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What is known about cookiecutter shark (*Isistius* spp.) interactions with cetaceans in Cape Verde seas?

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Keywords: cookiecutter sharks, *Isistius* spp., predation, Cetacea, North Atlantic, Cape Verde Islands

SUMMARY

In the North Atlantic, the waters surrounding the Cape Verde Islands are a 'potential hot spot' for cookiecutter shark *Isistius* spp. interactions with cetaceans. These occurrences were recently identified by the improved efforts of researchers to document cetacean strandings in the Cape Verde archipelago, as well as by the photo identification efforts of live whales and dolphins. The documentation of individual and mass stranding events confirmed that cookiecutter shark interactions with cetaceans in Cape Verde seas are remarkably common.

RESUMO

No Atlântico Norte, as águas que rodeiam as Ilhas de Cabo Verde constituem um 'hot spot' potencial para os tubarões-charuto *Isistius* spp., bem como para interações destes com cetáceos. As ocorrências foram identificadas em resultado de esforços recentes de investigadores para documentar arrojamentos de cetáceos no arquipélago de Cabo Verde, bem como através de fotografias de baleias e golfinhos vivos. A documentação quer de indivíduos quer de arrojamentos múltiplos de cetáceos confirmou que as interações destes com os tubarões-charuto nos mares de Cabo Verde são consideravelmente frequentes.

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INTRODUCTION

Two species of cookiecutter sharks have been identified in the North Atlantic, i.e. the cookiecutter shark *Isistius brasiliensis* (Quoy & Gaimard, 1824) and the largetooth cookiecutter shark *Isistius plutodus* Garrick & Springer, 1964. The latter was described less than 50 years ago (Garrick & Springer 1964) and is only known from 10 specimens, collected at scattered locations in the Pacific and Atlantic, with all specimens collected close to land (IUCN 2012). Its recent discovery and the rarity of records may be due to more localized or limited distribution or lower abundance and occurrence only in deeper waters (IUCN 2012). In August 2000, a specimen of *I. plutodus* was caught in a pelagic trawl at midnight at a depth of 90–100 m, over a water depth of 890–980 m, north of the Azores at 43°58′N, 28°32′W (Zidowitz *et al*. 2004) and this is believed to be the only record from the open North Atlantic. The cookiecutter shark *I. brasiliensis* is more widespread. In the eastern North Atlantic it has been documented in waters between Senegal, Guinea-Bissau and the Cape Verde Islands (Compagno 1984, Jahn & Haedrich 1987, Muñoz-Chápuli *et al*. 1988, SIAP *et al.* 2002, IUCN 2012).

I. brasiliensis is generally located in deep open oceanic waters, primarily in tropical regions, most often within 20 degrees latitude, north or south, of the equator. Cookiecutter sharks are found in deep water during the day and at night migrate towards the surface with the deep scattering layer (Parin 1966, Jones, 1971, Last & Stevens, 1994, Heithaus 2001). Although this shark is generally restricted to the tropics, its distribution extends into higher latitudes in regions of warm water currents (Jahn & Haedrich 1987).

Both *Isistius* shark species have been implicated for the oval scars found on cetaceans and pinnipeds (Jones 1971). *Isistius* sharks are often referred to as ectoparasites (Heithaus 2001) as they attach to prey with suctorial lips and a modified pharynx. Once attached, the shark spins and cuts out a plug of flesh with its large razor-sharp and serrated lower teeth. The plug is then sucked out, leaving a distinct circular wound (Compagno 1984, Clark & Kristof 1990, Shirai & Nakaya 1992, Gasparini & Sazima 1996). *Isistius* sharks also prey on large billfish, including marlin, as well as tuna, large squid, other sharks and stingrays (Papastamatiou *et al*. 2010). It is believed that *Isistius* sharks attract their prey by remaining motionless in the water column and using bio-luminescence to mimic bio-luminescent squid (Jones 1971, Reif 1985, Last & Stevens 1994, Widder 1998).

In the North Atlantic, there are documented cases of *Isistius* shark and cetacean interactions from the Gulf of Mexico, Caribbean, Bahamas, eastern Canada and the Azores (Table 1). So far, there has been little effort to document *Isistius* shark scars or wounds on free ranging or stranded cetaceans to establish which *Isistius* species may have been the predator. The present study promotes the necessity of studying the interactions between *Isistius* sharks and cetaceans in order to better understand their predator-prey relationships. In the eastern North Atlantic, this is the first study of the predator-prey relationships between cookiecutter sharks and cetaceans.

MATERIAL AND METHODS

We searched the literature for data on the occurrence of *Isistius* sharks in different parts of the North Atlantic. In addition, we scrutinized photographs (both published and unpublished) documenting free ranging and stranded cetaceans from the Cape Verde Islands for evidence of scars and wounds inflicted by *Isistius* sharks. Interest in this study was initially triggered by a mass stranding of 120+ rough-toothed dolphins *Steno bredanensis* near Sal Rei, Boavista, Cape Verde Islands, 19 October 2010. Fifty-three of these dolphins stranded alive and subsequently died at Praia do Estoril and at nearby Ilhéu de Sal Rei (16°17′N, 22°94′W), while *ca.* 50 more stranded but were returned to the sea with the help of local people or managed to return to the sea by themselves (Hazevoet *et al.* 2010). All dolphin carcasses inspected during this event had wounds or scars presumed to be the result of interactions with *Isistius* sharks. Some showed evidence of fresh bites (open and still bleeding), had open, intermediate or sub-dermal wounds

Table 1. North Atlantic cetaceans with evidence of *Isistius* shark interactions.

SPECIES	LOCATION	REGION	REFERENCE
Blainville's beaked whale *Mesoplodon densirostris*	Cape Verde Islands	North Atlantic	This paper, Fig. 6
Blainville's beaked whale *Mesoplodon densirostris*	Hatteras NC; Bahamas	North Atlantic	Mead (1989) Claridge (2006)
Bottlenose dolphin *Tursiops truncatus*	Texas	Gulf of Mexico	Weller *et al*. (1997)
Bryde's whale *Balaenoptera brydei*	Azores	North Atlantic	Steiner *et al*. (2008)
Clymene dolphin *Stenella clymene*	Caribbean	Caribbean	Perrin *et al*. (1981) Jefferson *et al*. (1995)
Clymene dolphin *Stenella clymene*	Gulf of Mexico	Gulf of Mexico	Mullin *et al*. (1994) Jefferson *et al*. (1995)
Cuvier's beaked whale *Ziphius cavirostris*	Puerto Rico	Caribbean	Pérez-Zayas *et al*. (2002)
Dwarf sperm whale *Kogia sima*	Venezuela	Caribbean	Bermúdez-Villapol *et al*. (2008)
Dwarf sperm whale *Kogia sima*	Veracruz, Mexico	Gulf of Mexico	Delgado Estrella *et al.* (1998)
False killer whale *Pseudorca crassidens*	Cape Verde Islands	North Atlantic	Hazevoet *et al*. (2010)
Fin whale *Balaenoptera physalus*	Cape Verde Islands	North Atlantic	Moore *et al*. (2003)
Gervais' beaked whale *Mesoplodon europaeus*	Hatteras NC	North Atlantic	Mead (1989)
Gervais' beaked whale *Mesoplodon europaeus*	Curaçao	Caribbean	Debrot & Barros (1992)
Harbour porpoise *Phocoena phocoena*	North Sea	North Atlantic	van Utrecht (1959)
Humpback whale *Megaptera novaeangliae*	Cape Verde Islands	North Atlantic	Moore *et al*. (2003) This paper, Fig. 7
Melon-headed whale *Peponocephala electra*	Cape Verde Islands	North Atlantic	Van Waerebeek *et al*. (2008)
Melon-headed whale *Peponocephala electra*	Florida	Gulf of Mexico	Bossart *et al*. (2007)
Melon-headed whale *Peponocephala electra*	Gulf of Mexico	Gulf of Mexico	Perryman *et al*. (1994) Barron & Jefferson (1993)
Minke whale *Balaenoptera acutorostrata*	eastern Canada	North Atlantic	Jefferson *et al*. (2008)
Pygmy killer whale *Feresa attenuata*	Cape Verde Islands	North Atlantic	López Suárez *et al.* (2012)
Pygmy killer whale *Feresa attenuata*	Veracruz, Mexico	Gulf of Mexico	Delgado Estrella *et al.* (1998)
Rough-toothed dolphin *Steno bredanensis*	Azores	North Atlantic	Steiner (1995)
Rough-toothed dolphin *Steno bredanensis*	Cape Verde Islands	North Atlantic	Hazevoet *et al.* (2010) This paper, Fig. 1-3
Rough-toothed dolphin *Steno bredanensis*	Senegal	North Atlantic	Cadenat (1949)
Sei whale *Balaenoptera borealis*	Azores	North Atlantic	Schilling *et al.* (1992)
Short Finned pilot whale *Globicephala macrorhynchus*	Cape Verde Islands	North Atlantic	This paper, Fig. 4
Sowerby's beaked whale *Mesoplodon bidens*	Sable Island Nova Scotia	North Atlantic	Lucas & Hooker (2000) Jefferson *et al*. (2008)
Sperm whale *Physeter macrocephalus*	Cape Verde Islands	North Atlantic	This paper, Fig. 5
True's beaked whale *Mesoplodon mirus*	New Jersey	North Atlantic	Mead (1989)

or completely healed scars (Fig. 2-3), which we assume having been caused by *Isistius* sharks, based on being similar in nature, shape and form to bites attributed to *Isistius* sharks found in the literature (cf. Jefferson 2002).

RESULTS

Our literature search and examination of photographs resulted in data on 20 North Atlantic cetacean species with documented interactions with *Isistius* sharks (Table 1). Of these, nine species photographed in the Cape Verde Islands showed evidence of interactions with *Isistius* sharks. Most cookiecutter shark scars were found on the ventral side of dead stranded odontocetes, but some scars were also found near the head and on the snout and flank. Larger dolphins appeared to have a greater number of scars than smaller dolphins, suggesting that larger or older dolphins may be subject to more frequent interactions than younger individuals or that scars simply accumulate through the dolphins' lifetime. Several humpback whales *Megaptera novaeangliae*, photographed on their Cape Verde wintering grounds, showed *Isistius* shark bites on the dorsal ridge and flanks.

Fig. 1. Rough-toothed dolphin *Steno bredanensis* with healed *Isistius* shark bites near the head, Praia de Estoril, Boavista, 7 March 2001 (Pedro López Suárez). Fig. 2. Presumed older rough-toothed dolphin with multiple healed *Isistius* shark scars, Praia de Estoril, Boavista, 19 October 2010 (Junior Ramos Fonseca).

DISCUSSION

Since the early 1900s, circular scars on cetaceans have been recognized and prompted numerous discussions regarding their source(s), usefulness and use in photo-identification studies (Lillie 1915, Mackintosh & Wheeler 1929, van Utrecht 1959). Initially, scientists suggested that these wounds and scars on whales and dolphins were possibly caused by ectoparasitic copepods *Penella* spp. (Ivashin & Golubovsky 1978) and/or lampreys (Pike 1951, Nemoto 1955). In the 1970s, scientists recognized that these wounds were caused by *Isistius* sharks (Jones 1971, Shevchenko 1977). Lillie (1915) and Mackintosh & Wheeler (1929) first described these oval scars and considered these 'marks' to be evidence of the regularity of whale migrations from cold to warm waters. This was based on the assumption that the scarring takes place in warm water and that their quantity increases with age (and subsequent migrations) of a given whale. This circular scar (matching a shark bite) suggested that the animal, at one time or another, resided in warmer tropical waters. The presence of these circular scars along the flanks of sei whale *Balaenoptera borealis*, Eden's whale *B. edeni*, Bryde's whale *B. brydei*, finback whale *B. physalus*, killer whale *Orcinus orca* and Cuvier's beaked whale *Ziphius cavirostris* facilitated photo-identification of individuals (Schilling *et al*. 1992, Moore *et al*. 2003, McSweeney *et al*. 2007, Steiner *et al*. 2008, Dwyer & Visser 2011). *Isistius* scars have also been used and suggested

Fig. 3. Rough-toothed dolphin *Steno bredanensis* with open wound and completely healed *Isistius* shark scars, Praia de Estoril, Boavista, 20 October 2010 (Mario Évora).

for cetacean population stock determination for several species (Shevchenko 1977, Moore *et al*. 2003, Goto *et al*. 2009). Dwyer & Visser (2011) provided detailed descriptions and photographs of *Isistius* shark bites on cetaceans in New Zealand waters, as well as categories and descriptions of bite marks on killer whales *Orcinus orca*.

Souto *et al*. (2007) recorded the regions of a cetacean's body which were most subject to *Isistius* shark attacks, i.e. flanks 40%, head and abdomen 20% each, dorsal 15% and genital 5%. The relatively high number of bites on the flanks is probably due to their surface being larger, offering greater opportunities for attack to the *Isistius* shark. As most scars are ventrally located, observers at sea conducting research based on photo-identification are unlikely to observe all the evidence, severity and degree of *Isistius* shark interactions. Stranded cetaceans have indeed shown that there are generally more *Isistius* scars on the flanks and ventral side of carcasses than on the dorsal side of the animals. *Isistius* sharks are likely to attack any animal which feeds on the organisms in the deep scattering layer and migrates through deep warm tropical waters. Cetaceans and large fish species which prey upon squid may be more susceptible to *Isistius* sharks interactions, as these species may be attracted to the ability of *Isistius* sharks to mimic potential prey such as luminescent squids. The prevalence of these oval shark bites on the ventral portion of the body may be related to the shark's preying tactic (Widder 1998). However, this does not explain the occurrence of oval bite scars on baleen whales and some odontocete species which do not eat squid.

The risk of *Isistius* shark predation most likely varies with migratory patterns of their prey, feeding behaviour of fish and cetacean populations, habitat, prey movements, residency over deep ocean waters, water temperature and water depth in both near shore and pelagic tropical waters. The extent of these interactions must be measured by investigative stranding networks and fisheries biologists. Fresh interactions between *Isistius* sharks and marine fauna may be more easily established on stranded marine mammals, as well as in fisheries involving large fish like swordfish, marlin and tuna (Papastamatiou *et al*. 2010).

The waters surrounding the Cape Verde Islands are rich with marine fauna. Greater effort to document cetacean and *Isistius* shark interactions describing *Isistius* shark bite marks, such as bite qualifier, bite depth and bite state (see Dwyer & Visser 2011), would aid in *Isistius* species identification.

CONCLUSIONS

Evidence of cetacean species documented with *Isistius* shark bite scars appears to be most often reported in tropical waters and at locations where marine mammal research communities are active. *Isistius* shark scars have been observed on many of the baleen whales passing through the Azores (L. Steiner pers. comm.), including blue *B. musculus*, finback, sei, Bryde's, minke *B. acutorostrata* and humpback whale. Dwyer & Visser (2011) provided an overview of 49 marine mammal species which have been targeted by *Isistius* sharks around the world. These worldwide predator-prey interactions and occurrences have been documented in Brazil, eastern Australia, Hawaii, the Gulf of Mexico, Caribbean and Azores (Dwyer & Visser 2011). Our Table 1 provides no new species, but adds additional references and localities for North Atlantic cetacean species.

The evidence of *Isistius* shark predation on 100% of the stranded rough-toothed dolphins on Boavista in October 2010 suggests that their movements between the islands and into deep tropical waters make this species particularly susceptible to *Isistius* shark predation. However, insufficient data exist on the rough-toothed

Fig. 4. Short-finned pilot whale *Globicephala macrorhynchus* with *Isistius* shark scars on ventral area, Praia de Boa Esperança, Boavista, 28 September 2010 (Gabriella Gatt).

Fig. 5. Sperm whale *Physeter macrocephalus* with *Isistius* shark wounds, Praia de Roque, Boavista, 8 March 2006 (Pedro López Suárez).

Fig. 6. Blainville's beaked whale *Mesoplodon densirostris* with multiple *Isistius* shark scars, off northern Boavista, 14 April 2011 (Richard White).

dolphin's migratory patterns. Possibly, diving and nocturnal swimming and foraging behaviour make this species more prone to interactions with *Isistius* sharks than other odontocete species. Additional research is required to better understand these predator-prey interactions and how they may or may not influence marine mammal health and stranding events. Rough-toothed dolphins have been observed with *Isistius* shark bites in other regions of the northeastern Atlantic. Cadenat (1949) observed 'crater or oval holes' on stranded rough-toothed dolphins in Senegal. Reporting on the first sightings of rough-toothed dolphins in the Azores, Steiner (1995: 125-126) reported that "many individuals [had] blotchy white/pinkish patches on the flanks and undersides". Most likely, these 'blotchy white/pinkish patches' referred to healed *Isistius* scars. Muñoz-Chápuli *et al*. (1988) described *Isistius* shark wounds on swordfish *Xiphias gladius* from the northeastern Atlantic and suggested that the bulk of the northeastern Atlantic *Isistius* shark population may be found between 11°N and 16°N, thus coinciding with the latitude of the Cape Verde Islands.

In Cape Verde, all cetaceans on which cookiecutter shark bites have been reported were pelagic species or coastal species known to migrate through deep tropical waters, such as the humpback whale. The rough-toothed dolphin, despite being a well-known pelagic species, is the delphinid most often reported in the coastal waters of the eastern islands of Sal, Boavista and Maio, which have a larger shelf than the islands more to the west. However, the lack of specific studies on the behavioural ecology and temporal and spatial distribution of this species in the archipelago preclude further interpretation on why it appears to be the species most exposed to *Isistius* attacks. The uneven prevalence of cookiecutter shark bites and scars in short-finned pilot whales and melon-headed whales, two deep diving species that account for most of the stranding events in Cape Verde, illustrate the gaps in our knowledge and understanding of the relationships between *Isistius* sharks and cetaceans in these islands.

At this time, there has been no effort to systematically document *Isistius* shark scars or wounds on cetaceans, which would help in identifying which *Isistius* species is the predator. The present paper confirms the necessity for continuing study of the interactions between *Isistius* sharks and cetaceans in order to better understand their predator-prey relationships.

Fig. 7. Humpback whale *Megaptera novaeangliae*, female, with numerous *Isistius* shark bite scars, off Sal Rei, Boavista, 16 March 2011 (Pedro López Suárez).

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