Spanish Journal of Palaeontology 37 (2), 249–256, 2022
https://doi.org/10.7203/sjp.25576
Sociedad Española de Paleontología ISSN 2255-0550 / eISSN 2660-9568

OPEN ACCESS SHORT COMMUNICATION

The confirmed fossil record of the blue shark *Prionace glauca* (Linnaeus, 1758) from the South Eastern Pacific

El registro fósil confirmado del tiburón azul *Prionace glauca* (Linnaeus, 1758) del Pacífico Sudeste

Jaime A. VILLAFAÑA, René KINDLIMANN & Martin CHÁVEZ-HOFFMEISTER

Abstract: We offer the first formal description of fossil specimens of the blue shark *Prionace glauca* from Chile. The teeth described in this study were collected from the Mina Fosforita locality and preliminary assigned to the late Neogene. The confirmation of the presence of the blue shark in the Neogene sediments of Chile is a significant contribution to our global knowledge of the past distribution of chondrichthyans, being the first well-documented record of the species for the southern hemisphere. Our work shows that future studies are still necessary to better understand the evolutionary history of this shark species in the region.

Resumen: En este estudio se ofrece la primera descripción formal de especímenes fósiles del tiburón azul, *Prionace glauca*, procedentes de Chile. Los dientes descritos en este estudio fueron colectados en la localidad de Mina Fosforita y preliminarmente asignados al Neógeno tardío. La confirmación de la presencia del tiburón azul en sedimentos neógenos de Chile es una contribución significativa para el conocimiento global de la distribución de condrictios, siendo el primer registro bien documentado de la especie en el hemisferio sur. Nuestro trabajo muestra que todavía son necesarios estudios futuros para un mejor entendimiento de la historia evolutiva de esta especie de tiburón en la región.

Received: 19 October 2022
Accepted: 13 November 2022
Published online: 7 December 2022

Corresponding author:
Jaime A. Villafaña
jaime.villafana@ceaza.cl

Keywords:
Teeth, Neogene, Chile, Bahia Inglesa, Mina Fosforita

Palabras-clave:
Dientes, Neógeno, Chile, Bahía Inglesa, Mina Fosforita

INTRODUCTION

The blue shark *Prionace glauca* is a worldwide distributed species in temperate and tropical oceanic waters (Ebert *et al.*, 2021). This is an oceanic-epipelagic shark occurring from the surface to at least 1,1160 m (Ebert & Dando, 2020). However, it can be found inshore at night, particularly around oceanic islands (Queiroz *et al.*, 2010). *Prionace glauca* is categorized as "Near Threatened" by the IUCN Red List, but "Critically Endangered" in other regions as in the Mediterranean Sea (IUCN, 2022).

The fossil record of *Prionace glauca* dates back to the early Pliocene (Cappetta, 2012). This species has been reported from the Pliocene of Europe (Landini, 1977; Cigala-Fulgosi, 1986; Sorbini, 1988; Bellocchio *et al.*, 1991; Cigala-Fulgosi *et al.*, 2009; Collareta & Casati, 2018; Goolaerts *et al.*, 2020), Pliocene (González-Barba & Thies, 2000) and Quaternary of North America (Kanakoff, 1956; Fitch, 1967; Langenwalter, 1975; Huddleston & Barker, 1978; González-Rodríguez *et al.*, 2013). In South America, its fossil record is very scarce, being preliminary reported from the Pliocene of Venezuela (Carrillo-Briceño *et al.*, 2018) and Peru (Kindlimann, 1990). The record of *Prionace glauca* from the Pleistocene of Brazil (Colasso, 2011, appendix F) has to be revised due to the possible misidentification (Colasso, 2011). In Chile, teeth have been mentioned in the Bahia Inglesa Formation (Bianucci *et al.*, 2006) and occasionally illustrated (Suárez & Marquardt, 2003; Suárez, 2015), although without providing high-quality figures or descriptions of these remains.

Here, we offer the first formal description of fossil specimens of *Prionace glauca* from the late Miocene–early Pliocene deposits from Northern Chile, which confirms its presence in the eastern Pacific of South America during the late Neogene.

MATERIAL AND METHODS

The teeth described in this study come from the Mina Fosforita locality, Caldera, Northern Chile (Fig. 1). The outcrops in this area are often included as part of the member of the same name of the Bahia Inglesa

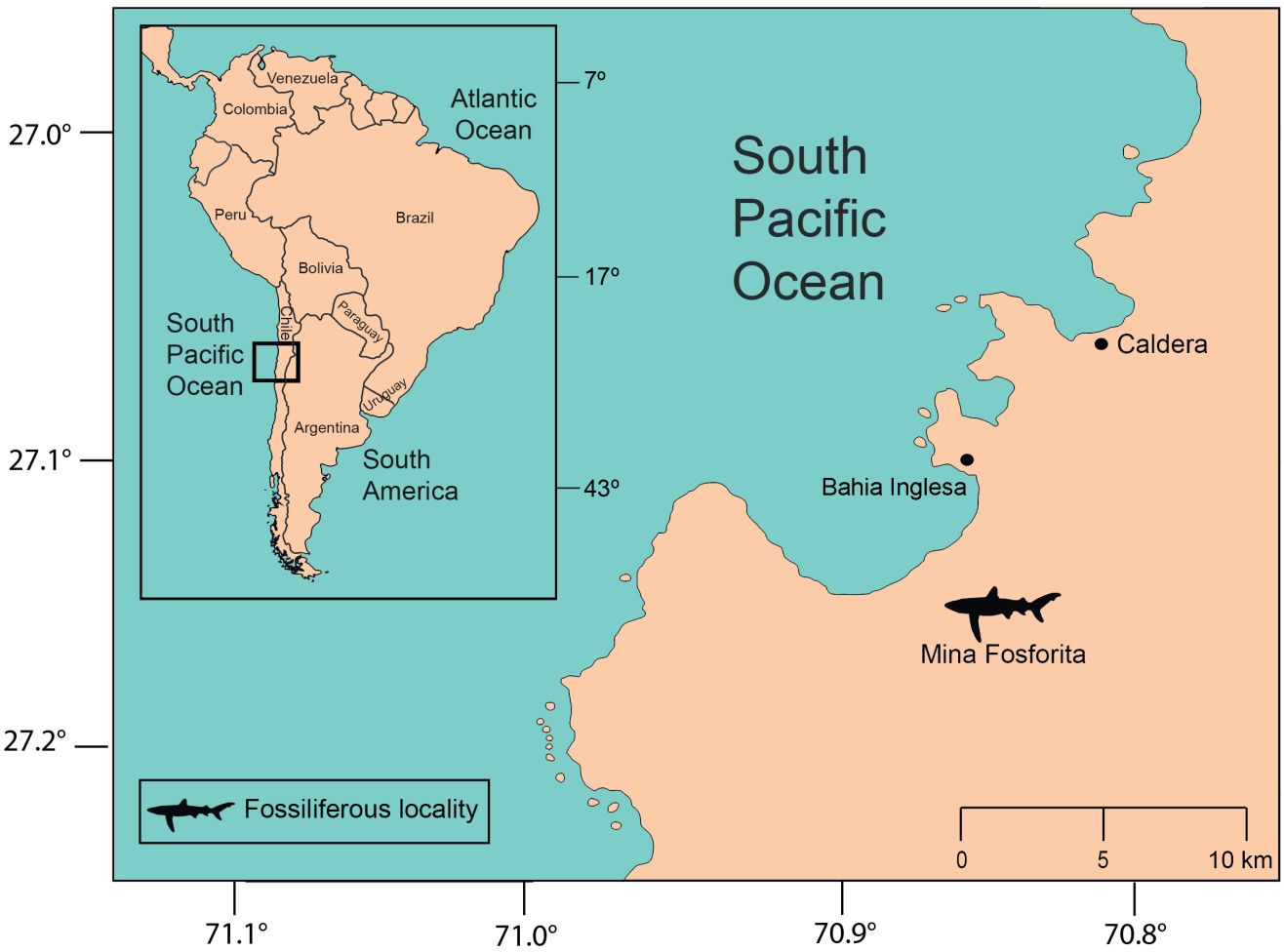

Figure 1. Location map of the Mina Fosforita locality.

Formation (Le Roux *et al.*, 2016). Its age has been assigned to the late Miocene (Godoy *et al.*, 2003; Henríquez, 2006), although Pliocene outcrops may also be present within the locality (see Discussion). For the locality, at least eight shark and two ray taxa have been reported (Suárez, 2015; Villafaña & Rivadeneira, 2018). The fossil record of vertebrates also includes bony fishes (Oyanadel-Urbina *et al.*, 2021), birds (Chávez-Hoffmeister, 2008), reptiles (Walsh & Suárez, 2005), and marine mammals (Gutstein *et al.*, 2009). The specimens are housed in the R. Kindlimann private collection and museum with public access, Aathal, Zurich, Switzerland. For the descriptions, we follow the dental terminology used in Cappetta (2012).

Comparative material. The following images of extant specimens were used for fossil comparison: upper antero-lateral tooth (UM REC 18) from the Mediterranean Sea in Cappetta (2012, fig. 290); upper teeth from the Northern Coast of Tunisia in Rafrafi-Nouira *et al.* (2015, fig. 6); upper tooth illustrated in Ebert *et al.* (2021, p. 562); upper jaw illustrated in Ebert and Dando (2020, p. 324); upper antero-lateral tooth from British Isles (7-768/R2). The fossil specimens also were compared to images of teeth provided by an online collection database of elasmo.com (Bourdon, 1999).

SYSTEMATIC PALEONTOLOGY

Class CHONDRICTHYES Huxley, 1880
Subclass ELASMOBRANCHII Bonaparte, 1838
Order CARCHARHINIFORMES Compagno, 1973
Family CARCHARHINIDAE Jordan & Evermann, 1896
Genus *Prionace* Cantor, 1849

Type-species. *Squalus glaucus* Linnaeus, 1758. Recent, worldwide in temperate and tropical oceanic waters.

Prionace glauca (Linnaeus, 1758)
Figure 2

Material. Two upper antero-lateral teeth (7-789 and 7-790).

Measurements. The teeth measure between 10.3 and 11.5 mm in total width; and 12.4 to 12.2 mm in total height.

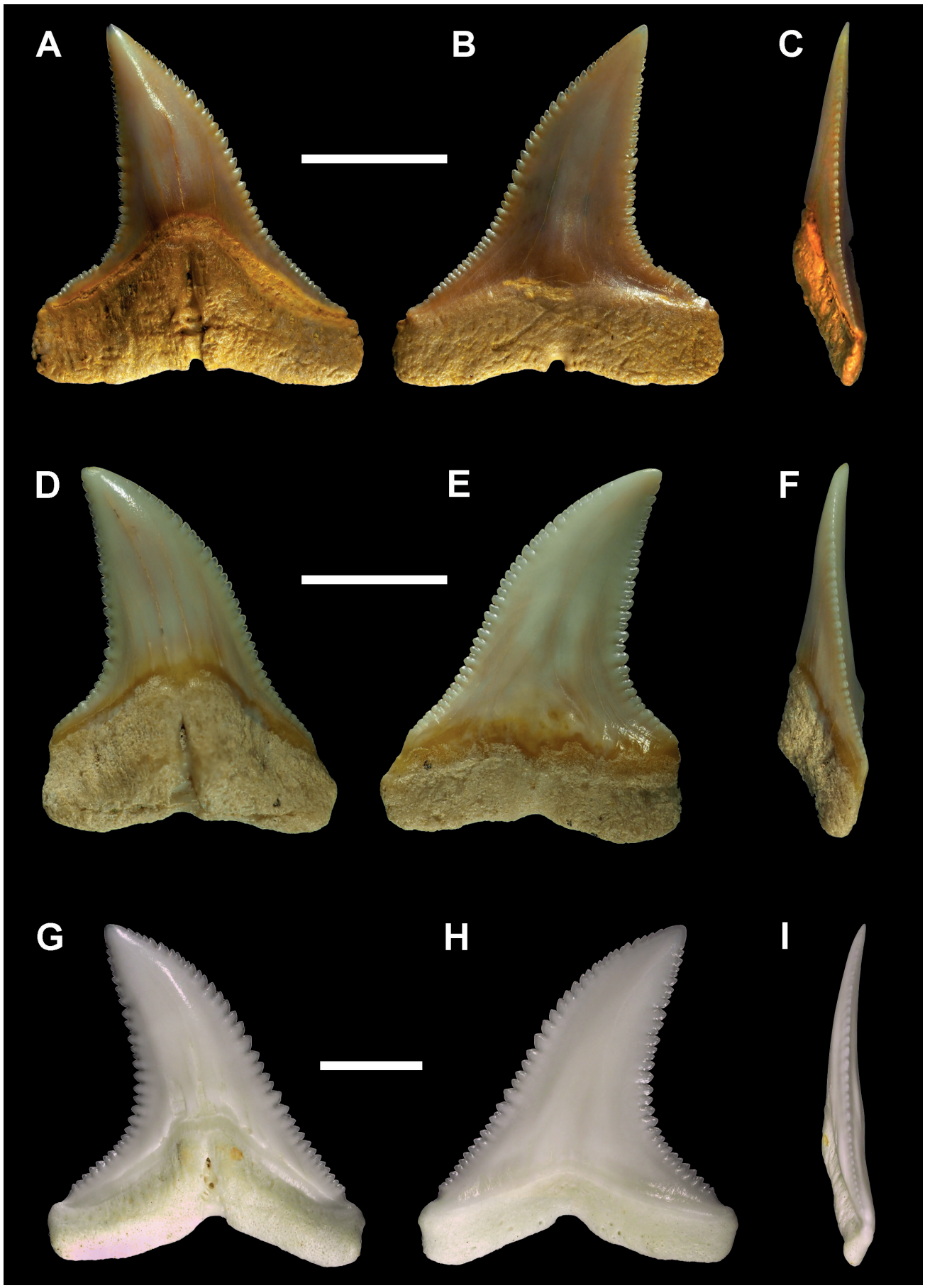

Figure 2. A–F, upper antero-lateral teeth of *Prionace glauca* from the Bahia Inglesa Formation, Caldera, Chile (7-789 and 7-790); **G–H,** upper antero-lateral tooth of *Prionace glauca* from British Isles (7-768/R2); scale bars = 5 mm.

Description. Antero-lateral teeth with a high triangular cusp with strongly serrated cutting-edges, but not reaching the apex (Fig. 2A–2F). The crown is higher than broad with a distally inclined cusp. The mesial edge is sigmoidal whereas the distal one is concave. The labial face of the crown is flat and smooth, with a short and shallow longitudinal medial ridge towards its base (Fig. 2B, 2C, 2E, 2F). The lingual face of the crown is convex and smooth (Fig. 2A, 2C, 2D, 2F). Very narrow bourlette on its lingual side. The root is high and subtriangular in lingual view, bifurcated by a well-developed nutritive groove which creates a notch in the basal edge (Fig. 2A–2D). In labial view, the root is subrectangular and bilobate. Small foramina present on both faces of the root.

Remarks. Specimens 7-789 and 7-790 share several diagnostic characters with those of extant individuals of *P. glauca*, including sharply serrated cutting edges that fade at the tip, distally inclined cusps, absence of lateral cusplets and high bifurcated roots in lingual view (Fig. 2G–2I) (Herman *et al.*, 1991; Ebert & Dando, 2020). These specimens can be distinguished from *Hemipristis* (Agassiz, 1835) by having a more regular serration instead of increasing in size toward the apex, lacking an un-serrated heel at the base of its mesial cutting edge, and having more symmetrical root lobes. Although both specimens share some distinctive characteristics when compared with extant individuals of *P. glauca* (*i.e.*, overall broader in profile, taller root with a straighter basal edge), these can be within the expected intraspecific variation and do not seem to justify the creation of a new taxon at the moment.

DISCUSSION AND CONCLUSION

The confirmation of the presence of *Prionace glauca* in the Neogene sediments of Chile is a significant contribution to our global knowledge of the past distribution of chondrichthyans, being the first well-documented record of the species for the southern hemisphere. This is also relevant due to the limited number of taxa identified to the species level in Chile (Villafaña & Rivadeneira, 2018), where most confirmed records can only be validated at the genus level. Indeed, compared to other Neogene localities in South and Central America (*e.g.*, Carrillo-Briceño *et al.*, 2016, 2018, 2020; Pérez *et al.*, 2017; Landini *et al.*, 2019), Chile has the lowest number of taxa identified to the species level. Therefore, the description of non-controversial specimens that allow us to confirm the presence of shark species in the local record is a fundamental step to improve our understanding of the evolutionary history of this group in the southeast Pacific.

The world record of *Prionace glauca* is concentrated in Central Europe and limited to the early Pliocene onwards (Landini, 1977; Cigala-Fulgosi, 1986; Sorbini, 1988; Bellocchio *et al.*, 1991; Cigala-Fulgosi *et al.*,

Figure 3. Fossil records of *Prionace glauca* from the Miocene-Pliocene (violet), Miocene (yellow), Pliocene (orange) and Quaternary (green). Records from Belgium (Goolaerts *et al.*, 2020), Chile (this study), Italy (Landini, 1977; Cigala-Fulgosi, 1986; Sorbini, 1988; Bellocchio *et al.*, 1991; Cigala-Fulgosi *et al.*, 2009; Collareta & Casati, 2018), Mexico (González-Rodríguez *et al.*, 2013), Sri Lanka (Deraniyagala, 1969), South Africa (Rich, 1980), United States (Kanakoff, 1956; Fitch, 1967; Langenwalter, 1975) and Venezuela (Carrillo-Briceño *et al.*, 2018).

2009; Collareta & Casati, 2018; Fig. 3). Although there have been reports from older sediments (*i.e.*, Miocene), the information provided is insufficient to validate this records (*e.g.*, Deraniyagala, 1969; Rich, 1980; Kindlimann, 1990; González-Rodríguez *et al.*, 2013; Goolaerts *et al.*, 2020; Fig. 3). Is for this reason that the presence of *Prionace glauca* has been used as an indicator of Pliocene age for some levels of the Bahia Inglesa Formation (Suárez & Marquardt, 2003; Walsh & Suárez, 2006; Valenzuela-Toro *et al.*, 2013). However, later studies assign a mean age of 7.0 My to the Mina Fosforita Member (Le Roux *et al.*, 2016), based on the overlapping error intervals produced by the available radiometric data (Godoy *et al.*, 2003; Henríquez, 2006). Nevertheless, it is worth noting that the stratigraphic columns available within the Mina Fosforita locality (Le Roux *et al.*, 2016) do not seem to include the upper levels present in nearby areas (*i.e.*, Los Dedos), which may belong to the base of the lower Pliocene Rocas Negras Member. Therefore, the age of these specimens can only be defined as late Tortonian to early Zanclean. Future stratigraphic studies and radiometric dating will be necessary to clarify its age and validate the chronostratigraphic use of this species. Regardless of the exact age of this particular record, it is clear that *Prionace glauca* is part of the chondrichthyan taxa who survived to the intense climatic and oceanographic events that occurred during the Pliocene–Pleistocene transition in the Chilean coast (Westerhold *et al.*, 2020), taking into account that the species still inhabit the region today. Its thermal tolerances, which explain the wide distribution of this shark (Ebert *et al.*, 2021), could have been one of the factors that allowed its persistence over time. However, more studies are needed to clarify both its evolutionary origin and the changes in its habits over time, in order to better understand how this species persisted while so many others became locally or globally extinct.

Supplementary information. This article has no additional data.

Author contributions. JAV, RK and MCH conceived the study and wrote the manuscript.

Competing Interest. We declare no competing interests.

Funding. We declare no funding for this study.

Author details. **Jaime A. Villafaña[1], René Kindlimann[2] & Martin Chavez-Hoffmeister[3]**. [1]Laboratorio de Paleobiología, Centro de Estudios Avanzados en Zonas Áridas (CEAZA), Avda. Bernardo Ossandón 877, 1781681, Coquimbo and Centro de Investigación en Recursos Naturales y Sustentabilidad, Universidad Bernardo O'Higgins, Avda. Viel 1497, 8370993 Santiago, Chile, jaime.villafana@ceaza.cl; [2]Zuerichstrasse 58, 8607 Aathal-Seegraeben, Switzerland, rene.j.kindlimann@bluewin.ch; [3]Corporación de Investigación y Avance de la Paleontología e Historia Natural de Atacama (CIAHN), Prat 58, 1570000, Caldera y Laboratorio de Paleontología, Instituto de Ciencias de la Tierra, Universidad Austral de Chile, Los Laureles s/n, 5090000, Valdivia, Chile; martinchavez@ciahn.cl.

Acknowledgments. We thank Marcelo Rivadeneira and Benjamin Araya for their helpful comments. This short communication was greatly improved by the comments and suggestion made by Jorge Cariillo-Briceño and one anonymous reviewer. Last but not least, thanks to the editors Humberto Ferron, Carlos Martínez-Pérez and Sonia Ros-Franch for the manuscript handling.

REFERENCES

Agassiz, L. (1835). *Recherches sur les poissons fossiles*. Petitpierre.

Bellocchio, G., Carboni, M. G., Nami, M., & Pallini, G. (1991). Fauna ad ittiodontoliti del Pliocene di Allegrona (Terni, Umbria). *Bollettino della Società dei Naturalisti in Napoli*, *100*, 41–73.

Bianucci, G., Sorbi, S., Suárez, M. E., & Landini, W. (2006). The southernmost sirenian record in the eastern Pacific Ocean, from the Late Miocene of Chile. *Comptes Rendus Palevol*, *5*(8), 945952. doi: 10.1016/j.crpv.2006.06.001

Bonaparte, C. L. (1838). Selachorum tabula analytica. *Nuovi Annali delle Scienze Naturali Bologna*, *1*, 195–214.

Bourdon, J. (1999). The life and times of long dead sharks. Available from: www.elasmo.com; consultation date on October 1st, 2022.

Cantor, T. E. (1849). Catalogue of Malayan fishes. *Journal of the Asiatic Society of Bengal*, *18*(2), 981–1443.

Cappetta, H. (2012). *Handbook of Paleoichthyology. Chondrichthyes: Mesozoic and Cenozoic Elasmobrachii: Teeth*. Gustav Fischer Verlag.

Carrillo-Briceño, J. D., Aguilera, O. A., De Gracia, C., Aguirre-Fernández, G., Kindlimann, R., & Sánchez-Villagra, M. R. (2016). An Early Neogene Elasmobranch fauna from the southern Caribbean (Western Venezuela). *Palaeontologia Electronica*,*19.2.27A*, 1–32. doi: 10.5167/uzh-125933

Carrillo-Briceño, J. D., Carrillo, J. D., Aguilera, O. A., & Sánchez-Villagra, M. R. (2018). Shark and ray diversity in the Tropical America (Neotropics)—an examination of environmental and historical factors affecting diversity. *PeerJ, 6,* e5313. doi: 10.7717/peerj.5313

Carrillo-Briceño, J. D., Villafaña, J. A., De Gracia, C., Flores-Alcívar, F. F., Kindlimann, R., & Abella, J. (2020). Diversity andpaleoenvironmental implications of an elasmobranch assemblage from the Oligocene–Miocene boundary of Ecuador. *PeerJ*, *8*, e9051. doi: 10.7717/peerj.9051

Chávez-Hoffmeister, M. F. (2008). *La ornitofauna de la Formación Bahía Inglesa, Caldera, Chile*. (Bachelor Thesis, Universidad Austral de Chile, Chile).

Cigala-Fulgosi, F. (1986). A deep water elasmobranch fauna from a lower Pliocene outcropping (Northern Italy). In T. Uyeno, R. Arai, T. Taniuchi, & K. Matsuura (Eds.), *Indo-Pacific Fish Biology: Proceedings of the Second International Conference on Indo-Pacific Fishes* (pp. 133–139). Ichthyological Society of Japan.

Cigala-Fulgosi, F., Casati, S., Orlandini, A., & Persico, D. (2009). A small fossil fish fauna, rich in Chlamydoselachus teeth, from the Late Pliocene of Tuscany (Siena, central Italy). *Cainozoic Research*, *6*(1/2), 3–23.

Collareta, A., & Casati, S. (2018). The porbeagle shark, Lamna nasus (Elasmobranchii: Lamniformes), from the late Pliocene of the central Mediterranean Basin. *Neues Jahrbuch für Geologie und Paläontologie*, *287*(3), 307–316. doi: 10.1127/njgpa/2018/0718

Colasso, G. G. (2011). *Diversidade e Abundância Relativa de Dentes de Selachii Ocorrentes no Sistema Deposicional Laguna-Barreira no Sul da Planície Costeira do Rio Grande do Sul, Brasil*. (Bachelor Thesis, Universidade do vale do Itajaí, Itajaí).

Compagno, L. J. V. (1973). Interrelationships of living elasmobranchs. *Zoological Journal of Linnean Society*, *53*, 15–61.

Deraniyagala, P. E. P. (1969). A Miocene vertebrate faunule from the Malu member of Ceylon. *Spolia Zeylanica*, *31*, 1–17.

Ebert, D. A., & Dando, M. (2020). *Field guide to sharks, rays & chimaeras of Europe and the Mediterranean*. Princeton University Press.

Ebert, D. A., Dando, M., & Fowler, S. (2021). *Sharks of the world: a complete guide*. Princeton University Press.

Fitch, J. E. (1967). The marine fish fauna, based primarily on otoliths, of a lower Pleistocene deposit at San Pedro, California. *Contributions in Science*, *128*, 1–23.

Godoy, E., Marquardt, C., & Blanco, N. (2003). *Carta Caldera, Región de Atacama. Serie Geología Básica, No. 76.* Servicio Nacional de Geología y Minería.

González-Barba, G., & Thies, D. (2000). Asociaciones faunísticas de condrictios en el cenozoico de la Península de Baja California, México. *XVII Simposio sobre la Geología de Latinoamérica, Abstract Book* (pp.1–4). Huelva.

González-Rodríguez, K. A., Espinosa-Arrubarrena, L., & González-Barba, G. (2013). An overview of the Mexican fossil fish record. In G. Arratia, H.-P. Schultze, & M. V. H. Wilson (Eds.), *Mesozoic Fishes 5 - Global Diversity and Evolution* (pp. 9–34). Verlag Dr. Friedrich Pfeil.

Goolaerts, S., De Ceuster, J., Mollen, F. H., Gijsen, B., Bosselaers, M., Lambert, O., Uchman, A., Van Herck, M., Adriaens, R., Houthuys, R., Louwye, S., Bruneel, Y., Elsen, J., & Hoedemakers, K. (2020). The upper Miocene Deurne Member of the Diest Formation revisited: unexpected results from the study of a large temporary outcrop near Antwerp International Airport, Belgium. *Geologica Belgica*, *23*(3–4), 219–252.

Gutstein, C. S., Cozzuol, M. A., Vargas, A. O., Suárez, M. E., Schultz, C. L., & Rubilar-Rogers, D. (2009). Patterns of skull variation of Brachydelphis (Cetacea, Odontoceti) from the Neogene of the Southeastern Pacific. *Journal of Mammalogy*, *90*(2), 504–519.

Henríquez, A. A. (2006). Variaciones locales del nivel del mar en las cuencas neógenas de Caldera, III Región y Arauco, VIII Región: Deducción de tasas de alzamiento y subsidencia tectónica. (Master Thesis, Universidad de Chile, Santiago, Chile).

Herman, J., Hovestadt-Euler, M., & Hovestadt, D. C. (1991). Contributions to the study of the comparative morphology of teeth and other relevant ichthyodorulites in living supraspecific taxa of chondrichthyan fishes. Part A: Selachii. No. 2c: Order: Carcharhiniformes, Families: Proscylliidae, Hemigaleidae, Pseudotriakidae, Leptochariidae and Carcharhinidae. *Bulletin de l'Institut royal des sciences naturelles de Belgique, Entomologie & biologie*, *61*, 73–120.

Huxley, T. H. (1880). On the applications of the laws of evolution to the arrangement of the vertebrata and more particularly of the Mammalia. *Proceedings of the Zoological Society of London*, *43*, 649–661.

Huddleston, R. W., & Barker, L. W. (1978). Otoliths and other fish remains from the Chumash midden at Rincón Point (SBa-1), Santa Barbara-Ventura Counties, California. *Natural History Museum of Los Angeles County Contributions in Science*, *289*, 1–36.

IUCN (2022). The IUCN Red List of Threatened Species. Version 2022-9. https://www.iucnredlist.org; consultation date on October 1st, 2022.

Jordan, D. S., & Evermann, B. W. (1896). The fishes of North and Middle America, a descriptive catalogue of the species of fish–like vertebrates found in the waters of North America, north of the isthmus of Panama. Part. I. *Bulletin of the United States National Museum*, *47*, 2183–3136.

Kanakoff, G. P. (1956). Fish records from the Pleistocene of southern California in the collections of the Los Angeles County Museum. *Bulletin of the Southern California Academy of Sciences*, *55*(1), 47–49

Kindlimann, R. (1990). Selacios del Terciario Tardío de Sacaco, Departamento de Arequipa. *Boletín de Lima*, *69*, 91–95.

Landini, W. (1977). Revisione degli "Ittiodontoliti pliocenici" della collezione Lawley. *Palaeontographia Italica*, *70*, 92–134.

Landini, W., Collareta, A., Di Celma, C., Malinverno, E., Urbina, M., & Bianucci, G. (2019). The early Miocene elasmobranch assemblage from Zamaca (Chilcatay Formation, Peru). *Journal of South American Earth Sciences*, *91*, 352–371. doi: 10.1016/j.jsames.2018.08.004

Langenwalter, P. E. (1975). Chordates: The fossil vertebrates of the Los Angeles–Long Beach harbors region. In D. F. Soule, & M. Oguri (Eds.), *Marine studies of San Pedro Bay, California* (pp. 36–54). University of Southern California.

Le Roux, J. P., Achurra, L., Henríquez, Á., Carreño, C., Rivera, H., Suárez, M. E., Ishman, S. E., Pyenson, N. D., & Gutstein, C. S. (2016). Oroclinal bending of the Juan Fernández Ridge suggested by geohistory analysis of the Bahía Inglesa Formation, north-central Chile. *Sedimentary Geology*, *333*, 32–49. doi: 10.1016/j.sedgeo.2015.12.003

Linnaeus, C. (1758). *Systema Naturae per Regna Tria Naturae: secundum classes, ordines, genera, species, cum charcteribus differentiis synonymis, locis, 10th ed*. Laurentius Salvius.

Oyanadel-Urbina, P., De Gracia, C., Carrillo-Briceño, J. D., Nielsen, S. N., Flores, H., Casteletto, V., Kriwet, J., Rivadeneira, M. M., & Villafaña, J. A. (2021). Neogene Bony Fishes from the Bahía Inglesa Formation, Northern Chile. *Ameghiniana, 58*(4), 345–368. doi: 10.5710/AMGH.26.05.2021.3375

Pérez, V. J., Pimiento, C., Hendy, A., González-Barba, G., Hubbell, G., & MacFadden, B. J. (2017). Late Miocene chondrichthyans from Lago Bayano, Panama: functional diversity, environment and biogeography. *Journal of Paleontology*, *91*(3), 512–547. doi: 10.1017/jpa.2017.5

Queiroz, N., Humphries, N. E., Noble, L. R., Santos, A. M., & Sims, D. W. (2010). Short-term movements and diving behaviour of satellite-tracked blue sharks Prionace glauca in the northeastern Atlantic Ocean. *Marine Ecology Progress Series*, *406*, 265–279. doi: 10.3354/meps08500

Rafrafi-Nouira, S., Kamel-Moutalibi, E., Reynaud, C., Boumaïza, M., & Capapé, C. (2015). Additional and unusual captures of elasmobranch species from the northern coast of Tunisia (central Mediterranean). *Journal of ichthyology*, *55*(6), 836–848. doi: 10.1134/S0032945215060181

Rich, P. V. (1980). Preliminary report on the fossil avian remains from late Tertiary sediments at Langebaanweg (Cape Province), South Africa. *South African Journal of Science*, *76*(4), 166–170.

Sorbini, L. (1988). Biogeography and climatology of Pliocene and Messinian fossil fish of Eastern-Central Italy. *Bollettino del Museo civico di storia naturale di Verona*, *14*, 1–85.

Suárez, M. E. (2015). Tiburones, rayas y quimeras (chondrichthyes) fósiles de Chile. In D. Rubilar-Rogers, R. Otero, A. Vargas, & M. Sallaberry (Eds.), *Vertebrados Fósiles de Chile* (pp. 17–33*)*. Publicacion ocasional Museo Nacional de Historia Natural.

Suárez, M. E., & Marquardt, C. (2003). Revisión preliminar de las faunas de peces elasmobranquios del Mesozoico y Cenozoico de Chile y comentarios sobre su valor cronoestratigráfico. *X Congreso Geológico Chileno, Abstract Book* (pp. 1– 9). Concepción.

Valenzuela-Toro, A. M., Gutstein, C. S., Varas-Malca, R. M., Suárez, M. E., & Pyenson, N. D. (2013). Pinniped turnover in the South Pacific Ocean: new evidence from the Plio-Pleistocene of the Atacama Desert, Chile. *Journal of Vertebrate Paleontology*, *33*(1), 216–223. doi: 10.1080/02724634.2012.710282

Villafaña, J. A., & Rivadeneira, M. M. (2018). The modulating role of traits on the biogeographic dynamics of chondrichthyans from the Neogene to the present. *Paleobiology*, *44*(2), 251262. doi: 10.1017/pab.2018.7

Walsh, S. A., & Suárez, M. E. (2005). First post-Mesozoic record of Crocodyliformes from Chile. *Acta Palaeontologica Polonica*, *50*(3), 596–600.

Walsh, S. A., & Suárez, M. E. (2006). New penguin remains from the Pliocene of northern Chile. *Historical Biology*, *18*(2), 119130. doi: 10.1080/08912960600640796

Westerhold, T., Marwan, N., Drury, A. J., Liebrand, D., Agnini, C., Anagnostou, E., Barnet, J. S. K., Bohaty, S. M., De Vleeschouwer, D., Florindo, F., Frederichs, T., Hodell, D. A., Holbourn, A. E., Kroon, D., Lauretano, V., Littler, K., Lourens, L. J., Lyle, M., Pälike, H., Röhl, U., Tian, J., Wilkens, R. H., Wilson, P. A., & Zachos, J. C. (2020). An astronomically dated record of Earth's climate and its predictability over the last 66 million years. *Science*, *369*(6509), 1383–1387. doi: 10.1126/science.aba6853