Environ Biol Fish (2018) 101:749–759
https://doi.org/10.1007/s10641-018-0735-1

First evaluation of the cookie-cutter sharks (*Isistius sp.*) predation pattern on different cetacean species in Martinique

A. Feunteun · C. de Schrevel · M. Verhaegen · D. Chevallier · M. Duchemin · N. Ziani · B. de Montgolfier

Received: 23 January 2017 / Accepted: 21 January 2018 / Published online: 25 January 2018

Abstract Cookie-cutter sharks (*Isistius sp.*) are small squaloid sharks that live in tropical and sub-tropical oceans. Their name comes from their unique tactic of feeding, which enables them to parasitize marine megafauna, like cetaceans. Due to their morphological and anatomical characteristics, they are responsible of crater-like wounds on the skin of marine mammals. Little is known on *Isistius sp*. around the globe especially in Martinique, which represents a potential habitat. The main goal of this study was to assess the impact of cookie-cutter sharks on cetaceans by determining (1) seasonal changes in the occurrence of bites, (2) intra- and interspecific differences in frequencies and locations of bites among the different species of cetaceans, and (3) link behavior patterns of both cookie-cutter sharks and cetaceans. Data were collected from a 3-year photo-identification database of Cetaceans in Caribbean coast of Martinique. 431 wounds of various stages on 396 individuals from nine species of marine mammals were recorded. Results did not show any significant variation in the occurrence of wounds between seasons. Intermediate state was more important, most injuries were observed on the SCF (Superior Central Flank) (62.40%) and in a lesser extent on young individuals (3.25%). The predation of cookie-cutter sharks on different cetacean species has been confirmed consistently in Martinique. Further studies are required with both scientists and fishermen to better understand their specific role in this marine ecosystem.

Keywords Cookie-cutter shark · *Isistius sp.* · Cetaceans · Wounds · Bites · Caribbean · Martinique

A. Feunteun · C. de Schrevel · M. Verhaegen · B. de Montgolfier (✉)
Aquasearch, ZAC Les coteaux, 97228 Sainte-Luce, France
e-mail: b.montgolfier@aquasearch.fr

D. Chevallier
Département Écologie, Physiologie et Éthologie (DEPE), Institut Pluridisciplinaire Hubert Curien (IPHC), UMR 7178 CNRS et Université de Strasbourg, 23 rue Becquerel, F-67087 Strasbourg Cedex 2, France

M. Duchemin
DM Conseil, 7 allée du bois rond, 69360 Serezin du Rhône, France

N. Ziani
Groupe phocéen d'étude des requins (GPER), 118 rue du Rouet, 13008 Marseille, France

Introduction

Interactions between sharks and marine fauna are of great interest to scientists but still poorly known (Motta and Wilga 2001). For example, cookie-cutter sharks (*Isistius sp.*) are known to be predators for numerous species, but heir pelagic and nocturnal lifestyle makes their direct observation very difficult (Jones 1971; Heithaus 2001; Papastamatiou et al. 2010; Wenzel and Suárez 2012). Consequently, biology and ecology of cookie-cutter sharks are sparsely documented, and mainly based by-catch or based on the patterns and frequency of bites on alive or stranded prey (Papastamatiou et al. 2010). *Isistius sp.* are pelagic little squaloid sharks reaching about 50 cm in maximum total length (Nakano and Tabuchi 1990; Papastamatiou et al. 2010; Ebert et al. 2015). For *I. brasiliensis*, size at birth is 14–15 cm, males are mature at 31–37 cm, females at 38–44 cm, maximum total length is 39 for males and 50 cm for females (Ebert et al. 2013). For *I. plutodus*, maximum total length is 34 cm for males and 42 cm for females (Ebert et al. 2013). Evolution endowed them with unique morphological and anatomical characteristics, which involved a specific foraging and feeding behavior (Strasburg 1963; Jones 1971; Motta and Wilga 2001).They are known to be responsible of a characteristic oval, oblong or C-shaped wounds on the skin surface of their prey, (Best and Photopoulou 2016). These singular shapes of the bite is due to their powerful mouth, teeth, tongue and modified pharynx (Jones 1971; Jahn and Haedrich 1988; Hayashi et al. 2015). Once close enough to their prey, cookie-cutter sharks clings to them with their sucking lip and their sharp lower teeth, and remove a piece of flesh by a revolution of the whole body (Jones 1971;Compagno 1984; Heithaus 2001). The dorsal part of their body is dark brownish-grey and their body is covered with a system of ventral photophores, except near gill slits, where there is a band of pigmented cells instead (King and Ikehara 1956). Thus, by remaining motionless, they could lure the prey or mimic bio-luminescent squids (Jones 1971; Compagno 1984; Wenzel and Suárez 2012; Claes et al. 2014). Therefore, despite their small size, cookie-cutter sharks can predate various organisms much larger than themselves, including other sharks (Hoyos-Padilla et al. 2013), pelagic fish (Papastamatiou et al. 2010), pinnipeds (Le Bœuf et al. 1987), and cetaceans (Jones 1971; Dwyer and Visser 2011; Wenzel and Suárez 2012). The latter group seems to be the most frequently observed with crater-like wounds (Dwyer and Visser 2011).

Actually two species of the genus *Isistius* are clearly identified in the Carribean Sea: the cookie-cutter shark (*I. brasiliensis*; Quoy and Gaimard 1824) and the largetooth cookie-cutter shark (*I.plutodus) (*Garrick and Springer 1964; Ebert et al. 2013; Petean 2014). Both species induce crater-like wound on the skin surface of marine mega-fauna (Jones 1971; Dwyer and Visser 2011). However, the wound pattern slightly differs from one species to another (Pérez-Zayas et al. 2002; Dwyer and Visser 2011). Moreover, *I. plutodus* is less frequently captured and is only described from 10 specimens (Zidowitz et al. 2004; Ebert et al. 2015). This suggests that their distribution is more limited, they are less numerous or they don't have the same ecological niche (Wenzel and Suárez 2012). Although *I. brasiliensis* seems to be wider distributed, the bitemarks found on cetaceans in our study case may be caused by the two species of the genus.

Cookie-cutter sharks inhabit epipelagic to bathypelagic waters, and are known to proceed in diel vertical migrations, especially during the night (Compagno 1984; Papastamatiou et al. 2010). They are more abundant throughout tropical and sub-tropical oceans, especially near islands (King and Ikehara 1956; Strasburg 1963; Compagno 1984). Martinique is a tropical island situated between Caribbean Sea and Atlantic Ocean, hosting a high specific diversity, making it a potential favorable habitat for cookie-cutter sharks (CEPF 2011). Indeed, in addition to a variety of sharks and other fish species, 26 different species of cetaceans can be observed, therefore as many potential prey (Petit and Prudent 2010; Mayol et al. 2016). In our study, we have observed 12 of them including: Pantropical spotted dolphin (*Stenella attenuata*), Fraser's dolphin (*Lagenodelphis hosei*), Short-finned pilot whale (*Globicephala macrorhynchus*), Bottlenose dolphin (*Tursiops truncatus*), Melon-headed whale (*Peponocephala electra*), Risso's dolphin (*Grampus griseus*), Rough-toothed dolphin (*Steno bredanensis*), Killer whale (*Orcinus orca*), Clymène dolphin (*Stenella clymene*), Sperm whale (*Physeter macrocephalus*), Dwarf sperm whale (*Kogia sima*), and Humpback whale (*Megaptera novaeangliae*). Finally, we focused only the four more frequently observed species of cetaceans: *S. attenuata*, *L. hosei*, *G. macrorhynchus* and *T. truncatus*, or/and individuals with the most numerous bites.

Our main goal was to study the impact of cookie-cutter sharks on cetacean species from Martinique by determining (1) seasonal changes in the number of bites, (2) intra- and interspecific differences in the frequency and location of bites, and (3) link behavior patterns of both cookie-cutter sharks and cetaceans (Papastamatiou et al. 2010). This new data permit to better know the ecological behaviour of the sharks of the genus *Isistius* and attest their presence in the waters off Martinique and may provide important impacts on the behaviour and lifestyle of hunted cetacean populations off Martinique (Heithaus 2001; Dwyer and Visser 2011). The expected results of this study have some limits to be determined: difficulty for in situ direct underwater observations of cookie-cutter sharks due to their little size and usual bathypelagic habitat (Ebert et al. 2013).

The determination at sea of cookie-cutter shark bites on hunted cetaceans can also be difficult and have some limits: difficulty to estimate the number of bitten cetaceans individuals, the limited access of the whole body of bitten cetaceans at sea (Papastamatiou et al. 2010).

Material and methods

Surveys were conducted weekly along the Caribbean coast of Martinique, from 14°48'03 N; 061°19'92 W to14°27'30 N; 061°07'70 W (Fig. 1). Data were collected over 3 years, from 04/04/2013 until 01/04/2016. To standardize the sampling effort, each survey lasted 5 h, from 08:00 to 13:00, aboard two different whale-watching vessels: a *Lagoon 421,* a motorized sailing catamaran, and a *Monocap 30,* equipped with a 340 horse-power motor. The monitoring of cetaceans at sea is led in accordance to the *Charte d'approche et d'observation des mammifères marins*, an ethical charter created in 2003 by the *Direction de l'Environnement, de l'Aménagement et du Logement de Martinique* (DEAL), which protects and limits cetaceans disturbance. Then, at each cetacean observation, the following rules were respected: boat speed (5 knots max. at 300 m distance from the animals), observation duration (30 min) and no animal was hurt, captured, killed, or harassed during the surveys.

Fig. 1 Map of the study area (source: Google maps)

For every observation, recorded both temporal (date, hour, observation duration), environmental (wind speed, estimated visibility, sea state, GPS position, presence of birds or wastes) in addition to biological data (species observed, groups composition, groups size estimation, presence of bitemarks or other identification criteria) were recorded. At the same time, photographs and videos were shot with a reflex digital Camera Nikon D7100, 24MPixels (Tokyo, Japan, 2013), and a GoPro HERO 3 (San Mateo, USA, 2001), respectively (Durban et al. 2010; Bertulli 2015).

Photographs and videos were sorted by observation date and treated with XnViewMp software (Version 0.79, Freeware) and QuickTime (Version 7.7.8, Windows), respectively. First, worst quality images were removed. Then, cetacean species observed were reported on file, group size estimation, number of bites, and age class of bitten individuals (young, immature, adults or indeterminate) were recorded in a database, in order to determine the proportion of individuals with cookie-cutter sharks bitemarks. Image quality was defined as follow: "excellent" (clear photograph, with 70% to 100% visible flank), "good" (clear photograph, with 30 until less of 70% visible flank), "correct" (slightly diffuse photograph, with less of 30% visible flank), "reasonable" (diffuse or backlighting photograph) or "poor" (really diffuse or backlighting photograph). According to Dwyer and Visser's (2011) protocol, bitemarks were also categorized as "assumed" (bite looks similar of those to *Isistius sp.*) or "suspected" (bite looks similar in shape but with less definition), and then listed by bite stage: "open" (fresh bite associated with crater and pink coloration),"intermediate" (bite has not completely closed, associated with a contraction of epidermis) or "scar" (completely healed bite associated with changes in coloration of skin pigmentation, Fig. 2). To limit bias, suspected bites have not been used in this study.

Location of each bite was also recorded in six areas for both right and left side (Fig. 3): Superior Front Flank (SFF); Inferior Front Flank (IFF); Superior Central Flank (SCF); Inferior Central Flank (ICF); Superior Back Flank (SBF); Inferior Back Flank (IBF; Papastamatiou et al. 2010).

Statistical analyses were performed using Statistica software 12.0 (Statsoft, Tulsa, OK). Data were normally distributed and were tested prior to parametric or non-parametric tests (Lilliefors test). Time spent to the sampling effort and total number of bites and open bites

Fig. 2 Representation of bitemarks inflicted by cookie-cutter sharks to the three states; **a**. open bite; **b**. intermediate bite; **c**. scar bite

were log-transformed respectively. We also used a Kruskal-Wallis test instead of one-way ANOVA's. Various ratio were calculated to:

- test seasonal changes in the sampling effort [sampling effort each month (hours)/total sampling effort over 3 years (hours)],
- test seasonal changes in the total number of bites and open bites for all species combined and for *S. attenuata* (number of total or open bites each month/number of total individuals each month)
- compare bites frequency between cetacean species (number of total bites (or open bites) for species «X» /number of total individuals for species «X»),
- determine proportions of bitemarks per individual for each species (number of total bites (or open bites) for species «X»/number of bitten individuals for species «X»).

We also performed a Pearson Chi-square test to compare bite frequencies with cetacean species. Focus was put on both most commonly observed cetacean species (over 20 observations) and those individuals presenting the highest occurrence of bites (over 15 bites), to detect interspecific differences in bites location. Finally, we focused on most observed cetacean species, in order to have a representative sample and detect intraspecific differences in age class of bitten individuals. Eventually, we calculated an index of presence for each species to reflect their abundance and determine the likelihood of encountering them per hour of observation (Flechet 2015):

$$I_{p\ (X)} =$$

With $Ip(X)$ = Index of Presence for species «X»; $N_{observations}$ (X) = number of time species «X» was observed; $E_{s.total}$ = total sampling effort (hours).

Results

We conducted 252 surveys, representing 1260 h of sampling effort. We treated 16,168 image files, that includes 15,957 photographs (98.70%), and 211 videos (1.30%; Table 1). Regarding image quality, 27.5% were qualified as "good", followed by "poor" (24.5%), correct (23.50%) "reasonable" (19.40%) and finally only 5.56% of the images were "excellent".

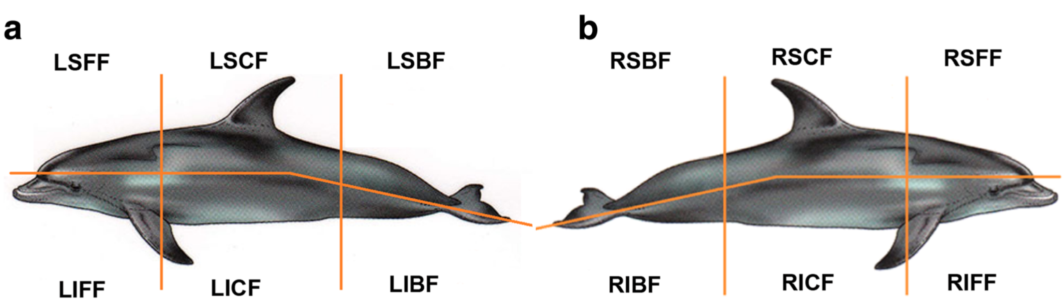


Fig. 3 Drawing of morphological cut of pantropical spotted dolphin (*S. attenuata*); **a**. LSFF: Left Superior Front Flank; LIFF: Left Inferior Front Flank; LSCF: Left Superior Central Flank; LICF: Left Inferior Central Flank; LSBF: Left Superior Back Flank; LIBF: Left Inferior Back Flank; **b**. RSBF: Right Superior Back Flank; RIBF: Right Inferior Back Flank; RSCF: Right Superior Central Flank; RICF: Right Inferior Central Flank; RSFF: Right Superior Front Flank; RIFF: Right Inferior Front Flank

Table 1 Synthesis of the data analysis

	Number of days	Sampling effort (h)	Observation duration (h)	Raw files	Treated files
Photographs	202 (80.16%)	1010	127.53 (75.77%)	27,462 (98.15%)	15,957 (98.7%)
Videos	50 (19.84%)	250	40.78 (24.23%)	517 (1.85%)	211 (1.3%)
Total of records	252	1260	168,31	27,979	16,168

There were no significant monthly ($p = 0.71$), or seasonal changes ($p = 0.86$) in the sampling effort during the 3 years (data not shown). From the 12 observed species (Table 2) including a mean of 12,379 individuals (sd = ± 27.8). *S. attenuata* was mostly observed (17.70%), followed by *L. hosei* (2.62%), *P. macrocephalus* (2.30%), *G. macrorhynchus* (1.98%), *T. truncatus* (1.75%), *M. novaeangliae* (0.63%) and *P. electra* (0.48%). *S. bredanensis* was observed twice (0.16%) and *G. griseus, K. sima, O. orca, and S. clymene* were only seen once (0.08%). The largest number of cetaceans observed was *S.attenuata* (9767 ± 26.35), followed by *L. hosei* (1410 ± 32.09), *G. macrorhynchus* (507 ± 15.44), *T. truncatus* (316 ± 9.26), and *P. electra* (229 ± 23.91). The largest group size was that of *L. hosei* (mean = 42.71 individuals per observation), followed by *S. attenuata* (mean = 41.92 individuals per observation).

Cookie-cutter shark bitemarks were recorded 431 times on 396 individuals, belonging to nine different cetacean species. Frequency of bites showed significant differences among cetacean species ($p < 0.05$). *S. attenuata* presented the highest number of occurrence of *Isistius sp.* bites (314 bitemarks) relatively to the sample size. *G. griseus* showed the highest percentage of individuals with bitemarks within species (25.0%) followed by *M. novaeangliae* (18.18%). No bite was observed in the following species: *K. sima*, *O. orca*, *S. clymene*. Only 18 individuals (4.55%) had multiple bitemarks, *M. novaeangliae* had the highest bites frequency per individual (ratio = 2.50 bites per individual), followed by *G. macrorhynchus* (ratio = 1.79 bites per individual; Table 2).

In terms of bite stages, a majority of intermediate bites were recorded (45.2%), followed by scar bites (35.3%) and to a lesser extent open bites (19.5%). Almost half of bitten individuals' class age could not be determinate (indeterminate = 49.9%). Indeed, as dolphins swam fast, and stayed very shortly in surface, it was really difficult to take the whole body in picture, thus, it was sometimes difficult to discriminate immatures and adults individuals from juveniles. From the known class age individuals, 3.25% bitemarks were seen on young individuals' skin 25.1% on immature and 21.8% on adults (Table 3).

There were no significant seasonal differences in the number of total bites and open bites all species combined (Fig. 4), nor in the number of total bites and open bites for *S. attenuata* (results not showed).

The majority of bites were mostly located on the Superior Flank, whose 62.40% on SCF and to a lesser extent on the SFF (19.72%), and on the SBF (10.44%). The Inferior Flank were largely less bitten (ICF: 3.94%, IFF: 2.08% and IBF: 1.40%, Fig. 5).

Location of the bites showed some differences among the most observed species and the most predated species. *S.attenuata, L. hosei* and *T. truncatus* showed the same profile than all species combined, with a majority of bites on the SCF (66.60%, 58.97% and 83.35%; respectively), followed by the SFF (17.50%, 10.26% and 11.77% respectively), SBF (9.87% and 17.95% respectively) and a minority for inferior flankson the ICF (4.14% and 7.69% respectively), IBF (1.27% and 2.56% respectively) and IFF (0.64%, 2.56% and 5.88% respectively). No bites were recorded in *T. truncatus* on the ICF, SBF and IBF. Conversely, *G. macrorhynchus* showed a clear different bites distribution, with much more occurrence on the SFF and SCF (44.12% for both), fewer on the SBF (8.82%) and IFF (2.94%) and no bites on ICF and IBF (Fig. 6).

In *S. attenuata,* immature and adults individuals showed higher number of occurrence all over the body than juveniles. However, on the inferior central flank the highest number of bites concerned young (30.77%) and immature individuals (53.85%; Fig. 7).

Table 2 Synthesis of the three years data by cetacean species

Observed species	Index of presence (%)	Mean of total individuals seen (+/− sd)	Mean of individuals by group	Bitten individuals[a]	Number of bites/Number bitten individuals	Percentage of bites (%)[c]
S. attenuata	17.70	9767 (+/− 26.35)	41.92	300 (314)	1.05	3.07 (3.22)
L. hosei	2.62	1410 (+/− 32.09)	42.71	38 (39)	1.02	2.70 (2.77)
P. macrocephalus	2.30	53 (+/− 1.25)	1.77	2 (2)	1.00	3.77 (3.77)
G. macrorhynchus	1.98	507 (+/− 15.44)	18.78	19 (34)	1.79	3.75 (6.71)
T. truncatus	1.75	316 (+/− 9.26)	14.36	16 (17)	1.06	5.06 (5.38)
M. novaeangliae	0.63	11 (+/− 0.52)	1.38	2 (5)	2.50	18.18 (45.46)
P. electra	0.48	229 (+/− 23.91)	38.17	15 (16)	1.07	6.55 (6.99)
S. bredanensis	0.16	39 (+/− 26.16)	19.50	1 (1)	1.00	2.56 (2.56)
G.griseus	0.08	12	–	3 (3)	1.00	25.00 (25.00)
K. sima	0.08	1	–	0	0.00	0.00 (0.00)
O. orca	0.08	15	–	0	0.00	0.00 (0.00)
S. clymene	0.08	20	–	0	0.00	0.00 (0.00)
Total	–	12,379 (+/−27.76)	–	396[b](431)	1.09	70.64 (11.31)

[a] Number indicate the number of individuals, number in brackets indicate the number of bites: 18 individuals (4.55%) presented multiple bites

[b] Including 13 young (3.28%), 99 immatures (25.00%), 83 adults (20.96%), 201 indeterminate individuals (50.76%).

[c] Number indicate the percentage of individuals with bites, number in brackets indicate the percentage of bites

Discussion

We present here the first study on *Isistius sp.* predation on different cetacean populations in Martinique waters, in order to better understand *Isistius sp.* cetaceans interactions assuming that oval injuries presented on the cetaceans' skin were caused the predaction acts of these little sealthy sharks (Jones 1971; McSweeney et al. 2007; Best and Photopoulou 2016). This new data permit to better know the ecological behaviour of the sharks of the genus *Isistius* and attest their presence in the waters off Martinique and may provide important impacts on the behaviour and lifestyle of hunted cetacean populations off Martinique (Heithaus 2001; Dwyer and Visser 2011).

First, our study confirmed the presence and the opportunistic lifestyle of *Isistius sp.* regarding to the large variety of cetacean species with bitemarks (Papastamatiou et al. 2010). It is interesting to note that all cetaceans with cookie-cutter sharks bitemarks were squid eaters, excepted *M. novaeangliae* (Souto et al. 2007). Conversely to Papastamatiou et al. (2010), who supposed cookie-cutter sharks migration during winter period in Hawaii, we were not able to detect any seasonal changes in the number of bites in our study. That suggests the permanent presence of *Isistius sp.* population(s) in the vicinity of Martinique, perhaps because their prey are available in this area all year round (CEPF 2011). The lower proportion of OPEN bite could be explained by a short SCAR stage (Dwyer and Visser 2011).

Bitemarks per individual vary a lot between species, and could be due to their respective ecological niche (Shirai 2007; Culik 2010). In fact, as more than 20 different

Table 3 Number of bites according to states and ages

	Young	Immatures	Adults	Indeterminate	Number of bites
Open	3	21	19	41	84 (19.49%)
Intermediate	8	51	35	101	195 (45.24%)
Scar	3	36	40	73	152 (35.27%)
Total	14 (3.25%)	108 (25.06%)	94 (21.81%)	215 (49.88%)	431

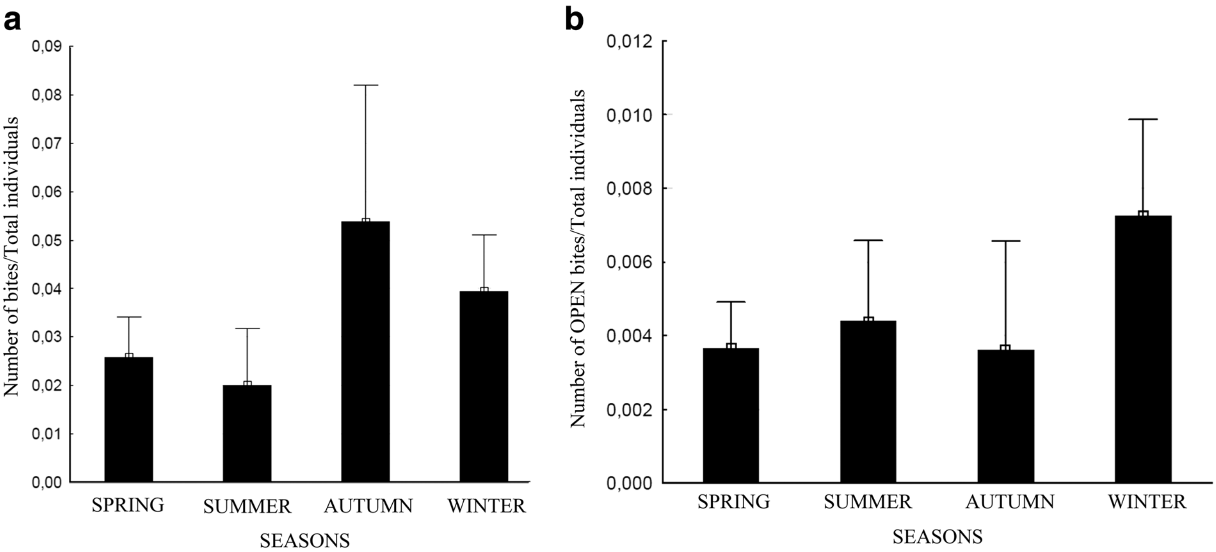
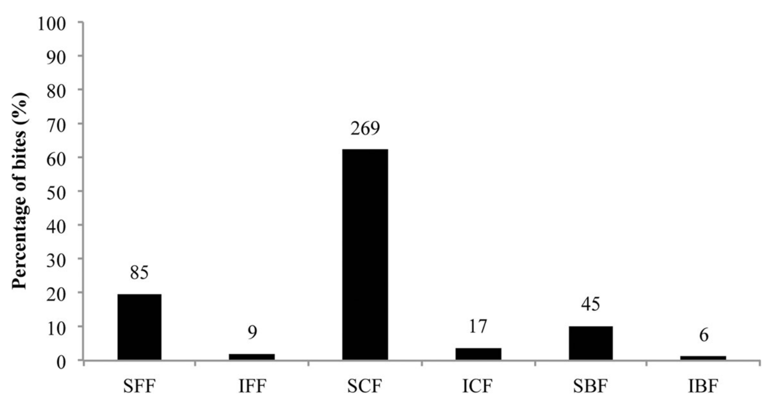


Fig. 4 Graphical representation of (**a**) total bites and (**b**) OPEN bites seasonally, all species combined

marine mammals species can be observed in Martinique waters, some of them are residents, i.e. same animals are observed all the year, as it is the case for *S. attenuata* and *P. macrocephalus*. Others species are encountered punctually, like *L. hosei*, *G. macrorhynchus*, *T. truncatus*, or migrate from North Atlantic to tropical region like *M. novaeangliae*. Consequently, species were not observed on the same frequency, and those very rarely observed or with low number of total individuals seen were not necessarily representative of the real population. For example, *K. sima*, *O. orca*, *S. clymene* were cetacean species surveyed for which no bites were observed in Martinique whereas several records exist worldwide (Jefferson and Curry 2003; Adam 2010; Dwyer and Visser 2011; Wenzel and Suárez 2012).

Our results demonstrated strong interspecific differences in the distribution pattern of bitemarks. Indeed, the head of *G. macrorhynchus* is more exposed to *Isistius sp.* bitemarks. This could be explained by abundant fatty tissue in their bulbous melon (Litchfield and Greenberg 1974; Culik 2010). They are also known to hunt between 500 and 800 m depth exclusively at night, and thus are more exposed at this ectoparasite (Baird et al. 2002; Stevens 2013). Moreover, they occasionally eat little sharks that lead them more vulnerable as they attack them (Heithaus 2001). Similar descriptions have been realized for *P. macrocephalus* in the literature, while we did not observed the same pattern in our study (Clarke 1978; Evans et al. 2002; Best and Photopoulou 2016). This difference between our results and those observed from other studies could be explained by the fact that we used essentially picture taken outside from water and sperm whales do rarely show their head outside from water.

Fig. 5 Graphical representation of the percentage of bites location



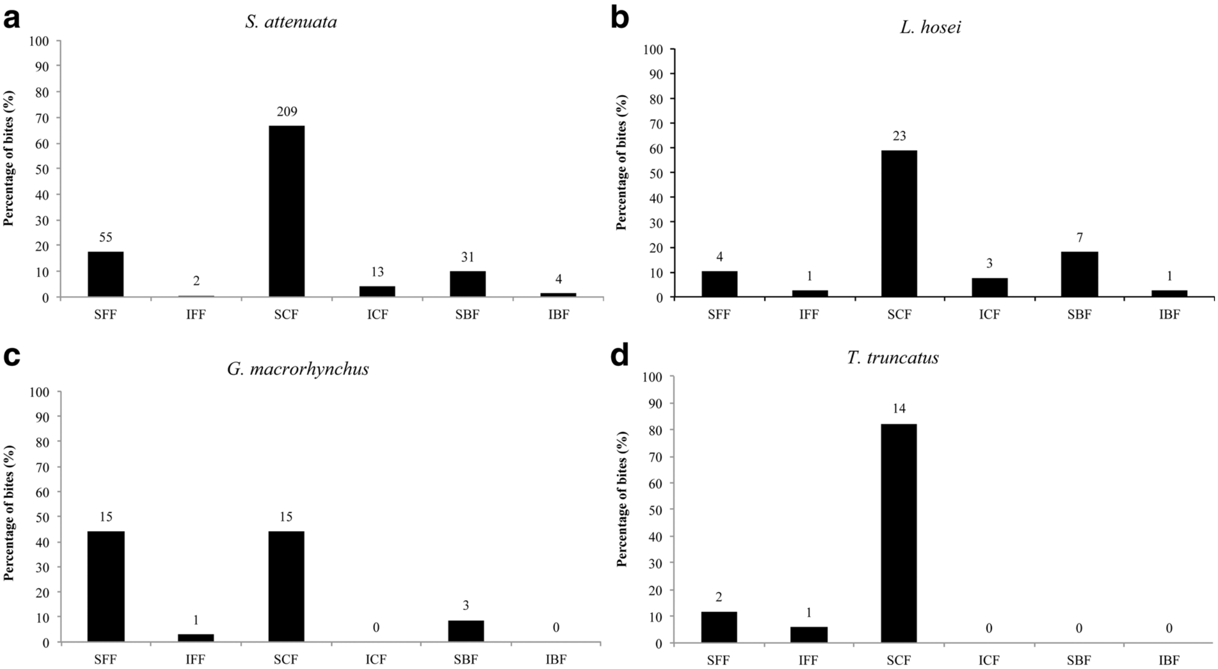


Fig. 6 Graphical representation of the proportion in bites location in *S. attenuata*; *L. hosei*; *G. macrorhynchus*; *T. truncatus*

Smaller cetaceans, like dolphins showed the great majority of bitemarks on SCF. Unlike the head or the fluke, flanks do not present any defense system and are less dynamic. That enables cookie-cutter sharks to feed with less risks and more success. This is also the largest part of the cetacean's body, which contains abundant blubber, i.e. a rich energetic substance (Struntz et al. 2004; Wenzel and Suárez 2012). *S. attenuata*, *L. hosei* and *T. truncatus* share similar ecological niche and they are often observed together during their travel that could explain some similarities in the location of bites (Culik 2010). Our results were similar with those in the literature. Souto et al. (2007) proposed the pattern distribution as follow: "20% was in the ventral part. The areas most subject to attack in cetaceans were: flanks 40%; head and abdomen 20% each; dorsal 15%; and genital with 5%". We have some limits to

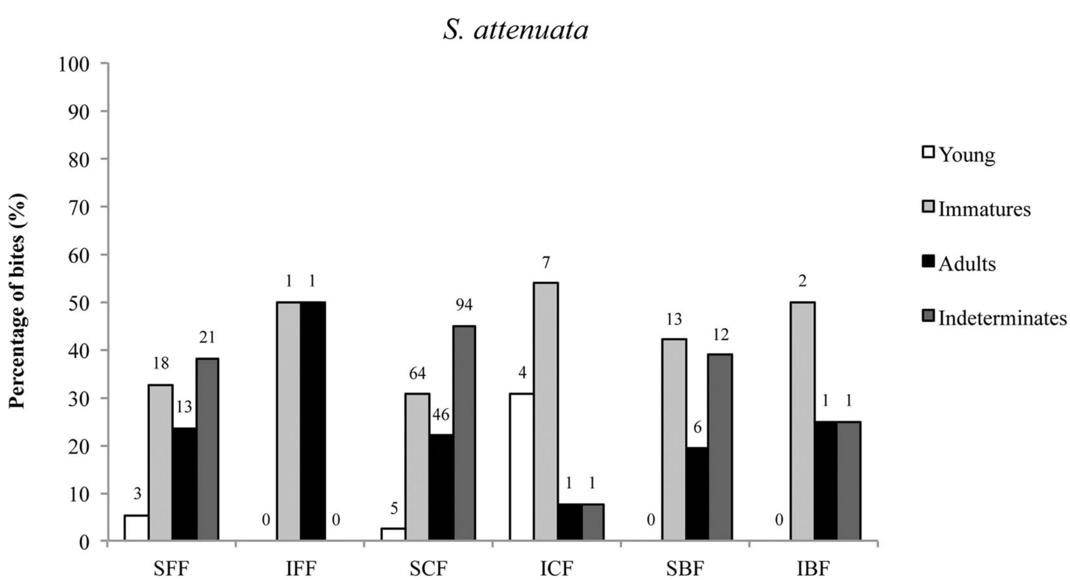


Fig. 7 Graphical representation of the percentage of bites according to the age and location in *S. attenuata*

have such complete attempted results we searched due to the limits of our chosen protocol, the whole body of the bitten cetacean can't be observed and 5.56% of the used images are excellent in the large amount of exploitable images (98.70%).

It is interesting to notice that most of cetacean species encountered in big groups (*S. attenuata* and *L. hosei*) seemed to present fewer bites per individual and, consequently, a lower percentage of bites than those in smaller group (*M. novaeangliae* and *G. macrorhynchus*). That suggests the benefits of the dilution and the collective predator's detection action by cetaceans living organized in pods, though to be attacked mainly during foraging activity (Hoezel 2009). The size of the prey can also explain the amount of bitemarks by species, large species as humpback or pilot whales present a larger body surface to be bitten than the two dolphins species.

We also noticed differences in bitemarks per individual by cookie-cutter sharks according to the individuals age, as described by Carrier et al. (2012), where the predation is based on age class and sex. Main of bitemarks observed on immature and adults individuals could be linked to their deepest foraging tactic than younger ones, leaving them more prone to encounter *Isistius sp.* Also, on 18 individuals with multiple scars, just one animal was a juvenile (with two bitemarks), suggesting that more mature individuals accumulate more bites in their live (Dwyer and Visser 2011; Wenzel and Suárez 2012). Perhaps, young individuals are also better protected by adults, and bitten at the surface at night during the nycthemeral migrations of *Isistius sp.* (Gallo-Reynoso and Figueroa-Carranza 1992). When we focused on *S. attenuata*, we observed that young and immature individuals were, in proportion, those more bitten on ICF. These results can be explained by their playful behavior in surface, allowing the photography of this part more conspicuous than adults when were observed.

To our knowledge, it's the first study which attempt to characterize cookie-cutter sharks bites on living cetaceans in Caribbean waters, certainly because it can present numerous difficulties and potential bias (Best and Photopoulou 2016). Indeed, the number of bites is certainly underestimated because only one part of the body is still visible during observation. The population size was also very difficult to estimate, and was only based on seen individuals. Given that some populations are sedentary, then some individuals were maybe counted several times. Moreover, the protocol has not always been well adapted to all cetacean species. For example, *P. macrocephalus* were really discreet on surface water, and it was rare to see more than 30% of their body. Also, it has been thought that they heal more rapidly than other species (Best and Photopoulou 2016). *L. hosei* were often seen in large group pod, leading difficult for a precise observation of each individuals and some bitemarks may be hidden.

Finally, the real impact of *Isistius sp.* on cetacean population is still not properly understood and more serious consequences are surely overlooked (Luksenburg 2014). We know that sharks attacks influence group and size composition, and individuals' behavior (Heithaus 2001; Motta and Wilga 2001). The serious wounds due to cookie-cutter sharks bites may weaken bitten cetaceans, more especially young individuals (Carrier et al. 2012). Then, they are perhaps least able to defend themselves against cookie-cutter sharks, other species of predators – others sharks or orcas - attacks or are more prone to infection. This phenomenon could potentially lead to a decrease in the size and diversity of the cetacean populations.

Nevertheless, our results described for the first time interaction of *Isistius sp.* with different cetacean populations in Martinique waters. Finally, *Isistius sp.* are themselves sometimes consumed by other animals (one have been found in tuna stomach: Best and Photopoulou 2016). Thus, in order to better understand dynamics, behavior and interactions of cetaceans and cookie-cutter sharks, it's important to increase cooperation with both scientists and fishermen.

Acknowledgements We gratefully thank our partners *Aliotis plongée* and *Dauphins passion,* who have enable us to realize sea excursion and cetaceans observation.

References

Adam S (2010) Head of a beached Dwarf Sperm Whale, Australian Museum, available on: http://australianmuseum.net.au/image/dwarf-sperm-whale-ashore-near-palm-beach

Baird RW, Borsani JF, Hanson MB, Tyack PL (2002) Diving and night-time behavior of long-finned pilot whales in the Ligurian Sea. Mar Ecol Progr Ser 237:301–305. https://doi.org/10.3354/meps237301

Bertulli C (2015) An assessment of the natural marking patterns used for photo-identification of common minke whales and white-beaked dophins in Icelandic waters. J Mar Biol 41: 343–350

Best PB, Photopoulou T (2016) Identifying the "demon whale-biter": patterns of scarring on large whales attributed to a

cookie-cutter shark *Isistius sp*. PLoS One 11(4):e0152643. https://doi.org/10.1371/journal.pone.0152643
Carrier JC, Musick JA, Heithaus MR (2012) Biology of sharks and their relatives. CRC Press, Boca Raton. https://doi.org/10.1201/b11867
CEPF (2011) Caribbean Islands biodiversity hotspot. Ecosystem Profile Summary, Critical Ecosystem
Claes J, Nilsson D, Straube N (2014) Iso-luminance counterillumination drove biolumescent shark radiation. Sci Rep 10:4328
Clarke MR (1978) Structure and proportions of the spermaceti organ in the sperm whale. JMBA 58:1–17
Compagno LJ (1984) FAO species catalogue. Vol. 4, Sharks of the World. An annotated and illustrated catalogue of shark species known to date (Part 1, Hexanchiformes to Lamniformes). FAO Fisheries Synopsis, 125, 4 (1). FAO, Rome
Culik B (2010) UNEP/CMS secretariat, Bonn, Germany. Available on: http://www.cms.int/reports/small_cetaceans/poster_download.htm
Durban J, Ellifrit D, Dahlheim M, Waite J (2010) Photographic mark-recapture analysis of clustered mammal-eating killer whales around the Aleutian Islands and gulf of Alaska. Mar Biol 157(7):1591–1164. https://doi.org/10.1007/s00227-010-1432-6
Dwyer SL, Visser IN (2011) Cookie cutter shark (*Isistius sp.)* bites on cetaceans, with particular reference to killer whales (orca)(*Orcinus orca*). Aquat Mamm 37(2):111–138. https://doi.org/10.1578/AM.37.2.2011.111
Ebert DA, Fowler S, Compagno LJV (2013) Sharks of the world: a fully illustrated guide to the sharks of the world. Wild Nature Press, Devon
Ebert DA, Pien C, Kamikawa DJ (2015) Confirmation of the cookiecutter shark, *Isistius brasiliensis*, from the eastern North Pacific Ocean (Squaliformes: Dalatiidae). Mar Biodiv Rec 8. https://doi.org/10.1017/S1755267215000962
Evans K, Morrice M, Hindell M, Thiele D (2002) Three mass strandings of sperm whales (*Physeter macrocephalus*) in southern Australian waters. Mar Mam Sci 18(3):622–643. https://doi.org/10.1111/j.1748-7692.2002.tb01063.x
Flechet A (2015) Caractérisation des populations de grands dauphins (*Tursiops truncatus*) et de globicéphales tropicaux (*Globicephala macrorhynchus*) en Martinique. University of St-Étienne, Master thesis
Gallo-Reynoso JP, Figueroa-Carranza AL (1992) A cookiecutter shark wound on a Guadalupe fur seal male. Mar Mam Sci 8(4):428–430. https://doi.org/10.1111/j.1748-7692.1992.tb00060.x
Garrick JAF, Springer S (1964) *Isistius plutodus*, a new Squaloid shark from the Gulf of Mexico. Copeia 1964(4):678–682. https://doi.org/10.2307/1441443
Hayashi T, Higo E, Orito H, Ago K, Ogata M (2015) Postmortem wounds caused by cookie-cutter sharks (*Isistius species*): an autopsy case of a drowning victim. Forensic Sci Med Pathol 11(1):119–121. https://doi.org/10.1007/s12024-014-9597-9
Heithaus MR (2001) Predator–prey and competitive interactions between sharks (order Selachii) and dolphins (suborder Odontoceti): a review. J Zool 253(1):53–68. https://doi.org/10.1017/S0952836901000061
Hoezel AR (2009) Marine mammal biology: an evolutionary approach. Wiley, Chichester
Hoyos-Padilla M, Papastamatiou YP, O'Sullivan J, Lowe CG (2013) Observation of an attack by a cookiecutter shark (*Isistius brasiliensis*) on a white shark (*Carcharodon carcharias*). Pac Sci 67(1):129–134. https://doi.org/10.2984/67.1.10
Jahn AE, Haedrich RL (1988) Notes on the pelagic Squaloid shark *Isistius brasiliensis*. Biol Oceanogr 5:297–309
Jefferson TA, Curry BE (2003) Stenella clymene. Mamm Species 726:1–5. https://doi.org/10.1644/726
Jones EC (1971) *Isistius brasiliensis*, a squaloid shark, probable cause of crater wounds on fishes and cetaceans. Fish Bull 69: 791–798
King JE, Ikehara II (1956) Some unusual fishes from the Central Pacific. Pac Sci 10:17–24
Le Bœuf BJ, McCosker JE, Hewitt J (1987) Crater wounds on northern elephant seals: the Cookiecutter shark strikes again. Fish Bull 85:387–392
Litchfield C, Greenberg AJ (1974) Comparative lipid patterns in the melon fats of dolphins, porpoises and toothed whales. Comp Biochem Physiol B 47(2):401–407. https://doi.org/10.1016/0305-0491(74)90069-8
Luksenburg JA (2014) Prevalence of external injuries in small cetaceans in Aruban waters, southern Caribbean. PLoS One 9(2):e88988. https://doi.org/10.1371/journal.pone.0088988
Mayol P, de Montgolfier B, Bordes R, Costales L, Iatropoulos D, Ortole C, Belhadjer A (2016) Caractérisation des activités d'observation commerciale à l'échelle du sanctuaire Agoa. Dissertation, Agoa
McSweeney DJ, Baird RW, Mahaffy SD (2007) Site fidelity, associations, and movements of Cuvier's (*Ziphius cavirostris*) and Blainville's (*Mesoplodon densirostris*) beaked whales off the island of Hawai 'i. Mar Mam Sci 23(3):666–687. https://doi.org/10.1111/j.1748-7692.2007.00135.x
Motta PJ, Wilga CD (2001) Advances in the study of feeding behaviors, mechanisms, and mechanics of sharks. In: Tricas TC, Gruber SH (eds) The behaviour and sensory biology of elasmobranch fishes: an anthology in memory of Donald Richard Nelson. Environ Biol Fish 60:131–156
Nakano H, Tabuchi, M (1990) Occurrence of the Cookiecutter shark. Isistius brasiliensis in surface water of the North Pacific Ocean Japanese Journal of Ichthyology 37:60–63
Papastamatiou YP, Wetherbee BM, O'Sullivan J, Goodmanlowe GD, Lowe CG (2010) Foraging ecology of cookiecutter sharks (*Isistius brasiliensis*) on pelagic fishes in Hawaii, inferred from prey bite wounds. Env Biol Fish 88(4):361–368. https://doi.org/10.1007/s10641-010-9649-2
Pérez-Zayas JJ, Mignucci-Giannoni AA, Toyos-González GM, Rosario-Delestre RJ, Williams EH (2002) Incidental predation by a largetooth cookiecutter shark on a Cuvier's beaked whale in Puerto Rico. Aquat Mamm 28:308–311
Petean FDF (2014) Taxonomic review and comparative morphology of the species of the genus *Isistius* gill, 1864 (Chondrichthyes, Squaliformes: Dalatiidae) doctoral dissertation Universidade de São Paulo
Petit J, Prudent G (2010) Climate change and biodiversity in the European Union overseas entities. IUCN, Gland
Quoy JRC, Gaimard P (1824) Zoologie, vol 3. Imprimerie royale 10:198
Shirai H, (2007) Guide des mammifères marins du monde: toutes les espèces décrites et illustrées. Delachaux et Niestlé

Souto LRA, Oliveira JGA, da Costa JDAC, Maia-Nogueira R, Sampaio CL (2007) Análise das mordidas de tubarões-charuto, Isistius spp.(Squaliformes: Dalatiidae) em cetáceos (Mammalia: Cetacea) no litoral da Bahia, Nordeste do Brasil. Biotemas 20:19–25

Stevens TS (2013) Guide d'identification baleines et dauphins Canada atlantique et Nord-Est des Etats-Unis. Broquet, Canada

Strasburg DW (1963) The diet and dentition of *Isistius brasiliensis*, with remarks on tooth replacement in other sharks. Copeia 1963(1):33–40. https://doi.org/10.2307/1441272

Struntz DJ, McLellan WA, Dillaman RM, Blum JE, Kucklick JR, Pabst DA (2004) Blubber development in bottlenose dolphins (*Tursiops truncatus*). J Morphol 259(1):7–20. https://doi.org/10.1002/jmor.10154

Wenzel FW, Suárez PL (2012) What is known about cookiecutter shark (*Isistius spp.*) interactions with cetaceans in Cape Verde seas? Zoologia Caboverdiana 3:57–66

Zidowitz H, Fock HO, Pusch C, Von Westernhagen H (2004) A first record of Isistius Plutodus in the north-eastern Atlantic. J Fish Biol 64(5):1430–1434. https://doi.org/10.1111/j.0022-1112.2004.00382.x