ORIGINAL RESEARCH

Beyond fishing: loggerhead turtle impalement by swordfish

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ABSTRACT. Sea turtles are susceptible to a wide range of impacts. In Brazil, the loggerhead turtle *Caretta caretta* (Linnaeus, 1758) is the main sea turtle species caught incidentally by longline fishing fleets that target the blue shark *Prionace glauca* (Linnaeus, 1758) and swordfish *Xiphias gladius* (Linnaeus, 1758). The latter is well known for its predation strategy, which consists of using the rostrum to injure and catch prey. In this study, we recorded for the first time the impalement of a juvenile loggerhead sea turtle by a swordfish during a fishing operation of a Brazilian longline vessel in 2018. Two videos of this interaction were recorded by the shipmaster around 260 km from the Brazilian coast. The sea turtle was incidentally caught with a hook and subsequently attacked by the swordfish. The rostrum initially pierced the anterior left shoulder of the turtle and passed through the body, exiting from the right posterior carapace. Given the position of the attack, considerable internal damage was most certainly done to the turtle. Although the turtle was hauled aboard to remove the hook and then returned to the sea alive, it probably died due to the extent of the injuries caused by the rostrum having passed through the center of the body. Since both swordfish and turtle are pelagic and these interactions are poorly recorded, such encounters may be relatively common. Therefore, this type of information should be included in the data collection protocols of fishery monitoring programs to better understand and scale the bill-stab phenomenon, not only for sea turtles but also in relation to other groups of fauna.

Key words: Sea turtle, incidental capture, species interaction, fisheries, Southwestern Atlantic Ocean.

Más allá de la pesca: empalamiento de una tortuga cabezona por el pez espada

RESUMEN. Las tortugas marinas son susceptibles a una amplia gama de impactos. En Brasil, la tortuga cabezona *Caretta caretta* (Linnaeus, 1758) es la principal especie de tortuga marina capturada incidentalmente por las flotas pesqueras de palangre que tienen como objetivo la tintorera *Prionace glauca* (Linnaeus, 1758) y el pez espada *Xiphias gladius* (Linnaeus, 1758). Este último, es muy conocido por su estrategia de depredación, que consiste en utilizar el rostro para herir y atrapar presas. En este estudio, se registró por primera vez el empalamiento de un juvenil de tortuga cabezona por un pez espada en 2018 durante una operación de pesca de un palangrero brasileño. El capitán del barco grabó dos videos de esta interacción a unos 260 km de la costa brasileña. La tortuga marina fue atrapada incidentalmente con un anzuelo y posteriormente atacada por el pez espada. El rostro perforó inicialmente el hombro izquierdo anterior de la tortuga y atravesó el cuerpo,

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saliendo por la parte posterior derecha del caparazón. Dada la posición del ataque, la tortuga sufrió un daño interno considerable. Aunque la tortuga fue subida a bordo para quitarle el anzuelo y luego fue devuelta viva al mar, probablemente murió debido a la extensión de las heridas causadas por el paso del rostro a través del centro del cuerpo. Dado que tanto el pez espada como la tortuga son pelágicos y estas interacciones no se registran acabadamente, estos encuentros pueden ser relativamente comunes. Por lo tanto, este tipo de información debe incluirse en los protocolos de recopilación de datos de los programas de monitoreo de pesquerías para comprender mejor y escalar este tipo de fenómenos, no solo para las tortugas marinas sino también en relación con otros grupos de fauna.

Palabras clave: Tortuga marina, captura incidental, interacción de especies, pesquerías, Océano Atlántico Sudoccidental.

INTRODUCTION

Sea turtles are subject to a wide range of impacts and threats from human activity throughout their life cycle (NRC 1990), such as exposure to pollutants, collisions with vessels, and mainly incidental capture by different fishing gear (Lazar et al. 2011; Lewison et al. 2014; Schuyler et al. 2014; Ataman et al. 2021). In the latter case, the loggerhead sea turtle *Caretta caretta* (Linnaeus, 1758) is one of the most widely incidentally captured species by longline fleets worldwide (Spotila et al. 2000; Yeung 2001; Lewison et al. 2004; Lewison and Crowder 2007). The Southwestern Atlantic Ocean is an important foraging and juvenile development area and is home to mixed stocks of loggerhead turtles (Shamblin et al. 2014), which is the species that most interacts with longline fleets in this region (Kotas et al. 2004; Sales et al. 2004, 2008; Domingo et al. 2006a, 2006b; López-Mendilaharsu et al. 2007; Giffoni et al. 2008; Pons et al. 2010).

The swordfish *Xiphias gladius* (Linnaeus, 1758) is widely distributed worldwide, and particularly across the West Atlantic Ocean, from Canada in the North to Argentina in the South (Palko et al. 1981; Weidner and Arocha 1999). In the Southwestern Atlantic, it is one of the main target species of longline fisheries in the southeast and south of Brazil and in Uruguay (Fiedler et al. 2015). Moreover, it is considered an opportunistic species with a broad trophic spectrum (Clarke et al. 1995; Figueiredo and Menezes 2000). The most striking morphological feature of this species is an elongated and dorsolaterally flat rostrum, which is mainly used to incapacitate prey with a lateral movement (Wisner 1958; McGowan 1988; Habegger et al. 2015).

Impalements caused by billfishes on different taxonomic groups such as whales (Jonsgard 1962; Machida 1970; Oshumi 1973; Major 1979), sharks (Fierstine et al. 1997; Penadés-Suay et al. 2017, 2019; Jambura et al. 2020; Romeo et al. 2020), even humans (Carvajal et al. 2002; Gooi et al. 2007; Mendonça-Caridad et al. 2008; Haddad Jr and Figueiredo 2009; Georgiadou et al. 2010; Galarza et al. 2016), and diverse inanimate objects, such as submarines (Zarudzki and Haedrich 1974) and ships (Gudger 1940; Romeo et al. 2017) have been recorded around the world. In contrast, records of turtles impaled by billfishes are rare (Frazier et al. 1994), even today, when images can be quickly captured using mobile phones. Furthermore, impalements by billfish are usually identified when the fishing gear is collected, when fishers are fully focused on their catch and have no time to record such events, which makes the opportunity to obtain images even more difficult. Among 32 records identified since the 1940s, only 7 include information on the interaction between billfish and sea turtles (Table 1). The turtle species involved were olive ridley *Lepidochelys olivacea* (3 records), leatherback *Dermochelys coriacea* (2 records), and loggerhead and green turtle *Chelonia mydas* (1 record each). The only two interactions previously reported with *Xiphias gladius* involved a *Lepidochelys olivacea* record-

Table 1. Literature review on the interaction of billfish and different groups of fauna (e.g. whales, sharks, and turtles), humans, and inanimate objects (e.g. ships and submarines). *Brazilian EZZ: Brazilian Exclusive Economic Zone.

Year of occurrence	Region/country	Species/structure	Billfish species	Evidence
Not reported	Not reported	Vessels	Unknow	Gudger 1940
1959	Antarctic sea	*Balaenoptera musculus*	*Xiphias gladius*	Jonsgard 1959
1962	Antarctic sea	*Balaenoptera physalus*	*Xiphias gladius*	Jonsgard 1962
1969	North Pacific	*Balaenoptera borealis*	*Xiphias gladius*	Machida 1970
1972	Antarctic sea	*Balaenoptera bonaerensis*	*Makaira mazara* or *Istiompax indica*	Oshumi 1973
1967	Western Atlantic Ocean	Submarine 'Alvin'	*Xiphias gladius*	Zarudzki and Haedrich 1974
1951	Karuku Point, Oahu, Hawaii	Unidentified whales	Unknow	Major 1979
1983	Off San José, Uruguay	*Dermochelys coriacea*	*Makaira nigricans*	Achaval and Prigioni 1988
1965	Off Cape San Lucas, Mexico	*Lepidochelys olivacea*	*Xiphias gladius*	Frazier et al. 1994
1987	Ogasawara, Japan	*Chelonia mydas*	*Istiophorus platypterus*	Frazier et al. 1994
1989	150 km SW of Acapulco, Mexico	*Lepidochelys olivacea*	*Istiophorus platypterus*	Frazier et al. 1994
1989	480 km SSW of Acapulco,	*Lepidochelys olivacea*	Unknow	Frazier et al. 1994
1992	Off Ventura, California, USA	*Caretta carreta*	*Kajikia audax* or *Makaira nigricans*	Frazier et al. 1994
1993	Off Algarve, Portugal	*Makaira nigricans*	*Kajikia albida* and *K. audax*	Fierstine 1997
1995	Off Enseñada, Mexico	*Isurus oxyrinchus*	*Makaira nigricans*	Fierstine et al. 1997
Not reported	Alicante, Spain	Human (young male)	*Xiphias gladius*	Carvajal et al. 2002
Not reported	Malaysia	Human (adult male)	*Xiphias gladius*	Gooi et al. 2007
Not reported	Spain	Human (adult male)	*Xiphias gladius*	Mendonça-Caridad et al. 2008
2008	Matinhos beach, Paraná, Brazil	Human (adult male)	*Tetrapturus albidus*	Haddad Jr and Figueiredo 2009
Not reported	Satorini Island, Greece	Human (adult woman)	*Xiphias gladius*	Georgiadou et al. 2010
2014	Grande Rivière beach,	*Dermochelys coriacea*	Unknow	Martin 2014
2000	Spain	Human (adult male)	*Xiphias gladius*	Galarza et al. 2016

Table 1. Continued.

Year of occurrence	Region/country	Species/structure	Billfish species	Evidence
Not reported	Senegal	Human (4 adult male and 1 young male)	*Xiphias gladius*	Ndiaye et al. 2017
2016	Valencia, Spain	*Prionace glauca*	*Xiphias gladius*	Penadés-Suay et al. 2017
1999-2014	Sicilian waters	Harpoon fishing vessels	*Xiphias gladius*	Romeo et al. 2017
Not reported	Malaysia	Human (adult male)	*Xiphias gladius*	Sriram et al. 2017
2017	Garrucha, Spain	*Prionace glauca*	*Xiphias gladius*	Penadés-Suay et al. 2019
2017	Ostia, Italy	*Prionace glauca*	*Xiphias gladius*	Penadés-Suay et al. 2019
2018	Vera, Spain	*Prionace glauca*	*Xiphias gladius*	Penadés-Suay et al. 2019
2018	Manacor, Spain	*Prionace glauca*	*Xiphias gladius*	Penadés-Suay et al. 2019
2020	Brega, Libyan	*Alopias superciliosus*	*Xiphias gladius*	Jambura et al. 2020
2018	Sicilian waters	*Prionace glauca*	*Xiphias gladius*	Romeo et al. 2020
2018	Southwestern Atlantic Ocean (Brazilian EEZ)	*Caretta caretta*	*Xiphias gladius*	This study

ed in the Pacific Ocean, in the Cabo San Lucas region (Mexico), and a *Chelonia mydas* recorded in Japan (Frazier et al. 1994). Few records on the interaction of swordfish with sea turtles were found; however, a relatively larger number of records were found of swordfish interacting with other fauna groups and even inanimate objects such as submarines, boats, and submersibles (Ellis 2013).

In this regard, the present study provides the first confirmed record of a loggerhead sea turtle *Caretta caretta* impaled by a swordfish *Xiphias gladius*.

METHODS

The impalement was recorded during the fishing trip of a Brazilian longline vessel that specifically fishes swordfish and shark, in August 2018. The master of the vessel recorded two videos each of 1 min 39 s using his smartphone. In the first video, the turtle and swordfish reported on herein were still in the water, before were brought aboard, while, in the second video, the swordfish and turtle were being boarded onto the vessel. These videos were voluntarily given by the master to the team of the Tamar Project Foundation (a Brazilian non-governmental organization that has been working for the conservation of sea turtles for more than 40 years), in the port of Itajaí, Santa Catarina state, southern Brazil.

RESULTS

On August 16th 2018, while reeling the third longline set at position 26° 25′ 78″ S and 46° 00′ 69″ W, about 260 km from the port of origin in Itajaí (SC), Brazil, between 500 m and 1000 m deep (Figure 1), a juvenile loggerhead turtle was found hooked, and at some point the hooked turtle had been impaled by a swordfish with its sword still piercing the body of the turtle (Figure

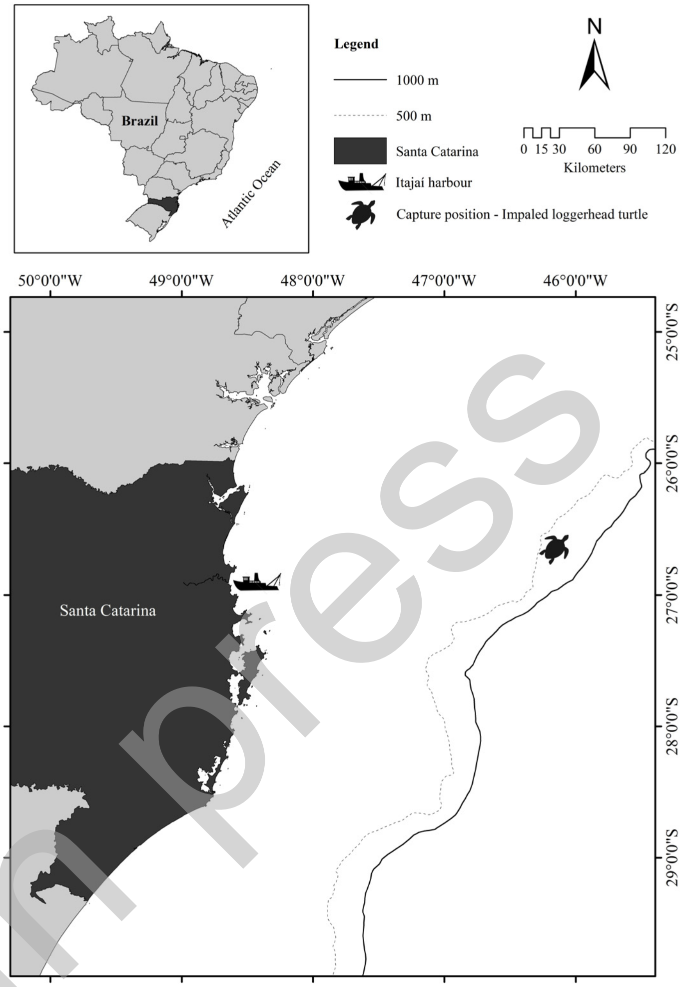

Figure 1. Location where the loggerhead turtle *Caretta caretta* was captured incidentally by longline vessel and impaled by a swordfish *Xiphias gladius*.

2 A). The rostrum of the swordfish pierced the anterior region of the turtle between the neck and the shoulder of the left flipper, passing through the carapace and exiting from the right side of the fourth central scute, approximately between the fourth and fifth right lateral scute (Figure 2 B). At the time of encountering between the two animals, the turtle was alive, and the swordfish was dead. Before boarding the two animals, the body of the swordfish was removed by the fishers to facilitate hauling onto the deck, and only the head with the rostrum remained attached to the turtle (Figure 2 B and 2 C). After recording, the head and rostrum of the swordfish were removed from the turtle (Figure 2 D) and the turtle was returned to the sea.

DISCUSSION

The way the swordfish was attached to the turtle suggests that the attack was made in the same horizontal plane as the turtle or at a slightly lower

Figure 2. A) Loggerhead sea turtle *Caretta caretta* (alive) with the swordfish *Xiphias gladius* (dead) that has impaled the turtle. B) At this point, the decapitated head of the swordfish with its rostrum passing through the turtle: red circles show sites of entry and exit of rostrum. C) Ventral view of the turtle, with the steel wire (red circle) or 'strop', part of the longline gear in the mouth of the turtle, indicating that the fishing gear first hooked the turtle. D) Fishers removing the rostrum of the swordfish from the body of the turtle. Images taken from the two videos recorded by the master of the vessel.

angle since the rostrum was attached longitudinally to the turtle's body. Considering the position/orientation in which the rostrum of the swordfish perforated the turtle, it is very likely that at least one of the turtle's lungs was struck since they occupy a large area just below the carapace. Furthermore, since the perforation occurred longitudinally, from anterior to posterior of the turtle's body, and relatively diagonally (from ventral to dorsal), other organs such as the gastrointestinal tract, heart, liver, and other structures such as veins and arteries were also affected. If indeed other organs and structures were perforated, the possibility of this turtle having survived was very low. Although the animal was returned to the sea alive, it probably died due to the extent of the internal injuries caused by the impalement.

In June 2014, a leatherback turtle was observed nesting on Grande Riviere beach in Trinidad, Caribbean, with the rostrum of a billfish stuck into its carapace (Martin 2014). This rostrum was approximately 60 cm long and entered the turtle transversely through the carapace and exited through the plastron. According to the published note, the rostrum perforating the turtle's carapace was encrusted by barnacles, indicating that it had been embedded in the turtle for some time. Therefore, the interaction of the turtle with the billfish had not been recent and, despite any damage caused by the impalement, the turtle had survived (Martin 2014). The fact that the rostrum traversed the turtle's body from one side to the other suggests that at least one of the turtle's lungs had been punctured. Regardless, the female leatherback turtle was able to leave the sea and climb up the beach to lay eggs, demonstrating the incredible resistance of these animals to the injuries suffered.

The first known record of a sea turtle impaled by a billfish was made in 1988, when Uruguayan researchers reported the case of a leatherback turtle impaled by the rostrum of a blue marlin *Makaira nigricans* (Achaval and Prigioni 1988). Four cases of turtle impalement, including the previous one, were subsequently described (Frazier et al. 1994). These include impalements by sailfish *Istiophorus platypterus*, blue marlin, and swordfish, and involve the leatherback turtle, olive ridley sea turtle, and the green sea turtle. In addition to these confirmed instances, the case of a loggerhead turtle with a fragment of the rostrum of the striped marlin *Kajikia audax* or *M. nigricans* in its carapace, parallel to the ribs, caught in a gill net in the USA was recorded. However, there was no photographic record for validation (Frazier et al. 1994).

The South Atlantic Ocean is an important area for the reproduction, feeding, and growth of swordfish, from larval to adult stage (Gorbunova 1969; Hazin and Erzini 2008). Swordfish migrate horizontally and move vertically daily from depths over 600 m, where they remain during the day, to the surface at night (Carey and Robison 1981). Therefore, it is during the night that swordfish and loggerhead turtles may occupy the same water strata. A study carried out on loggerhead turtles caught incidentally by pelagic longlines in the Southwestern Atlantic and subsequently released with satellite transmitters, revealed that the deepest dives carried out by these animals were between 200 m to 300 m deep. However, only 1% of all monitored dives exceeded 100 m in depth and the loggerhead turtles usually remained between depths of 10 m and 100 m (Barceló et al. 2013). Therefore, these interactions between swordfish and sea turtles should mainly occur at night, which is also the time the longline vessels targeting swordfish set their gear in the water.

At feeding times, swordfish can reach speeds of more than 100 km h^{-1}. The elongated, fusiform body and large, light, thin, and profoundly forked tail of the swordfish cause relatively little resistance and require less effort than would be required by less hydrodynamically designed fish, thus allowing the swordfish to achieve very high speeds (Ellis 2013). Moreover, top predators, such as the swordfish, have a highly specialized thermoregulatory system located in an extraocular muscle that maintains the eyes and brain up to 15 °C above water temperature (Carey 1982), significantly improving the temporal resolution (10 times better than that of fish with eyes at the same temperature as that of surrounding water), increasing movement detection and providing a huge advantage over the prey (Frietsches et al. 2005).

The rostrum has sensitive lateral lines that detect pressure differences in the water and enable the best angle for approach and attack (Scott and Tibbo 1968; Nakamura 1983; Lee et al. 2009; Sagong et al. 2013; Habegger 2014). Predators with narrow body profiles and great swimming speed, such as swordfish, can approach their prey without triggering an escape response, which increases their chances of successful attacks (Webb 1986). In this regard, the rostrum of billfish plays a critical role in feeding since these species have one of the lowest absolute bite forces among all bony and cartilaginous fish (Habegger et al. 2017).

Studies on the swordfish diet carried out in southeastern and southern Brazil recorded a higher frequency of the occurrence of cephalopods, followed by bony fish (Mazzoleni and Schwingel 2002; Vaske Júnior and Lessa 2005; Gorni et al. 2012, 2013). Although turtles are not part of the regular diet of swordfish or any other billfish, impalements may be caused by an accidental collision since this type of attack is not beneficial for the swordfish as corroborated by Frazier et al. (1994). These impalements may occur when the swordfish tries to capture prey close to the turtle, which often remains immobile on the surface and tends to float, thus serving as an aggregator of small fish that, in turn, can attract larger predators, such as the swordfish (Brock 1985; Frazier et al. 1994; Hirama and Witherington 2012). It could also be that billfish in urgent need of feeding may make risky attacks near to a dangerous object, which would otherwise be avoided by a billfish not under feeding stress.

In the present case, the turtle was attached to a longline hook, resulting in a limited swimming radius due to the length of the branchline (between 15 m and 20 m), which forces the turtle to swim in a circle or up and down to breathe or submerge. This unnatural swimming pattern may have attracted the attention of the swordfish. A similar event was recorded in Mexico, when an olive ridley sea turtle was captured by a longline boat and was also impaled by a swordfish (Frazier et al. 1994). Some abundant data about this species, including reports of interaction with different groups of fauna or structures can be found in Ellis (2013).

Accidents with humans have also been reported and, although rare, often result in serious injuries to those attacked (Carvajal et al. 2002; Mendonça-Caridad et al. 2008; Haddad Jr and Figueiredo 2009; Georgiadou et al. 2010; Galarza et al. 2016; Sriram et al. 2017). Many of these cases of human attacks involve fishers, who are evidently more susceptible to interactions with billfish. Such incidents generally occur when the billfish are provoked or when they feel threatened and use the rostrum to defend themselves (Romeo et al. 2017).

The amount of evidence to date on impalement of sea turtles and other taxa (including humans) by billfish raise the question about the frequency of these interactions. Therefore, this type of information should be included in the data collection protocols of fishery monitoring programs to better understand and scale the impalement phenomenon, not only for sea turtles but also in relation to other groups of fauna.

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REFERENCES

ACHAVAL F, PRIGIONI C. 1988. Reporte de colisión de 'Marlin' (*Makaira nigricans*) a una tortuga Laud (*Dermochelys coriacea*). V Reunión Iberoamericana de Conservación y Zoologia de Vertebrados, Montevideo, 26-30 julio. 93 p.

ATAMAN A, GAINSBURY AM, MANIRE CA, HOFFMANN SL, PAGE-KARJIAN A, HIRSCH SE, POLYAK MMR, CASSILL DL, AOKI DM, FRASER KM, et al. 2021. Evaluating prevalence of external injuries on nesting loggerhead sea turtles *Caretta caretta* in southeastern Florida, USA. Endang Species Res. 46: 137-146. DOI: https://doi.org/10.3354/esr01149

BARCELÓ C, DOMINGO A, MILLER P, ORTEGA L, GIFFONI B, SALES G, MCNAUGHTON L, MARCOVALDI M, HEPPELL SS, SWIMMER Y. 2013. High-use areas, seasonal movements and dive patterns of juvenile loggerhead sea turtles in the Southwestern Atlantic Ocean. Mar Ecol Progr Ser. 479: 235-250.

BROCK RE. 1985. Preliminary study of the feeding habits of pelagic fish around Hawaiian fish aggregation devices or can fish aggregation devices enhance local fisheries productivity? Bull Mar. Sci 37: 40-49.

CAREY F. 1982. A brain heater in the swordfish. Science. 216 (4552): 1327-1329. DOI: https://doi.org/10.1126/science.7079766

CAREY FG, ROBISON BH. 1981. Daily patterns in the activities of swordfish, *Xiphias gladius*, observed by acoustic telemetry. Fish Bull. 79 (2): 277-292.

CARVAJAL JMG, MADUEÑO JJM, BÓMEZ BB, PANIAGUA JMR. 2002. Swordfish attack: an usual cause of penetrating thoracic wound. Eur J Cardio-Thorac Surg. 21: 926.

CLARKE MR, CLARKE DC, MARTINS HR, SILVA HM. 1995. The diet of swordfish (*Xiphias gladius*) in Azorean waters. Arquipel Life Mar Sci. 13 (A): 53-69.

DOMINGO A, BUGONI L, PROSDOCIMI L, MILLER P, LAPORTA M, MONTEIRO DS, ESTRADES A, ALBAREDA D. 2006b. El impacto generado por las pesquerías en las tortugas marinas en el Océano Atlántico Sud Occidental. WWF Programa Marino para Latinoamérica y el Caribe, San José Costa Rica. 72 p.

Domingo A, Sales G, Giffoni B, Miller P, Laporta M, Mauruto G. 2006a. Distribución y composición de tallas de las tortugas marinas (*Caretta caretta* y *Dermochelys coriacea*) que interactúan con el palangre pelágico en el Atlántico Sur. Collect Vol Sci Pap ICCAT. 59 (3): 992-1002.

Ellis R. 2013. Swordfish: a biography of the ocean gladiator. Chicago: The University of Chicago Press.

Fiedler FN, Sales G, Giffoni BB, Port D, Sant'ana R, Barreto AS, Schwingel PR. 2015. Spatio-temporal distribution and target species of longline fisheries off Southeastern/Southern Brazil between 2000 and 2011. Braz J Oceanogr. 63: 83-97.

Fierstine HL. 1997. An Atlantic blue marlin, *Makaira nigricans*, impaled by two species of billfishes (Teleostei: Istiophoridae). Bull Mar Sci. 61 (2): 495-499.

Fierstine HL, Cailliet GM, Neer JA. 1997. Shortfin mako, *Isurus oxyrinchus*, impaled by blue marlin, *Makaira nigricans* (Teleostei: Istiophoridae). Bull South Calif Acad Sci. 96 (3): 117-121.

Figueiredo JL, Menezes N. 2000. Manual de peixes marinhos do sudeste do Brasil. VI. Teleostei (5) São Paulo: Museu de Zoologia, Universidade de São Paulo. 116 p.

Frazier JG, Fierstine HL, Beavers SC, Achaval F, Suganuma H, Pitman RL, Yamaguchi Y, Prigioni CM. 1994. Impalement of marine turtles (Reptilia, Chelonia: Cheloniidae and Dermochelyidae) by billfishes (Osteichthyes, Perciformes: Istiophoridae and Xiphiidae). Environ Biol Fishes. 39: 85-96.

Frietsches KA, Brill RW, Warrant EJ. 2005. Warm eyes provide superior vision in swordfishes. Curr Biol. 15: 55-58. DOI: https://doi.org/10.1016/j.cub.2004.12.064

Galarza M, Alfaro R, De la Rosa P, Piqueras C. 2016. Delayed spinal cord herniation after a swordfish attack. Oper Neurosurg. 12 (3): E307-E308. DOI: https://doi.org/10.1227/neu.0000000000001318

Georgiadou D, Zografos GN, Vaidakis D, Avlonitis S, Katopodi A, Tzirakis EN, Sioutos P, Drossos C, Lampropoulou P, Papastratis G. 2010. Swordfish bill injury involving abdomen and vertebral column: case report and review. BMC Surgery. 10: 2-8. DOI: https://doi.org/10.1186/1471-2482-10-30

Giffoni B, Domingo A, Sales G, Fiedler FN, Miller P. 2008. Interacción de tortugas marinas (*Caretta caretta* y *Dermochelys coriacea*) con la pesca de palangre pelágico en el Atlántico Sudoccidental: uma perspectiva regional para la conservación. Collect Vol Sci Pap ICCAT. 62 (6): 1861-1870.

Gooi BH, Khamizar W, Suhani MN. 2007. Swordfish attack-death by penetrating head injury. Asian J Surg. 30 (2): 158-159.

Gorbunova NN. 1969. Breeding grounds and food of the larvae of the swordfish *Xiphias gladius* Linnaeu (Pisces, Xiphllidae). Probl Lchthyol. 9: 375-387.

Gorni GR, Goiten R, Amorim AF. 2013. Description of diet of pelagic fish in the southwestern Atlantic, Brazil. Biota Neotrop. 13 (1): 61-69.

Gorni GR, Loibel S, Goiten R, Amorim AF. 2012. Stomach contents analysis of swordfish (*Xiphias gladius*) caught off Southern Brazil: a Bayesian analysis. Col Vol Sci Pap ICCAT. 68 (4): 1594-1600.

Gudger EW. 1940. The alleged pugnacity of the swordfish and the spear-fishes as shown by their attacks on vessels. A study of their behavior and the structures which make possible these attacks. Mem Roy Asiat Soc Bengal. 4: 272-273.

Habegger ML. 2014. Functional morphology and feeding mechanics of billfishes [PhD thesis]. Tampa: Scholar Commons, University of South Florida.

Habegger ML, Dean MN, Dunlop JWC, Mullins G, Stokes M, Huber DR, Winters D, Motta PJ. 2015. Feeding in billfishes:

inferring the role of the rostrum from a biomechanical standpoint. J Exp Biol. 218: 824-836. DOI: https://doi.org/10.1242/jeb.106146

HABEGGER ML, HUBER DH, LAJEUNESSE MJ, MOTTA PJ. 2017. Theoretical calculations of bite force in billfishes. J Zool. 303 (1): 15-26. DOI: https://doi.org/10.1111/jzo.12465

HADDAD VJR, FIGUEIREDO JL. 2009. Attack upon a bather by a swordfish: a case report. Wilderness Environ Med. 20: 344-346.

HAZIN H, ERZINI K. 2008. Assessing swordfish distribution in the South Atlantic from spatial predictions. Fish Res. 90: 45-55. DOI: https://doi.org/0.1016/j.fishres.2007.09.010

HIRAMA S, WITHERINGTON B. 2012. A loggerhead sea turtle (*Caretta caretta*) preying on fish within a mixed-species feeding aggregation. Chelonian Conserv Biol. 11 (2): 261-265. DOI: https://doi.org/10.2744/CCB-0918a.1

JAMBURA LP, TÜRTSCHER J, KRIWET J, AL MABRUK SAA. 2020. Deadly interactions between a swordfish *Xiphias gladius* and a bigeye thresher shark *Alopias superciliosus*. Ichthyol Res. 68: 317-321. DOI: https://doi.org/10.1007/s10228-020-00787-x

JONSGARD A. 1959. New find of sword from swordfish (*Xiphias gladius*) in blue whale (*Balaenoplera musculus*) in Antarctic. Nor Hvalfangst-Tid. 48 (352): 355-356, 359-360.

JONSGARD A. 1962. Three finds of swords from swordfish (*Xiphias gladius*) in the Antarctic fin whale *Baleonoptera physalus*. Nor Hvalfangst-Tid. 51: 287-291.

KOTAS JE, SANTOS S, AZEVEDO VG, GALLO BMG, BARATA PCR. 2004. Incidental capture of loggerhead (*Caretta caretta*) and leatherback (*Dermochelys coriacea*) sea turtles by the pelagic longline fishery off southern Brazil. Fish Bull. 102: 393-399.

LAZAR B, MASLOV L, ROMANIC SH, GRACAN R, KRAUTHACKER B, HOLCER D, TVRTKOVIC N. 2011. Accumulation of organochlorine contaminants in loggerhead sea turtles, *Caretta caretta*, from the eastern Adriatic Sea. Chemosphere. 82: 121-129. DOI: https://doi.org/10.1016/j.chemosphere.2010.09.015

LEE H-J, JONG Y-J, CHANG L-M, WU W-L. 2009. Propulsion strategy analysis of high-speed swordfish. Trans Japan Soc Aero Space Sci. 52 (175): 11-20. DOI: https://doi.org/10.2322/tjsass.52.11

LEWISON RL, CROWDER LB. 2007. Putting longline bycatch of sea turtles into perspective. Conserv Biol. 21: 79-86. DOI: https://doi.org/101111/j.1523-1739.2006.00592.x

LEWISON RL, CROWDER LB, WALLACE BP, MOORE JE, COX T, ZYDELIS R, MCDONALD S, DIMATTEO A, DUNN DC, KOT CY, et al. 2014. Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna hotspots. Proc Natl Acad Sci USA. 111 (14): 5271-5276. DOI: https://doi.org/10.1073/pnas.1318960111

LEWISON RL, FREEMAN SA, CROWDER LB. 2004. Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. Ecol Lett. 7: 221-231. https://doi.org/10.1111/j.1461-0248.2004.00573.x

LÓPEZ-MENDILAHARSU M, SALES G, GIFFONI B, MILLER P, FIEDLER FN, DOMINGO A. 2007. Distribución y composición de tallas de las Tortugas marinas (*Caretta caretta* y *Dermochelys coriacea*) que interactúan con el palangre en el Atlántico Sur. Collect Vol Sci Pap ICCAT. 60 (6): 2094-2109.

MACHIDA S. 1970. A sword-fish sword found from a north Pacific sei whale. Sci Rep Whales Res Inst. 22: 163-164.

MAJOR PF. 1979. An aggressive encounter between a pod of whales and billfish. Sci Rep Whales Res Inst. 31: 95-96.

MARTIN K. 2014. Trinidad Day 5. Canadian Sea Turtle Network. [accessed 2022 May]. https://seaturtle.ca/blog/2014/06/13/trinidad-day-5/.

MAZZOLENI RC, SCHWINGEL PR. 2002. Aspectos da biologia das espécies capturadas por espinhel pelágico na região sul das Ilhas de

Trindade e Martin Vaz no verão de 2001. Notas Téc FACIMAR. 6: 51-57.

McGowan C. 1988. Differential development of the rostrum and mandible of the swordfish (*Xiphias gladius*) during ontogeny and its possible functional significance. Can J Zool. 66: 496-503.

Mendonça-Caridad JJ, Lopez PJ, Rodriguez M. 2008. Swordfish bill injury involving the pterygomaxillary fossae: surgical management and case report. J Oral Maxillofac Surg. 66: 1739-1743. DOI: https://doi.org/10.1016/j.joms.2007.12.016

Nakamura I. 1983. Systematics of the billfishes (Xiphiidae Andistiophoridae). Publ Seto Mar Biol Lab. 28 (5-6): 255-396. DOI: https://doi.org/10.5134/176069

Ndiaye A, Gaye M, Ba PS, Diatta S, Diop MS, Ndiaye M. 2017. Penetrating chest injuries caused by swordfish sword used as a weapon. Asian Cardiovasc Thorac Ann. 25 (3): 229-232. DOI: http://doi.org/10.1177/0218492317694521

[NRC] National Research Council. 1990. Decline of the sea turtles: causes and prevention. Washington DC: National Academy Press.

Oshumi S. 1973. Find of marlin spear from the Antarctic mink whales. Sci Rep Whales Res Inst. 25: 237-239.

Palko BJ, Beardsley GL, Richards WJ. 1981. Synopsis of the biology of swordfish *Xiphias gladius* Linnaeus. NOAA Tech Rep NMFS Circular 441, FAO Fish Synop. 127.

Penadés-Suay J, García-Salinas P, Tomás J, Aznar FJ. 2019. Aggressive interactions between juvenile swordfish and blue sharks in the western Mediterranean: a widespread phenomenon? Medit Mar Sci. 20 (2): 314-319. DOI: https://dx.doi.org/10.12681/mms.18102

Penadés-Suay J, Tomás J, Aznar FJ. 2017. Fatal impalement of a blue shark *Prionace glauca* by a swordfish *Xiphias gladius*. Medit Mar Sci. 18 (2): 340-343. DOI: https://dx.doi.org/10.12681/mms.1959

Pons M, Domingo A, Sales G, Fiedler FN, Miller P, Giffoni B, Ortiz M. 2010. Standardization of CPUE of loggerhead sea turtle (*Caretta caretta*) caught by pelagic longliners in the Southwestern Atlantic Ocean. Aquat Living Resour. 23: 65-75. DOI: https://doi.org/10.1051/alr/2010001

Romeo T, Ammendolia G, Canese S, Andaloro F, Battaglia P. 2017. Recent records of swordfish attacks on harpoon vessels in the Sicilian waters (Mediterranean Sea). Acta Adriat. 58 (1): 147-156.

Romeo T, Battaglia P, Macaluso D, Tagliavia G, Vicchio TM, Falautano M, Serena F, Andaloro F. 2020. When prey becomes killer: does a double lethal attack on a blue shark reveal a precise defensive strategy in young swordfish? J Mar Biol Assoc UK. 100 (5): 831-836. DOI: https://doi.org/10.1017/S0025315420000661

Sagong W, Jeon W-P, Choi H. 2013. Hydrodynamic characteristics of the sailfish (*Istiophorus platypterus*) and swordfish (*Xiphias gladius*) in gliding postures at their cruise speeds. PLoS One 8 (12): e81323. https://doi.org/10.1371/journal.pone.0081323

Sales G, Giffoni, BB, Barata, PCR. 2008. Incidental catch of sea turtles by the Brazilian pelagic longline fishery. J Mar Biol Assoc UK. 88 (4): 853-864 DOI: https://doi.org/10.1017/S0025315408000441

Sales G, Giffoni BB, Barata PCR, Maurutto G. 2004. Interação de tortugas marinas com a pesca de palangre pelágico na costa brasileira - 1999-2003. Resúmenes de la II Reunión Sobre Investigación y Conservación de Tortugas Marinas del Atlántico Sur Occidental-ASO. San Clemente del Tuyú, Argentina.

Schuyler Q, Hardesty BD, Wilcox C, Townsend K. 2014. Global analysis of anthropogenic debris ingestion by sea turtles. Conserv Biol. 28: 129-139.

Scott WB, Tibbo SN. 1968. Food and feeding habits of swordfish *Xiphias gladius*, in the Western North Atlantic. J Fish Board Can. 25 (5): 903-919. DOI: https://doi.org/10.1139/f68-084

SHAMBLIN BM, BOLTEN AB, ABREU-GROBOIS FA, BJORNDAL KA, CARDONA L, CARRERAS C, CLUSA M, MONZÓN-ARGÜELLO C, NAIRN CJ, NIELSEN JT, et al. 2014. Geographic patterns of genetic variation in a broadly distributed marine vertebrate: new insights into loggerhead turtle stock structure from expanded mitochondrial DNA sequences. PLoS One. 9 (1): e85956.

SPOTILA JR, REINA RR, STEYERMARK AC, PLOTKIN PT, PALADINO FV. 2000. Pacific leatherback turtles face extinction. Nature. 405: 529-530.

SRIRAM PR, JIEN TCT, SELLAMUTHU P. 2017. Backstabbing swordfish: a rare cause of traumatic hemiparesis. J Neurosurg Spine. 27: 158-160. DOI: https://doi.org/10.3171/2016.12.SPINE16586

VASKE JÚNIOR T, LESSA RP. 2005. Estratégia alimentar do espadarte (*Xiphias gladius*) no Atlântico Equatorial Sudoeste. Trop Oceanogr. 33 (2): 223-232. DOI: https://doi.org/10.5914/tropocean.v33i2.5064

WEBB PW. 1986. Effect of body form and response threshold on the vulnerability of four species of teleost prey attacked by largemouth bass (*Micropterus salmoides*). Can J Fish Aquat Sci. 43: 763-771. DOI: https://doi.org/10.1139/f86-094

WEIDNER DM, AROCHA F. 1999. South America: Atlantic, Part A, Section 2 (Segment B) in “Latin America”, World swordfish fisheries: an analysis of swordfish fisheries, market trends, and trade patterns, Vol. IV NMFS Silver Spring, Maryland/USA.

WISNER RL. 1958. Is the spear of Istiophorid fishes used in feeding? Pac Sci. 12 (1): 60-70.

YEUNG C. 2001. Analysis of marine turtle bycatch by the U.S. Atlantic pelagic longline fleet. In: Stock assessments of loggerhead and leatherback sea turtles, and an assessment of the impact of the pelagic longline fishery on the loggerhead and leatherback sea turtles of the western North Atlantic. NOAA Tech Memo NMFS-SEFSC. 455: 120-142.

ZARUDZKI EFK, HAEDRICH RL. 1974. Sword-fish (*Xiphias gladius*) attacks submarin (Alvin). Oceanology. 3: 112-115.