

AN ASSESSMENT OF THE GEORGES BANK HADDOCK,
Melanogrammus aeglefinus, STOCK BASED ON
LARVAE COLLECTED ON MARMAP PLANKTON SURVEYS, 1977-1982

by

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ABSTRACT

Larval haddock, Melanogrammus aeglefinus, collected on 19 plankton surveys in the Georges Bank region were used to estimate spawning stock biomass for the period 1977-1982. The years 1977-1981 showed close agreement with research vessel catches and results from a cohort analysis. Estimates of spawning stock biomass ranged from 49 to 128 thousand tons. Larval collections in 1982 were anomalously low and the resulting biomass estimate was not representative.

INTRODUCTION

The study of the abundance of fish eggs and larvae to estimate the size of the parental stock that produced them has had a long and often erratic history. In 1895 the Nordsee-Expedition attempted to assess the North Sea fish stocks from plankton egg surveys but not until Sette (1943), working on Atlantic mackerel, Scomber scombrus, in the northwest Atlantic, was an estimate of spawning stock derived from the distribution and abundance of ichthyoplankton. During the next 20 years, as sampling methods and opportunities improved, numerous stock assessments from plankton surveys were made, notably Sayille (1956) and Simpson (1959) in the North Sea and Sette and Ahlstrom (1948) in the eastern Pacific. Today, 10+ year data sets useful for stock assessments from early life history stages exist only in the northeast Atlantic and eastern Pacific. Such data sets provide a fisheries independent estimate of spawning stock or at least an index of changes in the parental stock over time.

The impetus for this study resulted from the effects of management of the Georges Bank haddock stock and their impact on the traditional use of the commercial catch-at-age information to derive stock estimates using virtual population analysis (VPA). According to Clark et al. (1982), VPA estimates for 1974-1977 were in some doubt due to the lack of directed fishing effort data as a result of incidental catch regulations. Estimates of stock size in recent years (Overholtz et al., 1983) were derived using estimates of total mortality from research vessel trawl survey catch-at-age data to estimate a terminal F for VPA. A fisheries independent estimate of spawning stock sizes for the 1977-1982 time span was deemed useful for comparison with recent VPA stock estimates.

The MARMAP program is multinational and designed to measure changes in both physical and biological components of the continental shelf ecosystem from Cape Hatteras, North Carolina to Nova Scotia (Sherman, 1980). A minimum of six surveys a year provide information about nutrients, primary production, zooplankton, ichthyoplankton and water column temperature and salinity. The MARMAP program provides an opportunity to derive fisheries-independent estimates of spawning biomass from both fish egg and larvae catches.

MATERIALS AND METHODS

Survey Area and Sampling Intensity

MARMAP surveys are conducted in continental shelf and slope waters from Cape Hatteras, North Carolina to Nova Scotia, Canada in depths from about 10-1200 m (Fig. 1). From February 1977 to June 1982, 36 surveys were completed and haddock larvae were captured on 19 surveys (Table 1). A standard survey includes approximately 180 stations at fixed locations (Fig. 1). Nonstandard sampling locations were made during all or part of some surveys, particularly in 1977, to supplement incomplete areal and/or temporal coverage of standard survey stations. Station locations were selected from a stratified random sampling pattern used on Northeast Fisheries Center resource surveys (Grosslein, 1969). Sampling intensity was maintained at approximately one station per 1200 km².

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TABLE 1

For analysis of haddock data, the survey area was stratified into three subareas: northern Middle Atlantic Bight (NMAB), Georges Bank (GB) and southwestern Gulf of Maine (SGOM) (Fig. 1). These strata were selected based upon hydrography, topography, and spatial and temporal density gradients of haddock larvae abundance. Haddock larvae captured on the western edge of the Scotian Shelf were not included in this analysis.

Ichthyoplankton Sampling and Analysis

Ichthyoplankton was sampled with 61-cm bongo net frames fitted with 505- and 333- μ mesh nets. A double oblique tow was made at each station to a depth of 5 m above the bottom or to a maximum tow depth of 200 m. Vessel speed varied between 1 and 2 kts to maintain a constant 45° tow-wire angle. Calibrated flow meters suspended within the mouth of each net and a bathykymograph were used on each tow to determine water volume filtered and maximum tow-depth, respectively. Details of the net configuration are given by Posgay and Marak (1980) and field sampling methods by Smith and Richardson (1977).

Samples were preserved in a 5% formalin and seawater solution. Fish eggs and larvae from the 505- μ mesh net were sorted and larvae were identified, enumerated and measured to the nearest 0.1 mm SL. For taxa which were abundant in a tow, approximately 50-100 specimens were measured to obtain a representative length frequency. For this study all lengths of haddock larvae were rounded to the nearest mm. The total abundance of each taxon at a station was standardized as the number of larvae under 10 m² of surface area to the maximum tow depth (Smith and Richardson, 1977).

The analysis of ichthyoplankton survey data usually includes the calculation of mean catch-per-tow. The data set often contains stations where the species of interest is absent and the frequency of abundances at positive stations is non-normally distributed, usually negative binomially or lognormally distributed. Such data are described by the Δ -distribution (Aitchison, 1955). Therefore, the analysis of haddock data was made using the Δ -distribution to determine the mean catch-per-tow and its standard error (Pennington, 1983).

Net-Mesh Retention

The bongo net sampler provides suitable samples for analysis of retention rates of larvae at the lower end of the larval length frequency curve. Nets of mesh size 505- and 333- μ are arrayed simultaneously at all standard MARMAP stations. Many of the variables affecting larval catches, e.g. time of day, tow speed, tow depth, etc., are constant for the two nets at a station thus permitting direct comparison of the retention rates of the two nets.

Catches at 18 stations on Georges Bank where larval haddock were abundant were sorted from both nets and compared. Initial comparison of the length frequencies and total number of larvae caught indicated the 333- μ net retained a higher proportion of small (<6.0 mm) larvae and that total catch was greater (1860 vs 1090 larvae). Approximately 97% of the difference in total catch is accounted for in lengths 3.0-6.0 mm, therefore lengths greater than 6.0 mm were considered fully retained by the 505- μ mesh net.

The relationship of length and proportion retained by the 505- μ net relative to 333- μ net was calculated by applying the linear model of Lenarz (1972) such that $C_i = a + bL_i$; where C_i equals the relative numbers (percent of total number caught) at length i caught by the 505- μ mesh net divided by the relative numbers caught by the 333- μ mesh net and L_i equals length in mm. The relationship for lengths 3.0-6.0 mm equals $C_i = -1.059 + 0.0452 L_i$. The length where C_i equals 1 (4.6 mm) indicates the length at equal retention by both nets, therefore C_i at 5.0 mm was assigned a 1 and the regression recalculated. Thus for lengths 3.0, 4.0 and 5.0-mm, C_i equalled 0.272, 0.800 and 1.00, respectively and the linear equation equalled $C_i = -0.765 + 0.0364 L_i$. The correction factor for extrusion through the 505- μ mesh net is then

$$N_{it} = \frac{N_i}{C_i}$$

where N_{it} is corrected catch at length i and N_i is number caught at length i . Corrections were made for lengths <4.8 mm which equals the length at which C_i approaches 1.

Net Avoidance

The ability of fish larvae to actively avoid capture through sensory detection of an approaching net may result in a serious underestimation of total abundance. When visual detection by larvae of an oncoming net is the primary sensory cue then the difference between day- and night-caught larvae should give a measure of avoidance. Clutter and Anraku (1968) reviewed the problem of avoidance and concluded that due to high sampling variability it may be difficult to specify avoidance effects upon catches within useful confidence limits. However, various attempts have been made to account for at least some of the avoidance problem by investigating day-night differences in larval catches (Ahlstrom, 1954; Farris, 1961; Lenarz, 1973). Lenarz studied four species and developed an exponential equation to relate catch rates to larval length and time of day. He found night catches exceeded day catches and the ratio of night to day increased with increasing length of the larvae. This is expected if vision and swimming ability improved as larvae grow.

I investigated the day-night differences in catches of larval haddock from eight surveys of the Georges Bank subarea during the months April-June in 1977-1981. Daytime hours were from 1 hr after sunrise to 1 hr before sunset and night was designated as the time between 1 hr after sunset to 1 hr before sunrise. During these surveys, 142 day-stations and 83 night-stations were sampled. The difference in the number of day and night stations reflects the latitudinal difference in daylight and nighttime hours during the spring months on Georges Bank. The expected ratio of day:night equals 1.63:1 which

for exact proportioning of sampling effort day-stations would number 139 and night-stations would number 86.

Before comparing the day catches to night catches, effort must be standardized both spatially and temporally. Preliminary attempts to adjust effort by survey was confounded by the inclusion of stations where the probability of catching haddock larvae was zero. This confounding occurs because a zero tow will affect the day-night comparison when the probability of catching haddock larvae is not zero and thus avoidance is the determining factor producing a zero tow. It is clear then that zero tows may occur because of: 1) avoidance; 2) the tow was made beyond the areal limits of larval occurrence; or 3) larvae are not at the station because the sample was taken outside the spawning time.

When I analyzed relative abundance (percent abundance), the difference in day-night catches was again misleading because, on a relative scale (%), the total abundance is ignored. Day catches might be 10 times the night catches but when making relative comparisons this important difference is lost in the analysis. It is also evident that large differences in percent abundance at a few length increments between the day and night catches, usually the smallest lengths of the compared length frequencies, will determine the relationship of percentage of all subsequent lengths. This relationship is evident in the length frequencies (%) of Lenarz (1973). His catch curves for northern anchovy by day and night show approximately 80% of the day catches occur in the first two length intervals and only about 45% for the night catches. This leaves 20% and 55% to be apportioned throughout the remaining length intervals, thus producing the characteristic length-percent curves where night catches exceed day catches in the larger size intervals.

Since both night and day catches of haddock larvae appeared to conform to the Δ -distribution, I calculated the Δ -mean catch-per-tow for each mm length interval for day and night catches to determine if avoidance could be detected in the length frequencies. This approach eliminates the problems introduced when using a relative scale and zero tows are included in the calculated Δ -mean.

Shrinkage

The application of laboratory reared growth parameters to field collected larvae requires intercalibration to account for morphological differences due to preservation and net treatment (Theilacker, 1980). The factors of interest here are larval length (SL) and the determination of differences between the measured length of haddock larvae following collection and preservation from surveys and the lengths of live, laboratory reared larvae at the same development stage.

Preservation shrinkage was determined by measuring 25 (4.4-12.7 mm SL) larvae immediately after capture, one day after preservation in 5% buffered formalin solution and again seven days after capture. Mean shrinkage after one day was 3.9% ($S = 2.7$) and after seven days total shrinkage was 4.2% ($S = 3.1$). From these data it is clear that over 90% of the preservation shrinkage occurred after one day. The maximum shrinkage between days one and seven was only 1.9%. Mean shrinkage for length <7.9 mm was 5.0% and for lengths >8.0 mm the mean was 1.9%. This is expected because shrinkage is probably related to the degree of ossification (Theilacker, 1980) and the ratio of length after preservation to live length should reach an asymptote of one when ossification is complete.

Both the mechanical damage during net collecting and death upon larval length were documented by Blaxter (1971) and Theilacker (1980). Estimates of

shrinkage from these factors ranged from 19% for larvae 6 mm or less to between 3% and 8% (depending upon the length of time in the net) for larvae 26 mm or greater. Theilacker (1980) developed an exponential formula to describe net-treatment shrinkage for northern anchovy, Engraulis mordax, from 4 to about 35 mm long, at which time ossification is complete. Her formula was adopted for a mean net-treatment time of 10 min and adjusted to lengths between 4 mm, the approximate length at hatching, to 15 mm when ossification is essentially complete. Thus shrinkage was maximum at 4 mm and decreased exponentially to near zero at 15 mm. The equation describing the relationship for haddock of preserved and net-treated larval length (P_L) to live length (L_L) was:

$$L_L = 1.3899 P_L^{0.8872}$$

where lengths are mm.

Temperature-Dependent Larval Growth

Changes in larval growth rate, both between samples during a cruise and between seasons or years, affect the time (days) a larva spends within a given length interval. The greater the change in larval growth due to temperature, the more serious will be the bias upon estimates of larval production and mortality (Saville, 1956; Zweifel and Smith, 1981). Therefore, the age of each larva was determined using growth rates and length-weight relationships given by Laurence (1978, 1979).

The growth rate of larval haddock was assumed to be curvilinear in relation to temperature where the maximum rate occurs at an optimum temperature and decreases as the temperature varies above or below the optimum. Thornton and Lessem (1978) developed an algorithm for modifying

growth rates relative to environmental temperature which uses as input the temperature (t) and growth rate multiplier (K_t) at t. Information presented by Laurence (1978) showed optimum growth occurred at 9°C under laboratory conditions and 4°C was near the lower threshold temperature. By converting growth per week in weight to growth in mm per day from length-weight relations (Laurence, 1979), the average growth rate per day at 4°C was 0.81% and at 9°C it was 2.96%. Thus the age of larvae can be calculated as:

$$\text{Age (days)} = \frac{\ln\left(\frac{L_t}{L_0}\right)}{q}$$

where L_t is observed length, L_0 is length at hatching (4.0 mm) and $q = K_t \cdot 0.02964$. The value 0.02964 is the optimum instantaneous growth efficient at 9°C for haddock larvae. The growth rate multiplier (K_t) is determined from the growth rate multiplier at t_1 (4°C) which equals 0.274 (0.81/2.96), the observed temperature (t) and r_1 , the specific rate coefficient by the formula

$$K_t = \frac{K_1 \text{ EXP}[r_1(t-t_1)]}{1+K_1 \{ \text{EXP}[r_1(t-t_1)] - 1 \}}$$

where the specific rate coefficient is

$$r_1 = \frac{1}{t_0 - t_1} \ln \frac{K_0(1-K_1)}{K_1(1-K_0)}$$

As recommended by Thornton and Lessem (1978) K_0 is specified as 0.98 which results in the best fit of data. $t_0 = 9^\circ\text{C}$ for haddock, the optimum temperature for growth. Growth rates at temperatures greater than 9°C were

assumed to be near the optimum growth rate (i.e. $K_0 > 0.98$ and < 1.0) because information on haddock growth is insufficient to establish the growth rate-temperature relationship at temperatures above 9°C.

Mortality

The estimation of mortality from catch curves assumes: 1) that all individuals in a sample are from one source that has been producing at a constant rate over the time needed to reach the greatest age or length observed, and 2) that mortality is constant over the entire age or length range of the sample. Fishes, in general, do not spawn at a constant rate but rather exhibit an annual spawning peak with spawning intensity decreasing over time before and after the peak. The spawning curve can usually be approximated by a normal distribution. This description is particularly appropriate for temperate and boreal species (Cushing, 1975; Wyatt, 1980) and certainly describes haddock spawning on Georges Bank (Marak and Livingstone, 1970). Assuming a normal curve, spawning mortality will be overestimated from catch curves calculated during the ascending limb of the curve and underestimated on the descending limb. Hewitt and Methot (1982) have shown, through simulation studies, that when larval numbers are accumulated from monthly catch curves from systematic surveys that mortality estimation biases tend to cancel out and the calculated mortality from the combined monthly samples estimates the expected larval mortality if mortality is constant.

The assumption of constant mortality over the ages or lengths observed was not verified but rather that the calculated mortalities from accumulated samples for the entire spawning season represent an average value for all lengths or ages in the samples. The yearly catch curves appear to substantiate this because the decrease in numbers at age is not erratic but is reasonably smooth over the entire age range.

The instantaneous "mortality" coefficients (Z) were calculated from age-frequency curves for each year. Lengths were corrected for shrinkage and abundances were corrected for retention (see above) before construction of the frequency curves. The slope of the exponential relationship of abundance on age was used to estimate Z as

$$N = a \text{ EXP}(Z t)$$

where N = number of larvae at age t in days.

The exponential decrease in the age frequency of field-sampled larvae, here defined as Z, has two distinct components. One component measures the death rate of larvae caused by numerous factors including predation, starvation, genetic malformities, disease, etc. This represents the traditional definition of Z and is assumed to be exponential for the purposes of this study. The other component of Z is net avoidance by larvae which can be assumed to increase as larvae grow. The relationship of net avoidance to larval length is probably a power function which increases until 100% avoidance at some length. This seems reasonable because plankton nets are designed to capture only the very youngest life stages of fish and length frequencies of net samples are not continuous. The contribution by each of these two components to the calculated instantaneous "mortality" coefficient cannot be determined from the bongo net samples. An example of avoidance is given by Murphy and Clutter (1972) who found the purse seine catches of anchovy (Stolephorus purpureus) larvae over 5.5 mm in length were at least an order of magnitude greater than with towed plankton nets. However, if it is assumed that rate of increase in net avoidance with larval length is constant and that the smallest larvae cannot avoid capture or be extruded, then Z can

be used for backcalculating spawning stock size without introducing a systematic bias.

Spawning Stock Biomass Estimates

The relationship of spawning stock biomass to ichthyoplankton is usually expressed as

$$B = \frac{I}{R_I}$$

where B = spawning stock biomass, I = ichthyoplankton abundance and R_I is the production of I per unit weight of the spawning stock. I is determined from survey data and growth or incubation rates of larvae or eggs, respectively. R_I usually represents egg production per unit weight of mature females from fecundity studies adjusted for the ratio of females to males in the spawning stock. Thus by determining the total abundance of eggs produced during the entire spawning season and the production of eggs per gram of spawning stock will give an estimate of total grams of spawning stock.

The use of larval abundance, i.e. the number of larvae at hatching, and an estimate of egg mortality will yield a total egg abundance estimate. In this study, estimates of growth and mortality were applied to shrinkage and extrusion adjusted larval abundances to determine the number of larvae at hatching at each station. Since larval haddock remain vulnerable to sampling for as long as 53 days (see Table 3) and surveys were less than 53 days apart in an area, then newly hatched larvae in a survey could be captured again in the succeeding survey. This double sampling will overestimate spawning stock biomass and must be eliminated before the estimates are made. To accomplish this, the mean sampling date of tows containing haddock larvae in each of the three subareas by survey was determined and any larvae hatched on or before

this date in subsequent surveys in the same subareas were dropped from the biomass analysis.

An investigation of cod, Gadus morhua, and haddock eggs collected in April and early May 1979 on Georges Bank and in the Gulf of Maine revealed an average daily egg mortality of 7.5% (P. Berrien, personal communication). Mean surface water temperature in the survey area was 4.6°C which indicates incubation was 17 days and a total egg survival of 26.8%. Saville (1953), working on haddock eggs at Faroe, found egg mortalities were about 10% per day for the 1950-1953 spawning seasons. Given an average incubation of 14 days, total egg survival at Faroe (22.9%) is remarkably close to that found during 1979 in the Georges Bank-Gulf of Maine area. For this study, egg mortality was assumed to be 10% per day and an average incubation time of 14 days. Thus larval abundances were converted to egg abundances by calculating the number of eggs at each station by applying the assumed egg mortality rate. The Δ -mean eggs per 10 m² were then expanded for each survey using the subarea surface area to give total egg abundance. Subarea and survey totals were summed to give the total eggs spawned in each year.

Relative fecundity (eggs per gram of female) was estimated to be 640 from haddock length-weight relationships (Hodder, 1963) and length-fecundity relationships of haddock on Georges Bank (Morse et al., unpublished data). Sex ratio of the spawning stock was approximately 1:1 (Morse, unpublished data) and was assumed to be 1:1 for this analysis.

RESULTS

Net Avoidance

A total of 10,966 haddock larvae was captured during both day and night tows; 7,174 during daylight hours and 3,792 at night. Table 2 gives the Δ -mean catch-per-tow by millimeter length intervals for day and night

samples as well as the ratio of night to day Δ -means. Two conclusions are obvious from the table: 1) for larval lengths greater than 12 mm and less than 3 mm, the sample size is inadequate for day-night comparisons and 2) the ratio of night to day Δ -means is quite variable - ranging from 0.70 at 4 mm to 3.90 at 12 mm.

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If the assumption that visual detection of the approaching net by larvae is a significant factor contributing to net avoidance then the ratio of night to day catches should increase above 1.0 as larval swimming ability increases. The trend in ratios in Table 2 does not support the above hypothesis. In fact, ratios less than 1.0 occur at 4-, 5-, 9- and 11-mm lengths and the only consistent trend of increasing ratios occur between 4- to 8-mm lengths. For lengths greater than 8 mm the ratio fluctuates between 0.80 and 3.90 and this length interval would be expected to show consistently high ratios if visual detection and avoidance were a significant factor affecting the catches. Thus, differential net avoidance could not be detected by examining the difference in day and night catches.

Mortality

Age frequencies were developed for each year using the methods described above. Catches were corrected for extrusion loss through the 505 μ mesh net and preserved lengths were adjusted for shrinkage. The age of each larva was then determined using the surface temperature at the place of capture as the reference temperature to adjust for temperature-dependent growth. Age frequencies for each station were then combined for each year to give the total age frequency (Fig. 2). Numbers at age were grouped into 4-day intervals and exponential regressions were calculated for each year. The slope of the regression line was used as an estimate of larval mortality for all years except 1979. The age frequency for 1979 showed a modal age at

25 days indicating its unsuitability for mortality estimation. Mortality for 1979 was estimated as the average mortality of years 1977-1982, minus 1979.

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Daily percent mortality ranged from 9.0 ($Z = 0.0933$) in 1980 to 12.2 ($Z = 0.13062$) in 1982 (Table 3). The 1982 larval catches were quite small relative to the other years examined and show the magnitude of interannual variability of catches and indicate a possible problem when this variability is not accounted for or is unknown.

TABLE 3
Larval Abundance and Spawning Stock Biomass

The Δ -mean catch-per-tow of larvae at hatching was calculated for each subarea by survey (Table 4). The southern Gulf of Maine (SGOM) contributed only small numbers of larvae during 1977 and 1978 and no larvae from 1979-1982. SGOM accounted for 1.4% of all larvae. Georges Bank (GB) subarea contained 86.1% of the larvae and catches there were dominant during all but four surveys. The northern Middle Atlantic Bight (NMAB) subarea contributed 12.5% of the larvae captured with significant numbers caught during 1977, 1979 and 1980.

BLE 4
Total larval production by subarea, survey and year are given in Table 5. These represent expansions of Δ -mean catch-per-tow by the surface area of each subarea. Production increased from approximately 3.6×10^{12} larvae in 1977 to a peak of 9.3×10^{12} in 1979. A 49% decrease occurred from 1979 to 1981 and a precipitous decrease was found in 1982 to only 5.5% of the 1981 level.

Spawning stock biomass estimates shown in Table 5 are a function of larval production and thus follow the same trends. Peak biomass at 127,522 t occurred in 1979 and the lowest estimate was in 1982 of 3,590 t. Other years were between 49 and 94 thousand t.

TABLE 5

DISCUSSION

The techniques of using ichthyoplankton for spawning stock biomass estimation have been well documented, e.g. Smith and Richardson (1977) and Zweifel and Smith (1981), although surprisingly few data sets exist which meet even the minimum technical requirements necessary to derive meaningful estimates. The ichthyoplankton sampling of the MARMAP program has provided a unique opportunity to use a 6-year data set in the northwest Atlantic to estimate the spawning biomass of numerous species.

This study of haddock larvae on Georges Bank attempts to address what Zweifel and Smith (1981) call the "effective sampler size" by accounting for some of the most serious biases encountered in larval sampling. These biases include standardization of net catches to the number of larvae under 10 m² of surface area, net avoidance, extrusion through the net meshes, temperature-dependent growth and annual changes in larval mortality.

A comparison of spawning stock biomass from larval data and VPA and research vessel catch-per-tow (kg) (Overholtz et al., 1983) shows similar trends for all three values (Table 6). The greatest magnitude of change occurred in the biomass estimates from larval data when 1982 is included. However, as I mentioned earlier, the 1982 data appears anomalous is not adequate for biomass estimates. Omitting the 1982 larval estimate, there was a 2.6 fold change in spawning stock biomass with a minimum value in 1977 and the peak in 1979. VPA estimates peaked in 1978 and then decreased steadily to a minimum in 1982. The stratified mean catch-per-tow peaked in 1979, as the larval estimates did, and the minimum value occurred in 1982. The catch-per-tow showed the greatest variability with a 6.4 fold decrease from 1979 to 1982. All three values indicate a significant decrease in haddock spawning stock biomass from a peak in either 1978 or 1979 to minimum biomass in 1982.

TABLE 6

It is tempting to use a statistical comparison of the three data sets in Table 6 but each estimate contains its own variability and uncertainties which makes comparisons, such as correlation analysis, inappropriate. To illustrate this point, Grosslein (1971) has shown that the research vessel surveys will not detect a change in haddock abundance if the change is less than a factor of 2. This corresponds to a confidence interval of the mean catch-per-tow on the linear scale of $\pm 50\%$. The standard error of the Δ -mean catch-per-tow of the larval data is often greater than 50% of the mean (Table 6) which again illustrates the degree of sampling error inherent in the larval data. Overholtz et al. (1983) do not give the variance component for their VPA biomass estimates but, given the effects of misreporting of haddock landings in recent years and the sensitivity of VPA to terminal F-values, it seems reasonable to assume the VPA estimates contain significant uncertainties.

Although this study has attempted to derive an "effective sampler size" for haddock larvae, much work still needs to be done to reduce uncertainties and increase the reliability of spawning stock estimates from larval surveys. The two most important, and most difficult to define, variables used in this study are larval mortality and temperature-dependent growth. Mortalities estimated from age-frequencies pooled from a number of surveys during a spawning season seems adequate if spawning intensity over time is approximated by a normal curve and samples are collected frequently (monthly?) throughout the spawning season (Hewitt and Methot, 1982). However, the interdependence of the growth rate, temperature and food supply and their effects on the derived age-frequency curves need further study. Thus the next steps needed to improve our estimates of spawning stock biomass include seasonal and/or annual larval growth studies, in situ, to develop age-length information and broad scale vertical distribution studies to define the larval fish habitat in relation to water temperature.

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Table 1.--Summary of survey dates, total number of stations sampled and stations at which haddock larvae were captured by subarea.
 NMAB = northern Middle Atlantic Bight; GB = Georges Bank; SGOM = southern Gulf of Maine.

Survey	Dates	Number of stations by subarea			Number of stations with haddock by subarea		
		NMAB	GB	SGOM	NMAB	GB	SGOM
77-2	4 Mar-23 Apr	57	32	16	5	3	0
77-3	14 Apr-13 May	26	30	21	2	15	0
77-4	20 May-16 Jun	63	43	20	28	13	3
78-1	16 Feb-17 Mar	47	42	18	0	6	0
78-2	25 Apr-23 May	46	36	18	0	14	0
78-3	29 Jun-16 Jul	45	16	16	1	2	1
79-1	2 Mar-14 Mar	40	5	9	1	0	0
79-2	1 Apr- 7 May	44	33	22	0	16	0
79-3	12 May-29 May	44	30	21	8	14	0
80-1	20 Feb- 4 Apr	45	29	25	1	10	0
80-2	23 Apr-12 May	45	29	24	5	16	0
80-3	29 May-29 Jun	43	23	20	11	8	0
80-4	8 Jul- 9 Aug	44	24	23	0	1	0
81-1	18 Feb-21 Mar	43	30	23	1	6	0
81-2	7 Apr-12 May	45	30	11	0	13	0
81-3	21 May-14 Jun	43	29	24	4	14	0
81-4	1 Jul-19 Jul	35	26	0	1	0	0
82-2	25 Mar- 7 May	42	26	22	0	4	0
82-3	18 May-11 Jun	39	35	14	3	5	0

Table 2.--The Δ -mean catch-per-tow of haddock larvae on Georges Bank by day and night and the ratio of night caught to day caught by length interval.

Length (mm)	Day Caught		Night Caught		Ratio N/D
	Number of stations	Δ -mean catch/tow (D)	Number of stations	Δ -mean catch/tow (N)	
2	1	0.069	1	0.087	1.26
3	17	1.258	9	1.355	1.08
4	36	3.072	21	2.153	0.70
5	22	2.043	15	1.642	0.80
6	21	1.891	11	1.966	1.04
7	21	1.494	10	1.797	1.20
8	17	1.060	13	2.083	1.97
9	17	1.222	8	0.972	0.80
10	15	0.704	10	0.915	1.30
11	10	0.502	5	0.463	0.92
12	3	0.112	5	0.437	3.90
13	5	0.192	1	0.069	0.36
14	1	0.012	1	0.070	5.83
15	6	0.271	-	-	-
16	2	0.045	-	-	-
17	-	-	-	-	-
18	-	-	2	0.142	-

Table 3.--Summary of regression analysis of haddock larvae on Georges Bank for estimating mortality (Z).

Year	N	Age (days) interval	Regression constants		SE _Z	r ²
			a	Z		
1977	14	1-53	2054.54	-0.10206	±0.0391	.91
1978	13	1-49	1708.975	-0.11389	±0.0440	.78
1979	-	-	-	-0.10814*	-	-
1980	11	9-49	3285.560	-0.09386	±0.0346	.82
1981	13	1-49	1836.550	-0.10029	±0.0401	.94
1982	6	17-37	245.672	-0.13062	±0.0266	.68

*Average Z for 1977-1982

Table 4.--The Δ -mean catch-per-tow of haddock larvae at hatching by subarea and survey, 1977-1982.

Survey	SUBAREA					
	NMAB		GB		SGOM	
	Δ -mean	Std. error	Δ -mean	Std. error	Δ -mean	Std. error
77-2	6.75	4.41	5.98	3.72	-	-
77-3	3.26	2.61	523.12	372.58	-	-
77-4	124.12	43.94	87.66	35.54	45.57	42.63
78-1	-	-	9.81	7.23	-	-
78-2	-	-	1018.39	700.81	-	-
78-3	2.34	15.71	42.32	29.84	10.98	43.90
79-1	2.70	17.08	-	-	-	-
79-2	-	-	65.40	26.18	-	-
79-3	309.21	204.56	1720.76	952.70	-	-
80-1	8.95	60.03	173.39	95.62	-	-
80-2	202.45	145.28	1018.55	613.12	-	-
80-3	23.58	7.02	115.00	55.69	-	-
80-4	-	-	2.70	13.22	-	-
81-1	2.62	17.18	27.56	12.82	-	-
81-2	-	-	563.52	334.73	-	-
81-3	28.94	15.14	551.15	230.81	-	-
82-2	-	-	38.41	30.32	-	-
82-3	10.13	6.11	9.96	5.46	-	-

Table 5.--Total abundance of haddock larvae ($\times 10^9$) by subarea, survey and yearly total and spawning stock biomass estimates by survey and year.

Survey	Subarea			Larval abundance ($\times 10^9$)	Sp. stock biomass (t)
	NMAB	GB	SGOM		
77-2	40.45	24.99	-	65.44	893.92
77-3	19.52	2187.10	-	2206.62	30142.50
77-4	743.53	366.50	182.28	1292.31	17653.00
			TOTALS	<u>3564.37</u>	<u>48689.42</u>
78-1	-	41.03	-	41.03	560.48
78-2	-	4257.78	-	4257.78	58161.42
78-3	14.02	176.92	43.92	234.86	3208.20
			TOTALS	<u>4533.67</u>	<u>61930.10</u>
79-1	16.17	-	-	16.17	220.88
79-2	-	273.43	-	273.43	3735.06
79-3	1852.33	7194.32	-	9046.65	123577.54
			TOTALS	<u>9336.25</u>	<u>127533.48</u>
80-1	53.62	724.94	-	778.56	10635.16
80-2	1212.78	4258.47	-	5471.25	74737.46
80-3	141.27	480.81	-	622.08	8497.63
80-4	-	11.29	-	11.29	154.22
			TOTALS	<u>6883.18</u>	<u>94024.31</u>
81-1	15.76	115.24	-	131.00	1789.46
81-2	-	2356.03	-	2356.03	32183.45
81-3	173.38	2137.05	-	2310.43	31560.55
			TOTALS	<u>4797.46</u>	<u>65533.46</u>
82-2	-	160.57	-	160.57	2193.39
82-3	60.68	41.64	-	102.32	1397.69
			TOTALS	<u>262.89</u>	<u>3590.08</u>

Table 6.--Spawning stock biomass estimates and stratified mean catch-per-tow of the Georges Bank haddock stock.

Year	Spawning Stock Biomass (t)		Stratified catch/tow (kg)
	Larvae	VPA	
1977	48,699	60,596	23.13
1978	61,931	90,896	15.18
1979	127,533	78,826	26.87
1980	94,025	87,465	18.47
1981	65,534	40,701	11.77
1982	3,591	39,642	4.17

Figure 1. Standard MARMAP sampling locations and boundaries of subareas used for analysis of haddock larvae.

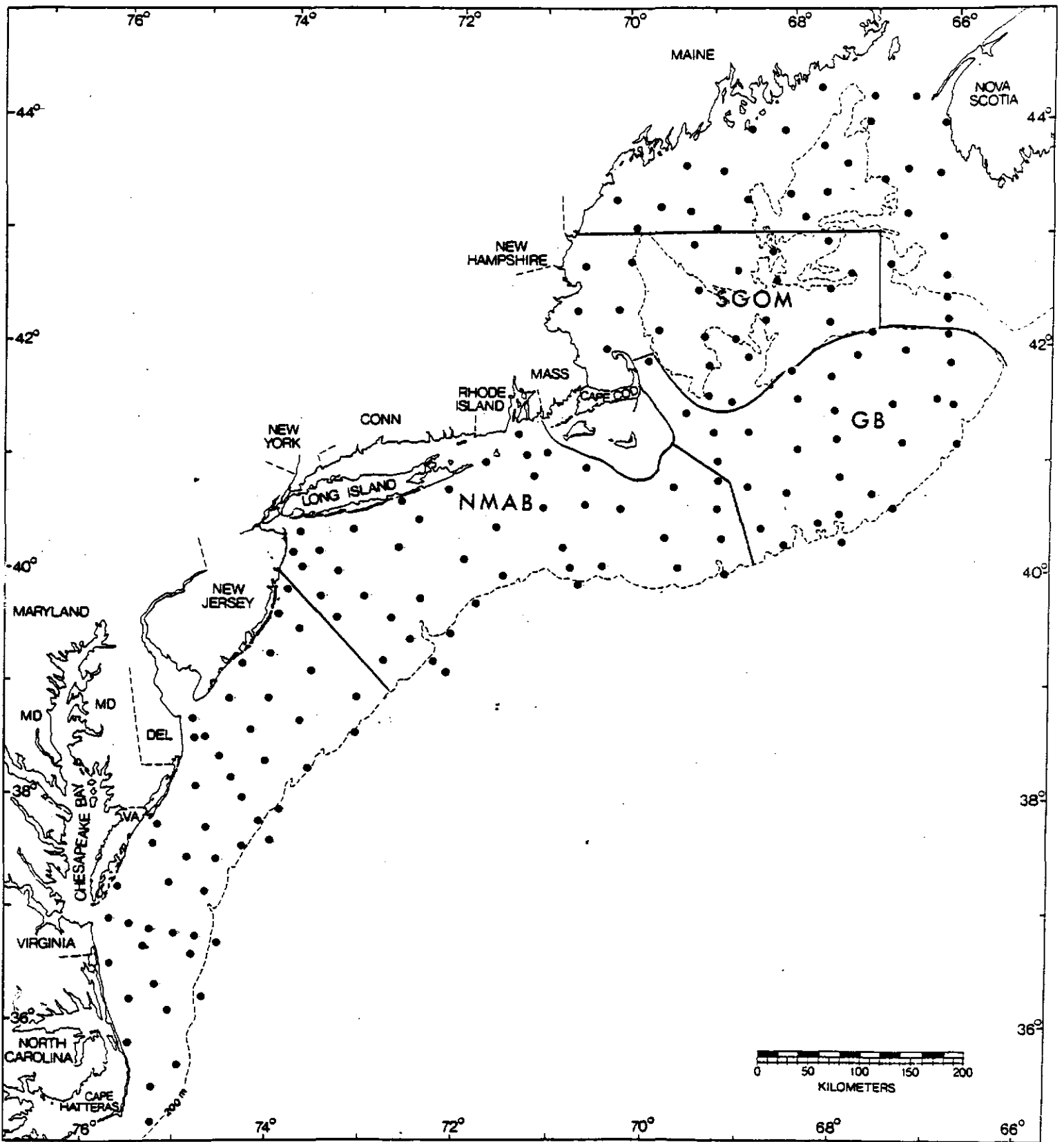


Figure 2. Age frequencies of haddock larvae for years 1977-1982.

