# Age, Growth, and Mortality of *Caulolatilus affinis* (Osteichthyes: Branchiostegidae) from the Southern Gulf of California [1]

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ABSTRACT: Age, growth, and mortality of the Pacific golden-eyed tilefish (*Caulolatilus affinis* Gill) were investigated. From a total sample of 7253 individuals taken from February 1986 to May 1987, the ages of a subsample of 3532 fish were determined using their otoliths. The eviscerated-total weight relationship was linear. The length-weight relationship was fitted to a potential model and the growth pattern can be considered as isometrical. Growth of *C. affinis* can be adequately described by the von Bertalanffy growth function; the parameter estimates were $L_\infty = 387.97$ mm SL, $k = 0.1729$ per year, $t_0 = -2.226$ yr, for males; $L_\infty = 478.28$ mm SL, $k = 0.0924$ per year, $t_0 = -3.768$ yr, for females; $L_\infty = 422.87$ mm SL, $k = 0.1327$ per year, $t_0 = -2.713$ yr, for the sexes combined. Asymptotic weights (eviscerated) were 1210.96 g, 2310.42 g, and 1571.13 g for males, females, and the sexes combined, respectively. The instantaneous rate of total mortality ($Z$) was 0.4829, 0.4253, and 0.5052, and the corresponding rate of natural mortality ($M$) was 0.2142, 0.1316, and 0.1697 for males, females, and the sexes combined, respectively.

THE PACIFIC GOLDEN-EYED TILEFISH, *Caulolatilus affinis* Gill, 1865, is a branchiostegid found from the northern Gulf of California to Cape San Lucas, Baja California Sur (México), and from Costa Rica to Pisco, Perú, and the Galápagos Islands (Dooley 1978). They are most commonly found at depths ranging from 80 to 150 m, over sandy or muddy substrata. Golden-eyed tilefish are included with ocean whitefish (*Caulolatilus princeps* Goode & Bean, 1842) in the common commercial designation of "pierna" by the Secretaría de Pesca Fisheries Statistics (Anonymous 1981), although they are easily distinguishable. These species form part of the subsistence fisheries of Baja California Sur. They are caught by hook and line, although they also appear in by-catches of shrimp trawlers. In the past few years the catch of both species has been increasing; the 1980 "pierna" catch from Baja California Sur was about 88% of the total Mexican catch, with around 50% of that from the Bay of La Paz area. The biology of *C. affinis* was unknown until recently, apart from Dooley (1978), who mentioned that ripe females were found in April and November in the Gulf of California. Elorduy-Garay and Diaz-Uribe (1994) validated the determination of age from otoliths, Elorduy-Garay and Pelaez-Mendoza (1996) described the diet and feeding habits, and Ceballos-Vazquez et al. (1996) described the reproductive biology of the species. For other species of branchiostegids (particularly from the Atlantic coast of the United States), there have been a number of reports on life histories and fisheries, including detailed descriptions of age and growth. There are no such reports on the species inhabiting the eastern Pacific coasts,

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except a report on *C. princeps* by Fitch and Lavenberg (1971) and the description of larvae of the same species by Moser et al. (1986). Elorduy-Garay and Ramirez-Luna (1994) described in detail the reproductive habits of *C. princeps.*

The calculation of individual growth is important in the biological knowledge of a fish population, because it is the basis for the calculation of other population parameters fundamental to the analysis and management of fisheries resources (Holden and Raitt 1974). There are several different ways of determining age and growth in fish (Bagenal and Tesch 1978, Brothers 1979, Schnute and Fournier 1980, FAO 1982, Pauly 1983, Boehlert 1985). The methods more commonly used are those that involve the reading of scales and otoliths, structures in which it is possible to observe concentric rings related to a defined time interval. Elorduy-Garay and

Diaz-Uribe (1994) showed that scales are useless for age determination purposes in *C. affinis,* but that otoliths are adequate structures for this purpose.

The objective of this study was to determine age and express the individual growth of *C. affinis* by means of a growth equation, and study the natural and fishing mortalities.

## MATERIALS AND METHODS

Samples of *C. affinis* were collected monthly from February 1986 to May 1987, mainly from commercial catches landed at La Paz, and whose origin was verified to be from the bays of La Paz, Cerralvo, or the San José Islands (Figure 1). A small number of samples was collected from research fishing using hook and line gear similar to that used by the commercial fishery.
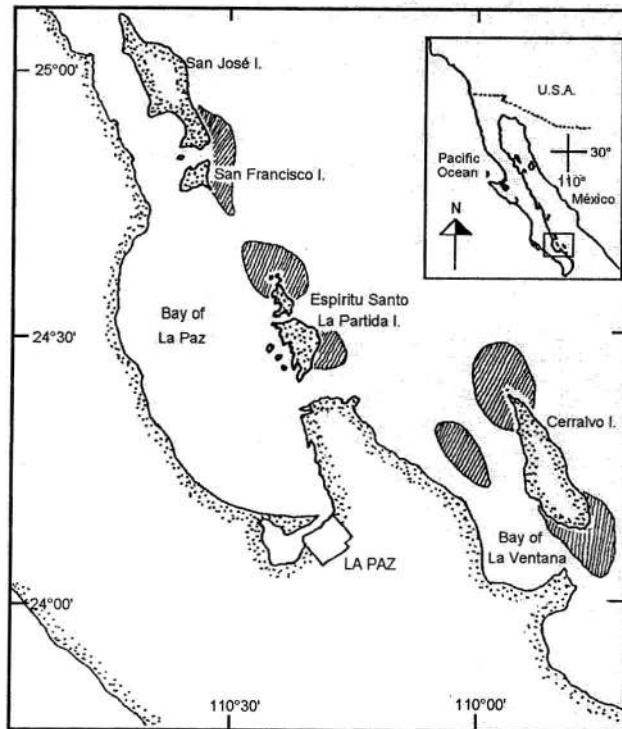


FIGURE 1. Fishing grounds for *C. affinis* (shaded areas) in the La Paz Bay area.

In a massive sampling, fish were measured in total length (TL) and standard length (SL) (to the nearest mm), and sex was determined when possible. From these, subsamples were selected at 25-mm intervals (fish SL classes), ranging from 125 mm to 500 mm, and the first 50 fish of a length class were taken each month; when the month's subsample reached 300 fish, only the length classes that were not well represented were sampled. These fish were weighed, as total weight (TW) where possible and eviscerated weight (EW), with an electronic balance (5 g precision).

Both sagittal otoliths were collected and stored dry in plastic envelopes for processing at the laboratory. Because most fish sampled were already eviscerated (without entrails and gills), functional regressions (Ricker 1973, 1975a, Jolicoeur 1975) were performed (separately for males, females, and the sexes combined), using specimens for which both measurements were available. The length-weight relationship was fitted to a potential regression line ($y = ax^b$), where $y$ is the weight of fish in grams and $x$ is the SL in millimeters. Because population dynamics models assume an isometric growth pattern, a Student's $t$-test was performed to determine if $b$ deviated significantly from three (Pauly 1984).

A detailed description of methods and procedures used in processing and reading the otoliths of Pacific golden-eyed tilefish can be found in Elorduy-Garay and Diaz-Uribe (1994). Whole burnt otoliths were read by three readers independently and without knowledge of fish characteristics. Otolith reading for age determination and growth estimation consisted of counting growth rings and determining the otolith's edge type. Ages and edges assigned to otoliths by the three readers were compared, and when coincident, that age and edge type was assigned to the fish; when there was disagreement among readers, otoliths were read again, and any otolith for which disagreement persisted was declared "unreadable" and discarded.

With the ages of the whole subsample, age-length keys were made (FAO 1982) for males, females, and the sexes combined. Also, age-length keys were made splitting

each age group by the type of edge of the otolith. Mean length at age was calculated for all cases. Von Bertalanffy's (Ricker 1975b) growth functions (VBGF) were fitted to these data, which for length and weight, respectively, are:

$$L_t = L_\infty(1 - e^{-k(t-t_0)}) \quad \text{and}$$

$$W_t = W_\infty(1 - e^{-k(t-t_0)})^b$$

where $L_t(W_t)$ is the standard length in millimeters (eviscerated weight in grams) at age $t$; $L_\infty(W_\infty)$ is the estimate of average maximum length (weight) attained; $k$ is the growth completion rate; $t_0$ is the theoretical age in years when fish is length 0; and $b$ is the exponent from the length-weight relationship.

The first estimation of $L_\infty$ was obtained by the Ford-Walford method (Walford 1946); the other parameters ($k$ and $t_0$) were calculated linearizing the VBGF. These parameters were used as "seeds" to estimate the final parameters by a nonlinear least squares regression using Marquardt's algorithm (Marquardt 1963, Conway et al. 1970). The method of Tomlinson and Abramson (1961) was also used to fit the VBGF to the age-length data.

The instantaneous rate of total mortality ($Z$) was calculated using the equation:

$$N_{t+1} = N_t e^{-Z_t}$$

where $N_t$ and $N_{t+1}$ are the number of fish in two consecutive age classes, beginning with the modal age, and $Z_t$ is the instantaneous rate of total mortality for age $t$. Then the value of $Z_t$ for each age class was weighted by the relative abundance of each age class considered in the total sample, and an average for each age class was calculated to obtain the final $Z$. This was done with the rationale that the hook and line gear used in this fishery is highly selective and strongly undersamples the biggest fish beyond some length class. The instantaneous rate of natural mortality ($M$) was estimated by two methodologies: the empirical equation of Pauly (1983) and the following method of Chen and Watanabe (1989):

$$M_t = \begin{cases} \dfrac{k}{1 - e^{-k(t-t_0)}}, & t \le t_M \\[2ex] \dfrac{k}{a_0 + a_1(t-t_M) + a_2(t-t_M)^2}, & t \ge t_M \end{cases}$$

where

$$t_M = -\frac{1}{k} \ln|1 - e^{kt_0}| + t_0$$

and

$$\begin{cases} a_0 = 1 - e^{-k(t_M - t_0)} \\[1ex] a_1 = ke^{-k(t_M - t_0)} \\[1ex] a_2 = -\frac{1}{2}k^2 e^{-k(t_M - t_0)} \end{cases}$$

The values of $M_t$ obtained were averaged from age 5 to the last age encountered. Only the averaged values of mortalities were used.

## RESULTS

Massive sampling produced data from 7253 fish: 3219 males, 2893 females, and 1141 whose sex could not be determined, with a sex ratio of 1.11:1. The subsample produced data and otoliths from 3632 individuals: 1725 males, 1471 females, and 436 of undetermined sex, with a sex ratio of 1.17:1.

Most of the monthly frequency distributions were unimodal, although there were polymodal distributions in some months. Standard length ranged from 145 mm to 483 mm for the total sample. For males the overall distribution was unimodal and practically unskewed, with the highest frequency (14.54%) in the 295-mm length class (Figure 2A); females also showed a unimodal distribution, but skewed to the left, with the highest frequency (14.55%) in the 245-mm length class (Figure 2B); the sexes combined showed a maximum (12.37%) in the 265-mm length class (Figure 2C). The frequency distributions for the eviscerated weight (Figure 3) from the subsample were unimodal, ranging from 57 g to 2345 g both for females and the sexes combined, and ranging from 60 g to 1500 g for males. Regressions of standard length on total length are highly significant ($R^2 > 0.98$) in all cases. Linear regres-
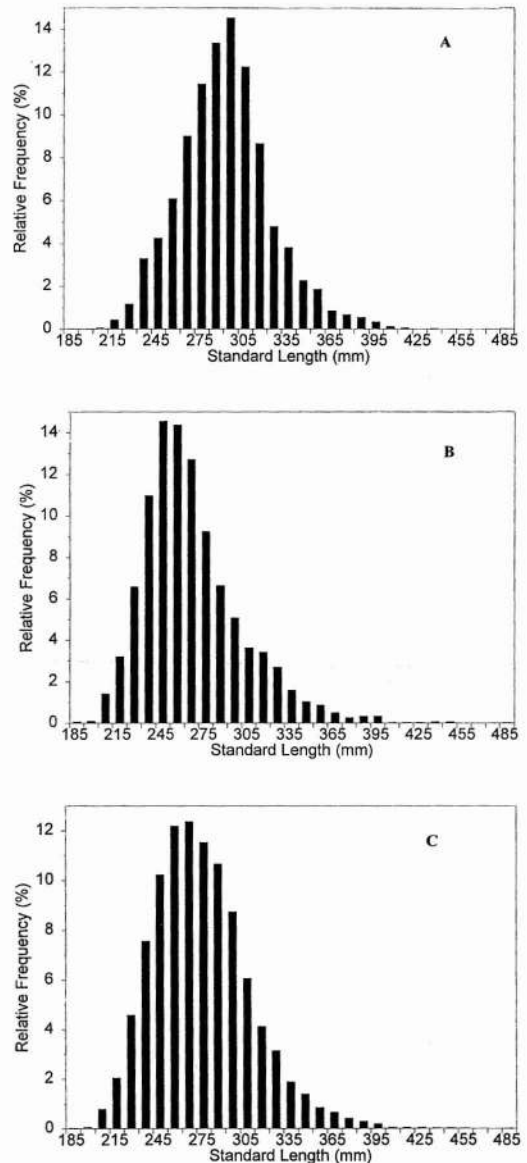


FIGURE 2. Frequency distribution of standard length of *C. affinis* from the total sample. (*A*) males, (*B*) females, and (*C*) sexes combined.

sion parameters for males, females, and the sexes combined, respectively, were as follows: intercept (mm) = $-5.93$, $-7.47$, $-6.97$; slope = 0.822, 0.826, 0.825. Regressions of eviscerated weight on total weight are highly significant ($R^2 > 0.99$) in all cases, so total
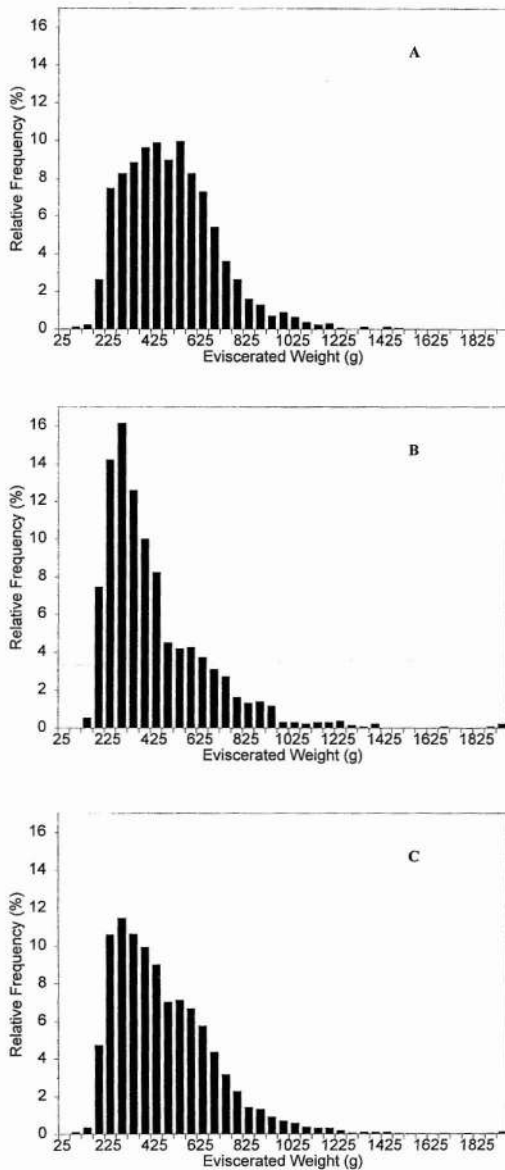
FIGURE 3. Frequency distribution of eviscerated weight of *C. affinis* from the subsample. (*A*) males, (*B*) females, and (*C*) sexes combined.

TABLE 1

PARAMETERS OF THE REGRESSIONS ($W_t = a + b \ W_e$) OF TOTAL WEIGHT (g) ON EVISCERATED WEIGHT (g) OF *C. affinis* FOR MALES, FEMALES, AND SEXES COMBINED

| PARAMETER | MALES | FEMALES | COMBINED |
|---|---|---|---|
| Intercept ($a$) | 2.0800 | 8.5210 | 6.4560 |
| $R^2$ | 0.9948 | 0.9932 | 0.9927 |
| No. of observations | 83 | 89 | 183 |
| Slope ($b$) | 1.0966 | 1.1172 | 1.1029 |

by this result, all calculations on condition factors and growth in weight at age should be performed using these $b$ exponents.

About 8% of all otoliths read were discarded: about 3.4% because of differences in ring counts among readers and about 4.7% because rings could not be counted.

Males were represented in age groups 1 to 12, predominating in age group 6 (20.56%). Females were represented in age groups 0 to 15 (except ages 1 and 13), the most abundant being age group 4 (22.41%) (Table 3, Figure 4).

Ages 0 and 1 are not recruited to the fishery. Although ages 2 and 3 are only partially recruited, they were considered for the estimation of the growth curve because their exclusion produced very unlikely values for $L_\infty$ and $t_0$. The very few age groups older than 12 yr (3 of 14 and 2 of 15) were also excluded from the estimation of the growth curve because their inclusion produced overestimates of $L_\infty$ and $t_0$ and underestimates of $k$.

Considering that back-calculated lengths at age agree reasonably well with observed mean lengths at age (Elorduy-Garay and Diaz-Uribe 1994), the growth curve was estimated from data grouped in the following way: back-calculated mean lengths at age were assigned integer ages (i.e., $1, \ldots, 15$), observed mean lengths at age without consideration of the otolith's edge were assigned half ages (i.e., $1.5, \ldots, 15.5$), and observed mean lengths at age considering the otolith's edge were assigned either age plus 0.25 for opaque edges or age plus 0.75 for translucent edges (i.e., $1.25, \ldots, 15.25$, and $1.75, \ldots, 15.75$, respectively).

weight could be estimated confidently from eviscerated weight (Table 1).

Length-weight relationships showed high values of $R^2$ in all cases, with slopes significantly higher than 3 (Table 2). Because of the positive allometric growth pattern shown

TABLE 2

PARAMETERS OF THE REGRESSIONS ($W = aL^b$, OR THE EQUIVALENT $\ln W = \ln a + b \ln L$) OF EVISCERATED WEIGHT (g) ON STANDARD LENGTH AND TOTAL LENGTH (mm) OF *C. affinis* FOR MALES, FEMALES, AND SEXES COMBINED

| | STANDARD LENGTH | | | TOTAL LENGTH | | |
|---|---|---|---|---|---|---|
| PARAMETER | MALES | FEMALES | SEXES COMBINED | MALES | FEMALES | SEXES COMBINED |
| Intercept (ln *a*) | −11.96 | −11.63 | −11.71 | −13.15 | −12.98 | −12.97 |
| $R^2$ | 0.9641 | 0.9682 | 0.9661 | 0.9701 | 0.9728 | 0.9715 |
| No. of observations | 1728 | 1470 | 3635 | 1728 | 1470 | 3635 |
| Slope (*b*) | 3.1977 | 3.1396 | 3.1536 | 3.2824 | 3.2548 | 3.2518 |
| *t* calculated | 13.63* | 9.563* | 16.00* | 20.61* | 18.20* | 27.67* |

*, Indicates *b* significantly different from 3 ($t_{(g.1,.0.05)} = 1.960$).

TABLE 3

MEAN STANDARD LENGTH, STANDARD DEVIATION (SD) AND NUMBER OF FISH (*n*) BY AGE GROUP FROM THE SUBSAMPLE OF *C. affinis* (ALL MEASUREMENTS IN MILLIMETERS)

| | MALES | | | FEMALES | | | SEXES COMBINED | | |
|---|---|---|---|---|---|---|---|---|---|
| AGE | *n* | MEAN | SD | *n* | MEAN | SD | *n* | MEAN | SD |
| 0+ | — | — | — | 1 | 145.0 | 0.0 | 1 | 145.0 | 0.0 |
| 1+ | 1 | 145.0 | 0.0 | — | — | — | 2 | 150.0 | 5.0 |
| 2+ | 68 | 227.2 | 12.6 | 76 | 219.7 | 13.4 | 158 | 223.3 | 13.4 |
| 3+ | 212 | 245.0 | 18.1 | 214 | 234.7 | 16.7 | 460 | 239.4 | 17.8 |
| 4+ | 201 | 264.9 | 20.1 | 288 | 250.6 | 18.9 | 535 | 256.1 | 20.5 |
| 5+ | 288 | 284.8 | 22.4 | 248 | 267.7 | 23.8 | 598 | 276.4 | 24.6 |
| 6+ | 316 | 299.2 | 20.7 | 176 | 285.6 | 27.3 | 565 | 293.9 | 24.0 |
| 7+ | 237 | 312.0 | 22.4 | 129 | 313.5 | 25.4 | 406 | 312.0 | 23.5 |
| 8+ | 136 | 330.7 | 23.8 | 75 | 325.9 | 27.3 | 235 | 329.7 | 24.9 |
| 9+ | 51 | 340.7 | 23.9 | 45 | 342.8 | 25.8 | 115 | 341.7 | 24.7 |
| 10+ | 22 | 352.2 | 29.4 | 17 | 349.4 | 40.4 | 49 | 352.7 | 35.8 |
| 11+ | 5 | 355.0 | 27.6 | 8 | 369.3 | 39.6 | 18 | 365.0 | 40.6 |
| 12+ | 3 | 335.0 | 0.0 | 7 | 365.0 | 21.6 | 13 | 359.0 | 21.1 |
| 14+ | — | — | — | 3 | 430.0 | 55.0 | 3 | 430.0 | 55.0 |
| 15+ | — | — | — | 1 | 455.0 | 0.0 | 2 | 435.0 | 20.0 |

The resulting VBGF fitted equations in terms of standard length and of eviscerated weight, following Marquardt's iterative method, are presented in Figures 5 and 6, respectively. Table 4 shows the VBGF parameter estimates for standard length and the explained variance ($R^2$), using the two nonlinear methods as well as the Ford-Walford method.

The inflection points of the weight at age curves are at 4.49 yr for males, at 8.60 yr for females, and at 5.94 yr for the sexes combined. Males attain 50% of their asymptotic weight at about age 7, whereas females attain it at about 13 yr of age. Curves diverge notably with age, and at 15 yr females weigh some 200 g more than males of the same age.

The weighted average of the instantaneous rate of total mortality, *Z*, was 0.4829 for males (ages 6 to 12), 0.4253 for females (ages 5 to 15), and 0.5052 for the sexes combined (ages 6 to 15). The rate of total mortality estimated from the catch-at-age curve was 0.8397, 0.5274, and 0.6702, for males, females, and the sexes combined, respectively. The averaged instantaneous rate of
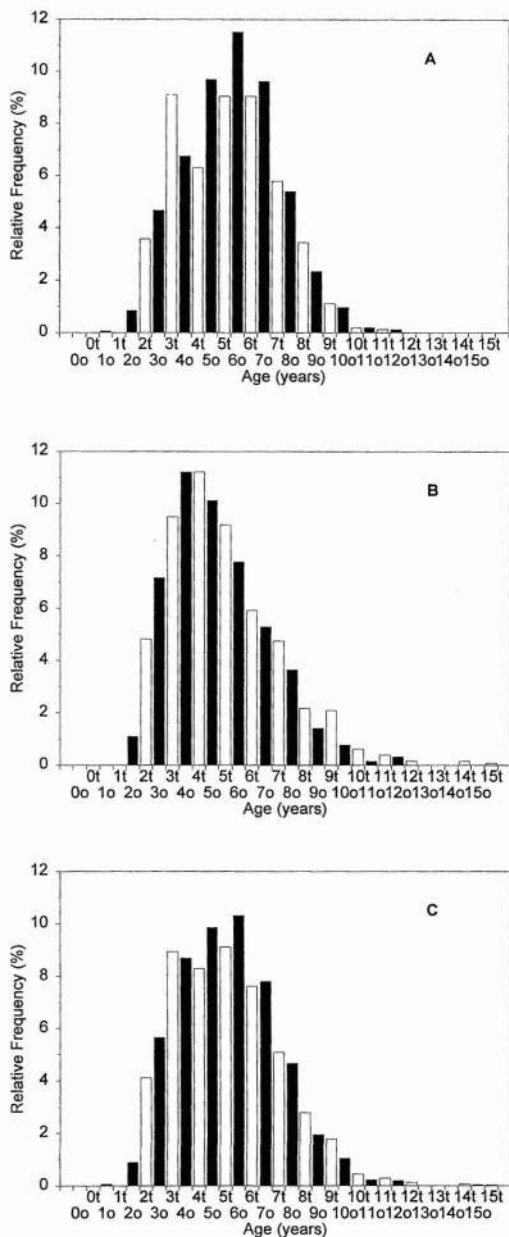
FIGURE 4. Frequency distribution by age group of *C. affinis*, considering the edge type of otoliths. (*A*) males, (*B*) females, and (*C*) sexes combined.

natural mortality, $M$, was 0.2142, 0.1316, and 0.1697 for males, females, and the sexes combined, respectively, using the method of Chen and Watanabe (1989), and 0.3886,

0.2434, and 0.319 for males, females, and the sexes combined, respectively, using the equation of Pauly (1983).

## DISCUSSION

Sex ratio was 1:1 for the total sample (independent of the sample type), although there was a slight predominance of males. Length frequency distributions show that there is a large difference (of some 40 mm) in the modes of males and females, the latter being smaller. The distribution of males is nearly symmetrical, whereas females are clearly skewed to the small length classes. The precise causes of this are not clear, but the possibility of sex reversal in *C. affinis* has been advanced (Ceballos-Vazquez et al. 1996). Because of a lack of small individuals, this possibility remained unresolved in our study. Various authors have reported important differences in sex ratios among branchiostegids, always with females predominating at small sizes and young ages, and males at larger sizes and older ages (Ross and Merriner 1983, Erickson and Grossman 1986); most of these authors have indicated the possibility of protogynous hermaphroditism in their reports.

If we assume that sex ratios are constant over the length distribution, a difference in behavior with the fishing gear by the two sexes has to be recognized, which in turn would lead to different selectivity for each sex. The reverse would be to assume the same behavior with the fishing gear and conclude that the difference is due to the sex ratios of the small length classes. Possible explanations of these sex ratios include the following: (1) there is sex reversal, as pointed out above; (2) there are differential mortality rates for males and females as shown by the natural mortality estimates; (3) males of small length classes are not present at the fishing grounds. We cannot distinguish among these possibilities with our data.

One of the postulates underlying the VBGF is the assumption of isometric growth (i.e., that $b = 3$). Our data indicate that *C. affinis* has a statistically allometric positive
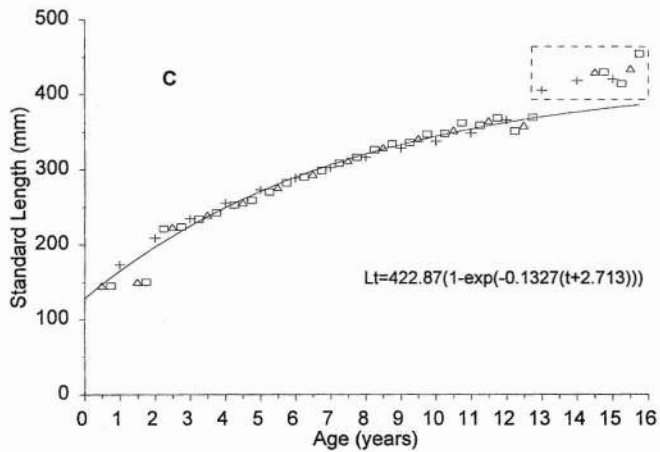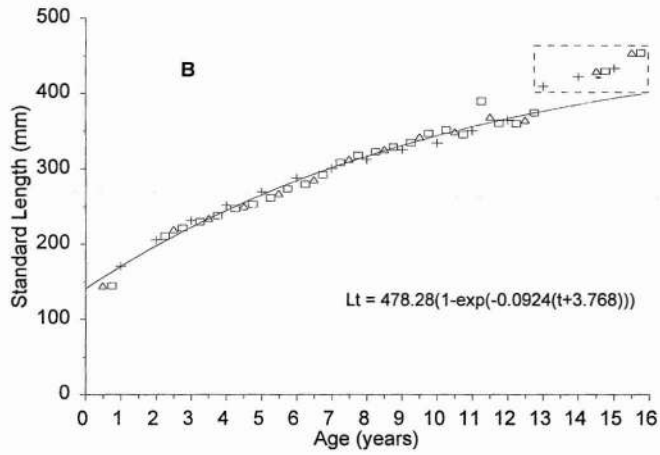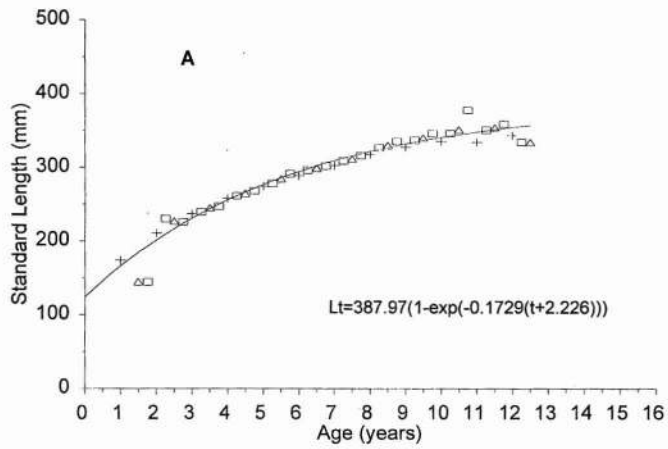
FIGURE 5. Mean standard lengths of *C. affinis* at age: (△) observed, regardless of edge type; (□) observed; and (+) back-calculated (from Elorduy-Garay and Diaz-Uribe 1994). Also von Bertalanffy growth curves fitted by Marquardt's method. (*A*) males, (*B*) females, and (*C*) sexes combined. Data of the points inside the dashed rectangles were not used for parameter estimation.
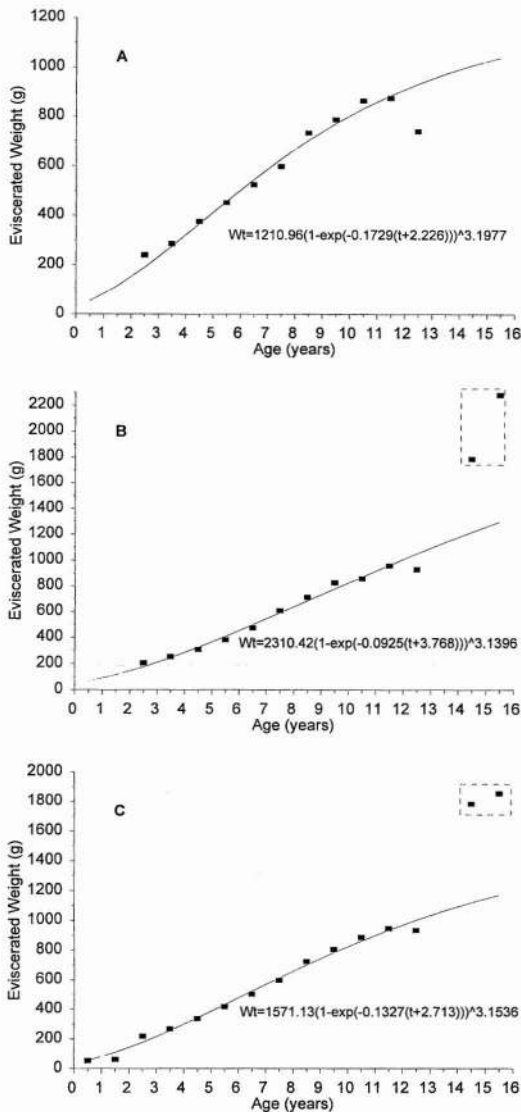
FIGURE 6. Mean observed weight (eviscerated) at age, as read from otoliths, and fitted von Bertalanffy growth curves of *C. affinis*: (*A*) males, (*B*) females, and (*C*) sexes combined. Data of the points inside the dashed rectangles were not used for parameter estimation.

growth pattern, but for practical purposes, the departure from isometry is very small. The value of the exponent in weight-length relationships is highly variable, which has been explained in a variety of ways (Hart et al. 1940, Kohler 1960, Southward and Chapman 1965, Forrester and Thomson 1969). If this *b* value is not very different from 3, it can be used reliably to estimate the condition factor and the weight-related growth parameters (Carlander 1977).

Most of the disagreements between readers of the otoliths of *C. affinis* occurred on those of larger size and those that apparently had double rings. In both cases, the problem appeared when counting the rings closest to the edge, mainly because the distance between some rings is so small and indistinct that two rings could be counted as one. The assignment of the kind of edge (often a source of disagreement) was also important for determining the age of *C. affinis*, and again more problems occurred with larger otoliths. The edge on these otoliths becomes so thick that in some areas it could completely cover rings that were clearly visible on other portions of the otolith.

The percentag of unreadable otoliths (8%) was low compared with results obtained for *C. microps* (29%) (Ross and Huntsman 1982) and similar to results reported for *Lopholatilus chamaeleonticeps* (10%) (Turner et al. 1983) and *Merluccius capensis* (10%) and *M. paradoxus* (6%) (Botha 1971). Dividing the otolith surface into discrete reading areas was helpful and decreased the confusion of rings that occurred when the readers tried to establish the continuity of them all along the otolith. This lack of continuity in the rings has also been noted in the otoliths of *L. chamaeleonticeps* (Turner et al. 1983).

Growth in *C. affinis* is adequately represented by the VBGF, with good agreement between the observed data and the fitted model, especially from ages 3 to 11–12; the major deviations occurred at both ends of the curve. A possible cause of these deviations is the origin of the samples, which came mainly from the commercial catch, which is highly size (and consequently age) selective; resulting in the under- and overestimation of the mean lengths calculated for those ages.

It is evident that all the VBGF parameters are much different between males and females; absolute values of $L_\infty$ and $t_0$ are larger for females whereas $k$ is smaller.

TABLE 4

Comparison Growth Parameters for Standard Length of *C. affinis* Estimated by Different Methods

| METHOD | SEX | $L_\infty$ (mm) | $k$ (yr$^{-1}$) | $t_0$ (yr) | $R^2$ |
|---|---|---|---|---|---|
| Marquardt | Males | 387.85 | 0.1729 | −2.2289 | 0.9551 |
| | Females | 478.27 | 0.0925 | −3.7678 | 0.9825 |
| | Combined | 422.78 | 0.1327 | −2.7106 | 0.9794 |
| Tomlinson and | Males | 367.44 | 0.2095 | −1.7250 | 0.9597 |
| Abramson | Females | 519.00 | 0.0708 | −5.1845 | 0.9748 |
| | Combined | 415.74 | 0.1378 | −2.6765 | 0.9783 |
| Ford-Walford | Males | 352.43 | 0.3733 | 0.4858 | 0.6624 |
| | Females | 507.83 | 0.0793 | −4.3040 | 0.9739 |
| | Combined | 369.44 | 0.2910 | 0.1225 | 0.8758 |

Growth parameters estimated by the Tomlinson and Abramson (1961) method agreed rather well with those estimated by the Marquardt (1963) algorithm and showed a somewhat larger discrepancy with most of those obtained by the Ford-Walford method (Walford 1946). The agreement between the first two methods reflects the similar procedures used when adjusting the equations. Both are nonlinear methods that allow the iterative correction of each parameter, whereas the other parameters are fixed. The largest discrepancies among the three methods are in the values of $t_0$ for males and the sexes combined; however it is obvious that the absolute Ford-Walford values of $t_0$ for males and combined sexes are much smaller, but possibly provide a better biological representation than the $t_0$ from the other methods. Nevertheless, the three estimates have the same tendencies, indicating that females have larger values of asymptotic length and smaller values of $k$ than males.

*Caulolatilus affinis* is a slow-growing fish of medium longevity, similar to demersal species such as the American species of hake: *Merluccius productus, M. gayi,* and *M. hubbsi,* whose longevity is 11 to 13 yr (Elorduy-Garay 1986). Among the Branchiostegidae studied so far, *L. chamaeleonticeps* is the species that attains greatest longevity (35 yr) and largest size (1150 mm FL) (Freeman and Turner 1977, Turner et al. 1983, Harris and Grossman 1985); *Branchiostegus japonicus japonicus* reaches maxima of 8 yr of age and 322 mm TL (Hayashi 1976).

Growth differences between the sexes have been observed for many fish species, including several species of Branchiostegidae. Freeman and Turner (1977) and Turner et al. (1983) reported that males of *L. chamaeleonticeps* grow faster than females and attain greater lengths, but that females live longer. Growth differences between sexes in this species are greater after ages 5 and 6, when 50% of the males and females reach sexual maturity (Erickson and Grossman 1986). Faster growth and greater asymptotic lengths for males has also been reported for *B. japonicus japonicus* (Lim and Misu 1974, Hayashi 1976) and for *C. chrysops* and *C. intermedius* (Ross et al., unpubl. data, in Ross and Huntsman [1982]). This divergence in the growth rates of Branchiostegidae is correlated with sexual maturity in females, probably a result of the high and early energetic cost of reproduction (Turner et al. 1983). *Caulolatilus affinis* is no exception in this characteristic, because the growth curves for separate sexes show a clear differentiation in growth (e.g., much larger $k$ values for males than for females). Therefore, in a random sampling, it is more likely to catch larger males than females if the sexes have similar natural mortality. Length frequency results are also evidence of the difference of growth between sexes.

Growth rates ($k$ values) obtained for *C. affinis* (0.173, 0.0925, and 0.133, for males, females, and combined sexes, respectively) are similar to the value observed by Ross and Huntsman (1982) for *C. microps* (0.137), but

smaller than those reported for *B. japonicus japonicus* (0.304 and 0.297 for males and females, respectively) (Hayashi 1976). Similar growth rates have been found in other demersal fishes such as *Mycteroperca phenax*, which reaches its maximum length very slowly ($k = 0.092$), but has a relatively long lifespan (more than 21 yr) (Matheson et al. 1986). This growth pattern is typical not only for several Serranidae (with $k$ between 0.06 and 0.18, and maximum ages from 13 to 28 yr), but also for other families from rocky-bottom deep waters, whose $k$ values range from 0.10 to 0.22 and maximum ages range from 9 to 16 yr (Matheson et al. 1986). Edwards (1984), comparing growth rates for demersal fishes from temperate waters, found that these species grow faster than their counterparts in tropical waters and suggested that this difference is related to the high metabolic cost of living in the Tropics compared with that in temperate waters. Such geographic differences in growth rates have been associated with differences in quality and quantity of food supplies, and this has been proposed as an explanation for smaller intrinsic potential for production of demersal fish stocks in tropical regions than in temperate waters.

$L_\infty$ values for both sexes are reasonable estimates for the maximum average standard lengths that *C. affinis* reaches; even though larger specimens were collected (as large as a 422-mm SL male and a 483-mm SL female). The greater length of the largest female specimens observed, and the considerably larger $L_\infty$ and $W_\infty$ for female *C. affinis,* are in contrast with the results of growth studies for other Branchiostegidae, for which males attain larger asymptotic sizes. The larger female $L_\infty$ of *C. affinis* and the differences in $k$ between the sexes cause a crossing of the growth curves at about age 8+ ($\sim 330$ mm SL). Part of this effect is probably the result of differences in natural mortality of the sexes after that age, which can be seen in the length and age composition. The crossing of growth curves has been noticed in other species such as *M. paradoxus* and *M. capensis* (Botha 1971), as well as in *Sebastes marinus* (Kelly and Wolf 1959) in the Gulf of Maine. They live in depths similar to those of *C. affinis* in the study area and have growth curves with patterns comparable with those of *C. affinis.* Estimated $t_0$ values for *C. affinis* ($-2.229$ for males and $-3.768$ for females) are within the expected interval, considering the existing data from species with similar demography (Manooch and Haimovici 1978, Nelson and Manooch 1982, Ross and Huntsman 1982, Turner et al. 1983, Moore and Labisky 1984). The low representation of 0+ and 1+ age fish is evident in this study, and the age frequencies by otolith edge show that the larger fish age 2+ were captured.

Instantaneous rate of total mortality is much higher than for *C. microps* (0.22) from North Carolina and South Carolina waters (Ross and Huntsman 1982) and *L. chamaeleonticeps* (0.10 to 0.25) from waters off Georgia (Harris and Grossman 1985), and similar to that of *L. chamaeleonticeps* (0.46, 0.60) from the Middle Atlantic–southern New England region (Turner et al. 1983). This fact is surprising because we consider that the rate of exploitation is relatively low in the area. The most probable cause of the relatively high $Z$ encountered is the selectivity of the hook employed in the commercial fishery from which the samples were taken, which produces a sampling bias for the older ages. Another possible cause is that there is a depth stratification, with the largest and oldest individuals more deeply distributed, and so not fished. Nevertheless, there has to be more-specific work done on this particular issue, because with the data at hand very little can be determined.

LITERATURE CITED

ANONYMOUS. 1981. Anuario Estadístico de Pesca 1980. Departamento de Pesca, Dir. Gral Planeación, Informática y Estadística, Secretaría de Pesca, México, D.F.

BAGENAL, T. B., and F. W. TESCH. 1978. Age and growth. Pages 101–136 in T. B. Bagenal, ed. Methods for assessment of fish populations in freshwaters. Blackwell Scientific Publications, London.

BOEHLERT, G. W. 1985. Using objective criteria and multiple regression models for age determination in fishes. Fish. Bull. 83:103–117.

BOTHA, L. 1971. Growth and otolith morphology of the Cape Hake, *Merluccius capensis* Cast. and *M. paradoxus* Franca. Invest. Rep. Div. Sea Fish. S. Afr. 97:1–32.

BROTHERS, E. B. 1979. Age and growth studies on tropical fishes. Pages 119–136 in S. B. Saila and P. M. Roedel, eds. Stock assessment for tropical small scale fisheries. Proceedings of an International Workshop, 19–21 September 1979, University of Rhode Island, Kingston, Rhode Island.

CARLANDER, K. D. 1977. Handbook of freshwater fishery biology, Vol. 2. Iowa State University Press, Ames.

CEBALLOS-VAZQUEZ, B. P., J. F. ELORDUY-GARAY, and F. A. GARCIA-DOMINGUEZ. 1996. First record of hermaphroditic specimens of *Caulolatilus affinis* (Pisces: Branchiostegidae) from the Gulf of California. Rev. Biol. Trop. 44: 689–690.

CHEN, S., and S. WATANABE. 1989. Age dependence of natural mortality coefficient in fish population dynamics. Nippon Suisan Gakkaishi 55:205–208.

CONWAY, G. R., N. R. GLASS, and J. C. WILCOX. 1970. Fitting nonlinear models to biological data by Marquardt's algorithm. Ecology 51:503–507.

DOOLEY, J. K. 1978. Systematics and biology of the tilefishes (Perciformes: Branchiostegidae and Malacanthidae), with descriptions of two new species. NOAA Tech. Rep. NMFS Circ. 411:1–79.

EDWARDS, R. R. C. 1984. Comparisons of growth in weight of temperate and tropical marine fish counterparts. Can. J. Fish. Aquat. Sci. 41:1381–1384.

ELORDUY-GARAY, J. F. 1986. Distribución y biología comparativa de las especies americanas del género *Merluccius* (Pisces: Merlucciidae). M.S. thesis, CICESE, Ensenada, B.C., México (in Spanish).

ELORDUY-GARAY, J. F., and J. G. DIAZ-URIBE. 1994. Age validation of *Caulolatilus affinis*, Gill 1865, (Pisces: Branchiostegidae) from the Gulf of California using otoliths. Sci. Mar. 584:277–287.

ELORDUY-GARAY, J. F., and A. K. PELAEZ-MENDOZA. 1996. Hábitos alimentarios de *Caulolatilus affinis* Gill 1865 (Perciformes: Branchiostegidae) en la Bahía de La Paz, B.C.S., México. Rev. Biol. Trop. 44:241–249 (in Spanish).

ELORDUY-GARAY, J. F., and S. RAMIREZ-LUNA. 1994. Gonadal development and spawning of female Ocean Whitefish, *Caulolatilus princeps* (Pisces: Branchiostegidae) in the Bay of La Paz, B.C.S., México. J. Fish Biol. 44:553–566.

ERICKSON, D. L., and G. D. GROSSMAN. 1986. Reproductive demography of tilefish from the South Atlantic Bight with a test for the presence of protogynous hermaphroditism. Trans. Am. Fish. Soc. 115:279–285.

FAO. 1982. Métodos de recolección y análisis de datos de talla y edad para la evaluación de poblaciones de peces. FAO Circ. Pesca. 736:1–101 (in Spanish).

FITCH, J. E., and R. L. LAVENBERG. 1971. Marine food and game fishes of California. University of California Press, Berkeley.

FORRESTER, C. R., and J. A. THOMSON. 1969. Length-weight relationships in some marine groundfish. Fish. Res. Board Can. Tech. Rep. 135.

FREEMAN, B. L., and S. C. TURNER. 1977. Biological and fisheries data on tilefish, *Lopholatilus chamaeleonticeps,* Goode and Bean. NOAA, NMFS, Sandy Hook Lab. Tech. Ser. Rep. 5.

HARRIS, M. J., and G. D. GROSSMAN. 1985. Growth, mortality and age composition of a lightly exploited tilefish substock off

Georgia. Trans. Am. Fish. Soc. 114:837–846.

HART, J. L., A. L. TESTER, D. BEALL, and J. P. TULLY. 1940. Proximate analysis of British Columbia herring in relation to season and condition factor. J. Fish. Res. Board Can. 45:478–490.

HAYASHI, Y. 1976. Studies on the growth of the red tilefish in the East China Sea—II. Estimation of age and growth from otolith reading. Bull. Jpn. Soc. Sci. Fish. 42:1243–1249.

HOLDEN, M. J., and D. F. S. RAITT, EDS. 1974. MANUAL OF SHERIES SCIENCE. PART 2—Methods of resource investigation and their application. FAO Fish. Tech. Pap. 115, rev. 1: 76–126.

JOLICOEUR, P. 1975. Linear regressions in fishery research: Some comments. J. Fish. Res. Board Can. 32:1491–1494.

KELLY, G. F., and R. S. WOLF. 1959. Age and growth of the red fish (*Sebastes marinus*) in the Gulf of Maine. Fish. Bull. 60(156): 1–31.

KOHLER, A. C. 1960. The growth, length-weight relationship, and maturity of haddock (*Melanogrammus aeglefinus* L.) from the region of Lockeport, N.S. J. Fish. Res. Board Can. 171:41–60.

LIM, P. Y., and H. MISU. 1974. On the age determination of the akaamadai, *Branchiostegus japonicus japonicus* (Houttuyn), in the adjacent waters of Tsushima Islands. Bull. Seikai Reg. Fish. Res. Lab. 46:41–51.

MANOOCH, C. S., III, and M. HAIMOVICI. 1978. Age and growth of the gag, *Mycteroperca microlepis,* and size-age composition of the recreational catch off the southeastern United States. Trans. Am. Fish. Soc. 107:234–240.

MARQUARDT, D. W. 1963. An algorithm for least-squares estimation of nonlinear parameters. J. Soc. Ind. Appl. Math. 11:431–441.

MATHESON, R. H., G. R. HUNTSMAN, and C. S. MANOOCH III. 1986. Age, growth, mortality, food and reproduction of the scamp, *Mycteroperca phenax,* collected off North Carolina and South Carolina. Bull. Mar. Sci. 38:300–312.

MOORE, C. M., and R. L. LABISKY. 1984. Population parameters of a relatively un-exploited stock of snowy grouper in the lower Florida Keys. Trans. Am. Fish. Soc. 113:322–329.

MOSER, H. G., B. Y. SUMIDA, D. A. AMBROSE, E. M. SANDKNOP, and E. G. STEVENS. 1986. Development and distribution of larvae and pelagic juveniles of Ocean Whitefish, *Caulolatilus princeps,* in the CalCOFI survey region. Calif. Coop. Oceanic Fish. Invest. Rep. 27:162–169.

NELSON, R. S., and C. S. MANOOCH III. 1982. Growth and mortality of red snappers in the west central Atlantic Ocean and northern Gulf of Mexico. Trans. Am. Fish. Soc. 111:465–475.

PAULY, D. 1983. Some simple methods for the assessment of tropical fish stocks. FAO Fish. Tech. Pap. 234:1–52.

———. 1984. Fish population dynamics in tropical waters: A manual for use with programmable calculators. ICLARM Stud. Rev. 8.

RICKER, W. E. 1973. Linear regressions in fishery research. J. Fish. Res. Board Can. 30:409–434.

———. 1975a. A note concerning Professor Jolicoeur's comments. J. Fish. Res. Board Can. 32:1494–1498.

———. 1975b. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board. Can. Bull. 191:1–382.

ROSS, J. L., and G. R. HUNTSMAN. 1982. Age, growth, and mortality of Blueline Tilefish from North Carolina and South Carolina. Trans. Am. Fish. Soc. 111:585–592.

ROSS, J. L., and J. V. MERRINER. 1983. Reproductive biology of the Blueline Tilefish *Caulolatilus microps,* off North Carolina and South Carolina. Fish. Bull. 81:553–568.

SCHNUTE, J., and D. FOURNIER. 1980. A new approach to length-frequency analysis: Growth structure. Can. J. Fish. Aquat. Sci. 37:1337–1351.

SOUTHWARD, G. M., and D. G. CHAPMAN. 1965. Utilization of Pacific halibut stocks: Study of Bertalanffy's growth equa-

tion. Int. Pac. Halibut Comm. Rep. 39:
    1–33
TOMLINSON, P. K., and N. J. ABRAMSON. 1961.
    Fitting a von Bertalanffy growth curve by
    least squares. Fish Bull. Calif. 116:1–69.
TURNER, S. C., C. B. GRIMES, and K. W.
    ABLE. 1983. Growth, mortality and age-
size structure of the fisheries for Tile-
    fish, *Lopholatilus chamaeleonticeps,* in the
    Middle Atlantic–southern New England
    Region. Fish. Bull. 81:751–763.
WALFORD, L. A. 1946. A new graphic method
    of describing the growth of animals. Biol.
    Bull. (Woods Hole) 90:141–147.