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Short communication

Updating the distribution and habitat pattern of *Maurolicus stehmanni* (Sternoptychidae, Stomiformes) in the Southwest Atlantic Ocean

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ABSTRACT

We updated the distribution and habitat patterns of *Maurolicus stehmanni* in the Southwest Atlantic Ocean by compiling data obtained from research surveys conducted on the Argentinean continental shelf, as well as from opportunistic records. This paper confirms the presence of *M. stehmanni* in the Argentinean continental shelf, extending its southernmost distributional limit by ca. 1000 km (from 43.0°S to 52.2°S). Adult specimens of *M. stehmanni* were collected in various locations from 2004 to 2016. Eggs and larvae of *Maurolicus* spp. were caught during ichthyoplankton tows carried out from 2003 to 2013. The present paper furthermore extends the habitat type in which this species was recorded: specimens were found in the inner continental shelf (between 46.2°S and 52.2°S) instead of the shelf break and continental slope. Two specimens were found lying dead upon the beach of Puerto Madryn, Nuevo Gulf (42.8°S). The presence of eggs and larvae in coastal embayments (San Matías and San José gulfs), in concomitant occurrence with adults, may suggest the establishment of this species in the region.

1. Introduction

Pearl sides of the genus *Maurolicus*, such as other pelagic fish from the open ocean, have enormous population sizes and broad distributions (Norris, 2000). They occur primarily on the outer continental shelf and upper slope, but some species also inhabit fjords and inner seas (Kristoffersen and Salvanes 1998; Landaeta et al. 2015). Pearl sides have several morphological adaptations to live in poorly light environments, including sensitive eyes, dark backs, silvery sides and ventral bioluminescent organs; and they have the ability to feed at night (Salvanes and Kristoffersen 2001; Landaeta et al. 2011). The known species of *Maurolicus* are allopatric, and usually exhibit a non-overlapping and restricted geographic range (Parin and Kobyliansky 1996). Although *Maurolicus* is considered the most specious genus in the subfamily Maurolicinae, with about 15 species (Parin and Kobyliansky 1996; Nelson et al. 2016), many of them are determined by poor morphological features, with overlapping ranges of morphometric characteristics. Also, species diagnoses are mainly based on geographical locations assuming isolation, and hence the species diversity of the genus may have been overestimated (Rees et al. 2017). For example, *Maurolicus* specimens off Namibia and South Africa (*Maurolicus walvisensis*), are indistinguishable from those from the northwestern Pacific (*Maurolicus japonicus*), southern Australia and eastern New Zealand (*Maurolicus australis*) on the basis of novel molecular techniques such as sequence data of the mitochondrial gene S16 (Kim et al. 2008; Rees et al. 2017). Molecular data also indicated that *Maurolicus muelleri* from the North Atlantic Ocean and *Maurolicus amethystinopunctatus* from the Mediterranean Sea are conspecifics (Rees et al. 2017). Moreover, the low level of genetic divergence between the *Maurolicus* taxa, congruent with the high homogeneity in their morphology, supports a recent evolutionary divergence (Suneetha et al. 2000).

Currently, one species of *Maurolicus* has been reported for the Southwest Atlantic Ocean: *Maurolicus stehmanni*, which distributes along the continental slope from Brazil (22°S) to Argentina (43°S) (Ciechomski 1971 cited as *M. muelleri*; Parin and Kobyliansky 1996; Bernardes et al. 2005; Almeida and Rossi-Wongtschowski 2007). Although *Maurolicus parvipinnis*, whose southernmost record came from the Southeast Pacific Ocean (type location: Orange Bay, Chile, 55.3°S 69.0°W, see Vaillant 1888), was also cited as present southwards to the

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Malvinas Islands (Eschmeyer et al. 2017), a confusion may have arisen because of the occurrence of another location also called Orange Bay in Malvinas Islands. Previous studies on *Maurolicus* in the Southwest Atlantic Ocean referred to the species found as *M. muelleri* (Smith 1961; Ciechomski 1971; Weiss et al. 1988) until a new species, *M. stehmanni*, was described for the region based on morphological characters but lacking a genetic validation (Parin and Kobyliansky 1996).

In this work we update the distributional range and the habitat patterns of *M. stehmanni* in the Argentine Sea. We focused on eggs, larvae and adult specimens collected in various locations from 2003 to 2016. This paper aims at: a) confirming the presence of adults of *M. stehmanni* and early life stages of *Maurolicus* spp. in the southern Argentinean continental shelf; and b) extending its southern distributional range in the Southwest Atlantic Ocean by several thousands of kilometers from its previously known southern distribution limit.

2. Material and methods

Two pearl side fish were captured in the San Jorge Gulf in January 2016, during a research cruise aboard the research vessel (RV) "Dr. Eduardo Holmberg", conducted by the Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP). Fish were caught with a Nichimo midwater trawl, with an inner mesh of 10 mm at the cod end. The Nichimo trawl worked between 70 and 90 m depth during 27 min from 46.2°S 66.3°W to 46.1°S 66.3°W, on a 100 m bottom depth (Fig. 1a). Fish were fixed and conserved in formaldehyde 4%, and deposited in the INIDEP icthyiological collection (catalogue code: INIDEP 861).

Other six pearl side fish were caught with a Nackthai high-speed sampler (20 cm mouth diameter, 2.5 m net length, 300 μm mesh size) in March 2004 on the southern Argentinean continental shelf during one research cruise aboard the RV "Dr. Eduardo Holmberg", conducted by INIDEP. Sample location was placed at 52.2°S 64.4°W, where depth was 155 m (Fig. 1a). The Nackthai sampler was towed at 130 m depth. The captured pearl sides were fixed and conserved in formaldehyde 4%.

Finally, in July 2010, another two pearl sides fish were found lying on the beach in the intertidal area of Puerto Madryn (Fig. 1b), by one of the authors (LAV). They were fixed and conserved in ETOH 96%.

These fish were identified based on the works by Smith (1961), Parin and Kobyliansky (1996), Almeida and Rossi-Wongtschowski (2007), and Rees et al. (2017). The following morphometrics measurements were recorded to the nearest 0.1 mm with a magnifying glass Leica MZ8 equipped with an ocular micrometer: standard length (SL, distance from the snout to the caudal peduncle); head length (HL, distance from the snout to the posterior edge of the operculum); eye diameter (ED) and body depth (BD, vertical distance perpendicular to

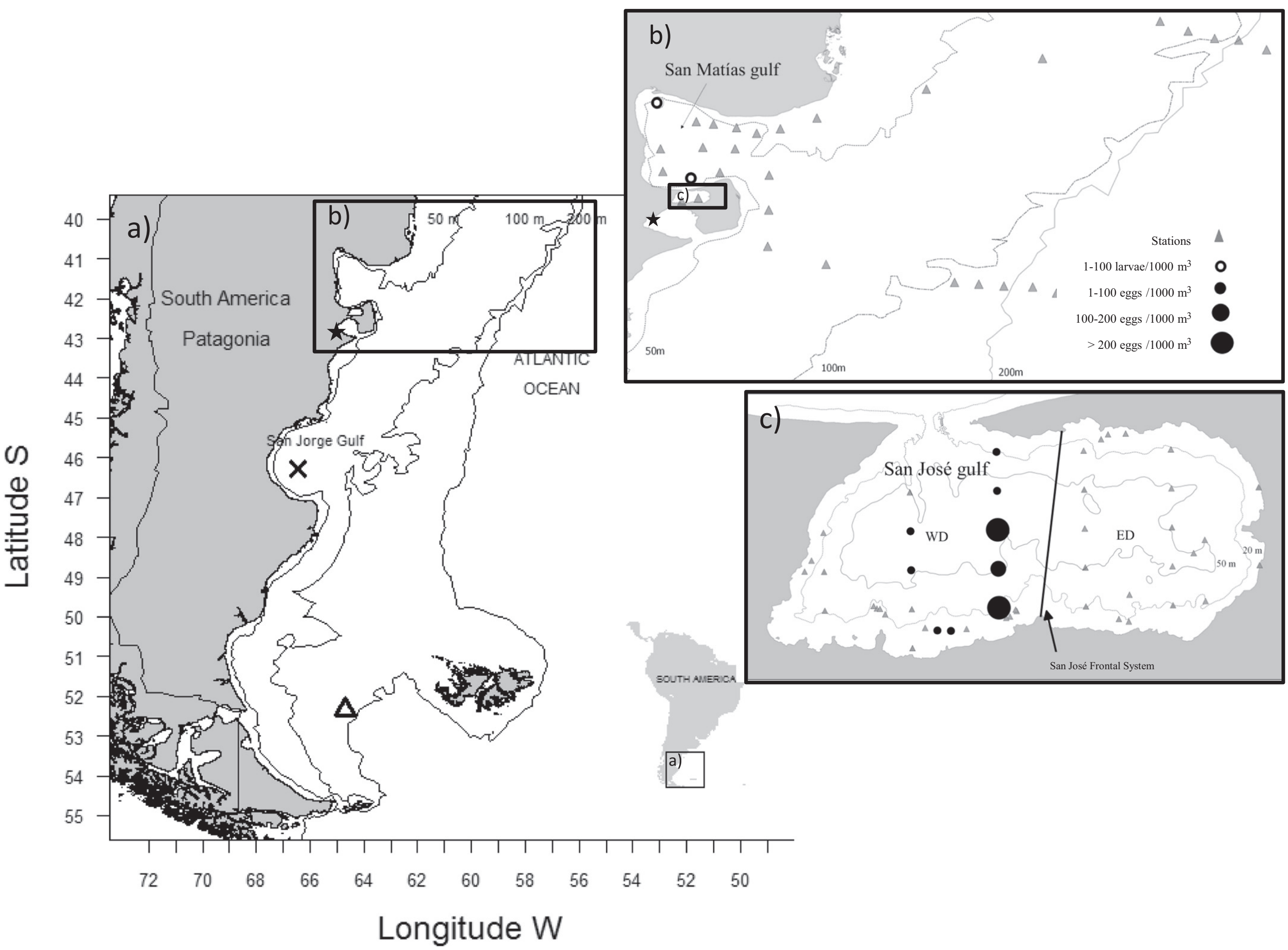

Fig. 1. Map of the study area indicating different locations where the specimens of *Maurolicus stehmanni* were caught. a) The cross indicates the location of two pearl side fish captured with a Nichimo midwater trawl in January 2016, and the open triangle shows the location of six pearl side fish captured with a Nackthai high-speed sampler in March 2004. The star in box b) indicates the position of two pearl side fish lying dead on the intertidal zone in July 2010. The b) and c) boxes show the distribution of eggs and larvae of *Maurolicus* spp. collected off Argentina from 2003 to 2013. The diameters of the dots, classified into three size categories, are proportional to the abundances of eggs and larvae. WD and ED indicate the western and eastern domains within the San José Gulf (sensu Amoroso and Gagliardini 2010).

the longitudinal axis between the dorsal and the ventral edges of the body). Body proportions of HL, ED and BD were calculated as percentages of SL (Table S1 in Supplementary material). The meristic data included: number of caudal photophores, dorsal and pectoral fin ray numbers, number of gill rakers in the first arch, and number of vertebrae (Table S1 in Supplementary material). In order to determine the vertebral counts, the specimens were mammographed using a high resolution mammography machine Selenia Dimensions, at the Instituto Radiológico Mar del Plata, Argentina. The relationships among variables were analyzed with the Kendall rank correlation test using the R software (R Development Core Team, 2018).

A total of 23 ichthyoplankton tows were conducted with outboard boats in the San José Gulf (SJG) during coastal surveys, between December 2003 and January 2004 (Table S2 in Supplementary material, Fig. 1c). In addition, 41 ichthyoplankton samples were obtained during the research cruise CONCACEN 2009, aboard the RV "Puerto Deseado" on the Argentine continental shelf in November 2009 (Table S2 in Supplementary material, Fig. 1b). Finally, 212 ichthyoplankton samples were collected in the SJG during a two-year survey, from October 2011 through March 2012 and from September 2012 through April 2013 (Table S2 in Supplementary material, Fig. 1c). No samples were available in January and November 2012 within the SJG. Ichthyoplancton tows were conducted with Hensen nets with mouth diameters of 50 cm (SJG: 2003–2004) and 70 cm (CONCACEN 2009 and SJG: 2011–2013 survey), all fitted with 300-μm mesh. General Oceanics (Miami, United States), Hydro-Bios (Altenholz, Germany), and T.S.K. (Tsurumi-Seiki Co., Ltd., Yokohama, Japan) flowmeters were mounted in the mouths of the nets to estimate the volume of filtered water. During CONCACEN 2009 research cruise, two plankton tows, one oblique and one horizontal, were conducted in each station. During the SJG surveys, tows were oblique or horizontal depending on bottom depth. Horizontal tows were made a few meters below the surface on the RV "Puerto Deseado", and close to the bottom of the seafloor in the SJG.

Water temperature-depth (TD) profiles were obtained during each zooplankton tow, using a custom-built TD datalogger attached to the net mouth, built and calibrated for this purpose at the CENPAT (Eng. J. Dignani, Electronics Lab). Temperature and depth resolution of the sensors were 0.06 °C and 0.05 m, respectively. Water temperature was not measured during the first survey in SJG (2003–2004), and maximum depth reached by the plankton net during this survey was estimated by trigonometry through a clinometer and the length of the released cable.

Plankton samples were fixed immediately after collection and preserved in formaldehyde 5%. Larval and egg abundances were expressed as number/1000 m^3. Identification of the eggs and larvae of *Maurolicus* spp. was based on the papers by Ciechomski (1971) and Ahlstrom (1974).

3. Results

The pearl side fish caught ranged between 16.9 mm and 58.1 mm SL (Table S1 in Supplementary material). They were identified as belonging to the genus *Maurolicus* by the adipose fin, and by the presence of photophores in groups in two series both on the isthmus and on the branchiostegal membrane. Head length, eye diameter and body depth increased linearly with length, ranging between 27.7% and 29.9% (HL/SL), 8.9% and 11.7% (ED/SL), and 22.5% and 25.4% (BD/SL), respectively (Fig. 2a, Table 1). No major changes or discontinuities in these body proportions were evident during the development (Fig. 2a). The values of the Kendall rank correlation coefficient ranged between 0.96 and 0.99 ($p < 0.001$, Fig. 2a). The numbers of rays were between 10 and 12 in the dorsal fin, and 17 in the pectoral fin. Gill rakers on the first arch ranged between 26 and 27, and there were 32 to 35 vertebrae (Table 1). The number of caudal photophores increased with pearl side fish size and ranged between 19 and 27 (Fig. 2b, Table 1), but it was

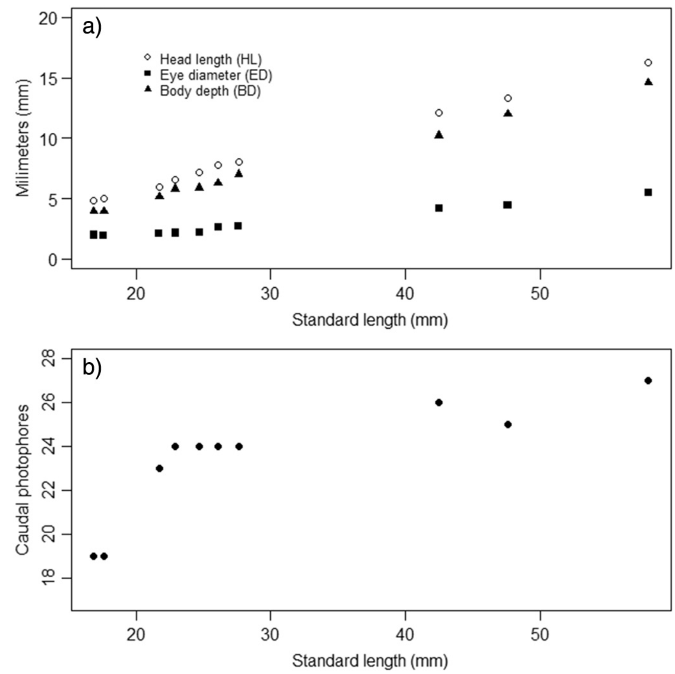

Fig. 2. a) Plot of the head length (HL), eye diameter (ED) and body depth (BD) against standard length (SL) of *Maurolicus stehmanni*; b) Number of caudal photophores plotted against standard length (SL) of *M. stehmanni* from the Southwest Atlantic Ocean.

established between 23 and 27 (mode = 24) in fish larger than 20 mm SL. The mammographies indicated that only specimens larger than 20 mm SL had well calcified bones and those fish did not present difficulties when counting the number of vertebrae (Fig. 3, Figs. S1, S2 in Supplementary material).

The comparison of the morphological characteristics with those reported for *M. muelleri*, the name originally used for the Southwest Atlantic species, allowed us to discard that the studied pearl side fish belonged to that species. Specifically, the number of gill rakers on the first arch was lower than the reported for *M. muelleri* (Table 1). However, the morphological and meristics characters provided in previous studies for *M. parvipinnis* and *M. stehmanni* overlapped largely (Table 1) and did not allow us to dismiss none of those species based solely on them. As *M. stehmanni* was already cited for the Southwest Atlantic Ocean up to 40°S, and larvae of this genus had been reported at 43°S, the more parsimonious hypothesis indicates that the pearl side fish studied here is *M. stehmanni*. This expands the known distribution of this species approximately 1000 km southwards along the Argentinean coast, from 43.0°S to 52.2°S (Fig. 1).

Eggs and larvae of *Maurolicus* spp. were collected in January and November in the San José Gulf (SJG) and in November in the San Matías Gulf (SMG), respectively. Eggs and larvae were found in the upper 30 m and 95 m of the water column, respectively (Fig. 1, Table S2 in Supplementary material). At the stations where eggs and larvae were captured, mean water temperature ranged between 11.8 °C and 12.8 °C. The frequency of occurrence and eggs density were low: between 1 (3.45 eggs/1000 m^3) and 5 eggs (171.76 eggs/1000 m^3) were collected in the SJG, mainly in the western domain and near its frontal system (Fig. 1, Table S2 in Supplementary material). Also, larvae of *Maurolicus* spp. only occurred in two plankton tows out of 276 stations, in the northeast and south of SMG. Five and 36 larvae were collected in each station (25.74 and 84.23 larvae/1000 m^3, respectively).

4. Discussion

In this paper we reported the extension of the distributional range of *Maurolicus stehmanni*, approximately 1000 km southwards along the

Table 1
Comparison of morphological features among three different species of pearl side fish *Maurolicus* spp. The numbers in parenthesis indicate the most common values within the ranges observed.

Morphological features	Parin and Kobyliansky (1996)			Almeida and Rossi-Wongtschowski (2007)	Rees et al. (2017)	This study
	M. muelleri	*M. parvipinnis*	*M. stehmanni*	*M. stehmanni*	*M. muelleri*	*M. stehmanni*
Maximum SL (mm)	65	54	46	–	54.3	58
HL/SL (%)	26–29	28.5–32.0	27.0–29.0	27.0–33.0	26.6–32.6	27.7–29.9
ED/SL (%)	8–10	9.5–12.5	8.5–10.0	8.0–11.0	8.4–12.3	8.9–11.7
BD/SL (%)	19–22	22.0–25.0	23.0–25.0	20.5–24.5	21.1–27.0	22.5–25.4
Caudal photophores	23–27 (25–26)	23–27 (24–25)	24–26 (25–26)	25–28 (26)	23–28 (25–26)	19–27
Dorsal fin rays	–	–	–	10–13 (11)	–	10–12
Pectoral fin rays	17–19	16–18	17–19	15–19 (17)	15–19 (17–18)	17
Gill rakers	28–32 (29–31)	26–29 (27–28)	27–29 (28–29)	25–30 (27)	26–32 (29–31)	26–27
Vertebrae	33–35 (34)	33–35 (34)	33–34 (33)	34 (33)	33–35 (34)	32–35

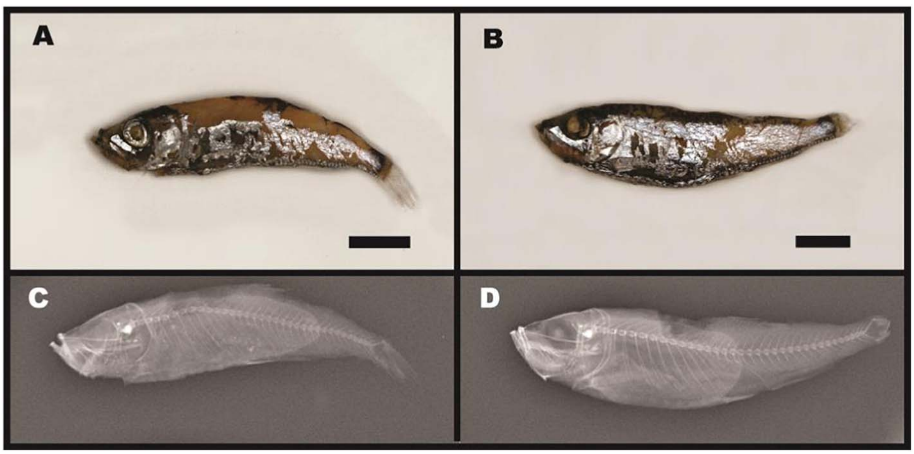

Fig. 3. Photographs of the two specimens of *Maurolicus stehmanni* captured with a Nichimo midwater trawl in the San Jorge Gulf in January 2016. A-B: Entire specimens. C-D: Mammographs of the specimens, placed below. The scale bar indicates 1 cm length.

Southwest Atlantic Ocean, from 43.0°S to 52.2°S. We interpreted that this species could have reached the southern Patagonian waters off Argentina through the oceanographic mechanism explained below. The complex oceanographic patterns described for the convergence between the southward flowing Brazilian Current and the northward flowing Malvinas current generate anticyclonic frontal eddies (Konstantinova et al. 1994; Figueroa et al. 1998) that could transport fish, eggs and larvae of the Brazil Current out of the subtropical zone into the subantarctic region. Indeed, mesopelagic larvae of *M. stehmanni* are commonly transported by eddies from the Brazilian current (Katsuragawa et al. 2014). The water within such eddies has temperature and salinity characteristics different from the surrounding waters and they can measure up to several kilometers wide (Acha et al. 2015). In the present work, the southernmost lot of pearl side fish was captured in March, at the end of the austral summer when eddies reach the most southern point (Garcia et al. 2004). The occurrence of species outside their usual ranges, especially warm and subtropical fish species moving into higher latitudes could be related to thermal anomalies processes, and could be used to indicate likely climate-driven range shifts (Fogarty et al. 2017). However, we cannot reject the possibility that this species has gone previously unnoticed in the region by the lack of systematic sampling of pelagic species, and by the fact that the distributional ranges for the Argentine marine fish fauna were described mainly based on demersal trawling samplings directed to the most fished species with high commercial value. Moreover, this kind of pearl side fish could have been confounded with other common lantern fishes in the region (e.g. myctophids and gonostomatids) due to their morphological similarities. In addition to reporting the occurrence of *M. stehmanni* in the southern Argentinean continental shelf, the presence of eggs in the shallow SJG, and of two fish in the intertidal area of the Nuevo Gulf allows including the inner continental shelf among the habitat types used by *M. stehmanni*, which was restricted to the shelf break and continental slope based on previous reports.

The presence of eggs and larvae of *Maurolicus* spp. in the Northern Patagonian gulfs San Matías and Nuevo had been previously reported by Ciechomski (1971) in February, March and September, with water temperature ranging between 10 °C and 16 °C, and depths exceeding 100 m. Here, we reported the occurrence of eggs in January and November within the SJG, in shallower areas, between 10 m and 73 m depth. Mean water temperature (ca. 12 °C to 13 °C) in the stations where eggs and larvae were collected was within the range reported by Ciechomski (1971). Through this paper, we referred to the eggs and larvae as *Maurolicus* spp. because no descriptions are available for the early stages of the South American pearl sides. The absence of eggs and larvae of *M. parvipinnis* along the Magellan Strait and south of 56°S (Bernal and Balbontín 2003), suggested a southward limit of *M. parvipinnis* early life stages at 54–55°S in the Southeast Pacific (Zenteno et al. 2014). In this context, and given that no other species of the genus had been reported for the Southwest Atlantic, the most parsimonious hypothesis suggests that the pearl side fish early stages should belong to *M. stehmanni*. The planktonic eggs of *Maurolicus* spp. were collected in the western domain of the SJG. The higher abundances were found near the thermal frontal system (Amoroso and Gagliardini 2010). Marine fronts offer adequate conditions for the development of the early life stages (abundant food, suitable physical-chemical ranges, etc.) and the possibility for eggs and larvae to be retained (Acha et al. 2015). The SJG, particularly its western domain, is greatly influenced by the nutrient enriched waters off Peninsula Valdés (Amoroso and Gagliardini 2010) that could carry eggs and/or larvae of fishes and other organisms. The occurrence of eggs within that gulf in concomitant occurrence with larger specimens in the region suggests the establishment of this species on the Argentinean continental shelf.

As the dichotomous key provided by Parin and Kobyliansky (1996) for 15 species of the genus *Maurolicus* employed overlapping characters, added to the fact that meristic characters and body proportions exhibited ontogenetic changes (Fig. 2 in Almeida and Rossi-Wongtschowski 2007; and this study), the best way to confirm the ambiguous identity of both species should involve molecular approaches (see for example, Rees et al. 2017). Unfortunately, the specimens herein studied were collected with zooplankton nets and were immediately fixed in formalin, what makes the extraction of DNA problematic, partly due to extensive DNA shearing and damage resulting from the exposition to formaldehyde (Simmons 2014). We unsuccessfully attempted to extract DNA from the specimens found on the beach, probably due to certain degree of tissue decomposition. Further studies involving molecular genetic data are needed to definitively establish the levels of genetic variation and the identity of the species inhabiting the Argentinean coast. The use of genetic markers will allow better understanding of the species taxonomy around southern South America and will provide answers to questions that could not been addressed solely from traditional morphological methods.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.seares.2018.03.003.

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