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Teratological records in blue shark *Prionace glauca* embryos from the South-western Atlantic Ocean

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Abstract

Abnormal embryonic development may result from mutations caused by genetics, environmental conditions or viruses. This study reports cases of cyclopia and a mouth malformation in two embryonic blue shark *Prionace glauca* collected off southern Brazil (South-western Atlantic). Such malformations are likely to reduce the chances of survival of embryos and neonates.

Introduction

Within the last two decades, reports of abnormalities in elasmobranch embryos have increased worldwide, and a wide variety of abnormal morphological conditions have been described. The reports come from a range of seas and oceans, including the Atlantic Ocean (Clark, 2002; Coelho & Erzini, 2006; Mancini *et al.*, 2006; Delpiani *et al.*, 2011; Zaera & Johnsen, 2011; Wagner *et al.*, 2013; Dos Santos & Gadig, 2014; Afonso *et al.*, 2016; Lamarca *et al.*, 2017; Ramírez-Amaro *et al.*, 2019; Prado *et al.*, 2020), Pacific Ocean (Goto *et al.*, 1981; Clark, 2002; Bejarano-Álvarez *et al.*, 2011; Galván-Magaña *et al.*, 2011; Hevia-Hormazábal *et al.*, 2011; Bejarano-Álvarez & Galvãn-Magaña, 2013; Muñoz-Osorio, *et al.*, 2013; Escobar-Sanchez *et al.*, 2014; Becerril-García *et al.*, 2017; Pastén-Marambio *et al.*, 2018; Rodriguez-Romero *et al.*, 2019), Mediterranean Sea (Saidi *et al.*, 2006; Bottaro *et al.*, 2008; Sans-Coma *et al.*, 2016), Caribbean (Ehemann *et al.*, 2016) and Indian Ocean (Moore, 2015).

The most frequently reported abnormalities are related to the anterior body region, such as: dicephaly (Galván-Magaña *et al.*, 2011; Rodriguez-Romero *et al.*, 2019), cyclopia (Bejarano-Álvarez & Galván-Magaña, 2013; Ramírez-Amaro *et al.*, 2019) and duplicate or absent structures (e.g. two mouths, Mancini *et al.*, 2006; missing gill slits, Saidi *et al.*, 2006). Furthermore, trunk abnormalities (e.g. spinal anomalies, Parenzan, 1979; Lamarca *et al.*, 2017; Kanagasuku *et al.*, 2020) and albinism (Escobar-Sanchéz *et al.*, 2014; Becerril-García *et al.*, 2017) have also been reported.

Blue shark *Prionace glauca* (Linnaeus, 1758) is the most abundant oceanic shark and represents an important fishery resource (Clarke *et al.*, 2014; Gilman *et al.*, 2016), especially in Brazil (Barreto *et al.*, 2017). This highlights the need of reporting abnormalities in an effort to elucidate the frequency of events of this nature. Additionally, the wide distribution and life-history characteristics of *P. glauca*, which includes placentotrophy, a gestation period of 9–12 months, litter size of 4–63 individuals (exceptionally up to 135 embryos) (Balon, 1975; Compagno, 1984; Dulvy & Reynolds, 1997; Compagno & Niem, 1998) and size at birth (35–44 cm total length; Compagno, 1984), makes *P. glauca* an important model organism to improve our knowledge about the causes and morphological consequences of embryonic abnormalities in viviparous elasmobranchs. This paper reports two different cases of abnormal development in *P. glauca* embryos, both collected from Southern Brazilian waters.

Methods

Two pregnant blue shark females were caught off the coast of Rio Grande do Sul, Brazil during commercial surface longline activities. The first specimen was caught on 7 September 2018 (32°50′S 50°05′W) by the fishing vessel 'Sambaqui III', and the abnormal embryo (embryo A) was extracted from the uterus during attempts to release the pups alive. The second specimen was caught on 16 November 2019 (35°27′S 49°04′W) by the fishing vessel 'Áustria'. This individual (197 cm fork length) was examined by a scientific observer and one embryo in a litter of 27 pups displayed abnormal development (embryo B). Both embryos were transferred to the Demersal Resources and Cephalopods Laboratory of Oceanography Institute of Federal University of Rio Grande (FURG).

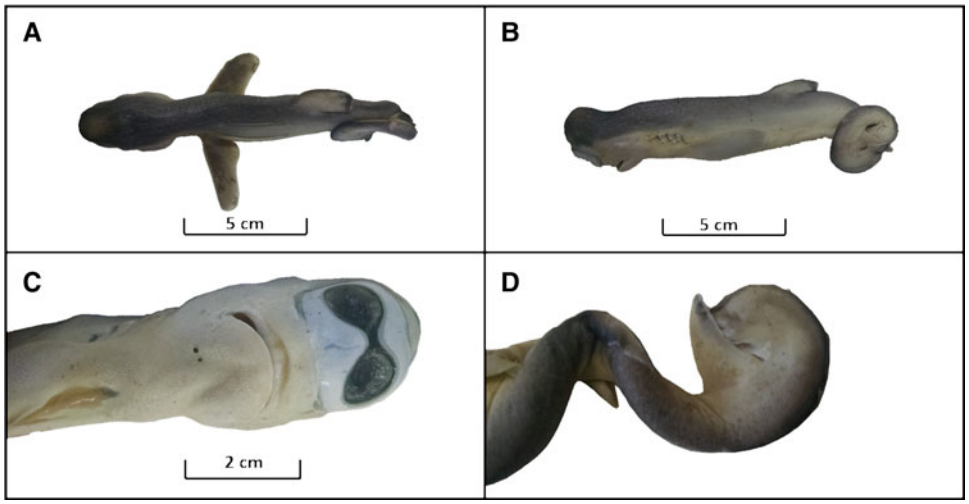

Fig. 1. *Prionace glauca* embryo A: (A) dorsal view exhibiting the trunk and chondrocranium malformations, (B) lateral view showing spiracles and gill slits, (C) ventral view displaying the synophthalmic eye and the mouth, and (D) rolled 'anticlockwise' body posterior part.

The abnormalities of both embryos were described based on a morphological perspective. Subsequently, the embryos were fixed in formaldehyde and deposited in the collection of the FURG.

Results

Embryo A (voucher specimen code CC00321) showed synophthalmia, a type of cyclopia (Torczynski *et al.*, 1977) and its caudal fin severely coiled anticlockwise (Figure 1A). This specimen showed a malformation in the rostrum by a deficient development of the chondrocranium. Spiracles were present, as well as five gill slits, however, nostrils were absent (Figure 1B). The two-eye-fusion was displaced ventrally, on a large single orbital cavity, possibly related to a malformation in the basitrabecular process. The mouth was normally developed and showed a well-built adductor mandibular complex (i.e. quadratomandibularis and preorbitalis muscles) and intermandibularis muscle (Figure 1C). The posterior region of the body, from the second dorsal fin onward, had coiled in an anticlockwise direction (Figure 1D).

Embryo B (voucher specimen code CC00322) presented an incomplete fusion at the right corner of the mouth that can be viewed ventrally and from a lateral angle. In dorsal view, a slight misalignment in the location of the eyes is observed (Figure 2A), but apart from that, the individual did not present other obvious visual deformations (Figure 2B). The ventral view of the anterior body end of embryo B compared with one of its siblings shows the difference in the position of the eyes of embryo B (Figure 2C). The lack of fusion in the right corner of the mouth (Figure 2D) suggests a lack of fusion in this region between the Meckel's cartilage and the palatoquadrate, that in turn generated a malformation in the right dorsal and ventral quadratomandibularis muscles and a displacement in the structures of the chondrocranium, causing misalignment in the orbits.

Discussion

According to the classification of morphological anomalies by Hennekam *et al.* (2013), embryo A presents a major morphology anomaly because it has significant consequences on its health and appearance at the time of evaluation, whilst embryo B has a minor morphological anomaly since there is a low impact on appearance with minimal health consequences.

Even though embryonic development was still in progress, the survival chance after birth would likely be small due to swimming disabilities for embryo A and feeding difficulties for both specimens.

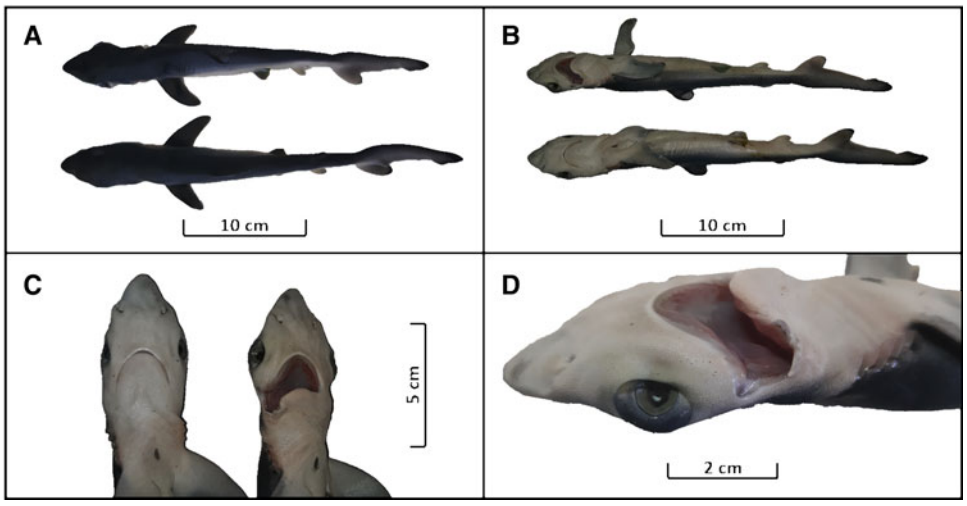

Fig. 2. *Prionace glauca* embryo B: (A) dorsal view (upper: embryo B; lower: sibling), (B) lateral diagonal view displaying the malformation in the mouth (upper: embryo B; lower: sibling), (C) ventral view comparing with its sibling (left: sibling; right: embryo B), and (D) zoom to the malformed mouth.

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Table 1. Morphological abnormalities reported in *Prionace glauca* embryos worldwide

Year	Region	Abnormality	Reference
1963	Mediterranean Sea	Two heads, deformed spine	Parenzan (1979)
1987–1990	North Atlantic Ocean	Two heads	Ramírez-Amaro *et al.* (2019)
1987–1990	North Atlantic Ocean	Two heads	Ramírez-Amaro *et al.* (2019)
1987–1990	North Atlantic Ocean	Diprosopia, twisted spine	Ramírez-Amaro *et al.* (2019)
1987–1990	North Atlantic Ocean	Diprosopia	Ramírez-Amaro *et al.* (2019)
1987–1990	North Atlantic Ocean	Diprosopia, twisted spine	Ramírez-Amaro *et al.* (2019)
1990s	Caribbean Sea	Two heads	Ehemann *et al.* (2016)
1995	South-east Pacific Ocean Peru	Two mouths, four eyes, thoracic lordosis, twisted spine	Kanagusuku *et al.* (2020)
1997	North Atlantic Ocean	Two heads	Galván-Magaña *et al.* (2011)
1998	South Pacific Ocean	Two heads, thoracic lordosis, twisted spine	Hevia-Hormazábal *et al.* (2011)
2000–2001	South-east Pacific Ocean Chile	Four eyes, deformed snout, thoracic lordosis, twisted spine	Pastén-Marambio *et al.* (2018)
2003	South-western Atlantic Ocean Brazil	Two mouths, twisted spine	Mancini *et al.* (2006)
2004	California Gulf	Two heads	Galván-Magaña *et al.* (2011)
2004	California Gulf	Smaller than siblings	Galván-Magaña *et al.* (2011)
2007	South-western Atlantic Ocean Brazil	Two heads, deformed spine	Lamarca *et al.* (2017)
2008	Pacific Ocean	Two heads, smaller than siblings	Bejarano-Álvarez *et al.* (2011)
2008	Pacific Ocean	No eyes, deformed snout, gills not fully open, smaller than siblings	Bejarano-Álvarez *et al.* (2011)
2008	Pacific Ocean	No eyes, deformed snout, smaller than siblings	Bejarano-Álvarez *et al.* (2011)
2012	Pacific Ocean	Deformed snout, only one nostril, twisted caudal fin	Rodriguez-Romero *et al.* (2019)
2012	Pacific Ocean	Deformed snout, only one nostril	Rodriguez-Romero *et al.* (2019)
2012	Pacific Ocean	Two mouths, twisted spine	Rodriguez-Romero *et al.* (2019)
2013	Pacific Ocean	Two heads	Rodriguez-Romero *et al.* (2019)
2013	Pacific Ocean	Hypoplasia, two less gill slits per side, deformed snout	Rodriguez-Romero *et al.* (2019)
2018	South-western Atlantic Ocean Brazil	Cyclopia, twisted caudal fin, deformed rostrum	This study
2019	South-western Atlantic Ocean Brazil	Deformed mouth	This study

Abnormalities related to cyclopia have been reported before for embryos of other elasmobranch species such as *Carcharhinus obscurus* (Bejarano-Álvarez & Galván Magaña, 2013), *Galeorhinus galeus* (Ramírez-Amaro *et al.*, 2019) and *Squatina californica* (synophthalmia; Escobar-Sánchez *et al.*, 2014), while specific mouth malformations have not been reported for elasmobranchs.

As shown in Table 1, malformations in *P. glauca* embryos have been widely reported in different marine regions. However, similar reports in the South Atlantic Ocean are less frequent in comparison with the North Atlantic Ocean. In both the Atlantic and Pacific Oceans, the most commonly reported malformations for this species at this stage of development are diprosopia (usually two heads) and twisted vertebral columns (Mancini *et al.*, 2006; Bejarano-Álvarez *et al.*, 2011; Galván-Magaña *et al.*, 2011; Hevia-Hormazábal *et al.*, 2011; Ehemann *et al.*, 2016; Lamarca *et al.*, 2017; Pastén-Marambio *et al.*, 2018; Rodriguez-Romero *et al.*, 2019; Ramírez-Amaro *et al.*, 2019; Kanagusuku *et al.*, 2020). In this study, we report the second embryo with a kind of cyclopia for the South-western Atlantic Ocean (Ferreira *et al.*, 2002).

The abnormalities observed in blue sharks and their relatively frequent occurrence could be explained by their high production of embryos, with a maximum litter size of 135 (Smith, 1997). The causes for embryonic abnormalities could include the effects of contaminants (Casarini *et al.*, 1997; Rosa *et al.*, 2004), as elasmobranchs are particularly vulnerable to bioaccumulation and biomagnification of pollutants due to their longevity and high trophic level (Gelsleichter & Walker, 2010). Moreover, abnormalities such as spinal malformations could be caused by arthritis, injuries, parasites, poor nutrition or tumours (Sadowsky, 1971; Schwartz, 1973; Heupel *et al.*, 1999). Theoretically, if population declines resulted in higher levels of inbreeding, this might also increase the likelihood of malformations in embryonic development (Dulvy *et al.*, 2014; Lamarca *et al.*, 2017).

The number of developmental abnormalities reported in sharks has increased over time, although it is uncertain as to whether this relates to anthropogenic impacts or simply an increase in sampling and reporting. More standardized sampling and reporting of embryos would be required to inform on this. Despite the difficulty in making assumptions about possible causes for embryonic abnormalities, reporting of morphological abnormalities needs to be encouraged because it will allow us to better understand their causes, if there are species with a greater predisposition to these malformations, or even to understand the juvenile survival rate, which is an essential parameter for stock assessment.

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