

Age and growth of three searobins (Pisces: Triglidae) off the western coast of Baja California Sur, México

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Abstract: The three dominant triglid species off the western coast of Baja California Sur are *Prionotus stephanophrys*, *Bellator gymnostethus* and *P. albirostris*. Nine bottom trawling cruises, from July 1987 to September 1991, yielded 4040, 173 and 94 individuals, respectively. Based on ageing by length frequency analysis and by annular marks in otoliths, we obtained weight-length and age-length relationships. Several growth models were tested on the age-length curves. Only the growth of *B. gymnostethus* is allometric; the other searobins grow isometrically. Although females grow larger, the weight-length equation does not differ significantly between sexes. The logistic model allows for good interpolations, but the extrapolations of the von Bertalanffy model for older fishes are closest to the maximum observed lengths. Growth curves of the three species are significantly different: the asymptotic maximum length accounts for most of the variation (*P. stephanophrys*, 325 mm SL; *B. gymnostethus*, 108 mm; *P. albirostris*, 191 mm).

Key words: Triglidae, *Prionotus stephanophrys*, *Bellator gymnostethus*, *Prionotus albirostris*, age, growth, Eastern Pacific.

Searobins are bottom fishes inhabiting tropical and subtropical continental shelves. Of the six species occurring off the west coast of Baja California, only *Prionotus stephanophrys* (lumptail searobin) and, to a lesser extent, *Bellator gymnostethus* and *P. albirostris*, have abundances that could potentially support a fishery (Schmitter-Soto and Castro-Aguirre in press).

Aurióles-Gamboa (1991) found significant relationships between otolith length and fish length and weight for lumptail searobin in our study area, thus providing the first step towards validation of otoliths for ageing this species. We proved (Schmitter-Soto and Castro-Aguirre 1991) that annuli deposition is yearly and growth is isometrical; furthermore, estimates of length-at-age from otolith reading and from

length frequency analysis are not significantly different. Thus we derived a descriptive growth model for the lumptail searobin population of the area, combining an exponential equation for the left part of the curve and a logarithmic equation for the right half. In a later study (Schmitter-Soto 1992) spatio-temporal fluctuations of the growth pattern, which is very variable among latitudinal subareas in winter and rather stable in summer, were discussed.

Our objectives in the present study were (1) to determine and compare growth patterns of *Prionotus stephanophrys*, *Bellator gymnostethus* and *P. albirostris* off the Pacific coast of Baja California Sur, and (2) to compare several growth models and to detect growth allometry.

MATERIAL AND METHODS

Sampling was done between 1987 and 1991 during nine cruises of the R/V "EL PUMA" (Table 1) over the Pacific continental shelf of Baja California Sur. Samples were taken between 24 and 26°N in depths of 30-200 m with trawl nets (21 m wide at the opening, 24 m long, and 3 cm mesh). Each trawl had a mean duration of 20 min, at an average speed of 3 kt.

All searobins in the catch were frozen on board; in the case of *P. stephanophrys*, whose biomass often reached hundreds of kilograms, we first took a random sample (but oversampled the largest and smallest individuals [McDonald 1987]) to study length frequency distribution and weight-length relationship. A stratified subsample of lump-tail searobin was used for the extraction of otoliths.

Otoliths were washed with tap water and viewed with a stereoscopic microscope at 3 to 10X using reflected or transmitted light. One of

us (JJSS) observed otoliths twice, with a minimum of one month between observations. If readings differed between the left and right sagittae or between observations, the otoliths were examined by the second author. Otoliths were omitted from the analysis if disagreement persisted. However, this was seldom the case (< 5%).

We obtained the parameters of the weight (W) - length (L) relationship by least squares regression. Condition factor (CF) was derived from the following formula:

$$CF = W/L^3$$

The values of CF for each length-at-age were averaged to have a representative CF for a given month.

We used the Cassie (1954) - Harding (1949) method to discriminate the normal components of the length frequency histograms. When the inflection points were not clear, we decided

TABLE 1

Sample sizes and lengths of searobins taken off western Baja California Sur

Species	Sample size	Year/ Month	Standard length (mm)			St. dev.
			Mean	Minimum	Maximum	
<i>Bellator gymnotethus</i>	3	87/Jul	84	50	102	30
	4	88/Oct	108	81	125	19
	7	89/Feb	91	40	122	26
	21	89/Jul	102	80	122	13
	49	90/Mar	91	39	126	27
	89	91/Sep	105	61	126	15
<i>Prionotus albirostris</i>	3	88/Jun*	131	95	192	53
	20	88/Jul	146	98	203	35
	12	88/Oct	137	25	200	70
	2	89/Feb	183	180	185	4
	14	89/Jul	183	166	193	9
	20	90/Mar	180	158	195	10
	19	90/Sep	176	123	205	30
4	91/Sep	194	186	207	8	
<i>Prionotus stephanophrys**</i>	1054	90/Mar	140	36	301	53
	1288	90/Sep	163	76	298	43
	120	91/Sep	144	75	270	28

* The cruise of June, 1988, took place on board the fishing vessel "Marsep XVI" instead of R/V "El Puma"

** Sample sizes for *P. stephanophrys* prior to 1990 were given by Schmitter-Soto and Castro-Aguirre (1991: Table 1)

their position by comparison with the temporal distribution sequence, including histograms from the previous and succeeding months (McDonald 1987).

The relationship between the temporal fluctuations of the condition factor and the percentage of opaque borders in otoliths, as well as the deposition periodicity, validated the direct ageing method (Schmitter-Soto and Castro-Aguirre 1991). To verify lengths-at-age, the values from the indirect and direct methods were compared by correlation analysis and by the closeness of slope of the linear regression to 1. Another criterion was the inclusion of a length-at-age in the confidence interval (90%) of the same length-at-age as estimated by the other method.

Several growth models were fitted to the resulting curves. Though Schnute (1981) considers them to be different expressions of the same model, each model produces a curve with different attributes and goodness of fit. The equations are (Moreau 1987):

a) von Bertalanffy model:

$$L = L_{\infty}(1 - \exp[-k(t - t_0)])$$

L_{∞} is the maximum theoretical length (asymptotic), k is a growth constant and t_0 is an adjustment parameter, the time when length would be zero.

b) logistic curve:

$$L = L_{\infty}/(1 + \exp[-k(t - t_0)])$$

This is an S-shaped curve, where the inflection point is at $L_{\infty}/2$. The parameter k is an instantaneous growth rate and t_0 is the time when k is highest.

c) Gompertz model:

$$L = L_{\infty} \exp(-\exp[-k(t - t_0)])$$

Unlike the logistic curve, this model is not antisymmetrical, which renders it more realistic (Pitcher and Hart 1982). The abscissa of the inflection point is t_0 .

d) von Bertalanffy model, reparametrized by Schnute and Fournier (1980):

$$L = L_{\min} + [(L_{\max} - L_{\min}) / (1 - \exp[-k(M - 1)])] [1 - \exp(-k < t - 1)]]$$

L_{\min} and L_{\max} are the minimum and maximum observed lengths and M is the difference between the mean ages for L_{\min} and L_{\max} . This reparametrization avoids trying to biologically interpret L_{∞} , t_0 or L_0 , a problem that led Roff (1980) to propose the abandonment of the von Bertalanffy model.

We fitted these equations by an iterative procedure and used initial parameters found by the Ford-Walford graphic method for the latter model (Walford 1946; Everhart *et al.* 1980).

The initial estimates thus obtained served also for the non-linear fitting of the other models. Goodness of fit was judged by the value of the coefficient of determination, R^2 (Lasserre 1978), at $p < 0.01$. We left the older age classes out of the regression because of small number of fishes and the uncertainty of the assigned age. This uncertainty is due to the poor resolution of peripheral annuli in otoliths and of inflection points in length frequency distributions.

Growth differences between species were tested with Hotelling's T^2 (Bernard 1981). Analysis of covariance (Scheffler 1981) was performed to compare weight-length curves (theoretical values, @ 25 mm) for each sex. Deviations from isometry were considered significant when the exponent in the weight-length equation differed from 3 (t-test, $p < 0.05$).

RESULTS

Bellator gymnostethus

More than half of the 173 fish were taken in September 1991 (Table 1). The largest individual, a female, was 126 mm long (SL) and weighed 64 g; the smallest appeared in winter (February 1989 and March 1990).

The weight-length curve followed the equation

$$W = (1.15931 \times 10^{-5}) L^{3.17212}$$

where $r^2 = 97.9\%$ and $p < 0.01$. Weight-length curves for males and females were not significantly different ($F = 9.00$, $\alpha = 0.01$). Growth was allometric ($t = 6.03$, $p < 0.05$).

Percentage of opaque borders in sagittae was higher when condition factor was lower,

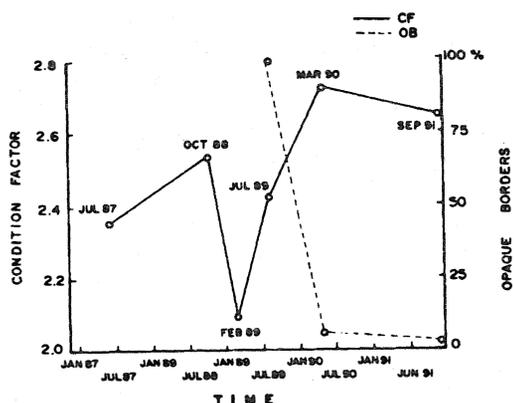


Fig. 1. Temporal fluctuations of the percentage of opaque borders in otoliths and condition factor in *Bellator gymnostethus* off western Baja California Sur.

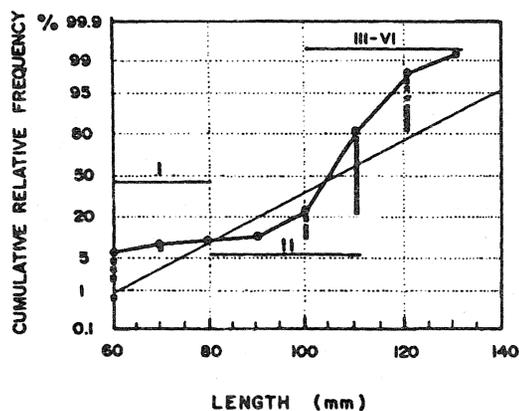


Fig. 2. Normal components of length frequency distribution for *Bellator gymnostethus* off western Baja California Sur (Cassie curve).

and vice versa (Fig. 1). The lack of data from September 1990 induced uncertainty, but the fluctuation period of the condition factor appeared to be roughly one year.

Indirect ageing was based on the samples whose variance was widest, March 1990 and September 1991 (Table 1). Cassie curves showed three normal components per sample (Fig. 2); however, the reading of 115 otolith pairs resulted in seven age classes.

To compare both methods we assumed that the third normal component represented a mixture of age classes, so that it was comparable to the average of classes III-VI from the direct method (omitting a class-VII individual); in fact, there was no significant difference among lengths-at-age III-VI (Table 2). A slope of 0.96 validated the procedure for March 1990; for September 1991, the value was not as satisfactory (0.80), perhaps because of underrepresentation of small-sized fish (Table 1).

All four growth models were applied to the otolith data (Table 3). The logistic model had the best fit; the rather low R^2 values were probably due to the unusually high length-at-age III (Table 2).

Prionotus albirostris

There were 94 individuals in the sample (Table 1). The largest fish was a 205 mm SL, 171 g female from September 1990. The smallest fish appeared in fall (October 1988).

The weight-length equation was

$$W = (1.69219 \times 10^{-5})L^{3.04868}$$

TABLE 2

Length-at-age of Bellator gymnostethus off western Baja California Sur, based on otolith readings and length frequency analysis

Method	Ages					
	I	II	III	IV	V	VI
Otoliths	59±14 (4)	80±8 (15)	108±16 (50)	105±6 (30)	105±8 (13)	108±21 (2)
Indirect (90/Mar)	49±14	101±13	116±12			
Indirect (91/Sep)	64±16	107±14	111±11			

Figures are lengths-at-age (mm, SL), with 90% confidence intervals; number of fish is given in parentheses

TABLE 3

Parameters of growth models for *Bellator gymnostethus* off western Baja California Sur

Model	L_{∞}	k	t_0	R^2
von Bertalanffy	107.9	0.876	0.125	93.32
Logistic	107.3	1.245	0.891	94.79
Gompertz	107.6	1.048	0.553	94.07
reparametrized von Bertalanffy	108.0	0.805		93.75

Symbols and formulae, in Materials and Methods. For the reparametrized von Bertalanffy model, maximum length-at-age is given instead of L_{∞} .

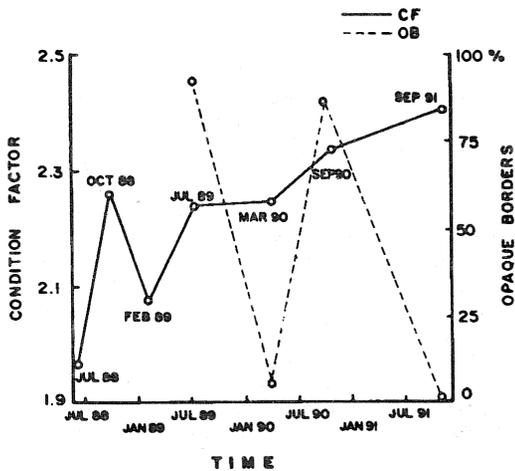


Fig. 3. Temporal fluctuations of the percentage of opaque borders in otoliths and condition factor in *Prionotus albiostris* off western Baja California Sur.

where $r^2 = 98.8\%$ and $p < 0.01$. Weight-length curves for males and females were not significantly different ($F = 4.43$, $\alpha = 0.01$). Growth was isometric ($t = 1.14$, $p < 0.05$).

This species was very uniform in size, most individuals being 175-195 mm SL, especially after 1988 (Table 1). Because of the scarcity of small fish, weight-length curves by month fitted poorly and had very low predictive capacities; thus, CF values were not dependable. To improve these aspects, we incorporated the datum from the smallest individual (a 25 mm SL fish from October 1988) in each regression before obtaining the time series of CF values (Fig. 3).

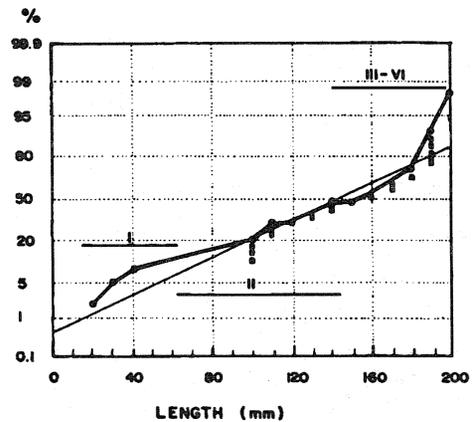


Fig. 4. Normal components of length frequency distribution for *Prionotus albiostris* off western Baja California Sur (Cassie curve).

The opaque band in otoliths formed while CF was relatively high (Fig. 3). However, CF yearly oscillations were obscured by an ascendent tendency from 1989 to 1991.

Indirect ageing was based on samples from July and October 1988, pooled together because of their closeness in time (Table 1). Cassie curves showed three normal components (Fig. 4), compared to the results of reading 50 otolith pairs; again, the third component was compared with the average of classes III-VI from the direct method (Table 4). The regression slope equaled 1, which validated the procedure.

All four growth models had satisfactory fits, but von Bertalanffy's L_{∞} was the best estimate of the observed maximum length (Table 5).

TABLE 4

Length-at-age of Prionotus albirostris off western Baja California Sur, based on otolith readings and length frequency analysis

Method	Ages					
	I	II	III	IV	V	VI
Otoliths	128±17 (5)	179±16 (13)	182±19 (11)	184±18 (15)	192±20 (6)
Indirect	30±19	120±33	176±33			

Figures are lengths-at-age (mm, SL), with 90% confidence intervals; number of fish is given in parentheses.

TABLE 5

Parameters of growth models for Prionotus albirostris off western Baja California Sur

Model	L_{∞}	k	t_0	R^2
von Bertalanffy	191.3	1.021	0.838	99.35
Logistic	186.3	2.422	2.677	99.74
Gompertz	188.1	1.606	1.385	99.68
reparametrized von Bertalanffy	192.0	0.962		99.17

Symbols and formulae, in Materials and Methods. For the reparametrized von Bertalanffy model, maximum length-at-age is given instead of L_{∞} .

Prionotus stephanophrys

The 4040-individual sample included 1578 fish from 1987 to 1989 (Schmitter-Soto and Castro-Aguirre 1991) (Table 1). We found individuals longer (301 mm SL) and heavier (599 g) than previously reported (*op. cit.*); they appeared in March and September 1990. The smallest fish were captured in fall (October 1988).

The weight-length curve (1990 data) followed the equation

$$W = (1.55309 \times 10^{-5})L^{3.04372}$$

where $r^2 = 98.0\%$ and $p < 0.01$. Weight-length curves for males and females were not significantly different ($F = 3.01$, $\alpha = 0.01$), though we found no male longer than 220 mm SL. Growth was isometric ($t = 0.29$, $p < 0.05$)

TABLE 6

Parameters of growth models for Prionotus stephanophrys off western Baja California Sur

Model	L_{∞}	k	t_0	R^2
von Bertalanffy	325.0	0.217	-0.044	99.72
Logistic	263.0	0.657	2.490	99.54
Gompertz	279.0	0.437	1.770	99.72
reparametrized von Bertalanffy	280.0	0.165		99.34

Symbols and formulae, in Materials and Methods. For the reparametrized von Bertalanffy model, maximum length-at-age is given instead of L_{∞} .

Lengths-at-age were reported in an earlier paper (Schmitter-Soto and Castro-Aguirre 1991). All four growth models had satisfactory fits, but the L_{∞} from von Bertalanffy was the best estimate of the observed maximum length (Table 6).

Growth rates of the three species were statistically different; according to Hotelling's T^2 test, most of the difference was attributable to the L_{∞} .

DISCUSSION

Judging by the exponent in the weight-length equation, growth of the *Prionotus* species was isometric, while *Bellator gymnostethus* grew allometrically. Indeed, the general aspect of the organism, especially the

shape of the head, changes the most with growth in the *Bellator* species (in the area, *B. gymnostethus*, *B. loxias* and *B. xenisma*), as well as in *Prionotus ruscarius*, whose weight-length exponent equaled 3.18 (Schmitter-Soto 1992).

P. stephanophrys develops bony protuberances on the forehead and caudal vertebrae as it grows, but these allometric features do not alter the exponent. Auriolles-Gamboa (1991) found an exponent of 3.15 for this species, using data from the summers of 1987 and 1988, and Schmitter-Soto and Castro-Aguirre (1991) obtained a value of 2.97, working mainly with samples from October 1988 and February 1989. These values are within the normal spatio-temporal fluctuations of growth in this searobin (Schmitter-Soto 1992).

Bellator species are smaller in length than *Prionotus*, but they increase their biomass faster, and, for a given length, are heavier. Trophic spectra of *B. gymnostethus* and lumptail searobin overlap widely, with resource partitioning based on feeding hour rather than diet (Schmitter-Soto 1992), so growth differences do not depend on food quality.

Periodicity of annulus formation was not clear for *B. gymnostethus* and *P. albirostris*. The statement that the fluctuation period of percentage of opaque borders is roughly one year for the former species is only weakly supported by Fig. 1, due to lack of otoliths from several collections. In the latter species, correlation between CF and percentage of opaque borders is obscured by an ascendent trend in CF. These seem to be problems related to sample size, as is perhaps the case for *B. gymnostethus* of ages IV and V being smaller in the average than those of age III.

We believe, nevertheless, that our growth curves are dependable, because of the agreement between lengths-at-age estimated directly and indirectly, and because of the yearly periodicity of annulus formation demonstrated for sympatric lumptail searobin (Schmitter-Soto and Castro-Aguirre 1991).

The logistic model, whose antisymmetric properties are considered unrealistic (Pitcher and Hart 1982), had the best fit for *B. gymnostethus* and *P. albirostris*, though the L_{∞} of von Bertalanffy was in all cases the best estimate of the observed maximum length (cf. Fontaine and Théret 1982). In other words, the

logistic curve allowed for more, exact interpolations, but the von Bertalanffy model was preferable for extrapolating towards higher age classes. Certainly, extrapolation has more applications (Lasserre 1978).

The Gompertz model provided parameter values intermediate between those of the logistic and von Bertalanffy equations. The reparametrized version of the von Bertalanffy model had the lowest determination coefficient values; perhaps abandoning parameter t_0 leads to some sacrifice in goodness-of-fit.

One can distinguish between two kinds of recruitment. The first is the end of the larval stage, and would be represented by L_0 , the smallest length described by the von Bertalanffy equation (Moreau 1987). The t_0 of von Bertalanffy would thus be an estimate of the larval stage duration (Alexandres *et al.* 1990) if the model included that stage; but it does not (Moreau 1987).

The second kind of recruitment is the onset of sexual activity, when the fish starts investing its energy in reproduction rather than somatic growth. The t_0 of Gompertz would supposedly be an estimate of the time of this energy shift.

Even though these are only adjustment parameters, if one were to take them as estimates of biological events, the values of t_0 and L_0 for the von Bertalanffy model would be too large for *B. gymnostethus* and *P. albirostris*. On the other hand, they seem more plausible in *P. stephanophrys*: 16 days and 49 mm (cf. *P. carolinus*, which leaves larval stage at 30 mm: Kuntz and Radcliffe 1917).

The t_0 of Gompertz would mean 202-325 days for *B. gymnostethus* and 506-977 days for *P. albirostris*. The concerned lengths in the latter case (ca. 120-150 mm) coincide with the observed first maturity length (Schmitter-Soto 1992).

Parameter k is the degradation rate (primarily of proteins). Indirectly, it expresses the exogenous factors that hinder growth (Rumohr 1975). The low value of k for *B. gymnostethus* as compared to the species of *Prionotus* means, as does its CF, faster growth.

We have discussed other growth models for *P. stephanophrys*, interpolating by means of a combination of exponential and logarithmic curve, but critically admitting the usefulness of the von Bertalanffy model for extrapolating (Schmitter-Soto and Castro-Aguirre 1991). The

value of L_{∞} then reported, 378 mm, is higher than what we report in this paper; it might seem excessive, compared with the maximum lengths observed here (301 mm) or in Peru (320 mm: Samamé *et al.* 1983). However, Miller and Lea (1972) claim that lump-tail searobin reaches 41 cm. Moreover, growth in fishes is exceedingly plastic (Weatherley and Gill 1987). Papaconstantinou (1982) mentions fluctuations as high as 30% in his L_{∞} values for *Lepidotrigla cavillone*.

Wootton (1991) argued that the models discussed herein, and others (Richards, monomolecular, Pauly's generalized version of the von Bertalanffy equation) are merely descriptive. We concur that only causal models, based on bioenergetics, will convey a scientific understanding of the complex process of growth. While these models develop, however, we will have to rely on empiricism.

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RESUMEN

Las tres especies de Triglidae dominantes frente a la costa occidental de Baja California Sur son *Prionotus stephanophrys* (trigla coronada), *Bellator gymnostethus* y *P. albirostris*. Nueve cruceros de arrastre a fondo, de julio de 1987 a septiembre de 1991, produjeron muestras de 4040, 173 y 94 individuos, respectivamente. Después de determinar la edad, por análisis de frecuencia de tallas y anillos en los otolitos, obtuvimos las relaciones peso-longitud y edad-longitud. Se probaron varios modelos sobre las curvas edad-longitud. Sólo el crecimiento de *B. gymnostethus* es alométrico; las otras triglas crecen isométricamente. Aunque las hembras alcanzan mayor tamaño, la ecuación peso-

longitud no difiere significativamente entre sexos. El modelo logístico permite hacer buenas interpolaciones, pero las extrapolaciones del modelo de von Bertalanffy para peces viejos se acercan más a las longitudes máximas observadas. Las curvas de crecimiento de las tres especies son significativamente diferentes: la longitud máxima asintótica causa la mayor parte de la variación (*Prionotus stephanophrys*, 325 mm LP; *Bellator gymnostethus*, 108 mm; *P. albirostris*, 191 mm).

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