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FULL PAPER

Egg capsules of the Filetail fanskate *Sympterygia lima* (Poeppig 1835) (Rajiformes, Arhynchobatidae) from the southeastern Pacific Ocean, with observations on captive egg-laying

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Abstract A total of 42 egg capsules of *Sympterygia lima* are examined in this study. Freshly laid egg capsules are pale yellow-brownish in color and turn to dark brown over time in sea water. Dorsal and ventral surfaces are soft and slightly striated. Anterior horns are shorter than posterior and are arranged in parallel. Posterior horns transition into long coiled tendrils, which are the first to emerge through the cloaca during egg-laying. Notes on oviposition rates are discussed; these were shown to vary from 4 to 20 days, with two eggs being deposited each time. The presence of tendril-like posterior horns is not common in rajids. They seem to occur only within the genus *Sympterygia*, becoming a useful character for distinguishing them from other egg capsules that may be found in the same latitudinal range. Egg capsule characteristics may be useful to help identify the species responsible for egg-laying sites and, indirectly, the reproductive cycle with a nonlethal method.

Keywords Single oviparity · Reproductive biology · Egg capsule morphology · Egg-laying rate · Reproductive behavior

Introduction

The genus *Sympterygia* Müller and Henle 1837 comprises four species inhabiting southern coasts of South America: the Bignose fanskate, *Sympterygia acuta* (Garman 1877), occurring exclusively from Brazil to Argentina; the Smallnose fanskate, *Sympterygia bonapartii* (Müller and Henle 1841), ranging from the southwestern Atlantic to the Magellan Strait; the Shorttail fanskate, *Sympterygia brevicaudata* (Cope 1877) and the Filetail fanskate, *Sympterygia lima* (Poeppig 1835), both restricted to Chilean coasts (McEachran and Miyake 1990b; Pequeño and Lamilla 1996; Pequeño 1997). Phylogenetic interrelationships and zoogeography within *Sympterygia* and its sister group, *Psammobatis* Günther 1870 have been investigated by McEachran and Miyake (1990a, b) and McEachran and Dunn (1998). *Sympterygia lima* was formerly placed into *Psammobatis* but was reallocated in *Sympterygia* by McEachran (1982).

Information available on *S. lima* has been restricted to taxonomy, feeding habits and notes on its biology (Lamilla et al. 1984). This species is known to be part of the batoid bycatch of coastal bottom trawl fisheries, which target bony fishes along the Chilean coasts (Leible 1987; Pequeño and Lamilla 1997). However, other relevant aspects of the reproductive biology and life history of *S. lima*, such as egg capsule description, egg-laying rate and incubation period, have not been previously documented. Moreover, the information on biological data for this genus has been restricted to Atlantic populations.

Since egg capsule morphology has been considered to be an important source of information on the systematics, taxonomy and reproduction in elasmobranchs (Ishiyama 1958; Ishihara et al. 2012), the aim of this work is to provide a detailed morphological description of the egg capsules of *S. lima*. Additionally, observations on its oviposition rate are presented for the first time, which will contribute to the information on the reproductive biology of this species.

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Materials and methods

Forty-two egg capsules were analyzed in this study. Sixteen were deposited by a single female (436 mm TL; 760 g TW) captured as bycatch in the artisanal trawl fishery, at 50 m depth, off Caleta Montemar, Central Chile (32°57′S, 71°33′W), in October 2010. After it had been landed, the skate was held in a tank (2,200 L) at a temperature of (mean ± SD) 13.58 ± 1.05 °C. The other 26 egg capsules were obtained by diving in shallow waters near this fishing port and were identified to species after hatching in aquaria. When skates had hatched, egg capsules were preserved in 80 % ethanol and deposited in the Chondrichthyan Collection of the Laboratorio de Biología y Conservación de Condrictios, Universidad de Valparaíso, Chile (CCM).

Measurements of the egg capsules were taken point-to-point to the nearest 0.01 mm (Fig. 1): capsule length (CL), capsule width (CW), capsule height (CH), posterior apron (PA), right lateral keel (RK), left lateral keel (LK), right anterior horn length (RAH), left anterior horn length (LAH), right posterior horn length (RPH), left posterior horn length (LPH), right tendril (RT) and left tendril (LT). Tendrils were measured only from egg capsules laid in captivity by means of disentangling them when recently laid. Measurements and terminology of egg capsules follow Ebert and Davis (2007) and Concha et al. (2009). Mean length of respiratory fissures (RF) was recorded from 15 egg capsules.

The tank that held the female was checked daily for newly deposited cases, which were labeled and maintained in an incubation tank (70 L) at a temperature of (mean ± SD) 13.58 ± 1.05 °C. The egg capsules were suspended from their posterior tendrils to simulate the natural position in which they are deposited in the wild.

Oviposition was recorded once with a digital subaquatic camera (Canon Power Shot D10; 12.1MP).

Results

The reproductive mode of *Sympterygia lima* is single oviparity, as with all other skate species, with only a single egg capsule deposited from each uterus at any one time, each containing a single ovum at the same stage of development. Freshly deposited egg capsules (Fig. 2) are pale yellowish-brown in color and mildly translucent against transmitted and reflected light. Coloration becomes darker with time, either in sea water or ethanol (80 %). Dorsal and ventral capsule surfaces are soft and slightly striated. Two dorsoventrally flattened horns arise from both the anterior and posterior ends of the capsule, becoming thinner at the distal ends. Horns are flexible and sticky when laid. Anterior horns are shorter than posterior and are arranged in parallel, becoming curved at the middle of their length and pointing to opposite faces of the egg capsule. The posterior horns form long coiled tendrils, which are the

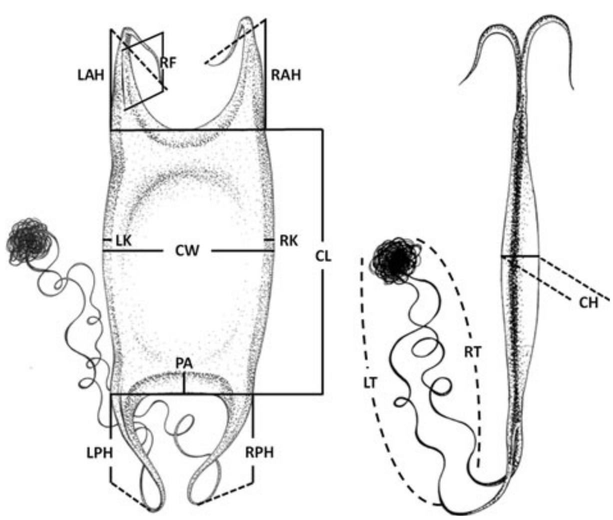

Fig. 1 Dorsal (*left*) and ventral (*right*) diagram of the egg capsule of *Sympterygia lima*. *CL* capsule length, *CW* capsule width, *CH* capsule height, *PA* posterior apron, *RK* right lateral keel, *LK* left lateral keel, *RAH* right anterior horn length, *LAH* left anterior horn length, *RPH* right posterior horn length, *LPH* left posterior horn length, *RT* right tendril, *LT* left tendril, *RF* respiratory fissure

Fig. 2 Dorsal (*left* and *center*) and lateral (*right*) views of fresh egg capsules of *Sympterygia lima*. *Scale bar* 20 mm

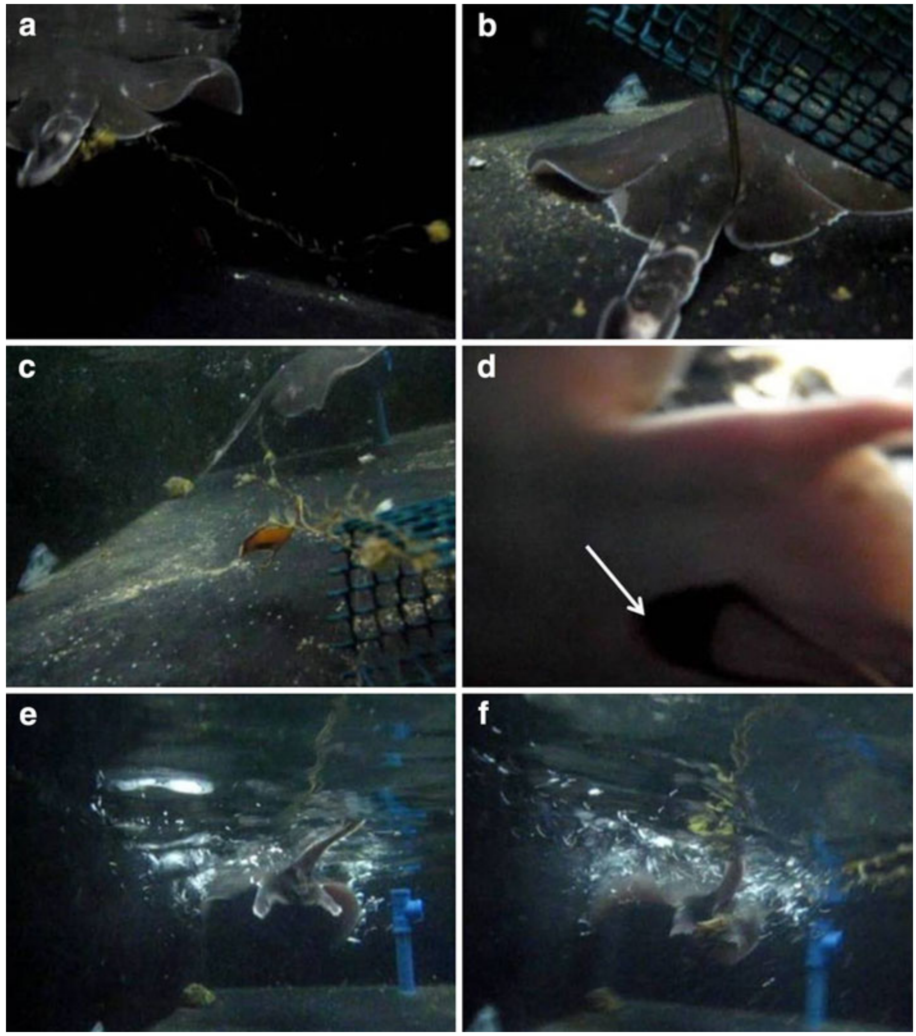

Fig. 3 Egg-laying by a female of *Sympterygia lima* under captive conditions. **a** Female swims along the tank prior to oviposition and posterior tendrils emerge through the cloaca, **b** posterior tendrils are attached to the substratum while the female rests on the bottom, **c** the female swims in order to eject the egg capsule, **d** after laying the first egg capsule, the second egg capsule (*white arrow*) leans out of the cloaca, **e** the female attaches the posterior tendrils of the egg capsule and starts to swim, **f** by means of hard swimming, a second egg capsule is deposited

first to emerge through the cloaca during the egg-laying process (Fig. 3). In dorsal view, one egg capsule of each pair has the left side slightly more convex than the right side, with the left anterior horn pointing dorsally and the right anterior horn pointing ventrally, while the other egg capsule of the same pair is an approximate mirror image of the former. In lateral view, dorsal and ventral faces are equally convex. The anterior border of the capsule is concave, lacking an apron, the opposite of the posterior border. Both flanges of the egg capsule are secured by lateral keels. Respiratory fissures of fresh egg capsules appear as closed grooves when first laid. Left and right respiratory fissures are situated dorsally and ventrally, respectively, at the base of the horn and tendril, measuring (mean ± SD) 9.7 ± 1.7 mm. All measurements are summarized in Table 1.

The egg-laying process (Fig. 3) of each pair of egg capsules occurred in 4 min when direct observation was possible. Both egg capsule tendrils were entangled in the female cervix and reached the outside together (Fig. 3a). The posterior end of the egg capsule can be seen emerging from the cloaca. When tendrils emerge, females search for substratum to attach them. After tendrils had been attached to the substratum, the female rested for less than a minute and then swam away from the fixation point of the tendrils to push out the egg capsule (Fig. 3b, c). After the first egg-laying, the second pair of tendrils, belonging to the second egg capsule, emerged from the cloaca (Fig. 3d). The female repeated the same procedure in order to deposit both egg capsules (Fig. 3e, f). The daily interval between the egg-laying of successive pairs of capsules ranged from 4 to 20 days (mean 10.7 ± 5.2 days) within 76 days. The observed egg-laying rate, until the female died, was 0.21 (egg capsules/day).

Discussion

Single oviparity has been previously reported for *Sympterygia lima* (see Lamilla et al. 1984) and the remaining

Table 1 Mean values and ranges of measurements of the egg capsules of *Sympterygia lima*

Measurements (mm)	Mean ± SD	Mean proportion ± SD	Range
Capsule length (CL)	48.95 ± 2.30	1	43.7–53.4
Capsule width (CW)	32.55 ± 1.19	0.67 ± 0.04	30.5–35.4
Capsule height (CH)	9.60 ± 1.27	0.20 ± 0.03	6.7–11.8
Posterior apron (PA)	6.41 ± 1.45	0.13 ± 0.03	3.9–10.1
Right lateral keel (RK)	2.60 ± 0.45	0.05 ± 0.01	1.9–4.0
Left lateral keel (LK)	2.56 ± 0.37	0.05 ± 0.01	1.8–3.1
Right anterior horn length (RAH)	30.73 ± 4.79	0.63 ± 0.09	16.4–41.2
Left anterior horn length (LAH)	30.97 ± 4.11	0.63 ± 0.08	24–39.9
Right posterior tendrils length (RPH)	371.59 ± 228.14	7.37 ± 4.65	21.6–946.9
Left posterior tendrils length (LPH)	338.51 ± 219.14	6.88 ± 4.37	29.4–675.7
Respiratory fissures (RF)	9.7 ± 1.7	0.20 ± 0.03	6.9–10.2

species of the genus (Mabragaña et al. 2002, 2011; Oddone and Vooren 2002). Nevertheless, observations on the behavior of skates during the egg-laying process and the oviposition rate, with the exception of *Sympterygia bonapartii* (see Jañez and Sueiro 2009), are absent from the literature. Descriptions of egg capsules and information on the egg-laying rate, fecundity and size at maturity are poorly documented for the overwhelming majority of skates occurring in the southeastern Pacific. Available information on reproductive aspects, other than for *Psammobatis scobina* (Philippi 1857) (Concha et al. 2009) and *Zearaja chilensis* (Guichenot 1848) (Licandeo et al. 2006; Licandeo and Cerna 2007; Quiroz et al. 2007; Paesch and Oddone 2008; Mabragaña et al. 2011; Bustamante et al. 2012; Concha et al. 2012), is mostly restricted to technical reports.

The results of this study indicate that the length and width of the egg capsules of *S. lima* are more similar to those of *S. acuta* than to the egg capsules of *S. bonaparti* and *S. brevicaudata* (Table 2). Asymmetrically positioned respiratory fissures are present in egg capsules with long tendrils to facilitate water flow for ventilation and for the removal of metabolic wastes from the egg capsule with a minimal metabolic cost for the embryo (Leonard et al. 1999) while suspended vertically by tendrils (Flammang et al. 2007).

Though long and coiled tendrils are not common within Chondrichthyes, these structures are seen among cat sharks (Scyliorhinidae) (Gomes and De Carvalho 1995; Hernández et al. 2005; Oddone and Vooren 2008; Flammang et al. 2007; Concha et al. 2010). These fibers are more unusual within skates, occurring only, as shown here, in the genus *Sympterygia* (Oddone and Vooren 2002; Mabragaña et al. 2011). The term "tendril" should be used only to describe the long fibers that hold the egg capsule to the substratum, entangling themselves and surrounding any firm structure for fixation. The development of extremely long horns, which helps to secure anchorage with the substratum, could have important biological implications, because vertical positioning of egg capsules is thought to encourage passive flow of oxygen (Flammang et al. 2007). In the southwestern Atlantic, the long tendrils of *S. acuta* were suggested to be an adaptation for attachment to surf-aggregated debris as a response to the lack of hard bottom substrata on sandy beach waters (Oddone and Vooren 2002). Therefore, the presence of long tendril-like posterior horns became recognized as a useful character for distinguishing this genus from *Rioraja* Müller and Henle 1841 and *Atlantoraja* Menni 1972 in the Atlantic (Oddone and Vooren 2002) and from *Psammobatis* in the southeastern Pacific, in which egg capsules lack long tendrils (Concha et al. 2009). The lack of tendrils in skates inhabiting deeper habitats suggests an evolutionary divergence, as proposed by Flammang et al. (2007) for the genus *Apristurus* Garman 1913.

It has been observed that the respiratory fissures became unplugged during the first two-thirds or slightly before the middle of the incubation period (Luer and Gilbert 1985; Luer et al. 2007). In this study, the respiratory fissures were open for about 3 months after they were deposited, which suggests that the incubation period could be 6 or 7 months,

Table 2 Morphometric measurement of egg capsules of the genus *Sympterygia*

	Capsule length	Capsule width	Capsule height	Tendrils	Author
S. acuta	48 ± 2	30 ± 2	–	Present	Oddone and Vooren (2008)
S. bonapartii	77.5 ± 2.7	45.4 ± 2.2	–	–	Jañez and Sueiro (2007)
	76.75 ± 3.92	48.37 ± 0.74	–	Present	Mabragaña et al. (2002)
S. lima	48.95 ± 2.30	32.55 ± 1.19	9.60 ± 1.27	Present	This study
S. brevicaudata	51.12 ± 2.76	34.88 ± 1.95	11.43 ± 1.06	Present	Concha unpublished data

which is more similar to the approximately 7-month incubation time observed in *S. bonapartii* (see Jañez and Sueiro 2007).

In this work, the oviposition of *S. lima* is documented for the first time. Although this was observed under captive conditions, the way in which the female attaches the egg capsules to available substrata when in the wild is likely to be similar to what is described here. The egg-laying rate has been documented before in skates by Clark (1922), Holden et al. (1971), Du Buit (1976), Luer and Gilbert (1985), Ellis and Shackley (1995) and Ishihara et al. (2002). The first observations on the egg-laying rate for *Sympterygia* were reported by Jañez and Sueiro (2009) for *S. bonapartii*, whose deposition interval between successive pairs of egg capsules ranged between 2 to 12 days. In this work, the authors observed that a single female was capable of laying two pairs of egg capsules in 4 days. This result is consistent with Clark (1922) and Holden et al. (1971), which suggested that the egg capsule formation process is completed over a short period of time. The complete egg-laying process may take approximately 1–3 h in *S. bonapartii* (see Jañez and Sueiro 2009), while the same procedure in *S. lima* can successfully accomplished in 4 min. On the other hand, this study has demonstrated that a mature female of *S. lima* was capable of producing viable embryos even after 11 weeks of isolation from other males. This is likely due to an ability to store sperm for an uncertain period of time, allowing post-copulation fertilization in elasmobranch fishes (Clark 1922). However, the male gene contribution should be tested since recent studies have confirmed parthenogenesis in *Sphyrna tiburo* (Linnaeus 1758) (see Chapman et al. 2007) and *Carcharhinus limbatus* (Müller and Henle 1839) (see Chapman et al. 2008).

Description of the egg capsules can shed light on the taxonomy, distribution and reproductive habits of both *S. lima* and *S. brevicaudata*, two species with overlapping distribution ranges in Chile (Pequeño and Lamilla 1997). The occurrence of egg capsules indicates the presence of species in places where adult individuals are not easy to obtain. Moreover, egg capsule descriptions will be useful to determine the location and timing of oviposition, since newly deposited egg capsules may be easily distinguished from others deposited in different seasons. Thus, egg capsule sampling and the systematic observation of egg-laying locations could emerge as an important and nonlethal method to assess the reproductive cycle in this genus and possibly in many other skate species.

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