plaice	6.3
Yellowtail flounder	2.3	Fourspot flounder	5.1
Pollock	2.6	Atlantic herring	5.1
Red hake	1.9	*Ceratoscopelus maderensis*	4.9
Windowpane	1.8	Atlantic mackerel	4.7
Longfin squid	1.5	Cunner	4.4
Butterfish	1.5	*Benthosema glaciale*	3.2
Sea raven	1.0	*Diaphus dumerili*	2.9
Goosefish	0.8	Pollock	2.4
White hake	0.7	Redfish	2.2
Atlantic herring	0.6	Witch flounder	2.2
Fourspot flounder	0.5	Snailfish	2.1

SOUTHERN NEW ENGLAND

TRAWL SURVEYS		ICHTHYOPLANKTON SURVEYS	
Taxa	Mean	Taxa	Mean
Spiny dogfish	74.9	Sand eel	2221.9
Butterfish	10.4	Atlantic Mackerel	125.7
Longfin squid	7.3	Hake	115.1
Little skate	6.1	Silver hake	50.1
Red hake	4.8	Cunner	32.2
Silver hake	4.4	Gulf Stream flounder	27.8
Ocean pout	4.0	Butterfish	23.5
Fourspot flounder	4.0	Yellowtail flounder	17.7
Winter skate	3.4	Fourspot flounder	16.5
Goosefish	3.2	Bluefish	11.0
Yellowtail flounder	3.1	*Ceratoscopelus maderensis*	5.8
Alewife	1.8	Summer flounder	5.4
Northern searobin	1.7	Anchovy	4.3
Shortfin squid	1.6	Atlantic mackerel	4.1
Winter flounder	1.3	Cusk eel	3.4
Atlantic cod	1.3	Offshore hake	3.4
Longhorn sculpin	1.0	Windowpane	3.0
Scup	1.0	Scup	2.9
Windowpane	0.8	*Benthosema glaciale*	2.8
Round herring	0.8	Seasnail	2.3

MIDDLE ATLANTIC BIGHT

TRAWL SURVEYS		ICHTHYOPLANKTON SURVEYS	
Taxa	Mean	Taxa	Mean
Spiny dogfish	58.6	Sand eel	72.6
Longfin squid	4.2	Bluefish	49.7
Atlantic croaker	2.9	Anchovy	31.7
Roughtail stingray	2.8	Gulf Stream flounder	26.5
Butterfish	2.2	Atlantic mackerel	19.3
Northern searobin	1.9	Searobin	17.2
Spot	1.9	Smallmouth flounder	16.0
Scup	1.8	Hake	10.5
Little skate	1.8	Butterfish	9.3
Smooth dogfish	1.4	Fourspot flounder	9.1
Silver hake	1.3	Atlantic mackerel	6.9
Shortfin squid	1.2	Atlantic croaker	6.6
Red hake	1.0	Cusk eel	5.5
Spotted hake	1.0	Yellowtail flounder	5.2
Alewife	1.0	Weakfish	5.2
Goosefish	1.0	Atlantic bonito	4.6
Fourspot flounder	0.8	*Benthosema glaciale*	4.1
Sand eel	0.8	Atlantic herring	3.9
Atlantic mackerel	0.6	Black sea bass	3.3
Summer flounder	0.6	Windowpane	2.3

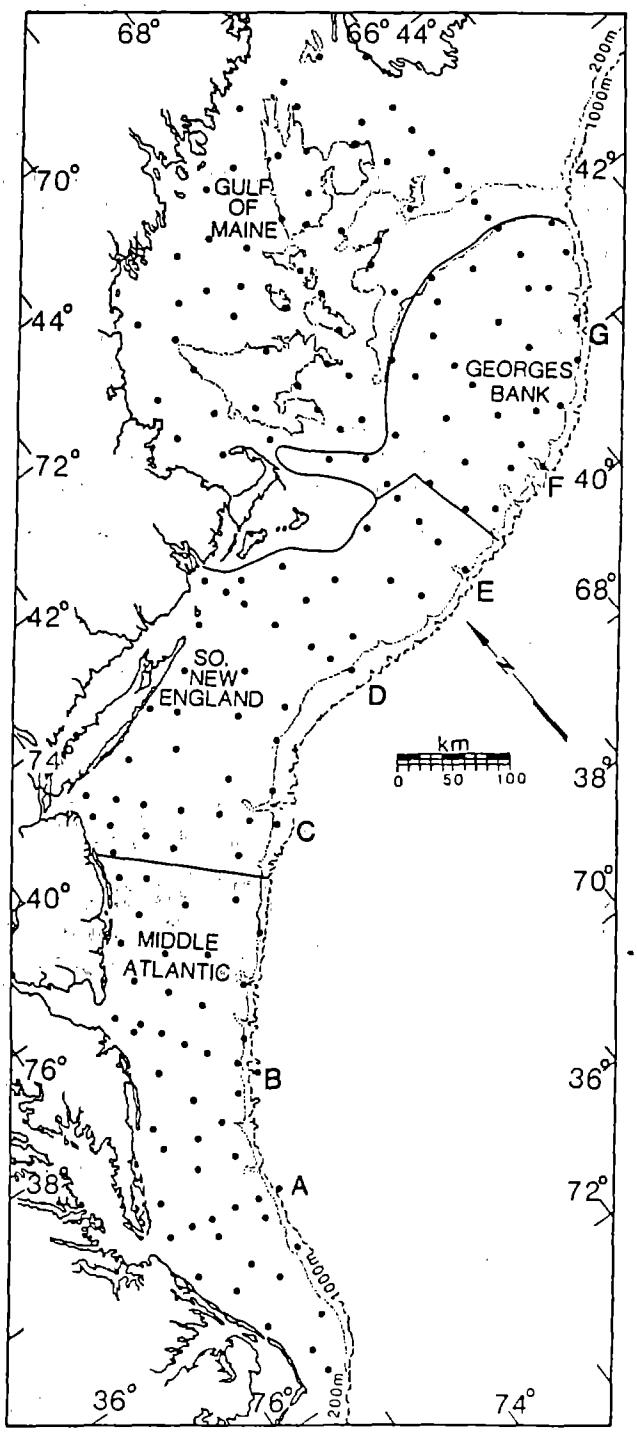

Fig. 1. Standard station plan and four subareas for NEFC ichthyoplankton surveys.

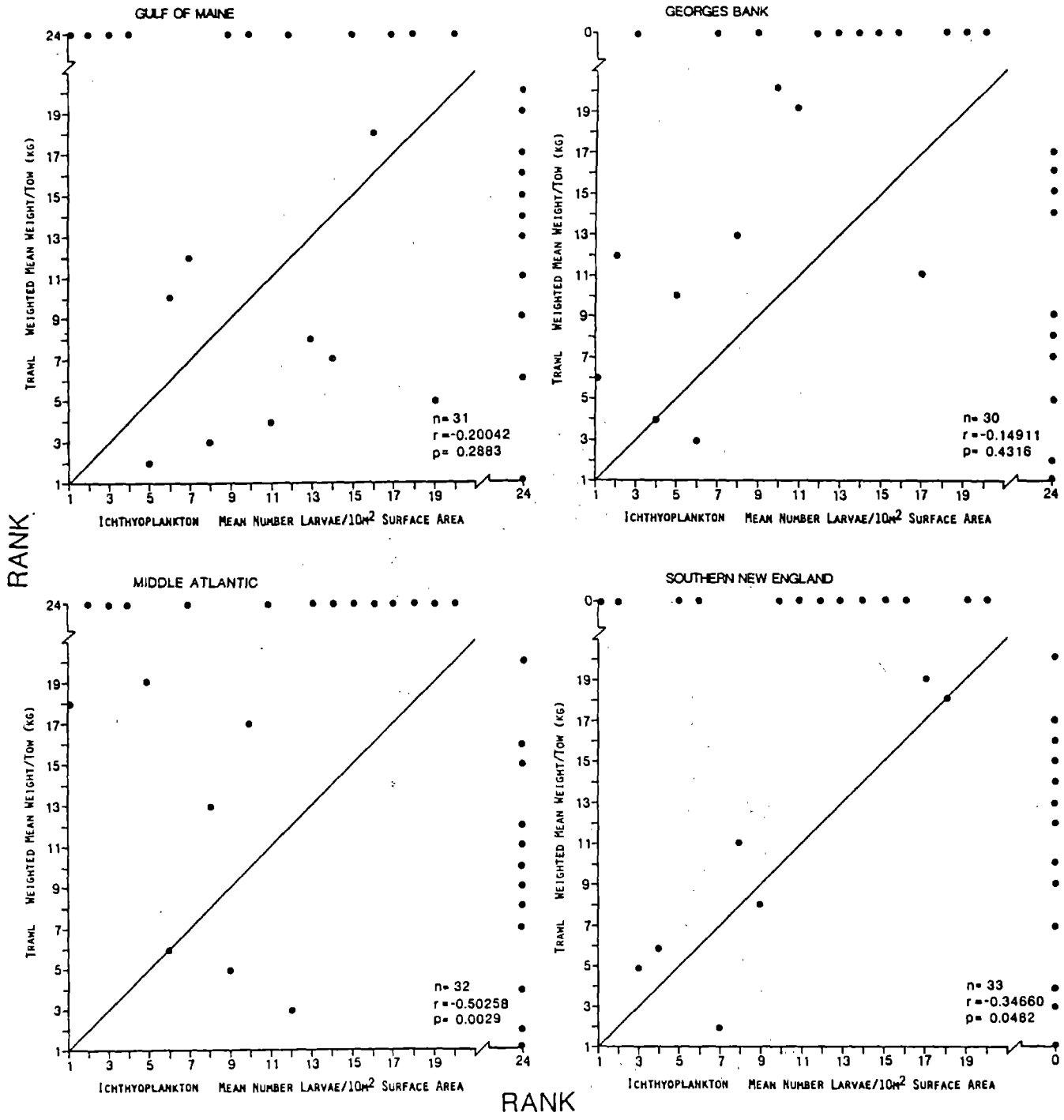

Fig. 2. Comparison of principal taxa from NEFC trawl (1977-1984) and ichthyoplankton (1977-1983) surveys in four subareas off the northeastern United States, using Spearman's Rank Correlation. Results show no significant ($P<0.05$) positive correlations for the two data sets. Sample size (n), correlation coefficient (r), and probability values (p) are noted for each subarea. Taxa appearing in only one of the two data sets were assigned the rank of 24.

USE OF EGG DATA TO ESTIMATE TOTAL FINFISH BIOMASS FOR THE NORTHEAST CONTINENTAL SHELF ECOSYSTEM

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ABSTRACT

The spawner biomass and total population biomass for the entire finfish community off northeastern United States were estimated for years 1979 to 1984 based primarily on egg surveys. Surveys were conducted 6 to 8 times per year between Nova Scotia and Cape Hatteras. Sampled egg densities were adjusted to account for mortality. The biomass of spawners was estimated assuming that the number of eggs spawned is proportional to the biomass of spawners. Further adjustments were made to take account of species that do not have pelagic eggs (e.g. sand eel, *Ammodytes* spp., and dogfish, *Squalus acanthias* and *Mustelus canis*) and the immature component of the population. Spawner biomass estimates for the six years ranged from 3.6 to 5.9 million metric tons (mmt) and total population biomass estimates from 5.3 to 8.6 mmt. These estimates are similar in magnitude to estimates derived from trawl surveys two decades earlier, but significantly higher than recent estimates using the same method.

INTRODUCTION

Ichthyoplankton surveys are a useful means for monitoring changes in structure and dominance within fish communities of marine ecosystems. Such surveys have been used widely in estimating spawner and population biomass of individual species including: Atlantic mackerel, *Scomber scombrus*, (Sette, 1943; Iversen, 1977; Berrien et al., 1981; Lockwood et al., 1981; Walsh et al., 1983; Iversen and Eltink, 1983); Atlantic herring, *Clupea harengus*, (Parrish and Saville, 1962, Hardwick, 1973); haddock, *Melanogrammus aeglefinus*, (Saville, 1964); round herring, *Etrumeus teres*, (Houde, 1977); and northern anchovy, *Engraulis mordax*, (Ahlstrom, 1968; Smith, 1972; Parker, 1980; Stauffer, 1980; Picquelle and Hewett, 1983). To date biomass estimates derived from ichthyoplankton data have only been applied on a species by species basis. However, the sampling strategy used to monitor ichthyoplankton of the northeastern United States continental shelf is suitable for estimation of spawner biomass and total population biomass for the entire finfish community, as described in this paper. Trends in total finfish biomass estimates are useful indicators of potential fishery yield. In addition an annual time series of total finfish biomass estimates is relevant to the hypothesis that fishing affects species composition but that production and finfish density are relatively constant (e.g., Hennemuth, 1979).

The methods we used for deriving total finfish biomass estimates are based on a model that: (1) assumes the number of eggs spawned is proportional to the biomass of mature fish; (2) assumes egg development time is a function of temperature, independent of species; (3) applies an egg mortality rate of $10\% \cdot d^{-1}$; and (4) treats ichthyoplankton survey data as a random sample in time and space. The model allows the mean catch of eggs per

unit of area to be converted into an estimate of spawner biomass for those species with pelagic eggs. A cohort model was developed to estimate the proportion of finfish biomass which is immature. This model was used to scale up spawner biomass estimates. An additional adjustment was made to take account of species with non-pelagic eggs. In the case of sand eel the spawner biomass is based on back-calculated larva abundance. For others (e.g., dogfish; skates [Rajidae]; squid [Cephalopoda]; redfish [*Sebastes* spp.]; and river herrings [*Alosa* spp.]) the amount added is based on methods of Clark and Brown (1977).

METHODS

Planktonic fish egg collections used in estimating spawner biomass and total population biomass reported in this paper are made during surveys conducted between Nova Scotia and Cape Hatteras (Fig. 1). The area was covered in full or in part six to eight times per year for the 1979 to 1984 reporting period. Each full survey included approximately 175 plankton sampling stations. Plankton sampling procedures are outlined in Smith and Goulet (this volume) and described in detail by Sibunka and Silverman (1984).

All fish eggs are removed from samples. For each station, the catch is adjusted to become the number of eggs sampled per 10 m^2 of sea surface area using the following relationship:

$$x_i = 10\, C_i\, (d_i/v_i) \qquad (1)$$

where x_i = number of eggs sampled per 10 m^2 at station i

C_i = catch of eggs at station i,

d_i = maximum sampling depth at station i,

v_i = volume (m^3) of water strained by the net at station i, and

i = the ith station of the non-zero catch series 1, ...n_i.

The expected density (per unit area, E(C)) of eggs caught during a survey is a function of the biomass of spawners (B) which produce pelagic eggs, the average number of eggs spawned per unit weight of spawners, both sexes combined (F), the mortality rate of eggs (Z), their development time to hatching (t), and the area (A) and period of time (T) sampled by the survey:

$$E(C) = \left(\int_0^t FBe^{-Zt}dt\right)/AT$$

$$= (FB[1-e^{-Zt}])/AZT \qquad (2)$$

If the sample mean catch per unit area ($\bar{C}$) is substituted for E(C), and equation (1) is solved for spawner biomass:

$$B = (\bar{C}AZTB)/(F[1-e^{-Zt}]) \qquad (3)$$

Equation (3) was applied to $\overline{C}$ for each survey and subarea. $\overline{C}$ and its standard error were calculated by Pennington's (1983) method based on the delta distribution. Term A was set equal to the surface area of each subarea. The mortality rate was assumed to be $10\% \cdot d^{-1}$ ($Z = 0.10536$). This is a reasonable, somewhat conservative, estimate of daily egg mortality based on observed rates of 5.0% for Atlantic mackerel in 1932 (Sette, 1943), 11.6% for Atlantic mackerel in 1977 (Berrien et al., 1981), 16.2% for yellowtail flounder (*Limanda ferruginea*) in 1977 (Berrien, 1981), 47.0% for silver hake (*Merluccius bilinearis*) in 1979 (Berrien, 1983), a mean of 11.8% for Atlantic cod (*Gadus morhua*) and haddock in 1979-1982 (Berrien, unpubl. data) and a mean of 26.6% for yellowtail flounder in 1979-1982 (Berrien, unpubl. ms.). Julian date midpoints of sampling corresponding to each calculated mean egg density were derived using first and last positive-tow occurrences in each subarea. The time span (T) representing each survey was defined as extending from halfway between preceding and following survey midpoints, truncated at year's end. The value for fecundity (F), the number of eggs produced annually per unit weight of spawners, was determined from existing information on 23 species (Table 1). Fecundity values for species co-occuring on Tables 1 and 2 were weighted by their respective percent abundances. For species whose fecundity is unknown the overall mean for 23 species (720 eggs per gm female) was used, weighted by the combined percent abundance of these species. Assuming a 1:1 sex ratio the weighted mean fecundity values per gm female were converted to the following fecundity values per metric ton (mt), both sexes included: Gulf of Maine 453,200,000, Georges Bank 342,450,000, Southern New England 504,550,000 and Middle Atlantic 374,450,000. In order to allow adjustment of catches for mortality a time period of egg incubation (t) was estimated. Incubation time was calculated from prevailing temperature and the function shown in Fig. 2. The data points and resulting fitted curve in this figure are based on existing information for 30 species of marine fish eggs. Prevailing water temperature at the time of each survey within each subarea was calculated from regressions of mean water-column temperature on Julian date from hydrographic survey data (Mountain, 1985; D. G. Mountain, pers. commun.).

The number of eggs spawned per day (K_s), which is an index of spawning intensity, is derived from equation (3) by multiplying by F and dividing by T:

$$K_s = \overline{C}AZ/1\text{-}e^{-Zt} \qquad (4)$$

Since the demersal eggs of sand eel are rarely seen in our plankton samples, and because this fish is known to constitute a significant portion of the finfish biomass within our survey area (Sherman et al., 1981), we added estimates of spawner biomass of sand eel based on larva data to that of other species based on egg data. Sand eel spawner biomass for the total survey area has been calculated at between 701,440 and 1,228,830 mt over the years 1979 to 1984 (W. W. Morse, pers. commun.).

In addition to the egg species comprising the bulk of our samples (Table 2) and sand eel noted above, certain other species do not produce pelagic eggs (e.g., herring, winter flounder, dogfish, and skates) and are not represented by our egg collections. These species currently account for about 29% of the finfish and squid biomass estimates based on otter trawl data using the method of Clark and Brown (1977) (S. H. Clark, pers. commun.). The biomass estimates derived from eggs were raised by 29% to account for these species.

ESTIMATING THE RATIO OF IMMATURE TO MATURE BIOMASS OF A FISH POPULATION

The concentration of eggs collected by a random sample can be used to estimate the biomass of mature fish in a population. In order to estimate total population biomass it is necessary to know or estimate the ratio of immature to mature biomass, i.e., $X = B_1/B_2$ where B_1 is the immature biomass and B_2 is the mature biomass. A statistically derived estimate is impractical for a variety of reasons. For example, random sampling is not possible since not all species or maturity stages have equal probability of being sampled.

X can be estimated by making a few simple, but plausible, assumptions about populations. We assume that the biomass of a cohort of fish increases monotonically from eggs until the age of maturity (t_1) at an instantaneous rate of g_1, and that it decreases monotonically at an instantaneous rate of g_2 until the biomass is diminished to 0. In theory, this will take an infinitely long period of time for an exponential model. The age at which the mature biomass has been reduced to 5% of its peak is t_2. B_0 is the biomass at time 0; i.e., biomass of eggs spawned. Then, the biomass of immature fish is:

$$\bar{B}_1 = \int_0^{t_1} B_0 e^{g_1 t}\, dt$$

$$= (B_0/g_1)\,(e^{g_1 t_1} - 1) \qquad (5)$$

The biomass of mature fish is:

$$\bar{B}_2 = \int_{t_1}^{\infty} B_0 e^{g_1 t_1} e^{g_2 (t - t_1)}\, dt$$

$$= (B_0 e^{g_1 t_1})/g_2\,(e^{g_2[\infty - t_1]} - 1)$$

$$= -(B_0 e^{g_1 t_1})/g_2 \qquad (6)$$

Of course B_0 is related to the mature biomass. It is reasonable to assume it is about 10% (Parrish, 1975). This assumption allows us to functionally relate g_2 to g_1 and t_1:

$$g_2 = -0.10\, e^{g_1 t_1} \qquad (7)$$

The age at which the mature biomass has diminished to 5% of its peak is:

$$t_2 = ([\log_e\{0.05\}]/g_2) + t_1 \quad (8)$$

The ratio of immature to mature biomass (X) is derived by dividing equation (5) by equation (6). The sensitivity of X, g_2 and t_2 to g_1 and t_1 is given in Table 3.

For the northeast region, maturity is typically at age two or three and most of the biomass has perished by age 10 or less. Therefore, it is reasonable to expect that the immature biomass is at least 45% of the mature biomass. To estimate total biomass, the mature biomass estimated from ichthyoplankton data should be multiplied by 1.45.

RESULTS

Subarea values of daily egg production are plotted (Figs. 3-6) along with accumulated values over the total survey area (Fig. 7). These graphs of egg production show that finfish spawning is at a minimum level during November through March, increases during April to June or July with a seasonal peak during June, July or August then declines in August to October.

Annual egg production estimates for 1979 to 1984 are listed by subarea and for the total survey area (Table 4). These values are annually integrated totals, or areas beneath the curves noted above. The Gulf of Maine consistently produced the fewest eggs over the six years examined. Although Georges Bank exhibited some of the highest egg densities, Southern New England and Middle Atlantic waters produced more eggs because of the larger size of these subareas.

Annual spawner biomass estimates, derived primarily from egg data and ranging from 3.6 to 5.9 mmt, are provided along with total finfish population biomass estimates of 5.3 to 8.6 mmt (Table 4 and Fig. 8). These estimates are compared directly to similar stock estimates given by Conservation and Utilization Division, NEFC (1985).

DISCUSSION

Previous estimates of total finfish biomass off the northeastern United States were based on a combination of trawl survey and commercial fisheres data (Clark and Brown, 1977; Conservation and Utilization Div., NEFC, 1985). While the methodology may be reasonable for the principal demersal species which are vulnerable to a bottom trawl it is less appropriate for pelagic and other unexploited species. Advantages of an ichthyoplankton-based estimate are that it is useful for all species with pelagic eggs or larvae, it is fishery independent and does not depend on the use of landing statistics. Furthermore it includes species not vulnerable to the otter trawl.

Resulting estimates provided here appear to be relatively stable between years, and the magnitude of the fishery resource appears to be greater than that reported by Clark and Brown (1977) and Conservation and Utilization Division, NEFC, (1985).

Fecundity values found in the literature and used in this paper represent results of several research efforts. With such a variety of studies and methodologies it follows that there may be inconsistencies between, and systematic problems among, the various studies, which in turn may have biased our population estimates. For example, if there is a

significant amount of unaccounted for resorption of eggs within the ovary which was wrongly attributed to be part of the annual fecundity, then the reported fecundity value is too high resulting in a reciprocal downward bias of the same magnitude in our spawner biomass estimate. Similarly, if an incorrect size threshold was applied in distinguishing between yolked oocytes which would be spawned in the current year from smaller oocytes to be spawned in future years, then the reported fecundity value will be biased and in turn cause a reciprocal bias of the same magnitude in our estimate of spawners.

While we agree that our use of an assumed, extrinsically based, $10\%\cdot d^{-1}$ egg mortality rate, rather than an intrinsically based one, has undoubtedly caused some bias in our results, we also feel that this bias is probably not profound. For example, halving the mortality rate used, to $5\%\cdot d^{-1}$, results in a reduction of 13.0% in the estimates provided and increasing the mortality rate by half (to $15\%\cdot d^{-1}$ per day) and doubling it (to $20\%\cdot d^{-1}$) result in increases of 10.8% and 19.5% respectively in the estimates of total eggs spawned.

Given additional species empirical egg mortality rates, we will be justified in future attempts such as this to adjust the rates on perhaps a seasonal or geographic basis. For the present, the $10\%\cdot d^{-1}$ rate is sufficiently accurate to demonstrate the utility of the method and illustrate population trends and levels noted above. Additional experimental measurement of stage duration at varying incubation temperatures for a variety of species would allow the determination of egg mortality rates for these same species. Therefore, while acknowledging that there may be biases in our estimates of spawner and total population biomass, it is important to note that the problems are not intractable. With improved and increased observations of fecundity, incubation rates and mortality rates the above-outlined method of estimating biomass can be improved.

LITERATURE CITED

Ahlstrom, E. H. 1968. An evaluation of the fishery resources available to the California fishermen. pp. 65-80. *In* D. Gilbert (ed.). The future of the fishing industry of the United States. Univ. Wash. Publ. Fish., New Ser. 4.

Berrien, P. 1981. Yellowtail flounder, *Limanda ferruginea*, estimates of egg abundance and population size during spring 1977 in Gulf of Maine, Georges Bank, southern New England and Middle Atlantic Bight waters. ICES C.M. 1981/G:65.

Berrien, P. 1983. Silver hake, *Merluccius bilinearis*, egg census and adult population estimate for 1979 in waters off eastern United States. ICES C.M. 1983/G:46. 17 pp. (mimeo).

Berrien, P. L., N. A. Naplin, and M. R. Pennington. 1981. Atlantic mackerel, *Scomber scombrus*, egg production and spawning population estimates for 1977 in the Gulf of Maine, Georges Bank and Middle Atlantic Bight. Rapp. P.-v. Reun. Cons. int. Explor. Mer 178:279-288.

Bigelow, H. B., and W. C. Schroeder. 1953. Fishes of the Gulf of Maine. Fish. Bull. Fish and Wildl. Serv. 53(74):577 pp.

Bowering, W. R. 1978. Fecundity of witch flounder (*Glyptocephalus cynoglossus*) from St. Pierre Bank and the Grand Bank of Newfoundland. J. Fish. Res. Board Can. 35(9):1199-1206.

Buzeta, M.-I., and K. G. Waiwood. 1982. Fecundity of Atlantic cod (*Gadus morhua*) in the southwestern Gulf of St. Lawrence. Canadian Tech. Rept. Fish. Aquat. Sci. 1110:6 pp.

Clark, S. H., and B. E. Brown. 1977. Changes in biomass of finfishes and squids from the Gulf of Maine to Cape Hatteras, 1963-74, as determined from research vessel survey data. Fish. Bull., U.S. 75:1-21.

Conservation and Utilization Division, NEFC. 1985. Status of the fishery resources off the northeastern United States for 1985. NOAA Tech. Mem. NMFS-F/NEC-42. 137 pp.

Cupka, D. M., R. K. Dias, and J. Tucker. 1973. Biology of the black sea bass, *Centropristis striata* (Pisces: Serranidae) from South Carolina waters. S. C. Wildl. Mar. Resour. Dep. (unpubl. ms.). 93 pp.

Earll, R. E. 1883. The Spanish mackerel, *Cybium maculatum* (Mitch.) Ag.; its natural history and artificial propagation, with an account of the origin and development of the fishery. Rep. U. S. Commer. Fish. 1880, pp. 395-426.

Freeman, B., and S. Turner. 1977. Biological and fisheries data on tilefish, *Lopholatilus chamaeleonticeps* Goode and Bean. SHL, NEFC, Tech. Ser. Rep. No. 5, 41 pp.

Hardwick, J. E. 1973. Biomass estimates of spawning herring, *Clupea pallasi*, herring eggs and associated vegetation in Tomales Bay. Calif. Fish Game 59(1):33-61.

Hennemuth, R. C. 1979. Man as predator. pp. 507-532. *In* Patil, G. P. and M. Rosenzweig (Eds.), Contemporary Quantitative Ecology and Related Ecometrics.

Hodder, V. M. 1963. Fecundity of Grand Bank haddock. J. Fish. Res. Board Can. 20:1465-1487.

Houde, E. D. 1977. Abundance and potential yield of the round herring, *Etrumeus teres*, and aspects of its early life history in the eastern Gulf of Mexico. Fish. Bull., U.S. 75:61-89.

Houghton, R. G., J. M. Last, and P. J. Bromley. 1985. Fecundity and egg size of sole (*Solea solea* (L.)) spawning in captivity. J. Cons. int. Explor. Mer 42:162-165.

Howell, W. H., and D. H. Kessler. 1977. Fecundity of the Southern New England stock of yellowtail flounder, *Limanda ferruginea*. Fish. Bull., U.S. 75:877-880.

Iversen, S. A. 1977. Spawning, egg production and stock size of mackerel (*Scomber scombrus* L.) in the North Sea 1968-1975. ICES C. M. 1977/H:17. 18 pp. (mimeo).

Iversen, S. A., and A. Eltink. 1983. Spawning, egg production and stock size of North Sea mackerel in 1982. ICES C.M. 1983/H:46. 12 pp. (mimeo).

Ivo, C.T.C. 1974. Epoca de desova e idade na primeira maturacao sexual da cavala, *Scomberomorus cavalla*, no Estado do Ceara. Arq. Cien. Mar. 12(1):27-29.

Jackson, H. W., and R. E. Tiller. 1952. Preliminary observations on spawning potential in the striped bass (*Roccus saxatilus*) (Walbaum). Md. Dep. Res. Educ., Publ. 93:16 pp.

Lassiter, R. R. 1962. Life history aspects of the bluefish, *Pomatomus saltatrix* (Linnaeus), from the coast of North Carolina. M.S. Thesis, N. C. State College, Raleigh. 103 pp.

Laurence, G. C., and W. H. Howell. 1981. Embryology and influence of temperature and salinity on early development and survival of yellowtail flounder *Limanda feruginea*. Mar. Ecol. Prog. Ser. 6:11-18.

Lockwood, S. J., J. H. Nichols, and W. A. Dawson. 1981. The estimation of a mackerel (*Scomber scombrus* L.) spawning stock size by plankton survey. J. Plank. Res. 3(2):217-233.

Mari, A., and I. Ramos. 1979. Fecundity of silver hake on the Scotian Shelf. ICNAF Res. Doc. 79/VI/66.

Merriner, J. V. 1976. Aspects of the reproductive biology of the weakfish, *Cynoscion regalis* (Sciaenidae), in North Carolina. Fish. Bull., U.S. 74:18-26.

Merriner, J. V., and J. L. LaRoche. 1977. Fecundity of the northern puffer, *Sphoeroides maculatus*, from Chesapeake Bay. Ches. Sci. 18(1):81-84.

Morse, W. W. 1980a. Spawning and fecundity of Atlantic mackerel, *Scomber scombrus*, in the Middle Atlantic Bight. Fish. Bull., U.S. 78:103-108.

Morse, W. W. 1980b. Maturity, spawning and fecundity of Atlantic croaker, *Micropogonias undulatus*, occurring north of Cape Hatteras, North Carolina. Fish. Bull., U.S. 78:190-195.

Morse, W. W. 1981. Reproduction of the summer flounder, *Paralichthys dentatus*. J. Fish. Biol. 19:189-203.

Mountain, D. G. 1985. A review of MARMAP hydrographic sampling. MARMAP Contribution No. FED/NEFC 85-24. Unpubl. ms.

Parker, K. 1980. A direct method for estimating northern anchovy, *Engraulis mordax*, spawning biomass. Fish. Bull., U.S. 78:541-544.

Parrish, J. D. 1975. Marine trophic interactions by dynamic simulation of fish species. Fish. Bull., U.S. 73:695-716.

Parrish, B. B., and A. Saville. 1962. The estimation of fishing mortality rate for bank spawners, from larval abundance data. ICES C.M. 1960, Doc. No. 40 (mimeo).

Pearson, J. C. 1929. Natural history and conservation of redfish and other commercial sciaenids on the Texas coast. Bull. U. S. Bur. Fish. 44:129-214.

Pennington, M. P. 1983. Efficient estimators of abundance, for fish and plankton surveys. Biometrics 39:281-286.

Picquelle, S. J., and R. P. Hewitt. 1983. The northern anchovy spawning biomass for the 1982-83 California fishing season. CalCOFI Rep. 24:16-28.

Saila, S. B. 1961. The contribution of estuaries to the offshore winter flounder fishery in Rhode Island. Proc. Gulf Caribbean Fish. Inst., 14th Ann. Session pp. 95-109.

Saville, A. 1964. Estimation of the abundance of a fish stock from egg and larval surveys. Rapp. P.-v. Reun. Cons. int. Explor. Mer. 155:164-170.

Sette, O. E. 1943. Biology of the Atlantic mackerel (*Scomber scombrus*) of North America. Part I: Early life history, including growth, drift and mortality of the egg and larval populations. U. S. Fish Wildl. Serv., Fish. Bull. 50(38):149-237.

Sheri, A. N., and G. Power. 1968. Reproduction of white perch, *Roccus americanus*, in the Bay of Quinte, Lake Ontario. J. Fish. Res. Board Can. 25:2225-2231.

Sherman, K., C. Jones, L. Sullivan, W. Smith, and P. Berrien. 1981. Congruent shifts in sand eel abundance in western and eastern North Atlantic ecosystems. Nature 291(5815):486-489.

Sibunka, J. D.,and M. J. Silverman. 1984. MARMAP surveys of the continental shelf from Cape Hatteras, North Carolina to Cape Sable, Nova Scotia (1977-1983). Atlas No. 1. Summary of operations. NOAA Tech. Mem. NMFS-F/NEC-33. 306 pp.

Smith, P. E. 1972. The increase in spawning biomass of northern anchovy, *Engraulis mordax*. Fish. Bull., U.S. 70:849-874.

Smith, W. G., and J. Goulet. This volume. MARMAP ichthyoplankton surveys: An overview of methods and data base management.

Stauffer, G. D. 1980. Estimate of the spawning biomass of the northern anchovy centeral subpopulation for the 1979-80 fishing season. CalCOFI Rep. 21:17-22.

Topp, R. W. 1968. An Estimate of fecundity of the winter flounder, *Pseudopleuronectes americanus*. J. Fish. Res. Board Can. 25:1299-1302.

Walsh, M., P. Hopkins, and P. Rankine. 1983. Results of the North Sea mackerel egg surveys in 1982. ICES C.M. 1883/H:49. 24 pp. (mimeo).

Westin, D. T., K. J. Abernathy, L. E. Meller, and B. A. Rogers. 1979. Some aspects of biology of the American sand lance, *Ammodytes americanus*. Trans. Am. Fish. Soc. 108(3):328-331.

Table 1. Fecundity values for 23 fish species used in calculating spawner biomass estimates from MARMAP I egg samples.

Taxon	No. eggs per gm of female		Source
Melanogrammus aeglefinus	640	$\bar{x}$ = 721.5	Hodder, 1963
	803		Bigelow and Schroeder, 1953
Gadus morhua	398.1		Buzeta and Waiwood, 1982
Pollachius virens	670		Bigelow and Schroeder, 1953
Merluccius bilinearis	815.2		Mari and Ramos, 1979
Ammodytes sp.	973.		Westin et al., 1979
Scomber scombrus	1400	$\bar{x}$ = 1237	Morse, 1980a
	1074		Bigelow and Schroeder, 1953
Scomberomorus maculatus	661	$\bar{x}$ = 606	Earll, 1883
	551		
Scomberomorus cavalla	248.5		Ivo, 1974
Lopholatilus chamaeleonticeps	750		Freeman and Turner, 1977
Morone saxatilis	176	$\bar{x}$ = 184	Jackson and Tiller, 1952
	192		
Morone americana	500		Sheri and Power, 1968
Micropogonias undulatus	1000		Morse, 1980b
Pogonias cromis	300		Pearson, 1929
Cynoscion regalis	1330.7	$\bar{x}$ = 1200.3	Merriner, 1976
	1070.0		
Pomatomus saltatrix	404		Lassiter, 1962
Sphoeroides maculatus	751		Merriner and LaRoche, 1977

Table 1 (continued).

Taxon	No. eggs per gm of female		Source
Solea solea	471		Houghton, Last and Bromley, 1985
Limanda ferruginea	2435.6		Howell and Kessler, 1977
Paralichthys dentatus	730		Morse, 1981
Pseudopleuronectes americanus	1687 1850 1220	$\bar{x}$ = 1586	Bigelow and Schroeder, 1953 Topp, 1968 Saila, 1961
Glyptocephalus cynoglossus	310.5		Bowering, 1978
Hippoglossus hippoglossus	43		Bigelow and Schroeder, 1953
Centropristis striata	223.4		Cupka et al., 1973
Mean fecundity for 23 species = 720 per gm of female			

Table 2. Fish-egg species-composition of MARMAP I samples, 1979 and 1980.

Taxon	Percent of total standardized catch	Percent occurrence
GULF OF MAINE		
Scomber scombrus	29.61	8.02
Enchelyopus cimbrius	18.71	34.60
Urophycis sp.	13.14	21.31
Melanogrammus aeglefinus	7.04	9.92
Hippoglossoides platessoides	5.93	14.35
Gadus morhua	4.06	17.72
Pollachius virens	3.76	6.33
Merluccius bilinearis	3.64	14.77
Peprilus triacanthus	3.52	4.43
Tautogolabrus adspersus	3.12	5.91
Limanda ferruginea	2.98	9.70
Brosme brosme	2.57	21.73
Glyptocephalus cynoglossus	1.57	8.23
	99.65	
10 other taxa	0.35	0.21 to 2.95
	100.00	
GEORGES BANK		
Gadus morhua	38.79	31.29
Urophycis sp.	29.89	26.07
Melanogrammus aeglefinus	9.37	23.93
Merluccius bilinearis	7.95	25.15
Limanda ferruginea	4.54	28.22
Hippoglossina oblonga	2.01	12.58
Merluccius albidus	1.65	13.50
Citharichthys/Etropus	1.61	11.66
Scophthalmus aquosus	1.03	13.80
Scomber scombrus	0.93	9.1
	97.77	
26 other taxa	2.23	0.31 to 12.88
	100.00	

Table 2 (continued).

Taxon	Percent of total standardized catch	Percent occurrence
SOUTHERN NEW ENGLAND		
Scomber scombrus	32.19	17.89
Urophycis sp.	21.61	41.24
Tautogolabrus adspersus	8.44	9.42
Limanda ferruginea	7.20	24.48
Peprilus triacanthus	6.68	12.99
Merluccius bilinearis	6.27	35.78
Hippoglossina oblonga	4.40	31.26
Citharichthys/Etropus	2.99	26.55
Scophthalmus aquosus	1.63	21.28
Merluccius albidus	1.44	12.43
Gadus morhua	1.38	17.89
Anchoa mitchilli	1.01	2.45
	95.24	
37 other taxa	4.76	0.19 to 15.07
	100.00	
MIDDLE ATLANTIC		
Anchoa mitchilli	49.22	14.34
Prionotus sp.	9.12	27.00
Citharichthys/Etropus	7.21	41.53
Urophycis sp.	6.42	37.99
Peprilus triacanthus	5.20	16.01
Cynoscion regalis	3.54	8.75
Scomber scombrus	2.69	8.57
Hippoglossina oblonga	2.64	33.71
Pomatomus saltatrix	2.43	8.38
Scophthalmus aquosus	2.24	26.26
Anchoa hepsetus	1.89	5.96
Merluccius bilinearis	1.34	14.90
Unknown #180 (*Micropogonias undulatus*?)	1.24	4.84
	95.18	
57 other taxa	4.82	0.19 to 16.76
	100.00	

Table 3. Response of g_2, t_2 and x to g_1 and t_1.

	t_1 = 2 yr			t_1 = 3 yr		
g_1	g_2	t_2	x	g_2	t_2	x
0.10	-0.12	26.6	0.22	-0.13	25.0	0.35
0.25	-0.16	20.2	0.25	-0.21	16.3	0.45
0.50	-0.27	13.0	0.34	-0.45	8.7	0.70
0.75	-0.45	8.7	0.46	-0.95	5.2	1.13
1.00	-0.74	6.1	0.64	-2.00	3.5	1.91

Table 4. Annual egg production, spawner biomass, and total population biomass estimates, 1979-1984.

	1979	1980	1981	1982	1983	1984
	Egg Production ($\times 10^{12}$) (coef. var. in parentheses)					
Gulf of Maine	99.366 (0.199)	225.099 (0.259)	105.662 (0.353)	201.757 (0.441)	96.816 (0.249)	103.950 (0.332)
Georges Bank	456.344 (0.395)	414.628 (0.294)	295.964 (0.237)	129.029 (0.279)	357.203 (0.357)	375.482 (0.281)
So. New England	518.157 (0.199)	389.724 (0.205)	362.855 (0.157)	375.320 (0.186)	455.620 (0.194)	409.929 (0.170)
Mid Atlantic	499.057 (0.180)	209.079 (0.158)	444.936 (0.212)	202.179 (0.173)	273.629 (0.300)	269.684 (0.147)
Total Area	1,572.924 (0.145)	1,238.530 (0.130)	1,209.417 (0.112)	908.285 (0.136)	1,183.269 (0.150)	1,159.045 (0.118)
	Plankton-based Spawner Biomass, includes sand eel (MT)					
Gulf of Maine	293,468	626,701	349,256	521,365	310,970	328,034
Georges Bank	1,388,675	1,309,028	952,004	434,358	1,116,648	1,171,024
So. New England	1,457,993	1,527,518	1,393,509	1,186,325	1,468,361	1,385,498
Mid Atlantic	1,472,887	803,822	1,407,446	683,765	914,524	906,489
Total Area	4,613,023	4,267,069	4,102,215	2,825,813	3,810,502	3,791,045
	Total Population Biomass (MT)					
Gulf of Maine	548,931	1,172,245	653,283	975,214	581,669	613,588
Georges Bank	2,597,517	2,448,537	1,780,724	812,467	2,088,690	2,190,401
So. New England	2,727,176	2,857,222	2,606,559	2,219,020	2,746,568	2,591,574
Mid Atlantic	2,755,035	1,503,549	2,632,627	1,278,982	1,710,617	1,695,588
Total Area	8,628,659	7,981,553	7,673,193	5,285,683	7,127,544	7,091,150

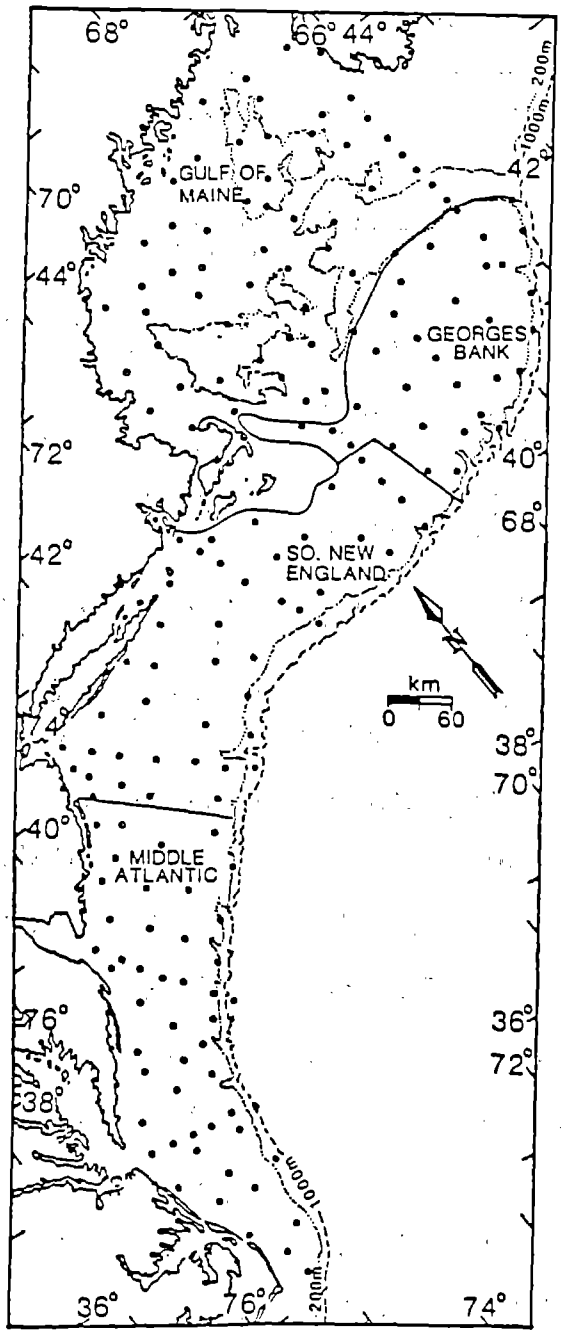

Fig. 1. Total survey area and subarea boundaries.

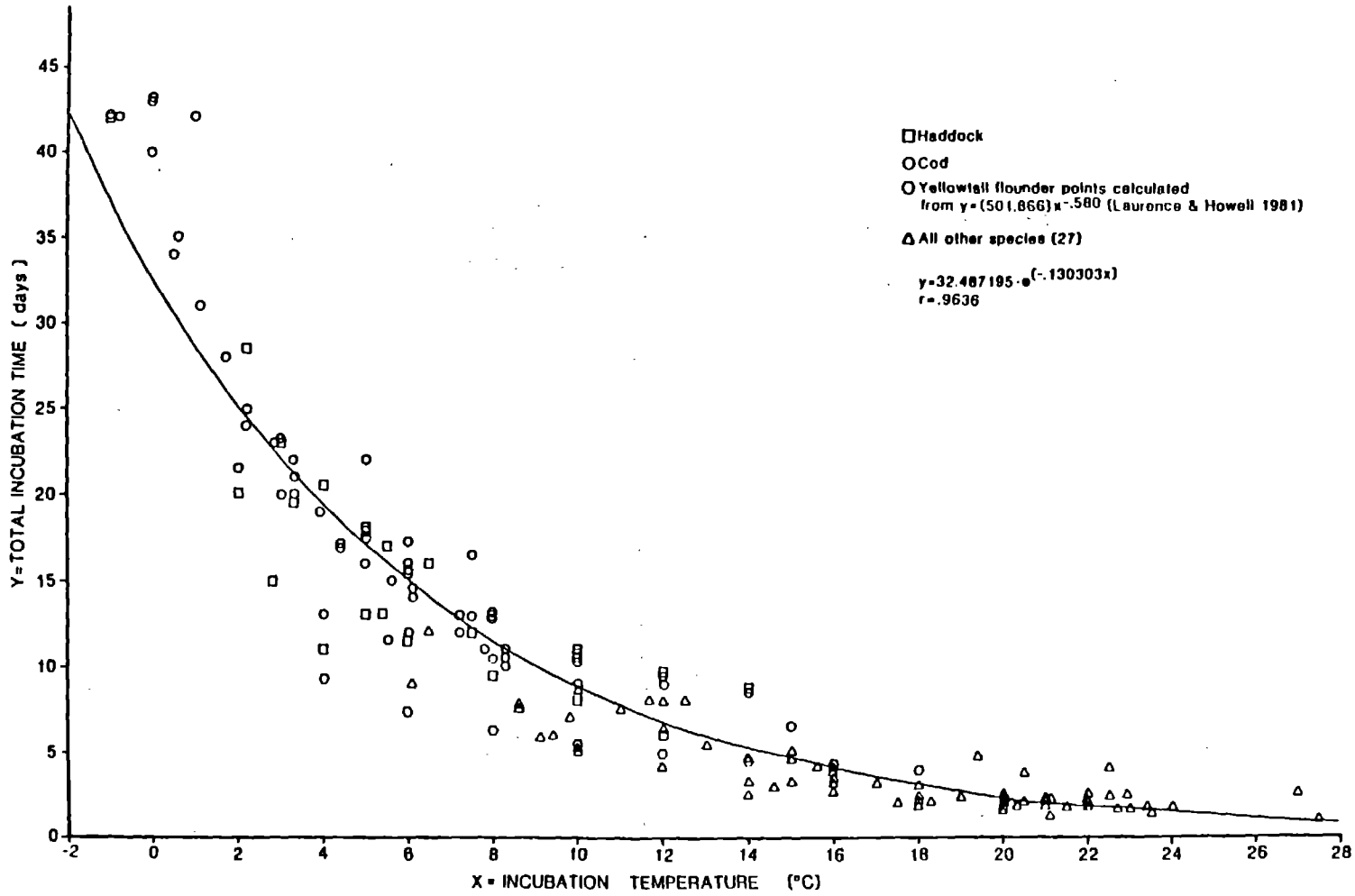

Fig. 2. Total incubation time until hatching regressed on temperature for 30 species of marine fish eggs.

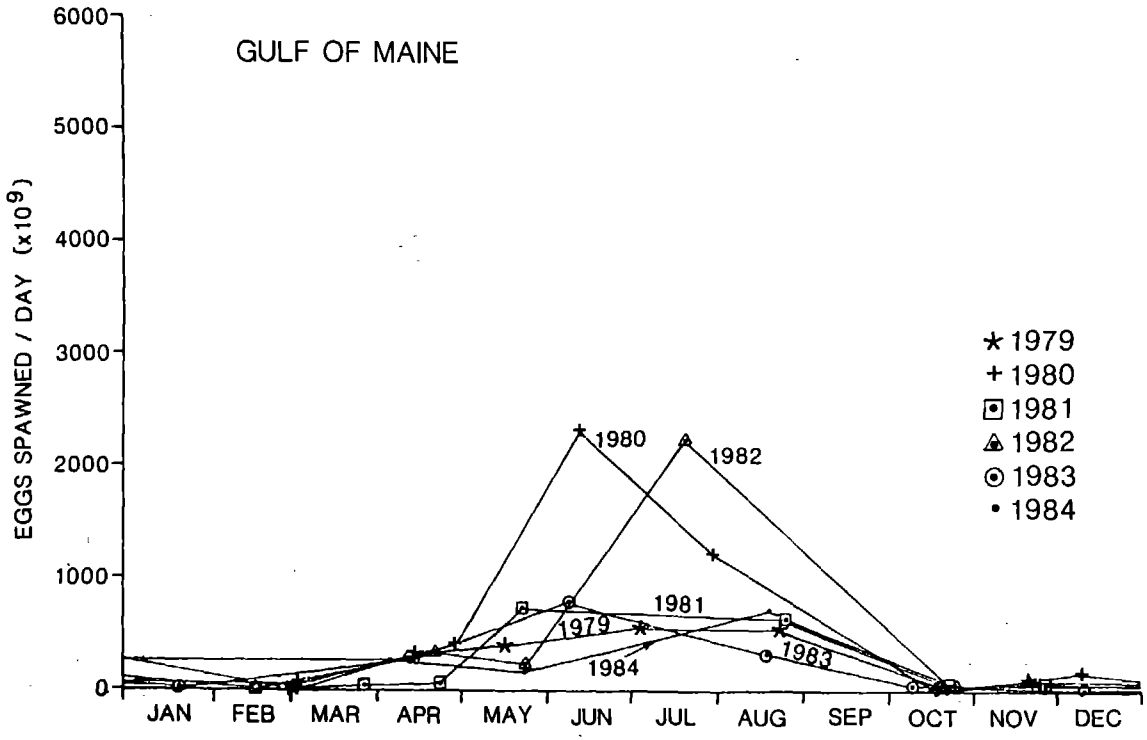

Fig. 3. Spawning intensity versus date in the Gulf of Maine for all fish egg species taken during bongo plankton tows, 1979-1984.

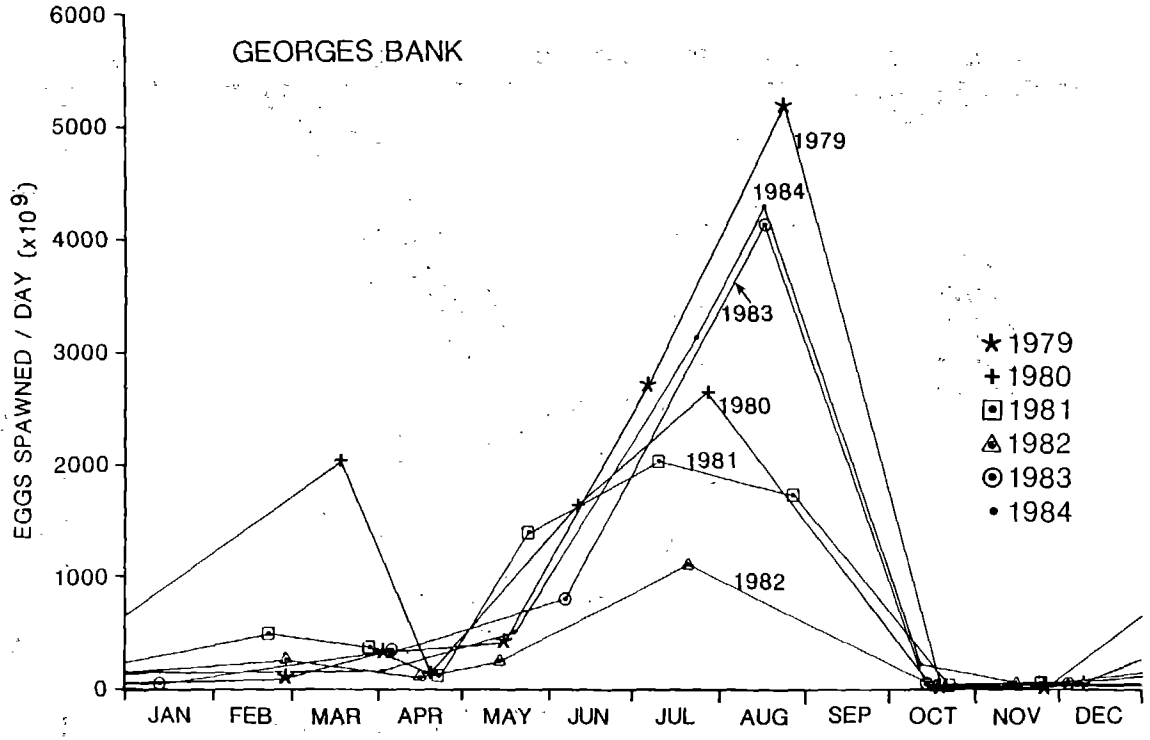

Fig. 4. Spawning intensity versus date on Georges Bank for all fish egg species taken during bongo plankton tows, 1979-1984.

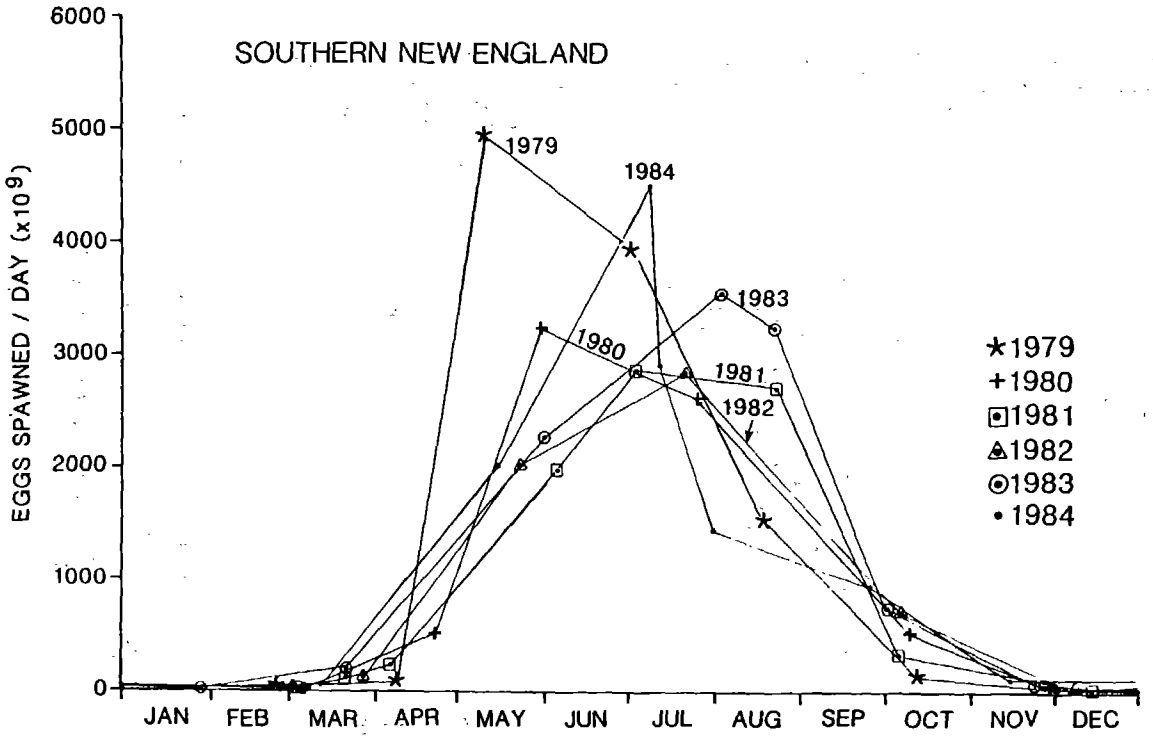

Fig. 5. Spawning intensity versus date in Southern New England waters for all fish egg species taken during bongo plankton tows, 1979-1984.

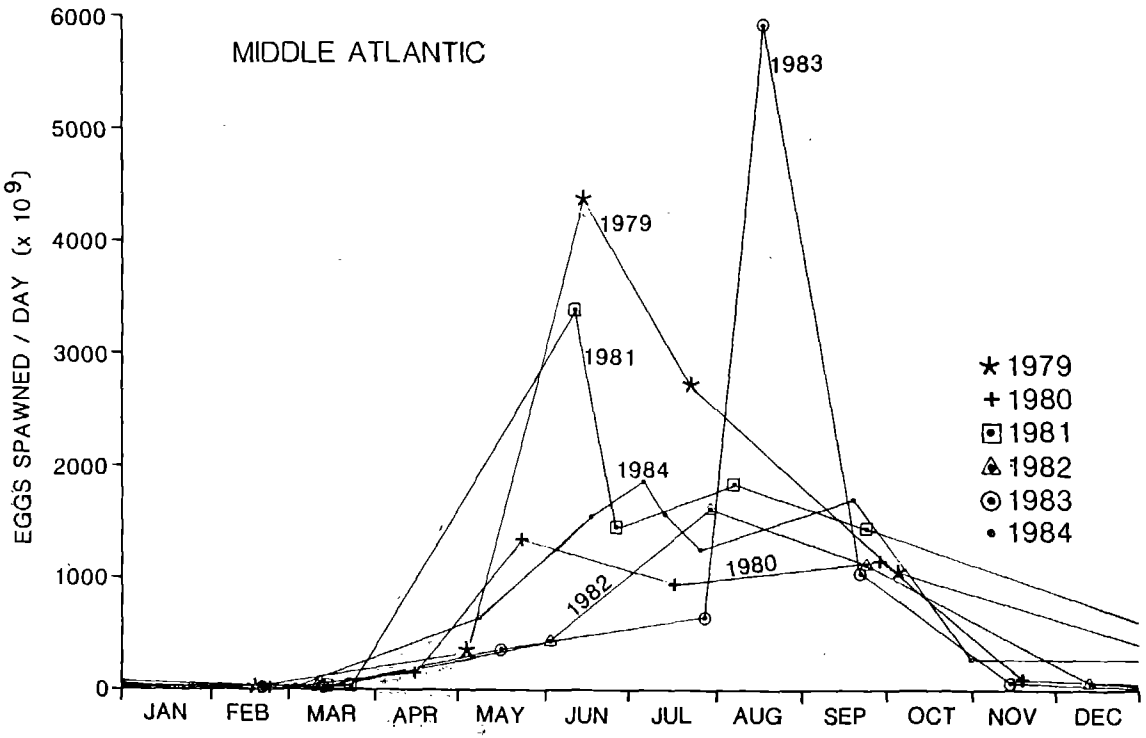

Fig. 6. Spawning intensity versus date in Middle Atlantic waters for all fish egg species taken during bongo plankton tows, 1979-1984.

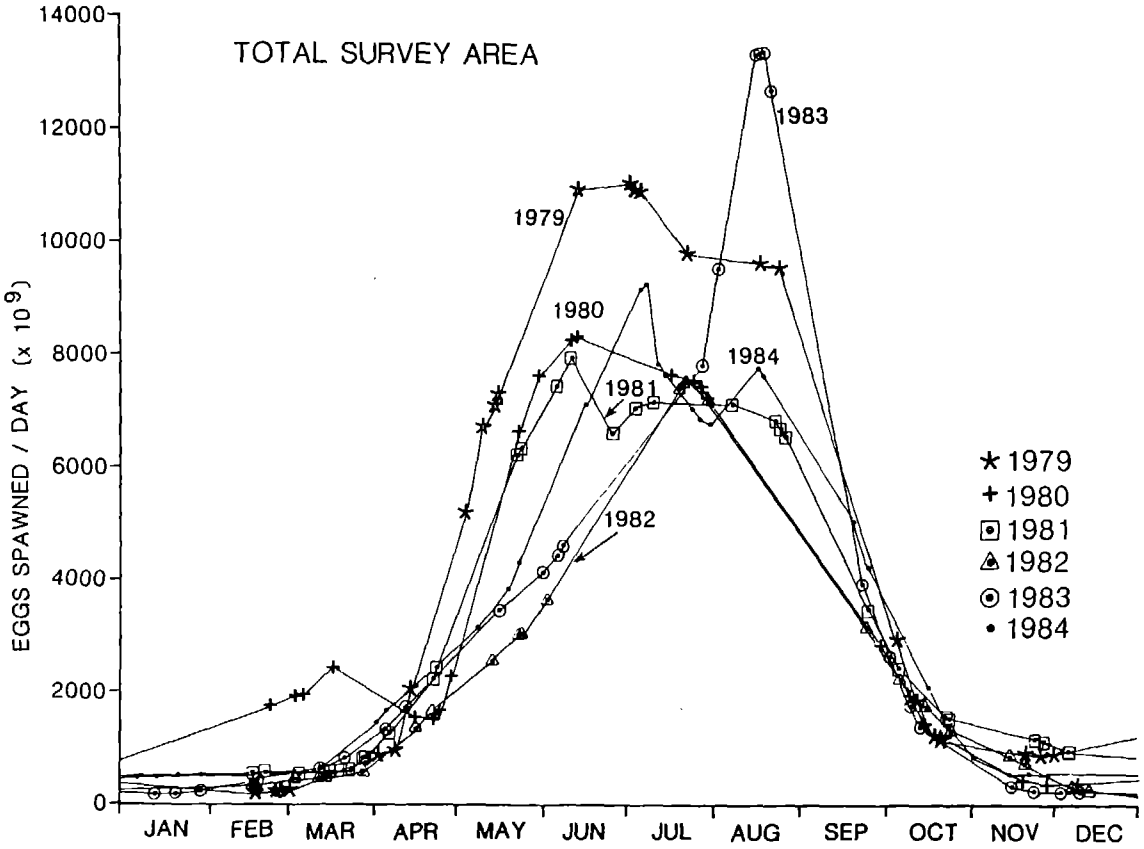

Fig. 7. Spawning intensity versus date in the total survey area for all fish egg species taken during bongo plankton tows, 1979-1984.

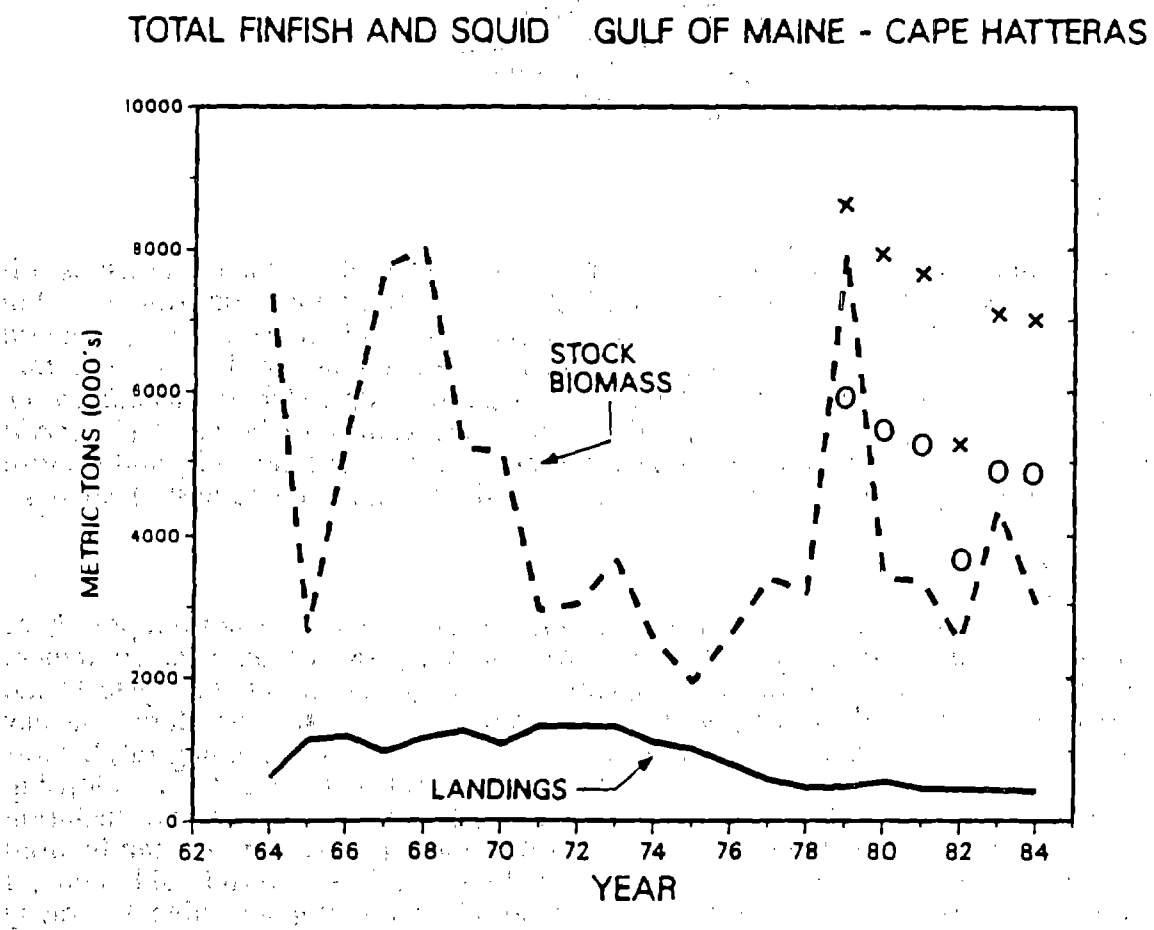

Fig. 8. Spawner biomass (0) and total fish population biomass (X) estimates, based primarily on planktonic fish egg data, superimposed on Fig. 3 of Cons. and Util. Div., NEFC (1985) illustrating alternative stock biomass estimates for 1979-1984.

LENGTH-DEPENDENT MORTALITY AND AN INDEX OF SPAWNING BIOMASS FROM LARVAL ABUNDANCE

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ABSTRACT

The average length dependent mortality rates for 15 taxa of marine larval fishes collected from 1977-1984 off the northeast United States show a seasonal trend from lowest in winter to a peak in summer. The mechanism to explain this trend appears to be predation upon the larvae which includes cannibalism. An index of annual production of 3 mm larvae was calculated for Atlantic cod (*Gadus morhua*), silver hake (*Merluccius bilinearis*), haddock (*Melanogrammus aeglefinus*), *Urophycis* spp., and yellowtail flounder (*Limanda ferruginea*). The index adjusts larval abundance for length dependent mortality and is more appropriate for relating spawner biomass to larval abundance than the unadjusted catches.

INTRODUCTION

In temperate and subarctic oceans the production of fish larvae is not temporally or areally constant throughout the year for any given species, or for all taxa combined. Various factors, both biotic and abiotic, contribute to producing an annual cycle in the spawning (Cushing, 1975). The abundance and length composition of fish larvae at any given time throughout the year is a function of the production rate (hatching rate), mortality rate, and larval growth rates. The interaction of these rates obscures the relationship between larval standing stock abundance and parental biomass, but backcalculation methods, described and evaluated elsewhere in this document (Hauser et al.), can be used to estimate the relationship. The backcalculation method requires a considerable body of information (e.g., estimates of mortality and fecundity) that is not available for many species.

This paper presents estimates of average (over years) larval mortality rates per unit length for 15 of the more abundant taxa in the larval finfish community of the Northwest Atlantic shelf ecosystem. Average mortality rates are used to derive an index of parental spawning biomass for six taxa. The index is applicable in those situations where backcalculated estimates of biomass are not feasible.

METHODS

The fish larvae collected on 50 MARMAP surveys conducted during 1977-1984 between Cape Hatteras, North Carolina, and Nova Scotia were used in this analysis (Sibunka and Silverman, 1984). To derive estimates of larval mortality for 15 taxa, the length frequency of each taxon for all surveys combined was compiled and the exponential decline in numbers at length (mm) was calculated by the method of least squares. The length intervals used were selected to eliminate unusually large specimens which would unduly influence the results. Examples of the length frequencies are shown in Figs. 1 and 2 for haddock and Atlantic herring (*Clupea harengus*).

The estimated instantaneous mortality rate per mm length was used to scale up the number at length to the number of 3 mm larvae produced by taxon, year, and subarea. These subareas are the Gulf of Maine, Georges Bank, Southern New England, and Middle Atlantic Bight. The mean abundance per 10 m^2 of 3 mm larvae, adjusted for mortality, was calculated for each subarea and survey. Figs. 3 and 4 show results of larval abundance scaled up to 3 mm for Atlantic cod and silver hake compared to the unscaled abundances. The scaled up abundance was then divided by the number of sampling days used to complete the survey within a subarea. This is an index of the daily production of 3 mm larvae per 10 m^2 for each survey and subarea. The average of these values gives an index of the production rate per day of 3 mm larvae during the entire spawning season.

An index of annual production of 3 mm larvae was determined by multiplying the daily production rate times the number of days within the spawning season for each subarea and taxon. The beginning of the spawning season was estimated as the midpoint day between the start of the first survey of the year which contained larvae for the target species and the end of the previous survey. The end of the spawning season was estimated as the midpoint day between the end of the last survey of the year with the target species and the beginning of the subsequent survey. The number of days between the midpoint days defined the spawning season. The daily index of larval production was multiplied by the total number of days within the spawning season to yield the index of annual larval production per 10 m^2. The annual production estimate was then multiplied by the surface area within each subarea and summed to give the total annual production within the survey area.

RESULTS AND DISCUSSION

Mortality Rates

The estimates of average instantaneous mortality rate per mm length for 15 taxa are given in Table 1. These rates do not account for interannual variability in mortality, but do indicate the considerable range and trends of values between species. The lowest rate (0.17) was found for sand eel (*Ammodytes* spp.), which is a slow-growing, winter-spawning taxon. The fast-growing, summer-spawning triglids have the highest rate (0.97). Little difference in mortality is seen for winter-spawning fish (range 0.17-0.20). The four spring-spawners have a low mortality of 0.23, higher than the highest winter spawner, and a high of 0.66. The summer spawners have one of the lowest mortalities listed at 0.20, but also have the two highest recorded at 0.75 and 0.97. Although both spring- and summer-spawner mortalities are quite variable, the average mortalities within each season show a clear trend of increasing from a low of 0.19 in winter to 0.40 in spring and 0.48 in summer.

The calculation of length-dependent mortality, whether daily, seasonal, or annual is, of course, interrelated to the growth rate of the individual larvae used in the calculation. A constant rate of growth and mortality must be demonstrated for all individuals in the samples for length-dependent mortality estimations to reflect actual changes in larval population mortalities. The assumption of constancy of growth and mortality rates is, of course, difficult to demonstrate from bimonthly survey catch data. However, assuming seasonal trends in growth rates, i.e., growth rates increase with increasing temperature, the classical Q_{10} function, leads to some interesting conclusions. By applying the Q_{10} function to larval growth qualitatively, then larval growth will increase from winter water temperature conditions to a peak during the summer. If this is the case, then a larva of a given length is older if captured during winter than if captured in summer, all else being equal. If age-dependent mortality remains constant regardless of season (water temperature) then estimates of length-dependent mortality would be higher in winter than in summer. This

study shows length-dependent mortalities trend in the contrary direction. If only growth and mortality are considered then age-dependent mortality must increase dramatically during summer to compensate for the increased growth rate.

The question to be answered is "What causes the increase in mortality with increasing water temperature?" The most often cited sources of larval mortality within this study area include the abiotic factors: advection, warm core rings, storm events, anomalous temperatures; and the biotic factors: starvation, predation, cannibalism. The abiotic factors which show clear seasonal trends include warm core rings, storm events, and, by inference, advection. These factors exert their greatest influence during the winter and spring so they can be eliminated as the causative factors. Anomalous temperatures are unlikely to have a seasonal trend and can also be dismissed, leaving biotic factors as the most promising.

Of the three biotic factors, cannibalism is the least understood source of mortality, though it must have a strong density-dependent component. The combined effects of serial spawning, which is characteristic of many species and assures a wide length (age) range of co-occurring larvae on the spawning grounds, and the clear seasonal trend in the density of larvae, with the lowest in early spring and peak in summer, make cannibalism a possible source of increased larval mortality.

Starvation has been hypothesized as a major source of larval mortality for the past 80 years. Emphasis has been placed upon the effects of prey density on the survival of first-feeding larvae and has been variously called the "critical period hypothesis" or "match-mismatch hypothesis." The survival, or lack of it, of first-feeding larvae does not play a role in this discussion because the length frequencies of the survey catches contain very few yolk-sac or first-feeding larvae (Table 1). These small larvae are, in general, extruded through the meshes of the 0.505-mm mesh nets. The events which shape the mortality curves in this study occur after the "critical period." Two indicators of prey availability, primary production (Campbell and O'Reilly, in press) and zooplankton density (Sherman, 1986), peak during the summer months and are at a minimum in winter over much of the shelf. Though starvation can not be ruled out as the source of increased mortality, the coincidence of seasonal cycles of larval density and the indicators of prey availability do not support the starvation hypothesis.

The last biotic factor is predation. The consumption rates of predators on larval fish is, at least partially, a function of water temperature as it relates to increasing metabolism with increasing temperature. The combined effects of high larval densities and high metabolic requirements of predators during summer as compared to winter make predation a likely mechanism to explain the increase in average mortality from winter through summer. High larval density decreases the required search time needed by predators to encounter their prey, which in turn should increase mortality rates. The seasonal changes in mortality rates and their possible relationship to predation will be investigated in more detail in the near future.

Biomass Index

Table 2 lists the indexes of annual production of 3-mm larvae for six taxa by year and subarea. Considerable variability is evident between years and, as expected, between subareas. Georges Bank production is highest for cod and silver hake for all years. Haddock production is highest on Georges Bank in all years except 1982 and 1983, when Southern New England and the Gulf of Maine dominated, respectively. Southern New England produces the highest numbers of *Urophycis* spp. larvae in all years. The produc-

tion of yellowtail flounder larvae was similar to haddock. Georges Bank produced the most larvae during 1977-1981, but in 1982 the Middle Atlantic Bight subarea had very high production and in 1983 Southern New England dominated.

Yearly production within a subarea often varies between 1 and 2 orders of magnitude, particularly in those subareas that are not the dominant producers. This is not surprising due to the effects of larval drift and the method of calculating production. Larval drift will move larvae into adjacent subareas, i.e., into subareas where they were not spawned, and, because these larvae are often relatively large, the mortality adjusted abundances are inflated in subareas where spawning is light. For example, calculated haddock production in Southern New England for 1983 is quite high, though the production of recently-hatched larvae (3-6 mm) is highest on Georges Bank. Therefore, some caution is needed when interpreting larval production as presented by subarea.

The total annual production index (see Table 2) summed over all subareas appears to be a better indicator of spawning biomass than either the individual subarea production indexes or the unadjusted for mortality catch per 10 m^2. The unadjusted abundances do not take account of the effects of mortality which is an unrealistic approach when larval abundance is related to spawner biomass.

LITERATURE CITED

Campbell, J. W., and J. E. O'Reilly. In press. Role of satellites in estimating primary productivity on the Northwest Atlantic Continental Shelf. Continental Shelf Res.

Cushing, D. H. 1975. Marine ecology and fisheries. Cambridge Univ. Press, Cambridge. 278 pp.

Hauser, J. W., M. P. Sissenwine, and W. W. Morse. This volume. A model to evaluate spawning stock size estimates derived from larval abundance.

Sherman, K. 1986. Measurement strategies for monitoring and forecasting variability in large marine ecosystems. pp. 203-231. *In* K. Sherman and L. M. Alexander (Eds.) Variability and management of large marine ecosystems. AAAS Selected Symposium 99, Westview Press, Boulder, CO. 319 pp.

Sibunka, J. D., and M. J. Silverman. 1984. MARMAP surveys of the continental shelf from Cape Hatteras, North Carolina, to Cape Sable, Nova Scotia (1977-1983). Atlas No. 1. Summary of operations. NOAA Tech. Mem. NMFS-F/NEC-33. 306 pp.

Table 1. Estimates of the instantaneous mortality rates per millimeter length for fish larvae collected on MARMAP ichthyoplankton surveys, 1977-1984. Spawning season is indicated as (W) = winter, (SP) = spring, and (SU) = summer.

Taxon	Season	Lengths (mm)	Mortality
Atlantic herring	(W)	8-42	-0.2033
Engraulidae	(SU)	4-17	-0.5951
Atlantic cod	(SP)	5-33	-0.2280
Haddock	(SP)	4-31	-0.3064
Silver hake	(SU)	4-41	-0.2529
Pollock	(W)	4-33	-0.2064
Urophycis spp.	(SU)	3-46	-0.2038
Ammodytes spp.	(W)	5-50	-0.1706
Atlantic mackerel	(SP)	3-17	-0.6555
Butterfish	(SU	3-35	-0.2117
Redfishes	(SU)	6-14	-0.7471
Triglidae	(SU)	3-12	-0.9733
Gulfstream flounder	(SU)	4-45	-0.4199
Smallmouth flounder	(SU)	4-27	-0.4023
Yellowtail flounder	(SP)	5-25	-0.4260

Table 2. Index of annual production of 3-mm larvae per 10 m^2 for six principal taxa by subarea and total annual production for all subareas combined (total x 10^{13}). Subareas are GOM = Gulf of Maine, GB = Georges Bank, SNE = Southern New England, and MAB = Middle Atlantic Bight.

Species	Year	GOM	GB	SNE	MAB	Total
Atlantic cod	1977	527.9	12511.6	1521.5	151.4	6.831
	1978	1110.0	3785.8	377.4	156.4	2.762
	1979	1919.2	36646.1	653.2	602.1	18.090
	1980	4133.1	19850.7	3408.6	98.6	13.708
	1981	9311.3	21382.9	2998.2	1097.2	18.424
	1982	3338.0	465.9	611.6	107.4	3.022
	1983	229.1	94966.3	2830.6	3.2	43.250
	1984	91.3	6657.6	2459.6	280.2	4.604
Silver hake	1977	3697.2	155808.3	2566.7	1918.5	73.216
	1978	18413.9	49941.0	1541.4	542.1	36.188
	1979	10666.8	37568.4	2925.4	2363.8	27.149
	1980	4457.3	16331.0	2216.0	2739.7	13.244
	1981	6696.0	13765.1	2941.5	4265.8	15.059
	1982	17587.2	335796.2	1299.2	4788.6	162.530
	1983	1374.8	57191.5	9537.2	411.5	31.862
Haddock	1977	3645.8	9956.8	1861.4		8.063
	1978	924.4	3773.0	26.0		2.322
	1979	754.3	29309.0	3768.2		15.570
	1980	1381.9	26790.8	3450.8		14.732
	1981	1136.6	10014.2	421.7		5.431
	1982	2445.9	191.8	84.0		1.885
	1983	0.0	10031.9	70259.0		46.438
	1984	15.4	4955.2	3960.2		4.542
Urophycis spp.	1977	5227.5	49519.8	119790.1	11524.6	103.814
	1978	99.2	911.2	21017.3	3680.0	15.213
	1979	829.8	10478.3	13540.1	1104.8	13.916
	1980	2852.6	15561.9	55640.7	4266.2	44.643
	1981	5937.3	5938.2	46587.5	10780.4	41.063
	1982	1034.6	5560.5	16480.2	17054.8	23.049
	1983	30288.8	14668.2	75182.5	970.8	73.656
Yellowtail flounder	1977		27993.2	9686.7	2368.1	19.391
	1978		28980.0	8493.6	2655.7	19.276
	1979		26748.5	13655.8	2999.7	21.596
	1980		49519.4	42802.6	4006.8	49.562
	1981		35064.0	31226.1	5563.8	37.246
	1982		2898.2	19722.8	42904.2	38.273
	1983		16719.4	72472.1	16223.5	60.207

Table 2 (continued).

Species	Year	GOM	GB	SNE	MAB	Total
Engraulidae	1977			6645.4	104424.4	65.317
	1978			11949.6	83291.6	56.079
	1979			182785.1	54411.1	141.398
	1980			4373.2	31330.9	21.022
	1981			1024.6	83409.9	49.608
	1982			4809.4	14399.1	11.337
	1983			10204.0	3122.4	7.943

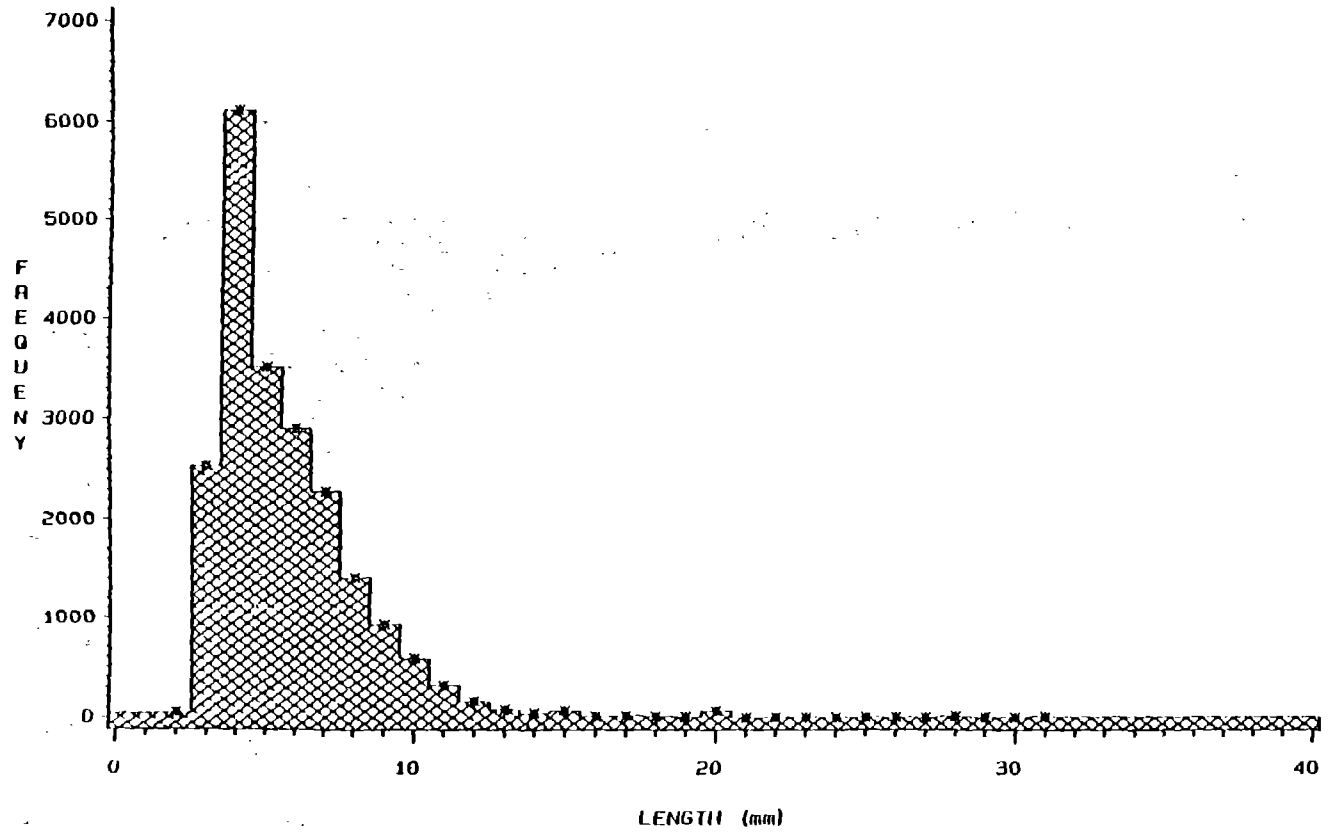

Fig. 1. Combined length frequency of all haddock larvae caught from 1977 to spring 1984 on MARMAP surveys.

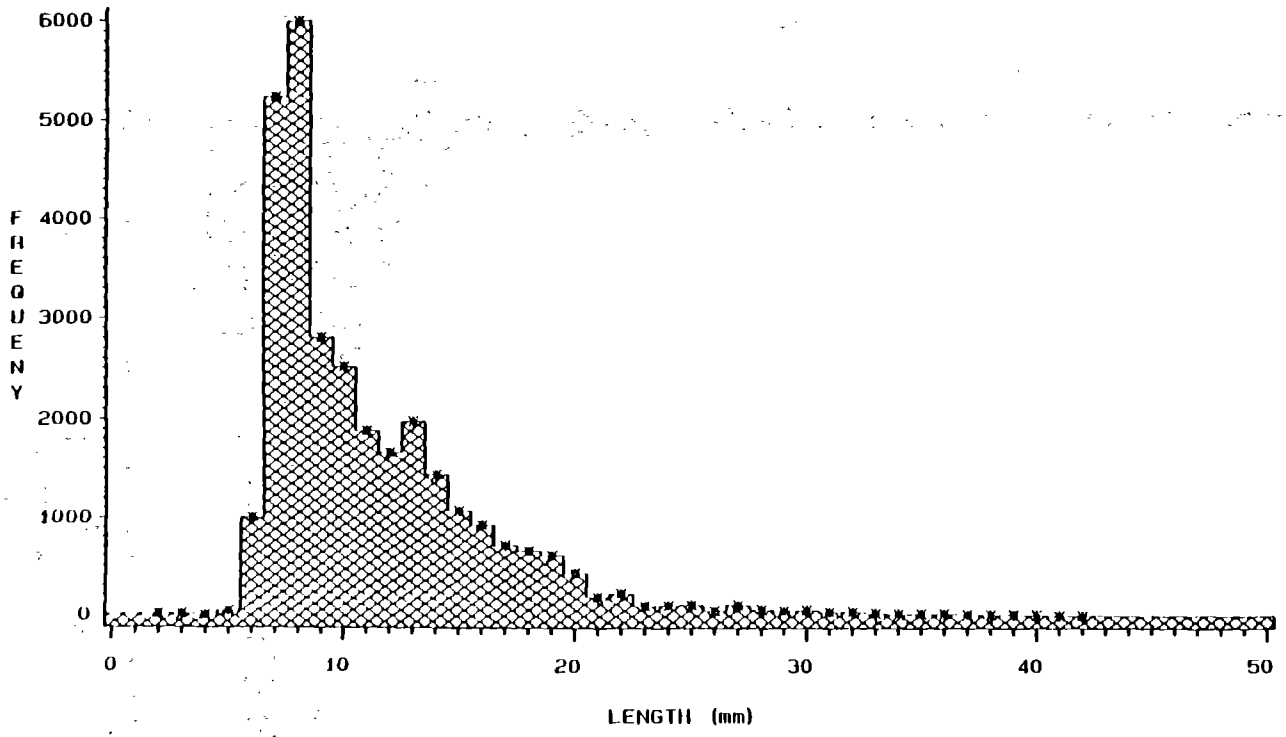

Fig. 2. Combined length frequency of all Atlantic herring larvae caught from 1977 to spring 1984 on MARMAP surveys.

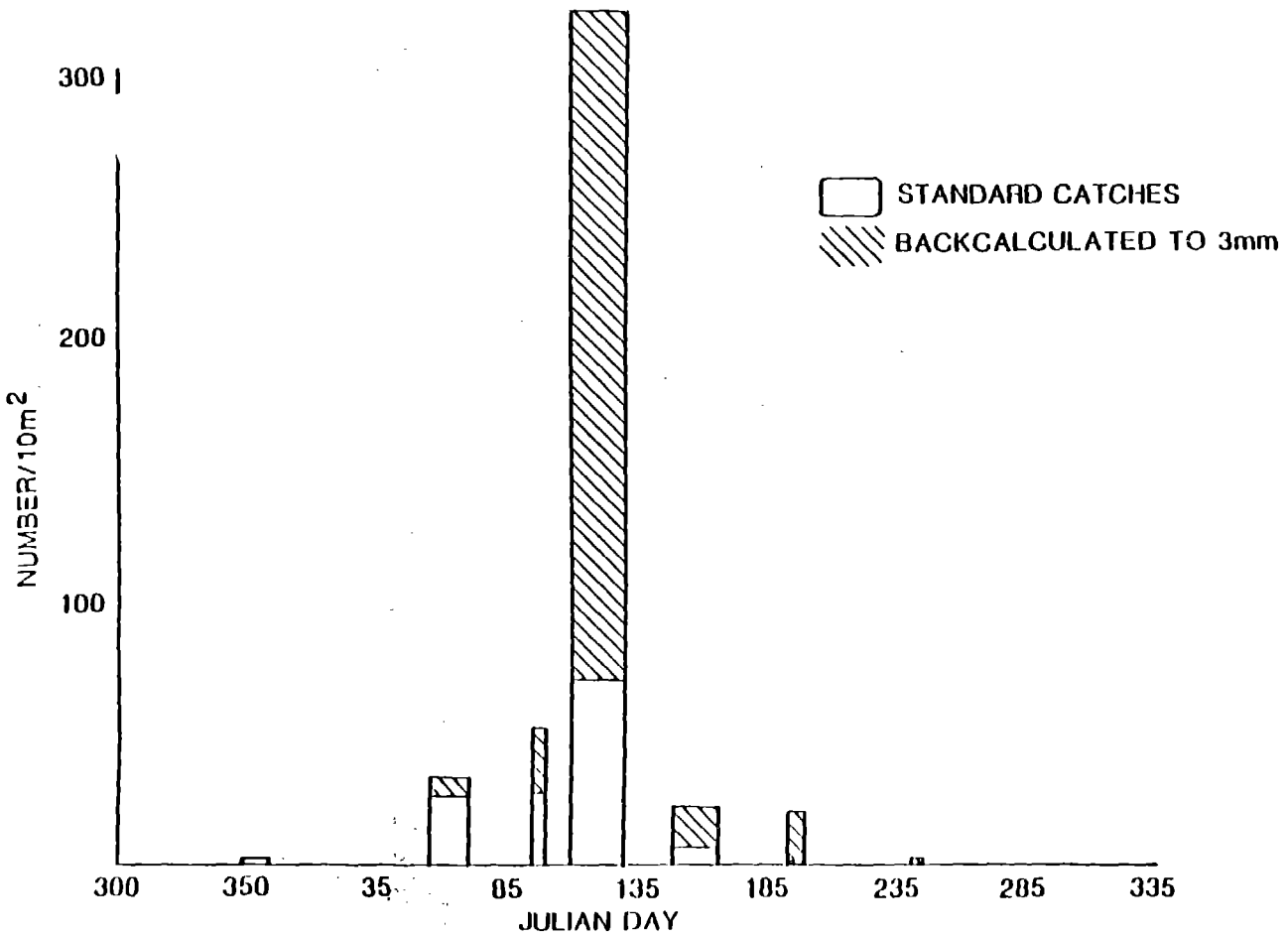

Fig. 3. Standard and mortality-adjusted abundances of Atlantic cod larvae caught on Georges Bank in 1980. The width of the bars shows the duration in days of each survey. The abundances are shown for both standard catch per 10 m^2 and back calculated to 3 mm.

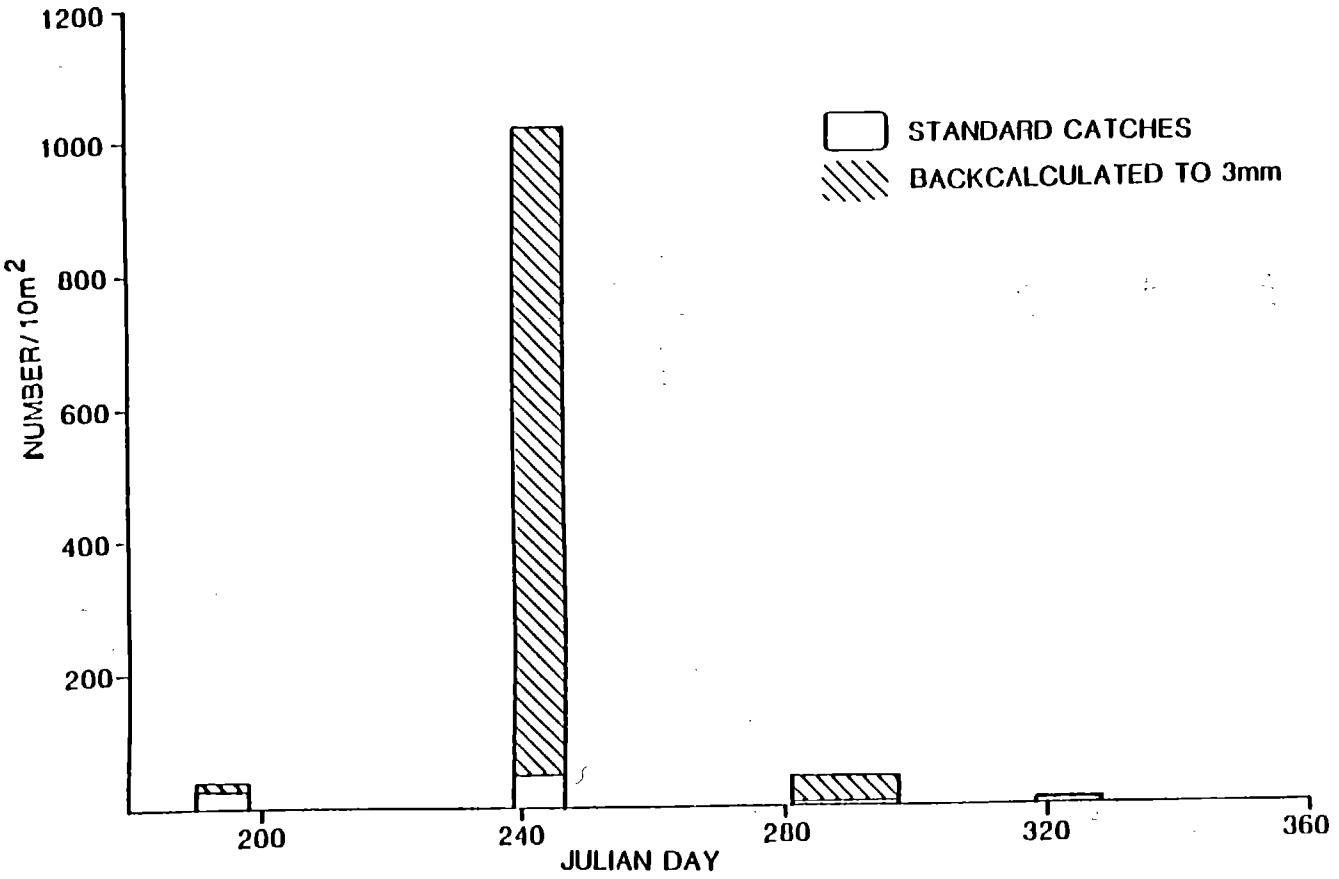

Fig. 4. Standard and mortality-adjusted abundances of silver hake larvae caught on Georges Bank in 1978. The width of the bars shows the duration in days of each survey. The abundances are shown for both standard catch per 10 m^2 and back calculated to 3 mm.

VARIABILITY IN MARMAP SURVEY MEAN CATCH PER TOW

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ABSTRACT

Nineteen taxa from the MARMAP larval fish data set were analyzed to determine the efficacy of using a logarithmic transformation to normalize the catch frequencies and to derive estimates of variability in mean catch per 10 m^2. The application of Taylor's power law indicated the logarithmic transformation is appropriate for larval catches. The mean coefficient of variation for all taxa for a sample size of 50 stations is 40.7 and the range of coefficients is 33.2 to 54.6. Correlation analysis indicated that between-length abundances were not strongly correlated except for adjacent-length intervals.

INTRODUCTION

A key population parameter estimated from the MARMAP ichthyoplankton surveys on the Northeast Continental Shelf is the mean catch of larvae per 10 m^2 and its associated variance. The mean is used to estimate the total number of larvae within a particular area by simple areal expansion. The distribution of larvae within the survey area has a highly aggregated distribution. The presence of larvae at a given station increases the probability of larvae occurring nearby, which results in large variances relative to the mean. A suitable model for the frequency distribution of larval catches is the negative binomial (Bliss and Fisher, 1953). The negative binomial distribution has two parameters, the mean μ and the exponent k. The reciprocal of k is a measure of the excess variance, or clumping, of individuals in the population (Elliot, 1971). A more general method to measure the dispersion of individuals in a population is by using Taylor's power law (Taylor, 1961) which says that the variance (σ^2) of a population is proportional to a fractional power of the mean (μ) where:

$$\sigma^2 = a\mu^b \text{ and therefore } \log\sigma^2 = \log a + b*\log\mu$$

The parameter b is a measure of dispersion within a population such that if b = 1, then the dispersion is random and as b increases above 1 to infinity, then the population is progressively aggregated. Samples from aggregated populations must be transformed to normalize the sample frequency distributions before the application of parametric statistics. The estimated parameter b is used to evaluate the appropriate transformation by replacing each sample count (X) by X^p, where $p = 1 - b/2$. Thus for b = 2, then p = 0 and a logarithmic transformation is applied to the original data (Elliott, 1971).

In this paper, Taylor's power law is applied to the MARMAP larval catch data to evaluate the use of logarithms as the appropriate transformation to normalize the frequency distributions and to estimate the population coefficient of variation, and to estimate the sample coefficient of variation for various sample sizes. The estimated coefficients of variation provide a baseline for evaluating the effects of altering the current

MARMAP sampling intensity and as input into computer simulations of spawning stock assessment, applying the backcalculation method to larval catch data (Hauser et al., this volume).

The population coefficient of variation, as an estimate of variability and uncertainty of each of the catch data, may be applied in the computer simulation to all length intervals without change, or may be randomly assigned for individual lengths, or sets of length intervals. The question is, are the abundances (No./10 m^2) of individual lengths (mm) correlated between stations within a cruise such that the coefficient of variation should not be randomly selected for each length? If autocorrelation does occur between lengths, the election of the coefficient of variation in the simulation should account for the degree of association indicated by the correlations. An analysis of this association is presented.

METHODS

A total of 50 MARMAP ichthyoplankton surveys made from 1977 to 1984 were used in this analysis (Sibunka and Silverman, 1984). Each survey was divided into four subareas, each subarea contains a maximum of 60 stations. Within each subarea, the mean catch of larvae per 10 m^2 and its variance were calculated for each of 19 taxa. Pennington (1983) applied the Delta distribution to fish egg and larval catches from MARMAP surveys to derive an efficient estimate of the variance for the mean when zero and nonzero tows are included in the calculation. His methods were used to calculate the means and variances of the larval catches. If the subarea contained less than 20 stations or the target taxon was present in less than 5 stations, the subarea was not included in the analysis. The means and variances were converted to logarithms (ln) and a least squares regression was calculated to estimate a common slope (b) and intercept (a) for each taxon (Elliot, 1971).

The sampling coefficient of variation was calculated as:

$$(\sqrt{a}/\sqrt{n}) \cdot 100$$

where n equals the number of stations sampled. Coefficients of variation were calculated for n equals 25, 50, 75, and 100.

Regressions were calculated by subarea for six taxa to determine if between-subarea differences could be detected in the underlying frequency distributions. No significant difference ($P < 0.05$) was found between subarea regressions within taxa; therefore, subareas were combined to calculate the common regression for each taxon.

Correlation matrices were calculated for silver hake, *Merluccius bilinearis*, and haddock, *Melanogrammus aeglefinus*, to measure the association in the abundance of catches at length within each station. Input to the calculation was the abundance (No./10 m^2) at length (3-14 mm) at each station where the target species was captured. A matrix of Pearson product-moment correlations was calculated for all combinations of lengths for each species.

RESULTS AND DISCUSSION

The results of the regression analysis and the coefficients of variation for various sampling intensities are listed in Table 1. The slopes (b) range from 1.6 for summer flounder, *Paralichthys dentatus*, to 2.3 for *Benthosema glaciale* and the average for all taxa is

2.0 (SD = 0.15). The regression coefficients for two species (summer flounder and yellowtail flounder, *Limanda ferruginea*) were significantly different than 2.0. It is not clear from this analysis why their coefficients are different and additional study is needed to determine if the logarithmic transformation of their catch data is appropriate. For the remaining taxa the appropriate transformation to normalize the catch frequencies is to convert to logarithms (Elliot, 1971).

With the present MARMAP sampling intensity of 25 to 50 stations per subarea, most taxa have a coefficient of variation between 35 and 55%. At a sample size of 50 stations the mean coefficient of variation for all 19 taxa is 40.7%, which would decrease to 28.8% if sample size was 100. For 50 stations the coefficient ranged from a low of 33.2 for Gulfstream flounder, *Citharichthys arctifrons*, to a high of 54.6 for the lanternfish, *Ceratoscopelus maderensis*. A combined plot of the coefficients of variation for all 19 taxa for sample sizes 25, 50, 75, and 100 stations is shown in Fig. 1. Plots of ln mean vs. ln variances for each of the 19 taxa are shown in Fig. 2.

The correlation matrices for silver hake and haddock are shown in Table 2. Of the 110 correlations calculated for both species, only 11 are significantly different than zero at $P > 0.01$ and an additional 7 at $P > 0.05$. An examination of Table 2 reveals that of the 18 significant correlations, 11 occur between adjacent length intervals and all are positive. Only two negative correlations, both for haddock, are significant and are between 4-mm catches and 11-mm and 12-mm catches. The overall pattern of correlation of catches between lengths indicates, at least for the simulation model of Hauser et al. (this volume) that the selection of the coefficient of variation as an input parameter need not integrate a function to account for autocorrelation of catches by length.

LITERATURE CITED

Bliss, C. I., and R. A. Fisher. 1953. Fitting the binomial distribution to biological data and a note on the efficient fitting of the negative binomial. Biometrics 9:176-200.

Elliot, J. M. 1971. Some methods for the statistical analysis of samples of benthic invertebrates. Freshwater Biol. Assoc. Spec. Publ. No. 25:148 pp.

Hauser, J. W., M. P. Sissenwine, and W. W. Morse. This volume. A model to evaluate spawning stock size estimates derived from larval abundance.

Pennington, M. P. 1983. Efficient estimators of abundance, for fish and plankton surveys. Biometrics 39:281-286.

Sibunka, J. D., and M. J. Silverman. 1984. MARMAP surveys of the continental shelf from Cape Hatteras, North Carolina, to Cape Sable, Nova Scotia (1977-1983). Atlas No. 1, Summary of operations. NOAA Tech. Mem. NMFS-F/NEC-33. 306 pp.

Taylor, L. R. 1961. Aggregation, variance, and the mean. Nature, Lond. 189:732-735.

Table 1. The results of the application of Taylor's power law to the MARMAP larval fish data. The slopes (b) and intercepts (a) were calculated by the equation $Y = aX^b$ where X equals the mean catch per 10 m^2 and Y equals its variance. r^2 = the coefficient of determination and S_b = the standard error of the slope. The coefficient of variation is given for sample size (n). * = slope is significantly different than 2.00 (P >0.01).

					Coefficient of Variation			
Taxon	b	a	r^2	S_b	n=25	n=50	n=75	n=100
Herring	2.124	7.774	.994	0.110	55.8	39.4	32.2	27.9
Engraulidae	2.013	9.266	.971	0.076	60.9	43.0	35.1	30.4
C. maderensis	1.935	14.927	.940	0.041	77.3	54.6	44.6	38.6
B. glaciale	2.264	7.053	.956	0.118	53.1	37.6	30.7	26.6
Urophycis spp.	1.993	7.166	.985	0.034	53.5	37.9	30.9	26.8
Atlantic cod	2.025	6.621	.975	0.044	51.5	36.4	29.7	25.7
Haddock	2.062	7.023	.980	0.058	53.0	37.5	30.6	26.5
Pollock	1.950	7.889	.915	0.136	56.2	39.7	32.4	28.1
Offshore hake	1.988	9.792	.972	0.101	62.6	44.3	36.1	31.3
Bluefish	2.113	6.421	.982	0.074	50.7	35.8	29.3	25.3
Atlantic croaker	2.065	9.157	.999	0.037	60.4	42.8	34.9	30.3
Atlantic mackerel	2.088	8.864	.985	0.073	59.5	42.1	34.4	29.8
Butterfish	1.895	7.373	.946	0.076	54.3	38.4	31.4	27.5
Redfishes	1.744	10.029	.947	0.103	63.3	44.8	36.6	31.7
Gulf Stream flounder	2.058	5.517	.972	0.061	47.0	33.2	27.1	23.5
Smallmouth flounder	1.913	8.425	.981	0.061	58.1	41.0	33.5	29.0
Summer flounder*	1.640	10.494	.946	0.093	64.8	45.8	37.4	32.4
American plaice	2.218	7.049	.956	0.213	53.1	37.5	30.7	26.6
Yellowtail flounder*	1.853	8.773	.973	0.050	59.2	41.9	34.2	29.6

Table 2. Pearson product-moment correlations of abundance of larvae for lengths between 3 and 14 mm for silver hake and haddock. Significant correlations are indicated as: * = P <0.05, ** = P < 0.01.

Length (mm)	3	4	5	6	7	8	9	10	11	13	14
					Silver hake Southern New England Survey 44						
3	1.000										
4	0.662**	1.000									
5	0.011	0.738**	1.000								
6	0.046	0.743**	0.993**	1.000							
7	0.026	0.058	0.123	0.085	1.000						
8	-0.091	-0.022	0.094	0.039	0.939**	1.000					
9	0.050	0.084	-0.054	-0.063	0.025	0.037	1.000				
10	-0.124	-0.145	-0.093	-0.088	-0.017	0.225	0.364	1.000			
11	-0.160	-0.192	-0.124	-0.118	-0.035	0.189	0.192	0.545*	1.000		
13	-0.162	-0.196	-0.120	-0.117	-0.031	0.050	0.069	0.283	0.124	1.000	
14	-0.095	-0.116	-0.075	-0.076	-0.078	-0.077	-0.068	-0.065	-0.084	0.399	1.000
					Haddock Georges Bank Survey 16						
3	1.000										
4	0.453	1.000									
5	0.171	0.173	1.000								
6	-0.182	0.026	0.635*	1.000							
7	-0.231	-0.367	0.395	0.650**	1.000						
8	-0.218	-0.463	0.085	0.144	0.677**	1.000					
9	-0.242	-0.432	0.041	0.003	0.288	0.659**	1.000				
10	-0.036	-0.410	0.402	0.121	0.311	0.622*	0.795**	1.000			
11	-0.109	-0.653**	0.029	0.094	0.463	0.452	0.544*	0.560*	1.000		
12	-0.273	-0.677**	-0.366	-0.314	-0.035	0.279	0.544*	0.266	0.283	1.000	
14	-0.105	-0.259	-0.213	-0.145	-0.164	-0.217	0.441	0.265	0.530*	0.382	1.000

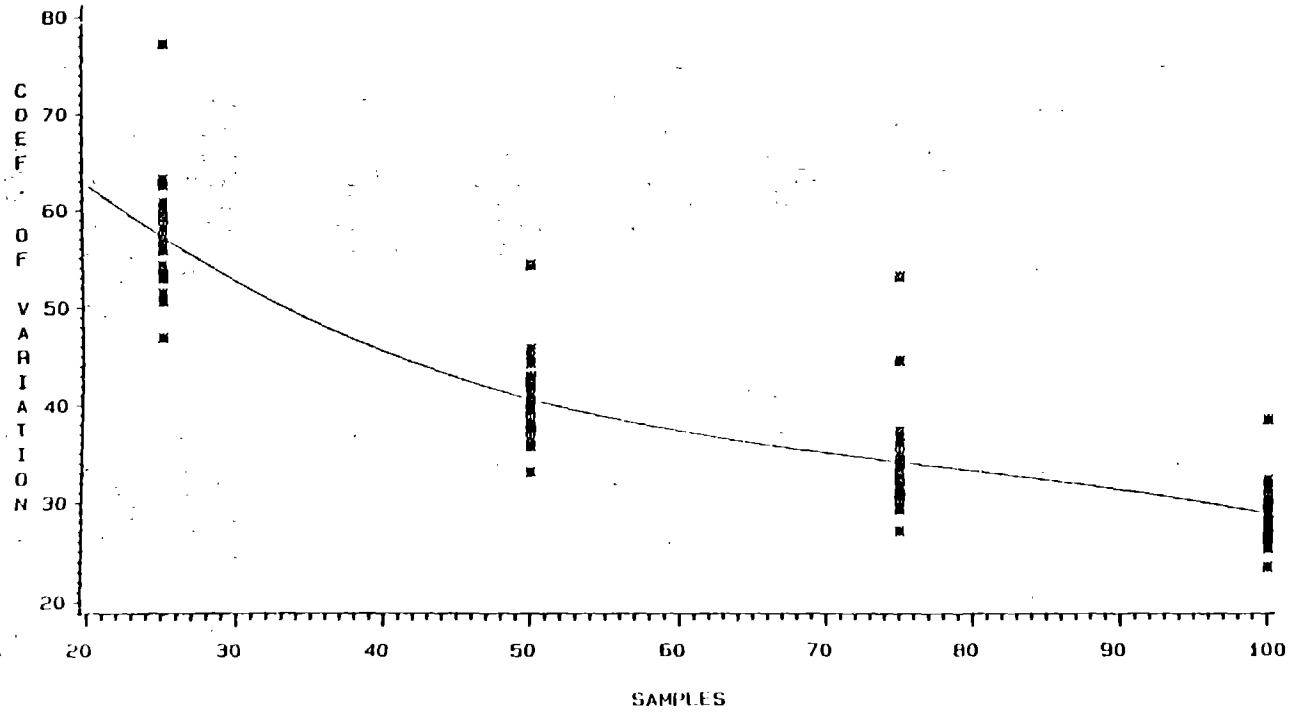


Fig. 1. A plot of the coefficient of variation and number of samples within a subarea for nineteen taxa from MARMAP larval fish surveys, 1977-spring 1984.

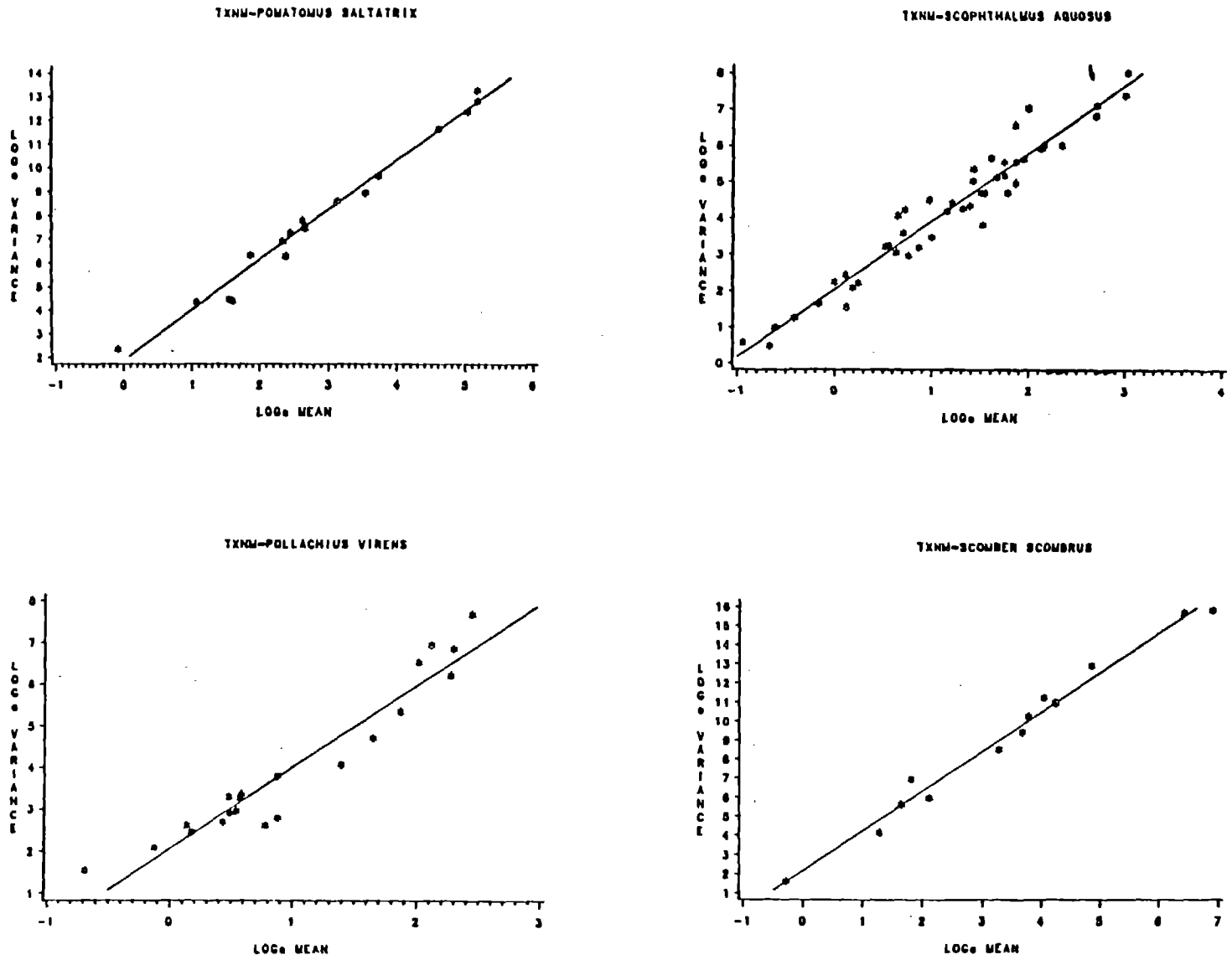
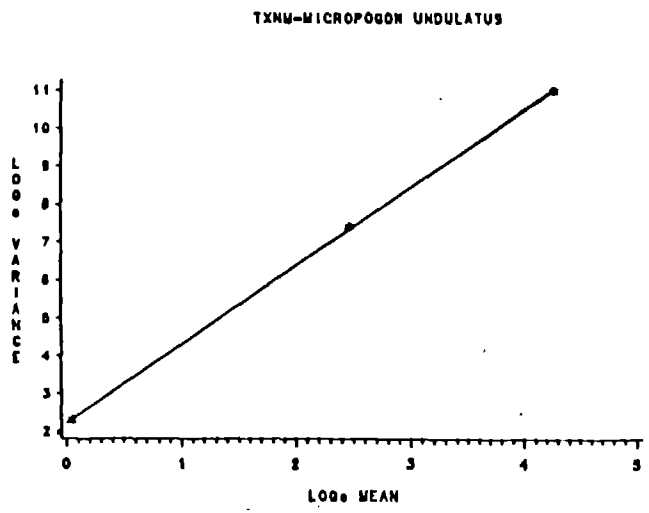
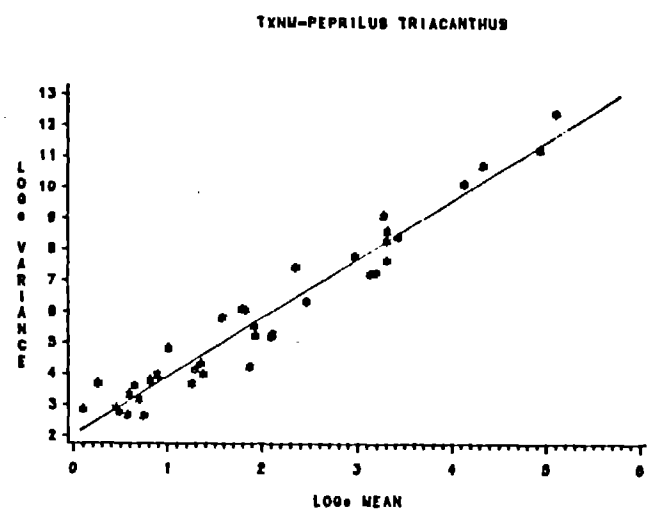
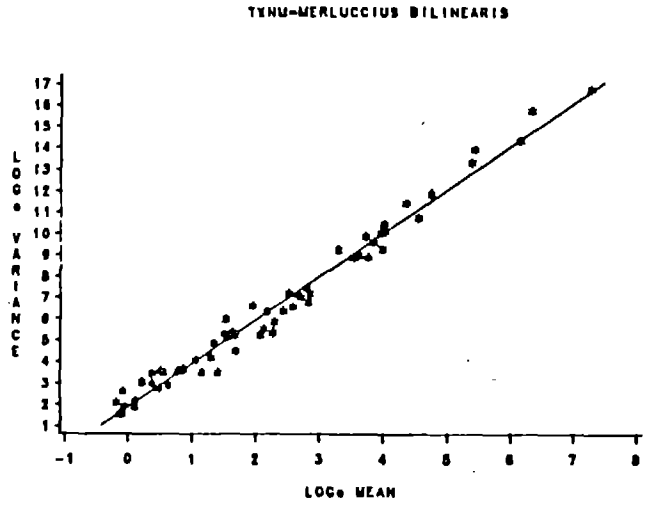
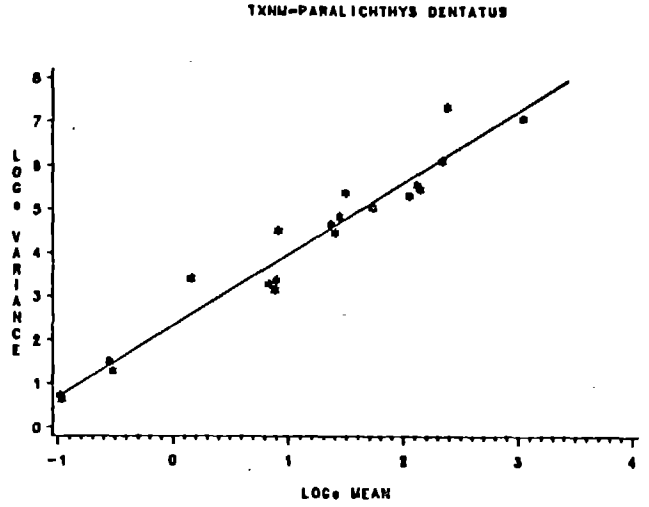


Fig. 2. Linear regressions of $\log_e$ variance and $\log_e$ mean catch per 10 m^2 for MARMAP larval fish surveys, 1977-spring 1984.









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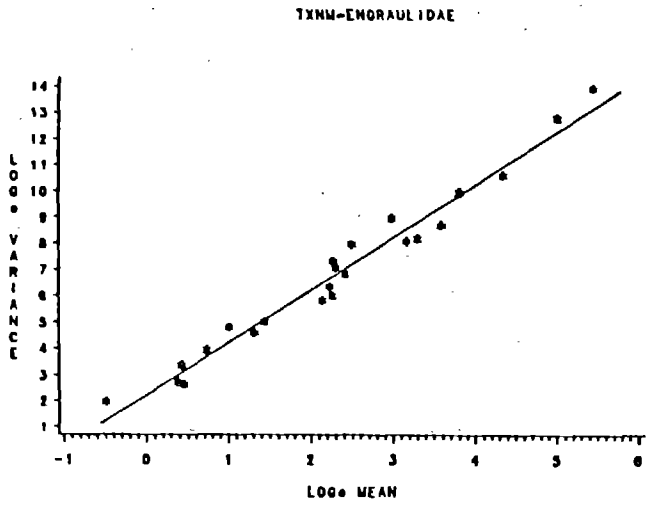

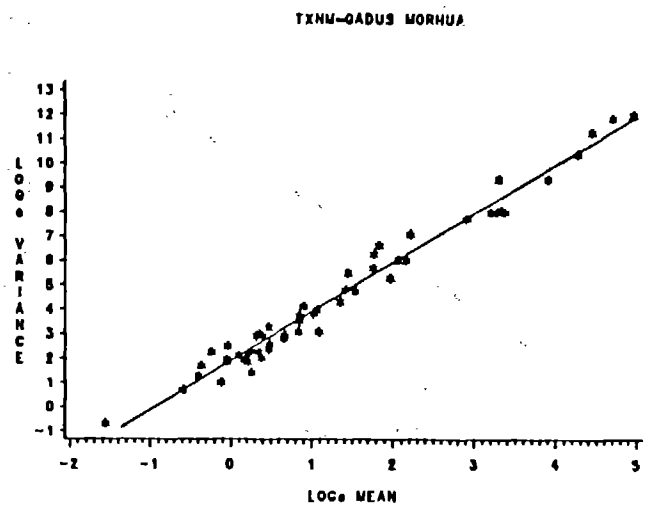

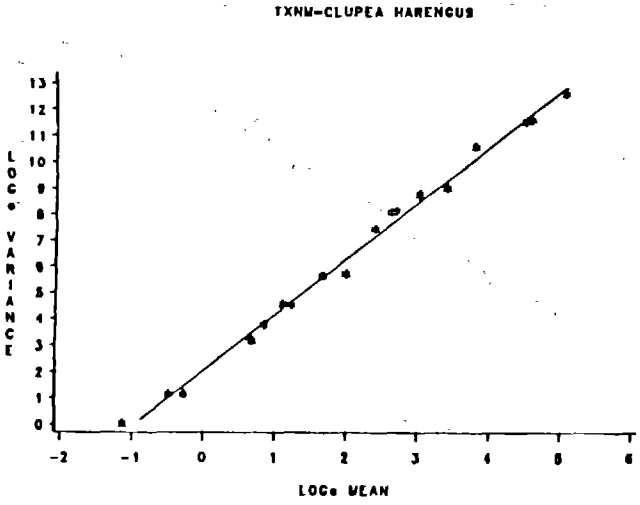

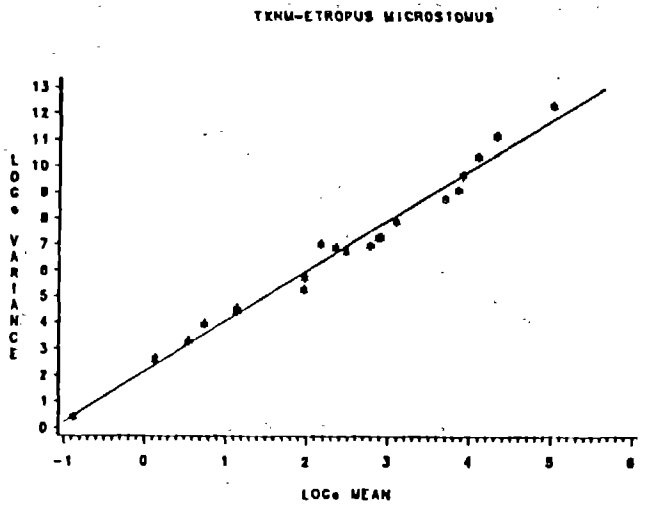

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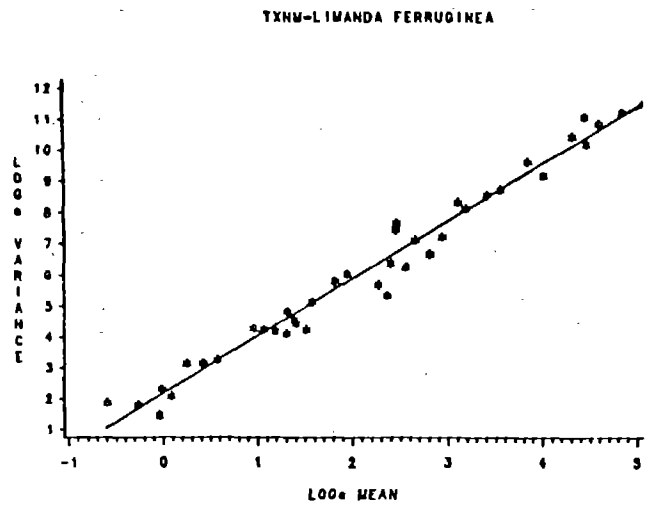

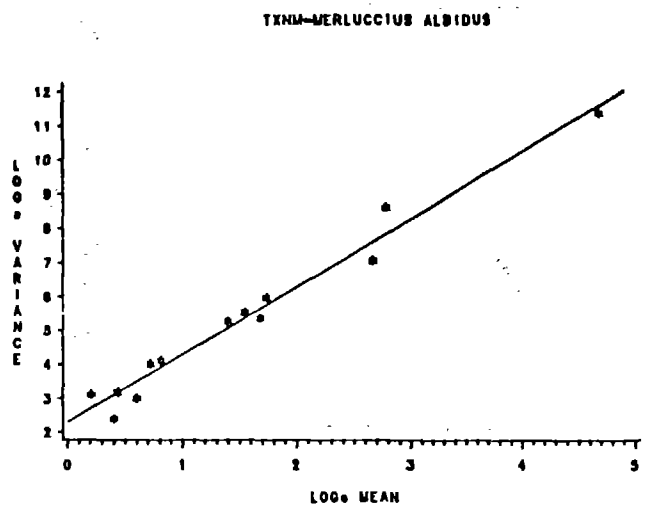

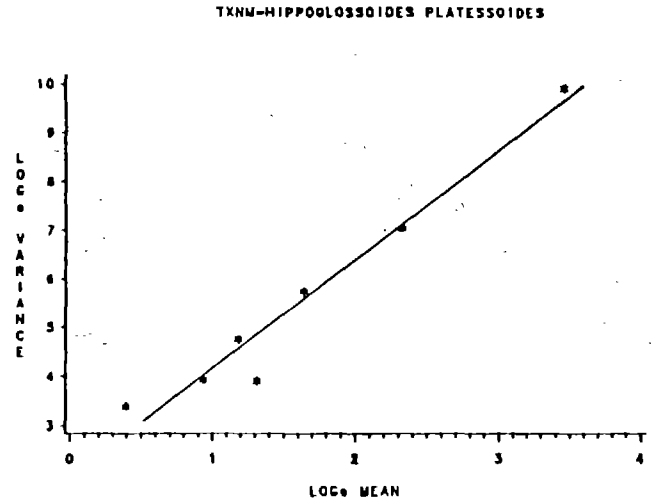

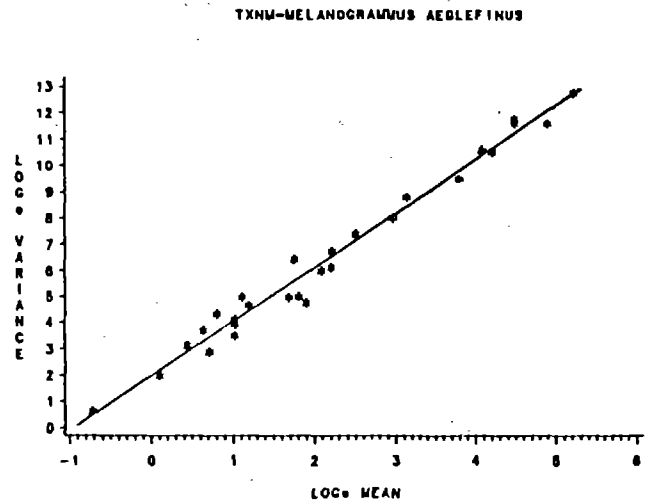

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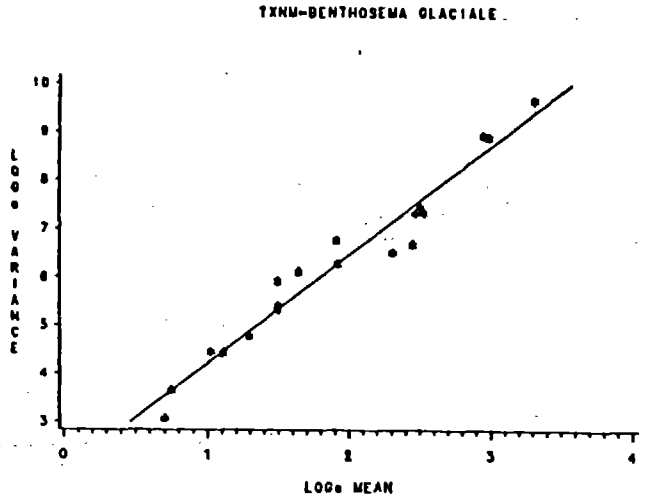

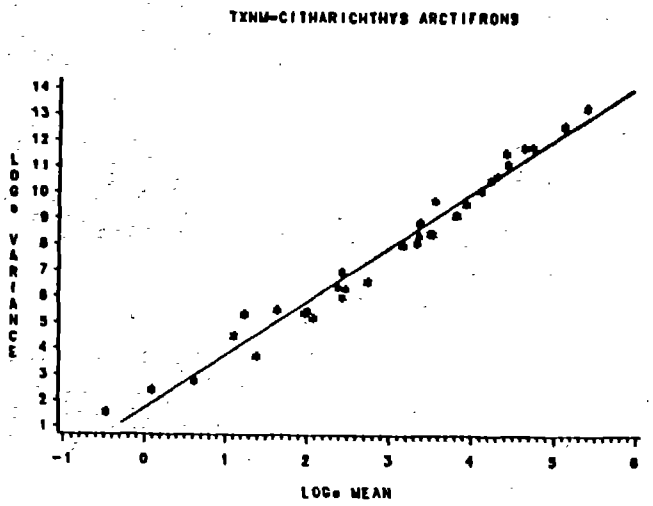

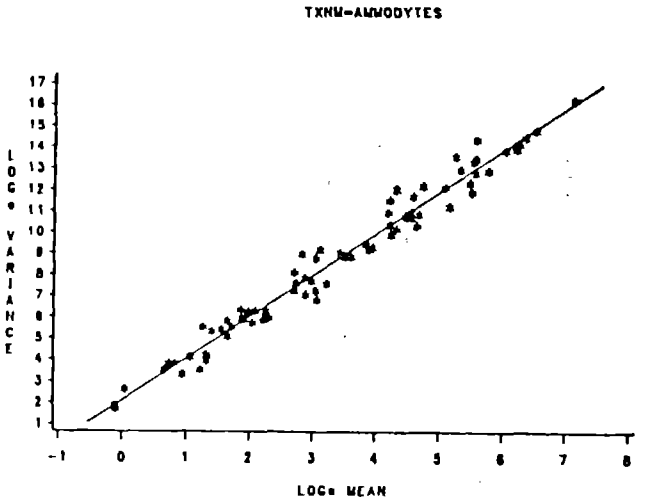

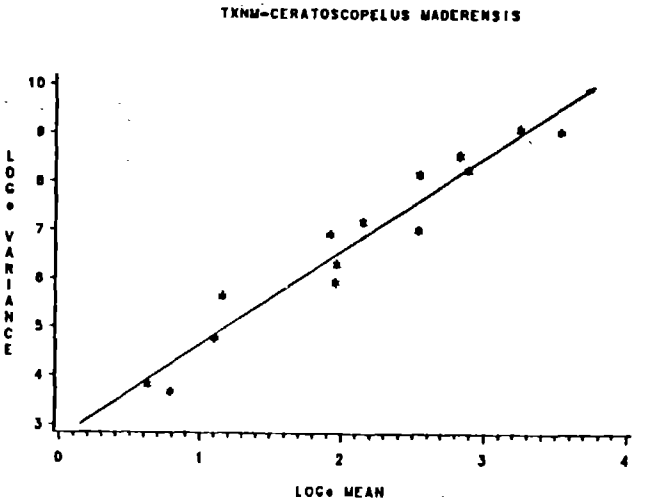

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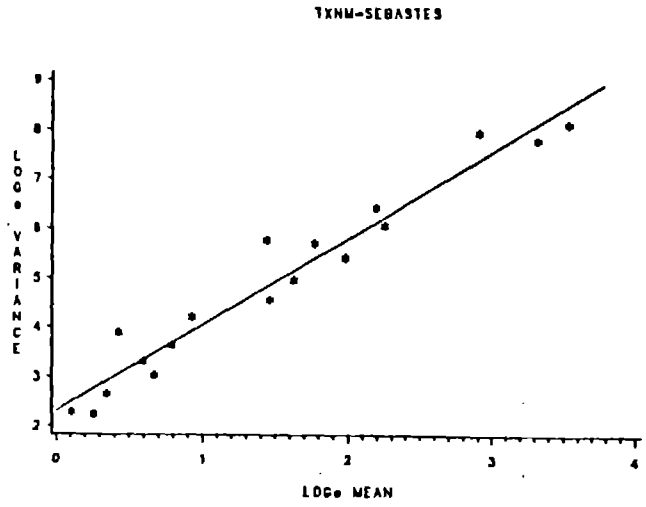

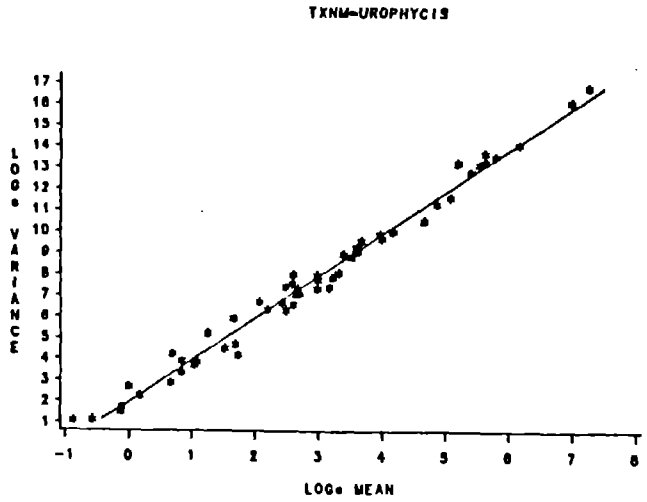

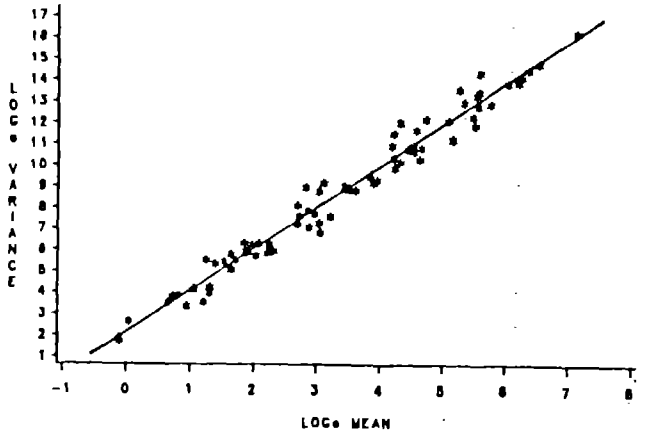

Fig. 2 (continued).

A MODEL TO EVALUATE SPAWNING STOCK SIZE ESTIMATES DERIVED FROM LARVAL ABUNDANCE

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ABSTRACT

Larval fish abundance data have been used to back calculate estimates of eggs spawned and the spawning stock which produced them. This paper describes a simulation model designed to determine the accuracy and precision of estimates under various conditions. The model simulates a population of a specific species subject to the effect of environmental temperature, sampling, and the estimation procedure. Egg estimates were compared to simulated egg production. The model can be used to examine the effects of cruise frequency, number of samples per cruise, measurement and analysis techniques, species growth characteristics, species spawning characteristics, and mortality rates.

Preliminary results indicated that the standard deviation of the spawning curve is the most important biological parameter with respect to precision. Estimates of egg production are more precise for silver hake (*Merluccius bilinearis*) than haddock (*Melanogrammus aeglefinus*); the former's spawning curve has a larger standard deviation. Both cruise frequency and within-cruise sample size strongly influence precision and accuracy. The current sampling intensity appears minimally adequate.

INTRODUCTION

There are several approaches to estimating the abundance of fish populations (Sissenwine et al., 1983). One approach uses data that characterizes the spatial and temporal distribution of larvae and their size composition (Berrien et al., 1984). The size composition data is used to estimate larval mortality rate and to adjust the density of larvae to correspond to their density at hatching. These adjusted densities are integrated over time and space to estimate production of larvae which presumably is proportional to the biomass of spawners.

The approach is based on numerous assumptions. It combines estimates derived at different stages of the analysis. This makes it difficult to evaluate the accuracy and precision of spawning stock size estimates analytically, but a numerical approach is feasible.

This paper describes a Monte Carlo simulation model which is used to evaluate estimates of spawning biomass. The model relates precision and accuracy to sampling intensity. It can be used to evaluate alternative estimation methods.

The paper describes preliminary results (model runs) for three important species off the northeastern USA; haddock, silver hake, and sand eel (*Ammodytes* sp.) The model can be used to draw more generic conclusions by varying the parameters.

DATA COLLECTION AND METHOD OF ANALYSIS

Six to seven ichthyoplankton surveys have been conducted each year (1977-present). Stations are 25 to 35 km apart, and approximately 180 stations were sampled with 35 to 50 in each of four subareas of the Northeast Continental Shelf ecosystem, Mid-Atlantic, Southern New England, Georges Bank, and Gulf of Maine. A standard 61-cm bongo net array fitted with 0.505- and 0.333-mm mesh nets (Posgay and Marak, 1980) was used. All larvae from the 0.505-mm net were enumerated and identified to the lowest taxon possible. The larvae were measured to the nearest 0.1 mm. Survey methods are outlined in this volume by Smith and Goulet and described in detail by Sibunka and Silverman (1984).

The larval data were then used to develop spawning stock estimates. The length and abundance of larvae were corrected for net extrusion, net avoidance, and shrinkage (Smith and Richardson, 1977). Length frequencies were converted to age frequencies using a temperature dependent growth function and the temperature at time of capture. Larval mortality was calculated by summing age frequencies over all surveys of the year and determining the slope of the exponential regression line of age vs. frequency. This larval mortality was used to back-calculate frequencies to hatching. Estimates of egg mortality and egg incubation time were used to back calculate to the number of eggs spawned at each station. The total number of eggs spawned in the survey area was then determined. Spawning stock biomass was calculated from the eggs spawned using appropriate length, weight, fecundity, and sex ratio information. See Morse (1984), Zweifel and Smith (1981), and Hewitt and Methot (1982) for a more detailed explanation.

This method contains assumptions and approximations which influence the biomass estimation. These lead to numerous questions. Are there sufficient cruises per year to develop an adequate spawning curve? Is the calculated larval mortality rate based on these cruises sufficiently accurate? Is the within-survey variability excessive for accurate determination of spawning stock biomass? How important are precise length measurements? How important are precise estimates of larval growth rates? How important is precise temperature information? Which species are appropriate for this method? What spawning and growth characteristics must such species have? What degree of random variability can be tolerated in the environment, the species characteristics, and the cruise schedule? The computer model is designed to answer questions such as these.

MODEL DESCRIPTION

A simplified flow chart of the computerized simulation model is given in Fig. 1. The model simulates fish eggs and larvae in their environment, sampling of fish larvae, and estimation of the number of eggs spawned. The ratio of the estimated to simulated number of eggs spawned is a measure of effectiveness of spawning stock size estimates derived from larval abundance data.

The model has three modules. The first module simulates the spawning of eggs, egg development and mortality, and larval growth and mortality. Inputs to the model include a species-specific spawning curve (eggs spawned per day vs. day of the year) and an annual temperature regime (temperature vs. day). Mortality rates for eggs and larvae are input. Egg development time and larval growth rate are modelled as functions of daily temperature. The larval growth rate function has species-specific parameters, the egg development time function does not. The model simulates anomalies (random variations) in temperature and biological rates.

The second module simulates the sampling of larvae. The control variables that characterize the sampling regime and determine its effectiveness are the target interval between cruises, precision of larval abundance estimates within cruises (which is a function of sample size), and the resolution of length measurements. The model allows for an anomaly in the cruise date (relative to the target date) and sampling error in larval density at the time of each cruise.

The third module uses the simulated data from module two to estimate the number of eggs spawned. The same annual temperature regime, egg development parameters, and growth rate parameters that were used in module one are used here. Larval mortality rate is estimated from the simulated length composition data. This estimate of mortality rate is used to back calculate the number of eggs spawned.

In general, the simulation is run one hundred times for each set of parameters. The hundred simulations differ due to the random variables. Not all of the random variables need be exercised during each set of one hundred simulations. In this way, the sensitivity of the results to these random factors can be evaluated. A more detailed description of the model follows. Deterministic and random components of the model are described separately.

Water temperature is modelled as a sine/cosine function of the day of the year. The parameters of the function are specific to the location where larval samples are collected. All the simulations described in this paper apply to Georges Bank (off the northeastern USA). The appropriate model is:

TEMP=9.46-4.86*SIN(0.0172*DAY)-1.43*COS(0.0172*DAY)

where TEMP equals the temperature in degrees Centigrade, DAY equals the day of the year (Fig. 2). The parameters are for Georges Bank for the period 1977-1986 at a depth of 0 to 50 m (Mountain, 1986).

A normal spawning function truncated to 0 at ~ 3 standard deviations is used. The mean, standard deviation, and the area under the curve are specified as input parameters. In the first module of the model, the abundance of each simulated daily cohort (individuals spawned on a specific day) is maintained up to a maximum age (AMAX) specified as an input parameter. The maximum age corresponds to the maximum age vulnerable to sampling.

The spawned eggs are subjected to egg development, egg mortality, larval growth, and larval mortality. The simulation uses a 1-day timestep.

The mortality rates are used in the formula:

N2=N1*EXP(-M)

where M is the mortality rate
N2 is the number of organisms on a given day
N1 is the number of organisms on the preceding day.

Egg development time from spawning to hatching (Fig. 3) is calculated from the formula:

TIME=0.0495462*EXP(6.63757*EXP[-0.0266*TEMP])

where TIME is the development time in days
TEMP is the water temperature in degrees centigrade.

The larval growth rate is used in the formula:

$$L2=L1*EXP(Q)$$

where Q is the growth rate
L2 is the length of the larvae on a given day
L1 is the length of the larvae on the preceding day.

The growth rate (Fig. 4) is determined from the formula:

$$Q=QMAX*(K1*EXP[R1*\{T-T1\}])/(1.0+K1*[EXP\{R1*(T-T1)\}-1.0])$$

where R1 = $(1.0/[T2-T1])*LN([K2*\{1.0-K1\}]/[K1*\{1.0-K2\}])$
QMAX = the maximum growth rate
T = the environmental temperature
T1 = the lower threshold temperature
K1 = the growth rate multiplier near the lower threshold
T2 = the upper threshold temperature
K2 = the growth rate multiplier near the upper threshold

(Thornton and Lessem, 1978). The input constants are species specific.

In the second module, the date of the first cruise is selected randomly for each of the one hundred simulations. The target date of subsequent cruises is evenly spaced from this date using the target cruise interval specified as an input parameter.

The simulated population of eggs and larvae is sampled according to the cruise schedule. Each cruise samples organisms from age 0 up to the maximum age vulnerable to sampling (AMAX). The spawning date of these cohorts ranges from the date of the cruise to AMAX days prior to the cruise (Fig. 5).

Cruises which do not sample eggs or larvae (they are either before the spawning period or more than AMAX days after the spawning period) are eliminated from further consideration.

Fig. 6 shows larval length vs. age for various cruises. The various curves reflect the various temperature regimes during egg development and larval growth. Fig. 7 shows larval abundance vs. length for various cruises. The shapes of the various curves reflect the relation of the cruise date to the spawning curve. Early in the spawning period small larvae are well represented while toward the end of the spawning period larger larvae receive better representation.

The estimation of the number of eggs spawned requires that each length category represented in the simulated sample of larvae be assigned an age. The ages are assigned using the same temperature-dependent egg development time and larval growth rate functions and the temperature regime described above. If these functions apply exactly, converting from age to length and then back to age does not introduce an error. But the model allows for anomalies from these functions (as described below). These anomalies are not taken account of in the estimation module of the model (because they are not observable). Therefore, they contribute to uncertainty in the estimates. Fig. 8 gives an

example of the simulated abundance for each cohort (daily spawning group) within each cruise.

An estimate of mortality rate is obtained by summing the larval abundances over all cruises for each age interval (Fig. 9). The log of the summed abundance is taken and plotted against the age (Fig. 10). The slope of the regression line gives the mortality rate. This mortality rate is used to back calculate from larval abundances to abundances of eggs spawned (Fig. 11). In those cases where there are calculated egg spawning estimates for the same time period from two cruises, the estimate based on the youngest larvae is used. The area under the calculated spawning curve is compared to the area under the actual spawning curve (Fig. 12).

As described above, the only source of uncertainty in the estimate of the number of eggs spawned is due to the random date of the first cruise. In addition, random variability may be applied to the temperature, the spawning curve, the cruise dates, the egg and larval mortality rates, the egg development rate, the larval growth rate, and the sampled larval abundances. The mortality rates may be made temperature dependent, and the larval mortality rate may be made length dependent. The resolution at which the larvae are measured can be altered as can other parameters specifying how the subsequent calculations are done.

The temperature may be subjected to a normally distributed variability with a standard deviation specified by the input. The same random variation applies for a certain number of days and then a new random variation is generated; the number of days is specified in the input.

The cruise dates may also be subjected to a normally distributed variability with a standard deviation specified by the input. A new variation applies to each cruise date.

The initial spawning curve, the egg and larval mortality rates, the egg development rate, and the larval growth rate may be subjected to random variability having a log normal distribution. For the log normal distributions, the variability is applied in a multiplicative fashion rather than the additive fashion used with normally distributed random variability. Thus the log normal random variability can never reduce the parameter to negative values. The coefficient of variation is specified in the input. The same random variation applies for a certain number of days and then a new random variation is generated; the number of days is specified in the input.

The sampled larval abundance data may be subjected to random variability to represent the variability caused by using a finite number of stations (samples) for each cruise. This variability is log normally distributed with a coefficient of variation specified by the input. The same random variation may be applied to all length intervals of a cruise and changed only for a new cruise; or the random variation may be changed for each cruise and for sets of length intervals as specified in the input.

While constant egg and larval mortality rates are normally used, the mortality rates may be linear functions of temperature. The larval mortality rate may also be a function of larval length according to the formula:

$$M=MO*EXP(-MD*[L-LO])$$

where L is the larval length
M is the mortality rate for larvae of length L

LO is the hatching length
MO is the mortality rate for larvae at hatching length
MD is the rate at which the mortality decreases with length.

While 100 simulations are normally run and summarized, this number can be altered. When run for one simulation, diagnostic data and graphs can be produced.

Four statistics are recorded concerning the 100 calculated mortality rates of the 100 simulations. These are the mean, the standard deviation, the minimum, and the maximum. A larger number of statistics are recorded concerning the 100 ratios of calculated to simulated egg production. First the median, the mean, the standard deviation, the minimum, the maximum, the lower 90% confidence bound, and the upper 90% confidence bound are recorded. These are determined from an ordered table of results. Then the natural logarithms of the ratios are taken and the mean and standard deviation of the logarithms are recorded. The antilog of the mean of the logarithms is calculated. The standard deviation factor is calculated as the antilog of the standard deviation of the logarithms. A value of 1.0 is then subtracted from the standard deviation factor and the result multiplied by 100 to estimate the percent standard deviation. The logarithmic statistics are also used to calculate antilogarithmic values for the mean, standard deviation, lower 90% confidence bound, and upper 90% confidence bound which are also recorded. Confidence bounds are equal to the antilog of the mean of the logarithm multiplied or divided by the antilog of the standard deviation of the logarithm raised to the power of the Z statistic for the confidence level desired.

The large number of statistics is recorded for possible future use depending on the probability distribution of the results of the simulations. If the ratios of estimated to simulated eggs are not very variable, then their distribution might approximate normal. But for the simulations of interest we expect the ratios to be quite variable. Their possible range is from zero to infinity. Therefore, they are likely to have a skewed distribution such as log-normal. In this case the antilog of the mean of the logarithms is a useful statistic. It is the geometric mean and it is an estimate of the median (the value displayed in the figures that are given in the results). The median is a more suitable statistic than the mean for skewed distributions since it is less sensitive to extreme values. The percent standard deviation is a useful measure of precision (also displayed in the figures). About two thirds of the ratios are within the range of the estimated median times or divided by (1 + [percent standard deviation/100]).

RESULTS AND DISCUSSION

Some examples of results from exercising the model are shown in Figs. 13 through 30. Each point represents the percent standard deviation or estimate of the median of 100 simulations.

Silver hake input parameters were used except where otherwise noted; haddock parameters and sand eel parameters were used in some of the simulations. The only difference between species in these runs of the model was in their temperature-dependent growth parameters and in their spawning curves. The temperature-dependent growth curves are shown in Fig. 4. Haddock has maximum spawning at 90 Julian days (spring) and silver hake at 195 Julian days (summer). The standard deviations of the spawning curves were 21 days for haddock and 36 days for silver hake.

Standard parameters were used except where otherwise noted. The present sampling strategy consists, on the average, of six cruises per year, or 61 days between cruises. Standard parameters were 61 days between cruises, a mortality rate of 0.1 per day, a

minimum larval length of 3 mm, a maximum larval length of 20 mm, and a length interval of 0.1 mm. A 50% sampling coefficient of variation was calculated from actual silver hake data based on a sample size of about 50. The sampling coefficient of variation is proportional to the square root of sample size. The standard value of the sampling coefficient of variation was taken as 50%. A new random variation was applied to each 1 mm length interval within each cruise. This was done because preliminary analysis of actual data indicated minimal covariance between 1 mm length intervals. For these preliminary simulations the only sources of uncertainty that were modelled were the random start date of the first cruise and the sampling variability.

Use of the standard parameters resulted in a 118% standard deviation for silver hake and a 159% standard deviation for haddock. This means that two-thirds of the ratios for silver hake were between 0.46 and 2.18; for haddock the range was about 0.39 to 2.59. The medians of the results were in most cases close to one and present less of a problem than the percent standard deviations which can be large.

Figs. 13 and 15 show how the percent standard deviation may be reduced by increasing the number of cruises. Very few cruises produced grossly unsatisfactory results while a very high number of cruises produced little advantage over a moderately high number. The different results for the two species was due in large measure to the smaller standard deviation of the haddock spawning curve. Fig. 21 shows how silver hake would respond if the standard deviation of its spawning curve was changed. If it was changed to 21 days, the result would be a 145% standard deviation.

Figs. 17 and 19 show how the sampling coefficient of variation effects results. Decreasing the sampling variation decreases the variability of the results. The current sampling coefficient of variation of 50% was attained by using 50 samples per cruise (n=50). The number of samples per cruise necessary to attain various sampling coefficients of variation is also indicated on Figs. 17 and 19. The diminishing returns of increasing the number of samples per cruise is thus made evident.

Figs. 17 and 19 may be used to estimate the effects of various sampling strategies. Suppose that it were possible to change the cruise interval from 61 days to 30 days. Would this be a cost effective way of improving the estimate of silver hake spawning? Fig. 17 shows that this would have the same effect as retaining a cruise interval of 61 days and decreasing the sampling coefficient of variation to about 37. That sampling coefficient of variation corresponds to about 90 samples per cruise. Decreasing the cruise interval from 61 to 30 days would about double the cost. Since the number of samples per cruise could be increased from 50 to 90 for less than double the cost, this would be more cost effective than doubling the number of cruises. The same rationale can be applied to haddock in Fig. 19. In this case, however, about 300 samples per cruise would be needed to produce the same improvement as reducing the cruise interval to 30 days.

These figures may also be used to evaluate a reduction in sampling intensity. If the cruise interval is changed from 61 to 91 days for silver hake, it would have the same effect as changing the number of samples per cruise from 50 to 28. However, if the cruise interval were changed to 91 days, the results for haddock would deteriorate beyond the point of being useful; a deterioration for which an increased number of samples per cruise could not compensate.

A notable feature of Fig. 17 is that the curves for 91 and 61 days are parallel while those for 30 and 61 days merge for low values of sampling coefficient of variation. The parallel form also appears in Fig. 19 for haddock. This means that the beneficial effects of reduced cruise interval is independent of sampling coefficient in some cases. However, as

the cruise interval was further reduced from 61 to 30 days for silver hake, the beneficial effect was reduced most markedly if the sampling coefficient of variation was low. A low sampling coefficient of variation permits precise back calculations which make a moderate cruise interval satisfactory. If the sampling coefficient of variation is higher, additional cruises can help by reducing the time over which back calculations need to be made.

The description of the model indicated many input parameters that could be varied. Some of them have been varied to give additional perspective on the characteristics of the model and to indicate how the model might be used in the future. Figs. 21 through 30 vary certain parameters, while retaining the parameters that were used for silver hake, unless otherwise noted.

Fig. 21 demonstrates the importance of the standard deviation of the spawning curve. There is a nonlinear relationship which is similar to the curves in Fig. 15 which examines the effect of cruise interval. The relationship between the cruise interval and the width of the spawning curve is important, though not necessarily simple. Insufficient cruises for the width of the spawning curve give rapidly deteriorating results, while a very large number of cruises during the spawning period offers little advantage. It may be worthwhile to introduce the ratio of the number of days between cruises to the standard deviation of the spawning curve as a new combined parameter to be examined in the future.

In Fig. 23 the effect of the date of peak spawning (i.e., mean of the spawning curve) is examined. The results deteriorate if peak spawning is during the coldest time of the year. The large percent standard deviations shown in Fig. 23 are accompanied by high median values shown in Fig. 24. The graphs of the medians have not been discussed very much as the medians are generally near 1.0, or they are overshadowed by the effects of the percent standard deviation. In the case of Fig. 24, however, they are noteworthy. The mean calculated mortality rates and the standard deviations of the mortality rates were also high in these cold temperature cases.

These poor results for winter were due to the fact that a silver hake larvae would grow very slowly (Fig. 4) at cold temperatures. Silver hake do not, in fact, spawn in winter. The example is also unrealistic, since mortality rates might well be reduced in winter. Fig. 25 uses growth parameters for sand eel, a winter spawner (Fig. 4). Much better winter results were obtained. The results (not shown) were also better (for silver hake) when temperature was held constant at its winter time low level instead of varying it realistically.

Slow growth may be expected in winter. This is an advantage in that larvae will be in the water column for a long time, thus filling the gaps between cruises. Slow growth is, however, a disadvantage in that mortality operates over a longer time so that the effects of errors in mortality estimation are exagerated. Furthermore, the larval life extends through a wide range of temperatures, introducing additional complexity into the calculations. Thus, winter is, from a larval point of view, a time of varying temperature as well as low temperature. Further work will be necessary to determine how well the procedures work in winter.

Fig. 27 shows the effects of varying the mortality rate. There is little effect. The procedure should work well with a good range of mortality rates. However, the effect of randomly varying mortality rates as well as many other random variations still has to be investigated.

The effect of reducing the maximum larval length from 20 mm is shown in Fig. 29. Reducing the maximum larval length produces a slow and then a rapid deterioration of

results. Since only a small number of organisms are captured at 20 mm, and there may be some avoidance, it is worthwhile to consider reducing the maximum larval length used in these estimates.

CONCLUSIONS

Monte Carlo simulation is a useful tool to evaluate the accuracy and precision of spawning stock size from larval abundance data. The results reported in this paper are preliminary. They were intended to demonstrate how the simulation model can be used to examine alternative levels of sampling intensity. The method can be used to determine the sensitivity of estimates to various biological parameters. It can be used to examine alternative estimation methods.

While the results are only preliminary, they do indicate that the current sampling regime (target cruise intervals of 61 days, sample size of 50 producing a coefficient of variation of about 50%) is reasonable. Spawning stock size estimates are not precise, but they are useful for monitoring major changes in the ecosystem that are known to occur and persist for relatively long periods of time (i.e., decadal). The precision of the result can be improved by combining estimates over several years, although this approach eliminates the possibility of monitoring interannual variability.

Analysis using this model is continuing. The model is being applied to additional species. Results for herring, sand eel, and Atlantic cod (*Gadus morhua*) have been obtained. The sensitivity of the results to additional parameters is being investigated. The effects of random variability are being determined for various parameters singly and in combination. Application of the model to egg data is being considered, and program modifications have been made to facilitate an investigation of egg and larval results.

LITERATURE CITED

Berrien, P. 1983. Silver hake, *Merluccius bilinearis*, egg census, and adult population estimate for 1979 in waters off eastern United States. ICES C.M. 1983/G:46.

Berrien, P., W. Morse, and M. Pennington. 1984. Recent estimates of adult spawning stock biomass off the northeastern United States from MARMAP ichthyoplankton surveys. NOAA Tech. Mem. NMFS-F/NEC-30. 111 pp.

Boreman, J. 1983. Simulation of striped bass egg and larva development based on temperature. Trans. Am. Fish. Soc. 112:286-292.

Hewitt, R. P., and R. D. Methot, Jr. 1982. Distribution and mortality of northern anchovy larvae in 1978 and 1979. CalCOFI Rep. 23:226-245.

Morse, W. W. 1984. An assessment of the Georges Bank haddock stock based on larvae collected on MARMAP plankton surveys, 1977-1982. pp. 67-87. *In* P. Berrien, W. Morse, and M. Pennington (Eds.) Recent estimates of adult spawning biomass off northeastern United States from MARMAP ichthyoplankton surveys. NOAA Tech. Mem. NMFS-F/NEC30.

Morse, W. W., and J. W. Hauser. 1985. A study of factors affecting the precision of spawning stock estimates using MARMAP fish egg and larval surveys. NEFC, Sandy Hook Laboratory, Rep. SHL 85-07:67 pp.

Mountain, D. 1986. Internal memorandum of 2 June 1986. Woods Hole Laboratory, Northeast Fisheries Center, Woods Hole, MA.

Posgay, J. A., and R. R. Marak. 1980. The MARMAP bongo zooplankton samplers. J. Northw. Atl. Fish. Sci. 1:91-99.

Sibunka, J. D., and M. J. Silverman. 1984. MARMAP surveys of the continental shelf from Cape Hatteras, North Carolina, to Cape Sable, Nova Scotia (1977-1983). Atlas No. 1. Summary of operations. NOAA Tech. Mem. NMFS-F/NEC-33:306 pp.

Silverman, M. J. 1983. Distribution, abundance, and production estimates of yellowtail flounder, *Limanda ferruginea*, larvae off northeastern United States, 1977-1981. ICES C.M. 1983/G:47.

Sissenwine, M. P., T. Azarovitz, and J. B. Suomala. 1983. Determination of fish abundance. pp. 51-101. *In* A. G. MacDonald and I. G. Prievy (Eds.) Experimental biology at sea. Academic Press, New York.

Smith, W. G., and J. Goulet. This volume. MARMAP ichthyoplankton surveys: An overview of methods and data base management.

Smith, P. E., and S. Richardson. 1977. Standard techniques for pelagic fish eggs and larval surveys. FAO Fish. Tech. Pap. 175:100 pp.

Smith, W. G., P. Berrien, D. G. McMillan, and A. Wells. 1981. The distribution, abundance, and production of Atlantic cod and haddock larvae off northeastern United States in 1978-79, and 1979-80. ICES C.M. 1981/G:52.

Thornton, K. W., and A. S. Lessem. 1978. A temperature algorithm for modifying biological rates. Trans. Am. Fish. Soc. 107(2):284-287.

Zweifel, J. R., and P. E. Smith. 1981. Estimates of abundance and mortality of larval anchovies (1951-75): Application of a new method. Rapp. P.-v. Reun. Cons. int. Explor. Mer 178:248-259.

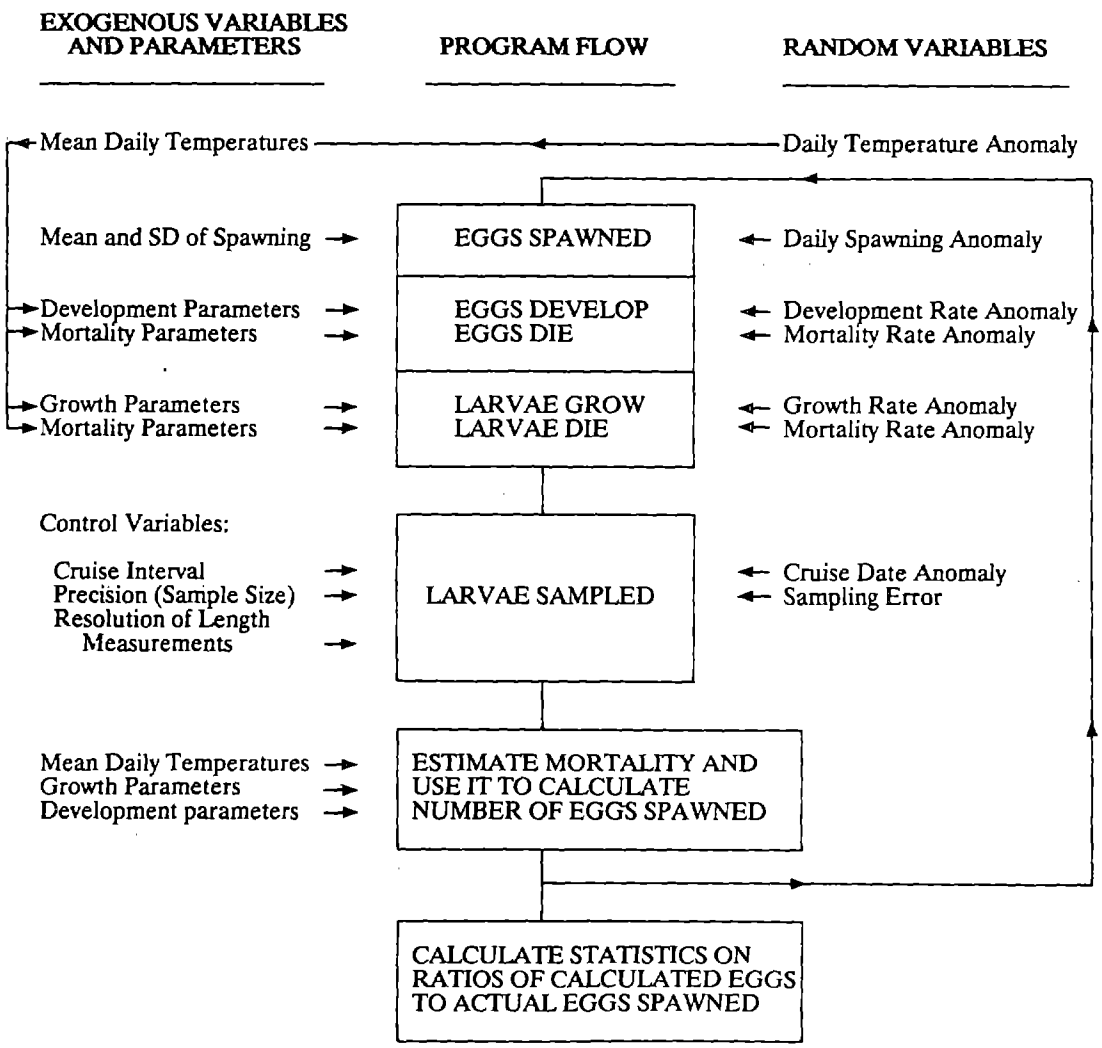

Fig. 1. Computer simulation program flow diagram showing exogenous and randomly assigned variables.

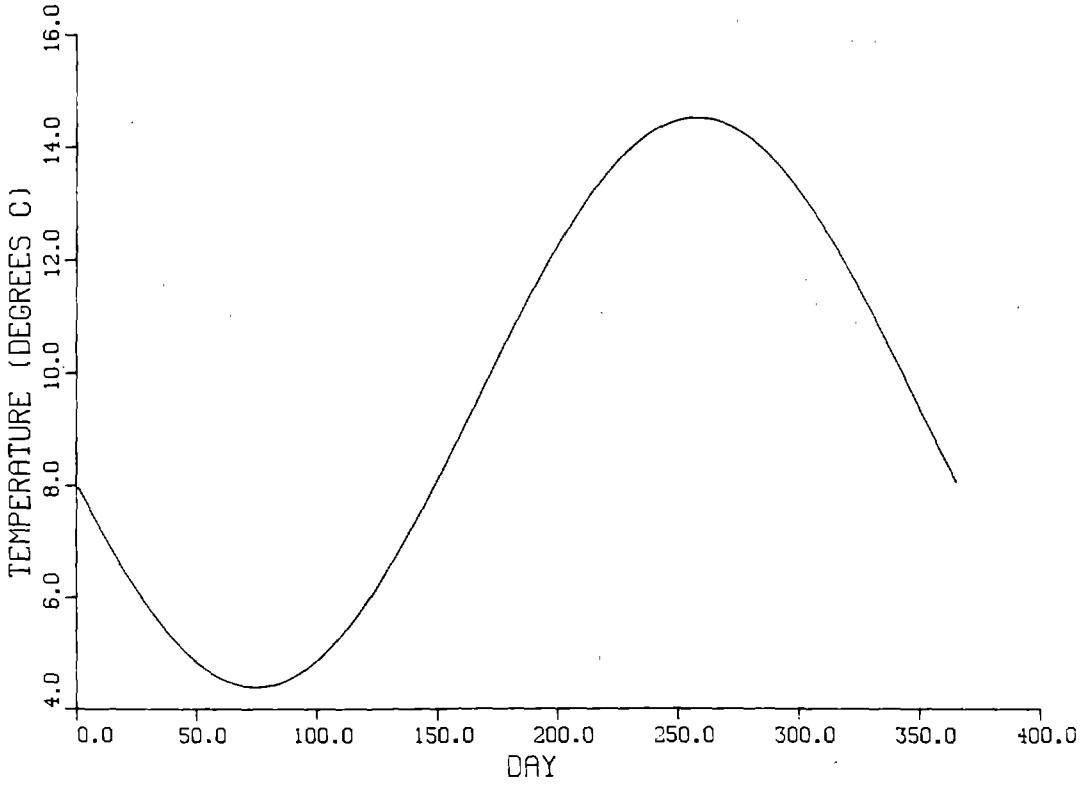

Fig. 2. Environmental temperature for the year.

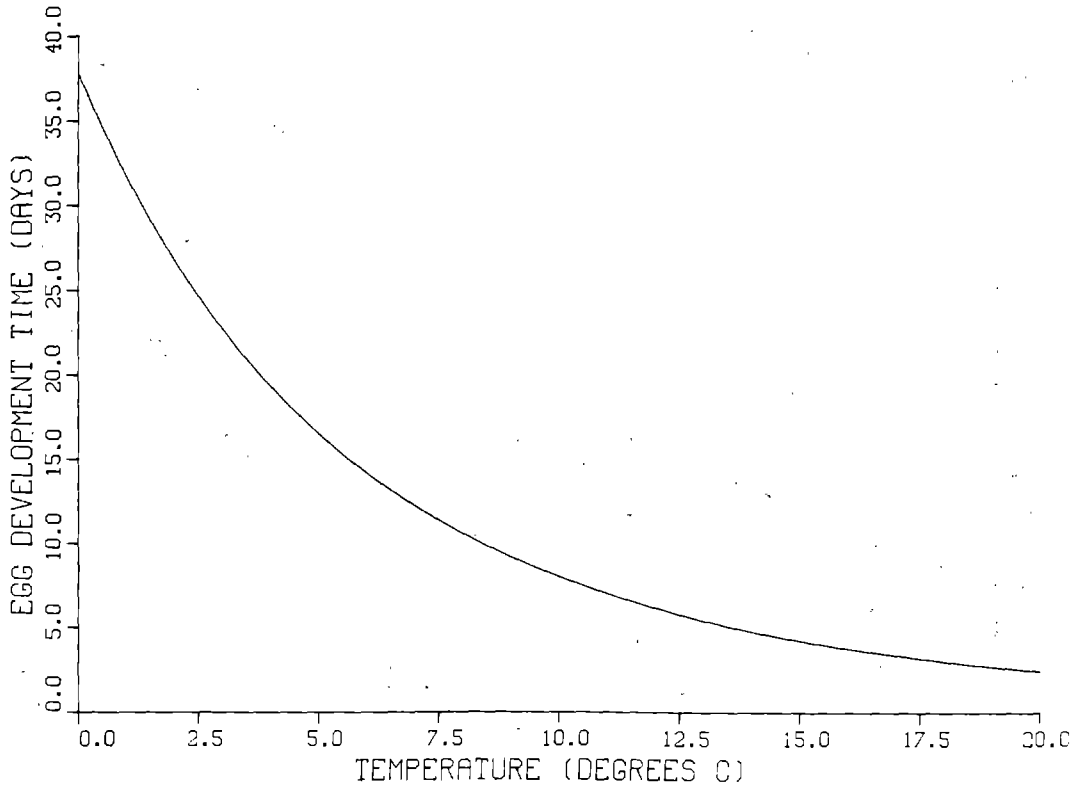

Fig. 3. Egg development time as a function of temperature.

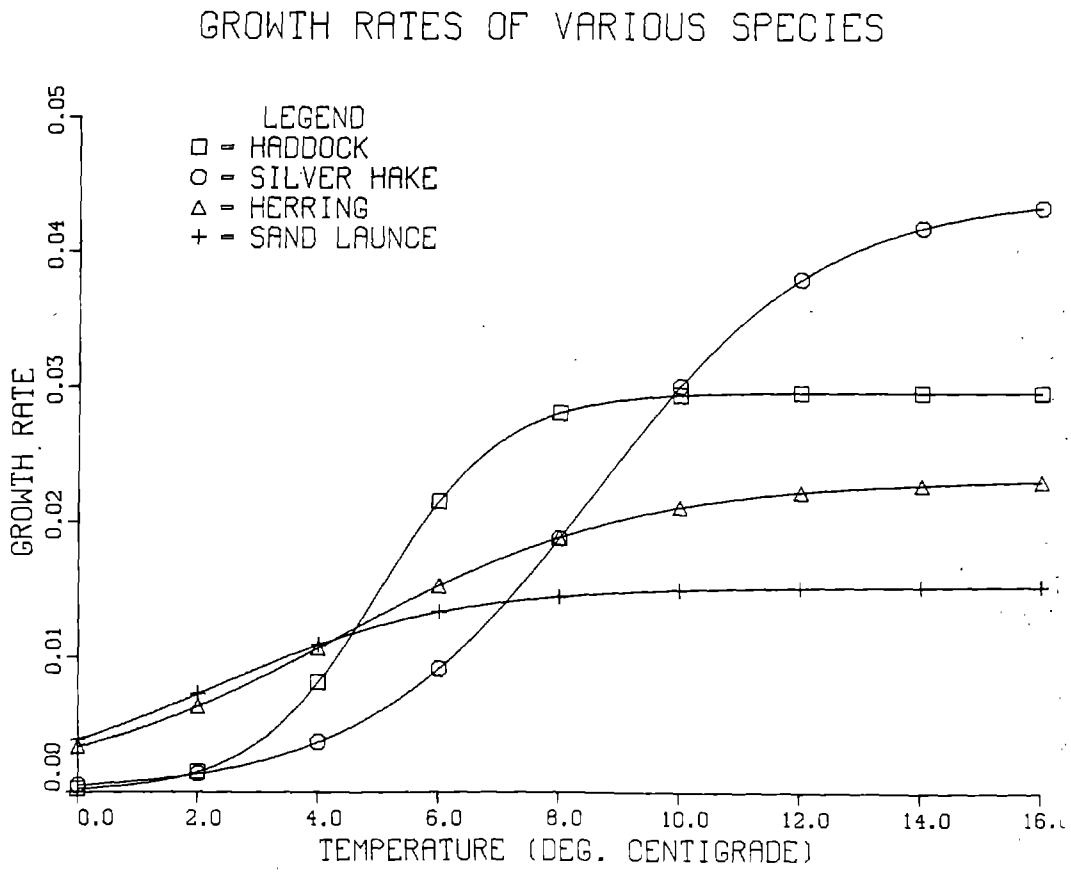

Fig. 4. Growth rates of various species as a function of temperature.

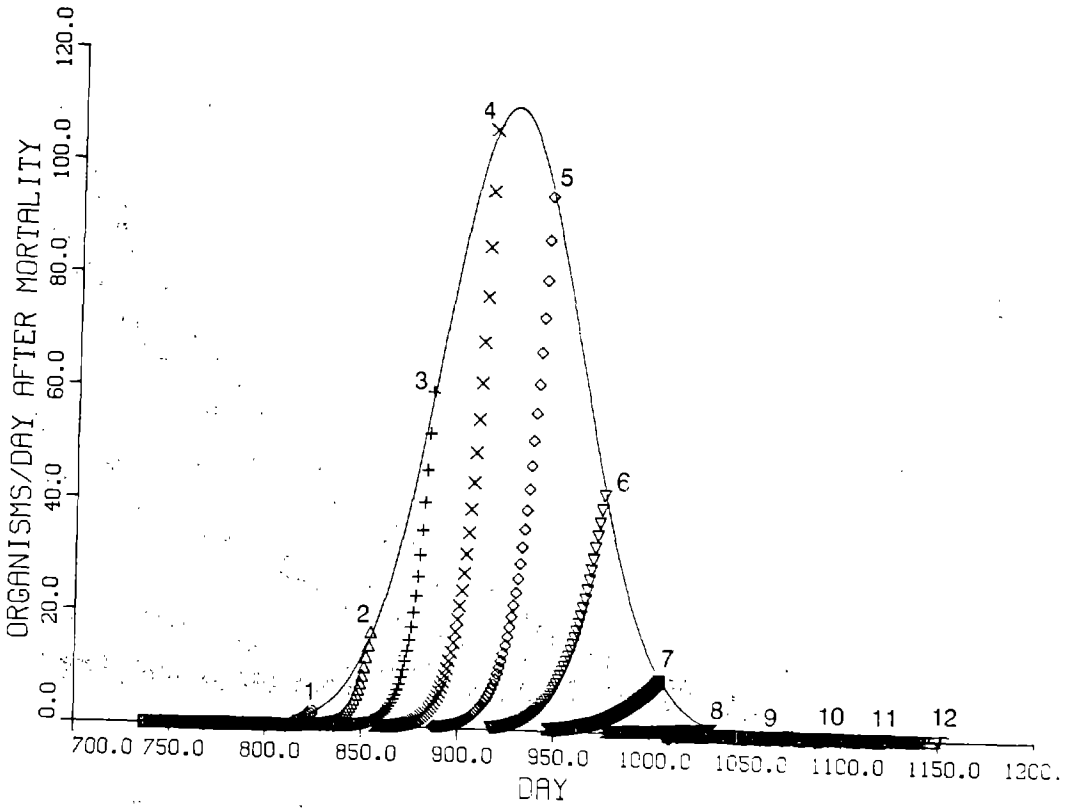

Fig. 5. Abundance of organisms subject to sampling for various cruises during the spawning period as a function of the day the organisms were spawned.

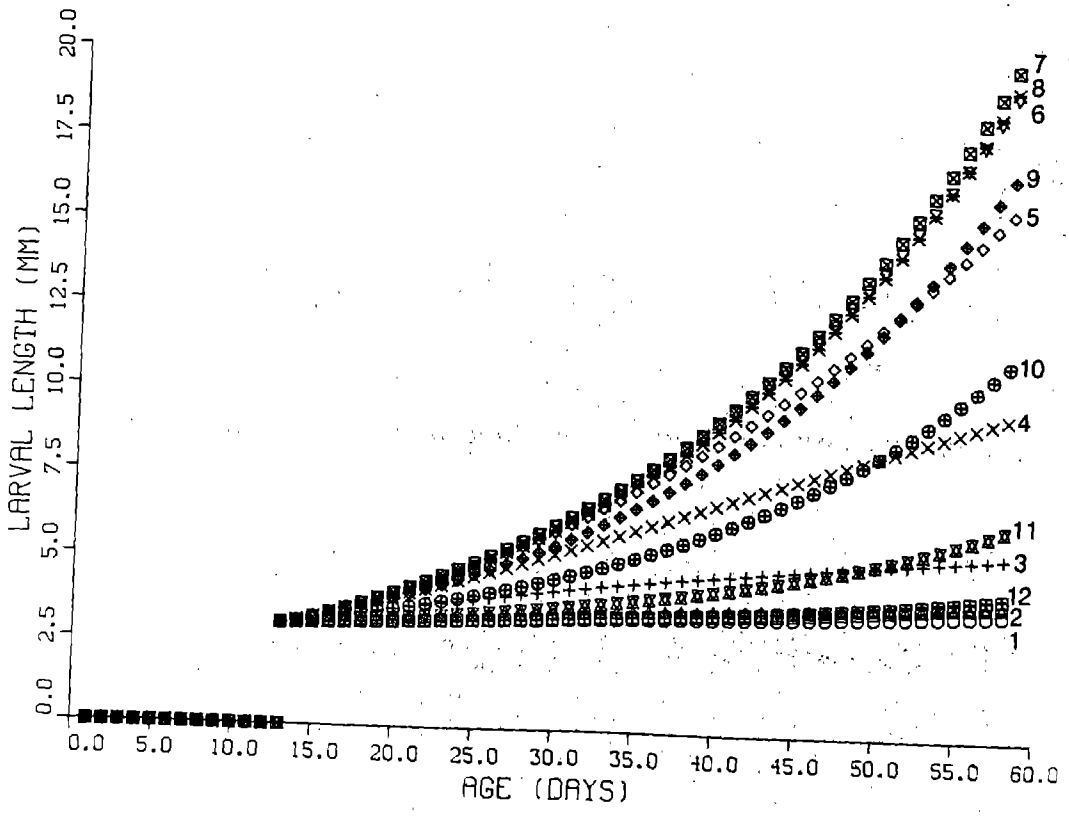

Fig. 6. Larval length as a function of age.

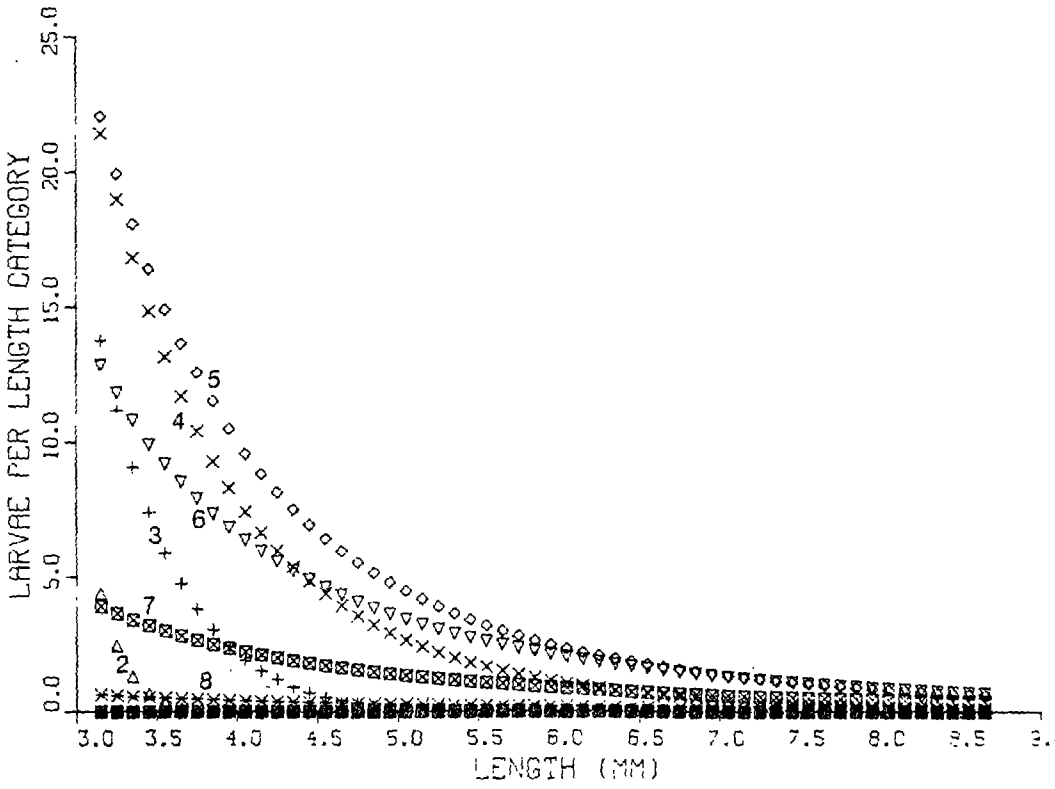

Fig. 7. Larval length frequencies for various cruises.

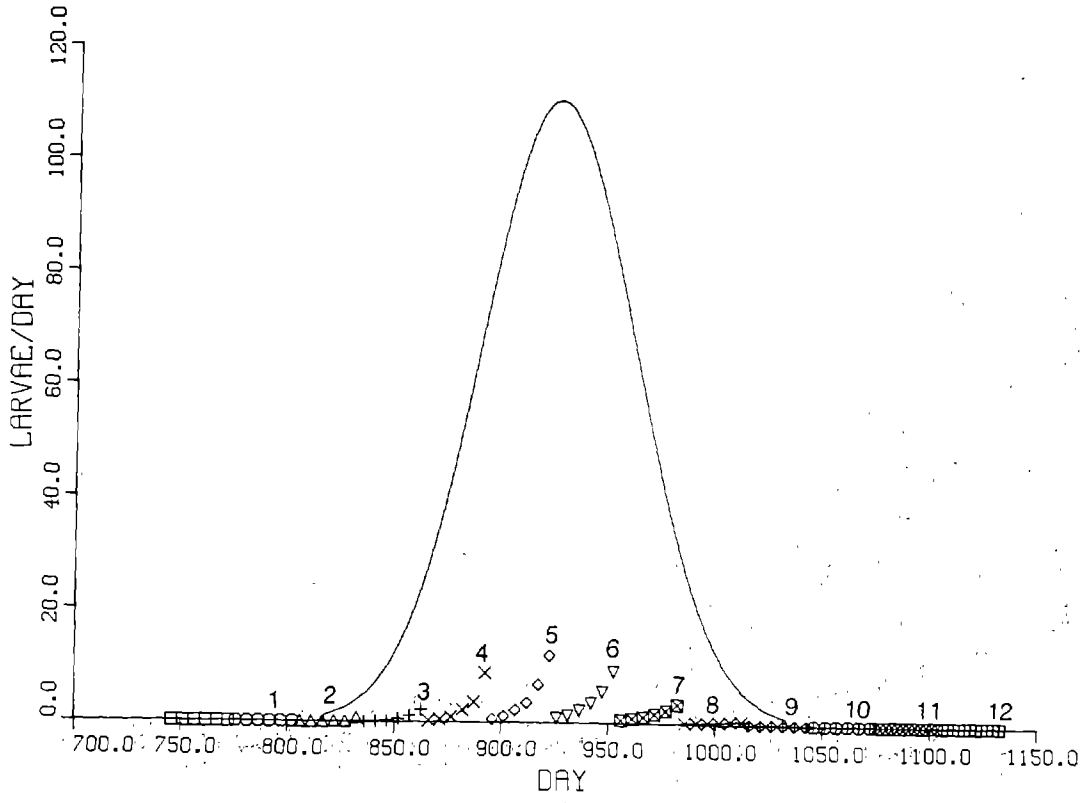

Fig. 8. Calculated larval frequencies by age category as a function of day spawned for various cruises during the spawning season.

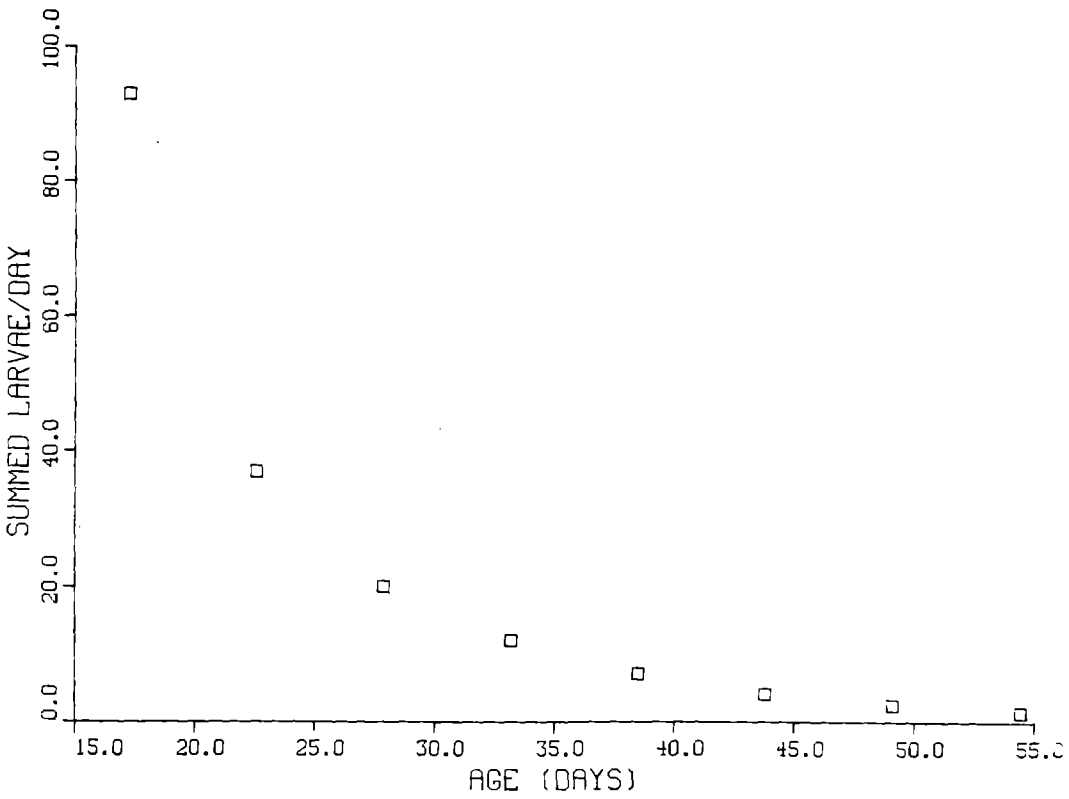

Fig. 9. Age frequencies summed over all cruises.

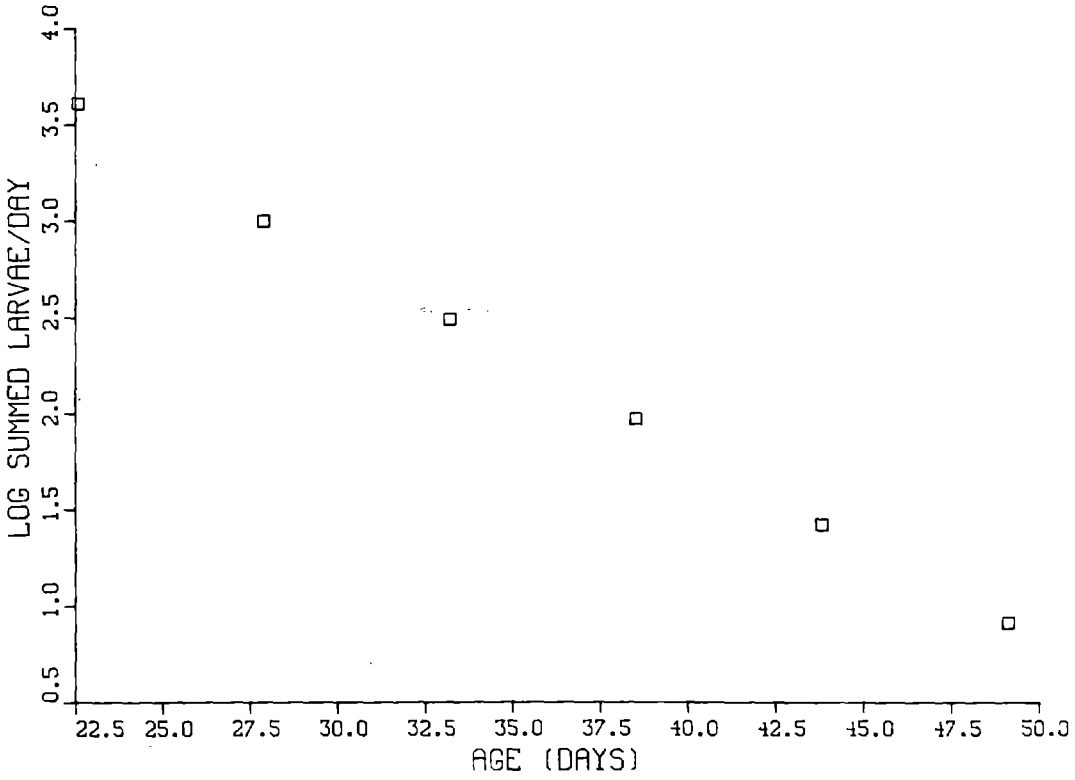

Fig. 10. Logarithms of age frequencies summed over all cruises.

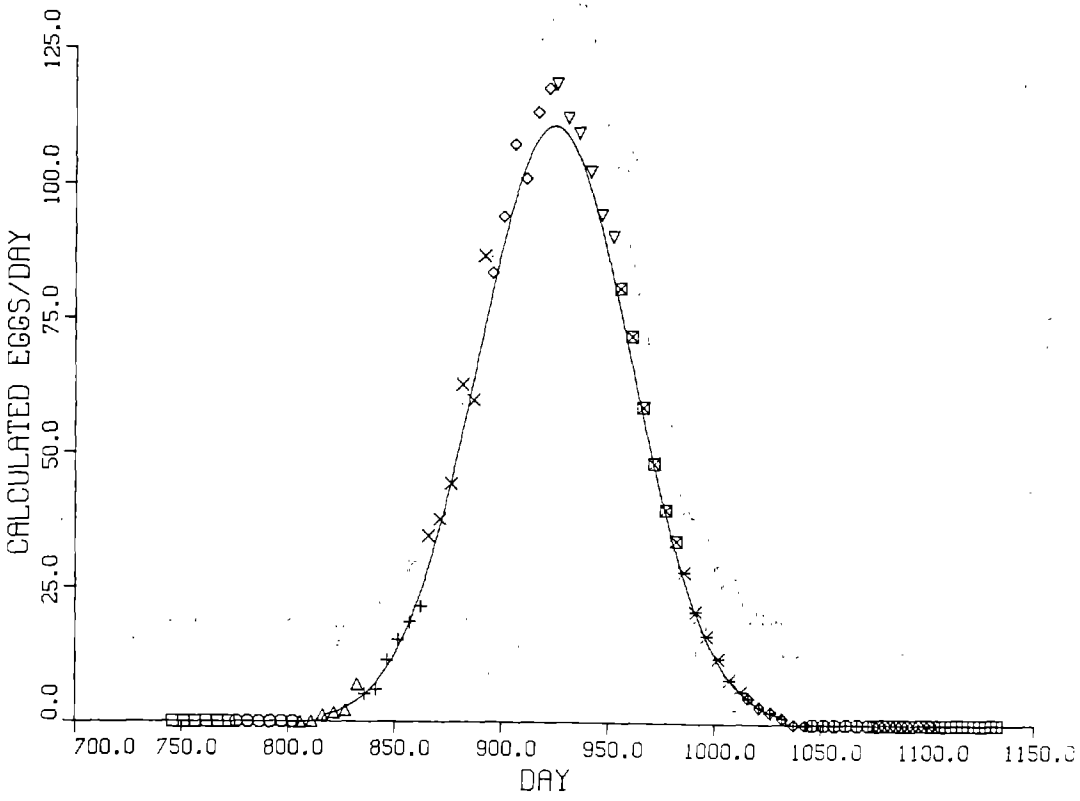

Fig. 11. Back-calculated eggs spawned compared to original spawning curve.

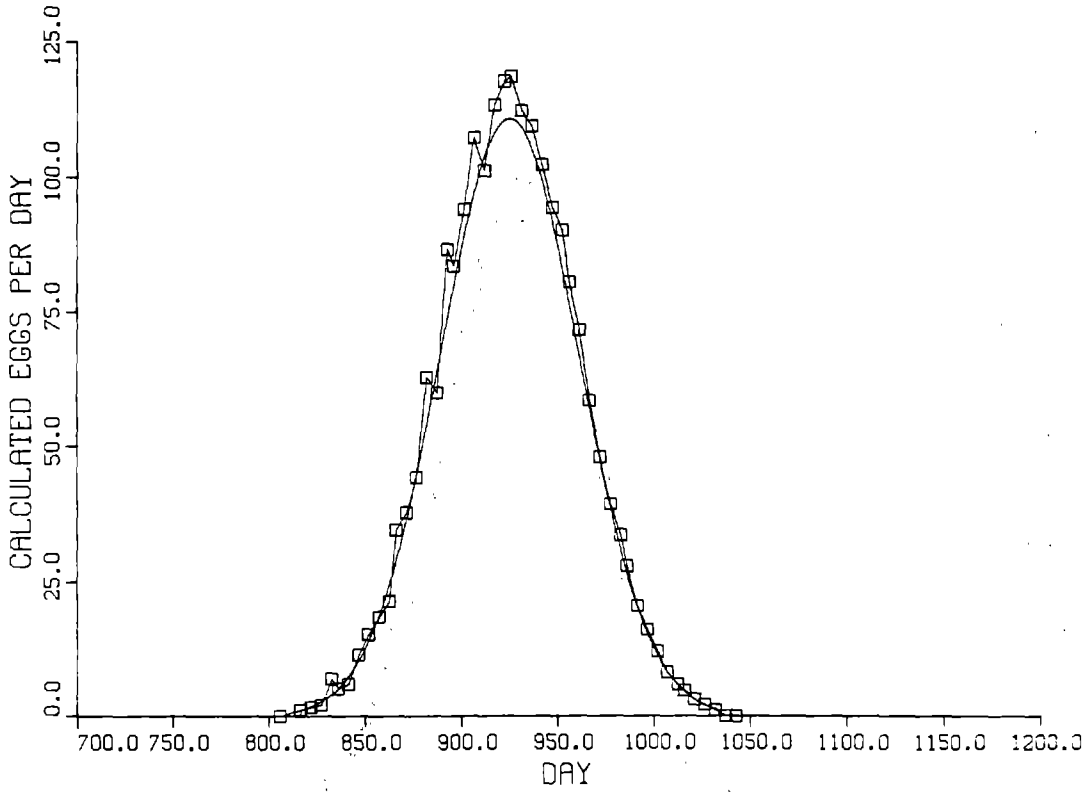

Fig. 12. Area under curve of back-calculated eggs spawned compared to original spawning curve.

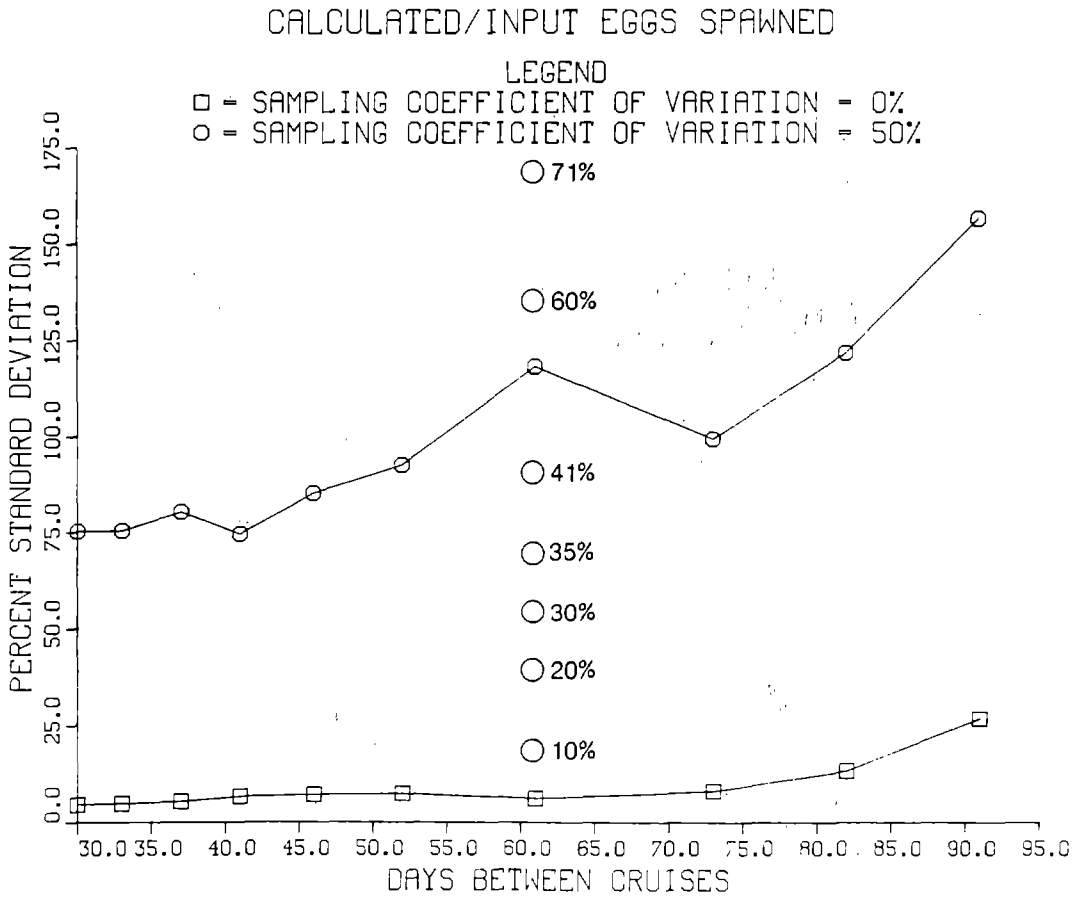

Fig. 13. Silver hake percent standard deviation as a function of days between cruises.

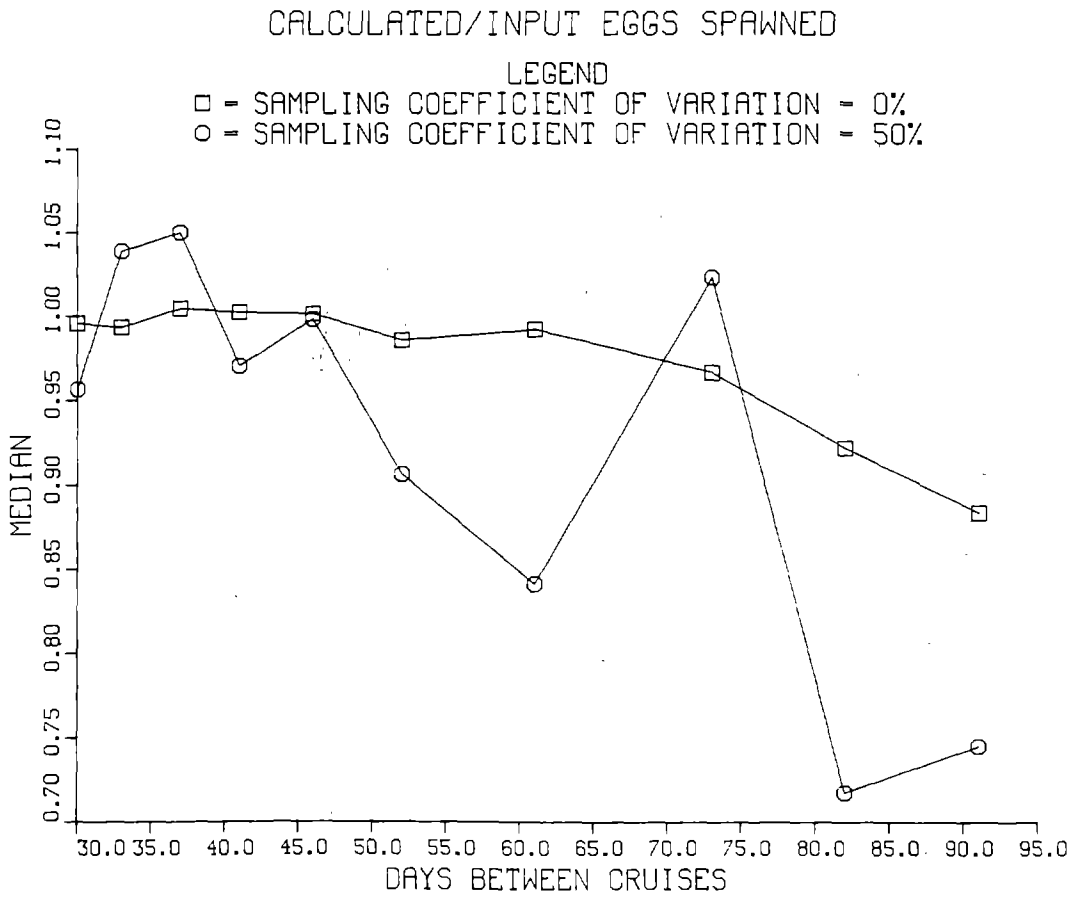

Fig. 14. Silver hake median as a function of days between cruises.

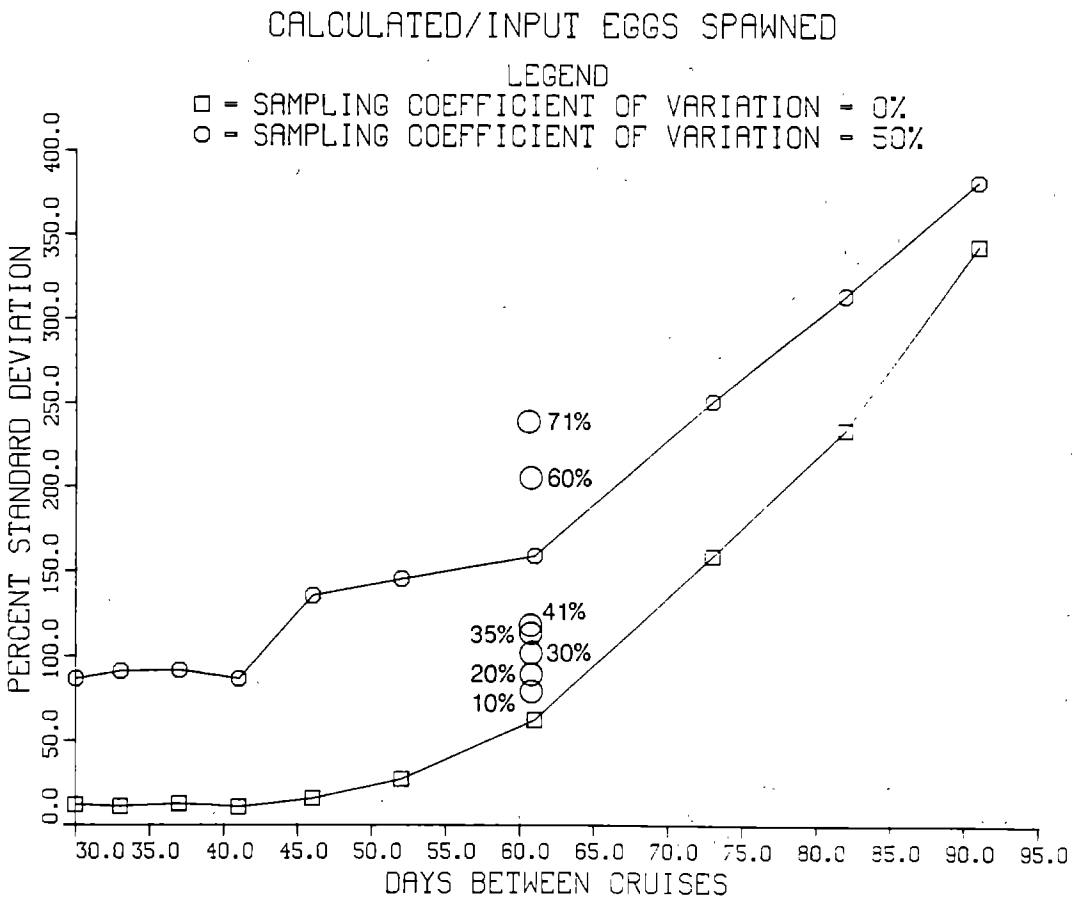

Fig. 15. Haddock percent standard deviation as a function of days between cruises.

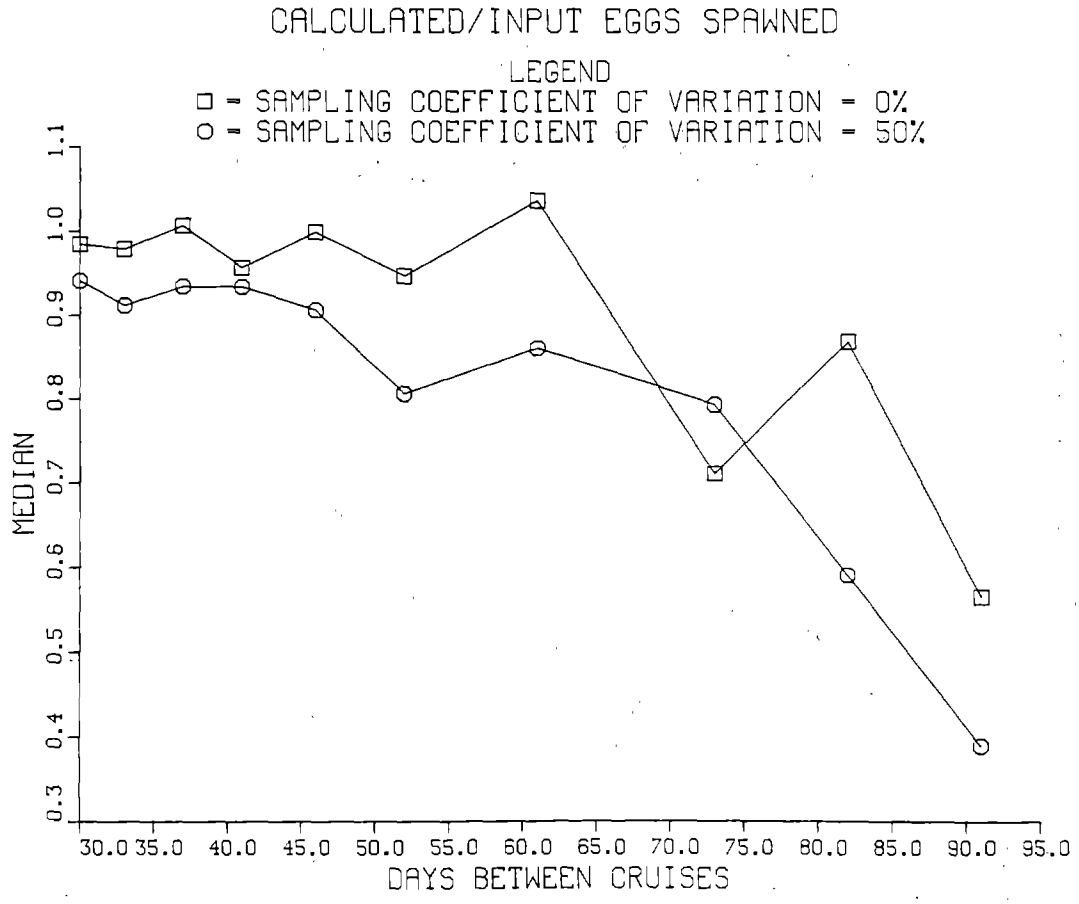

Fig. 16. Haddock median as a function of days between cruises.

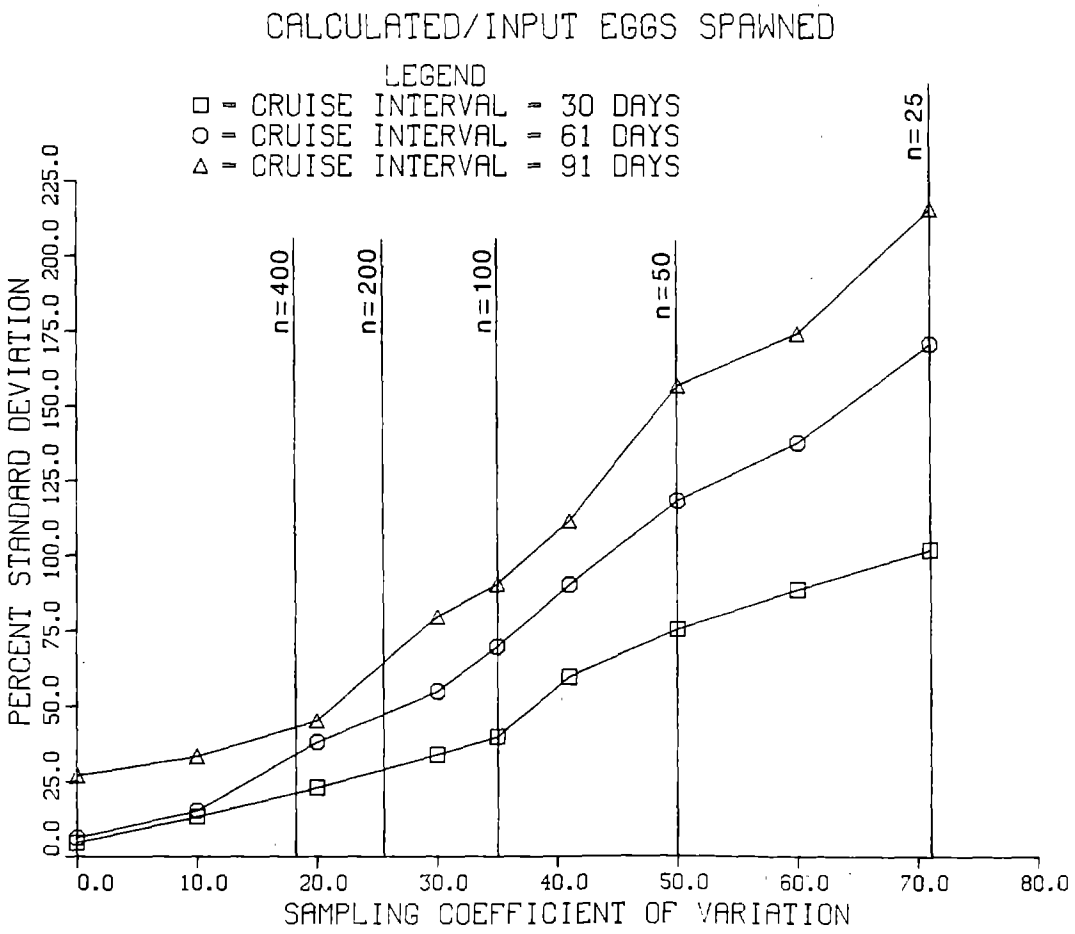

Fig. 17. Silver hake percent standard deviation as a function of sampling coefficient of variation.

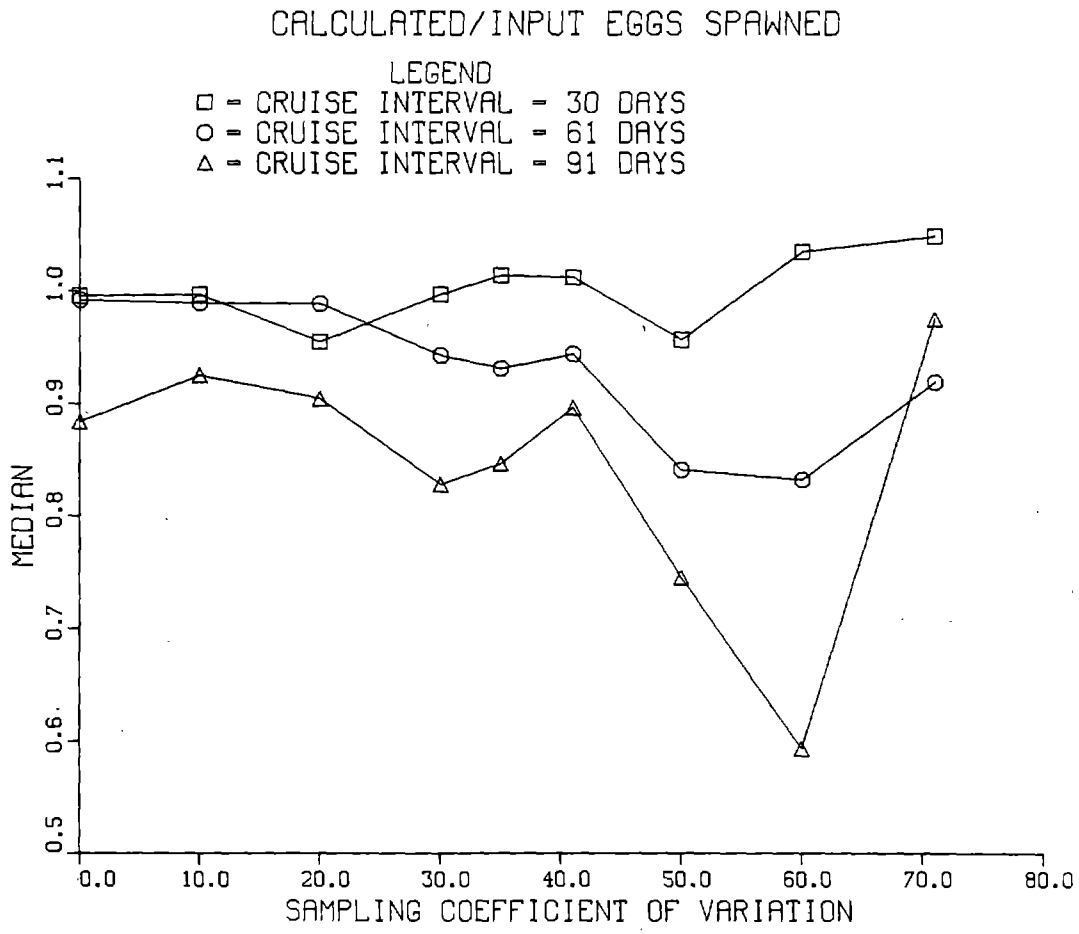

Fig. 18. Silver hake median as a function of sampling coefficient of variation.

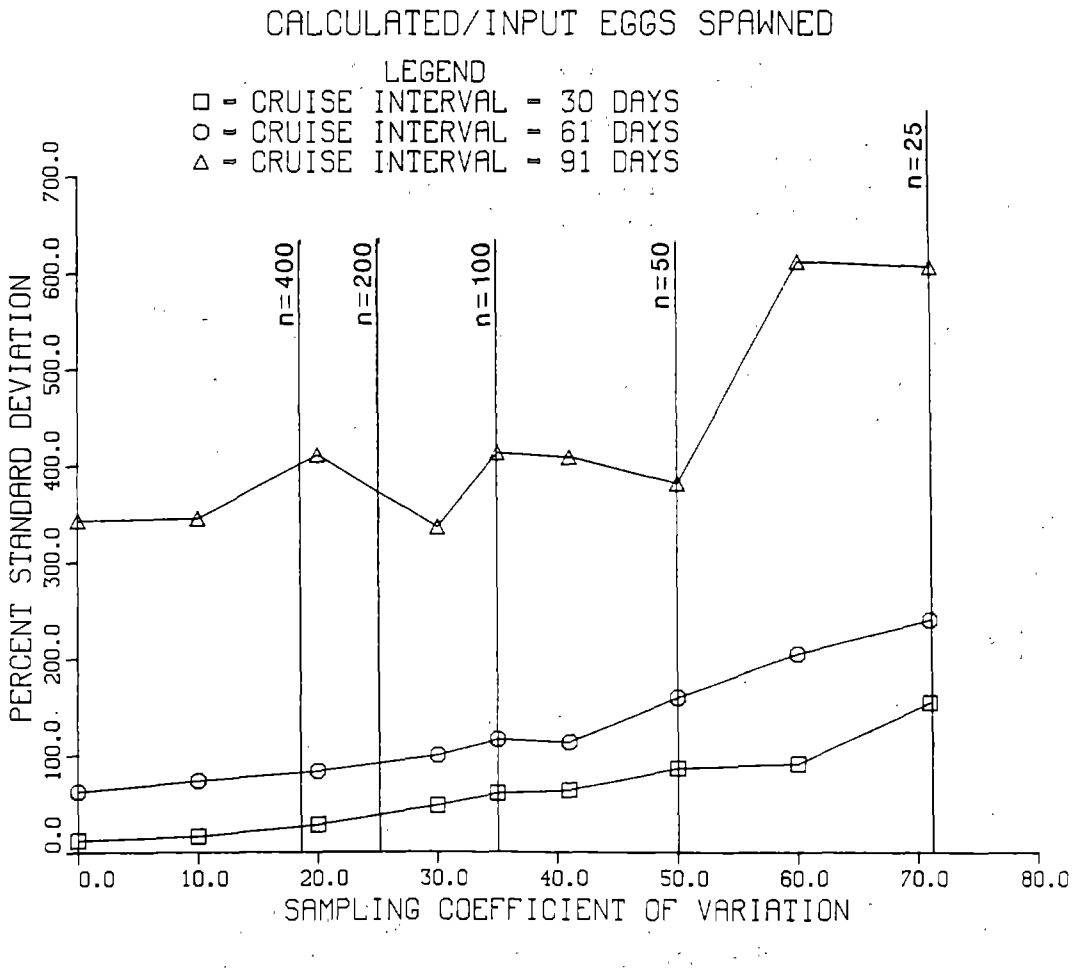

Fig. 19. Haddock percent standard deviation as a function of sampling coefficient of variation.

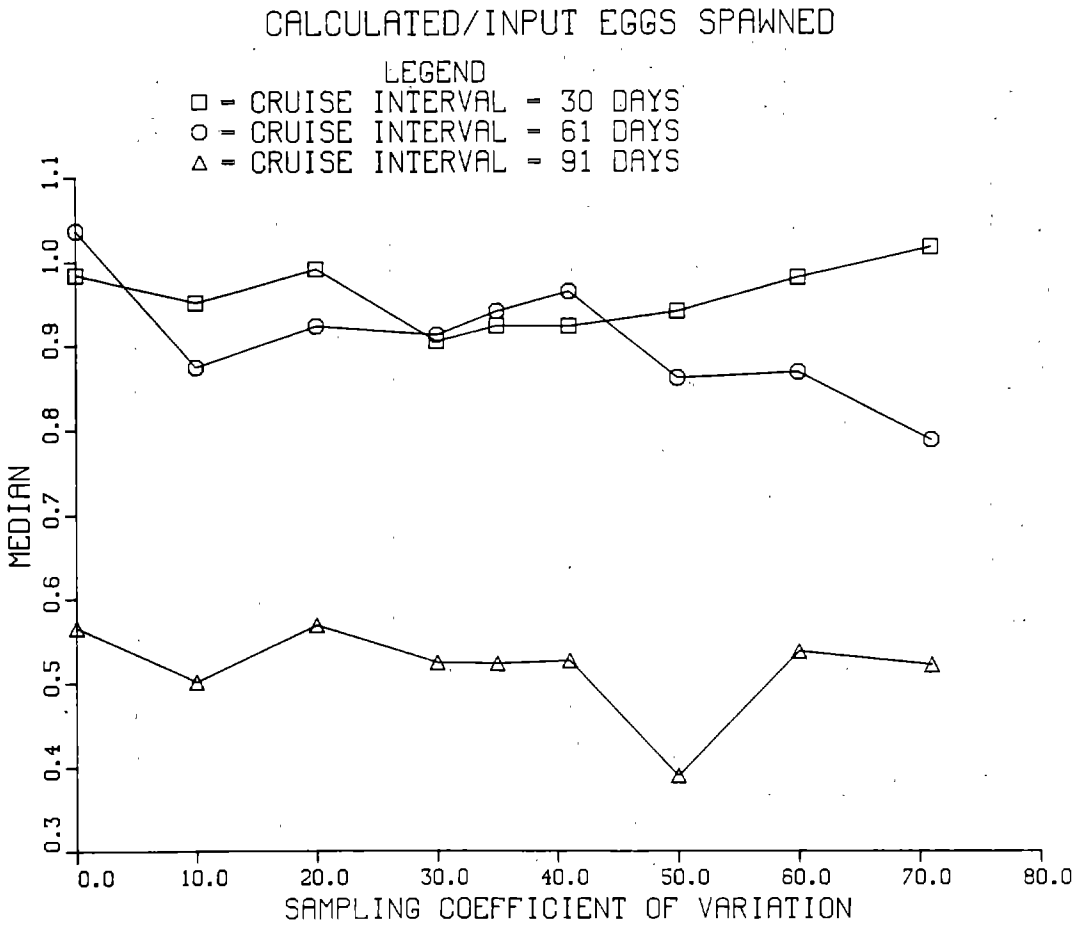

Fig. 20. Haddock median as a function of sampling coefficient of variation.

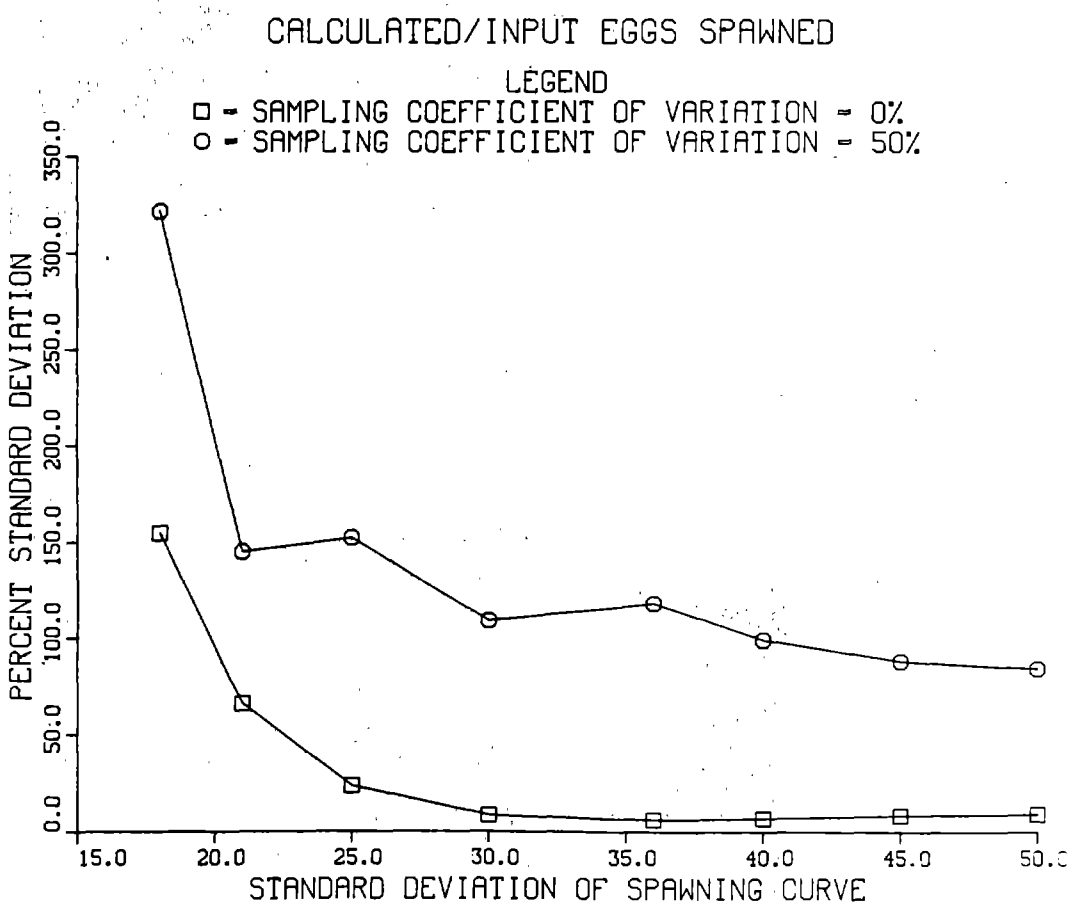

Fig. 21. Percent standard deviation as a function of standard deviation of the spawning curve.

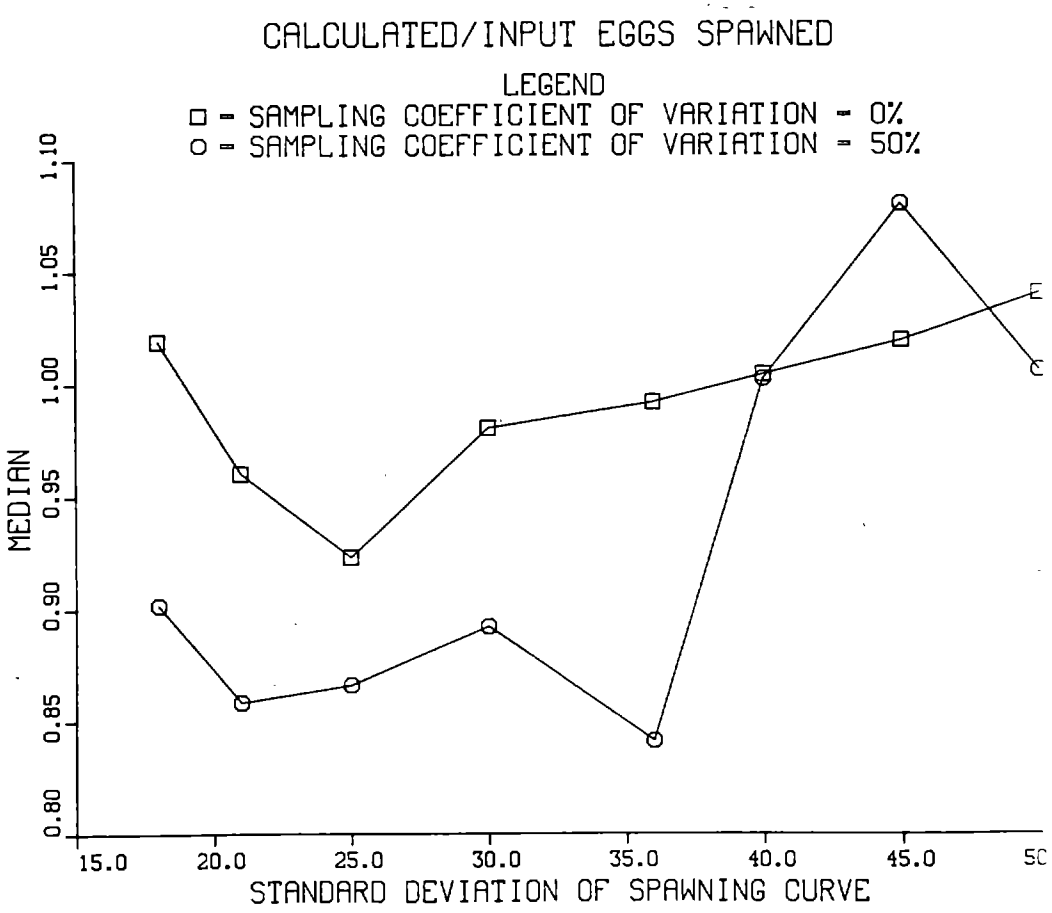

Fig. 22. Median as a function of standard deviation of the spawning curve.

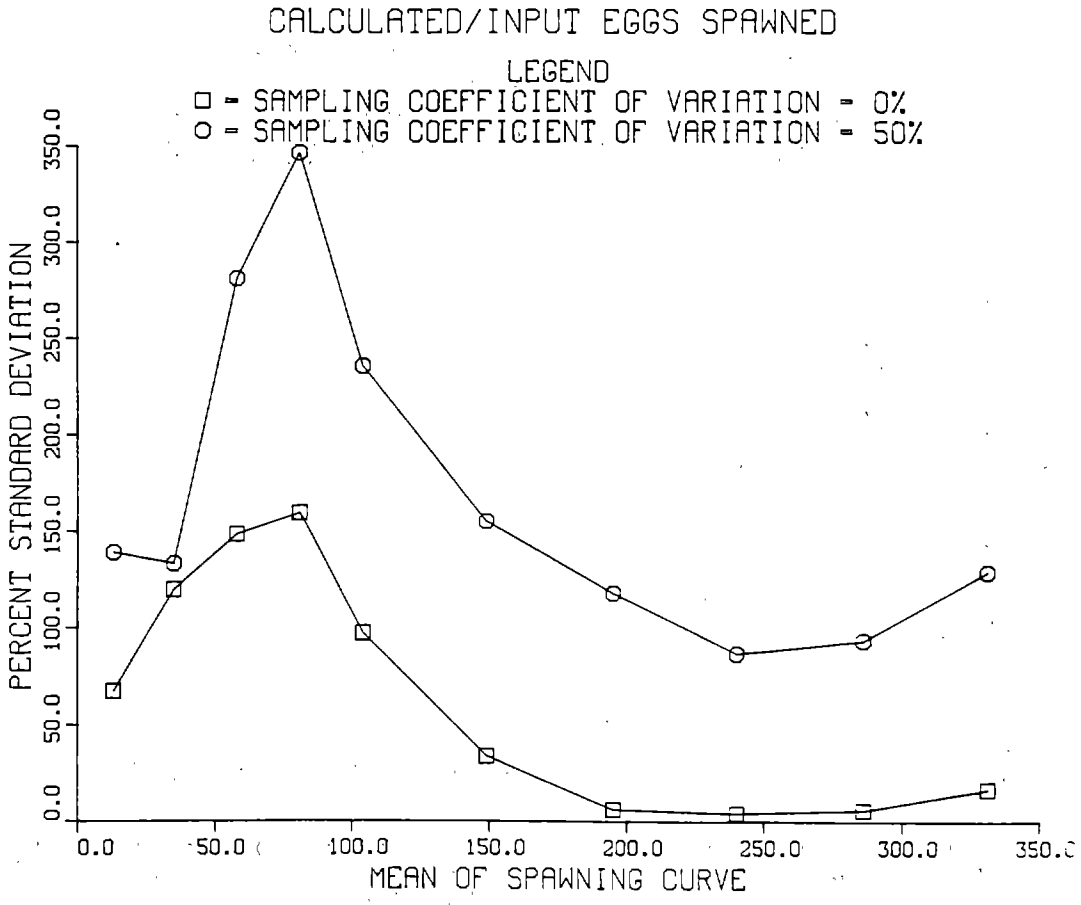

Fig. 23. Percent standard deviation as a function of mean of spawning curve using silver hake parameters.

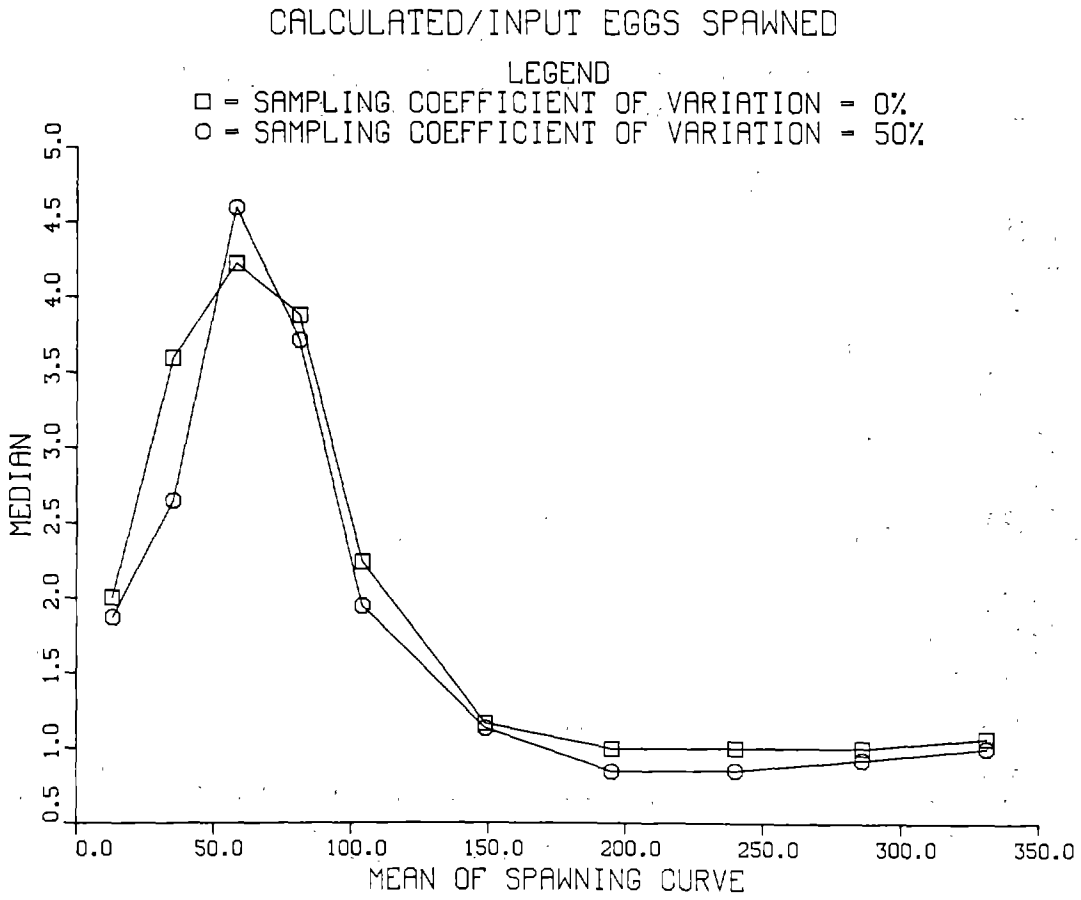

Fig. 24. Median as a function of mean of spawning curve using silver hake parameters.

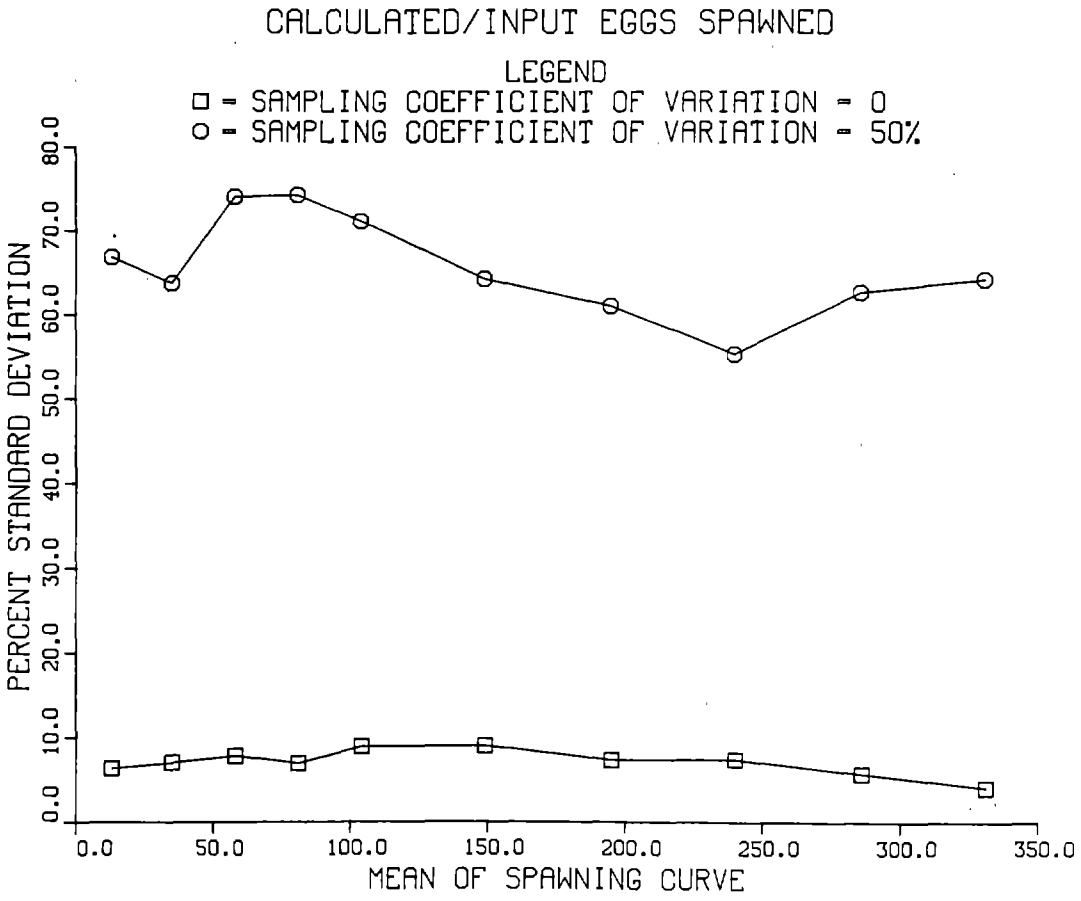

Fig. 25. Percent standard deviation as a function of mean of spawning curve using sand eel parameters.

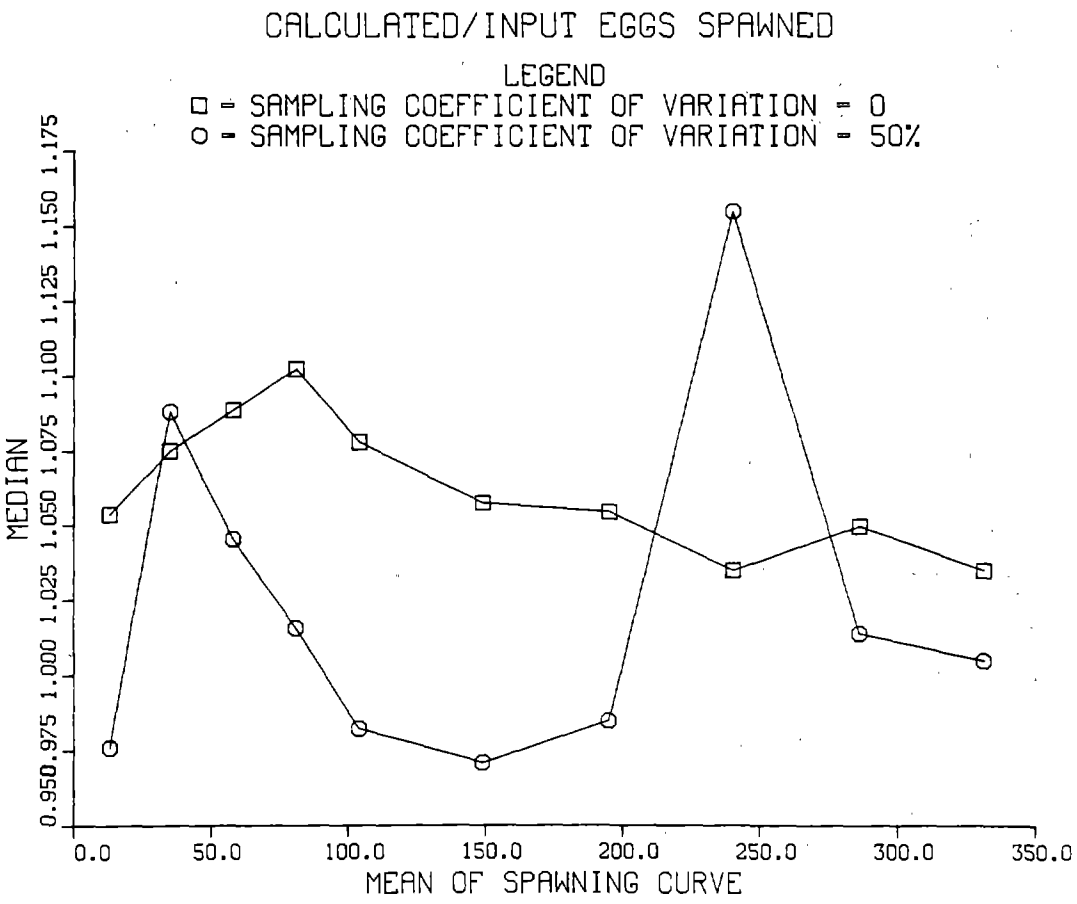

Fig. 26. Median as a function of mean of spawning curve using sand eel parameters.

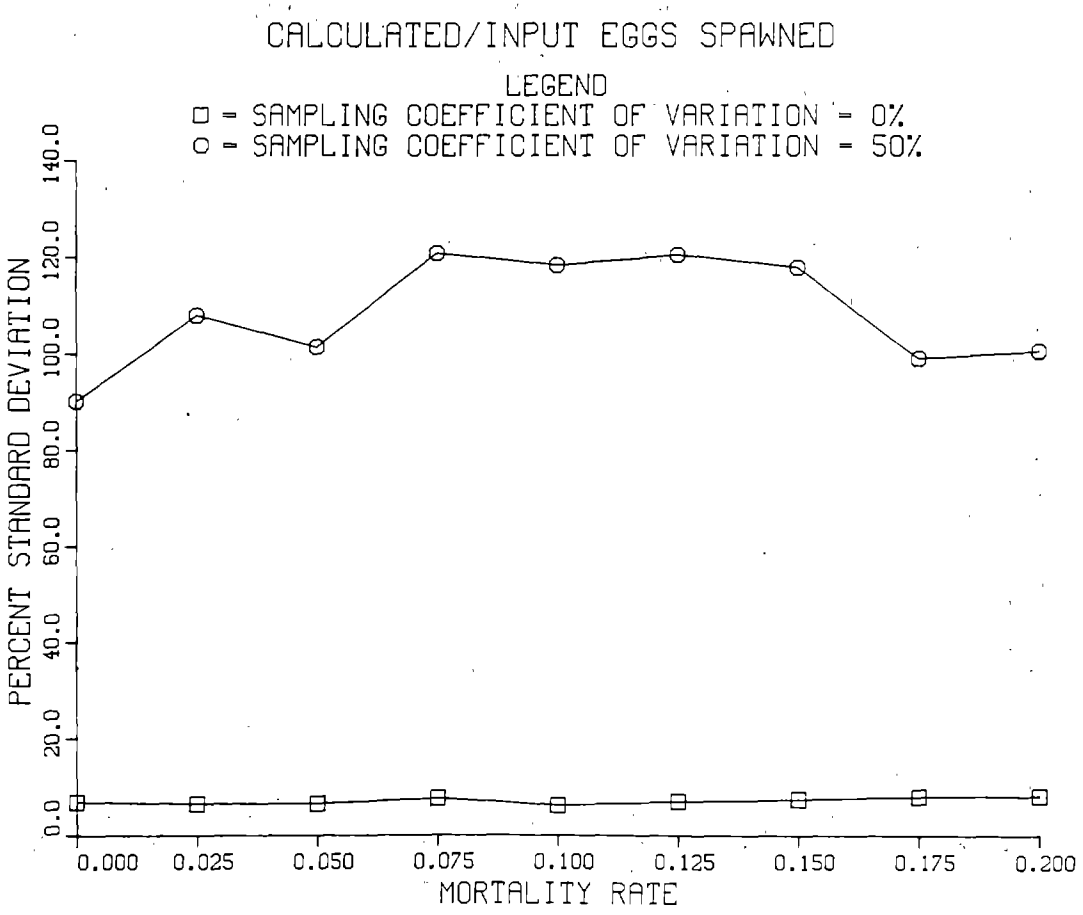

Fig. 27. Percent standard deviation as a function of mortality rate.

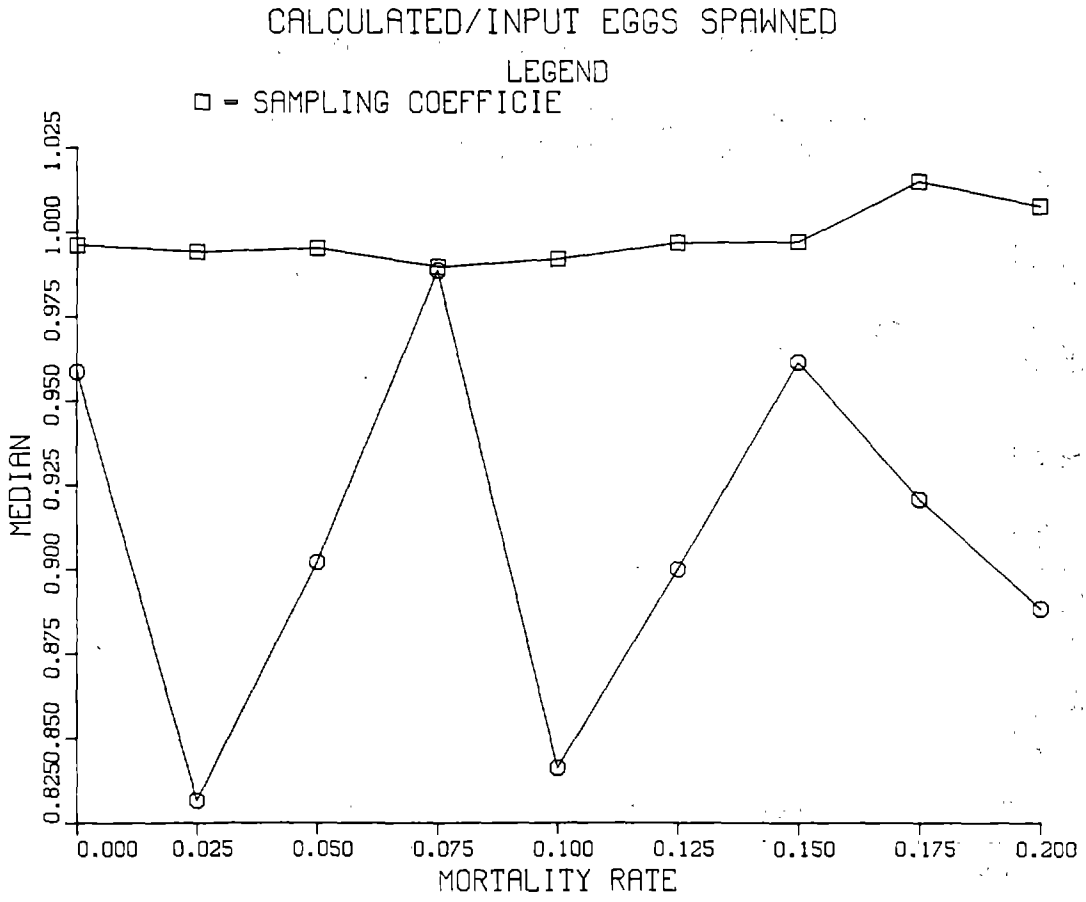

Fig. 28. Median as a function of mortality rate.

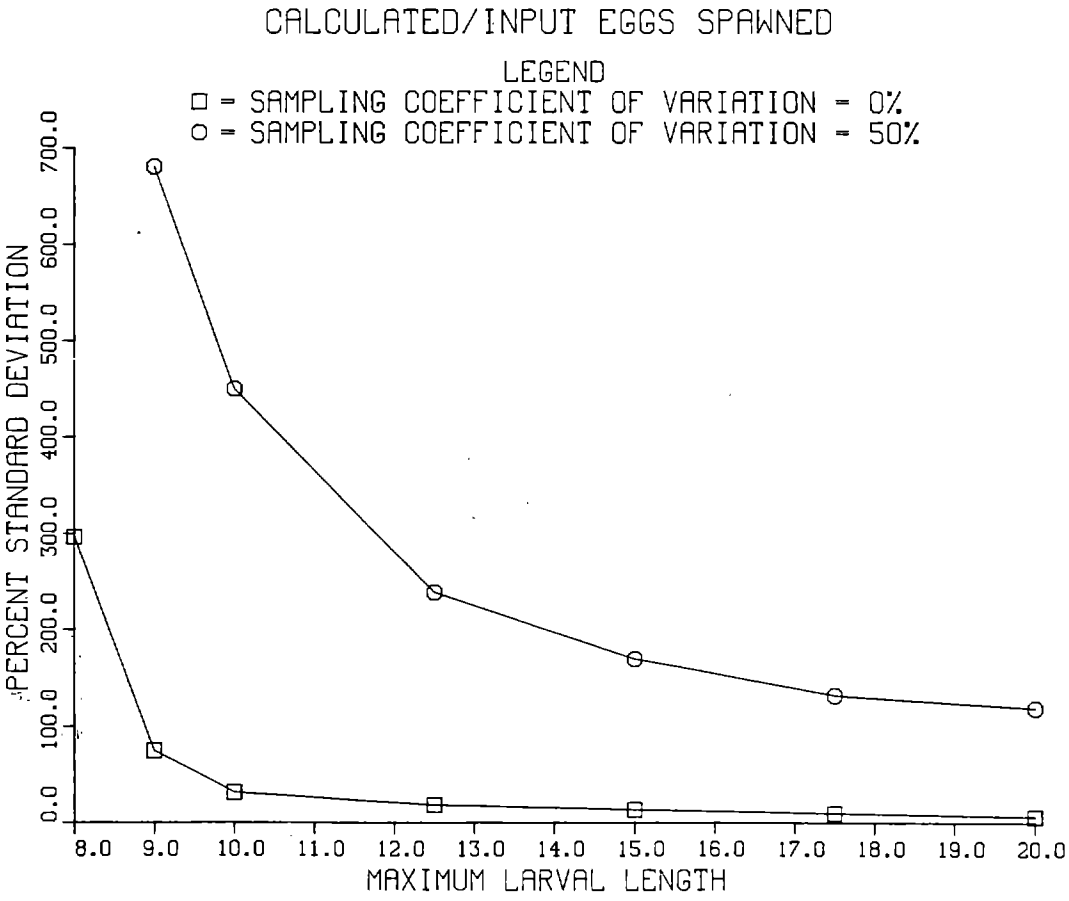

Fig. 29. Percent standard deviation as a function of maximum larval length.

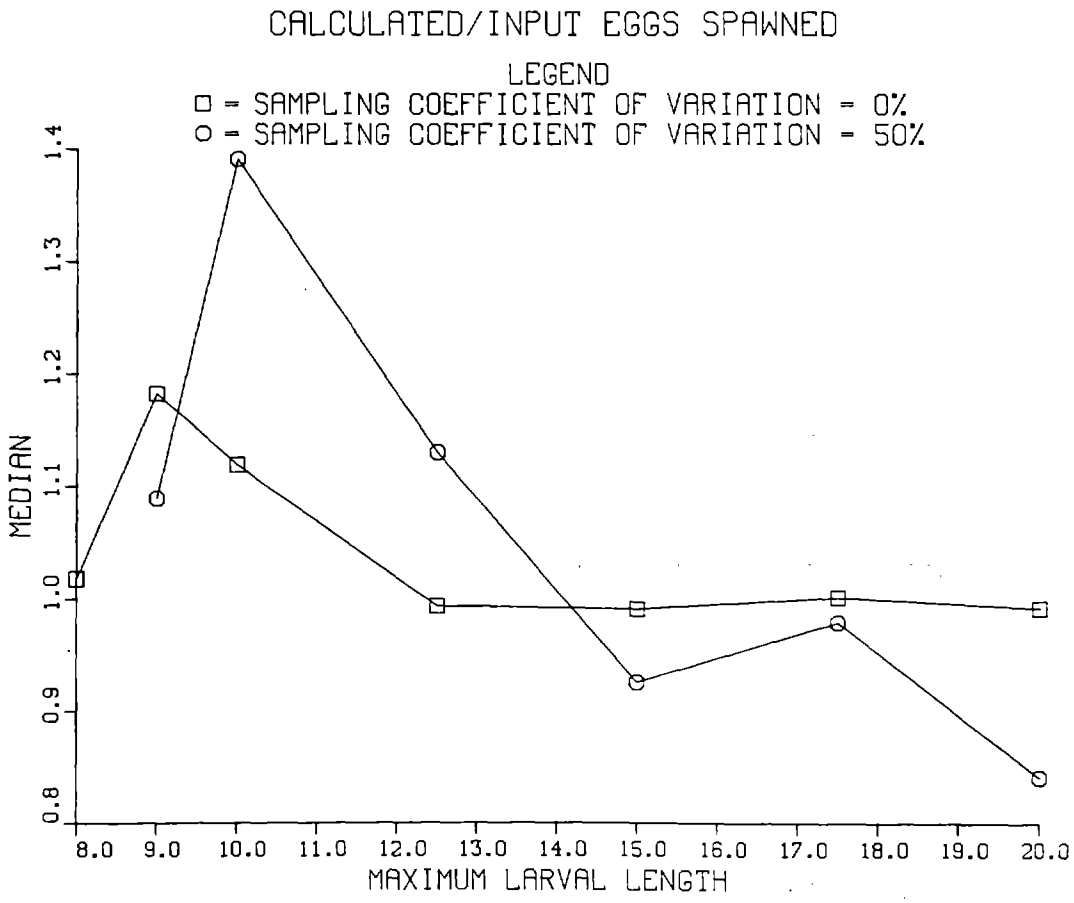

Fig. 30. Median as a function of maximum larval length.

ABSOLUTE ABUNDANCE ESTIMATES USING TRAWL AND ICHTHYOPLANKTON SURVEY DATA

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ABSTRACT

Planktonic egg surveys and bottom trawl surveys both provide unique and valuable measures of the abundance and composition of fishery resources, but the type of information derived from each survey is quite different. The egg surveys can provide estimates of the absolute abundance of fish, whereas the trawl surveys produce relative measures of abundance (i.e., catch per standard haul). An estimate of the mean ratio of the absolute-to-relative abundance provides a basis for converting trawl survey indices from relative to absolute measures of abundance. The technique is illustrated with data on the yellowtail flounder, *Limanda ferruginea*, in Southern New England and Georges Bank waters.

INTRODUCTION

For many species, egg surveys are the only fishery independent means to estimate the absolute abundance of adults. Even for major exploited species, spawning stock estimates derived from egg surveys may be needed to check the accuracy of other stock size estimates. However, several egg surveys throughout the spawning season are needed along with considerable sample processing to obtain estimates of acceptable precision for a single species/stock. The plankton samples must first be sorted back in the laboratory, and then further laboratory analysis must be done on eggs (staging) for the species of interest before deriving abundance estimates. In addition, it is necessary to know (or determine) temperature-dependent egg development rates and age/length fecundity relationships for the stock. At best there is a lag of six months to a year before the estimates are available.

In contrast, a single trawl survey can generate abundance data on a large number of species (including immature stages) within a matter of a few days or weeks, but the resulting indices are estimates of relative abundance, not of absolute abundance. The trawl index is assumed to be proportional to the actual population of fish, and if this is the case, the time series of trawl surveys can be used to monitor trends in abundance. However, the constants of proportionality are generally not known and may be different for each species or even for different stocks of the same species. Thus, it is often difficult to compare the abundance of different species or stocks.

The egg surveys can be used to calibrate the trawl index, that is, to estimate the proportionality constant relating the trawl survey index and the actual abundance of fish. Given several years with both egg and trawl survey data, we can use these proportionality constants to check the critical assumption that they are consistent over time. If this assumption holds, then one can use the mean coefficient for calculating the changes in absolute abundance for the entire time series of the trawl surveys. The objective of this paper is to illustrate the technique.

METHODS

Trawl survey procedures are described by Azarovitz (1981). The trawl survey indices were constructed using a technique described in Pennington (1985). Briefly, the method filters the original catch per tow series to remove the effects of yearly random fluctuations in catchability. Ichthyoplankton survey procedures are reviewed elsewhere in this volume by Smith and Goulet and described in detail by Sibunka and Silverman (1984). Procedures for the use of egg data to estimate yellowtail stock size are described by Berrien et al. (1984) and Berrien (1987). Data on the abundance of yellowtail flounder were derived from trawl and ichthyoplankton surveys conducted during the 4-year period between 1979 and 1982.

It is assumed that the functional relationship between the actual population of fish in year t, P_t, and the expected value of the trawl survey index, Z_t, is of the form

$$P_t = kZ_t \qquad (1)$$

where k is assumed to be constant over time (see Pennington, 1986). The estimates of P_t based on the egg surveys, and of Z_t from the trawl surveys are assumed to be lognormally distributed with equal coefficients of variation (see Collie and Sissenwine, 1983; Berrien et al., 1984; Pennington, 1985). Thus

$$\ln \hat{P}_t = \ln \hat{Z}_t \qquad (2)$$

is normally distributed with mean equal to ln k. The average value of expression (2) over the years for which data are available is an estimate of ln k and from the assumptions, it follows that the anti-log of the average is a consistent estimator of k.

RESULTS

Table 1 gives the absolute abundance estimates for 1979-1982 based on egg surveys for yellowtail flounder on Georges Bank and in Southern New England, along with the corresponding indices of relative abundance from the trawl surveys. In the last column are the estimates of ln k for each year and region along with the areal estimates. The two areal estimates are not statistically different. Hence the average of the two (15.99) is used to estimate ln k in both regions. Fig. 1 shows the estimates of the actual abundance of age one and older yellowtail flounder on Georges Bank and in Southern New England from 1968 to 1985 obtained by applying a proportionality constant equal to exp [15.99] to each (smoothed) trawl survey series.

The standard error of the adjustment factor (last row, Table 1) reflects the variability of the egg-based estimates and the trawl survey index. As the number of egg surveys increases, the standard error of k will decrease to 0, but the final variance of the abundance estimates can be no smaller than the variance of the trawl survey index.

DISCUSSION

The variability of k appears to be small relative to the variability commonly observed in stock size over time. Therefore, only a limited number of egg surveys may be necessary to estimate k. Ideally, however, egg surveys should be done periodically to determine the consistency of the proportionality constants over time, and especially over a range of population sizes. In addition, comparisons should be made between VPA and egg-based estimates whenever possible to check for consistency between the two measures

of absolute abundance since significant sources of potential bias exist for both estimators.

Collie and Sissenwine (1983) estimated the catchability coefficient of the survey trawl for yellowtail flounder on Georges Bank and in Southern New England using commercial catch statistics. Specifically, they assume:

$$Z_t = qP_t$$

where q is the catchability coefficient of the survey, that is, q = l/k. Table 2 gives their estimates of q and estimates based on the egg surveys. It is seen that the estimates of q are nearly the same for Georges Bank, but are markedly different for Southern New England. This implies, because the information provided by the trawl surveys is used similarly in both methods (Pennington, 1986), that the population estimates of the Georges Bank stock are nearly identical and the Collie-Sissenwine estimates for Southern New England are approximately one-third of the egg based stock size estimates. This discrepancy may be due to bias in the egg estimates or inaccuracies in the catch data.

It should be noted that the lack of a significant difference between the estimates of ln k for the two regions implies that the relative difference in the average trawl survey index is not significantly different from the relative difference in the average population estimates given by the egg surveys (Table 1). That is, both fishery-independent surveys generate similar estimates of the mean relative difference in population between the two areas.

Likewise, if k (or q) is the same in both areas (and if the assumptions made are valid) then the combined plot of ln $\hat{P}_t$ vs. ln $\hat{Z}_t$ (from Table 1) would be linear with slope equal to one. Fig. 2 shows the plot of the estimates from the two regions. The estimated slope of 1.1 is not significantly different from one.

Even though the amount of egg data is at present limited, it is evident that the population estimates based on the plankton surveys can provide an important verification of the consistency of the trawl survey index. For example, the adjustment factors (last column in Table 1) display no major trends over time, which gives further support to the assumption that the (smoothed) trawl survey index is proportional to the actual population. Thus, if combined, the two types of surveys can provide the basis for generating a timely fishery-independent estimate of absolute abundance and also provide population estimates for the entire trawl survey period. This is especially important for a species such as yellowtail flounder, for which VPA estimates of abundance are not yet available.

LITERATURE CITED

Azarovitz, T. 1981. A brief historical review of the Woods Hole Laboratory Trawl Survey Time Series. *In*: W. G. Doubleday and D. Rivard (Ed.). Bottom trawl surveys. Can. Spec. Publ. Fish. Aquat. Sci. 58:62-67.

Berrien, P., and J. Sibunka. 1987. Yellowtail flounder, *Limanda ferruginea*, total annual egg production and population biomass estimates for northeast U.S. waters, 1979-1982. (Unpublished ms.)

Berrien, P., W. Morse, and M. Pennington. 1984. Recent estimates of adult spawning stock biomass off the northeast United States from MARMAP ichthyoplankton surveys. NOAA Tech. Mem. NMFS-F/NEC-30. 111 pp.

Collie, J. S., and M. P. Sissenwine. 1983. Estimating population size from relative abundance data measured with error. Can. J. Fish. Aquat. Sci. 40:1871-1879.

Pennington, M. 1985. Estimating the relative abundance of fish from a series of trawl surveys. Biometrics 41:197-202.

Pennington, M. 1986. Some statistical techniques for estimating abundance indices from trawl surveys. Fish. Bull., U.S. 84:519-525.

Sibunka, J., and M. Silverman. 1984. MARMAP surveys of the continental shelf from Cape Hatteras, North Carolina, to Cape Sable, Nova Scotia (1977-1983). Atlas No. 1. Summary of operations. NOAA. Tech. Mem. NMFS-F/NEC-33. 306 pp.

Smith, W. G., and J. Goulet. This volume. MARMAP ichthyoplankton surveys: An overview of methods and data base management.

Table 1. Summary statistics for Georges Bank and Southern New England yellowtail flounder stocks. All values are $\log_e$.

Region	Year	Trawl Index	Egg Survey Population Estimate	$\ln \hat{k}$
Georges Bank	1979	1.74	17.88	16.14
	1980	2.16	17.37	15.21
	1981	1.94	17.96	16.02
	1982	1.73	17.54	15.80
Average		1.89	17.69	15.79
Standard Error		.10	.14	.21
Southern New England	1979	2.40	19.13	16.73
	1980	2.48	18.63	16.15
	1981	2.86	18.36	15.50
	1982	3.22	19.57	16.35
Average		2.74	18.92	16.18
Standard Error		.19	.27	.26
Average of both regions				15.99
Standard Error				.17

Table 2. Estimates of the catchability coefficients (q) of the trawl survey for yellowtail flounder based on egg surveys (ES) and Collie and Sissenwine method (C-S).

Method	Region	q ($x10^{-6}$)	95% Confidence Interval ($x10^{-6}$)
ES	SNE	.094	0.041 - 2.130
C-S	SNE	.313	0.189 - 0.437
ES	GB	.139	0.072 - 0.267
C-S	GB	.107	0.061 - 0.153
ES	GB & SNE	.114	0.076 - 0.170

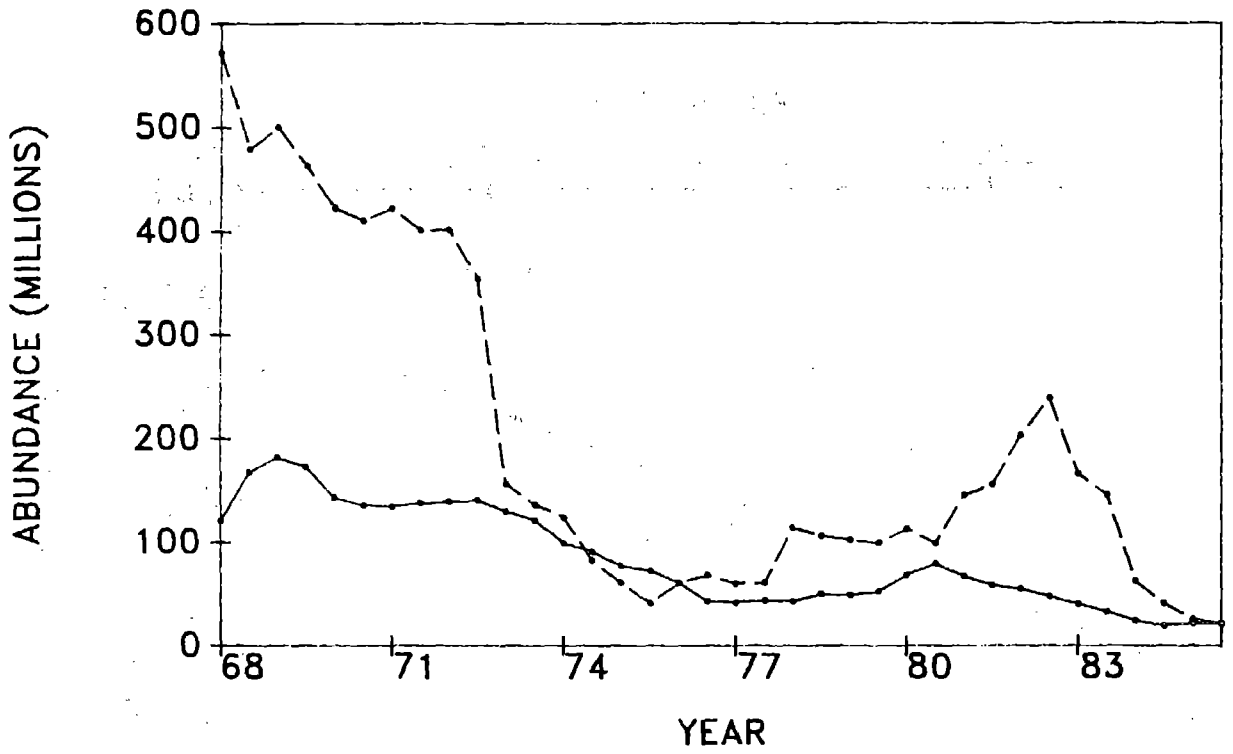

Fig. 1. Biannual (spring and fall) estimates of the abundance of one-year-and-older yellowtail flounder on Georges Bank (solid line) and in Southern New England (broken line).

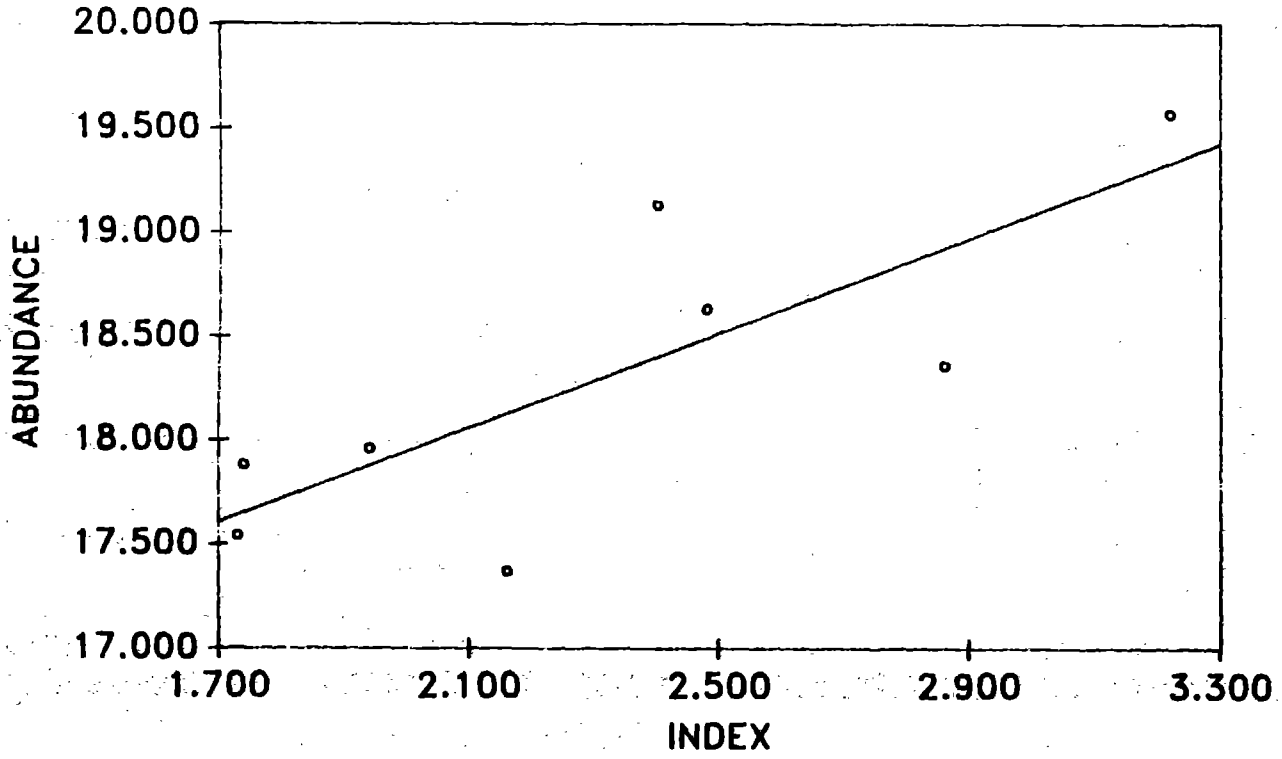

Fig. 2. Linear relationship between the egg survey abundance estimate and the trawl survey index of relative abundance. All values are $\log_e$.

APPENDIX: LIST OF REPORTS BASED ON MARMAP SURVEYS

Able, K. W., M. P. Fahay, and D. F. Markle. 1987. Development of larval snailfishes (Pisces: Cyclopteridae: Liparidae) from the western North Atlantic. Can. J. Zool. 64:2294-2316.

Able, K. W., D. F. Markle, and M. P. Fahay. 1984. Cyclopteridae: development. pp. 428-438. *In* H. G. Moser, W. J. Richards, D. M. Cohen, M. P. Fahay, A. W. Kendall, Jr., and S. L. Richardson (Eds.) Ontogeny and systematics of fishes. Am. Soc. Ichthyol. Herpetol., Spec. Publ. 1:760 pp.

Azarovitz, T. R., C. J. Byrne, M. J. Silverman, B. L. Freeman, W. G. Smith, S. C. Turner, B. A. Halgren, and P. J. Festa. 1980. Effects on finfish and lobsters. Chap. 13, pp. 295-314. *In* R. L. Swanson and C. J. Sindermann (Eds.) Oxygen depletion and associated benthic mortalities in New York Bight, 1976. NOAA Prof. Paper 11.

Berman, M. S., H. P. Jeffries, R. M. Lambert, and K. Sherman. 1981. Environmental gradients on a coastal megalopolis II: Size frequency distributions in zooplankton. ICES C.M. 1981/L:28.

Berrien, P. 1981. Comments on efficiency of NEFC surveys. ICES Larval Fish Ecology Working Group Report, Lowestoft, Suffolk, UK, 1-3 July 1981. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr., Sandy Hook Lab. Ref. 82-2.

Berrien, P. L. 1981. Yellowtail flounder, *Limanda ferruginea*, estimates of egg abundance and population size during spring 1977 in Gulf of Maine, Georges Bank, Southern New England, and Middle Atlantic Bight waters. ICES C.M. 1981/G:65.

Berrien, P. 1983. Silver hake, *Merluccius bilinearis* egg census and adult population estimate for 1979 in waters off eastern United States. ICES C.M. 1983/G:46.

Berrien, P. 1984. Silver hake, *Merluccius bilinearis*, egg census and adult population estimates for 1979 and 1980 in waters off eastern United States. ICES C.M. 1984/G:29. (MARMAP Contribution No. MED/NEFC 84-14).

Berrien, P., W. Morse, and M. Pennington. 1984. Recent estimates of adult spawning stock biomass off northeastern United States from MARMAP Ichthyoplankton Surveys. NOAA Tech. Mem. NMFS-F/NEC-30. 111 pp.

Berrien, P. L., N. A. Naplin, and M. R. Pennington. 1981. Atlantic mackerel, *Scomber scombrus*, egg production and spawning population estimates for 1977 in the Gulf of Maine, Georges Bank, and Middle Atlantic Bight. Rapp. P.-v. Reun. Cons. int. Explor. Mer 178:279-288.

Busch, D., and J. Green (Compilers). 1981. Reference document: U.S.-U.S.S.R. cooperative fisheries research in the Northwest Atlantic, 1981 meeting, 16-19 November, Moscow. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr., Narragansett Lab. Ref. No. 81-79.

Busch, D. A., and D. Mountain. 1982. Phytoplankton biomass and physical conditions on Georges Bank in an area of larval cod and haddock concentrations. EOS, Trans. Am. Geophys. Union 63(3). Abstract only.

Busch, D., and J. O'Reilly. 1979. Summary of ^{14}C simulated *in situ* measurements MARMAP cruises 1978. For joint meeting in Moscow, U.S.S.R. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Narragansett Lab. Ref. 79-08.

Cain, T. E. 1981. Temperature structure and surface salinity in the Gulf of Maine in 1979. ICES Annales Biologiques 36:36-43.

Campbell, J. W., and J. E. O'Reilly. In press. Role of satellites in estimating primary productivity on the Northwest Atlantic continental shelf. Continental Shelf Res.

Cohen, E. B. 1980. A preliminary summary of available data on nutrients, primary productivity, and chlorophyll *a* for the ICNAF larval herring research area, 1975-1978. (Also NAFO, SCR Doc. 80/IX/140).

Cohen, E. B. 1985. Recent research at the Northeast Fisheries Center on some factors affecting the recruitment of Georges Bank cod and haddock. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Woods Hole Lab. Ref. Doc. No. NG. (MARMAP Contribution No. FED/NEFC 85-09).

Cohen, E. B., and M. Grosslein. Ecosystem modelling in the Marine Ecosystems Division. A status report. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Woods Hole Lab. Ref. Doc. No. 84-08. (MARMAP Contribution No. MED/NEFC 84-08.)

Cohen, E. B., and M. D. Grosslein. 1987. Production on Georges Bank compared with other shelf ecosystems. pp. 383-391. *In* R. H. Backus (Ed.) Georges Bank, MIT Press, Cambridge.

Cohen, E. B., M. D. Grosslein, M. P. Sissenwine, F. Steimle, and W. R. Wright. 1982. An energy budget for Georges Bank. Can. Fish. Aquat. Sci. Spec. Publ. 59:95-107.

Cohen, E. B., G. Laurence, and W. Smith. 1984. The role of starvation and predation in regulating year class strength in several fish stocks on Georges Bank. ICES C.M. 1984/G:32.

Cohen, E. B., D. G. Mountain, and S. H. Clark. 1982. Comparison of energy flow in three Northwestern Atlantic ecosystems. ICES C.M. 1982/L:47.

Cohen, E., D. Mountain, and W. Smith. 1982. Physical processes and year-class strength of commercial fish stocks on Georges Bank. EOS. Trans. Am. Geophys. Union 63(45):956 Abstract #L031C-38.

Cohen, E. B., D. G. Mountain, and W. G. Smith. 1984. Comparison of cod and haddock spawning in 1982 and 1983 on Georges Bank. NAFO SCR Doc. 84/VI/75.

Cohen, E., W. R. Wright, and R. J. Schlitz. 1981. Primary productivity on Georges Bank with an explanation of why it is so high. p. 50. *In* Third informal workshop on the oceanography of the Gulf of Maine and adjacent seas, Univ. New Hampshire, Durham, 2-5 Mar. 1981. (Abstract only).

Colton, J. B., Jr., J. L. Anderson, J. L. O'Reilly, C. A. Evans-Zetlin, and H. G. Marshall. 1985. The shelf/slope front south of Nantucket Shoals and Georges Bank as delineated by satellite infrared imagery and shipboard hydrographic and plankton observations. NOAA Tech. Mem. NMFS-F/NEC-38. 22 pp.

Colton, J. B., Jr., and J. L. Anderson. 1983. Residual drift and residence time of Georges Bank surface waters with reference to the distribution, transport, and survival of larval fishes. MARMAP Contribution MED/NEFC 82-10. NOAA Tech. Mem. NMFS-F/NEC-24. 44 pp.

Colton, J. B., Jr., J. R. Green, R. R. Byron, and J. L. Frisella. 1980. Bongo net retention rates as effected by towing speed and mesh size. Can. J. Fish. Aquat. Sci. 37:606-623.

Colton, J. B., W. G. Smith, A. W. Kendall, P. Berrien, and M. P. Fahay. 1979. Principal spawning areas and times of marine fishes, Cape Sable to Cape Hatteras. Fish. Bull., U.S. 76:911-915.

Davis, C. S. 1987. Components of the zooplankton production cycle in the temperate ocean. J. Mar. Res. 45:947-983.

Evans, C. A., J. E. O'Reilly, and J. P. Thomas. 1987. A handbook for the measurement of chlorophyll *a* and primary production. Biomass Scientific Ser. No. 8. SCAR/SCOR and NOAA/NMFS. Texas A&M Univ., College Station, TX. 114 pp.

Fahay, M. P. 1983. Guide to the early stages of marine fishes occurring in the western North Atlantic Ocean, Cape Hatteras to the Southern Scotian Shelf. J. Northw. Atl. Fish. Sci. 4:423 pp.

Fahay, M. P. 1987. Larval and juvenile hakes (*Phycis-Urophycis* sp.) examined during a study of the white hake, *Urophycis tenuis* (Mitchell), in the Georges Bank-Gulf of Maine area. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Sandy Hook Lab. Ref. No. 87-03. 22 pp.

Fahay, M. P., and P. Berrien. 1981. Preliminary description of larval tilefish *Lopholatilus chamaeleonticeps*. Rapp. P.-v. Reun. Cons. int. Explor Mer 178:600-602.

Fahay, M. P., and D. F. Markle. 1984. Gadiformes: Development and relationships, pp. 265-283. *In* H. G. Moser , W. J. Richards, D. M. Cohen, M. P. Fahay, A. W. Kendall, Jr., and S. L. Richardson (Eds.) Ontogeny and systematics of fishes. Am. Soc. Ichthyol. Herpetol. Spec. Publ. No. 1:760 pp.

Goulet, J. 1981. Information resource management for MARMAP ecosystems research. Proceedings of the Federal Information Processing Council of New England Conference. Woods Hole, 23-24 April 1981.

Goulet, J. R., Jr. 1985. Data management for analysis of large marine ecosystems. ICES C.M. 1985/L:1.

Goulet, J. R., Jr., J. K. Sailor, J. K. Berry, and K. Sherman. 1981. Computer-assisted map analysis and marine ecosystem information. pp. 264-272. *In* Proceedings of Oceans '81 Conference, Sept. 1981. Mar. Technol.

Green, J. 1981. Aspects of *Calanus finmarchicus* trophodynamics in the area of high larval haddock abundance in spring on Georges Bank. ICES C.M. 1981/L:32.

Green, J. R. 1983. Seasonal zooplankton standing stock, and dominant species abundance in continental shelf waters in and near the area potentially influenced by dumping at

DWD 106. *In* J. B. Pearce, D. C. Miller, and C. Berman (Eds.) 106-Mile site characterization update. NOAA Tech. Mem. NMFS-F/NEC-26. 483 pp. NTIS Access No. PB84-118363.

Jewell, C. 1984. Temperature structure and surface salinity in the Gulf of Maine during 1983. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Woods Hole Lab. Ref. Doc. No. 84-24.

Jossi, J. W., and R. R. Marak. 1983. MARMAP plankton survey manual. NOAA. Tech. Mem. NMFS-F/NEC-21. 258 pp.

Kane, J. 1982. Effect of season and location on the relationship between zooplankton displacement volume and dry weight in the Northwest Atlantic. MARMAP Contribution No. MED/NEFC 81-8. Fish. Bull., U.S. 80:631-642.

Kane, J. 1984. The feeding habits of co-occurring cod and haddock larvae from Georges Bank. MARMAP Contribution No. MED/NEFC 82-38. Mar. Ecol. Prog. Ser. 16:9-20.

Kendall, A. W., Jr., and D. Gordon. 1981. Growth rate of Atlantic mackerel (*Scomber scombrus*) larvae in the Middle Atlantic Bight. Rapp. P.-v. Reun. Cons. int. Explor. Mer 178:337-341.

Kirschner, R. A. 1978. Temperature structure and surface salinity in the Gulf of Maine during 1978. ICES Annales Biologiques 35:30-41.

Kirschner, R. A. 1979. Fall temperature structure in the northern Gulf of Maine: A four-year comparison. Coastal Oceanogr. Climatol. News 1(2):16-17.

Kirschner, R. A. 1980. Hydrographic work on MARMAP cruises. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Woods Hole Lab. Ref. No. 80-25.

Lough, R. G. 1982. Absence of cod and haddock larvae on Georges Bank spring, 1982. Red Flag Report. 9 pp.

McKenney, T. 1981. A checklist of some fishes taken with neuston and bongo nets in the vicinity of Deep Water Dumpsite 106. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Sandy Hook Lab. Ref. No. 81-26. 35 pp.

McKenney, T. W. 1983. Distribution and abundance of *Merluccius albidus* larvae in shelf waters off the northeastern United States, 1977-1981. ICES C.M. 1983/G:48.

McKenney, T. W., A. Johnson, and A. Wells. 1984. Distribution and abundance of *Citharichthys arctifrons* larvae in shelf waters off the northeastern United States, 1977-82. ICES C.M. 1984/G:31.

Miller, D. S., P. M. Payne, and K. D. Powers. 1980. Marine observer manual. Appendix B. A marine mammal observer training program. U.S. Dep. Commer. NMFS/NEFC Contract No. NA-80-FA-D-0004. Woods Hole, MA. 147 pp.

Morse, W. 1982. Spawning stock biomass estimates of sand lance, *Ammodytes* sp., off northeastern United States, determined from MARMAP plankton surveys, 1974-1980. ICES C.M. 1982/G:59.

Morse, W., M. P. Fahay, and W. Smith. 1987. Surveys of the continental shelf from Cape Hatteras, North Carolina, to Cape Sable, Nova Scotia, 1977-84. Atlas No. 2. Annual distribution patterns of fish larvae. NOAA Tech. Mem. NMFS-F/NEC-47. 215 pp.

Morse, W. W., and J. W. Hauser. 1985. A study of factors affecting the precision of spawning stock estimates using MARMAP fish egg and larval surveys. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Sandy Hook Lab. Ref. No. 85-07. (MARMAP Contribution No. FED/NEFC 85-12.)

Moser, H. G., W. J. Richards, D. M. Cohen, M. P. Fahay, A. W. Kendall, Jr., and S. L. Richardson (Editors). 1984. Ontogeny and systematics of fishes. Am. Soc. Ichthyol. Herpetol. Spec. Publ. No. 1:i-ix + 760 pp.

Mountain, D. G., and E. B. Cohen. 1982. The effect of water residence time on the plankton population levels of Georges Bank. EOS, Trans. Am. Geophys. Union, 1982. 63(3) (Abstract only).

Mountain, D., and E. Cohen. 1982. Biological implications of the Georges Bank physical oceanography. EOS, Trans. Am. Geophys. Union, 1982. 63(18) (Abstract only).

Mountain, D. G., and E. B. Cohen. 1983. The effect of water residence time on the plankton population levels on Georges Bank. ICES C.M. 1983/L:25.

Mountain, D. G., and P. F. Jessen. 1983. Variations in the deep water of the Gulf of Maine, 1979-1980. EOS, Trans. Am. Geophys. Union 1983. (Abstract only).

Naplin, N. A., and C. L. Obenchain. 1981. A description of eggs and early larvae of the snake eel, *Pisodonophis cruentifer* (Ophichthidae), with comments on egg stages collected in the plankton. Rapp. P.-v. Cons. Int. Explor. Mer 178:580-582.

Nickerson, S., and D. Mountain. 1983. Surface and bottom temperature and bottom salinity distributions on the continental shelf, Cape Hatteras to Cape Sable from MARMAP cruises, 1977-1982. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Woods Hole Lab. Ref. Doc. 83-11.

O'Reilly, J., and D. A. Busch. 1979. Summary of measurements of primary productivity made during MARMAP surveys (*Belogorsk* 78-01, 78-03, 78-04). NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Sandy Hook Lab. Ref. No. 79-09.

O'Reilly, J. E., and D. A. Busch. 1982. Preliminary estimates of the annual phytoplankton primary production for the Northwest Atlantic shelf (Middle Atlantic Bight, Georges Bank, Gulf of Maine). ICES C.M. 1981/L:16.

O'Reilly, J. E., and D. A. Busch. 1984. Phytoplankton primary production for the Northwestern Atlantic shelf. Rapp. P.-v. Reun. Cons. Int. Explor. Mer 183:255-268.

O'Reilly, J. E., D. A. Busch, R. A. Bruno, and J. Nickels. 1981. Summary of measurements of primary productivity made during MARMAP surveys (*Albatross* 79-06, 79-11, *Evrika* 80-01, 80-02, and *Delaware* 80-03/*Evrika* 80-04). NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Sandy Hook Lab. Ref. No. 81-14, 51 pp.

O'Reilly, J. E., C. A. Evans, and D. A. Busch. 1981. Distribution of phytoplankton biomass (chlorophyll *a*) and primary productivity in shelf water between Cape Hatteras and Nova Scotia. pp. 66-67. *In* Third informal workshop on the oceanography of the Gulf of Maine and adjacent seas, Univ. New Hampshire, Durham, N. H. 2-5 March 1981. (Abstract only).

O'Reilly, J. E., C. Evans-Zetlin, and D. A. Busch. 1987. Primary production. pp. 220-233. *In* R. H. Backus (Ed.) Georges Bank. MIT Press, Cambridge.

O'Reilly, J. E., C. Evans, V. Zdanowicz, A. Draxler, R. Waldhauer, and A. Matte. 1980. Baseline studies on the distribution of phytoplankton biomass, organic production, seawater nutrients, and trace metals in coastal water between Cape Hatteras and Nova Scotia. First Annual Report, Northeast Monitoring Program.

Pastuszak, M., D. Mountain, D. Busch, and W. Smith. 1984. On the influx of Slope Water and plankton through the Great South Channel and its implications for the recirculation of water around Georges Bank. EOS, Trans. Am. Geophys. Union 1984 (Abstract only).

Patanjo, D., S. R. Nickerson, and F. Steimle. 1982. Report on temperature and dissolved oxygen measurements made on MARMAP surveys between October 1977-December 1978. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Woods Hole Lab. Ref. Doc. 82-03.

Payne, P. M., and J. P. Ross. [1988.] Loggerhead turtle. *In* T. French (Ed.) Endangered, threatened, and special concern vertebrate species in Massachusetts. A publ. of the Massachusetts Nongame and Endangered Species Program, Div. Fish. Wildl., Boston, MA (in press).

Payne, P. M., J. R. Nicholas, L. O'Brien, and K. D. Powers. 1986. Distribution of the humpback whale (*Magaptera novaeangliae*) on Georges Bank and in the Gulf of Maine in relation to densities of the sand eel (*Ammodytes americanus*). Fish. Bull., U.S. 84:271-277.

Payne, P. M., K. D. Powers, and J. E. Bird. 1983. Opportunistic feeding on whale fat by Wilson's storm-petrels *Oceanites oceanicus* in the western North Atlantic. Wilson Bull. 95:478-479.

Payne, P. M., and L. A. Selzer (Editors). 1980. Characterization of whale use of the Massachusetts Bay and Cape Arundel, Maine, areas. Report to Sanford Ecological Services, Natick, MA. Army Corps of Engineers, New England Div., Contract No. DACW33-85-D-0002-0003.

Payne, P. M., R. Sears, and F. W. Wenzel. [1988.] Blue whale. *In* T. French (Ed.) Endangered, threatened, and special concern vertebrate species in Massachusetts. A publ. of the Massachusetts Nongame and Endangered Species Program, Div. Fish. Wildl., Boston, MA (in press).

Payne, P. M., L. A. Selzer, and A. R. Knowlton. 1984. Distribution and density of cetaceans, marine turtles, and seabirds in the shelf waters of the northeastern United States, June 1981-December 1983, based on shipboard observations. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Contract NA-81-FA-C-00023. 246 pp.

Pennington, M. 1983. Efficient estimators of abundance for fish and plankton surveys. (MARMAP Contribution MED/NEFC 81-9). Biometrics 39:281-286.

Pennington, M. and P. Berrien. 1981. Measuring the effects of the variability of egg densities over space and time on egg abundance estimates. ICES C.M. 1981/G:70.

Powers, K. D. 1980. How seabirds adapt to ocean processes. Oceanus 26(1):11-18.

Powers, K. D. 1980. Pelagic distributions of marine birds off the northeastern U.S. NOAA Tech. Mem. NMFS-F/NEC-27. 285 pp.

Powers, K. D. 1982. A comparison of two methods of counting birds at sea. J. Field Ornith. 53:209-222.

Powers, K. D., and E. H. Backus. 1987. Energy transfer to seabirds. pp. 372-374. *In* R. H. Backus (Ed.) Georges Bank. MIT Press, Cambridge. 632 pp.

Powers, K. D., and R. G. B. Brown. 1987. Seabirds. pp. 359-371. *In* R. H. Backus (Ed.). Georges Bank. MIT Press, Cambridge. 632 pp.

Powers, K. D., and J. Cherry. 1983. Loon migrations off the coast of the northeastern United States. Wilson Bull. 95:125-132.

Powers, K. D., and P. M. Payne. 1982. Ecological coherence of Georges Bank to populations of marine mammals. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Woods Hole Lab., Woods Hole, MA. Unpl. Rep.

Powers, K. D., and P. M. Payne. 1983. Distribution of marine mammals, birds and turtles near the Deepwater Dumpsite 106 (DWD-106) and the Philadelphia Dumpsite (PDS). pp. II-1-92. *In* J. B. Pearce, D. C. Miller, and C. Berman (Eds.) Northeast monitoring program 106-mile site characterization update. NOAA Tech. Mem. NMFS-F/NEC-26. 483 pp.

Powers, K. D., and W. T. Rumage. 1978. Effect of the *Argo Merchant* oil spill on bird populations off the New England coast, 15 Dec. 1976-Jan. 1977. pp. 142-148. *In* In the Wake of the *Argo Merchant*, Proceedings of a Symposium held 11-13 January 1978. Center for Ocean Management Studies, Univ. Rhode Island, Kingston.

Powers, K. D., and J. A. Van Os. 1979. A concentration of greater shearwaters in the western North Atlantic. Am. Birds 33:253.

Powers, K. D., P. M. Payne, and S. J. Fitch. 1982. Distribution of cetaceans, seabirds and turtles, Cape Hatteras to Nova Scotia, June 1980-December 1981. U.S. Dep. Commer, NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Contract No. NA-81-FA-C-00023. Woods Hole, MA. 165 pp.

Powers, K. D., P. M. Payne, and D. S. Miller. 1980. A marine mammal observer training program. U.S. Dep. Commer., NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Contract No. NA-80-FA-D-0004, Woods Hole, MA. 73 pp.

Prezioso, J., and C. A. Griswold. 1981. Zooplankton community structure in the area of the *Ocean 250* gasoline spill. pp. 20-21. *In* Barge *Ocean 250* gasoline spill. NOAA Tech. Rep. NMFS SSRF 751. 30 pp.

Sand, R. L., J. R. Goulet, L. J. Bass, and S. H. Koelb. 1985. The design and management of a large ecosystem database using a scientific data base management system. Paper for presentation at the 4th Working Symposium on Oceanographic data systems, Scripps, La Jolla, CA. Sponsored by IEEE. (NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Narragansett Lab. Ref. No. 85-21; also MARMAP Contribution No. FED/NEFC 85-22).

Schneider, D. C., G. L. Hunt, and K. D. Powers. 1980. Energy flux to pelagic birds: A comparison of Bristol Bay (Bering Sea) and Georges Bank (Northwest Atlantic). pp. 259-277. *In* J. P. Crosall (Ed.) Seabirds: Feeding ecology and role in marine ecosystems. Cambridge Univ. Press, Cambridge (UK). 408 pp.

Selzer, L. A., and P. M. Payne. [1988.] Ecological differences in the distribution of the white-sided dolphin (*Lagenorhynchus acutus*) and common dolphin (*Delphinus delphis*) in the shelf waters of the northwest Atlantic. Mar. Mamm. Sci. (in press).

Sherman, K. 1978. Ecological implications of biomass changes in the Northwest Atlantic. ICES C.M. 1978/L:24.

Sherman, K. 1979. Oil, fisheries, and the Georges Bank ecosystem. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Narragansett Lab. Ref. No. 79-38.

Sherman, K. 1979. MARMAP fishery ecosystems study news. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Narragansett Lab. Ref. No. 79-12.

Sherman, K. 1979. Report of the ICES Working Group on Larval Fish Distribution. ICES C.M. 1979/L:10.

Sherman, K. 1979. Fisheries ecosystem studies off the northeast coast of the United States: Summary of the initial results. ICNAF Res. Doc. 79/VI/114.

Sherman, K. 1979. Emerging ecosystem theory in relation to plankton studies in the Northwest Atlantic. ICNAF Res. Doc. 79/VI/117.

Sherman, K. 1980. MARMAP, a fisheries ecosystem study in the NW Atlantic: Fluctuations in the ichthyoplankton-zooplankton components and their potential for impact on the system. pp. 9-37. *In* F. P. Diemer, F. J. Vernberg, and D. Z. Mirkes (Eds.) Advanced concepts in ocean measurements for marine biology. Belle W. Baruch Institute for Marine Biology and Coastal Research. Univ. South Carolina Press, Columbia.

Sherman, K. 1980. MARMAP fisheries ecosystem studies off the northeast coast of the U.S. Paper presented to the Workshop on Remote Sensing, held at Estes Park, CO, 19-25 August 1979. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Narragansett Lab. Ref. No. 79-62.

Sherman, K. 1980. Biomass: Organization of a large-scale ecosystem study. Working paper for International Scientific Workshop on Management of Southern Ocean Organisms. Co-sponsors: The Oceanic Society of the U.S., The Center for Law and Social Policy, and International Union for Conservation of Natural Resources, Carnegie Conference Center, Washington, DC. 31 March-2 April 1980. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Narragansett Lab. Ref. No. 80-23.

Sherman, K. 1981. NOAA's MARMAP program in the northeast. MARMAP Circular MED/NEFC 81-1.

Sherman, K. 1981. Draft report of the Working Group on Larval Fish Ecology to the Biological Oceanography Committee of ICES, Lowestoft, England, 3-6 July 1981. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Narragansett Lab. Ref. 81-69.

Sherman, K. 1981. Fisheries ecosystem studies and underway samplers. pp. 227-250. *In* Water sampling while under way. Proceedings of a Symposium and Workshops 11-12 Feb. 1980, Washington, DC.

Sherman, K. 1981. Zooplankton of Georges Bank and adjacent waters in relation to fishery ecosystem studies. pp. 40-43. *In* Third informal workshop on the oceanography of the Gulf of Maine and adjacent seas. Univ. New Hampshire, Durham.

Sherman, K. (Editor). 1982. MARMAP fisheries ecosystem news. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Narragansett Lab. Ref. No. 82-06.

Sherman, K. 1982. Report of the Working Group on Larval Fish Ecology to the Biological Oceanography Committee of ICES, 1982. ICES C.M. 1982/L:3.

Sherman, K. 1982. Perturbations in the structure of fisheries ecosystems in the North Atlantic. Presentation at Cherry Hill, N. J., 13-15 April 1982. Abstract. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Narragansett Lab. Ref. No. 82-32.

Sherman, K. 1982. Report of the Eighth Annual Meeting of the Advisory Committee of the Plankton Sorting and Identification Center, Narragansett, RI, 30 March-1 April 1982. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Narragansett Lab. Ref. No. 82-18.

Sherman, K. 1984. Report of the Working Group on Larval Fish Ecology to the Biological Oceanography Committee of ICES, Hirtshals, Denmark, 25-27 June 1984. ICES C.M. 1984/L:37.

Sherman, K. 1985. Background reports on the ecology of sand lance within the northeast shelf ecosystem. Briefing for Mid-Atlantic Fisheries Management Council, Philadelphia, PA, March 1985. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Fisheries Ecology Div., Narragansett Lab. Ref. No. 85-06.

Sherman, K. 1986. Introduction to parts one and two: Large marine ecosystems as tractable entities for measurement and management. pp. 3-7. *In* K. Sherman and L. M. Alexander (Eds.) Variability and management of large marine ecosystems. AAAS Selected Symposium 99, Westview Press, Boulder, CO. 319 pp.

Sherman, K. 1986. Measurement strategies for monitoring and forecasting variability in large marine ecosystems. pp. 203-236. *In* K. Sherman and L. M. Alexander (Eds.) Variability and management of large marine ecosystems. AAAS Selected Symposium 99, Westview Press, Boulder, CO. 319 pp.

Sherman, K. In press. Biomass flips in large marine ecosystems. *In* K. Sherman and L. M. Alexander (Eds.) Biomass and geography of large marine ecosystems. AAAS Selected Symposium Series, Westview Press, Boulder, CO.

Sherman, K. [1988.] Large marine ecosystems as global units for recruitment experiments. *In* B. Rothschild (Ed.) Toward a theory on biological-physical interactions in the world ocean. D. Reidel Publishing Co., Dordrecht, Holland. (in press).

Sherman, K., and L. Alexander (Editors). 1986. The variability and management of large marine ecosystems. AAAS Selected Symposium 99, Westview Press, Boulder, CO. 319 pp.

Sherman, K., and B. E. Brown. 1982. Fisheries management and marine ecology, a case history from the northeastern United States. MARMAP Contribution MED/NEFC 82-73. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Narragansett Lab. Ref. No. 82-74.

Sherman, K., and J. R. Goulet, Jr. 1986. Management of time-series data for large marine ecosystems. (MARMAP Contribution No. FED/NEFC 86-01) NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Narragansett Lab. Ref. No. 86-05.

Sherman, K., and C. Jones. 1980. The zooplankton component of a Northwest Atlantic ecosystem. ICES C.M. 1980/L:67.

Sherman, K., D. Bearse, and L. Sullivan. 1979. Variations in the zooplankton biomass of Georges Bank: Spring 1976 and 1977. ICES Annales Biologiques 34:87-89.

Sherman, K., L. Bivins, P. Jeffries, A. Poularikas, C. Katsinis, M. Berman, and R. Maurer. 1982. Technical constraints to understanding very large marine ecosystems (VLE's). Presentation to J.O.A. Meeting, August 1982 at Halifax, N.S. Abstract. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Narragansett Lab. Ref. No. 82-22. (MARMAP Contribution MED/NEFC 82-34.)

Sherman, K., J. W. Deming, J. F. Grassle, R. V. Lynch, E. Shulenberger, and C. Taillie. 1980. Marine populations: Processes and interactions. pp. 539-544. *In* F. P. Diemer, F. J. Vernberg, and D. Z. Mirkes (Eds.) Advanced concepts in ocean measurements for marine biology. Belle W. Baruch Inst. for Mar. Biol. and Coastal Research, Univ. of South Carolina Press, Columbia.

Sherman, K., J. R. Green, and M. Berman. 1984. Zooplankton of the northeast shelf ecosystem with a focus on waters of Southern New England and the Mid-Atlantic Bight. RAP Report. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Narragansett Lab. Ref. No. 84-14. (MARMAP Contribution No. MED/NEFC 84-15).

Sherman, K., M. Grosslein, D. Mountain, D. Busch, J. O'Reilly, and R. Theroux. 1988. The continental shelf ecosystem off the northeast coast of the United States. Chapter 9, pp. 279-337. *In* H. Postma and J. J. Zijlstra (Eds.) Ecosystems of the world Vol. 27, Continental Shelves. 406 pp. Elsevier Scientific Publishing Co., Amsterdam, The Netherlands.

Sherman, K., C. Jones, and J. Kane. 1979. Zooplankton of continental shelf nursery and feeding grounds. ICES C.M. 1979/L:27.

Sherman, K., C. Jones, L. Sullivan, W. Smith, P. Berrien, and L. Ejsymont. 1981. Congruent shifts in sand eel abundance in western and eastern North Atlantic ecosystems. Nature 291(5815):486-489.

Sherman, K., R. Lasker, W. Richards, and A. W. Kendall, Jr. 1983. Ichthyoplankton and fish recruitment studies in large marine ecosystems. (MARMAP Contribution MED/NEFC 82-75.) Mar. Fish. Rev. 45(10-12):1-25.

Sherman, K., R. Maurer, R. Byron, and J. Green. 1979. Relationship between larval fish communities and zooplankton prey species in an offshore spawning ground. Rapp. P.-v. Reun. Cons. Int. Explor. Mer 178:289-294.

Sherman, K., W. G. Smith, J. R. Green, E. Cohen, M. S. Berman, K. Marti, and J. R. Goulet. 1987. Zooplankton production and the fisheries of the northeastern shelf. pp. 268-282, Chapter 25. *In* R. H. Backus (Ed.) Georges Bank. MIT Press, Cambridge. 593 pp. (MARMAP Contribution No. MED/NEFC 83-47).

Sherman, K., W. Smith, W. Morse, M. Berman, J. Green, and L. Ejsymont. 1984. Spawning strategies of fishes in relation to circulation, phytoplankton production, and pulses in zooplankton off the northeastern United States. Mar. Ecol. Prog. Ser. 18:1-19.

Sherman, K., L. Sullivan, and R. Byron. 1978. Pulses in the abundance of zooplankton prey of fish on the continental shelf off New England. ICES C.M. 1978/L:25.

Sibünka, J. D., and M. J. Silverman. 1984. MARMAP surveys of the continental shelf from Cape Hatteras, North Carolina, to Cape Sable, Nova Scotia (1977-1983). Atlas No. 1, Summary of operations. NOAA TM NMFS-F/NEC-33. 306 pp.

Silverman, M. J. 1982. The distribution and abundance of silver hake, *Merluccius bilinearis*, larvae off northeastern United States, 1977-1980. ICES C.M. 1982/G:58.

Silverman, M. J. 1983. Distribution, abundance, and production estimates of yellowtail flounder, *Limanda ferruginea*, larvae off northeastern United States, 1977-1981. ICEA C.M. 1983/G:47.

Silverman, M. J. 1985. Distribution, abundance, and production estimates of yellowtail flounder, *Limanda ferruginea*, larvae off the northeastern United States, 1982-1984. ICES C.M. 1985/L:18.

Sissenwine, M. P. 1986. Perturbation of a predator-controlled continental shelf ecosystem. pp. 55-83. *In* K. Sherman and L. M. Alexander (Eds.) Variability and management of large marine ecosystems. AAAS Selected Symposium 99, Westview Press, Boulder, CO. 319 pp.

Smith, W. G. 1980. What studies of young fish tell about fish populations. Underwater Naturalist 12(4):9-16.

Smith, W. G. 1981. Fish egg/larval surveys in the Northwest Atlantic. Highlight--NEFC Newsletter, May-June 1981. 8 pp.

Smith, W. 1982. Sand lance population explosion continues off northeastern United States. Am. Inst. Fish. Res. Biol. Briefs 11(2):2.

Smith, W. G. 1982. Sand lance abundant; Atlantic herring larvae disappear. Coast. Oceanogr. Climatol. News 4(2):21.

Smith, W. G. 1982. Surveys reveal Atlantic herring larvae missing from Georges Bank. Coast. Oceanogr. Climatol. News 5(1):7.

Smith, W. 1983. Temporal and spatial shifts in spawning times of selected fish and invertebrate species in the Georges Bank region. (MARMAP Contribution MED/NEFC 83-28). NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Sandy Hook Lab. Rep. No. SHL 83-08. 22 pp.

Smith, W. G. 1985. There are no shortcuts to understanding information required for managing interdependent fish populations. Comm. Fish. News June 1985. p. 22.

Smith, W. 1987. BIOMAC: A proposal for a joint U.S.-Polish-Canadian spawning biomass assessment of Atlantic mackerel (*Scomber scombrus*) off northeastern United States and Canada, April through August 1987. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Sandy Hook Lab. Ref. No. SHL 87-01. 10 pp.

Smith, W., P. Berrien, D. G. McMillan, and A. Wells. 1981. The distribution, abundance and production of Atlantic cod and haddock larvae off northeastern United States in 1978-79 and 1979-80. ICES C.M. 1981/G:52.

Smith, W., and E. Johnson. 1986. Contrasts in distribution patterns of larval Atlantic herring in the Georges Bank area, early 1970's vs. early 1980's. NAFO SCR 86/93:17 pp.

Smith, W., and W. Morse. 1984. Monthly distribution patterns of larval haddock, *Melanogrammus aeglefinus*, off northeastern United States 1977-82, with observations on transport in the Georges Bank region. ICES C.M. 1984/G:30.

Smith, W. G., and W. W. Morse. 1985. Retention of larval haddock, *Melanogrammus aeglefinus*, in the Georges Bank region, a gyre-influenced spawning area. Mar. Ecol. Prog. Ser. 24(1-2):1-13.

Smith, W. G., and W. Morse. 1985. Seasonal distribution, abundance, and diversity patterns of fish eggs and larvae in the Middle Atlantic Bight. ICES C.M. 1985/L:27. 15 pp.

Smith, W. G., D. G. McMillan, C. Obenchain, P. Rosenberg, A. Wells, M. Silverman, E. Baranowski, and N. Adamus. 1980. Spawning cycles of marine fishes off the northeastern United States based on broad scale surveys of eggs and larvae, 1977-79. ICES C.M. 1980/L:66. 22 pp.

Smith, W., D. McMillan, and W. Wells. 1981. Changes in northeastern ichthyoplankton populations may be weather related. Coast. Oceanogr. Climatol. News 3(3):32-33.

Smith, W., D. G. McMillan, and A. Wells. 1981. The distribution and abundance of Atlantic herring larvae in the Gulf of Maine region as determined from MARMAP surveys, 1980-81. NAFO SCR Doc. 81/IX/115.

Smith, W., M. Pennington, P. Berrien, J. Sibunka, M. Koniecza, M. Baranowski, and E. Meller. 1979. Annual changes in the distribution and abundance of Atlantic cod and haddock larvae off the northeastern United States between 1973-74 and 1977-78. ICES C.M. 1979/G:47.

Smith, W., A. Wells, and D. G. McMillan. 1979. The distribution and abundance of ichthyoplankton in the Middle Atlantic Bight as determined from coastal surveys and site-specific studies 1965-1976. NOAA-BLM Interagency Agreement AA550-IA7-35. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Sandy Hook Lab. Ref. SHL 79-02. 263 pp.

Stoddard, A., J. E. O'Reilly, T. E. Whitledge, T. C. Malone, and J. F. Hebard. 1986. The application and development of a compatible historical data base for the analysis of water quality management issues in the New York Bight. Oceans '86 Symposium, Conference Record, Monitoring Strategies Symposium, Vol. 3 of 5, Sept. 23-25, 1986, Washington, D.C.

Sullivan, L. 1980. Distribution, abundance and mortality estimates of larval butterfish, *Peprilus triacanthus*, from MARMAP surveys, 1977 and 1978. ICES C.M. 1980/G:18.

Sullivan, L. F., J. R. Goulet, Jr. 1980. Protocol for data flow through the MIS (MARMAP Information System): Ichthyoplankton zooplankton, and related sampling data. NOAA, Nat. Mar. Fish. Serv., Northeast Fish. Ctr. Narragansett Lab. Ref. No. 80-53.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1988—501-716/80074

(continued from inside front cover)

44. **NOAA's Northeast Monitoring Program (NEMP): A Report on Progress of the First Five Years (1979-84) and a Plan for the Future.** By Robert N. Reid, Merton C. Ingham, and John B. Pearce, eds., and Catherine E. Warsh (water quality), Robert N. Reid (sediments & bottom organisms), Adriana Y. Cantillo (trace contaminants in tissues), and Edith Gould (biological effects), topic coords. May 1987. xi + 138 p., 13 figs., 1 table, 9 app. NTIS Access. No. PB87-210100.

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46. **Influence of Freshwater Inflows on Estuarine Productivity.** By James G. Turek, Timothy E. Goodger, Thomas E. Bigford, and John S. Nichols. May 1987. iii + 26 p. NTIS Access. No. PB87-213666/AS.

47. **MARMAP Surveys of the Continental Shelf from Cape Hatteras, North Carolina, to Cape Sable, Nova Scotia (1977-1984). Atlas No. 2. Annual Distribution Patterns of Fish Larvae.** By Wallace W. Morse, Michael P. Fahay, and Wallace G. Smith. May 1987. viii + 215 p., 27 figs., 2 tables. NTIS Access. No. PB87-232831/AS.

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49. **Northeast Fisheries Center Framework for Inshore Research.** By Research Planning & Coordination Staff, Northeast Fisheries Center. July 1987. vi + 44 p., 2 figs., 2 tables. NTIS Access. No. PB87-232286/AS.

50. **Status of the Fishery Resources Off the Northeastern United States for 1987.** By Conservation & Utilization Division, Northeast Fisheries Center. October 1987. iii + 132 p., 48 figs., 50 tables. NTIS Access. No. PB88-148549.

51. **An Annotated List of the Fishes of Massachusetts Bay.** By Bruce B. Collette and Karsten E. Hartel. February 1988. x + 70 p., 1 fig., 1 table. NTIS Access. No. PB88-179247/AS.

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