Estimation of Growth and Mortality of bay anchovy, *Anchoa mitchilli*, in Florida Bay, Florida USA

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ABSTRACT

Growth parameters and mortality rates of the bay anchovy, *Anchoa mitchilli*, were estimated by using the ELEFAN method from length-frequency data collected during offshore seine surveys conducted throughout Florida Bay, Florida, from January 1994 to October 1997. The parameters of the von Bertalanffy growth model based on length-frequency analysis were L_{∞} = 95 mm SL (TL=110 mm, 11.0 cm) and K = 0.60/year. Results showed that seasonal growth is important (C ≈ 1, WP ≈0.8). The estimates of growth parameters in this study fall within the reported values of other engraulid populations and are consistent with the assumption that engraulids are small, fast- growing, and short- lived species. Natural mortality was 1.33/year and total mortality was Z = 1.50/year.

KEY WORDS: Florida Bay, *Anchoa mitchilli*, bay anchovy, age and growth

INTRODUCTION

The bay anchovy, *Anchoa mitchilli*, is ubiquitous in bays and estuaries along the east coast of the United States and around the coast of the Gulf of Mexico (Houde and Zastrow 1991). Due to its great abundance, this species has considerable economic and ecological importance. Although not commercially exploited in the United States, it is canned whole and used in the production of anchovy paste in Mexico (Castillo-Rivera et al. 1994). The bay anchovy is an important source of forage for commercially and recreationally valuable fish species, such as snook, *Centropomus undecimalis*, red drum, *Sciaenops ocellatus;* spotted seatrout, *Cynoscion nebulosus;* silver perch, *Bairdiella chrysoura,* Atlantic needlefish, *Strongylura notata;* and crevalle jack, *Caranx hippos* (Carr and Adams 1973, Killam et al. 1992).

In Florida, Except for the work on the growth and recruitment of bay anchovy larvae conducted by Leak and Houde (1987) and Peebles et al. (1996), information on the life history and population dynamics of this species in Florida is limited to reports on its abundance and distribution. The Fisheries Independent Monitoring (FIM) Program of the Florida Marine Research Institute has collected a large body of information on the distribution and relative abundance of the bay anchovy throughout Florida. The primary objective of this study was to estimate growth and mortality parameters for *A. mitchilli* in

Florida Bay and then to compare these parameters with those published for other engraulids.

METHODS

Bay anchovies were collected monthly between January 1994 and October 1997 at 16 fixed sites in Florida Bay (Figure 1) by using a 23.1-m x 1.8-m nylon, center-bag seine with 3.2-mm mesh. Seines were hauled over a standardized area of 152 m^2. At beach stations, seines were set adjacent to the shoreline and hauled onshore; at offshore stations (< 1.4 m), seines were set in open-water habitats away from the shoreline and retrieved offshore. For all hauls, total numbers of bay anchovy were counted and standard lengths (SL) of 20 randomly selected individuals were measured (± 1 mm). When a large number of individuals (> 1,000) were captured, the total number was estimated by fractional expansion of subsampled portions of the total catch split with a modified Motoda splitter (Winner and McMichael, 1997). At the time each sample was collected, physical data, including water temperature (°C), salinity (‰), pH, and dissolved oxygen (ppm), were recorded by using a Hydrolab Surveyor II.

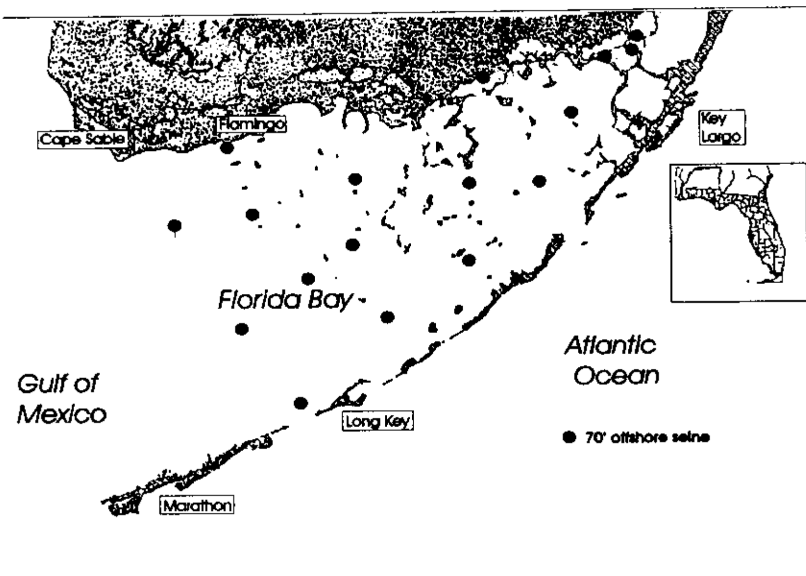

Figure 1. Map of Florida Bay, Florida, U.S.A., showing trawl and seine sampling sites.

Estimation of Growth parameters and Mortality

Length-based methodologies were used to estimate growth parameters and mortality rates (Gallucci et al. 1996). Growth of bay anchovies was modeled by using a seasonally oscillating version of the von Bertalanffy growth function (VBGF) of the following form:

$$L_t = L_\infty[1\text{-exp}(\text{-K}(t\text{-}t_0)\text{-}CJ/2\pi(\sin 2\pi(t\text{-}t_s)\text{-}\sin 2\pi(t_0\text{-}t_s)))]$$

where L_t is length at time t; L_{oo} is the asymptotic length an individual would reach if it lived indefinitely, K is the rate at which L_{oo} is approached; t_s represents the winter point (WP), which is the midpoint of the year at which growth rate is slowest; C is the amplitude of the seasonal oscillations of the growth curve; and t_0 is a location parameter (Gayanilo et al., 1995). Estimates of L_{oo} and K were made using two different techniques. The first technique was the Wetherall et al. (1987) method, which obtains preliminary estimates of L_{oo} and the Z/K ratio where Z is the instantaneous rate of total mortality. Their method assumes a steady-state population and an unbiased sample. To smooth out recruitment variations, all data were pooled into a single length-frequency (Posada and Appeldoorn 1996). The second technique used was ELEFAN I of the FAO-ICLARM stock-assessment tools in the FISAT software package (Gayanilo et al. 1995). ELEFAN I does not assume a steady-state population and requires only an unbiased sample of the catch. The logic of ELEFAN I relies on a goodness-of-fit score function that varies according to the correspondence of observed and predicted length-frequency modes for given pairs of von Bertalanffy growth parameters (L_{oo} and K) and the imposition of biological constraints that are based on the life history of bay anchovy. Using the ELEFAN I routine, L_{oo} and K were allowed to vary, and different combinations of both parameters were used to generate a response surface of the goodness-of-fit index (Rn). Several runs were performed using initial L_{oo} values that ranged from 70 to 100 mm in 1 to 5 mm steps and K values that ranged from 0.40 to 0.80 in 0.01 steps, which encompassed a wide range of values around the preliminary estimates generated by the Wetherall et al. (1987) method. The best estimates from these runs were used to generate a range for the parameters estimated. The final L_{oo} and K values were selected at the maximum Rn value.

To allow direct comparisons of growth parameters with those obtained in other studies, standard lengths were converted to total length by means of a regression equation [TL = 4.142 + 1.1263 (SL), r^2 = 0.94, n = 1283] generated from a sub sample of the catch before the analysis. To compare my estimates of bay anchovy growth parameters with estimates reported for other engraulids, the empirical growth performance index (ϕ' = phi prime) was calculated using the equation by Pauly and Munro (1984):

$$\phi' = \text{Log}_{10} K + 2 \text{ Log}_{10} (L_{\infty}).$$

The calculation of ϕ' serves as a check to see if the estimate lies within an acceptable range for that species. Pauly et al. (1998) have shown that closely related species have similar values of ϕ', even if their L_{∞} and K values differ.

Because the bay anchovy is not commercially or recreationally exploited in the study area, the estimates of the total mortality should reflect only natural mortality (Z =M). Four methods were used for mortality estimation:

A) Natural mortality rate (M) was estimated from the empirical equation of Pauly (1980):

$$\text{Log}_{10} M = 0.0066 - 0.279 \log_{10} L_{\infty} + 0.6543 \log_{10} K + 0.4634 \log_{10} T,$$

where L_{∞} and K are parameters of the VBGF and T is mean local sea temperature. Mean temperature (25°C) was estimated from fixed-station measurements. The empirical equation for M tends to overestimate the natural mortality rates of small schooling pelagics such as *A. mitchilli,* so it is recommended that M be reduced by using a correction factor of 0.8 (Csirke, 1988).

B) Length-converted catch curve analysis was used to estimate total mortality (Z) implemented using the FISAT (Gayanilo et al. 1995). For this analysis, all data were pooled into a single length-frequency sample. A regression line was fitted to points immediately to the right of the highest point on the catch curve. The slope of the regression line is an estimate of Z. The L_{∞} and K values used for this analysis were those developed using the ELEFAN I method.

C) The Beverton-Holt estimator was also used to estimate total mortality rate from mean length. It takes the form

$$Z = K(L_{\infty} - l')/(l' - l_c),$$

where l' is mean length in the sample and l_c is the smallest length fully represented in the sample (Beverton and Holt 1956).

D) The ratio of Z/K derived from the method of Wetherall et al. (1987) was used in conjunction with the ELEFAN I estimate of K to estimate total mortality. Z was calculated by Z = (Z/K)*K (Wetherall et al. 1987). The length data from each monthly sample were converted to percent frequency and then weighted by the square root of the sample size. Giving all monthly samples proportional weight prevents a single large monthly sample from being a major source of bias or from overly affecting the total annual sample.

RESULTS

Monthly mean length of bay anchovy increased from January to May and decreased from June to October (Figure 2). Analysis of variance of the log-transformed data found no significant differences in the annual mean length (32 mm SL) of capture between years ($F_{[3,9338]} = 1.72$, $P > 0.05$). However, significant differences in mean length of capture were found among months in each of the years sampled. Bonferroni's multiple range test indicated that individuals captured from July to October were significantly smaller than those captured in all other months. This was largely due to the recruitment of juvenile bay anchovy into the study area during this period. The largest mean lengths of capture were observed between March and May.

The estimated parameters of the von Bertalanffy growth model based on length-frequency analysis were L_{∞} = 95 mm SL (TL = 111 mm, 11.0 cm) ranging from 84 mm to 99 mm S; K = 0.60/year, ranging from 0.50 to 0.70; C = 1; and WP = 0.8. Bay anchovies grow at a fast rate throughout their short lifespan. They do not appear to survive in Florida Bay long enough to reach the estimated L_{∞} of 95 mm SL (11.0 cm TL). The largest bay anchovy collected by the FIM program in Florida Bay was 85 mm SL. The length-frequency distributions with the superimposed growth curves generated by ELEFAN I for bay anchovy by year are presented in Figure 3.

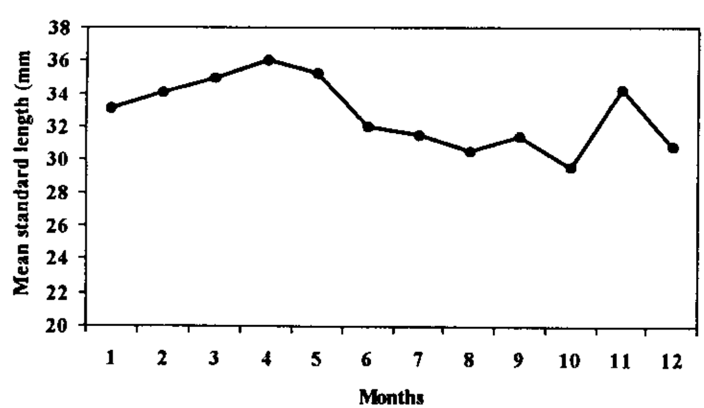

Figure 2. Monthly mean length of capture (mm) of bay anchovy in Florida Bay 1994-1997.

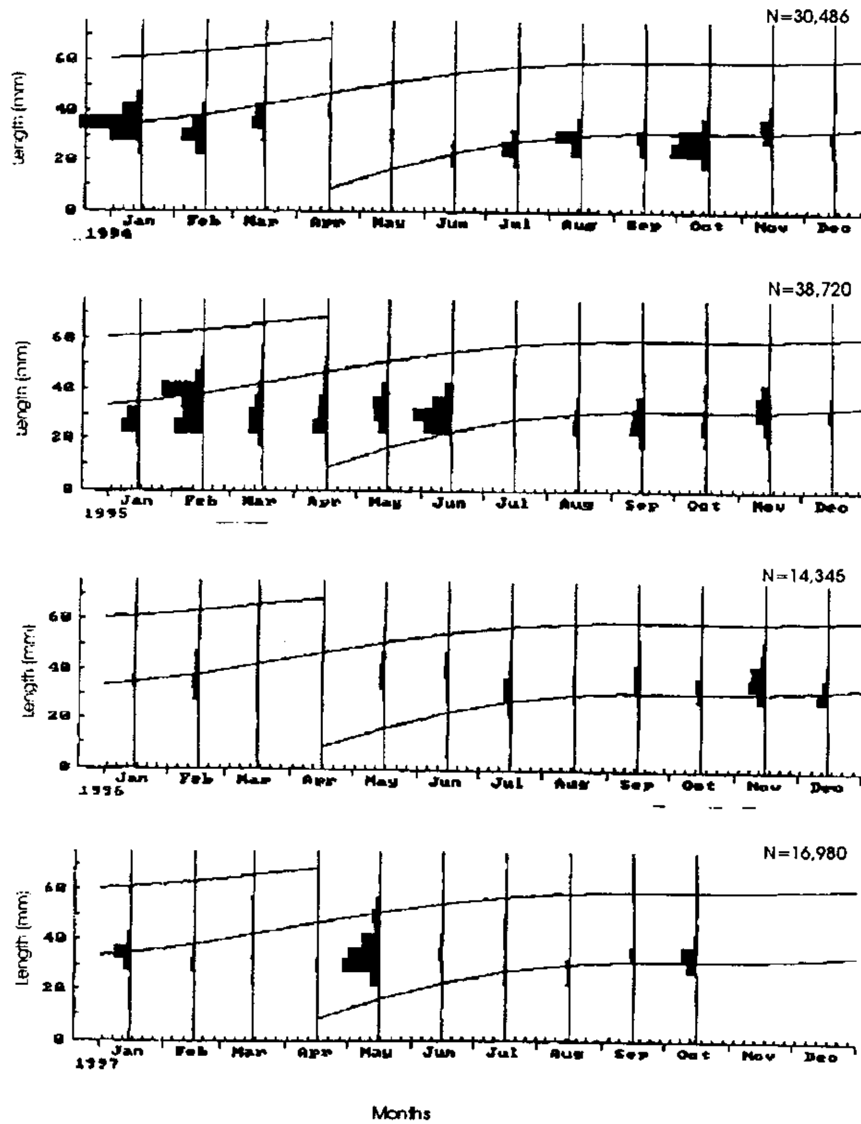

Figure 3. Monthly length-frequency distribution of bay anchovy by year and the von Bertalanffy growth curves generated by ELEFAN. N is the number of bay anchovy measured.

Table 1. Comparison of growth parameters and mortality rates for 3 engraulid species, including bay anchovy. All rates are per year.

Species	L_{∞} (TL cm)	K	M	f'	Source
Anchoa mundeola	16	6.2	-	3.2	Palacios & Phillips (1984)
Anchoa nasus	8.6	1.78	-	2.11	Bayliff (1967)
Anchoa nasus	8.5	1.82	-	2.11	Joseph (1963)
Anchoa mitchilli[1]	11.8	0.21	2.19	1.41	Newberger & Houde (1995)
Anchoa mitchilli[2]	15.1	0.36	2.95	1.91	Newberger & Houde (1995)
Anchoa mitchilli[3]	11.3	0.61	1.74	1.89	Ayala-Pérez et al (1997)
Anchoa mitchilli	11	0.6	1.33	1.86	Present study

[1] Based on the mean back-calculated lengths from otholith analysis
[2] Based on seasonally oscillating version of the von Bertalanffy model
[3] Based on ELEFAN method

Reported von Bertalanffy growth parameters for engraulids are highly variable both within and between species. The estimated value of K for bay anchovy in this study (0.6) falls well within the values of K reported for other engraulids (Table 1). In other studies, the L_{∞} reported for engraulids ranged from 8.5 to 23.2 cm TL (85 to 232 mm TL) (Table 1). The empirical overall-growth-performance parameter (ϕ') for *A. mitchilli* in Florida Bay lies well within the lower limit of the 95% confidence interval (mean = 2.06, sd = 0.55, and 95% CI = 1.55-2.57) for ϕ' derived from the literature (Table 1). This indicates that the ϕ' value obtained here is reasonable for the genus *Anchoa*.

Using the parameters L_{∞} = 95 mm and K = 0.60 in a linearized, length-converted catch curve gave an estimated of total mortality (Z) = 5.9. The Z estimated from Wetherall et al.'s method with a K of 0.60 was 4.2. The total mortality values obtained by using these two methods are high and probably upwardly biased. Pauly's formula, which has an estimated mean water temperature of 25 °C, produced an estimate of natural mortality of M = 1.67. This value was multiplied by a correction factor of 0.8, which accounted for the effects of fish schooling, yielding an estimate of M = 1.33. The Beverton and Holt (1956) estimator yielded a value of Z = 1.50.

DISCUSSION

Worldwide, studies on the age and growth of engraulids indicate that they are short lived, fast growing, and have relatively high rates of natural mortality (Newberger and Houde 1995). The results of the present analysis clearly reflect these characteristics and also indicate that seasonal oscillations in growth are important in the estimation of bay anchovy growth parameters. Similar results were reported by Newberger and Houde (1995) in Chesapeake Bay and Ayala-Pérez et al. (1997) in Campeche, Mexico. These results show that anchovy seasonal growth is important, which was to be expected given the temperatures, ranging from 12.6 °C to 35 °C, observed during the four years of sampling in Florida Bay. Winter-summer temperature differences in Florida Bay were large, approximately 11°C, during each year sampled. Pauly and Ingles (1981) reported that differences in winter-summer temperatures as small as 2 °C are sufficient to induce detectable seasonal growth oscillations.

Mortality rates estimated by using catch-curve analysis and the Wetherall et al. (1987) method were well above those previously reported for other engraulid species (Table 1). This overestimation may have been due to older fish being underrepresented in the samples and to K being overestimated by the Wetheral et al. method. Additionally, length-converted catch curves tend to overestimate Z when growth is seasonal, especially in small, short-lived species (Hampton and Majowski 1987).

Natural mortality rates of engraulids reported in the literature ranged from

1.4 to 2.9 per year and appear to be inversely related to their respective L_{∞} estimates (Newberger and Houde 1995). The estimates from Pauly's (1980) and Beverton and Holt's (1956) equations probably provide the best estimates of bay anchovy mortality rates. The bay anchovy's high mortality rates are somewhat mitigate by their early maturation and high reproduction rate (Newberger and Houde 1995, Peebles et al. 1996).

The suitability of length-frequency analysis depends on the structure of the available data. The progression of the modes gives the absolute rate of growth (i.e., mm per year) only over the range of sizes in which clear modes can be distinguished (Pertierra and Morales-Nin 1989). The overlapping size ranges of older fish in the length distribution make it difficult to fit a growth curve to the length data. This would increase the rate at which the fish reaches maximum size, and thus K could be overestimated. However, in the case of bay anchovy, the data used in this analysis represent the younger age classes, that have distinct modes, which can support the age determination. Newberger and Houde (1995) reported minimal differences in the growth parameters derived from observed length-at-age and back-calculated otolith data for *A. mitchilli*. Even given the conditions of variable growth and recruitment reported for *A. mitchilli* , and using a moderate degree of subjectivity and a stepwise procedure of evaluation, I was able to generated growth parameters consistent with previous interpretations. Overall, the estimates determined in this study should be considered to be preliminary estimates of the basic parameters governing growth and mortality of *A. mitchilli* in Florida Bay.

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