ELSEVIER

Fisheries Research 60 (2003) 551–560

FISHERIES RESEARCH

www.elsevier.com/locate/fishres

Short communication

Ecomorphological patterns of the sagitta in fish on the continental shelf off Argentine

Alejandra Volpedo*, Dinorah Diana Echeverría

Laboratorio de Vertebrados, FCEyN, Departamento de Ciencias Biológicas, Universidad de Buenos Aires, Ciudad Universitaria Pab. II, Buenos Aires 1428, Argentina

Received 26 September 2001; received in revised form 11 July 2002; accepted 19 August 2002

Abstract

Morphology and morphometry of the sagittae otolith were studied in fish associated with different substrates. The shape, margins and rostrum of three groups of otoliths from several species were analyzed: group 1 (fish associated with soft substrates, $N = 10$ species), group 2 (fish associated with hard substrates, $N = 10$ species) and group 3 (pelagic fish, not associated with the bottom, $N = 6$ species). E and R indexes were calculated for each species. The value of E = maximum width of the sagitta (WO)/maximum length of the sagitta (LO)%, expresses the relative tendency in the shape otolith (from circular to elongate). The value of R = length of the rostrum (LR)/LO%, expresses the percentage in the total length of the otolith that corresponds to the rostrum. The sagittae of group 1 were circular or polygonal with rounded borders. The rostrum can be absent or poorly developed. The sagittae shape of group 2 was elongated, with ornamented borders and a rostrum. The sagittae of group 3 possessed a prominent rostrum, a deep V-shaped cisure and ornamented borders. Statistical analysis showed no significant differences in the E index of groups 1 and 2, while R values of the three groups were significantly different. These results were compared with 80 other species, belonging to 12 families, from the publisher literature. E and R values could be used to characterize the sagittae of the marine fish and could be considered a useful tool for fish ecology studies.

Keywords: Otolith; Ecomorphology; Morphometry; Ecotypes

1. Introduction

Several authors recognized different ecomorphologic types of fishes from the Argentine shelf (Ringuelet and Aramburu, 1960; López, 1963; Cervigón, 1972; Menni, 1983). These authors assigned each species to a certain ecomorphologic category, based on its external morphology, diet and distribution area.

Fish inhabit different depths of the water column, according to the environmental factors (Menni, 1983). Fish that live associated with soft (sand and mud) or hard (rocks and rock shells) substrates have different morphology and physiological specializations of the internal and external structures (Todd, 1973). Species of soft substrates are the most dependent of the substrate (Menni, 1983; Cousseau and Perrota, 2000), while those of the hard substrates are more independent of the substrate and are usually active swimmers (Lindsey, 1978). Pelagic fish usually have a high growth and may have a high swimming speed (Menni, 1983; Lindsey, 1978). Sagittae permit the analysis of

* Corresponding author. Fax: +54-1148676066.
E-mail address: volpedo@bg.fcen.uba.ar (A. Volpedo).

0165-7836/02/$ – see front matter © 2002 Elsevier Science B.V. All rights reserved.
PII: S0165-7836(02)00170-4

different aspects of fish biology and their environment (Morales-Nin, 1987; Radtke and Shafer, 1992). They are composed of calcium carbonate and grow by continuous apposition (Carlström, 1963; Morales-Nin, 1987).

Environmental factors (Lombarte and Lleonart, 1993; Arellano et al., 1995; Ralston, 1995), ontogeny (Nolf, 1985; Lombarte and Castellón, 1991; Volpedo and Echeverría, 1999) and the phylogeny (Nolf, 1985, 1995), could affect the morphology, the morphometry (Burke et al., 1993) and the microstructure of the sagitta (Campana et al., 1995; Severin et al., 1995). Paxton (2000) considered the relationship between relative size of sagittae and habitat, and observed bigger relative size related to luminescence and other ecological factors.

The aim of the present paper is to analyze whether the morphological features showed by the sagitta could be associated with the fish ecomorphologic type.

2. Materials and methods

Altogether 2592 sagittae were sampled from 26 fish species (Table 1) collected from nine areas of the Argentine shelf (Fig. 1). The total length (TL) of the fish was measured in mm. The fish were assigned to two groups: group 1, those associated with soft substrates, and group 2 those associated with hard substrates. The criteria used to separate the fish into these groups were taken from literature: trophic habits, reproduction, swimming style and habitat (Cervigón and Fisher, 1979; Menezes and Figueiredo, 1980; Menni, 1983; Menni and López, 1984; Szpilman, 1991; Nelson, 1994; López et al., 1996; Cousseau and Perrota, 2000).

Group 1 includes fish from the following families: Ariidae, Sciaenidae, Percophididae, Paralichthyidae, and Achiropsettidae. Group 2 includes fish from the Zoarcidae, Scorpaenidae, Triglidae, Serranidae and Nototheniidae families.

A third group, not associated with the bottom, pelagic fish, was considered in order to compare morphological and morphometric sagittae features with groups 1 and 2. This third group included Clupeidae, Carangidae, Bramidae, Scombridae and Centrolophidae.

Table 1
List of taxa studied and morphometrics proportions taken on the sagittae[a]

Taxon	*N*	*E*	*R*
Group 1 (range *E*: 21–96; range *R*: 0–25)			
Ariidae			
N. barbus (Lacépède, 1803)	27	74	0
Sciaenidae			
M. furnieri (Demarest, 1823)	804	91	0
U. canosai (Berg, 1895)	80	66	0
Percophidae			
P. brasiliensis (Quoy and Gaimard, 1824)	10	21	25
Paralichthyidae			
E. longimanus (Norman, 1933)	8	63	10
P. isosceles (Jordan, 1891)	19	72	16
P. patagonicus (Jordan, 1889)	98	66	0
Paralichthys orbinyanus (Jenyns, 1842)	48	58	19
X. rasile (Jenyns, 1842)	52	69	0
Achiropssettidae			
A. tricholepis (Norman, 1830)	14	96	0
Group 2 (range *E*: 41–67; range *R*: 6–28)			
Zoarcidae			
A. laticinctus (Berg, 1895)	10	41	19
I. fimbriatus (Jenyns, 1842)	19	53	12
I. elongatus (Smitt, 1898)	11	64	6
Scorpaenidae			
H. lahillei (Gmelin, 1788)	294	60	22
S. capensis (Steindachner, 1891)	244	50	21
Triglidae			
P. nudigula (Ginsburg, 1950)	554	66	10
Serranidae			
A. brasilianus (Valenciennes, 1828)	90	67	18
Notothenidae			
P. magellanica (Foster, 1801)	6	50	26
P. ramsayi (Regan, 1913)	16	42	26
P. tessellata (Richardson, 1844)	12	42	28
Group 3 (range *E*: 35–50; range *R*: 30–52)			
Carangidae			
P. signata (Jenyns, 1842)	34	30	52
S. lalandei (Valenciennes, 1833)	10	40	50
Bramidae			
B. brama (Bonaterra, 1788)	10	48	51
Clupeidae			
B. aurea (Agassiz, 1829)	41	48	50
Scombridae			
S. japonicus (López, 1955)	72	50	33
Centrolophidae			
S. porosa (Guicheneto, 1848)	9	45	30

[a] Group 1: soft substrate; group 2: hard substrate; group 3: pelagic fish; $E = \mathrm{WO/LO\%}$, N = total number of sagittae sample; $R = \mathrm{LR/LO\%}$.

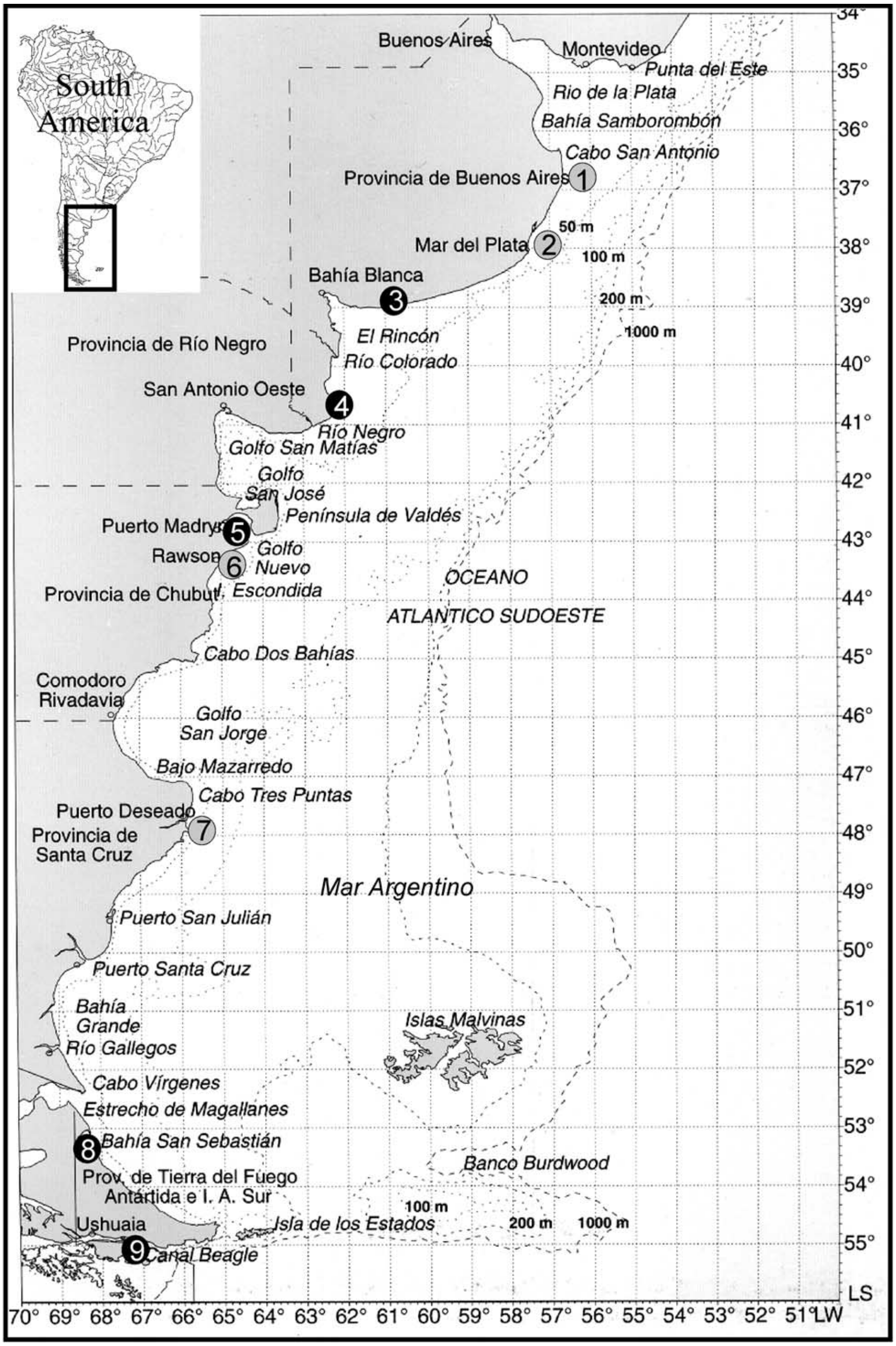

Fig. 1. Map of the area of the research on the Argentine shelf. Gray: soft substrate, black: hard substrate. 1: Partido de La Costa, 2: Mar del Plata, 3: Claromecó, 4: Bahía Anegada (San Blas), 5: Puerto Madryn, 6: Rawson, 7: Puerto Deseado, 8: Bahía San Sebastián, 9: Canal de Beagle.

The sagittae were measured according to the methodology described by Volpedo and Echeverría (2000). The following measurements were recorded from the sagittae: WO (maximum width of the sagitta), LO (maximum length of the sagitta), LR (length of the rostrum) in millimeters, with an error less than 0.01 mm. Two indexes were calculated, E and R. The E value ($E = \mathrm{AO}/\mathrm{LO}\%$) expresses the tendency in the shape of the sagittae (circular or elongate). The R value ($R = \mathrm{LR}/\mathrm{LO}\%$) expresses the percentage in the TL of the sagittae that corresponds to the rostrum. The R and E indexes were calculated from the sagittae of 26 species of the present study and 80 species from the literature, in order to compare results. The statistical analyses were based on the mean values of E and R calculated for each species (Table 1). The mean value of E and R for each group was compared using analysis of the variance (ANOVA) (Sokal and Rohlf, 1995) and multiple comparisons between groups (Zar, 1999). The software used in the statistical analysis was Statistica 5.1 (Statsoft® 1999).

3. Results

Sagittae of group 1 showed a circular or polygonal shape and rounded borders. The rostrum and the cisure were absent in the sagittae of *Netuma barbus*, *Micropogonias furnieri*, *Umbrina canosai*, *Paralichthys orbignyanus*, *Xystreuris rasile* and *Achiropsetta tricholepis* (Fig. 2A–C, and H–J). The rostrum was present but less evident in the sagittae of *Percophis brasiliensis*, *Etropus longimanus*, *Paralichthys isosceles* and *Paralichthys patagonicus* (Fig. 2D–G). The mean values of the E index for group 1 was 67.5 ± 0.20 and the R index was 8.6 ± 0.09.

The sagittae of group 2 showed an elongated shape and ornamented margins (Fig. 3). In all the sagittae of this group, the rostrum was present with different degrees of development. The most developed rostrum was found in *Austrolycus laticinctus*, *Helicolenus lahillei*, *Sebastes capensis*, *Paranotothenia magellanica*, *Patagonotothen ramsayi* and *Patagonotothen tessellata* (Fig. 3A, D, E, and H–J). The mean values of the E index (Table 1) for group

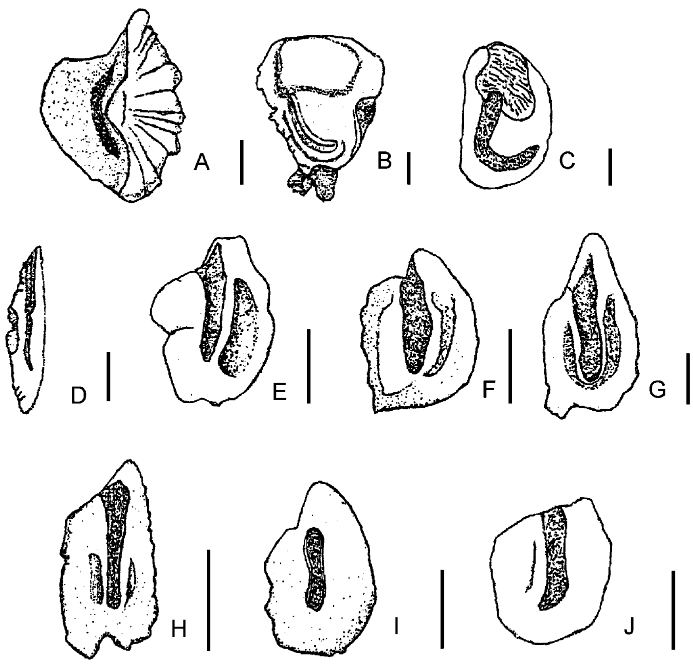

Fig. 2. Morphology of sagittae group 1. A: *N. barbus*, B: *M. furnieri*, C: *U. canosai*, D: *P. brasiliensis*, E: *E. longimanus*, F: *P. isosceles*, G: *P. patagonicus*, H: *P. orbignyanus*, I: *X. rasile*, J: *A. tricholepis*. Scale: 3 mm.

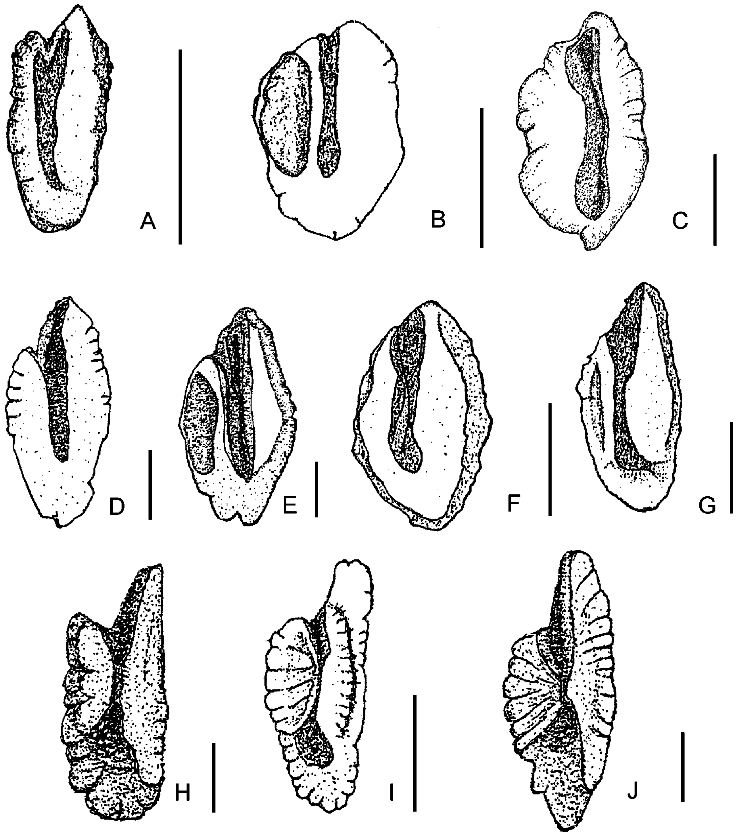

Fig. 3. Morphology of sagittae group 2. A: *A. laticinctus*, B: *Iluocoetes fimbriatus*, C: *Iluocoetes elongatus*, D: *H. lahillei*, E: *S. capensis*, F: *Prionotus nudigula*, G: *Acanthistius brasilianus*, H: *P. magellanica*, I: *P. ramsayi*, J: *P. tessellata.* Scale: 3 mm.

2 was 53.6 ± 0.10 and the *R* index was 18.8 ± 0.07.

The sagittae of group 3 showed the smallest dimensions in relation to the TL of the fish. They had a prominent *rostrum* and a deep V-shaped cisure (Fig. 4). The sagittae of *Brevoortia aurea*, *Parona signata*, *Seriola lalandei* and *Brama brama* had ornamented borders and a long sharp rostrum (Fig. 4A–D.). The mean value of the *E* index was 44.2 ± 0.05 and of the *R* index was 43 ± 0.11.

The statistical analysis (ANOVA) showed significant differences between the *E* values of the different

Table 2
Results of the multiple comparisons on the *E* index of each group[a]

Group	1	2
1	–	–
2	0.0928 ns	–
3	0.0075*	0.0385*

* $P < 0.05$.

[a] 1: soft substrate; 2: hard substrate; 3: pelagic fish; *N*: total number of sagittae sample.

Table 3
Results of the multiple comparisons on the *R* index of each group[a]

Group	1	2
1		
2	0.0464*	
3	0.0001***	0.001***

* $P < 0.05$.

*** $P < 0.001$.

[a] 1: soft substrate; 2: hard substrate; 3: pelagic fish; *N*: total number of sagittae sample.

Table 4
Values of *E* and *R* derived from literature data[a]

Taxon	*E*	*R*	Group	Author	Source date
Clupeidae					
Alosa alosa (Berg, 1948)	48	44	3	Q	Im
Clupea harengus (Linnaeus, 1758)	44	44	3	N	V
Clupea harengus (Linnaeus, 1758)	47	44	3	H	Im
Clupea pilchardus (Walbaum, 1792)	49	34	3	Q	Im
Ethmidium maculatum (Valenciennes, 1847)	50	43	3	L	V
Ramnogaster arcuata (Jenyns, 1842)	50	42	3	R	Im
Sardinops sagax (Jenyns, 1842)	38	44	3	L	V
Sprattus fuegensis (Jenyns, 1842)	46	27	3	R	Im
Strangomera benticki (=*Clupea benticki* Norman, 1936)	50	33	3	L	Im
Engraulidae					
Anchoa marinii (Hildebrand, 1943)	48	31	3	R	Im
Engraulis anchoita (Hubbs and Marini, 1935)	50	25	3	R	Im
Engraulis encrasicholus (Linnaeus, 1758)	45	30	3	Q	Im
Engraulis ringens (Jenyns, 1842)	40	28	3	L	V
Scorpaenidae					
Scorpaena papillosus (=*Helicolenus papillosus*, Richardson, 1845)	51	26	2	J	Im
Sebastichthys capensis (Gmelin, 1789)	47	22	2	J	Im
Serranidae					
Epinephelus aeneus (Geoffroy and Saint Hilaire, 1817)	46	20	2	P	V
Epinephelus gigas (Brünnich, 1768)	44	28	2	P	V
Carangidae					
Caranx crysos (Mitchill, 1815)	33	34	3	A	Im
Caranx hippos (Linnaeus, 1766)	45	36	3	A	Im
Caranx latus (Agassiz, 1831)	33	30	3	A	Im
Chloroscombrus chrysurus (Linnaeus, 1766)	49	31	3	A	Im
Hemicaranx amblyrhynchus (Cuvier, 1833)	41	38	3	A	Im
Oligoplites palometa (Cuvier, 1833)	50	36	3	A	Im
Oligoplites saliens (Bloch, 1793)	54	45	3	A	Im
Oligoplites saurus (Bloch and Schneider, 1801)	56	32	3	A	Im
Parona signata (Jenyns, 1841)	40	52	3	R	Im
Selene setapinnis (Mitchill, 1815)	68	31	3	A	Im
Selene vomer (Linnaeus, 1758)	61	35	3	A	Im
Trachinotus coralinus (Linnaeus, 1766)	41	36	3	A	Im
Trachinotus falcatus (Linnaeus, 1758)	40	50	3	A	Im
Trachinotus goodeii (Jordan and Evermann, 1896)	40	35	3	A	Im
Trachurus lathami (Nichols, 1920)	50	28	3	R	Im
Trachurus murphyi (Nichols, 1920)	37	37	3	L	Im
Trachurus trachurus (Linnaeus, 1758)	41	36	3	H	Im
Sciaenidae					
Cynoscion acoupa (Lacépède, 1802)	46	0	1	F	Im
Cynoscion analis (Jenyns, 1842)	43	0	1	S	Im
Cynoscion jamaicensis (Vaillant and Boucort, 1883)	56	0	1	I	Im
Cynoscion leiarchus (Cuvier, 1830)	50	0	1	F	Im
Cynoscion microlepidotus (Cuvier, 1830)	52	0	1	F	Im
Cynoscion nebulosus (Cuvier, 1830)	38	0	1	D	Im
Cynoscion regalis (Bloch and Schneider, 1801)	55	0	1	D	Im
Cynoscion similis (Rabdall and Cervigón, 1968)	44	0	1	I	Im
Cynoscion virescens (Cuvier, 1830)	31	0	1	I	Im
Menticirrhus americanus (Linnaeus, 1758)	35	0	1	B	Im

Table 4 (*Continued*)

Taxon	*E*	*R*	Group	Author	Source date
Sciaenidae					
Menticirrhus littoralis (Holbrook, 1855)	34	0	1	F	Im
Menticirrhus ophicephalus (Jenyns, 1842)	38	0	1	K	Im
Menticirrhus saxantilis (Bloch and Schneider, 1801)	40	0	1	E	Im
Micropogonias altipinnis (Günther, 1864)	77	0	1	S	Im
Micropogonias furnieri (Demarest, 1823)	82	0	1	K	Im
Micropogonias undulates (Linnaeus, 1766)	83	0	1	D	Im
Paralonchurus brasiliensis (Steindachner, 1875)	34	0	1	F	Im
Paralonchurus peruanus (Steindachner, 1875)	47	0	1	S	Im
Sciaena aquila (Cuvier, 1817)	48	0	1	P	V
Sciaena bathytatos (Chao and Miller, 1975)	63	0	1	D	Im
Sciaena deliciosa (Tschudi, 1845)	64	0	1	K	Im
Umbrina ronchus (Valenciennes, 1843)	63	0	1	P	V
Nototheniidae					
Notothenia acuta (Günther, 1880)	47	20	2	J	Im
Notothenia angustifrons (Fisher, 1885)	46	26	2	J	Im
Notothenia coriiceps (Richardson, 1884)	51	23	2	J	Im
Notothenia cyanobrancha (Richardson, 1844)	47	16	2	J	Im
Notothenia neglecta (Nybelin, 1951)	54	19	2	J	Im
Notothenia rossii (Richardson, 1844)	53	24	2	J	Im
Harpegiperidae					
Artedidraco loennbergi (Roule, 1913)	59	16	2	J	Im
Artedidraco orianae (Regan, 1914)	55	24	2	J	Im
Dolloidraco longedorsalis (Roule, 1913)	57	19	2	J	Im
Harpagifer antarticus (Nybelin, 1947)	55	20	2	J	Im
Harpagifer bispinis (Forster, 1801)	56	18	2	J	Im
Harpagifer veliger (Regan, 1914)	55	22	2	J	Im
Harpagifer georgianus (Nybelin, 1947)	52	19	2	T	Im
Pogonophryme barsukovi (Andriashev, 1967)	64	20	2	J	Im
Pogonophryme phyllopogon (Andriashev, 1967)	66	26	2	J	Im
Pogonophryme scotti (Regan, 1914)	64	17	2	J	Im
Channichthyidae					
Chaenichthys aceratus (Lonnberg, 1906)	63	25	2	J	Im
Scombridae					
Sarda chiliensis chiliensis (Cuvier, 1832)	41	51	3	O	Im
Sarda Chiliensis chiliensis (Cuvier, 1832)	46	52	3	P	Im
Scomberomorus maculatus (Mitchill, 1815)	36	46	3	Q	Im
Thunnus albacares (Bonnaterre, 1788)	30	46	3	Q	Im
Thunnus thynnus (Linnaeus, 1758)	31	46	3	G	Im
Ariidae					
Arius guatemalensis (Gunther, 1864) (=*Galeichthys caerulences*)	66	0	1	U	Im
Soleidae					
Solea theophilus (Risso, 1810)	72	0	1	M	Im
Solea senegalensis (Kaup, 1858)	83	0	1	C	Im
Solea vulgaris (Quensel, 1806)	88	0	1	C	Im

[a] 1: soft substrate; 2: hard substrate; 3: pelagic fish; N = total number of sagittae sample). A: Albihôa and Correa (1993), B: Baldás et al. (1997), C: Bori (1986), D: Chao (1978), E: Chao (1986), F: Correa and Vianna (1993), G: Dennis and Prince (1995), H: Geldenhyns (1973), I: González Cabello (1977), J: Hecht (1987), K: Kong and Valdés (1990), L: Leible and Miranda (1989), M: Marinaro (1991), N: Messieh (1972), O: Sama (1997), P: Sanz Echeverría (1950), Q: Sterquert et al. (1995), R: Torno (1976), S: Volpedo and Echeverría (2001), T: Williams and Mc Eldowney (1990), U: Yañez-Arancibia and Leyton de Yañez (1977). Im: value measured on an illustration edited by other authors; V: value registered by other authors.

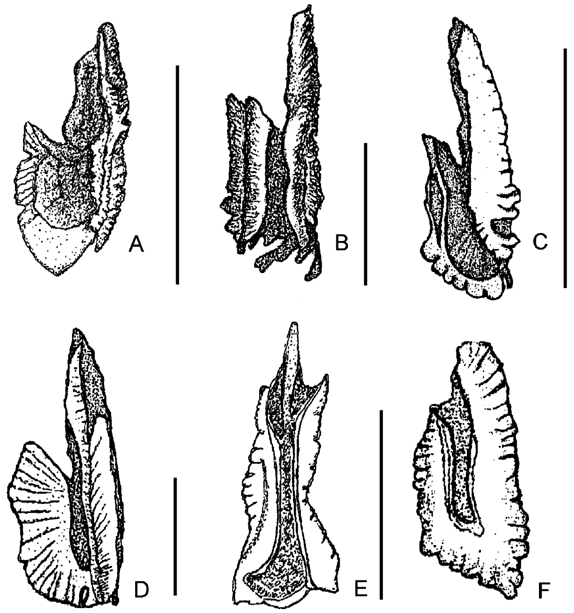

Fig. 4. Morphology of sagittae group 3. A: *B. aurea*, B: *P. signata*, C: *S. lalandei*, D: *B. brama*, E: *Scomber japonicus*, F: *Seriolella porosa*. Scale: 3 mm.

environments ($F_{(2;24)} = 5.85$, $P < 0.05$). Group 3 showed the smallest value of the *E* index. The multiple comparisons between groups showed that the *E* values between groups 1 and 2 did not show significant differences (Table 2). In the three groups, the *R* values were significantly different ($F_{(2;24)} = 28.35$, $P < 0.05$) (Table 3). The *E* and *R* values obtained from the literature (Table 4) were included in the ranges of *E* and *R* found for each group (Table 1).

4. Discussion

The sagittae showed different morphologic patterns in the ecological groups studied. The sagittae of fish associated with the bottom (groups 1 and 2) presented differences in their borders and topography, the common feature of the morphology was rounded. The rostrum of the sagittae was absent or insinuated in fishes related to soft bottoms, the rostrum of fishes related to hard substrates was short and not prominent.

The *E* index can be used to discriminate between the sagittae of the fish associated to the substrate and the sagittae of pelagic fish. The *R* index can be used to discriminate between the sagittae of the different ecotypes: indexes over 30 were found in pelagic fish and indexes lower than 30 were found in all the fishes related to the substrate (26 species of the present study and 80 species reported by other authors). High *R* values to pelagic habitat low *R* values were related to soft substrate. This was corroborated in the 106 species analyzed. We found the smallest sagittae in all the pelagic species measured. This conclusion is similar to that from previous studies performed by Sanz Echeverría (1950) on the sagittae of the Scombridae and Clupeidae.

Gauldie (1988) postulated that the ratio of the macula area/the otolith area and subsequently the ratio of sulcus area/the otolith area of pelagic fishes is higher than for demersal fishes. We found this in the pelagic sample. Of the ecological information available *S. porosa*, it appears that pelagic habits are predominant (Cervigón and Fisher, 1979). This would not be reflected clearly in the R index value because this value is at the limit between the pelagic *R* minimum and the *R* maximum of the fish associated to the substrate. Therefore, the strict assignation of *S. porosa* to the pelagic ecotype should be revised.

The three groups of fish analyzed in this study included species from several families that have no close phylogenetic relationships. In this sense, we suggest that the differences found in the *R* values of the sagittae between the three groups may be better explained at least by environmental and physiological factors (Popper and Fay, 1993; Paxton, 2000) rather than phylogenetic aspects. *E* and *R* values could be used to characterize the sagittae of marine fish and may be used as other another indices in fish ecology studies.

References

Albihôa, V., Correa, M.F.M., 1993. Catálogo de otolitos de Carangidae (Osteicties, Perciformes) do litoral da Estado do Paraná Brasil. Neritica Curitiba 7, 119–131.

Arellano, R.V., Hammerlynck, O., Vinex, M., Mees, J., Hostens, K., Gijselink, W., 1995. Changes in ratio of sulcus acusticus area to the sagitta area of *Ponatochistus minutus* and *P. lozanoi* (Pisces, Gobiidae). Mar. Biol. 122, 355–360.

Baldás, M., Pérez Macri, G., Volpedo, A.V., Echeverría, D.D., Morfología de la sagitta de peces marinos de la costa bonaerense de la Argentina. 1. Carangidae, Sciaenidae, Mullidae, vol. 19. Atlántica, Río Grande, 1997, pp. 99–112.

Bori, C., 1986. Análisis morfométrico comparado del otolito (sagitta) de *Solea vulgaris* y *S. senegalensis* (Teleostei: Soleidae) del delta del Ebro. Inv. Pesq. 50 (2), 247–264.

Burke, J.S., Peters, D.S., Hanson, G.Y., 1993. Morphological indices and otolith microstructure of Atlantic croaker, *Micropogonias undulatus*, as indicators of habitat quality along an estuarine pollution gradient. Environ. Biol. Fish. 36, 25–33.

Campana, S.E., Gagne, J.A., McLoren, J.W., 1995. Elemental fingerprinting of fish otolith using ICPMS. Mar. Ecol. Prog. Ser. 122, 115–120.

Carlström, P., 1963. A crystallographic study of vertebrate otolith. Biol. Bull. 125, 441–463.

Cervigón, F., 1972. Los peces. In: Ginés, H., Margalef, R. (Eds.), Ecología Marina. Fundación Lasalle, Venezuela, Monografía, vol. 14, pp. 309–355.

Cervigón, F.M., Fisher, W., 1979. INPESCA. Catálogo de especies marinas de interés económico actual o potencial para América Latina. Parte 1, Atlántico Centro y Suroccidental, FAO/UNDP, Roma, SIC 79, 1–372.

Chao, L.N., 1978. A basis for classifying western Atlantic Sciaenidae (Teleostei: Perciformes). NOAA. Tech. Rep. NMFS Tech. Circ. 415, 1–64.

Chao, N.L., 1986. A synopsis of zoogeography of the Sciaenidae. In*:* Uyeno, T., Arai, R., Tainuchi, T, Matsura, M. (Eds.), Indo-Pacific Fish Biology: Proceedings of Second International Conference on Indo-Pacific Fishes. Ichthyological Society of Japan, Tokyo, pp. 570–589.

Correa, M.F.M., Vianna, S.M., 1993. Catálogo de otolitos de Sciaenidae (Osteichthyes: Perciformes) do litoral do Estado do Paraná, Brasil. Nerítica Curitiba 7, 13–41.

Cousseau, M.B., Perrota, R.G., 2000. Peces Marinos de Argentina. Biología, Distribución, Pesca, 2nd ed. INIDEP, Argentina, 163 pp.

Dennis, W.L., Prince, E.D., 1995. Analysis of otolith and vertebrae from nine tag-recaptured atlantic bluefin tuna (*Thunnus thynnus*). In: Secor, D., Dean J.M., Campana S.E. (Eds.), Recent Developments in Fish Otolith Research. University of South Carolina Press, pp. 361–374.

Gauldie, R.W., 1988. Function, form and time-keeping properties of fish otoliths. Comp. Biochem. Physiol. A 91, 395–402.

Geldenhyns, N.D., 1973. Growth of the South African maasbanker *Trachurus trachurus* Linnaeus and age composition of the catches 1950–1971. Sea Fisheries Branch Investigation Report No. 101, pp. 1–23.

González Cabello, L.W., 1977. Aspectos técnicos de la preparación de otolitos para estudios de edad en algunas especies del género *Cynoscion* (Sciaenidae). Lagena 39–40, 4–48.

Hecht, T., 1987. A guide to the otoliths of Southern Ocean Fishes. S. Afr. J. Ant. Res. 17 (1), 1–87.

Kong, J., Valdés, J., 1990. Sciaenidos de Chile: análisis taxonómico y morfológico. Estud. Oceanol. 9, 13–56.

Leible, M., Miranda, P., 1989. El otolito sagitta en el reconocimiento de diferentes especies de teléosteos de la costa central de Chile. Bol. Soc. Biol. Concepción, Chile 60, 149–160.

Lindsey, C.C., 1978. Form, function and locomotory habits in fish. Fish Physiol. 7, 1–100.

Lombarte, A., Castellón, A., 1991. Interespecific and intraespecific otolith variability in the genus *Merluccius* as determinated by image analysis. Can. J. Zool. 69, 2442–2449.

Lombarte, A., Lleonart, J., 1993. Otolith size changes with body growth, habitat depth and temperature. Environ. Biol. Fish. 37, 297–306.

López, R.B., 1963. Problemas sobre la distribución geográfica de los peces marinos sudamericanos. Rev. Mus. Arg. Cs. Nat. Bernardino Riv. 1 (3), 109–135.

López, H.L., Garcia, M.l., San Román, N.A., 1996. Lista comentada de la ictiofauna del canal de Beagle, Tierra del Fuego, Argentina. Contribución del CADIC, pp. 1–85.

Marinaro, J.Y., 1991. Croissance de la Sole de Sable *Solea* (*Pegusa*) *theophilus* (Poissons: Soleides) sur la côte du Roussillon (France). Vieu Milleu 41 (2/3), 141–151.

Menezes, N.A., Figueiredo, J.L., 1980. Manual de peixes marinhos do sudeste do Brasil. IV Teleostei (3). Museu de Zoología, Universidad de San Paolo, Brasil, 96 pp.

Menni, R.C., 1983. Los peces en el medio marino. Editorial Estudio Sigma, Buenos Aires, 359 pp.

Menni, R.C., López, H.L., 1984. Distributional patterns of Argentine marine fishes. Phys. Sec. A 42 (103), 71–85.

Messieh, S.N., 1972. Use of otoliths in identifying herring stocks in the southern gulf of St. Lawrence and adjacent waters. J. Fish. Res. Bd. Can. 29, 1113–1118.

Morales-Nin, B.Y.O., 1987. The influence of environmental factors on microstructure of otoliths of three demersal fish species caught off Namibia. In: Payne, A.I.L., Gulland, J.A., Brink, K.H. (Eds.), The Benguela and Comparable Ecosystems. S. Afr. J. Mar. Sci. 5, 255–262.

Nelson, J.S., 1994. Fishes of the World, 3rd ed. Wiley, New York, 600 pp.

Nolf, D., 1985. *Otolithum piscium*. In*:* Schultze, H.P. (Ed.), Handbook of Paleoichthyology. Fisher, Stuttgart, New York, pp. 1–145.

Nolf, D., 1995. Studies on fossil otoliths: the state of the art. In: Secor, D., Dean, J.M., Campana, S.E. (Eds.), Recent Developments in Fish Otolith Research. University of South Carolina Press, pp. 513–544.

Paxton, J.R., 2000. Fish otoliths: do sizes correlate with taxonomic group, habitat and/or luminescence? Phil. Trans. R. Soc. Lond. B 355, 1299–1303.

Popper, A.N., Fay, R.R., 1993. Sound detection and processing by fish: critical review and major research questions. Barin. Behav. Evol. 41, 14–38.

Radtke, R.L., Shafer, D.J., 1992. Environmental sensitivity of fish otolith microchemistry. Aust. J. Mar. Freshw. Res. 43, 935–951.

Ralston, S., 1995. The influence of oceanographic variables on time series of otolith growth in pelagic young-of-the-year rockfish, *Sebastes* sp. In: Secor, D., Dean, J.M., Campana, S.E. (Eds.), Recent Developments in Fish Otolith Research. University of South Carolina Press, pp. 97–118.

Ringuelet, R.A., Aramburu, R.H., 1960. Peces marinos de la República Argentina. Agro 2 (5), 1–141.

Sama, M., 1997. Edad y crecimiento del bonito *Sarda chiliensis chiliensis* (Cuvier). Bol. Inst. Mar. Perú 16 (10), 1–19.

Sanz Echeverría, J., 1950. Notas sobre otolitos de peces procedentes de las costas del Sahara. Segunda Parte (1). Bol. Inst. Esp. Ocean. 27, 1–20.

Severin, K.P., Carroll, J.L., Norcross, B.L., 1995. Electron microprobe analysis of juvenile walleye pollock, *Theregra chaleogramma*, otoliths from Alaska: a plot stock separation study. Environ. Biol. Fish. 43, 269–283.

Sokal, R.R., Rohlf, J., 1995. Biometry. Freeman, New York, 887 pp.

Sterquert, B., Pnafili, J., Dean, J.M., 1995. Age and growth of yellowfin tuna, *Thunnus albacares*, from the western Indian Ocean, based on otolith microstructure. Fish Bull. 94, 124–134.

Szpilman, M., 1991. Guía practica de identificaçao dos peixes do litoral brasileiro. Guía Aqualung de Peixes. Cabicieri Editorial, Brasil, 284 pp.

Todd, E.S., 1973. Terrestrial sojourns of the longbow mudsuker, *Gillichthys miriabilis*. Copeia 1, 192–194.

Torno, A., 1976. Descripción y comparación de los otolitos de algunas familias de peces de la plataforma argentina. Rev. Mus. Arg. Cs. Nat. Bernardino Riv. 12 (4), 1–18.

Volpedo, A.V., Echeverría, D.D., 1999. Diferencias morfológicas en las sagittae de adultos de *Micropogonias furnieri* (Sciaenidae) de la costa bonaerense. Rev. Ciencias Mar. Thalassas 15, 19–24.

Volpedo, A.V., Echeverría, D.D., 2000. Catálogo y claves de otolitos para la identificación de peces del Mar Argentino. 1. Peces de importancia comercial. Editorial Dunken, Buenos Aires, 90 pp.

Volpedo, A.V., Echeverría, D.D., 2001. Morfología y morfometría de las sagittae de sciaenidos marinos del norte de Perú. Bol. Soc. Biol. Concepción 72, 147–154.

Williams, R., Mc Eldowney, A., 1990. A guide to the fish otoliths from waters off Australian Antarctic, herad and Macquarie Islands. An. Res. Noter. 75, 1–173.

Yañez-Arancibia, A., Leyton de Yañez, V., 1977. Desarrollo del otolito embrionario, patrón de su crecimiento y comparación morfológico con otolitos juveniles y adultos del bagre marino *Galeichthys caerulescens* (Günther). An. Centro. Ciencias del Mar y Limnología. Universidad Nacional Autónoma de México 4 (1), 115–124.

Zar, J.H., 1999. Biostatistical Analysis, 4th ed. Prentice-Hall, New York, 929 pp.