Biología Pesquera 14: 3-10, 1985 ISSN N° 0067 - 8767

LARVAL GROWTH RATES OF THE PACIFIC SARDINE *SARDINOPS SAGAX* OFF CENTRAL CHILE, DETERMINED BY DAILY RING COUNTS IN OTOLITHS[1]

TASA DE CRECIMIENTO LARVARIO DE LA SARDINA ESPAÑOLA *SARDINOPS SAGAX* FRENTE A CHILE CENTRAL, DETERMINADA POR CONTEO DE ANILLOS DIARIOS EN OTOLITOS[1]

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ABSTRACT

Growth rates of *Sardinops sagax* (Jenyns, 1842) were determined using counts of daily increments on sagitta otoliths in field collected larvae from the Talcahuano zone (36°35'S; 73°03'W). Size ranged from 5 to 22 mm length that corresponded to an age interval from 3 to 41 days after yolk absorption. Otolith's radius and diameter show an allometric relationship with respect to larval size, and consequently with age. A simple power regression fitted best the data on age and larval size. Growth rates are lower than those reported elsewhere for this species, probably in response to low environmental temperature (12.5°C). Typically *S. sagax* grows 0.4 mm/day when 13.0 mm in size, a rate equivalent to 50% of the rate at 18,6°C. Ecological implications of this finding are discussed.

Key words: Pacific sardine, larvae, growth, daily increments, Chile.

RESUMEN

Se determina la tasa de crecimiento de *Sardinops sagax* (Jenyns, 1842), mediante el análisis de incrementos diarios en otolitos sagitta de larvas recolectadas en el área de Talcahuano (36°35'S; 73°03'W). El rango de tallas estudiado va desde 5 a 22 mm de longitud larval, lo que corresponde a ejemplares de entre 3 y 41 días después de la reabsorción del vitelo. El diámetro y radio de los otolitos se relaciona alométricamente con la talla, y consecuentemente con la edad. Las tasas de crecimiento son menores que las reportadas en otras áreas geográficas para esta especie, probablemente en respuesta a las bajas temperaturas ambientales (12.5°C). Se determina que *S. sagax* crece 0.4 mm/día a los 13 mm de longitud, tasa que equivale al 50% de la tasa de crecimiento a 18.6°C. Se discuten las implicaciones ecológicas de estos resultados.

Palabras claves: Sardina del Pacífico, larva, crecimiento, incrementos diarios, Chile.

INTRODUCTION

After the 1972 "El Niño" (ENSO) phenomenon, that marked the collapse of the anchovy (*Engraulis ringens*) fishery off Perú and northern Chile, the Pacific sardine or "sardina española" (*Sardinops sagax*) extended its geographical range from two refuge areas between Cabo Blanco-Salaverry in Perú and Arica-Mejillones in Chile (Bernal *et al.* 1982). This extension has been suggested as representing a case of ecological replacement among the dominant species in an upwelling ecosystem. In its extension to the south, *S. sagax* has established local populations in several locations. The existence of these local populations can be ascertained by the presence and persistence

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[1] Research partially funded through DIUC Projects, 4002-85 to G. Herrera and 166-83 to Dr. E. Tarifeño. BIOTEC-MAR Contribution N° 01 to the IOC-FAO Programme OSLR/SARP.

of localized and geographically disjointed spawning areas, with extremely large areas of coast in between where eggs and larvae of this species have not been recorded during the spawning season. Presently the southernmost extension of the geographical range of *S. sagax* has been established in the coastal region of Chiloe island (42°S).

Around Concepción Bay (Talcahuano) and the Gulf of Arauco a spawning center is located, where eggs and larvae of *S. sagax* have been found all year around in significant numbers in the plankton (Herrera, personnal comm.). Reproduction studies in adults, confirm the fact that this species is a serial spawner, and mature individuals have been observed in samples from the fishery throught the year (Aguilera 1984).

Therefore, it seems as a relevant research objective, to study the growth of *S. sagax* in this habitat at temperatures decidedly low and near to the southernmost limit for this species. In order to analyze growth using field information, it is necessary to have an accurate method of ageing the sampled material. Daily growth increments or rings in otoliths provide such a method that has been succesfully used in several fresh-water and marine species.

In this paper the daily otolith ring technique is used to: i) establish a relationship between the size of the sagitta otoliths of *S. sagax* and larval size, in order to make possible back calculations of growth rates; ii) to estimate growth rates of field collected larvae of *S. sagax* in the Talcahuano area (Concepción Bay); and iii) to relate the obtained rates with those obtained for other populations of the same species, and with related species inhabiting other geographical areas.

MATERIALS AND METHODS

Samples for this study were collected during April 1985 (18-IV; 24-IV) from the plankton off Concepción Bay (36°35'S; 73°03'W), with a 0.6 m diameter and 333 μm mesh plankton net, and were preserved in 80% ethyl alcohol. At the station, SST was measured and recorded. Larvae were sorted and identified in the laboratory. Standard (SL) or Notochordal (NL) lengths were obtained to the closest 0.1 mm. Both otic capsules were dissected under 80 X magnification, using polarized transmitted illumination. A pair of polarizing filters (Splindler & Hoyer, Göttingen, FRG) were used, one of which was located between the light source and the specimen, and the second in the light path between the specimen and the scope objective. Rotation of the second filter, allowed the observer to produce almost total interference, point at which the polarized illumination highlighted the otoliths, that could be seen as brilliant, shining objects inside the otic capsules. This very useful optic phenomenon is produced by the bi-refringent nature of the mineral structure of the otoliths.

In all the specimens, at least two otoliths were dissected (right and left sagitta) and mounted on slides using Entellan (Merck T.M.), a synthetic fast mounting medium. Sometimes, more than two otoliths were mounted, when daily growth marks could also be seen on them.

The major axis (diameter, D), and principal radius (the longest distance between the nucleus and the margin, R) of the otoliths were measured under a compound scope to the closest 2.5 μm.

Rings were independently enumerated by two observers under 1000 X magnification. Readings were accepted when they did not depart by 3 units one of each other and the average of the two readings was used. In reporting our results, we followed the practice proposed by Methot & Kramer (1979) wereby "the number of increments (rings) represents the age in days after yolk absorption". Comparisons of growth rates were done considering growth after that developmental event.

In order to check the daily nature of otolith increments, a series of experimentally incubated larvae was obtained from wild collected eggs. Incubation temperature was 12.5 ± 0.5°C under 12 L: 12 D photoperiod. Otoliths from experimentally reared larvae of known age, were dissected and processed similarly than field collected ones.

Non linear regression was performed using BMDP statistical software.

RESULTS

The sagitta is circular when the larvae are small and young (< 7 mm NL). After they reach this size, their growth becomes asymmetrical, developing a major axis and gradually becoming ellipsoidal in shape.

Clear and distinct increments and rings were observed in all otoliths sampled (Plate 1).

Experimentally reared larvae showed otoliths with increments that corresponded to their age in days after yolk absorption. However the rings were less clear than those observed in the otoliths from field collected larvae (Table 1).

Relationships between larval length and either diameter or radius of the otolith, (Figure 1), are best represented by a power curve for the size interval investigated in this study. Table 2 shows the form of the equation fitted and the value of the parameters.

The relationship between age and larval length was best described by a simple power model, that fitted the data with a lower residual sum squares than other kind of regression tested (Figure 2 and Table 3). Growth rates for different size classes are presented in Table 4, where available data for the same or related species are also included.

The observed temperature in the upper layer of the ocean (between surface and 10 m) at collection time was 12.5°C.

Plate I. Daily rings in sagitta otoliths

Upper panel: Left and Right sagitta otoliths showing typical view of daily rings under compound scope. Total number of rings: 25. Diameter 82 µm. Lower panel: Enlargement of one of the otoliths

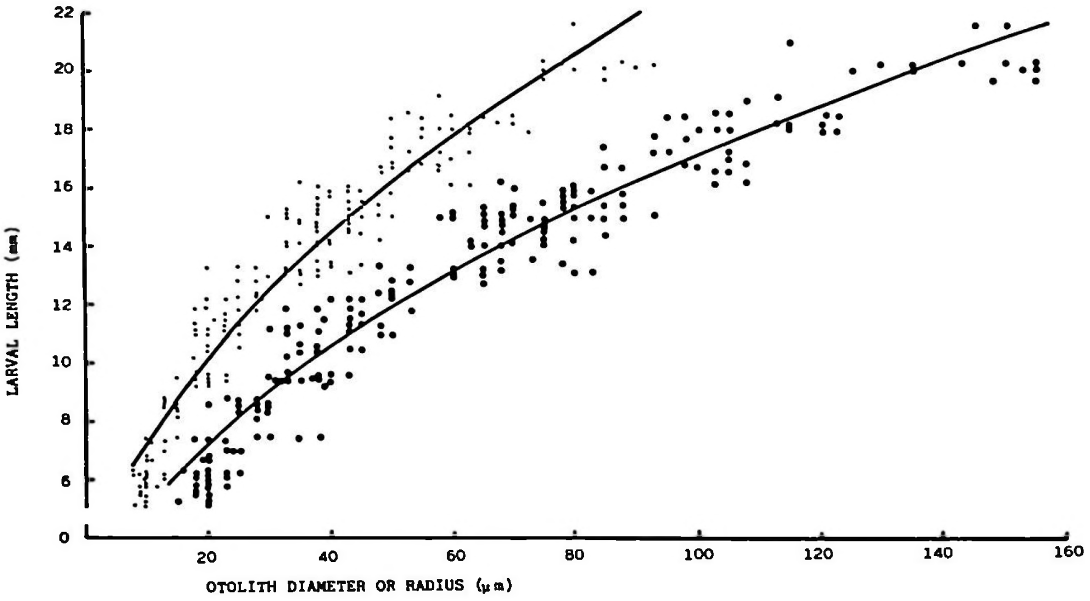

Figure 1. **Relationship between larval length and otolith size.** Small black circles: otolith radius (upper line). Black dots: otolith diameter (lower line)

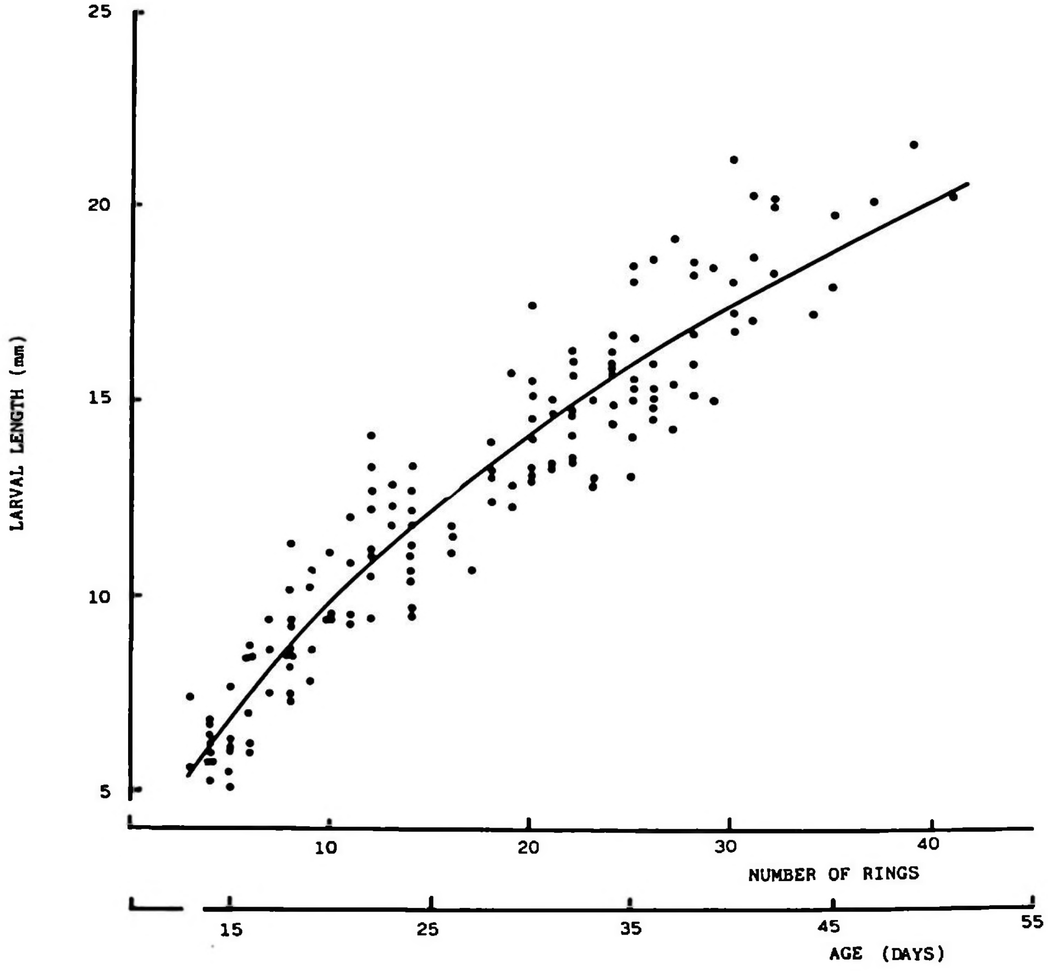

Figure 2. **Power relationship between age (number of rings) and larval length**

TABLE 1
Ring counts from experimentally reared larvae

Age in days after yolk absorption	Number of observations	Average ring number ± 1
1	3	2.0
5	2	6.0
10	6	9.6
14	1	12.0

TABLE 2
Relationship between otolith radius and diameter with larval length

Relationship $Y = ax^b$	Parameters a	b
Otolith radius vs. Length	2.2066	0.5100**
Otolith diameter vs. Length	1.4848	0.5300**

**P < 0.001

TABLE 3
Growth relationships

MODEL		PARAMETERS	RESIDUAL SUM OF SQUARES
Power	$Y = aX^b$	$a = 2.9405$	260.3
		$b = 0.5226$	
Schnute[1]	$Y = \left(a^b + (c^b - a^b)\frac{(1-e^{-dx})}{(1-e^{-d100})}\right)^{1/b}$	$a = 1.0000$	267.2
		$b = 0.3771$	
		$c = 25.8196$	
		$d = 0.0398$	
von Bertalanffy[2]	$L = L_\infty (1-e^{-Kt})$	$L_\infty = 50.000$ $K = 0.0109$	272.4

[1] Shnute (1981).

[2] L_∞ is only a parameter that describes larval growth. It does not have the conventional meaning.

TABLE 4
Comparison of growth rates for some clupeiform species

Growth rates in mm/day

Species	Size intervals [mm] 5-10	11-15	16-20	21-25	T°C	Reference
Sardinops sagax	1.00	0.75	1.00	0.66	18.6	Butler & Rojas 1985
Sardinops sagax	0.65	0.40	0.29	—	12.5	This study
Engraulis ringens	0.66	0.40	0.30	0.24	12.5	Herrera *et al.*, 1985
Engraulis mordax	0.54	0.67	0.63	—	16.2	Methot & Kramer, 1979
Engraulis mordax	0.33	0.42	—	—	14.4	Methot & Kramer, 1979
Engraulis mordax	0.45	0.48	—	—	13.0	Methot & Kramer, 1979

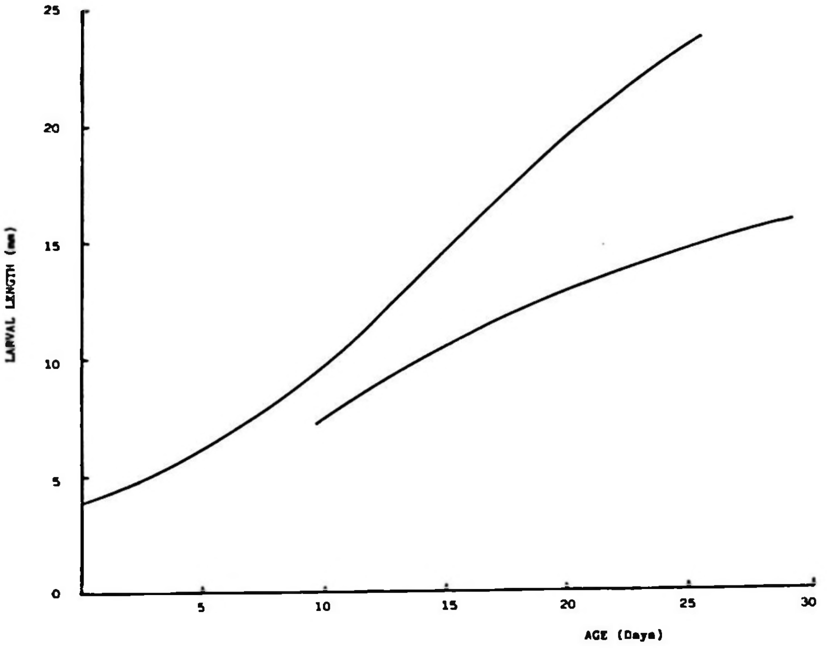

Figure 3. **Comparison of *S. sagax* growth curves at 18.6 and 12.5°C**
Upper Curve: growth curve for Perú at 18.6°C (from: Butler & Rojas de Mendiola 1985).
Lower Curve: Growth curve for Talcahuano at 12.5°C (this study)

DISCUSSION

In order to apply the daily ring method, it is necessary to know at what age is the first ring deposited, and at what rate does the subsequent deposition of rings proceed. We will deal with these assumptions in the same order.

Daily growth marks are first seen on the otolith at certain distance of its geometrical center. Methot & Kramer (1979), working with the northern anchovy (*Engraulis mordax*) have shown that normally the first ring is deposited at the end of the yolk absorption period, and/or when eye pigmentation is completed. Our data for *S. sagax* tend to confirm that in general among clupeiforms, the first ring is formed when the same developmental event is reached, point in time which is a function of temperature. Depending on environmental temperature, this event takes place 3 days after hatching (or 5 days after spawning) at 18°C. Garretón & Balbontín (1982) report that at 12.5°C, yolk absorption is completed 5 days after hatching or 10 days after spawning. Accordingly, it can be assumed that the first ring observed in our samples, corresponds to the 11-th day of life.

Brothers *et al.* (1976) demonstrated the daily nature of ring deposition, by direct examination of larvae of known age of several species. However, in some species such as *Clupea harengus*, some doubt have been cast on the periodical nature of rings (Geffen, 1982; McGurk, 1984). When the appropriate techniques are employed, involving sometimes the use of SEM, the daily nature of increments has been confirmed. The data presented here for the experimentally reared series, confirm the daily nature of the increments for *S. sagax*. It has been assumed that the rate of deposition is constant (one ring/day), an assumption based on the work by Pannella (1971) that demonstrated the daily nature of rings among tropical fishes. More recently it has been demonstrated experimentally, that daily ring formation follows a circadian rhythm controlling the metabolism of calcium, as shown by the level of calcitonin activity and calcium concentration in the blood (Mugiya *et al.* 1981, Butler *et al.* in press).

Sea water temperature at the time of collection (12.5°C), is close to the lowest range of temperature under which development can take place in the laboratory for this species (Garretón & Balbontín 1982), therefore, the growth rates reported here, are low in comparison with what has been observed elsewhere, and might be one of the lowest obtainable for *S. sagax* under natural conditions. Butler & Rojas de Mendiola (1985) reported a growth rate of 0.85 mm/day for *S. sagax* larvae 12.7 mm SL, at 18.6°C in Perú, while off Talcahuano, larvae of equivalent size (11-15 mm SL) are growing 0.40 mm/day at 12.5°C (Figure 3).

Butler & Rojas de Mendiola (1985) suggested that the high growth rate observed for *S. sagax* compared with that of anchovy, could represent "a fundamental ecological difference" for otherwise very similar species. According to these authors, faster growth in *S. sagax* implies a higher ration and hence, at a given food density, larger search volumes, greater swimming speeds and lower predation risk to size specific predators. These advantages are no longer present in the Talcahuano area, and other mechanisms might be acting. *S. sagax*, although a serial spawner over the whole year, shows in Talcahuano a spawning peak during June through September (Aguilera, 1984), the same period for this species in their northern stocks (Chimbote, Arica-Mejillones). This wintry peak is uncoupled with the production cycle in Talcahuano waters, which shows a peak during late Spring and Summer months, while in the north of Chile a close coupling between spawning and production does exist (Retamales & González, 1984, 1985; Bernal *et al.* 1982). As suggested by Butler & Rojas de Mendiola (1985) for the northern stocks, if the differences in growth rates induced by temperature, could contribute to lower competitive pressures between sardine and anchovy, those differences do not exist in Talcahuano during the Fall (this study) and might not exist during the rest of the year due to the small range of variability in temperature.

Our results do not have a simple interpretation in terms of adaptive strategies for the species. Slower growth implies lower rations and longer times to reach the point of no-return, potential advantages for larvae inhabiting poor and cold environments, but also implies, a distinct disadvantage by increasing the duration of one of the most vulnerable stages to predation. The factor that could help to explain the anomalous, off-season, persistance of the "northern timing" in the south, is the reduced predation that could be experienced by the larvae and juveniles spawned in Winter. Evidence in support of this hypothesis, i.e. lower mortality during Winter months, is provided by ichthyoplankton surveys conducted in the northern and southern populations off the chilean coast during Winter and early Summer (Rojas et al. 1983). In Table 5 the average number of eggs and larvae per positive station are compared for each cruise. The ratio of the average number of larvae over the average number of eggs provides a rough index of survival. Comparing the ratios for north and south, it can be seen that in the south there is a ten fold drop from 0.296 to 0.034, suggesting that those larvae spawned in Winter survive better than those spawned in Summer.

ACKNOWLEDGEMENTS

Research partially funded through DIUC project 4002-85 to G. Herrera and 166-83 to Dr. E. Tarifeño. This contribution is the result of a four day visit by John Butler to Biotecmar, under the sponsorship of project UNESCO/PNUD CHI-84/003. In that op-

TABLE 5

Relative abundance of eggs and larvae *S. sagax*. Ichthyoplankton survey data

(From: Rojas *et al.*, 1983)

	DATE	No. Stat.	$\bar{X}$ E [+ St.]	$\bar{X}$ L [+ St.]	$\bar{X}$ L / $\bar{X}$ E
SOUTH	81-VIII	87	1402 [18]	415 [43]	0.296
	81-XI/XII	86	1042 [16]	35 [42]	0.034
NORTH	81-VIII/IX	75	2257 [25]	1194 [46]	0.529
	82-II	91	273 [9]	366 [36]	1.341

$\bar{X}$ E Average number of eggs per positive station.
$\bar{X}$ L Average number of larvae per positive station.
[+ St.] Number of positive stations with eggs or larvae.

portunity, the authors of this note participated in a practical training session on the daily ring technique. We would like to than Mr. Victorino Martínez and the crew of M/V Tobago for their help with field work and José Morillas for his help with photographs. Parts of the statistical analysis was performed on the SWFC/UCSD computer center during a visit of G. Herrera to La Jolla sponsored by UNESCO/IOC. The order of the authors was determined by a stratified random sorting.

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