Journal of the Marine Biological Association of the United Kingdom, page 1 of 7. © Marine Biological Association of the United Kingdom, 2017
doi:10.1017/S0025315417001904

Juveniles recruitment and daily growth of the southern stock of *Mugil liza* (Actinopterygii; Fam. Mugilidae): new evidence for the current life-history model

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Mugil liza *is distributed along the western Atlantic coast. It is a commercially exploited species in Argentina, supporting a small-scale fishery conducted by an artisanal fleet. Age determination of fishes constitutes an important key issue for fishery management. The age, growth and recruitment of* M. liza *juveniles in Mar Chiquita coastal lagoon and Las Brusquitas creek (Buenos Aires, Argentina), were estimated by means of the analysis of the sagittal otoliths of fish collected during January to December of 2014. Ages were estimated by counting and measuring daily growth increments in otoliths under a light microscope. A total of 735 specimens ranging from 19 to 71.5 mm SL and from 67 to 212 days age was analysed. Lengths at previous ages were determined by back-calculation, a linear growth model was fitted to the back-calculated data:* $SL = 0.2468 + 2.0516$; $R^2 = 0.9945$. *Two peaks of recruiters were observed from February to March, and from October to November in 2014. Mean ages in days of Querimana and juveniles at the recruitment time were 84.07 ± 14.43 days and 87.56 ± 19.51 days, respectively. The hatching dates of specimens showed two spawning seasons. One was from December 2013 to January 2014, and the second one from July to August 2014. The assessment carried on this work generated age determination values that support previous findings, contributing to make a more accurate description of the life-history model currently used. In addition, valuable information has been generated to give better advice for improving the management of the fishery resource.*

Keywords: Mugilidae, otolith, recruitment, daily growth, Querimana, mullet, *Mugil liza*

Submitted 7 June 2017; accepted 27 October 2017

INTRODUCTION

Mugilids occur in both coastal marine and brackish waters of all tropical and temperate seas (Nelson *et al.*, 2016). The striped mullet, *Mugil liza* is a pelagic fish distributed in the western Atlantic Ocean from Venezuela to Argentina (González-Castro *et al.*, 2012; Whitfield *et al.*, 2012). It is commercially exploited in Argentina where it supports a small-scale fishery conducted by an artisanal fleet, which operates mainly in Bahía Samborombón (56°45′W 35°27′S to 56°35′W 36°22′S) (González-Castro *et al.*, 2009a). Commercial catches were between 5.4 and 78.8 t from 2000 to 2010, with a maximum capture of 194.0 t in 2004 (Navarro *et al.*, 2014). This fishery resource, shared between Argentina, Brazil and Uruguay, was declared overexploited by the Brazilian Ministry of Environment in 2004 (Ministério do Meio Ambiente, 2004). No specific regulation for the exploitation of this resource has been established so far in the region due to the lack of information regarding the structure and dynamics of the mullet population (González-Castro *et al.*, 2015).

Although the white mullet *Mugil curema* has been occasionally recorded in Argentinean waters (González-Castro *et al.*, 2006), *M. liza* is the only permanent mullet occurring in Argentina. It is regarded as an estuarine-dependent marine fish (González-Castro *et al.*, 2009a) inhabiting estuaries, coastal lagoons and some freshwater beds (Cousseau *et al.*, 2005; González-Castro, 2007).

Mugil liza is classified as a total spawner (González-Castro, 2007; Albieri & Araújo, 2010; González-Castro *et al.*, 2011; Lemos *et al.*, 2014), and a hypothetical life-history model for adult stocks based on ovarian maturity stages, gonadosomatic index (GSI), allometric growth coefficient *b*, and border analyses of otoliths, has been proposed (González-Castro *et al.*, 2011). This model, which is correlated with preparation for spawning, includes a reproductive migration from the Argentine estuaries or coastal lagoons (~36°S) towards southern Brazil (~26°S) from May to the end of June. The spawning season of the southern population of *M. liza* takes place from May to August, and appears to have a peak in June in offshore waters in Santa Catarina and Paraná states, as

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indicated by the presence of hyaline oocytes (Lemos *et al.*, 2014). From August to September, the reproductive events end, and probably, the mullet start feeding and migrating to estuaries and coastal lagoons. Eggs and larvae drift towards the surf zone by surface currents generated by the wind (Vieira & Scalabrin, 1991). However, a small secondary spawning event (probably in more southern latitudes than the main spawning event) cannot be disregarded, as the presence of females in advanced sexual maturity during November and December were observed uninterruptedly over several years (González-Castro, 2007; González-Castro *et al.*, 2011). Several authors (Bruno & Acha, 2015; Bruno *et al.*, 2014, 2015) have conducted studies on the recruitment of fish larvae and juveniles in Mar Chiquita coastal lagoon. These studies were carried out at 1.6 km offshore from the mouth to the inner continental shelf, the Surf zone adjacent to Mar Chiquita lagoon's mouth and the lagoon's inlet channel, using a conical net with a 300 µm mesh net to collect larval stages and a 4 m long, 1 m height nylon beach seine-net with a 5 mm stretch mesh size for juveniles. The results of these studies show that *M. liza* individuals of less than 22 mm were not detected in the lagoon.

In Mugilidae, young mullet usually ranging between 23 and 40 mm are commonly known as Querimana, this stage being characterized by the presence of two anal-fin spines. When the third anal-fin spine develops, then this individual can be consider to be a juvenile (Jacot, 1920; Thomson, 1997).

The daily growth and age information obtained from fish otoliths can be used to understand the factors affecting the recruitment (Stevenson & Campana, 1992). Quantifying the age range of Querimana and juvenile stages of *M. liza*, can be an important step to generate useful and valuable information to manage the fishery resource in the region, a difficult task due to the shared nature of the stock.

A strong recruitment of Querimana captured in summer from Mar Chiquita coastal lagoon has been observed (Acha, 1990). According to the current life-history model, a delay is therefore expected between the date of hatching and the entry into the estuaries of Querimana, depending on the distance between spawning sites (southern Brazil) and the areas of recruitment. Two recruitment peaks would be expected according to the spawning periods proposed by González-Castro (2007) and the González-Castro *et al.* (2011) life cycle model. Moreover, it is important to correlate these facts with the distribution, abundance and age of larvae that were recruited in estuaries or related environments, in order to know if these match the model.

The aim of the present study was to assess the recruitment periods and estimate the hatching dates of Querimana and juvenile of *M. liza* that inhabit the coastal area of Buenos Aires province (Argentina), employing otolith readings and age-growth models. The final purpose was to contrast the current hypothetical life-history model, in order to improve the knowledge of this ecologically and economically important South American species.

MATERIALS AND METHODS

Study area

Two sampling sites were chosen: Mar Chiquita coastal lagoon and an exoreic creek called Las Brusquitas. Mar Chiquita coastal lagoon is located on the South-west Atlantic Ocean in Buenos Aires province, Argentina (37°32′–37°45′S 57°19′–57°26′W) (Figure 1). It is a shallow estuarine system with a maximum length of 25 km and a maximum width of 4.5 km, delimiting a total area of 46 km² (Rivera Prisco *et al.*, 2001). Depth varies between 0.5 and 3 m. Seawater enters in the lagoon with the high tides, and the volume depends on wind direction and intensity. Freshwater inflow comes from several streams and artificial channels. Water temperature usually varies from 9.1 to 21.3°C throughout the year and salinity values from 0 to 35 PSU daily (Reta *et al.*, 2001). Mar Chiquita is regarded a World Reserve of Biosphere since 1996 by the Coordination Council of the Man and Biosphere Program (MaB) of UNESCO (Iribarne, 2001). Las Brusquitas creek is located 64 km south of Mar Chiquita (38°14′40″S 57°46′40.5″W) (Figure 1). This exoreic creek belongs to the south of the basin slope of Tandil and receives scarce tributary inflow. It is regarded as a subhumid-humid mesothermal area without water deficiency. It has a significant flow of overall runoff, a combination of surface and underground water. It also has regular rainfall patterns of about 800 mm year^{-1}, the summer season being the rainiest (Kruse, 1986).

Sampling design

The samples of *M. liza* (Querimana and juveniles) were collected from both the mouth of Mar Chiquita coastal lagoon (González-Castro *et al.*, 2009a) and Las Brusquitas creek. Sampling was carried out monthly from January to December 2014. Trawls were performed by means of a 10 m beach seine (10 m in length × 1.8 m high; each wing measured 4 m in length and the cod-end was 3 m in length; the mesh in the lateral wings was 10 mm, and the mesh in the cod-end was 5 mm), covering approximately an area of 200 m². Fish were taxonomically identified according to Cousseau & Perrotta (2013) and González-Castro *et al.* (2012). Standard length (SL) of the individuals was measured to the nearest 0.01 mm; body weight was registered to the nearest 0.01 g. In addition, water temperature (in °C), and salinity, measured in PSU, were recorded using an alcohol thermometer and a hydrobios refractometer, respectively.

The sagittal otoliths of Querimana and juveniles were removed, placed onto glass slides and covered with

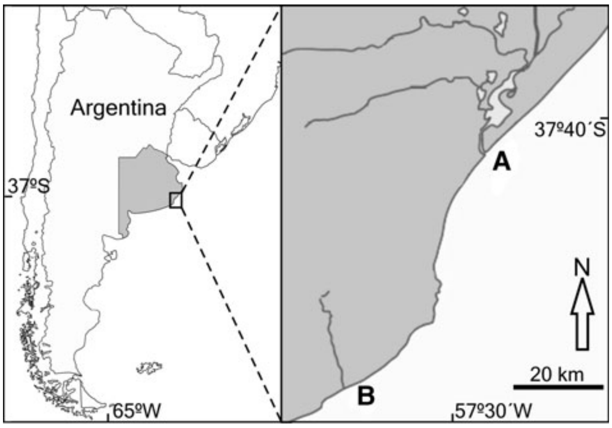

Fig. 1. Sampling sites of *M. liza*. Mar Chiquita coastal lagoon (a) and Las Brusquitas creek (b).

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Pro-texx® (a transparent mounting medium) for examination by light microscopy. Otolith increments were observed under a Zeiss Axioscop binocular microscope (400×) connected to a computer equipped with an image analysis system. Image enhancement and analysis was conducted using the Kontron® software (Brown *et al.*, 2004). The widths of daily increments were examined along the longest otolith radius. The increments were counted and measured from the otolith nucleus (hatch check) to the otolith edge (Campana & Jones, 1992). Because the daily deposition of increments in otoliths has not been experimentally validated for this species so far, the process was assumed according to the observations made for the striped mullet *M. cephalus* (Radtke, 1984; Chang *et al.*, 2000). We considered the ring deposited immediately after the hatching mark as the first daily increment.

Data analysis

A linear relationship was established:

$$SL = a \times OR + b,$$

where SL was the standard length measured in mm, a and b the regression parameters, and OR was the longest otolith radius measured in μm.

Due to the absence of initial larvae, the growth was established by back-calculation methods. The biological intercept method (Campana, 1990; Campana & Jones, 1992) was used as follows: after verifying linearity between SL and OR, the fish size at a previous age of capture (L_X) was estimated for each individual according to:

$$L_X = L_c + (OR_X - OR_c) \times (L_c - L_o) \times (OR_c - OR_o)^{-1}$$

where L_c is the fish length at capture time; L_o, 2.65 ± 0.23 mm, represents the mean larval size at first increment deposited, based on Kuo *et al.* (1973) for *M. cephalus*. OR_X is the otolith radius measured at previous ages, OR_c is the otolith radius measured at capture time, and OR_o represents the otolith radius measured at first increment deposition. A linear model was fitted to the back-calculated sizes at previous ages.

The hatching dates of all specimens were determined by subtracting to the sampling dates the number of daily increments enumerated in the otoliths. For those specimens in whom otoliths were not analysed, the age of each individual was determined by converting its respective SL in days by using the linear model fitted to the back-calculated sizes, as a function of age. Because *M. cephalus* embryos hatch around 59–64 h after fertilization (Meseda & Samira, 2006; González-Castro & Minos, 2016), hatching dates were determined up to spawning period. Spawning period was grouped monthly.

RESULTS

Environmental data

Temperatures ranged between 12.8 and 23°C (Mar Chiquita) and between 9.8 and 21.5°C (Las Brusquitas). Salinity values were 0–6 PSU in Las Brusquitas, while in Mar Chiquita lagoon large variations were observed, from 0–33.5 PSU, as has been reported earlier by several authors (Cousseau *et al.*, 2001; González-Castro *et al.*, 2009b). The average temperature was 20.3°C during the summer recruitment peak, and 20.0°C in spring.

Length frequency distribution

A total of 735 specimens ranging between 19 and 71.5 mm SL was collected from January to December 2014 (Table 1). The more representative size classes were 22 mm SL (N = 106) and 24 mm SL (N = 146) (Figure 2). The individuals between 18 and 40 mm SL represented more than 90% of the total catch. Two recruiting peaks were observed, the first one occurred from February to March 2014, and the second one, from October to November 2014 (Figure 3). Mean SL was 23.1 ± 3.5 mm for the first peak and 23.6 ± 4.8 mm for the second one.

Age and growth

A successive pattern of alternating light and dark bands was microscopically observed; those bands define the daily growth increments (Figure 4).

A total of 735 specimens were captured during a one-year sampling period. A representative sample was taken each month, thus 250 otoliths were extracted. After processing

Table 1. Total monthly catches of Querimana and juveniles of *Mugil liza*.

Date	MCH	BRU	Total sample	Mean SL (mm)	SD	Interval SL (mm)
January 2014	0	5	5	33.0	10.66	23.6–47.1
February 2014	0	145	145	21.7	1.93	19–34.7
March 2014	94	0	94	25.2	4.22	19.3–49.0
April 2014	0	10	10	22.7	1.52	20.3–25.1
May 2014	0	47	47	32.3	6.85	21.8–46.8
June 2014	0	13	13	33.1	8.46	25.9–56.1
July 2014	0	21	21	38.7	4.07	32.8–52.6
August 2014	3	0	3	29.8	2.49	27.6–32.5
September 2014	18	0	18	39.8	5.91	30.0–49.2
October 2014	232	14	246	23.6	4.83	20.5–56.5
November 2014	72	27	99	29.2	11.19	20.9–71.5
December 2014	0	34	34	34.5	8.48	23.9–56.2
Total	419	316	735			

MCH, Mar Chiquita; BRU, Las Brusquitas creek; SD, standard deviation; SL, Standard length.

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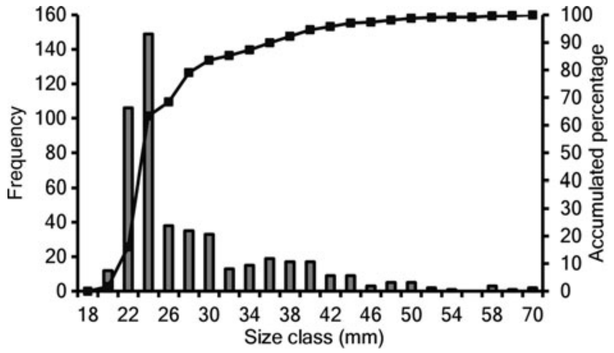

Fig. 2. Size class frequency distribution of *M. liza* specimens analysed in this study. Size classes are grouped in 2 mm intervals. N = 735. Solid line is accumulated percentage.

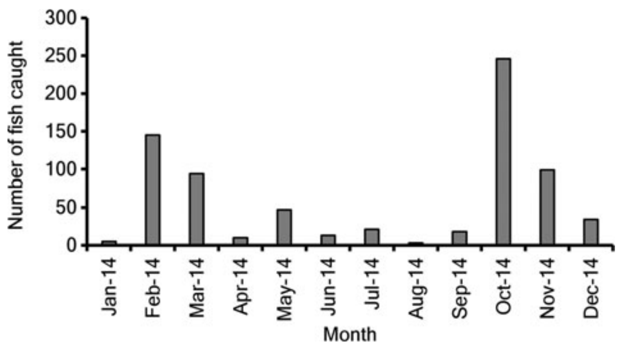

Fig. 3. Monthly catches of *M. liza* specimens.

only 109 were in good condition for reading. Otolith radius ranged from 434.83 to 1377.29 μm. The linear relationship between otolith radius and SL was:

$$SL = 22.41 \times OR + 16.70; \quad R^2 = 0.89, \ P < 0.001.$$

The mean ages of *M. liza* Querimana in the estuary were estimated by converting SL in larval age, using the linear model to the back-calculated ages (Figure 5).

The estimated age of the total individuals ranged from 67 to 212 days old (N = 735). The mean daily ages of Querimana recruited at the study area were estimated to be 82.81 ± 10.96 days ranging from 67 to 117 days (February and March) and 84.31 ± 8.22 days ranging from 73 to 114 days (October and November). The determination of hatching dates of Querimana and juveniles of *M. liza* suggested two spawning seasons. The first one would occur from December (2013) to January (2014), and the second, from July to August (2014) (Figure 6). The linear model fitted to the back-calculated sizes at previous ages was: SL = 0.2468 + 2.0516; $R^2 = 0.9945$ (Figure 5).

DISCUSSION

Estuaries and coastal lagoons are high fish productivity areas (Yáñez-Arancibia *et al*., 1985; Cousseau *et al*., 2001) and play an important role in biological and reproductive cycles of many marine species (Galván-Piña *et al*., 2003; González-Castro *et al*., 2009a, b, 2011; Lajud *et al*., 2016). More than 30 fish species have been recorded in Mar Chiquita coastal lagoon, many of which constitute valuable resources for game fishing, such as mugilids, sciaenids, flatfishes and atherinopsids (Cousseau *et al*., 2001; González-Castro *et al*., 2009b, 2016). Regarding *M. liza*, several studies have been conducted on taxonomy (Cousseau *et al*., 2005; González-Castro *et al*., 2008), age and growth (González-Castro *et al*., 2009a), ecology (González-Castro *et al*., 2009b; Bruno *et al*., 2013) and reproductive biology in Mar Chiquita (González-Castro *et al*., 2011). Mar Chiquita coastal lagoon constitutes an important area for juvenile recruitment, but also for feeding and growth of adults previous to the reproductive migration (González-Castro *et al*., 2009a, b, 2011; Bruno *et al*., 2013).

In the present work, *M. cephalus* was utilized as a model species to make comparisons of the obtained results for *M. liza*. *Mugil liza* belongs to one of the 14 lineages within the *M. cephalus* species complex (González-Castro & Gasemsadeh, 2016). Moreover, *M. cephalus* is the type-species of this genus,

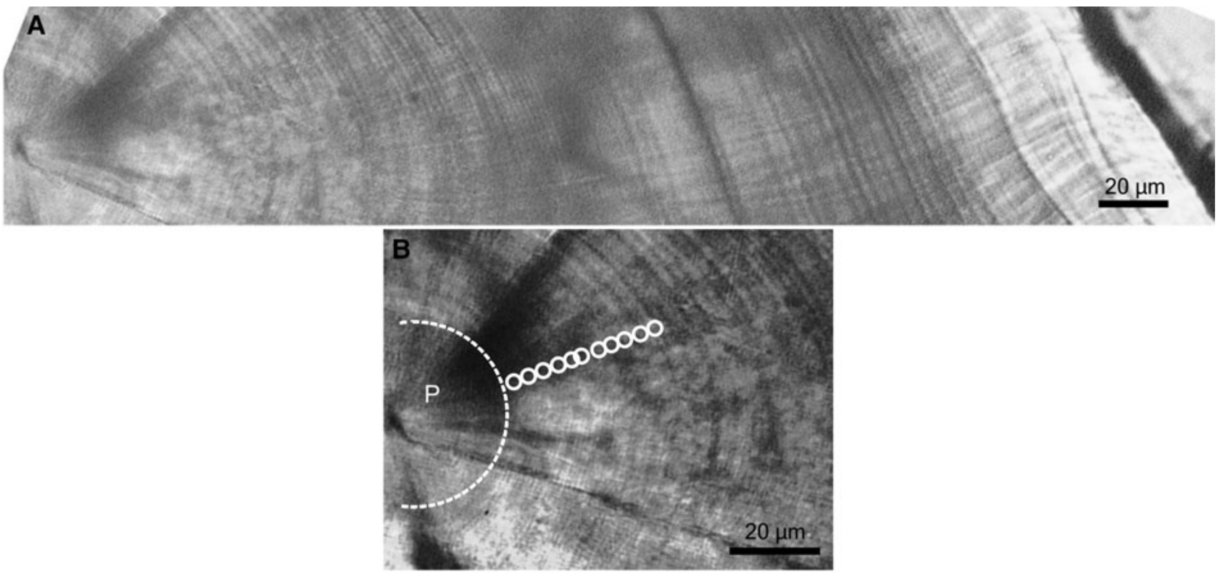

Fig. 4. Light microscope photographs of microstructure of daily growth increments in otoliths of *M. liza* Querimana (A, B). White circles: daily growth increments; white dotted line: primordium (P).

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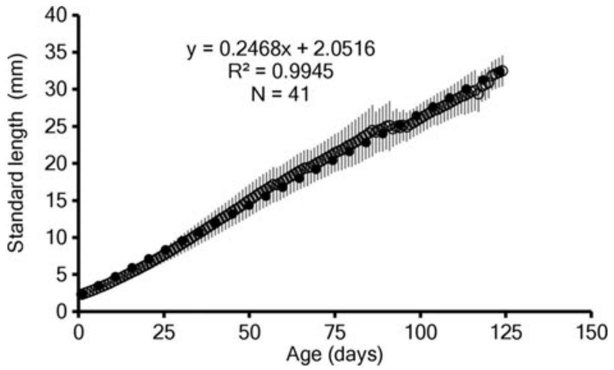

Fig. 5. Back-calculated standard length at age of Querimana and juvenile of *Mugil liza* (open circles) and linear model fitted to data (black dots).

being the most studied taxon from a biological, genetic and taxonomic point of view.

Garbin *et al.* (2014) performed back-calculation on otoliths of adult individuals of *M. liza*, determining that the larval primordium would form around an average size of 21.2 mm total length. So far, no studies related to age determination and daily growth of *M. liza* at recruitment are reported for this species. Working in ideal conditions, it would be desirable to have specimens with a broader range size and larvae, to represent the daily growth of Querimana and juveniles of *M. liza*. Unfortunately, larvae were not available because the spawning sites are far away from the study site. Thus, the back-calculation procedures were employed in order to resolve this.

Most of the captured individuals in this study corresponded to Querimana, constituting more than 80% of the catch (Figure 2). It was also observed that 79.5% of the collected individuals belonged to catches of February, March, October and November (Table 1). These high values correspond to the recruitment of Querimana in the surveyed area (i.e. the entrance of Querimana of *M. liza* to diverse oligohaline systems). High abundance of juveniles and Querimanas has been observed in Mar Chiquita coastal lagoon, from January to February, and individuals between 18 to 60.8 mm total lengths have been collected throughout the year (Acha, 1990). In the same study, larvae were collected between 4 mm and 14 mm SL in the Samborombón Bay throughout the year. Furthermore, Bruno *et al.* (2013) recorded highest abundances of *M. liza* juveniles in summer and spring. Conversely, Vieira (1991), recorded the highest recruitment of *M. liza* juveniles between July and October in dos Patos lagoon, Brazil. However, Rodrigues & Vieira (2013), found for the same lagoon a uniform recruitment of juveniles with a total length smaller than 50 mm throughout the year.

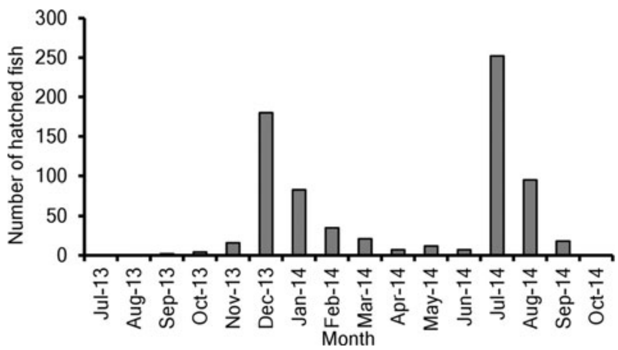

Fig. 6. Monthly distribution of hatching dates obtained by back-calculated length data of specimens of *M. liza*.

According to the present work, the spring recruitment (October to November) in the study area was constituted by Querimanas with sizes from 19 to 31.9 mm SL, whereas recruitment in summer (February to March) presented sizes between 20.5 to 31.2 mm SL, at ages from 67 to 117 and from 73 to 114 days, respectively. Chang *et al.* (2000) reported the recruitment of *M. cephalus* between 17 and 39 mm total length and ages between of 29 and 67 days in the Thanshui estuary. Hsu *et al.* (2009) calculated the mean age and the total length at estuarine arrival in several estuaries of the north of Taiwan as 32.9 ± 5.5 days and 28.3 ± 2.8 mm. The differences between age and SL of the of *M. liza* captured during 2014 and the results registered in previous research for *M. cephalus*, could be attributed to the long distances that *M. liza* larvae must travel from Brazil (the hypothetical place where they were born, probably located in the south, Lemos *et al.*, 2014) to the area of recruitment (i.e. 1500 km from the study area and the spawning area in Brazil, *vs* 200 km between recruitment and spawning areas in Taiwan). Additionally, growth differences between both species could exist.

The presence of two annual peaks of recruitment agree with the existence of two reproductive populations, as outlined by González-Castro *et al.* (2009a, 2011): a resident population (that would reproduce more locally) and a migrant one. This last group would be constituted by migrating adults from Argentina toward the coast of Brazil, as mentioned by González-Castro *et al.* (2009a) and Lemos *et al.* (2014). The other reproductive group could be hypothetically constituted by adults that migrate to the area of the estuary of Rio de la Plata and they would spawn in summer. The results obtained in this work contribute to the knowledge of the early life history of the species, providing more accurate information to improve the management of the fishery resource which is being subject to overexploitation.

CONCLUSIONS

We conclude that during 2014 two recruitment peaks of *M. liza* were detected in the study area. Daily increments were easily identifiable under optical microscopy. A growth linear model was fitted: SL = 0.2468 + 2.0516, where slope represents the mean daily growth rate in mm day^{-1}. Two hatching periods were detected; this information supports the hypothesis previously verified from the reproductive biology of adults, and it raises the question about the effect that the second reproductive event produces in recruitment and larval dynamic of *M. liza*. Further studies will be needed to understand the population dynamics of this species of the estuary of Rio de la Plata; inter-annual variations in recruitment should be tested.

ACKNOWLEDGEMENTS

The authors would like to thank Julio Mangiarotti (forest guard in the Mar Chiquita Biosphere Reserve) and the Mar Chiquita coastal lagoon authorities (Jorge Paredi, Luis Facca,

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Mónica Iza, Florencia Celesia and Gladys Eiras). We thank Matías Delpiani for helping in collecting specimens. Contribution INIDEP No. 2082.

FINANCIAL SUPPORT

This work was supported by UNMdP 15/E525, EXA 577/2 and UNMdP 15/E619, EXA 669/14 grants.

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