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ABUNDANCE OF BLUEFIN TUNA LARVAE AND ESTIMATES OF SPAWNING STOCK SIZES IN THE GULF OF MEXICO IN 1977 AND 1978

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SUMMARY

Using the results of ichthyoplankton surveys conducted in the Gulf of Mexico in 1977 and 1978, estimates of the size of the spawning stock were made. These estimates showed a spawning stock size for bluefin tuna to be 699,951 ± 622,956 fish in 1978. Variances were extremely high for 1977 and were not considered reliable but the 1978 estimates are believed to be sound estimates. The methods for arriving at the variances are described and comment is made on this fishery independent method for estimating spawning stock sizes.

RESUME

On a estimé l'importance du stock reproducteur à partir des résultats des recherches sur l'ichthyoplancton effectuées dans le golfe du Mexique en 1977 et 1978. Ces estimations donnent un chiffre de 699.951 ± 622.956 poissons pour 1978. La variance de 1977, extrêmement variable, n'a pas été jugée fiable, mais les estimations de 1978 ont été considérées correctes. Le présent document décrit les méthodes employées pour calculer la variance et fournit des observations sur cette méthode, indépendante de la pêcherie, d'estimer l'importance du stock reproducteur.

RESUMEN

Partiendo de los resultados obtenidos del estudio sobre ictioplancton, efectuados en el Golfo de México en 1977 y 1978, se efectuó una estimación del tamaño del stock reproductor, que resultó ser de 699.951 ± 622.956 peces en 1978. Las variaciones fueron muy altas en 1977, y no se consideraron fiables, pero se cree que las de 1978 ofrecen bastante exactitud. Se describen los métodos para llegar a las variaciones, y se comenta el método independiente de esta pesquería para estimar el tamaño del stock reproductor.

Introduction

Ichthyoplankton surveys were made in the Gulf of Mexico and Straits of Florida during April and May, 1977 and May 1978 by the FRV OREGON II. The distribution and abundance of bluefin tuna larvae were reported by Richards and Potthoff (1980). The purpose of this paper is to discuss bluefin tuna larval abundance in more detail and provide estimates of spawning stock sizes.

Methods

Plankton sampling

Methods used to collect plankton and subsequent identification methods are given in Richards and Potthoff (1980).

Determining larval abundance

Catches of bluefin tuna larvae at each station were standardized to give abundance in numbers under 10 m^2 of sea surface:

$$n_j = \frac{c_j z_j}{v_j} \, 10 \qquad (1)$$

where n_j = the number of individuals at each station j under 10 m^2 of sea surface

c_j = the catch of larvae at station j

z_j = the depth of tow (in meters) at station j

v_j = the volume filtered by the net (in cubic meters) at station j.

Numbers of larvae also were estimated in the areas represented by each station. These areas were determined by the polygons described by the perpendicular bisectors of lines from the station in question to the adjacent stations (Sette and Ahlstrom, 1948):

$$p_j = \frac{c_j z_j}{v_j} \cdot A_j \qquad (2)$$

where p_j = the estimated total number of eggs or larvae in the area represented by station j

c_j, z_j and v_j are defined in equation (1)

A_j = the area (in square meters) represented by station j.

Stations represented areas ranging from 2.6 to 44.7 x $10^9 m^2$ in the 1977 cruise and from 2.6 to 10.9 x $10^9 m^2$ in the 1978 cruise.

The total number of larvae was estimated for the entire area represented by each cruise:

$$P_i = \sum_{j=1}^{k} p_j \qquad (3)$$

where P_i = the cruise estimate (i.e. the total number of eggs or larvae estimated in the area represented by cruise i)

k = the number of stations sampled during cruise i

p_j = is defined by Equation (2)

Variance estimates on the abundance of larvae were obtained for each cruise using a combination of methods outlined by Cushing (1957) and Taft (1960). An estimate of the variance in larval abundance under a square meter of sea surface (s_{ij}^2) was obtained from the $\log_{10}$ transformed data of $[(c_j z_j)/v_j] + 0.1$ at each station during a cruise (Cushing 1957). The quantity 0.1 was added to allow logarithms to be taken for abundance estimates at stations with zero catches. The $\log_{10}$ variance estimate so obtained was backtransformed to obtain an estimate of the standard deviation of abundance under a square meter of sea surface. The variance estimate for a cruise was calculated using the estimator given by Taft (1960) that assumes random sampling. It is:

$$S_{P_i}^2 = D_i^2 \sum_{j=1}^{k_i} \frac{A_{ij}^2 s_{ij}^2}{d_{ij}^2} \qquad (4)$$

where $S_{P_i}^2$ = variance estimate on the abundance of larvae spawned during the period represented by cruise i

D_i = the number of days represented by the spawning season of bluefin tuna. This value is 60 days since the bluefin tuna is known to spawn between April 15 and June 15.

A_{ij} = the area (m^2) represented by the j^{th} station in the i^{th} cruise

d_{ij} = the duration (days) of the larval stage of bluefin tuna captured during the cruise. Based on growth rings in otoliths we estimate an average age of 7.5 days

s_{ij}^2 = the variance estimate for the number of larvae present under $1\ m^2$ of sea surface for cruise i

k_i = the number of stations included in the variance estimate for cruise i

Sampling was not random in these surveys. Also, larval catches were not normally or log-normally distributed, nor did the distribution of catches fit contagious distributions like the negative binomial. Thus the variance estimates that we obtained are not the best estimates, but they may be reasonable approximations (Saville 1964) for variance in the area represented by our cruises. Variation in spawning that occurs over time (i.e. day to day variation) has not been accounted for, which is the usual situation in ichthyoplankton abundance surveys (Saville 1964).

An estimate of the abundance of larvae spawned over the entire spawning season is:

$$P_a = \sum_{i=1}^{r} \frac{P_i D_i}{d_i} \qquad (5)$$

where P_a = the total number of larvae produced in the spawning season

r = the number of cruises upon which the estimate is based, which is one in this case (i.e. one cruise each year)

P_i, D_i and d_i are defined in Equation (4)

Biomass estimating procedure

Spawning stock size can be estimated if the larval abundance, sex ratio of adults, and relative fecundity (eggs produced per gram adult female per year) are known (Saville, 1964; Ahlstrom, 1968). Biomass of adults is

$$B = \frac{P_a}{F_r \cdot K} \qquad (6)$$

where B = biomass of adults in the stock

F_r = mean relative fecundity (eggs per gram female per year)

K = the proportion of adults that are females

P_a = is defined in equation (5)

An estimate of F_r was obtained from studies of eastern and western Atlantic bluefin (Baglin and Rivas, 1977). This was based on a sample of 12 fish - seven from the western Atlantic ranging from 88.8 to 177.8 kg and five from the eastern Atlantic ranging from 180 to 235 kg. A comparison of the mean relative fecundity estimates using Student's t test revealed no significant differences between eastern and western Atlantic populations (P = 0.5). Relative fecundities were not correlated with weight. The mean relative fecundity with 95% confidence limits was 128.5 ± 14.77. The sex ratio was obtained by observers on Japanese longliners in 1978 who sampled 757 bluefin tuna and found 319 males and 438 females. In 1979 observers sampled 943 fish and found 445 males and 498 females. For our estimate both years' data were combined yielding the proportion of adults that is female of 0.55.

A further refinement was to estimate the number of fish comprising the biomass. This allows comparison with fishery dependent analyses that have used virtual population analysis to estimate bluefin tuna abundance. The 1978 observers' sample had an average weight of 294 kg which was divided into our biomass (weight) estimates to give an estimate of numbers of adults.

Results

Larval population estimates

The estimated total number of larvae in 1977 was 2.5648×10^{12} and in 1978 was 5.9408×10^{12}. The estimates with 95% confidence limits are $2.5648 \times 10^{12} \pm 8.259 \times 10^{12}$ larvae in 1977 and $5.9408 \times 10^{12} \pm 4.6097 \pm 10^{12}$ larvae in 1978.

The estimated abundance of larvae under one square meter for 1977 and 1978 were as follows:

	1977	1978
arithmetic mean	0.447	1.198
geometric mean	0.098	0.779
variance of the geometric mean	8.868	19.874
95% confidence limits	0.098 ± 0.864	0.779 ± 0.752

The estimates of variance are high, particularly in 1977. The high proportion of stations with zero catches and a relatively few stations with high catches serve to inflate variance estimates. The higher variances in 1977 also resulted because fewer stations were sampled for the same total area, which yielded extremely large areas for many stations. For example, of the 48 stations in 1977, 16 stations represented areas greater than 30 x $10^9 m^2$ and only 13 stations represented areas less than 10 x $10^9 m^2$. In 1978 there were 135 stations, only 12 of which were greater than 10 x $10^9 m^2$ and all were less than 11 x $10^9 m^2$. This single factor could account for the great difference in variance between years.

Biomass estimates

Based on the larval population estimates, biomass estimates are given in Table 1. Since larval mortalities are unknown, several mortalities were assumed. The .95 C.L. determined for fecundity ($\pm$ 11.4%) and those calculated for population size ($\pm$ 322% in 1977 and $\pm$ 77.6% in 1978) also must be considered here. The very high variances found for 1977 indicate that data from 1977 perhaps are unreliable. The much lower variances for 1978 indicate that reasonable approximations of stock size can be estimated if a correct larval mortality rate were chosen. To arrive at a reasonable estimate for larval mortality, we referred to the survival estimates compiled by Dahlberg (1979). Using an average of his daily survival estimates for six species of marine postlarvae (equivalent to larvae), we estimated mean survival after 9 days (1 day as an egg, 1 day as yolksac larvae and 7 days as larvae) to be 40.8% (mortality of 59.2%). Based on these criteria and using the 1978 data (converted to numbers in Table 2), our best estimate is that the spawning population in the Gulf of Mexico in 1978 was 699,951 $\pm$ 622,956 fish.

A fishery dependent analysis (virtual population analysis) carried out by Parrack (1980) estimated that the stock size of bluefin age 6 and older in the western Atlantic was 268,699 fish in 1978. We believe that one could conclude with confidence that both fishery dependent and independent analyses yielded results in the same order of magnitude.

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Table 1. Biomass estimates in metric tons of the size of the bluefin tuna spawning stock

Mortality (%)	1977 Stock Size ($x10^4$)	1978 Stock Size ($x10^4$)
0	3.625	8.396
10	4.028	9.329
25	4.833	11.195
50	7.250	16.792
75	14.500	33.584
90	36.250	83.960

Table 2. Estimates of the number of spawning bluefin tuna

Mortality (%)	1977 Number ($x10^4$)	1978 Number ($x10^4$)
0	12.330	28.558
10	13.701	31.731
25	16.439	38.078
50	24.660	57.116
75	50.340	114.231
90	123.299	285.578