LENGTH-BASED GROWTH ESTIMATES FOR PACIFIC SARDINE (*SARDINOPS SAGAX*) IN THE GULF OF CALIFORNIA, MEXICO

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ABSTRACT

Monthly length-frequency distributions for *Sardinops sagax* in the Gulf of California for fishing seasons 1972–73 to 1989–90 were used to estimate growth by the Shepherd length-composition analysis (SLCA). Data were organized into annual sets, and the parameters of the von Bertalanffy growth curve were computed. Estimates for K and L_∞ values were compared to others reported for the Gulf of California and derived from otoliths, scales, and other length-based methods. Otoliths and scales supported growth estimates with SLCA. On the assumption that variability observed in the values of growth parameters over 16 years represents individual variation, a maximum likelihood algorithm was used in the growth performance index, ϕ', to estimate confidence intervals (CI), for K and L_∞, as well as an average. Ranges for 90% CI were $0.34 < K\ \mathrm{year}^{-1} < 0.39$, $27.0 > L_\infty$ (TL) cm > 25.2; ranges for 75% CI were $0.33 < K\ \mathrm{year}^{-1} < 0.43$, $26.6 < L_\infty$ (TL) cm < 23.5. The best estimate was $L_\infty = 25.7$ cm, $K = 0.38\ \mathrm{year}^{-1}$, and $t_0 = -0.3$. This variability was interpreted as influences in the annual cohorts. These estimates were also compared with those from the Pacific coasts of Mexico, the United States, and Canada. Results suggest there are differences. In general terms, both K and L_∞ tend to be lower in the Gulf of California. This was interpreted to be a consequence of differences in the ecosystem dynamics.

INTRODUCTION

Structured stock-assessment models require growth estimations as part of the information used to estimate stock size and fishing mortality. For such studies, the von Bertalanffy growth equation (VBGE) is generally assumed to be valid. Currently, the information required by managers includes a good estimation of the growth coefficient (K) and the asymptotic length (L_∞). An important aspect emerges when relatively large series of length-frequency distributions are available and are used to estimate growth. These analyses can indicate variability of growth patterns and estimates of the biomass gain for a given fish per unit of time, with the obvious consequences on stock size, yield estimations, and accurate confidence intervals for biomass estimations. In this paper we deal with three major issues for the Monterrey sardine, *Sardinops sagax* (Jenyns 1842; Parrish et al. 1989) in the Gulf of California: (1) growth estimates from length-frequency distributions of commercial catch, (2) recognition of growth-pattern variability, and (3) growth validation.

[Manuscript received 28 July 1997.]

MATERIALS AND METHODS

Catch-at-length data from landings at Guaymas, Sonora (fig. 1) for the fishing seasons of 1972–73 to 1989–90 were organized as monthly length-frequency distributions. Sample size in the period 1972 to 1983 was 60 kg, collected from 2 to 5 vessels daily. From 1984 to 1990, a minimum sample of 10 kg was collected from 2 to 5 vessels daily (Cisneros-Mata et al. 1995).

The length-weight relationship was used to expand samples to the whole catch for each period with a single transformation:

$$C(l) = \frac{w(l)s \cdot Wc}{Ws \cdot \bar{w}(l)}$$

where $C(l)$ = catch numbers at length; $w(l)s$ = sample total weight of the length class; Wc = total weight of the whole catch; Ws = sample total weight; and $\bar{w}(l)$ = average weight at length class.

Growth analysis was developed for annual periods: monthly length-frequency distributions were used to obtain a set of K and L_∞ values as an estimate of the average growth pattern and its variability. For this, we used the Shepherd length-composition analysis, SLCA (Shepherd 1987). The SLCA is based on an oscillatory test function $T(l)$ whose period is defined by the VBGE parameters, with the form

$$T(l) = \frac{\sin \pi(t_{max} - t_{min})}{\pi(t_{max} - t_{min})} \cos 2\pi\ (\bar{t} - t_s) \qquad (1)$$

where t_{max} and t_{min} are the ages-at-length corresponding to the upper and lower bounds of a given length class (and computed from the VBGE); $\bar{t}$ is the average age; and t_s is the fraction of the year in which the sample was

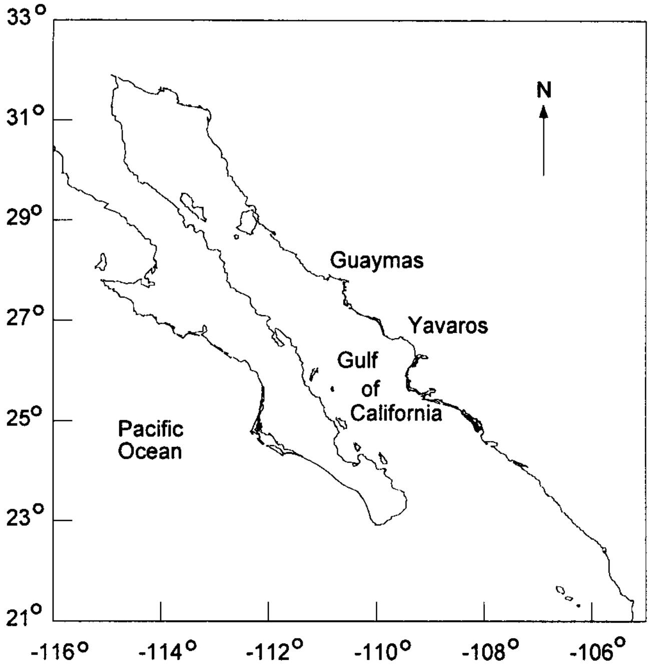

Figure 1. Area of study, showing landing ports in the Gulf of California.

taken. This test function varies between −1 and 1. Because this test function needs seed values for K and L_∞, the criterion for the appropriate K and L_∞ values is expressed by a Score function S with the form

$$S = \sum_{l=1}^{k} \sum_{i=1}^{n} N(l, i)^{0.5} \cdot T(l, i) \qquad (2)$$

where l indexes the length groups; i indexes the various distributions available; and N indexes the observed frequencies.

The test function (equation 1) is modulated by the parameters of the VBGE. When adequate values are given, larger positive values for $T(l)$ coincide with larger values for $N(l)$, giving higher values for S. When inadequate values for the growth parameters are used, negative values (or smaller than above) for $T(l)$ will coincide with larger values for $N(l)$, giving smaller values for S (as computed with equation 2). As Shepherd (1987) explains, the criterion for selecting K and L_∞ is to maximize the score function represented by equation 2.

We used the growth-pattern index suggested by Pauly and Munro (1984) to make interannual comparisons and to compare our results with those in the literature. The index is computed as $\phi' = \log_{10} K + 2 \cdot \log_{10} L_\infty$.

We validated growth in two ways: (1) by comparing our growth estimates with other estimates reported for the Gulf of California, including those based on hard parts (otoliths, scales), and (2) by comparing with estimates for *Sardinops sagax* from other regions.

RESULTS

Growth Estimates and Variability of Growth Patterns

Growth parameters of the VBGE estimated with SLCA are shown in table 1. Values for ϕ' involving all estimates for *S. sagax* (tables 1–3) ranged from 2.27 to 2.77, with an average of 2.399 and a coefficient of variation of 5.44%. Since longevity of *S. sagax* has been calculated to be 6 to 7 years, each single cohort will contribute information through the length distributions of several years. This means that yearly estimations do not represent variance in annual growth but rather variability of individual growth patterns. Thus the set of ϕ' values provides an estimate of mean and standard deviation, which we used to obtain confidence intervals for growth pattern from a single maximum likelihood algorithm using a normal distribution for the ϕ' values (Pauly and Munro 1984):

$$L\{\phi' \mid \mu,\sigma\} = \frac{1}{\sigma\sqrt{2\pi}} \exp(-(\phi'-\mu)^2/2\sigma^2) \qquad (3)$$

According to ϕ' values in tables 1–3 (involving K and L_∞), the 90% confidence interval provides ranges of $0.34 < K$ year$^{-1} < 0.39$, and $27.0 < L_\infty$ (TL) cm < 25.2.

TABLE 1
Growth Values for the von Bertalanffy Growth Curve for *Sardinops sagax* in the Gulf of California, after Application of SLCA

Fishing season	Growth coefficient K (year^{-1})	Asymptotic length, TL (cm)	t_0(year^{-1})	ϕ'[a]
1972–73	0.34	27.0	−0.69	2.39[b,c]
	0.32	26.0	−0.53	2.34
1973–74	0.38	25.7	−0.30	2.40[b,c]
1974–75	0.38	25.7	−0.38	2.40[b,c]
1977–78	0.36	25.3	−0.78	2.36[c]
1978–79	0.32	24.1	−0.65	2.27
	0.39	24.4	−0.32	2.36[c]
1979–80	0.31	26.3	−0.60	2.33
	0.37	23.4	−0.65	2.31
1983–84	0.39	25.2	−0.08	2.39[b,c]
1984–85	0.32	24.5	−0.87	2.28
	0.39	23.0	−0.10	2.32
1985–86	0.33	25.9	−0.19	2.35
1986–87	0.38	27.4	−0.96	2.45
	0.37	27.6	−0.93	2.45
1987–88	0.32	25.4	−0.97	2.32
	0.34	25.2	−0.11	2.33
1988–89	0.31	26.3	−0.72	2.33

Note: SLCA (Shepherd length-composition analysis) from Shepherd 1987.
[a]ϕ' Growth performance index according to Pauly and Munro 1984.
[b]Values within a 90% confidence interval, range $2.394 < \phi' < 2.399$.
[c]Values within a 75% confidence interval, range $2.363 < \phi' < 2.425$.

TABLE 2
Growth Parameters of the von Bertalanffy Growth Curve for *Sardinops sagax* in the Western Pacific as Reported in Fishbase 1996

Location[a]	Growth coefficient K (year^{-1})	Asymptotic length, length, TL (cm)	t_0(year^{-1})[b]	ϕ'	Method	Reference
BC	0.52	29.3		2.65		Pauly 1978
BC	0.52	30.0		2.67		Pauly 1978
BC	0.55	29.1		2.67		Pauly 1978
BC	0.57	25.1		2.56		Pauly 1978
BC	0.53	30.2		2.68	Nonlinear regression	Pauly 1979
Mexico	0.50	26.0		2.53		Granados-R. 1958
Mexico	0.34	23.4	−0.26	2.12		Cisneros-Mata et al. 1990
Mexico	0.60	27.0		2.48	ELEFAN I	Cisneros-Mata et al. 1990
USA	0.40	29.5	−2.10	2.54	Nonlinear regression	Pauly 1978
USA	0.40	30.5	−0.59	2.57	Nonlinear regression	Pauly 1978
USA	0.37	25.9		2.39		Erzini 1991
USA	0.46	31.0		2.65		Pauly 1978
USA	0.60	29.0		2.70		Pauly 1978
USA	0.70	27.0		2.71		Pauly 1978
USA	0.59	26.8		2.63		Pauly 1979
USA	0.56	26.9		2.61		Pauly 1979
USA	0.55	25.7		2.56		Pauly 1979
USA	0.54	26.0		2.56		Pauly 1979
USA	0.53	27.6		2.61		Pauly 1979
USA	0.52	26.1		2.55		Pauly 1979
USA	0.44	26.2		2.48		Erzini 1991
USA	0.45	29.3		2.59		Beverton 1963
USA	0.35	30.0		2.50	Nonlinear regression	Pauly 1980

[a]BC, British Columbia, Canada.
[b]Blank cells mean that authors did not provide value for this parameter.

TABLE 3
Growth Parameters of the von Bertalanffy Growth Curve for *Sardinops sagax* in the Gulf of California, Mexico

Growth coefficient K (year^{-1})	Asymptotic length, length, TL (cm)	t_0(year^{-1})	ϕ'	Method	Reference
0.43	31.0	−0.21	2.62	ELEFAN I	Estrada-G. et al. 1986
0.34	23.6	−0.26	2.28	Otoliths	Estrada-G. et al. 1986
1.22	20.3	−0.13	2.70	Lopez-Veiga	Félix-U. 1986
0.60	27.0	−0.15	2.64	ELEFAN I	Cisneros-Mata et al. 1990
0.43	30.0	−0.40	2.59	ELEFAN I	Cisneros-Mata et al. 1991
0.43	29.0	−0.40	2.56	ELEFAN I	Nevárez-M. et al. 1993
0.41	23.5	−0.13	2.36	Scales, Walford-Gulland	Gallardo-C. et al. 1991
0.43	23.5	−1.03	2.38	Scales, Beverton	Gallardo-C. et al. 1991
0.36	23.8	−1.63	2.31	Scales, Tomlinson-Abrahamson	Gallardo-C. et al. 1991
0.38	23.6	−1.42	2.33	Scales, Beverton	Gallardo-C. et al. 1991
0.33	23.9	−1.82	2.27	Scales, Allen	Gallardo-C. et al. 1991
0.35	23.9	−1.62	2.30	Scales, Beverton	Gallardo-C. et al. 1991
0.28	26.6	−0.60	2.30	Otoliths, Gulland & Holt	Jiménez-R. 1991
0.30	26.6		2.33	Otoliths, Ford-Walford	Jiménez-R. 1991
0.33	26.6	−1.66	2.37	Otoliths, von Bertalanffy	Jiménez-R. 1991
0.55	24.4	−0.74	2.51	Otoliths, nonlinear regression	Jiménez-R. 1991
0.27	26.6		2.28	Modal progression	Jiménez-R. 1991
0.45	30.0		2.61	ELEFAN I	Jiménez-R. 1991
0.40	25.8	−0.23	2.43	Gulland & Holt	Jiménez-R. 1991
0.45	25.8		2.48	Ford-Walford	Jiménez-R. 1991
0.59	25.8	−0.21	2.59	Von Bertalanffy	Jiménez-R. 1991
0.47	25.9	−0.82	2.50	Nonlinear regression	Jiménez-R. 1991
0.68	29.5		2.77	Modal progression	Jiménez-R. 1991
0.44	29.6		2.59	ELEFAN I	Jiménez-R. 1991

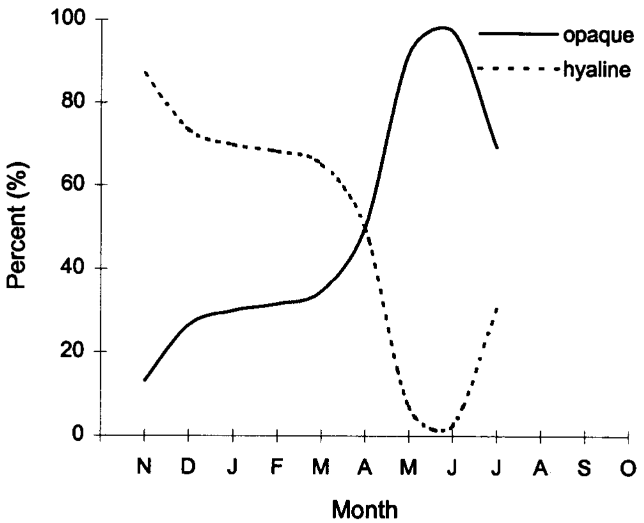

Figure 2. Monthly relative frequency in percentage of hyaline and opaque edge in otoliths of *Sardinops sagax* from the Gulf of California for the seasons 1988–89 and 1989–90 (from Jiménez-R. 1991).

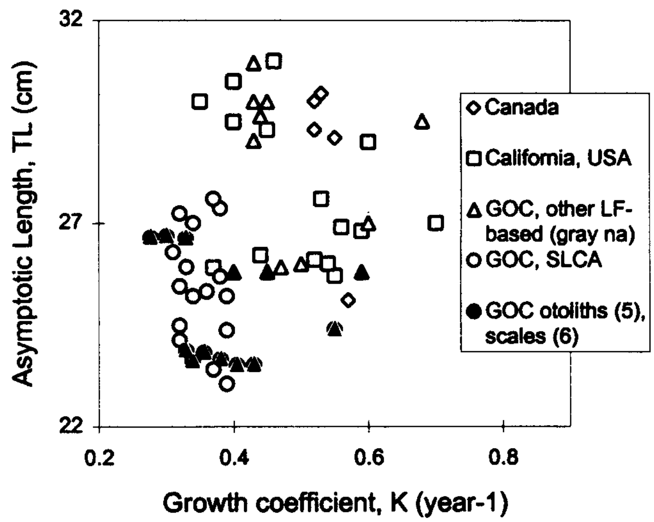

Figure 3. Estimates of growth parameters for *Sardinops sagax* from the Gulf of California (GOC), and the Pacific coasts of Mexico, the United States, and Canada (LF = length-frequency; na = not available).

Growth Validation

One of the main problems with growth estimates from length-frequency distributions is validation. Even when estimates are not directly validated with otoliths and scales, they can be compared with reports in the literature. Table 2 shows growth estimates for *S. sagax* reported in FishBase 1996. Table 3 lists other reports, particularly for the Gulf of California, in which estimates from otoliths and scales are emphasized. In general terms, and for both tables, estimates computed here correspond with those derived from otoliths, scales, and other procedures. In particular, otolith analysis validates annual ages (fig. 2).

DISCUSSION

Length-based growth estimates for *S. sagax* in the Gulf of California obtained with SLCA (table 1) seem reasonable when compared with age and growth estimates derived from otoliths and scales (table 3). We think that, for *S. sagax*, annual sets of length distributions provide a partial interannual variation of growth because in each year only one new cohort affects the growth pattern, whereas other ages contribute the same information over several years. Here, we suggest that the observed year-to-year variability in growth-parameter estimates reflects individual growth variability. According to this, and using a maximum likelihood function, the 90% confidence interval for ϕ' values provided values for the von Bertalanffy growth curve within a range of $0.34 < K\ \text{year}^{-1} < 0.39$ and $27.0 < L_\infty$ (TL) cm < 25.2.

Like many clupeoids, *S. sagax* has been characterized as a highly variable species strongly influenced by environmental variables. For this reason, we also computed a confidence interval of 75%, which yielded a range of values of $0.33 < K\ \text{year}^{-1} < 0.43$ and $26.6 < L_\infty$ (TL) cm < 23.5. Assuming these modal values for distribution of ϕ', we believe the best estimated values to be $L_\infty = 25.7$ cm, $K = 0.38\ \text{year}^{-1}$, and $t_0 = -0.3$.

Another aspect of interest is that growth performance for *S. sagax* in the Gulf of California appears to differ from that for the same species along the Pacific coast. This is shown in figure 3, where most estimates for the Gulf of California have lower K and L_∞ values than those from the Pacific coast of Mexico, the United States, and Canada. These estimates suggest that the metabolism of *S. sagax* within the Gulf of California is probably different. This observation agrees with those of some authors (Roden 1964; Wrash and Wrash 1971; Vandel Spoel 1984) who have noted that ecosystem dynamics within the Gulf of California differ from those in adjacent regions.

ACKNOWLEDGMENTS

The authors would like to acknowledge the Instituto Nacional de la Pesca, especially Miguel A. Cisneros Mata and Manuel O. Nevárez Martínez for supplying data on length-frequency distribution for the Monterrey sardine fishery in the Gulf of California. F.A.S. thanks S. Rodríguez, who contributed ideas and comments, and also the National Polytechnic Institute for support through COFAA and EDD, as well as through project DEPI 966525. Thanks also to Ellis Glazier, CIBNOR, for editing the English-language text.

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