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ABNORMALITIES IN TWO SHARK SPECIES, THE BLUE SHARK, *PRIONACE GLAUCA,* AND THE SCHOOL SHARK, *GALEORHINUS GALEUS* (ELASMOBRANCHII: CARCHARHINIFORMES), FROM THE CANARY ISLANDS, EASTERN TROPICAL ATLANTIC

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Abstract. A total of six abnormal embryos of shark species, five blue shark, *Prionace glauca* (Linnaeus, 1758), and one school shark, *Galeorhinus galeus* (Linnaeus, 1758), are herewith reported from the Canary Islands (eastern central Atlantic). Two *P. glauca* embryos showed two totally separated heads on one trunk (bicephalism), while the other three embryos had a single head with some duplicated parts, such as the mouth or the eyes (diprosopia). *Galeorhinus galeus* embryo showed cephalic abnormalities. Possible causes of these abnormalities are briefly discussed.

Keywords: bicephalism, Canary Islands, diprosopia, *Galeorhinus galeus*, *Prionace glauca*

INTRODUCTION

The blue shark, *Prionace glauca* (Linnaeus, 1758), and the school shark, *Galeorhinus galeus* (Linnaeus, 1758), are pelagic sharks widely distributed in temperate, subtropical, and tropical waters including the Canary Islands (Uiblein et al. 1996, Compagno 2002, Ebert et al. 2013). Both shark species belong to the order Carcharhiniformes, but with different reproductive strategies; while the blue shark is a placental viviparous species, the school shark is an aplacental viviparous species (Ebert et al. 2013).

Bicephalism and diprosopia abnormalities have mainly been documented in sharks (Table 1), but they are commonly confused (Sans-Coma et al. 2016). While the former anomaly is related to two-headed conjoined twins, with two totally separated heads on one body or trunk (Bondeson 2001), the latter anomaly refers to a single trunk and a single head where some craniofacial parts are duplicated (Hähnel et al. 2003, Biasibetti et al. 2011). The majority of cases of both abnormalities have been reported in the blue shark *P. glauca* in different oceanic areas, such as the northwest Pacific (Goto et al. 1981), eastern central Pacific (Bejarano-Álvarez et al. 2011, Galván-Magaña et al. 2011), south-eastern Pacific (Hevia-Hormazábal et al. 2011, Gondo et al. 2016), south-western Atlantic (Ferreira et al. 2000, Mancini et al. 2006), western central Atlantic (Ehemann et al. 2016), and even in the Mediterranean Sea (Parenzan 1979). In contrast, only one bicephalous school shark, *G. galeus*, has been described from the south-western Atlantic (Delpiani et al. 2011).

This study reports multiple embryonic abnormalities in two shark species, the blue shark, *Prionace glauca*, and the school shark, *Galeorhinus galeus*, from the Canary Islands. Two *P. glauca* embryos showed two totally separated heads on one trunk (bicephalism) and three embryos had a single head with some duplicated parts (diprosopia), while *G. galeus* embryo showed cephalic abnormalities.

MATERIAL AND METHODS

The six malformed embryos were removed from different pregnant females captured from 1987 to 1990 by the Spanish longline fleet on the Conception Bank, a

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Table 1

Summary according to the chronological order of the literature that report cases of bicephalism and diprosopia in shark species.

Species	Common name	Geographic area	Reference
BICEPHALISM			
Squalus blainville (Risso, 1827)	Longnose spurdog	Mediterranean Sea	Lozano-Cabo 1945
Rhizoprionodon acutus (Rüppell, 1837)	Milk shark	Northern Central Indian	Gopalan 1971 [As "*Carcharias walbeehmi*"]
Prionace glauca (Linnaeus, 1758)	Blue shark	Northwest Pacific	Goto et al. 1981
Prionace glauca (Linnaeus, 1758)	Blue shark	Southwest Atlantic	Ferreira et al. 2000
Galeorhinus galeus (Linnaeus, 1758)	School shark	Southwest Atlantic	Delpiani et al. 2011
Prionace glauca (Linnaeus, 1758)	Blue shark	Eastern Central Pacific	Bejarano-Álvarez et al. 2011
Prionace glauca (Linnaeus, 1758)	Blue shark	Eastern Central Pacific	Galván-Magaña et al. 2011
Carcharhinus leucas (Valenciennes, 1839)	Bull shark	Western Central Atlantic	Wagner et al. 2013
Mustelus higmani Springer et Lowe, 1963	Smalleye smooth-hound	Western Central Atlantic	Ehemann et al. 2016
Prionace glauca (Linnaeus, 1758)	Blue shark	Western Central Atlantic	Ehemann et al. 2016
Galeus atlanticus (Vaillant, 1888)	Atlantic Sawtail Catshark	Mediterranean Sea	Sans-Coma et al. 2016
Squalus blainville (Risso, 1827)	Longnose spurdog	Mediterranean Sea	Capapé and Ali 2017
DIPROSOPIA			
Squalus acanthias Linnaeus, 1758	Picked dogfish	Mediterranean Sea (Black Sea)	Bosinceano 1934
Prionace glauca (Linnaeus, 1758)	Blue shark	Mediterranean Sea	Parenzan 1979
Prionace glauca (Linnaeus, 1758)	Blue shark	Northwest Pacific	Goto et al. 1981
Prionace glauca (Linnaeus, 1758)	Blue shark	Southwest Atlantic	Mancini et al. 2006
Prionace glauca (Linnaeus, 1758)	Blue shark	Southeast Pacific	Hevia-Hormazábal et al. 2011
Carcharhinus porosus (Ranzani, 1839)	Smalltail shark	Eastern Central Pacific	Muñoz-Osorio et al. 2013
Prionace glauca (Linnaeus, 1758)	Blue shark	Southeast Pacific	Gondo et al. 2016

seamount located 75 km north of the island of Lanzarote, in the Canarian Archipelago (Fig. 1). Pregnant sharks were identified following Compagno (1984). The embryo specimens were initially preserved in 10% formaldehyde solution, subsequently replaced with 90% ethyl alcohol. All embryos were transferred, after a long period of storage in the Algeciras Port (Spain), to the Marine Fauna Collection (CFM-IEOMA*) based at the Centro Oceanográfico de Málaga (Instituto Español de Oceanografía, Spain). Unfortunately, the measurements and other biological data of these pregnant sharks were not reported. Identifying catalogue codes of CFM-IEOMA, the sex and main morphometric measurements for each embryo (CFM-IEOMA samples) are compiled in Table 2. In addition, each embryo was photographed and subsequently radiographed using a radiographic equipment (Multimage UNIVET 160 LX; Fujifilm Computer Radiography CR-IR 392).

RESULTS

The first pregnant shark was identified as *Prionace glauca* because showed a dark blue body in the dorsal part, the origin of first dorsal fin was far behind the pectoral fins and the second dorsal fin was much smaller than the first, and its origin was slightly posterior to the anal fin. The second pregnant shark was identified as *Galeorhinus galeus* since it had a greyish colour in the dorsal part, its snout was moderately long without obvious anterior nasal flaps, and showed a long terminal caudal lobe. Of the six embryos, five were identified as *Prionace glauca* and one as a *Galeorhinus galeus*. Two *P. glauca* embryos (CFM-IEOMA 6094 and CFM-IEOMA 6096) showed a body or trunk with two clearly separated heads, laterally fused at the fifth gill opening (Fig. 2). In both embryos, the total length of the right and left parts were similar (Table 2). Each head had five pairs of gills, a pair of eyes and nostrils, and a mouth with well-developed jaws. The CFM-IEOMA 6094 specimen showed in its trunk a first and a second dorsal fin, while CFM-IEOMA 6096 specimen had both dorsal fins duplicated, as well as the dorsal lobe of the caudal fin. Both embryos presented a single pair of pectoral and pelvic fins, and a unique umbilical cord. The corresponding X-ray photos (Fig. 2) showed a well-developed vertebral column, bifurcated in different areas of the trunk, to the posterior second dorsal fin for CFM-IEOMA 6094, and to the anal fins for CFM-IEOMA 6096.

Three *P. glauca* embryos, CFM-IEOMA 6093, 6095, and 6381, exhibited a single trunk with a partial craniofacial duplication (Fig. 3). Both CFM-IEOMA 6093 and CFM-IEOMA 6095 specimens had duplicated faces fused at the fourth gill opening. Each embryo had a cephalic region with two mouths opened laterally, and a pair of eyes, but only one of the three embryos shared the ocular socket (CFM-IEOMA 6095). All the three embryos had a single trunk with two dorsal and two pectoral fins, one anal fin and one caudal fin. CFM-IEOMA 6093 and 6381 embryos showed an atrophied trunk, anticlockwise rolled from the

* *http://www.ma.ieo.es/cfm/.*

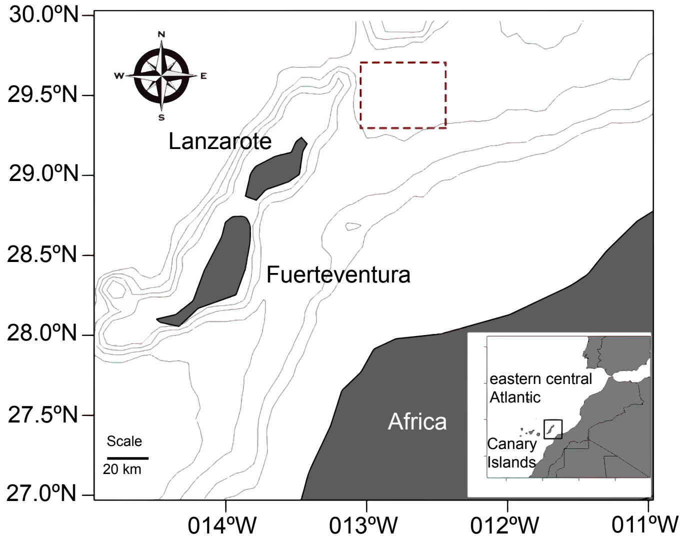

Fig. 1. Map of the study area (Canary Islands, eastern central Atlantic), indicating the Conception Bank (dashed-line square) where the samples were collected; isobaths between 100 and 2000 m (by each 500 m) are also shown

Table 2

Morphometric measurements (mm) of six abnormal embryos, five blue sharks (*Prionace glauca*) and one school shark (*Galeorhinus galeus*) collected in the Canary Islands

	Prionace glauca										*Galeorhinus galeus*
Abnormality	Bicephalism		Bicephalism		Diprosopia		Diprosopia		Diprosopia		Cephalic abnormalities
Catalogue numbers	CFM-IEOMA 6094		CFM-IEOMA 6096		CFM-IEOMA 6093		CFM-IEOMA 6095		CFM-IEOMA 6381		CFM-IEOMA 6108
Sex	Female		Female		Male		Male		Male		Male
Side	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	—
Total length	265	255	240	233	230	230	240	247	240	237	286.0
Fork length	208	200	183	186	—	—	200	212	190	—	245.0
Prenarial length	19	19	15	15	21	21	7	19	31	—	10.0
Preorbital length	30	30	22	22	32	32	18	31	37	—	19.0
Preoral length	33	33	22	22	35	35	35	34	38	43	36.0
Prebranchial length	63	62	52	52	62	64	48	61	77	—	60.0
Prepectoral length	72	68	63	58	86	85	80	75	93	90	6.6
Prepelvic length	110	105	121	115	127	130	121	131	115	—	149.0
Pre-first dorsal length	109	101	95	89	105	102	106	110	108	—	102.0
Pre-second dorsal length	151	142	147	140	160	185	166	172	—	—	193.0
Preanal length	149	135	145	140	—	—	161	170	—	—	182.0
Internarial space	15	15	12	12	12	12	4	13	12	14	12.0
Mouth width	22	21	17	14	15	20	5	19	21	21	21.0
Mouth length	12	12	—	—	—	—	3	7	12	13	16.0
1st gill opening length	9	9	56	53	10	15	1	12	11	11	7.0

pelvic fin to the caudal fin (named ‘screw-shaped’), as shown in the X-ray photo (Fig. 3). Table 2 summarizes the body measurements recorded for each specimen.

Galeorhinus galeus embryo CFM-IEOMA 6108 showed cephalic abnormalities (Fig. 4), with two eyes positioned in front of the mouth opening (close one to another). The two orbits shared a common large opening and thus formed a big eye or ‘cyclops’ whose nictitating membrane was fused into a single distorted and non-functional eyelid. The X-ray photo shows the presence of a single orbital opening (Fig. 4).

DISCUSSION

Several morphological abnormalities have been recorded on diverse elasmobranch species (sharks and rays) around the world (Table 3). However, no morphological anomalies have been reported to date for shark species in the Canarian Archipelago (eastern tropical Atlantic). Thus, this study is the first record of embryonic abnormalities described for two shark species captured off the Canary Islands.

Many of the morphological abnormalities have mainly been recorded in the embryonic phase. In sharks, the bicephalism and diprosopia anomalies have been documented in placental viviparous (Goto et al. 1981, Muñoz-Osorio et al. 2013, Dos Santos and Gadig 2014) and aplacental viviparous (Lozano-Cabo 1945, Delpiani et al. 2011, Sans-Coma et al. 2016, Capapé and Ali 2017). Although these congenital morphological abnormalities are poorly understood, they can be due to several causes, either natural or anthropogenic (Heupel et al. 1999, Moore 2015). Historically, the Canarian Archipelago has not shown high levels of pollution on their coasts, so we cannot consider it as a cause for abnormalities, as envisaged in other shark studies (Heupel et al. 1999, Galván-Magaña et al. 2011). It is generally assumed that conjoined monozygotic twins may develop when one twin derived from a single fertilised ovum is not completely separated following a partial duplication that occurs in early stages of intrauterine life (Lugones Botell et al. 1999). An incomplete splitting of the embryonic axis may occur during a later stage of twinning development due to its exposure to different factors, such as chemical pollutants, viral or metabolic infections, genetic disorders or unfavourable environmental conditions (Kaufman 2004). Craniofacial duplications or diprosopia observed in three of *P. glauca*'s embryos may result from several developmental errors, including: duplication of parts derived from the branchial arch; the split or the bifurcation of the notochord complex; the blockage of totipotent cells; the duplication of the olfactory placodes, of the maxillary and of the neural crest derivates (Maisels 1981, Carles et al. 1995, Sans-Coma et al. 2016). In addition, it has been suggested that the pathogenetic mechanism, such as the mutation of *dlx* homeobox genes, might produce craniofacial duplication (Costa et al. 2014).

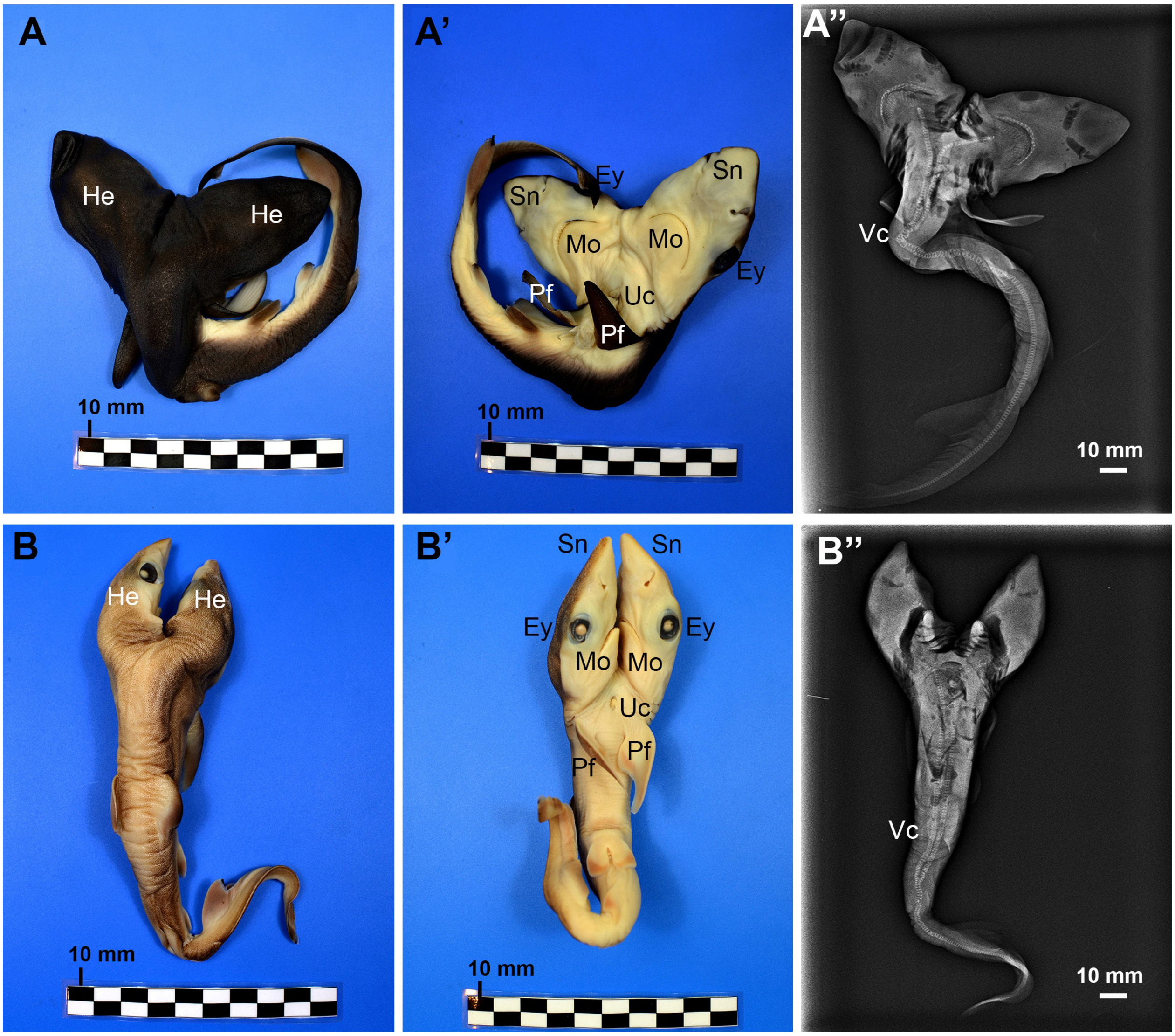

Fig. 2. Photographs of two embryos of *Prionace glauca* with bicephalism representing CFM-IEOMA 6094 (**A**) and CFM-IEOMA 6096 (**B**); dorsal view (**A**, **B**), ventral view (**A'**, **B'**), X-ray images (**A''**, **B''**); abbreviations used: Ey = eyes, Sn = snouts, Mo = mouths, He = heads, Pf = pectoral fin, Vc = vertebral column, Uc = umbilical cord

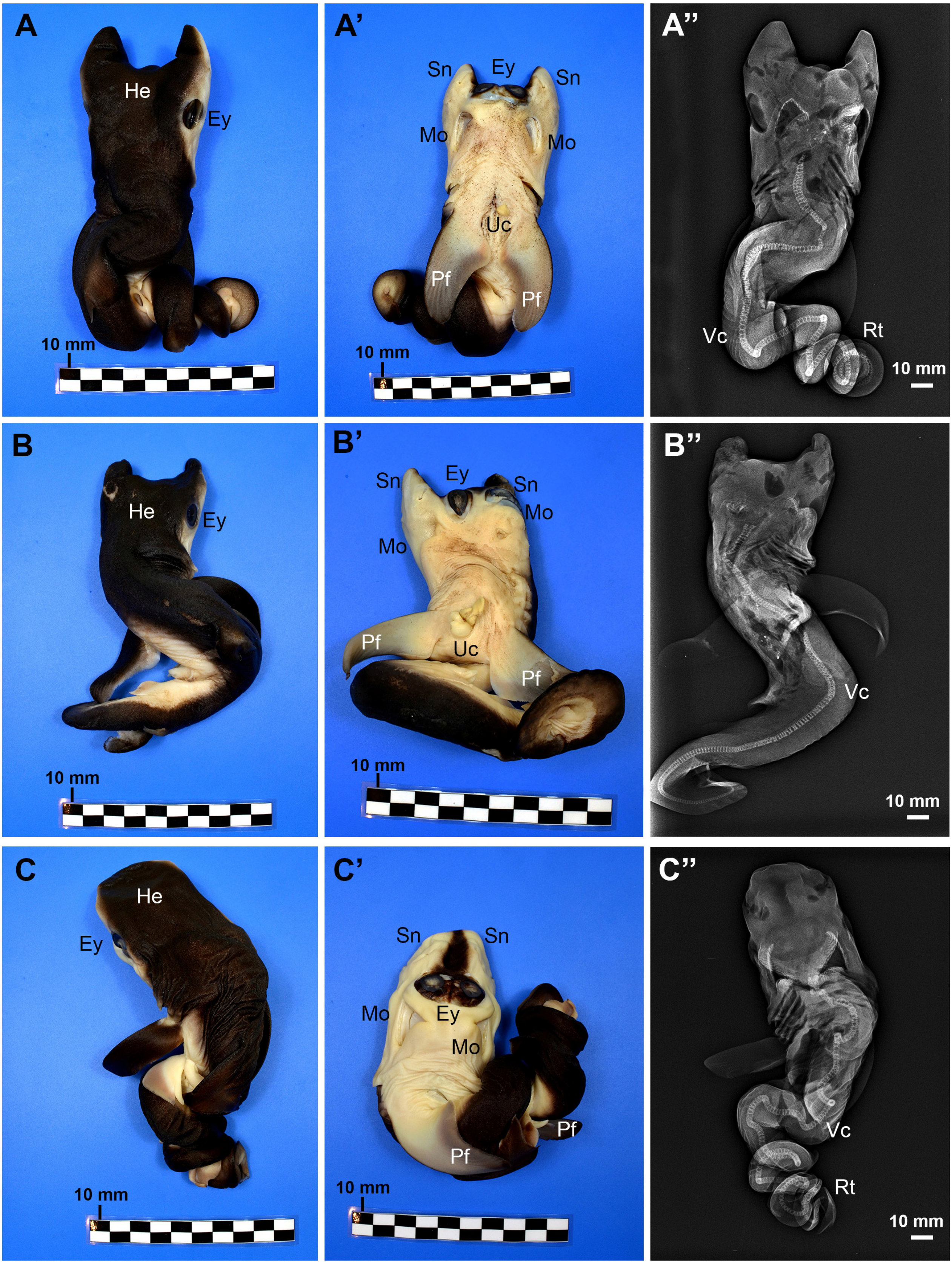

Fig. 3. Photographs of three embryos of *Prionace glauca* with diprosopia representing CFM-IEOMA 6093 (**A**), CFM-IEOMA 6095 (**B**), and CFM-IEOMA 6381 (**C**); dorsal view (**A**, **B**, **C**), ventral view (**A'**, **B'**), X-ray images (**A"**, **B"**, **C"**); abbreviations used: Ey = eyes, Sn = snouts, Mo = mouths, He = heads, Pf = pectoral fin, Vc = vertebral column, Uc = umbilical cord, Rt = rolled anticlockwise trunk

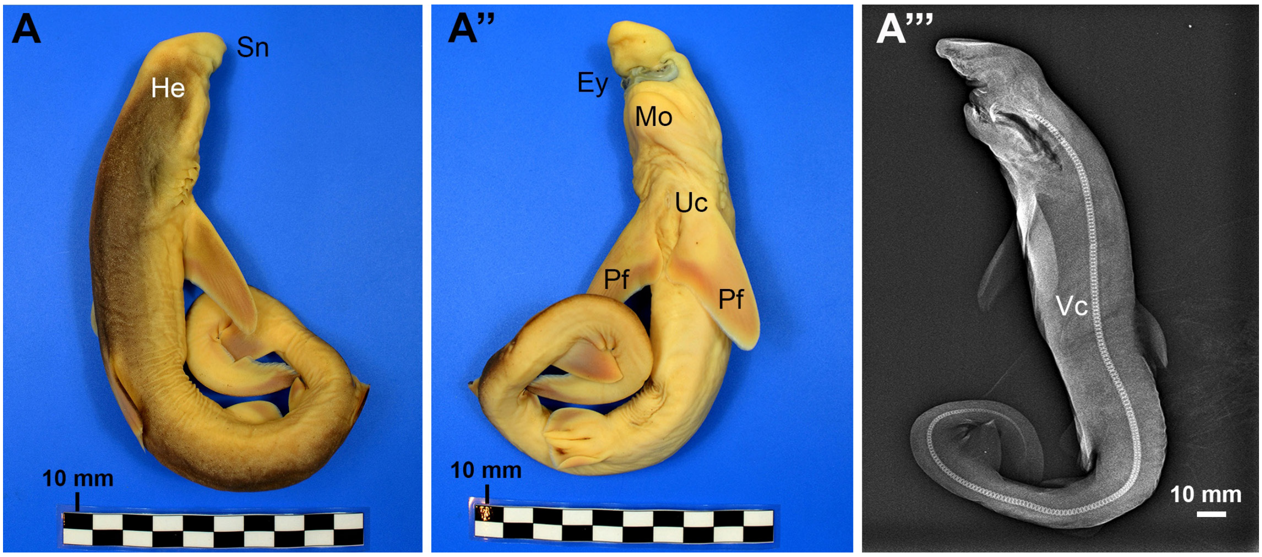

Fig. 4. Photographs of an embryo of *Galeorhinus galeus* with cephalic abnormalities representing CFM-IEOMA 6108); dorsal view (**A**), ventral view (**A'**), X-ray image (**A''**); Photographs showing the dorsal (**A**) and ventral view (**A'**), and X-ray photo (**A'''**); abbreviations used: Ey = eyes, Sn = snouts, Mo = mouths, He = heads, Pf = pectoral fin, Vc = vertebral column, Uc = umbilical cord

In sharks, the uterus is a small-sized area, mainly for those species with a high number of embryos, like *P. glauca* and *G. galeus*, which can produce up to 135 (Compagno 1984) and 52 (Capapé et al. 2005) pups per litter, respectively. The intrauterine pressure may induce the lateral and posterior curvature of the spine (scoliokyphosis), resulting in a screw-shaped trunk (Pastore and Prato 1989), as the observed in our two *P. glauca* diprosopic embryos, CFM-IEOMA 6093 and CFM-IEOMA 6381. According to Wimberger (1993), vitamin C deficiency also induces curvature of the spine, particularly towards the end of the vertebrae column (lordosis). These spinal deformities might also be associated with scoliosis, central fusion, and arthritic changes (Springer 1960, Bonfil 1989). Both the above-mentioned *P. glauca* embryos are particular cases of sharks with multiple anomalies (diprosopia and scoliokyphosis), which to date have only been described in two shark species, *P. glauca* (see Goto et al. 1981) and the small tail shark *Carcharhinus porosus* (see Muñoz-Osorio et al. 2013). Also, this unfavourable condition during prenatal development of sharks often affects the development of the cephalic region, mainly the neurocranium and splanchnocranium (Bensam 1965, Bonfil 1989, Pastore and Prato 1989), as reported here for *G. galeus* embryo CFM-IEOMA 6108 (Fig. 4). On the other hand, the fusion of the eyes observed in this *P. glauca* embryo is a rare congenital malformation associated with a failure of the forebrain to divide into lobules, a fact that causes a poor development of facial features (holoprosencephaly), such as the palate and the snout (Gaffield and Keeler 1996, Bejarano-Álvarez and Galván-Magaña 2013). Since this type of abnormality has only been previously recorded in the sandbar shark, *Carcharhinus plumbeus* (Nardo, 1827) (see Springer 1960), and the Caribbean reef shark, *Carcharhinus perezii* (Poey, 1876) (see Bonfil 1989), our record is the first report of this anomaly in a *G. galeus* embryo.

Current and past reports of morphological abnormalities shed light on the possible causes of these deformations in sharks, but more studies are necessary for knowing how frequent these abnormalities are in certain geographic areas. In this sense, we can hypothesise that the high numbers of abnormal *P. glauca* embryos reported in the literature, higher than for any other shark species, must be related to the abundant and cosmopolitan distribution of this species, and certainly to its high birth rate.

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Table 3

Summary according to the chronological order of the literature that report different cases of morphological abnormalities in elasmobranch species

Species	Anomaly	Reference
Carcharhinus plumbeus (Nardo, 1827)	Mummification	Springer 1960 [As "*Eulamia milberti*"]
Scoliodon laticaudus Müller et Henle, 1838	Malformed twins	Devadoss 1983
Pateobatis jenkinsii (Annandale, 1909)	Deformed disc	Devadoss 1983 [As "*Dasyatis jenkinsii*"]
Narke dipterygia (Bloch et Schneider, 1801)	Deformed disc	Devadoss 1983
Carcharhinus plumbeus (Nardo, 1827)	Skeletal deformities	Hoening and Walsh 1983
Negaprion brevirostris (Poey, 1868)	Skeletal deformities	Hoening and Walsh 1983
Carcharias taurus Rafinesque, 1810	Skeletal deformities	Hoening and Walsh 1983 [As "*Odontaspis taurus*"]
Carcharhinus plumbeus (Nardo, 1827)	Mummification	Rosa-Molinar et al. 1983
Carcharhinus perezii (Poey, 1876)	Snout reduction	Bonfil 1989
Carcharhinus signatus (Poey, 1868)	Cranial and vertebral deformities	Pastore and Prato 1989
Galeorhinus galeus (Linnaeus, 1758)	Vertebral deformities	Officer et al. 1995
Potamotrygon motoro (Müller et Henle, 1841)	Malformation of pectoral fins	Rosa et al. 1996
Triaenodon obesus (Rüppell, 1837)	Deformed tail	Huepel et al. 1999
Hemiscyllium ocellatum (Bonnaterre, 1788)	Skeletal deformities	Huepel et al. 1999
Mustelus antarcticus Günther, 1870	Skeletal deformities	Huepel et al. 1999
Glyphis sp.	Skeletal deformities	Thorburn and Morgan 2004
Carcharhinus plumbeus (Nardo, 1827)	Albinism	Saïdi et al. 2006
Galeocerdo cuvier (Péron et Lesueur, 1822)	Albinism	Sandoval-Castillo et al. 2006
Narcine entemedor Jordan et Starks, 1895	Albinism	Sandoval-Castillo et al. 2006
Carcharhinus falciformis (Müller et Henle, 1839)	Mummification	Sandoval-Castillo and Villavicencio-Garayzar 2008
Dalatias licha (Bonnaterre, 1788)	Albinism	Bottaro et al. 2008
Hypanus longus (Garman, 1880)	Deformed disc	Escobar-Sánchez et al. 2009 [As "*Dasyatis longa*"]
Carcharhinus obscurus (Lesueur, 1818)	Cyclopia	Bejarano-Álvarez and Galván-Magaña 2013
Myliobatis californica Gill, 1865	Cephalic anomaly	Ramírez-Amaro et al. 2013
Rhizoprionodon acutus (Rüppell, 1837)	Lack of pelvic fins and lack of a portion of snout	Moore 2015
Rhizoprionodon oligolinx Springer, 1964	Asymmetrical snout	Moore 2015
Carcharhinus limbatus (Valenciennes, 1839)	Abnormal caudal fins	Moore 2015
Glaucostegus granulatus (Cuvier, 1829)	Asymmetrical snout tip	Moore 2015
Glaucostegus halavi (Forsskål, 1775)	Lack of a clasper	Moore 2015

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