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Abundance of Sea Herring (*Clupea harengus* L.) Larvae in Relation to Spawning Stock Size and Recruitment for the Gulf of Maine and Georges Bank, 1968-1978.

by

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1. INTRODUCTION

Herring in the Gulf of Maine, from Cape Hatteras to Southwest Nova Scotia, originate each autumn from historic spawning beds along the southwestern Scotian shelf, the western Gulf of Maine, and the Georges Bank -Nantucket Shoals areas. The relative contribution of larvae among the parental stocks--their abundance, distribution, and intermixing among the spawning areas, and eventual survival to recruitment in the juvenile and adult fishery--has been the object of many studies over the last couple of decades. The most intensive study of the early life of sea herring in this region has been the ICNAF[1] larval herring surveys which began in autumn 1971 and continued through the 1978 season. The surveys were designed to measure major variations in larval production, dispersal, growth, and mortality among the various spawning areas within the Georges Bank and Gulf of Maine, with the long-term objective of understanding the recruitment process. Preliminary analysis of the available 505 mesh larval herring data for the Georges Bank-Nantucket Shoals area, 1968-78, has been made by Lough et al. (1979). A summary of the basic larval herring survey data used in abundance estimates for the Georges Bank and Gulf of Maine area has been made by Lough and Bolz (1979). We present here in a third manuscript a report of the analyses made so far on the abundance of herring larvae in relation to spawning stock size and recruitment for the Gulf of Maine in a manner previously done for the Georges Bank-Nantucket Shoals.

2. SAMPLING METHODS AND AREA

Most of the larval herring data base for the Gulf of Maine area is

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[1] International Commission for the Northwest Atlantic Fisheries

represented by standard ICNAF 3.5 knot bongo-net (61-cm dia., .505-mm mesh samples) hauls made on a grid of standard stations covering the Gulf of Maine and Georges Bank area over the years 1971-1978. Details of the sampling program, including cruise tracks, larval abundance estimates and plots by size frequencies, and deviations in the sampling methods over the 1968-1977 larval herring seasons, can be found in Lough and Bolz (1979). The coastal Western Gulf of Maine spawning area received better sampling coverage over the time series than the southwestern Scotian Shelf spawning area, in terms of density of stations and frequency of surveys. However, sampling coverage in the Gulf of Maine was not as intensive as that of the Georges Bank area which received first priority. A number of special inshore western Gulf of Maine surveys were conducted most seasons to supplement the standard ICNAF larval herring surveys which did not adequately cover the inshore areas in the Gulf of Maine. The southwestern Scotian Shelf area received lowest priority for sampling coverage and only on standard ICNAF stations, for an index of the magnitude of larval production. Complete sampling of the Bay of Fundy was never attempted under the ICNAF surveys and sampling of older herring larvae in the Central Gulf of Maine, usually was not completed due to the lack of survey time.

The Gulf of Maine larval catch data was consolidated into western and eastern Gulf of Maine subareas (Figure 1) corresponding to the ICNAF statistical division of 5Y and 4X, respectively, to be able to relate larval abundance with the reported adult stock assessments.

3. LARVAL DISTRIBUTION AND ABUNDANCE

Larval herring catches were first standardized to numbers per m^2 sea surface area by 1-mm, 5-mm, and total length classes and expanded to the average rectangular area ($1.16 \times 10^9 m^2$) represented by each standard station on the ICNAF sampling grid according to the methods in Lough, et al. (1979) and Lough and Bolz (1979). When more than one sampling station was located within a standard rectangular area, such as along the coastal western Gulf of Maine, an average larval abundance estimate was calculated within each standard area.

Plots of the standardized station larval catches for larvae less than 10 mm length and total are provided in Lough and Bolz (1979) for each survey conducted during the 1969-1977 seasons. Also, cruise estimated larval abundances are summarized by 5-mm length classes for the subareas western and eastern Gulf of Maine. It is difficult to make a detailed comparison of the seasonal timing of spawning (hatching) and their abundance and distribution because of the inadequate sampling coverage in these two subareas, but some general observations can be made by referring to these plots and tables in Lough and Bolz (1979).

Recently hatched larvae first appear in the northern part of the study area in late August-early September along the southwestern Scotian Shelf region, then southwest along the Maine coast by mid-September and then off Portland and on Jeffreys Ledge-Stellwagen Bank by the first part of October. Herring larvae reach their maximum abundance shoreward of the 100 m depth contour off southwest Nova Scotia by mid-October and off the western Gulf of Maine by late October-early November. The spawning season occurs from September through November (see Table 1). Larvae are found throughout the

southwestern Scotian Shelf, particularly in dense concentrations on Lurcher Shoals, an historic spawning area. Few larvae were observed on Browns Bank except in November 1973 (ALBATROSS IV 73-08), but this may be attributed to fortuitous sampling that year. The most complete sampling coverage for the eastern Gulf of Maine subarea was during the 1971, 1973, 1974 and 1975 seasons. Most of the larval production along the western Gulf of Maine occurs north of Cape Small (Boothbay Harbor). Some spawning occurs in the coastal region off Portland and on the Jeffreys Ledge and Stellwagen Bank, but the intensity of spawning activity in these areas as indicated by recently hatched larvae, was variable over the time series. Relatively high densities of larvae were observed on Jeffreys Ledge in 1971, 1972, 1974, and 1976. High densities of larvae were observed just south of Grand Manan Island off Machias Bay in 1975 and 1976. Dispersal of larvae is generally southwest along the coastal western Gulf of Maine by following the distribution of older larvae through the season. Older larvae can be collected in the deeper waters of the Gulf of Maine as evidence that larvae have been transported off the coastal areas from all the spawning sites. The region off Penobscot Bay seems to be an area where larvae are transported off the coast eastward into the Gulf of Maine in greater numbers than other areas, especially notable during the 1974 and 1976 seasons. Larvae originating from the Jeffreys Ledge and Stellwagen Bank area disperse southerly as far as Massachusetts Bay (see 1972 season), but there is no good evidence to indicate any significant numbers of larvae originating along the coastal western Gulf of Maine transported south of Cape Cod into the Nantucket Shoals. In terms of providing the best seasonal coverage of the coastal western Gulf of Maine, the 1971, 1972, and 1974 seasons are most complete. In 1973, none of the standard larval herring surveys sampled sufficiently inshore of the 100 m depth contours to adequately assess larval production that season.

In 1975, the DELAWARE II 75-15, and in 1976, the ANNANDALE 76-01 surveys provided fairly intensive coverage of the coastal western Gulf of Maine close to the peak period of larval production.

4. INITIAL PRODUCTION ESTIMATES

4.1 Methods.

Two methods were used to estimate the initial production of larvae: (1) the normal curve approximation method of Saville (1956), and (2) the expanded day and area method of Sette and Ahlstrom (1948). The application of these methods to estimate the initial production of larvae in the Georges Bank-Nantucket Shoals subarea is detailed in Lough et al. (1979). The initial abundance estimates of larvae (4-9 mm length classes) derived from both of the above methods were corrected for duration and mortality based on average seasonal values estimated for the Georges Bank-Nantucket Shoals larval population. Growth and mortality estimates calculated for some of the more complete sampling seasons in the Gulf of Maine were similar to those calculated for the Georges Bank-Nantucket Shoals. The 10-15 mm length classes of larvae also were used to estimate the corrected initial production of larvae by the Sette and Ahlstrom (1948) method because, in many cases, the late timing of the surveys missed the less than 10 mm larvae in the northern part of the study area. Details of the correction factors are noted on the appropriate tables.

4.2 Results.

The uncorrected initial abundance estimates of herring larvae less than 10 mm length based on the Saville (1956) method are given in Tables 1 and 2 for the western Gulf of Maine and eastern Gulf of Maine, respectively. The

single surveys of 1968 and 1969 collected so few larvae that an abundance estimate could not be made for these seasons. Also, for both subareas, only the 1971-75 seasons had more than one survey to make several independent seasonal estimates of larval abundance.

A summary of the corrected larval production estimates for the Gulf of Maine subareas, as well as the Georges Bank-Nantucket Shoals subarea for comparison, using the Saville (1956) method is given in Table 3 and, using the Sette and Ahlstrom (1948) method, in Table 4. Keeping in mind the incomplete and tentative nature of the Gulf of Maine sampling program, some comparisons can be made among production of herring larvae in the three subareas estimated by the two methods.

In all cases the production estimate of larvae less than 10 mm is somewhat higher derived from the Sette and Ahlstrom (1948) method than the Saville (1956) method. Also, production estimates for the Gulf of Maine subareas using the 10-15 mm larvae by the Sette and Ahlstrom (1948) method (Table 4) are always higher than estimates using the less than 10 mm larvae, except for the 1975 season, western Gulf of Maine. In 1975, the primary coastal western Gulf of Maine survey, DELAWARE II 75-15, collected larvae predominately less than 10-mm length. The highest production estimates in each case is considered to be the best possible estimate of initial larval production for the three subareas. The 1972-75 Georges Bank-Nantucket Shoals production estimates were considered by Lough et al. (1979) to have the best sampling coverage in that area, and the 1973 and 1974 seasons were relatively free of serious sampling biases as most of the larvae were spawned on northeast Georges Bank and little on Nantucket Shoals where sampling could not be extended into the shoaler areas. All other seasons are considered to be

underestimates of larval production. The most complete sampling coverage for the western Gulf of Maine was during the 1971, 1972, and 1974 seasons, and for the eastern Gulf of Maine, the 1971, 1973, 1974, and 1975 seasons. Referring to Table 4 and comparing the highest seasonal production values, the relatively low production of larvae during the 1971 season was similar for all three subareas. In the 1972 season, larval production was about a factor higher than 1971 on Georges Bank-Nantucket Shoals and western Gulf of Maine, but lower on eastern Gulf of Maine. Production of larvae in 1973 was the highest recorded of the time series for the Georges Bank-Nantucket Shoals subarea, the western Gulf of Maine had the lowest estimated production, and the eastern Gulf of Maine production remained about the same as the previous two years. Larval production in 1974 continued high for the Georges Bank-Nantucket Shoals, about a third as much for the western Gulf of Maine but still the highest production estimated for that subarea, and extremely high for the eastern Gulf of Maine. The 1974 eastern Gulf of Maine production estimate of 717.40×10^{11} larvae was approximately double that of the high 1973 and 1974 production on Georges Bank-Nantucket Shoals. In 1975, production was reduced on Georges Bank-Nantucket Shoals and western Gulf of Maine to the 1971 and 1972 levels, while production of larvae in the eastern Gulf of Maine declined to a similar level as that of the Georges Bank-Nantucket Shoals subarea. The northeastern Georges Bank herring fishery collapsed after 1976; larvae production in the Georges Bank-Nantucket Shoals subarea in 1977 was primarily on Nantucket Shoals. The larval data is incomplete for the 1976 and 1977 seasons, but is appears that most of the larval herring production in the study region originated along the western Gulf of Maine, especially in 1976 which had the second highest production

of the time series for that subarea, and perhaps more equally distributed between western Gulf of Maine and Nantucket Shoals during the 1977 season.

In summary, production of herring larvae prior to the collapse of the northeast Georges Bank herring fishery in 1976 was higher on Georges Bank-Nantucket Shoals than the Gulf of Maine coastal areas. Production of larvae from the western Gulf of Maine was generally higher than from the eastern Gulf of Maine, but all three subareas could have a common low level or anyone of the subareas at one time or another may have the greatest production for that year. The eastern Gulf of Maine subarea may have had extremely high larval production during the 1974 season. After the 1976 season, most of the larval herring may be produced from the western Gulf of Maine and Nantucket Shoals spawning.

5. POTENTIAL EGG PRODUCTION FROM LARVAL AND VPA ASSESSMENT DATA

5.1 Methods.

A comparison of independent egg-production estimates derived from the larval data and back-calculated from the VPA assessment of the spawning stock size in the subareas is a useful exercise to test the methodology and and assumptions used and to infer probable bias or causes to discrepancies between the two estimates. Much of the background material underlying these calculations is given in Lough et al. (1979) in an analysis of the Georges Bank-Nantucket Shoals stock. Estimates of the mature female fraction and separate fecundity estimates at age for the three subareas are listed in Table 5. A sex ratio of 1:1 was used for all spawning stocks and age classes in the Gulf of Maine and Georges Bank region (Scattergood 1952, McKenzie 1964; Pankratov and Sigajev 1973; Giedz 1979). The VPA stock size data

was for the separate subareas based on NEFC's estimates as of late 1978. An example of this procedure is given in Table 6 for the 1973 Georges Bank-Nantucket Shoals stock.

Potential egg production derived from the VPA stock assessments was based on age-class composition and age specific maturity and fecundity data. The number of eggs contributed from the estimated number of mature females within an age class multiplied by its fecundity estimate were summed for the various age classes within a given spawning area and season (see Table 7 for example calculation).

Egg production estimated from the larval data was calculated for each subarea and season by applying a conservative correction factor of 10% to the estimated initial production of larvae derived by the various methods mentioned previously. Ratios of VPA/larval egg production are shown in Tables 8 and 9 for the western and eastern Gulf of Maine subareas, respectively. A similar table of ratios for the Georges Bank-Nantucket Shoals subarea can be referred to in Lough et al. (1979, Table 9).

5.2 Results.

Examining first the western Gulf of Maine VPA/larva potential egg production ratios in Table 8, the number of eggs estimated from the larval data is significantly less in almost every case than the number of eggs estimated from the VPA spawning stock. The positive VPA/larval ratios are to be expected since we do not know very accurately the amount of egg and early larval mortality prior to the time larvae are collected on the surveys. The lowest VPA/larval egg ratios for the time series were derived from the larval estimate using the 10-15 mm larvae by the method of Sette and Ahlstrom (1948) with the exception of the 1975 season's estimate of 12.1. We have already stated

that most of the larvae collected on the single most important survey of the 1975 season were less than 10-mm length so that the other two ratios of 2.9 and 4.9 are more likely to be closer to the better estimates. The 1973 season's ratio of 37 is very high as expected since there was virtually no inshore coastal western Gulf of Maine coverage that season to sample the larvae. The 1971 and 1977 seasons values of 3.4 and 3.1, underestimate the number eggs produced based on the larval data by a factor of 3 to 4 which isn't too far off. More credibility should be given to the 1971 seasons value since there were five surveys over the spawning season in contrast to the single survey in 1977 which skirted the inshore coastal area. The 1972, 1974, and 1976 seasons ratios are remarkable in that they approach unity. The 1976 season's estimate of eggs produced from the larval data was made essentially from one inshore survey.

The eastern Gulf of Maine VPA/larval egg production ratios in Table 9 also are positive; the lowest reasonable ratios (<15) were estimated for the 1971-1975 seasons using the 10-15 mm larval estimate of eggs produced by the method of Sette and Ahlstrom (1948). These ratios were expected to be longer than for the other subareas since sampling coverage of the eastern Gulf of Maine was not as complete. The 1974 season's ratio of 1.1 as the only ratio indicating a pariety of the estimates of potential egg production derived from the VPA stock assessments on one hand and the larval data on the other, further confirming the evidence that a very large spawning population (or good egg and early larval survival) was located on the southwestern Scotian Shelf during the 1974 season!

6. RECRUITMENT

The best estimates of the initial production of larvae made in Table 4 for the three subareas, Georges Bank-Nantucket Shoals; western and eastern Gulf of Maine, were summed for each of the 1971-1977 seasons and compared in Table 10 with an optimistic (20%) and conservative (90%) virtual population analysis (VPA) assessment of recruited herring at age 3 (Sissenwine and Waring 1979). An holistic approach was recently made on the herring catches to overcome the limitations of the unknown amount of intermixing of populations throughout the area and the various assumed fishing mortality (F) rates, and with the collapse of the eastern Georges Bank fishery after 1976, a consolidation of all the herring fisheries catch data from Cape Hatteras to southeast Nova Scotia for analyses was warranted. Prior to 1977 reasonable correlations have been made between the western Gulf of Maine juvenile herring catches and the corresponding year class at age 3 on Georges Bank (Anthony 1977). VPA was applied to the pooled catch data using various high and low assumed age-specific mortality rates to derive a probabilistic assessment of risks in estimating the fishery for the 1965-1977 period. The range of the various assessments of age 3 fish after 1974 can be compared to the base period of 1965-73 to make a "poor-to-good" judgment of the population size at recruitment.

Recruitment of the strong 1970 year class in 1973 only is considered "poor-to-average" and the 1971, 1972, 1974, and 1975 recruited year classes are considered "poor". The 1976 year class recruited as 3-year-olds in 1979 is believed to be one of the largest year classes yet documented (Sissenwine and Waring 1979).

Anthony and Waring (1979) and Waring, Sissenwine, and Dornheim (1979) report that in the Maine juvenile fishery, the 1976 year class at age 1 and the 1975 year class at age 2 had the highest catches since the 1970 year class at age 1 and the 1966 year class at age 2. In 1978 catches of both the 1975 and 1976 year classes have remained high in the Maine juvenile fishery. Large numbers of juvenile herring believed to have come from the 1977 year class have been reported by Waring (1979) for the first time in a decade in the estuaries of southern Massachusetts. So there is some evidence that perhaps the 1977 year class may be large as well.

The total larval production estimates listed in Table 10 show a corresponding increase in relation to recruitment for the 1971-73 year classes, peak in 1974 when recruitment was estimated to be poor, in line for the 1975 year class, and very low larval production for the 1976 year class which was estimated to have exceptionally high recruitment. It is tempting here to speculate on appearance of a density-dependent relationship where recruitment is poor when larval production exceeds that of the 1973 seasons level as in 1974, and where recruitment is high when larval production is very low as in 1976, but the limitations of the data perhpas do not give an accurate representation of the data and anyway, a density-dependent relationship is probably an oversimplication of the recruitment process. The high larval production estimated for the 1974 year class was due mostly to the unusually high production estimated from the eastern Gulf of Maine (southwest Scotian Shelf) and those larvae may not have recruited to the Gulf of Maine populations for a number of reasons. The high recruitment of the 1976 year class came from a year when larval production was the lowest observed in the time series.

The inshore western Gulf of Maine was the only area observed in 1976 to have high larval production but production in this area was similar to that observed in 1974 and 1972. If the larval and recruited year class data depict the true magnitude of population size in the various subareas, then it doesn't appear that the strength of the recruited year class is not overwhelmingly correlated with the magnitude of spawning in any one of the areas. But recruitment success must depend on a unique combination of conditions, events which we do not fully understand yet.