

AN INJURED SPECIMEN OF *Carcharodon carcharias*; PROSPECTIVE ASSESSMENT OF THE SPECIES' HUNTING COSTS

Un espécimen herido de *Carcharodon carcharias*: examen prospectivo del costo de sus cacerías

RESUMEN. Aunque culturalmente se percibe al gran tiburón blanco (*Carcharodon carcharias*) como un depredador invulnerable, en el presente se reporta la muerte de un espécimen sub-adulto atrapado en una red de pesca; dicho espécimen se encontraba herido por la espina de una raya pelágica que penetró la columna vertebral del tiburón, lo que posiblemente mermó su capacidad para nadar. El evento sugiere que los tiburones blancos pueden sufrir lesiones e incluso muerte, mientras cazan presas peligrosas; ello genera preguntas del cómo los individuos de la especie toman decisiones de caza. Las teorías de "Forrajeo óptimo" y "Búsqueda de recursos con riesgo de depredación" combinadas con tecnología de seguimiento, permitirían responder este tipo de preguntas.

Flores-Ramírez, Sergio¹, Francisco Omar López-Fuerte², Hector Reyes-Bonilla¹, Ulianov Jakes Cota³ & Marc Aquino – Baleyto³. ¹Universidad Autónoma de Baja California Sur. Departamento Académico de Biología Marina - Centro de Estudios y Conservación de Biodiversidad. Carretera al Sur km 5.5, CP. 23080. La Paz, B.C.S., México. ²Universidad Autónoma de Baja California Sur. Departamento Académico de Economía, Laboratorio de Sistemas Arrecifales, Carretera al Sur, Km. 5.5. AP. 19-B, CP. 23080, La Paz, B.C.S., México. ³Centro Interdisciplinario de Ciencias Marinas - Instituto Politécnico Nacional (CICIMAR-IPN). Av. Instituto Politécnico Nacional s/n. Col. Playa Palo de Santa Rita, CP. 23096. La Paz, B.C.S., México. email: folopez@uabcs.mx.

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The study of predator-prey interactions is important in marine ecology given their important role in shaping population, community and evolutionary dynamics of predators and their prey (Preisser *et al.*, 2005; Creel & Christianson, 2008; Heithaus *et al.*, 2008). Recent studies mostly analyse how human impacts on predator and prey populations have altered the functionality of their communities and ecosystems (e.g. Heithaus *et al.*, 2014; Kroeker *et al.*, 2014), and how predation shape the behaviour of predators and their prey (Lima, 1998; Brown & Kotler, 2004). The great white shark *Carcharodon carcharias* (Linnaeus, 1758) is distributed in sub-tropical waters worldwide. It is culturally perceived as an invulnerable apex predator, with selective feeding habits that shift along its ontogeny. Studies in South Africa and the Northeast Pacific report that young sharks consume a variety of bony fishes as well as diverse chondrichthyans, including other sharks (genera: *Galeorhinus*, *Mustelus*, *Carcharhinus*, *Rhizoprionodon*, *Sphyrna*, *Squalus*), stingrays, eagle rays (*Myliobatis*) and chimaeras. In contrast, mature sharks consume large dead cetaceans, harbour porpoises, dolphins, and a variety of pinnipeds (Bruce, 2008; Hussey *et al.*, 2012; Kim *et al.*, 2012).

Here we present the first report of a white shark severely wounded by a pelagic ray's spine, which penetrated the shark's trunk just below the first dorsal fin, to become embedded in one of its posterior thoracic vertebrae. Based on this event, we propose some insights for studies pertaining the costs incurred by white sharks while hunting dangerous prey.

Observations.- In September 8, 2014, a male white shark was incidentally captured approximately 32 km offshore from the Santa María shark-fishing camp located 11 km north of the city of Santa Rosalía, western Gulf of California (27°31'36"N, 112°04'30"W). The individual was found entangled in a drift net (*chinchorro*) by local fishermen. As the shark was processed for consumption fishermen noticed its emaciated condition, and a large stingray spine (Fig. 1a) jabbed into the right side of its trunk just below the first dorsal fin. One of us (FOLF) collected the stingray's spine, recorded its total length and number of right and left serrations, and contrasted such features to those of 50 stingray species distributed Pacific Ocean (Schwartz, 2005; 2008) to identify the species that caused the injury. Also, FOLF obtained access to the shark's mandibles to measure the crowns of several teeth, in order to estimate its total body length, using functions relating the increase of total body length (*TL*) to tooth crown size (*CH*) (Shimada, 2002). Estimations of *TL* were used to estimate the shark's body using functions described by NOAA (<http://nefsc.noaa.gov/nefsc/Narragansett/sharks/calc.html>, Kohler *et al.*, 1995).

The length of the spine (118 mm) and its number of right (92) and left serrations (88) (Fig. 1a), indicates that a pelagic stingray *Pteroplatytrygon violacea* (Bonaparte, 1832) inflicted the injury to the shark. *This stingray* can reach a maximum length of 160 cm (McEachran & Notobartolo di Sciara, 1995; Fisher *et al.*, 1995). The species is widely distributed in tropical and temperate seas of the Atlantic and Pacific Oceans (Nishida & Nakaya, 1990), near the margin of the continental shelf, from shallow waters to depths of 250 m (Neer, 2008; Santana-Hernández *et al.*, 2011). In the tropical Mexican Pacific captured specimens measure 26 to 130 cm in disk width and are commonly associated to blue *Prionace glauca* and silky *Carcharhinus falciformis* sharks, striped marlin *Kajikia audax*, and dolphinfish *Coryphaena hippurus*, especially from February to April, during low sea surface temperatures (Santana-Hernández *et al.*, 2011).

In addition, by solving regression functions between tooth crown (*CH*) and total body length (*TL*) (Shimada, 2002) we estimated that the injured white shark measured between 370 and 392 cm in total length and weighted ca. 500 Kg, according to func-

tions implemented in NOAA's NE Fisheries Science Center's website (*op cit.*). Close examination of the wound revealed that the ray's spine penetrated the right side of the shark, just below the first dorsal fin, following a cephalocaudal trajectory (Fig. 1b) before it became deeply imbedded into the right dorsal surface of one of the posterior thoracic vertebra (Fig. 1c). It is likely that this white shark became wounded by a large *P. violacea* in open waters of the Pacific Ocean before entering the Gulf of California, since the presence of *P. violacea* is seldomly recorded in the latter area (Mariano-Melendez & Villavicencio-Garayzar, 1999; Dávalos-Dehullu & González-Navarro, 2003). The shark's estimated total length (< 400 cm) supports such argument. It corresponds to that of sub-adult white shark males (Weng *et al.*, 2007; Sosa-Nishizaki *et al.*, 2008), which commonly roam among three areas within the north-eastern Pacific, where *P. violacea* is fairly common: the shelf waters of California, the slope and offshore waters around Hawaii, and an area located halfway between the Baja Peninsula and the Hawaiian Islands (*e.g.* Jorgensen *et al.*, 2010). Therefore, is probable that the shark attempted to prey on the ray still within the north-eastern Pacific before it entered to white sharks' recognized migratory and feeding grounds in the Gulf of California (Galván-Magaña *et al.*, 2010).

Close examination of the wound suggested that it likely hindered the lateral undulatory motion of the shark's hind body, impeding the proper thrust and lift of the tail (Maia *et al.*, 2012) and causing a concomitant loss of speed and manoeuvrability, required to capture their mobile prey. This hypothesis is supported by the emaciated condition of the shark and fishermen's observation that sharks of similar size usually tear the fishing gear in which the refe-

rred white shark became entangled.

Incapacitating or mortal stingray attacks on large predators are not uncommon. In the Western Atlantic, several bottlenose dolphins *Tursiops truncatus* wounded by southern *Dasyatis americana* and Atlantic *D. sabina* stingrays have been recorded. In six out of seven cases the dolphins died because the stingray's spine penetrated the lungs, liver or pancreas (Walsh *et al.*, 1988). Similar events have occurred in the Red Sea and New Zealand (Duignan *et al.*, 2000; Spanier *et al.*, 2000). In México a common dolphin (*Delphinus delphis*) was found stranded at Tiburón Island (28°N, eastern Gulf of California) displaying a spine of a whiptail stingray *D. brevis* (Lamilla *et al.*, 1995) that caused a 1 cm deep orifice on the right dorsal section of the L16 vertebra, fracturing the bone (Gallo-Reynoso & Tovar 1989). Also in Bahía de La Paz (24°N, south-western Gulf of California) the authors recorded a bottlenose dolphin (*T. truncatus*) injured by a 10 cm long spine, which penetrated 8 cm in the chest. This case raises important questions about the trophic ecology of the species calling for insights for future studies regarding the costs incurred by white sharks while hunting dangerous prey. For example, under what conditions are white sharks more or less likely to attack dangerous prey? Such questions can be addressed within the framework provided by "Optimal foraging theory (OFT)" and "Foraging under predation risk" theories. OFT predicts that natural selection will favour those predators that exploit profitable prey in terms of net energy content, minus search and handling costs (Gerking, 2014) and those that select the most profitable food items among diverse and abundant high-quality prey (Helfman *et al.*, 1997). Therefore, white sharks may have evolved to discriminate between non-profitable and profitable

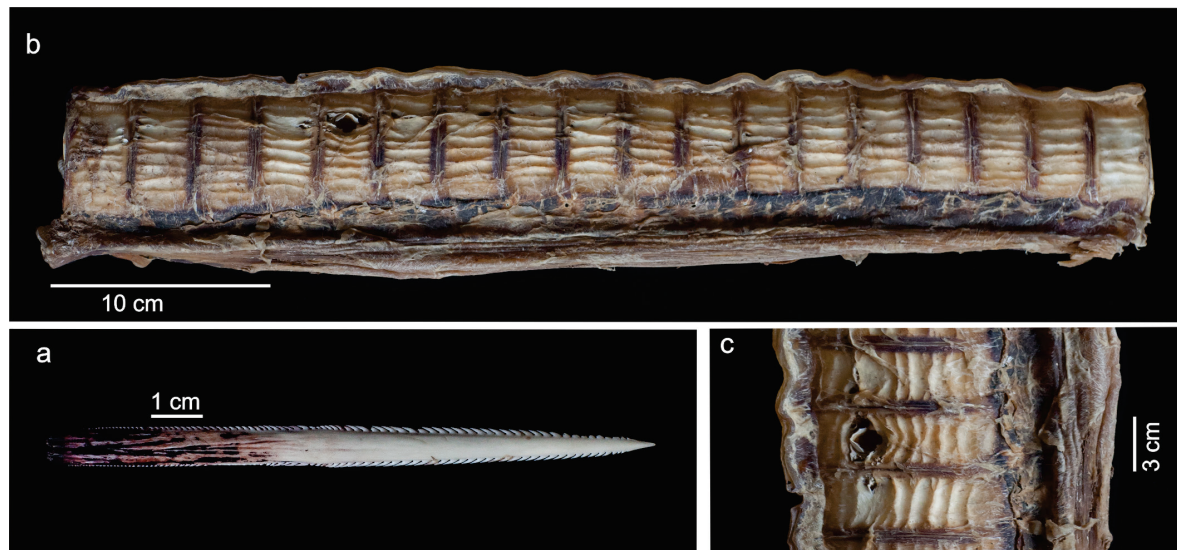


Figure 1. Photographs of (a) stingray's spine found stuck in the shark's backbone; (b) white shark's backbone segment displaying the site at which the spine became embedded; and (c) detail of the puncture caused by the spine.

prey, assessing the balance between energetic gain from the prey, divided by its anti-predator behaviour (the time required to pursue, capture and consume it) (Stephens & Krebs, 1986; Sih & Christensen 2001). To test the latter might seem overwhelming, but new technologies are emerging to assess the relationship between time spent hunting a given prey and the number of attacks/attempts required to successfully hunt it (e.g. Klimley *et al.*, 2001; Sundström *et al.*, 2001), and will provide insights into the perceived risk of injury from dangerous prey (e.g. Klimley *et al.*, 2001; Hopcraft *et al.*, 2005; Sundström *et al.*, 2001; Huvneers *et al.*, 2015).

On the other hand, theory based on food versus predation-risk trade-offs can provide a basis for developing insights into when white sharks will be in risk of injury. An approach similar to that of Lima and Dill (1990) can be adopted to quantify risk of injury P (Injury) for white sharks, as a function of the rate of encounter with dangerous preys, the probability of injury given an encounter and the time spent vulnerable during an encounter, all variables that are likely assessed by white sharks (Martin *et al.*, 2005; 2009). Also Brown's (1992) model, which predicts that natural selection will favour predators that stop hunting certain dangerous prey when its harvest rate or reward equals the sum of its metabolic cost, missed opportunity cost and cost of risk of injury (Berger-Tal *et al.*, 2010) should be explored to learn in what cases white sharks decide to stop hunting specific dangerous prey.

Finally, do white sharks take risk of injury into account when deciding where to hunt? Recent studies on great white sharks suggest it is feasible to assess the latter. For example, location data from 340 predatory interactions between white sharks and Cape fur seals *Arctocephalus pusillus pusillus*, and associated environmental factors were assessed using geographic profiling to find that spatial patterns of shark predation are non-random at Seal Island in False Bay, South Africa (Martin *et al.*, 2009).

In summary, white sharks hunt dangerous prey and the evolutionary ecology implications of such interactions may be better understood within the framework of foraging behaviour and predator-prey theories. Detailed data on the foraging costs that white sharks incur while hunting dangerous prey will provide relevant insights on the forces that have shaped the evolution of communities visited by these top predators. The same can be said regarding the foraging decisions and behavioural ontogenetic responses of white sharks to minimize risk of injury. Though quantifying the costs of risk of injury in the wild is challenging, the collection of such data is becoming an important field for behavioural ecologists.

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