Online ISSN: 0718-1957 RBMO

Revista de Biología Marina y Oceanografía
Vol. 59(1): 29-38, 2024
<https://doi.org/10.22370/rbmo.2024.59.1.4423>

ARTICLE

Reproductive cycle of the sub-Antarctic nototheniid *Patagonotothen cornucola* (Nototheniidae) in the Argentine Patagonian Shelf

Ciclo reproductivo del nototénido subantártico *Patagonotothen cornucola* (Nototheniidae) en la costa de la Patagonia Argentina

Mauro S. Marcinkevicius[1,2*], Carolina C. Serrano-Aguirre[2], Bárbara A. Jones[2] and María V. Álvarez[1,2]

[1]Instituto de Desarrollo Costero, Universidad Nacional de la Patagonia San Juan Bosco, Ciudad Universitaria, Km 4, Comodoro Rivadavia, Chubut, Argentina, CP (9005)
[2]Facultad de Ciencias Naturales, Universidad Nacional de la Patagonia San Juan Bosco, Ciudad Universitaria Km 4, 9005 Comodoro Rivadavia, Chubut, Argentina
*Corresponding author: msmarcin@gmail.com

Resumen.- La familia Nototheniidae es la más numerosa entre los nototénidos y, a pesar de ser principalmente Antárticos, están muy bien representados en aguas patagónicas. Desde la Antártida hasta las aguas de Sudamérica, han adoptado una gran variedad de estrategias reproductivas. Los peces antárticos suelen tener un ciclo reproductivo bienal mientras que en aguas sub-antárticas los nototénidos pueden reproducirse anualmente o bianualmente. En la zona intermareal de la Patagonia central, el pez más abundante es *Patagonotothen cornucola* y, a pesar de esto, hay poca información sobre su biología. Por esto, el objetivo principal de este trabajo fue estudiar su ciclo reproductivo en la zona intermareal rocosa usando métodos histológicos y morfológicos. Las muestras fueron recolectadas mensualmente en dos sitios intermareales en el Golfo San Jorge, y se calculó el factor de condición, índices hepatosomáticos y gonadosomáticos y se realizaron cortes histológicos de las gónadas que fueron teñidas con tricrómico de un tiempo para determinar los estadios gonadales, además se estimó la fecundidad potencial y relativa. Se determinó que machos y hembras maduran sincrónicamente alcanzando los valores máximos de índices gonadosomáticos entre julio y agosto. En las hembras el índice hepatosomático aumenta simultáneamente con el gonadosomático mientras que en machos se mantiene constante durante todo el ciclo. Se concluye que *P. cornucola* tiene un ciclo reproductivo anual y que el desove ocurre en el invierno. La fecundidad potencial máxima fue de 27.095 oocitos en una hembra de 11,7 cm y se incrementa con la talla.

Palabras clave: *Patagonotothen cornucola*, reproducción, Patagonia, Nototénidos

Abstract.- Nototheniidae is the most numerous family of notothenioids and, although they are mainly Antarctic, they are also well represented in Patagonian waters. In both Antarctic and sub-Antarctic waters, they adopt a wide variety of reproductive strategies. In Antarctic waters they usually have a biennial reproductive cycle, whereas in sub-Antarctic ones, they reproduce annually or biannually. In the intertidal zone of central Patagonia the most abundant nototheniid fish is *Patagonotothen cornucola* and, despite this, there is little information about their biology. The aim of this work was to study its reproductive cycle in a rocky intertidal coast of Argentine Patagonia by means of histological and morphological analyses. Samples were collected monthly at two intertidal sites in the San Jorge Gulf. Condition factor, gonadosomatic and hepatosomatic indexes were calculated and thin sections of gonads were stained with one-step trichrome to determine gonadal stages. Relative and potential fecundity were also estimated. Males and females mature synchronously and reach maximum gonadosomatic index between July and August. In females the hepatosomatic index increases synchronously with gonadosomatic index, while in males it remains constant throughout the cycle. It is concluded that *P. cornucola* has an annual reproductive cycle and that spawning occurs in winter. Maximum potential fecundity is approximately 27,095 oocytes in a 11,7 cm female and it increases with size.

Key words: *Patagonotothen cornucola*, reproduction, Patagonia, notothenioids

INTRODUCTION

The suborder Notothenioidei is a large group of fishes, comprising eight families, distributed mainly in the cold waters of the Antarctica as well as in temperate sub-Antarctic waters. Among notothenioids, the family Nototheniidae is the most numerous, with 12 genera and about 49 species (Eastman & Eakin 2021). On the coast of Argentine Patagonia, notothenioids are represented by the family Bovichtidae with two genera, *Bovichtus* and *Cottoperca*, the monotypic family Eleginopidae with the species *Eleginops maclovinus*, and the family Nototheniidae, with one species of the genera *Dissostichus*, *Paranotothenia* and *Lepidonotothen*, two species of the genus *Notothenia*, and eleven species of the genus *Patagonotothen* (Menni *et al*. 1984, López *et al*. 1996).

In Patagonia, some species like *Bovichtus chilensis* and *Notothenia angustata* are benthic and live in rocky reefs (Menni & Gosztonyi 1982, Torres *et al*. 2006), whereas others such as *Eleginops maclovinus* is bentho-pelagic fish living along the coast (Gosztonyi 1974, Sánchez & Prenski 1996, Ceballos *et al*. 2012). Other species like *Patagonotothen ramsayi* and *Dissostichus eleginoides* are abundant in deeper waters (Martínez & Wöhler 2010, Bovcon *et al*. 2013) and are bentho-pelagic. Some of these species grow in intertidal habitats protected under rocks or in rockpools until they migrate to the definitive areas where adults live (Hidalgo *et al.* 2007). In the intertidal zone, they coexist with other representatives such as *Patagonotothen cornucola* and *P. sima* (Gosztonyi & Lopez-Arbarello 2000, Hidalgo *et al*. 2007).

Patagonotothen cornucola Richardson, 1844 is one of the most abundant intertidal fishes of central Patagonia. This species is a typical benthic fish that lives under rocks, among algae or in tidal pools. It is distributed in the southern American cone, including the Falkland Islands (Lloris & Rucabado 1991). The feeding habits of this species are well known throughout much of its distribution (Moreno & Jara 1984, Hidalgo *et al.* 2007, Hüne & Vega 2016, Marcinkevicius *et. al.* 2021), but there are no data about its reproductive cycle.

It is well known that Antarctic nototheniids have a biennial sexual cycle and that the season in which they spawn depends on latitude. Those living in the seasonal-pack ice zone spawn in autumn and winter, while those living in the high Antarctic zone spawn in spring and summer (Duhamel *et al*. 1993, La Mesa *et al*. 2006). In the Beagle Channel, at the southernmost tip of South America, *Patagonotothen tessellata* has a biannual sexual cycle and spawns in July and February (Rae & Calvo 1995a, b), *Paranotothenia magellanica* has an annual cycle with winter spawning (Rae 1991), and *Harpagifer bispinis* has an annual cycle and spawns from mid-July through August (Llompart *et al*. 2020).

The aim of the present study was to provide first and original data on the reproductive cycle of *P. cornucola* in an intertidal rocky shore, using histological and morphological techniques.

MATERIALS AND METHODS

STUDY SITE

The study was carried out in two sites of an intertidal rocky coast of the San Jorge Gulf (central Patagonia), 12 km apart: “El Pique” in the north (45°43‘06”S-67°20’38”W) and “Playa Km 8” in the south (45°48’47”S-67°24’46”W) (Fig. 1). Both sites are broad rocky platforms with shallow tide pools, scattered free rocks and channels that connecting them to open waters.

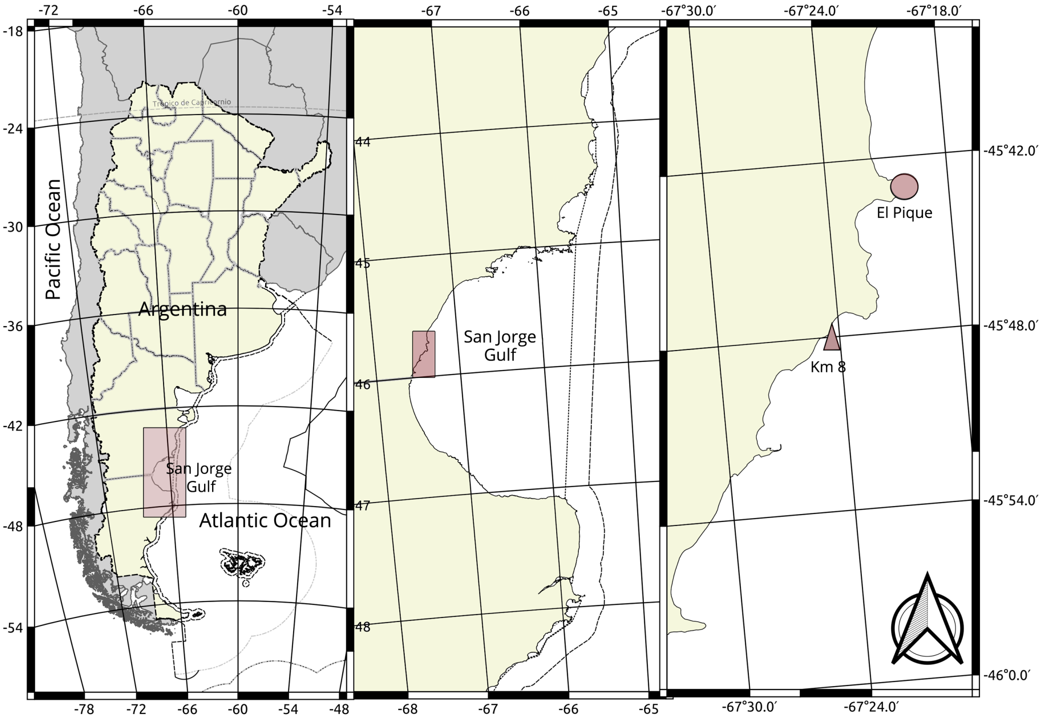

Figure 1. Sampling sites at "El Pique" and "Playa Km 8" beaches in the San Jorge Gulf, Chubut, Argentina / Sitios de muestreo en las playas "El Pique" y "Playa Km 8" del Golfo San Jorge, Chubut, Argentina

Sampling and analysis methods

Sampling was performed monthly from June 2008 to January 2011. A total of 1,214 fishes were collected (Table 1). Specimens were collected by hand under rocks and processed in the laboratory. The total length (TL) of each fish was recorded to the nearest mm. Sex was determined macroscopically by observing the gonads, which were preserved in 10% formalin solution. Eviscerated weight (EW), liver weight (LW) and formolized gonadal weight (GW) were determined with a precision of 0.01 g.

For histological analyses, 435 specimens (176 males and 259 females) were selected from June 2008 to November 2010 (Table 1). Gonads were refixed in Bouin's solution (Kristoffersson & Pekkarinen 1975) and stored in 70% ethanol. They were then dehydrated in ethanol and butanol, and embedded in paraffin. Sections between 5 µm and 7 µm were cut and stained with the one-step trichrome procedure (Gabe 1968).

Following the terminology proposed by Brown-Peterson *et al*. (2011), gonads were histologically classified into four stages: developing, spawning, regressing and regenerating. The gonadosomatic index (GI), calculated as GI= (GW/EW)·100, was considered a proxy indicator of energy invested in reproduction. The hepatosomatic index (HI), calculated as HI= (LW/EW)·100, was considered as a proxy for the energy reserve stored in the liver. Finally, Fulton's condition of factor (K), calculated as K= (EW/TL^3)·100, was considered as a proxy for energy stored in muscle. Gonadal reproductive phases, GI, HI and K were plotted against month, and data from both sites were pooled (Muñoz *et al*. 2010, Hajji *et al*. 2013).

Potential fecundity was estimated gravimetrically with fixed ovarian samples from 73 specimens (Murua *et al*. 2003, Witthames *et al*. 2009). The anterior, middle and posterior sections of each ovary were sampled, weighed to the precision of 0.1 mg and the number of oocytes counted. Only vitellogenic oocytes were used to estimate fecundity. Potential fecundity was calculated as the ratio of ovary weight to sample weight multiplied by the number of oocytes in the sample. Relationships of potential fecundity with TL and EW were assessed by simple linear regression (Sokal & Rohlf 1995). Relative fecundity was calculated as potential fecundity divided by EW.

Sex ratio was tested using the "prop.test" function of the "stats" package of the R software (R Core Team 2020) in RStudio (2020).

Table 1. Distribution of *Patagonotothen cornucola* samples by month and year of sampling in the San Jorge Gulf intertidal / Distribución de las muestras de *Patagonotothen cornucola* por mes y año de recolecta en el intermareal del Golfo San Jorge

	2008		2009		2010		2011	
	N	H	N	H	N	H	N	H
January	-	-	18	10	30	-	26	-
February	-	-	20		64	40	-	-
March	-	-	49	13	54	27	-	-
April	-	-	63	13	30	20	-	-
May	-	-	66	29	64	22	-	-
June	15	4	65	45	60	6	-	-
July	25	5	64	29	31	-	-	-
August	20		64	28	30	-	-	-
September	27	14	55	35	59	-	-	-
October	25	-	53	34	28	-	-	-
November	16	6	11	16	46	31	-	-
December	22	8	-	-	14	-	-	-

N: number of specimens collected by month
H: number of specimens used in histological analyses by month

Results

Out of a total of 1,214 fish sampled, 526 were females and 688 males. The TL of females varied between 5.1 and 13.2 cm, whereas the EW varied between 1.56 and 30.07 g. The TL of males varied between 4.4 and 13.2 cm and the EW varied between 1.25 and 34.89 g. The overall sex ratio (male:female) was 1.3:1 (*i.e.*, significantly different from the expected ratio of 1:1) (X^2= 21.352, df= 1, $P < 0.0001$).

In females, the plot of GI against month showed an annual reproductive cycle with one reproductive event (Fig. 2). GI remained low from September to May, when it started to increase until August. Spawning occurred between July and August. HI had approximately the same cycle as GI. Maximum HI values were observed in June, shortly before GI reached its maximum values. Although K it did not show a great annual variation, values decreased in June, before spawning.

In males, the GI plot against month also showed an annual reproductive cycle with one reproductive event (Fig. 3). Corresponding to what was observed in females, GI remained low between September and May, reaching the maximum value in August. HI and K showed no variation during the year.

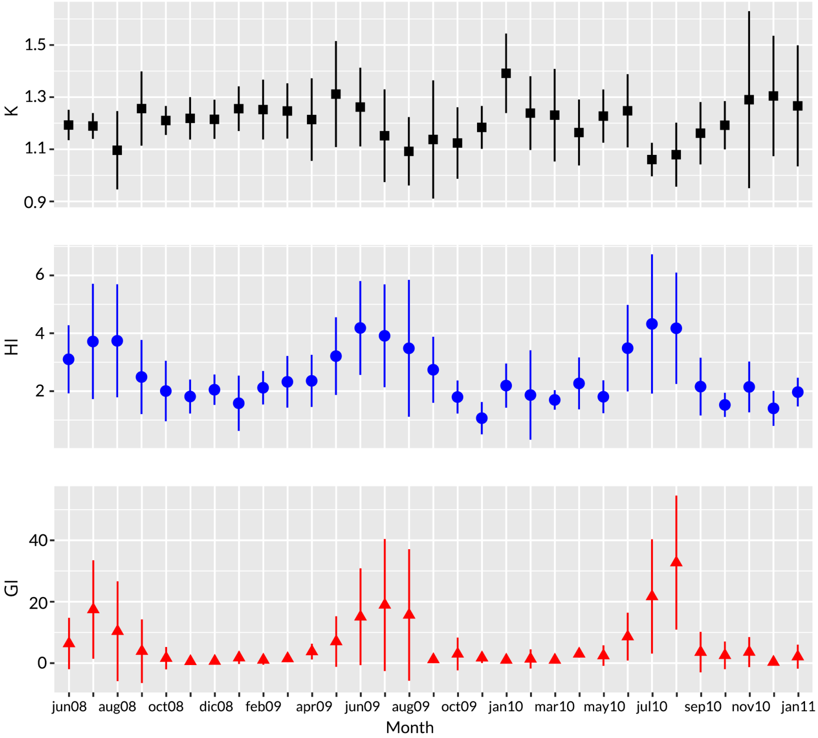

Figure 2. Monthly variation of gonadosomatic index (GI), hepatosomatic index (HI) and Fulton's condition factor (K) for *P. cornucola* females / Variación mensual del índice gonadosomático (GI), índice hepatosomático (HI) y el factor de condición de Fulton (K) para hembras de *P. cornucola*

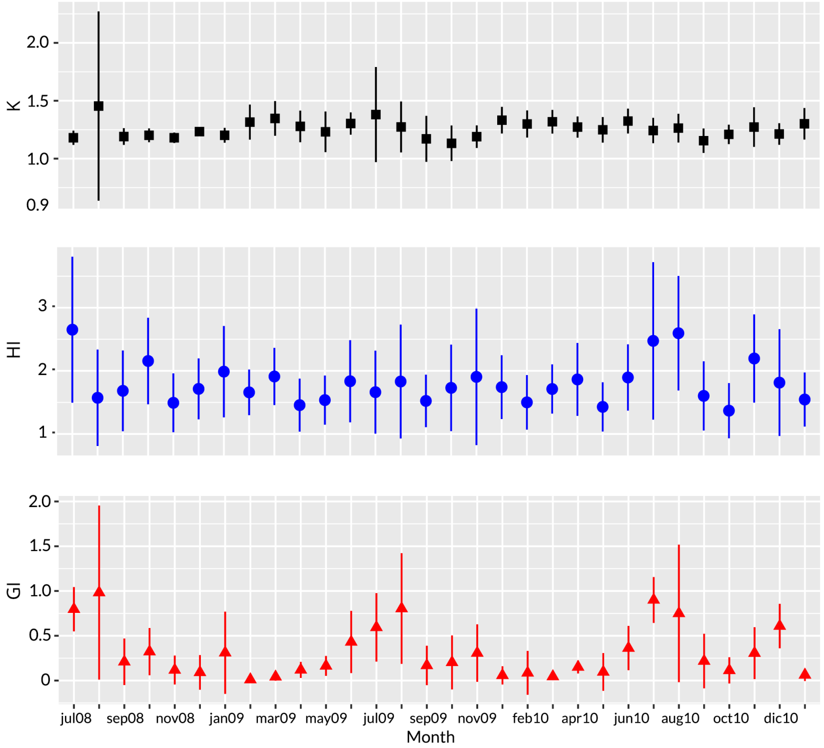

Figure 3. Monthly variation of gonadosomatic index (GI), hepatosomatic index (HI) and Fulton's condition factor (K) for *P. cornucola* males / Variación mensual del índice gonadosomático (GI), índice hepatosomático (HI) y el factor de condición de Fulton (K) para machos de *P. cornucola*

Histological analysis confirmed the results of the annual GI cycle. Maximum abundance of vitellogenic oocytes 3 (Vit3) was observed in July, while the presence of oocytes in germinal vesicle migration phase (GVM) was observed in July and August (Figs. 4A and 5). This indicates that oocytes were ready to spawn. In September, most oocytes were in the cortical alveoli (CA) phase, indicating that spawning had been completed. Maximum frequency of testis in spawning capable phase (SC) was observed in July and August, whereas that of testis in regressing phase (Rss) was observed in September and October (Figs. 4B and 6). This observation is consistent with the maturation phases of females and confirms that spawning occurs between July and August.

The TL of the specimens used to determine fecundity ranged between 6.5 cm and 11.7 cm, whereas their EW ranged between 3.42 g and 18.68 g. Potential fecundity ranged between 1,826 to 27,095 oocytes per female and relative fecundity ranged between 260.4 and 2,651.7 oocytes per gram of EW. The variation of potential fecundity with TL (AdjR^2= 0.39) and EW (AdjR^2= 0.42) is shown in Figure 7A and B. In both cases, an increase in potential fecundity was observed with increasing size.

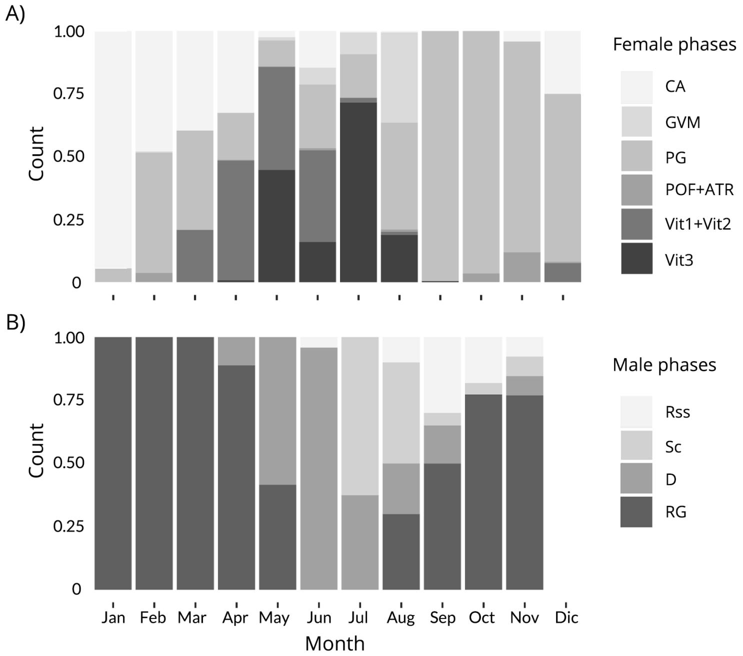

Figure 4. Monthly variation of gonadal phases during reproductive cycle of *P. cornucola*. A) Female phases. B) Male phases. ATR: atretic oocyte, CA: oocyte in cortical alveolar phase, D: development stage, GVM: oocyte in germinal vesicle migration phase, PG: oocyte in primary growth phase, POF: post-ovulatory follicle, RG: regenerating stage, Rss: regression stage, Sc: spawning capable stage, Vit1: oocyte in primary vitellogenic, Vit2: oocyte in secondary vitellogenic, Vit3: oocyte in tertiary vitellogenic / Variación mensual de las fases gonadales durante el ciclo reproductivo de *P. cornucola*. A) Fases de hembras. B) Fases de machos. ATR: oocito atrésico, CA: oocito en fase cortical alveolar, D: fase de desarrollo, GVM: oocito en fase de migración de la vesícula germinal, PG: oocito en fase de crecimiento primario, POF: folículo post ovulatorio, RG: fase de regeneración, Rss: fase de regresión, Sc: fase de preparados para el desove, Vit1: oocito en vitelogénesis primaria, Vit2: oocito en vitelogénesis secundaria, Vit3: oocito en vitelogénesis terciaria

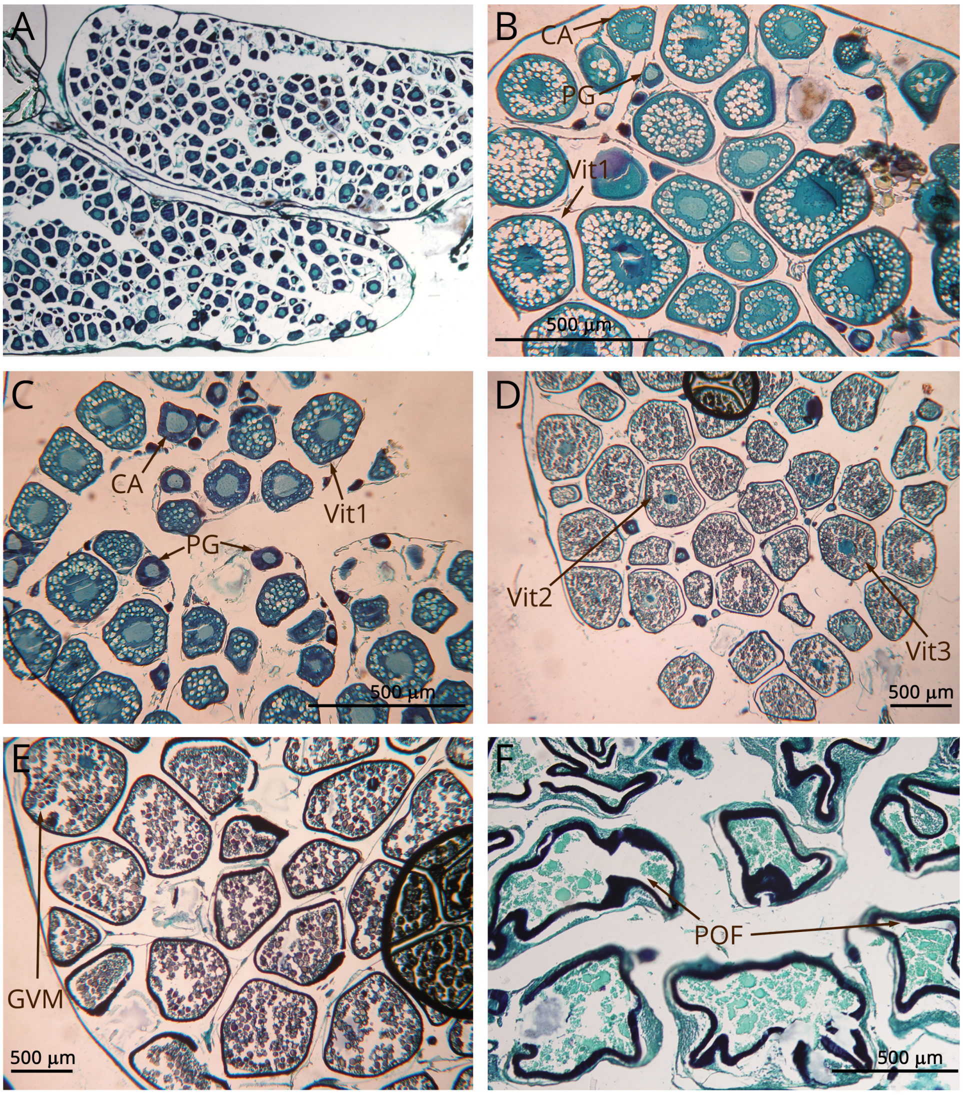

Figure 5. Photomicrograph showing the stages of ovary development in *P. cornucola*. A) Overall view of a regenerating ovary, B-C) ovary in early development stage, D) ovary in advanced development stage, E) ovary in spawning capable stage, F) ovary in regressing stage. CA: oocyte in cortical alveolar phase, GVM: oocyte in germinal vesicle migration phase, PG: oocyte in primary growth phase, POF: post-ovulatory follicle, Vit1: oocyte in primary vitellogenic, Vit2: oocyte in secondary vitellogenic, Vit3: oocyte in tertiary vitellogenic / Microfotografía mostrando los estadios de desarrollo del ovario en *P. cornucola*. A) Vista general de un ovario en regeneración, B-C) ovario en estadio de desarrollo temprano, D) ovario en estadio de desarrollo avanzado, E) ovario en estadio preparado para desovar, F) ovario en estadio de regresión. CA: oocito en fase cortical alveolar, GVM: oocito en fase de migración de la vesícula germinal, PG: oocito en fase de crecimiento primario, POF: folículo post ovulatorio, Vit1: oocito en vitelogénesis primaria, Vit2: oocito en vitelogénesis secundaria, Vit3: oocito en vitelogénesis terciaria

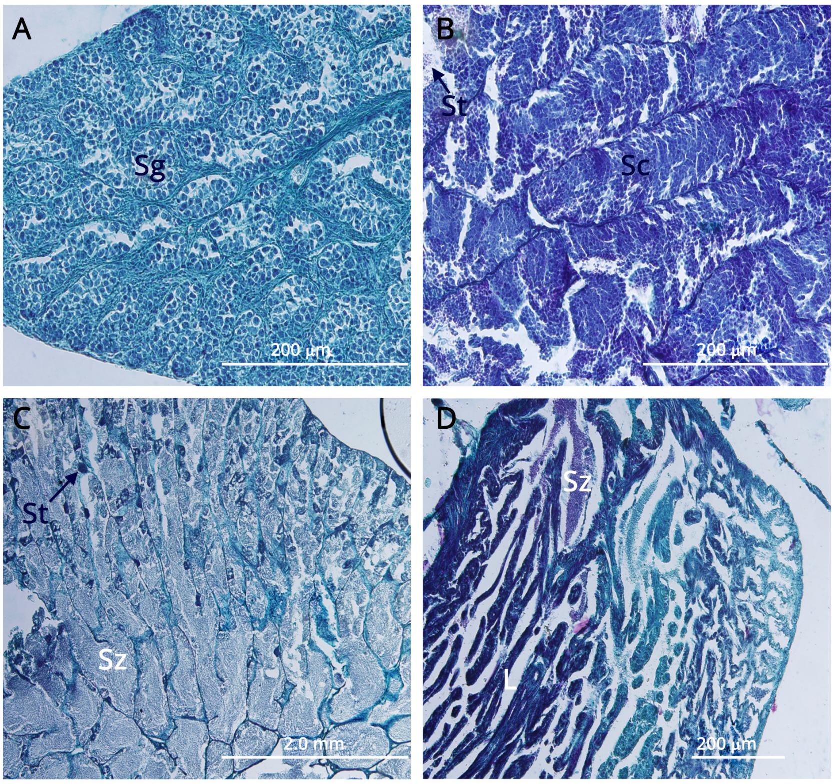

Figure 6. Photomicrograph of testicular development stages in *P. cornucola*. A) testis in regenerating stage, B) testis in developmental stage, C) testis in spawning capable stage, D) testis in regression stage. L: lumen, Sc: spermatocyte, Sg: spermatogonia, St: spermatid, Sz: spermatozoa / Microfotografía los estadios de desarrollo testiculares en *P. cornucola*. A) testículo en estadio de regeneración, B) testículo en estadio de desarrollo, C) testículo en estadio preparado para desovar, D) testículo en estadio de regresión. L: lumen, Sc: espermatocisto, Sg: espermatogonia, St: espermátida, Sz: espermatozoide

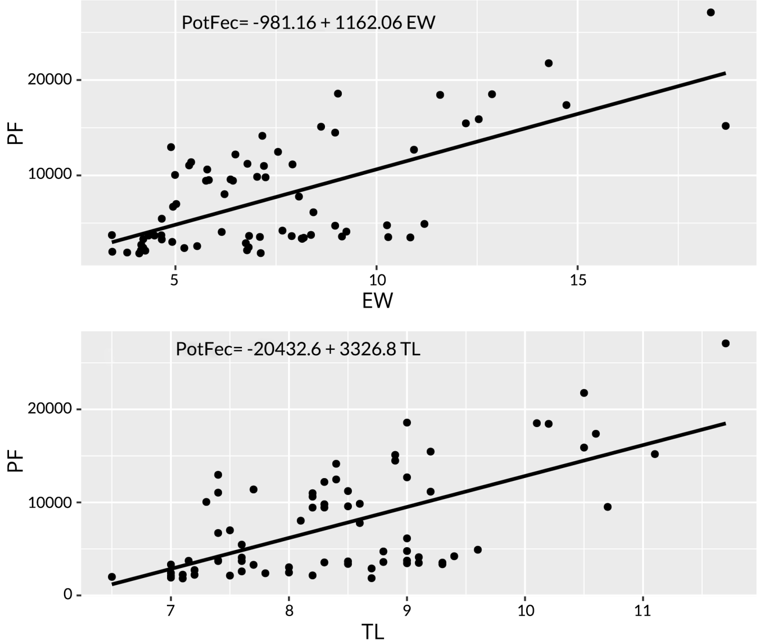

Figure 7. Regression of potential fecundity (PF) with respect to: A) evicerated weight (EW) and B) total length (TL) in *P. cornucola* from Patagonian intertidal rocky shores / Regresión de la fecundidad potencial (PF) respecto de: A) peso eviscerado (EW) y B) longitud total (TL) en *P. cornucola* de intermareales rocosos patagónicos

DISCUSSION

This study provides the first data on the reproductive cycle of the nototheniid fish *Patagonotothen cornucola*. The gonads are like those of most teleosts: females have cystovarian-type ovaries, in which the coelom forms a closed sac, the lumen, where ovulation occurs (McMillan 2007), whereas males have unrestricted lobular-type testes, with blind lobules at their distal end, and cysts with developing germ cells distributed around them (Vizziano *et al*. 2008).

According to the annual GI trend, *P. cornucola* gonads remain underweight from spring to mid-autumn and then undergo rapid growth until mid-winter, when they reach the maximum weight. This was confirmed by histological analyses, which showed that, from spring to mid-autumn, females move from the regressing (post-ovulatory follicles + atretic oocytes) and regenerating phases [primary growth oocytes (PG)] to the developing phases (PG+CA+Vit1+Vit2); and then, until mid-winter, to the SC phase (Vit3+GVM). Two groups of oocytes at different development stages were observed at the same time: one group of PG oocytes appearing throughout the year and a second group that shift to the developing phases to spawn in that season. This is clear evidence that *P. cornucola* spawn synchronously.

In the case of males, the maximum frequency of SC testes was observed in mid-winter, following the sequence of gonadal phases observed in females. This indicates that *P. cornucola* has only one reproductive period during the year and that spawning occurs in winter, between July and August. This differs from that observed in the Beagle Channel by Rae (1991), who, based on the observation of females at different stages of maturation in winter and summer, suggested that *P. cornucola* has two spawning periods in one year. However, this author did not develop a complete reproductive study. It would thus be interesting to study whether *P. cornucola* has one reproductive period per year in the north and two periods in the south of its distribution.

Results of this and previous studies allow concluding that notothenioids show different reproductive patterns. For example, in central Patagonia, *P. cornucola* has an annual oocyte maturation cycle with one yolked oocytes batch and one reserve stock of oocyte, and therefore one spawning period per year during winter. In the Beagle Channel, *P. tessellata* has a biannual oocyte maturation cycle with a batch of yolked oocyte and one reserve stock of oocyte, and therefore two spawning periods per year, one in winter and another in summer (Rae 1991, Rae & Calvo 1995a). In Antarctica, nototheniids have a biennial oocyte maturation cycle, with seasonal-pack ice species spawning in autumn/winter and high-Antarctic zone species spawning in spring/summer (Kock & Kellerman 1991).

Temperature also seems to play a very important role in the sexual cycle of nototheniids, as there is latitudinal variation in reproductive seasons related to temperature. In central Patagonia, *P. cornucola* reproduces in winter with water temperatures ranging between 8 to 11 °C (per. obs of the main author), whereas, in the Beagle Channel, *P. cornucola* has one or two reproductive periods, one in winter, with temperatures around 4.3 °C, and the other in summer, with temperatures between 9 and 11 °C (Rae & Calvo 1995a). Apparently, nototheniids do not prefer temperatures above 11 °C, so it would be interesting to study species living north of the San Jorge Gulf.

Another effect of the environmental conditions on the reproductive cycle of *P. cornucola* can be seen at the beginning and end of the SC phase: in 2008 and 2009 females reached this phase in August, whereas in 2010 they reached it in July. In contrast, in 2008 and 2009 males reached this phase in July, whereas in 2010 they reached it in August. Variability of the sexual cycle in relation to environmental conditions has also been observed in other notothenioids species, such as in *Trematomus* from Antarctic waters, which show plasticity with respect to environmental and ecological conditions that can vary geographically and temporally (La Mesa *et al*. 2006), and *P. tessellata*, in which gametogenesis occurs more rapidly in summer than in winter (Rae & Calvo 1995a).

Vitellogenin, which is involved in oocyte maturation and largely responsible for oocyte growth, is produced in the liver (McMillan 2007). The simultaneous increase in HI and GI in *P. cornucola* females and their subsequent decrease indicate that vitellogenesis is occurring. In June, just before spawning, there was a slight decrease in K. Perhaps the high energy demand in the last part of the vitellogenesis process requires an extra source of energy from somatic tissues.

In males, HI and K did not show seasonal variation as observed in GI. This is evidence of the low energy required for testicular maturation. In *P. tessellata* males from the Beagle Channel, Rae & Calvo (1995a) observed a decrease in HI during evacuation and suggested that this species uses energy stored in the liver to sustain general metabolism during nesting, a period during which males do not feed. In *P. cornucola* from San Jorge Gulf, parental care was observed during August, after spawning, but it could not determine whether it is the male or female that care of the nest or whether they feed during nesting. These issues are subject for future research.

Finally, a maximum potential fecundity (PF) of 27,095 oocytes was observed in the largest female (11.7 cm TL). As expected, the number of oocytes per female was size-dependent and increased with increasing size. These results are in agreement with those previously reported for other sub-Antarctic and Antarctic notothenioids, which showed a wide range of PFs in relation to parental fish size and latitudinal distribution. As an example, *P. tessellata* spawned 62,033 oocytes in the Beagle Channel at 24 cm TL, *Notothenia angustifrons* spawned 12,900 oocytes off the South Sandwich Islands at 17 cm TL, and *Nototheniops nudifrons* spawned 9,866 oocytes in South Georgia at 18 cm TL (Kock & Kellerman 1991, Rae & Calvo 1995b).

ACKNOWLEDGMENTS

We thank Dr. Atila Gsztonyi (from CENPAT-CONICET, Puerto Madryn, Argentina) for counseling on the biology of *P. cornucola* and Lic. Héctor Zaixso† and Dr. Julio Vinuesa (from the Instituto de Desarrollo Costero, Comodoro Rivadavia, Argentina) for counseling on histological techniques. This study was supported by the Project “Reproducción y dieta de *Patagonotothen cornucola* (Nototheniidae) en el área central del golfo San Jorge” - PI: 973, Secretaría de Ciencia y Técnica, Universidad Nacional de la Patagonia San Juan Bosco, Chubut, Argentina.

LITERATURE CITED

Bovcon ND, ME Góngora, C Marinao & D González-Zevallos. 2013. Composición de las capturas y descartes generados en la pesca de merluza común *Merluccius hubbsi* y langostino patagónico *Pleoticus muelleri*: un caso de estudio en la flota fresquera de altura del Golfo San Jorge, Chubut, Argentina, Revista de Biología Marina y Oceanografía 48(2): 303-319.

Brown-Peterson NJ, DM Wyanski, F Saborido-Rey, BJ Macewicz & SK Lowerre-Barbieri. 2011. A standardized terminology for describing reproductive development in fishes, Marine and Coastal Fisheries 3(1): 52-70.

Ceballos SG, EP Lessa, MF Victorio & DA Fernández. 2012. Phylogeography of the sub-Antarctic notothenioid fish *Eleginops maclovinus*: evidence of population expansion. Marine Biology 159: 499-505.

Duhamel G, KH Kock, E Balguerias & JC Hureau. 1993. Reproduction in fish of the Weddell Sea. Polar Biology 13: 193-200.

Eastman JT & Eakin RR. 2021. Checklist of the species of notothenioid fishes. Antarctic Science 33(3): 273-280.

Gabe M. 1968. Techniques histologiques, 1113 pp. Masson et Cie, Éditeurs, Paris.

Gosztonyi AE. 1974. Edad y crecimiento del “Robalo” *Eleginops maclovinus* (Osteichthyes, Nottotheniidae) en aguas de la Ría Deseado y sus adyacencias. Physis A 33(86): 1-8.

Gosztonyi AE & A Lopez-Arbarello. 2000. Sexual dimorphism in *Patagonotothen sima* (Richardson, 1844). Antarctic Science 12(4): 427-428.

Hajji F, A Ouannes-Ghorbel, M Ghorbel & O Jarboui. 2013. Reproductive biology of the black goby, *Gobius niger* (Teleostei: Gobiidae), in the Gulf of Gabès (Tunisia, Central Mediterranean). Journal of the Marine Biological Association of the United Kingdom 93(6): 1685-1693.

Hidalgo FJ, BR Silliman, MC Bazterrica & MD Bertness. 2007. Predation on the Rocky Shores of Patagonia, Argentina. Estuaries and Coasts 30(5): 886-894.

Hüne M & R Vega. 2016. Feeding habits in two species of Notothenioidei, *Patagonotothen cornucola* and *Harpagifer bispinis*, in the Chilean Patagonian channels and fjords. Polar Biology 39: 2253-2262.

Kristoffersson R & M Pekkarinen. 1975. Histological changes in the testes of brackish-water *Zoarces viviparus* (L.) in relation to the reproductive cycle. Annales Zoologici Fennici 12: 205-210.

Kock KH & A Kellermann. 1991. Reproduction in Antarctic notothenioid fish - a review. Antarctic Science 3: 125-150.

La Mesa M, L Ascoli & V Caputo. 2006. Gametogenesis and reproductive strategies in some species of the Antarctic fish genus *Trematomus* (Nototheniidae) from Terra Nova Bay, Ross Sea. Polar Biology 29: 963-970.

Llompart FM, DA Fernández, D Aureliano & M La Mesa. 2020. Life-history traits of the Magellan plunderfish *Harpagifer bispinis* (Forster, 1801) in the Beagle Channel (Tierra del Fuego, South America). Polar Biology 43: 1643-1654.

Lloris D & J Rucabado. 1991. Ictiofauna del Canal Beagle (Tierra de Fuego), aspectos ecológicos y análisis biogeográfico. Publicaciones Especiales, Instituto Español de Oceanografía 8: 1-182.

López HL, ML García & NA San Román. 1996. Lista comentada de la ictiofauna del Canal de Beagle, Tierra del Fuego, Argentina. Contribución Científica, Publicación Especial CADIC 23: 1-81.

Marcinkevicius M, BA Jones, CC Serrano-Aguirre & MV Álvarez. 2021. Food habits of *Patagonotothen cornucola* (Nototheniidae) in Patagonian Shelf (Southwest Atlantic). Journal of Ichthyology 61(6): 891-899.

Martínez PA & OC Wöhler. 2010. Estimación de la abundancia y el potencial pesquero de la merluza negra (*Dissostichus eleginoides*) del Atlántico Sudoccidental. Periodo 1986-2009, Informe Técnico INIDEP 19: 1-35.

McMillan DB. 2007. Fish histology: Female reproductive systems, 598 pp. Springer, Dordrecht.

Menni RC & AE Gosztonyi. 1982. Benthic and semidermersal fish associations in the Argentine Sea. Studies on Neotropical Fauna and Environment 17: 1-29.

Menni RC, RA Ringuelet & RH Aramburu. 1984. Peces marinos de la Argentina y Uruguay. 359 pp. Hemisferio Sur, Buenos Aires.

Moreno CA & FH Jara. 1984. Ecological studies on fish fauna associated with *Macrocystis pyrifera* belts in the south of Fueguian Islands, Chile. Marine Ecology Progress Series 15: 99-107.

Muñoz M, C Dimitriadis, M Casadevall, S Vila, E Delgado, J Lloret & F Saborido-Rey. 2010. Female reproductive biology of the bluemouth *Helicolenus dactylopterus dactylopterus*: spawning and fecundity. Journal of Fish Biology 77: 2423-2442.

Murua H, G Kraus, F Saborido-Rey, PR Witthames, A Thorsen & S Junquera. 2003. Procedures to estimate fecundity of marine fish species in relation to their reproductive strategy. Journal of Northwest Atlantic Fishery Science 33: 33-54.

Rae GA. 1991. Biología reproductiva comparada de dos especies de Notothenidos del Canal de Beagle. Tesis Doctoral, Universidad Nacional de La Plata, La Plata, 148 pp.

Rae GA & J Calvo. 1995a. Annual gonadal cycle and reproduction in *Patagonotothen tessellata* (Richardson 1845 (Nototheniidae: Pisces) from the Beagle Channel, Argentina. Journal of Applied Ichthyology 11: 60-70.

Rae GA & J Calvo. 1995b. Fecundity and reproductive habits in *Patagonothen tessellata* (Richardson, 1845) from the Beagle Channel, Argentina. Antarctic Science 7: 235-240.

R Core Team. 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, version 3.6.3, Vienna. <https://www.R-project.org/>

RStudio Team. 2020. RStudio: Integrated Development Environment for Rstudio, Version 1.2.5033. Posit Connect, Boston. <http://www.rstudio.com/>

Sánchez F & LB Prenski. 1996. Ecología trófica de peces demersales en el Golfo San Jorge, Revisa de Investigación y Desarrollo Pesquero 10: 57-71.

Sokal R & J Rohlf. 1995. Biometry: the principles and practice of statistics in biological research, 887 pp. W. H. Freeman and Company, San Francisco.

Torres ER, A Manero & FA Vargas. 2006. Listado sistemático y distribución temporal de los peces del estuario Río Gallegos (Santa Cruz, Argentina). Anales del Instituto de la Patagonia, Chile 34: 59-64.

Vizziano D, A Fostier, M Loir & F Le Gac. 2008. Testis development, its hormonal regulation and spermiation induction in teleost fish. In: Alavi SMH, J Cosson, R Rafiee & K Coward (eds). Fish spermatology, 465 pp. Alpha Science International, Melbourne.

Witthames PR, A Thorsen, H Murua, F Saborido-Rey, LN Greenwood, R Dominguez, M Korta & OS Kjesbu. 2009. Advance in methods for determining fecundity: application of the new methods to some marine fishes. Fishery Bulletin 107: 148-164.

Received 16 May 2023
Accepted 06 October 2023

Editor: Pilar Muñoz Muga

RBMO CITATION STYLE

Marcinkevicius MS, CC Serrano-Aguirre, BA Jones & MV Álvarez. 2024. Reproductive cycle of the sub-Antarctic nototheniid *Patagonotothen cornucola* (Nototheniidae) in the Argentine Patagonian Shelf. Revista de Biología Marina y Oceanografía 59(1): 29-38. <https://doi.org/10.22370/rbmo.2024.59.1.4452>