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Evidence of shark attacks on Atlantic spotted dolphins (*Stenella frontalis*) off Bimini, The Bahamas

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Predators can influence prey communities through direct predation and also through the costs of antipredatory behavioral responses or risk effects (Heithaus 2001*a*, Heithaus and Dill 2006, Wirsing *et al.* 2008). The risk of predation by sharks may be a selective pressure for social evolution (Norris 1994) and perhaps seasonality in calving rates (Fearnback *et al.* 2012) in dolphins. Sharks are considered to prey on dolphins when they attack free-swimming individuals as opposed to scavenging on terminally ill, severely wounded, or stranded animals (Heithaus 2001*a*). Stomach content studies have shown delphinid species consumed by at least five different shark species (Cockcroft *et al.* 1989, Monteiro *et al.* 2006). First-hand observations of shark attacks on small cetaceans (Mann and Barnett 1999, Maldini 2003, Gibson 2006, Silva-Jr *et al.* 2007, Turnbull and Dion 2012, Dudzinski[2]) are rare and therefore alternative methods for assessing shark predation must be developed. One method is by assessing failed attempts; that is, documenting fresh injuries and scars on reliably reidentified dolphins that can be attributed to sharks.

Here, we report on shark attacks on Atlantic spotted dolphins (*Stenella frontalis)* near Bimini, The Bahamas, and examine occurrence of attacks as a function of body parts, sex, and age class. We also discuss how the rate of scarring attributed to nonlethal shark attacks at our study site compares to others, and the possible shark species responsible for these attacks.

The waters north and west of North Bimini, The Bahamas, have been the site of longitudinal, long-term research by the Dolphin Communication Project (DCP)

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since 2001. The survey area is along the northwestern corner of the Great Bahama Bank, immediately adjacent to the northerly flowing Gulf Stream (see Melillo 2008 for a map of study area), ranges from 6 to 12 m in depth, and generally consists of a white, sandy sea floor. Data were collected from local dolphin watch/swim vessels (inboard and outboard, all monohull). From 2003 to 2011, dolphin surveys ($n = 533$) were completed, totaling >2,300 h of effort, resulting in 619 *S. frontalis* sightings and an additional 85 sightings of mixed species groups (*S. frontalis* and *Tursiops truncatus*). Cumulatively, dolphin sightings totaled >480 h, with dolphins in view on underwater video data for >43 h. Data collection was biased seasonally (May–September) and toward time of day (4–5 h before sunset). In addition to archived (2001–2002) images of 74 individuals, the following number of individuals were assessed for wounds each year: 29 (2003), 31 (2004), 30 (2005), 31 (2006), 38 (2007), 36 (2008), 35 (2009), 34 (2010), 31 (2011).

A small community (~120 individuals; DCP, unpublished data 2001–2011) of *S. frontalis* are thought to be year-round, life-long residents of the waters near Bimini (Melillo *et al.* 2009). They are habituated to boats and human swimmers; however, physical contact between dolphins and humans is rare and the dolphins are not provisioned. Each individual's spot pattern is unique, allowing for reliable photo-identification over time, and age estimates based on spot development (Perrin 1970, Herzing 1997). To confirm sex, a clear view of the genital region or repeated nursing observations and/or calf associations was required. DCP's *S. frontalis* photo-identification catalog included 92 individuals at the conclusion of this study. The sex ratio is 2:1 (females:males); however, over one-third of cataloged individuals are of unknown sex (Greene *et al.* 2011). Because the photo-ID catalog is comprised of mainly underwater images, most, if not all angles of any given dolphin's body are documented, allowing the observation of scars and injuries to be unbiased toward the dorsal surface. In addition, trained observers routinely surveyed dolphins' entire bodies, in real time, during underwater photograph and video collection; these notes supplemented the photo-ID catalog.

Images for the photo-ID catalog were collected using digital, underwater cameras with occasional supplemental surface photographs. Video data were collected using a mobile video/acoustic array system (Dudzinski *et al.* 1995). Still photos were captured from video as needed, when quality allowed. Camera models varied between years, and included Olympus (various point and shoot models, with a minimum resolution of 6 MP) and Canon (Rebel XT) digital still cameras and Sony (TRV230, PC101, PC102) video cameras.

DCP's photo-ID catalog was reviewed for evidence of shark attacks on identified and cataloged individuals. Scars or fresh injuries were considered to have been inflicted by sharks if they were crescent-shaped or included deep, widely spaced tooth marks that did not match a tooth rake of another dolphin (Heithaus 2001*b*). Particularly jagged injuries to pectoral or dorsal fins were also deemed as inflicted by sharks when there was extreme confidence that the injury could not have been inflicted by another source, such as a boat propeller, fishing line or another dolphin. There were only two such cases and both were confirmed by an additional trained researcher. Only images of individuals from DCP's photo-ID catalog with evidence of a shark attack were used in this analysis. Uncataloged individuals were not included.

Following Heithaus (2001*b*), the dolphin's body was divided into 12 zones: head, body, and tail/peduncle for dorsal, ventral, and left and right surfaces. The dorsal fin, each pectoral fin and the flukes were also included. These locations were then broadly categorized as dorsal, ventral, or extremity, with the dorsal fin included in the dorsal region, not extremities. Bites were coded for their location on the dolphin's body. Age class and sex of the dolphin were noted as well as relative freshness of the bite (*e.g.*, scar >1 yr, wound <1 yr; Heithaus 2001*b*).

A total of 14 *S. frontalis* (15% of 92 cataloged animals) showed some sign of shark attack, and a further 15 (16%) exhibited scars that could not conclusively be classified as shark induced or not. These unconfirmed scars were not included in further analysis. There was no significant difference between the location of scars and wounds (dorsal side, including dorsal fin: $n = 7$, 50%; extremities: $n = 5$, 36%; ventral side: $n = 2$, 14%; $\chi 2 = 2.71$, df = 2, $P = 0.257$). No shark-related injuries were observed on the head or rostrum. It is assumed that sharks will have a greater success rate (*i.e.,* the attack is fatal for the dolphin) if the softer, ventral side of a dolphin is attacked (Heithaus 2001*b*). White sharks, for example, are known to attack the caudal peduncle or abdomen of a variety of small odontocetes (Long and Jones 1996).

There was no difference in shark-induced scars or wounds between the sexes (male: $n = 6$, 43%; female: $n = 7$, 50%; unknown: $n = 1$, 7%; $\chi 2 = 0.08$, df = 1, $P = 0.782$). We were able to estimate what age class the *S. frontalis* were at the time of attack for 10 individuals (after Herzing 1997). Seven of these were calves (four males, three females) and one was juvenile, one subadult, and one adult, all female. Observations of neonates in the study community were rare and to date none has been observed with injuries.

Of the 14 individuals with confirmed shark injuries, only two (14%) exhibited wounds: juveniles ID#64 (Fig. 1) and ID#87 (Fig. 2). The low rate of wound observations may be a factor of predominantly late spring and summer research efforts and/or an individual's avoidance of boats during times of stress, such as following a shark attack. It was not readily apparent which shark species was responsible for either injury.

Nonlethal injuries to dolphins heal quite well and relatively quickly (Corkeron *et al.* 1987*b*, Orams and Deakin 1997, Elwen and Leeney 2010); therefore, less severe

Figure 1. Photograph, taken on 20 August 2005, of an injury, first observed on 9 August 2005, to male *S. frontalis,* ID#64. Note the double bite mark on two different peduncle surfaces. ID#64 was the only dolphin with evidence of multiple (2) shark attacks, which were several years apart.

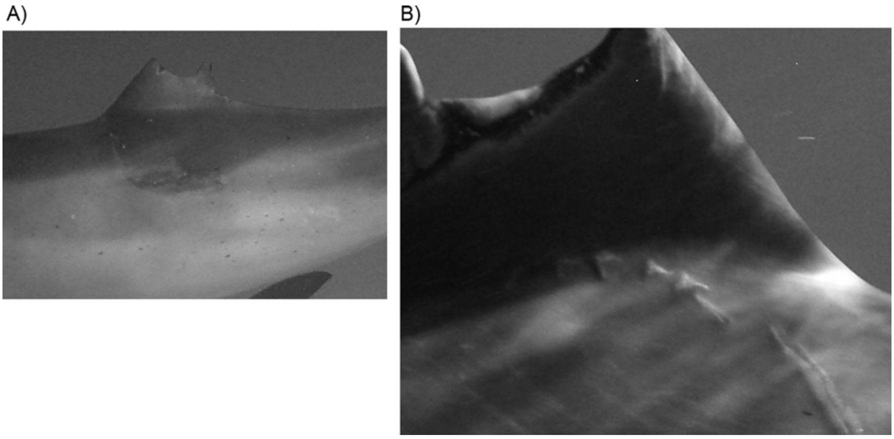

Figure 2. Photographs, taken on 5 May 2010, of an injury to a female *S. frontalis,* ID#087. A) Note the damage to left side and B) the uniform scars, on the right, just below the damaged dorsal fin, suggesting the possibility that as many as five of the shark's teeth became embedded in the dolphin's flesh.

attacks may not be accounted for, and discriminating between scar and wound may have inherent error. Because of these challenges, and the 16% of *S. frontalis* with scars from unknown sources, the percentage of individuals within our cataloged community with a history of shark attack is likely an underestimation. This is particularly pertinent for adult *S. frontalis*, whose continued pigment development can camouflage or obscure old injuries.

The *S. frontalis* off Bimini show less evidence of failed shark attacks than *Tursiops sp.* in several other parts of the world: Moreton Bay (36.6%, Corkeron *et al.* 1987*a*), Shark Bay (74.2%, Heithaus 2001*b*), Sarasota (31%),[3] and Indian River Lagoon (32%).[4] These differences are in contrast to the *T. truncatus* off Natal (Cockroft *et al.* 1989), which, with 10.3% of dolphins exhibiting shark-induced injuries, were similar to the *S. frontalis* off Bimini, and to *T. truncatus* in the Adriatic Sea where there may be very little shark predation (Bearzi *et al.* 1997). Differences in study locations, species, and methods prevent a robust statistical comparison; yet, that a minimum of 15% of the cataloged *S. frontalis* had shark-induced scars indicates that this dolphin community, like others elsewhere, is subject to predation by large shark species. This likely influences habitat choice and space use across various spatio-temporal scales. However, few shark-related scars in a dolphin population may not equate to low direct predation; it may simply indicate very few unsuccessful predation attempts (Cockcroft *et al.* 1989).

Heithaus (2001*a*) considers the following flaws in using photo-ID to assess the predation rate of sharks on dolphins: scars are evidence of failed predation attempts, the ratio of successful and failed attempts varies between shark species and sizes, and the

[3]Unpublished observations from Kim Urian, Duke University Marine Lab, Beaufort, NC, August 2013.

[4]Unpublished observations from Sarah Bechdel, Harbor Branch Oceanographic Institute, North Fort Pierce, FL, September 2013.

size of the dolphins should bias this ratio with young dolphins successfully taken by sharks more often than older ones. Despite these reservations, using photo-ID to assess the percent of shark-scarred individuals in a community or population and comparing different populations is still worthwhile (Heithaus 2001*a*).

Of the large sharks found in and around Bimini, tiger (*Galeocerdo cuvier)* and bull sharks (*Carcharhinus leucas*) are the most likely predators of dolphins (Corkeron *et al.* 1987*a*, Heithaus 2001*a*, Santos and Gadig 2009) and are abundant throughout the year (Kessel 2010). Dusky (*Carcharhinus obscurus*), sixgill (*Hexanchus griseus,* Heithaus 2001*a*) and shortfin mako sharks (*Isurus oxyrinchus*, Wood *et al.* 1970, Stevens 1984, Monteiro *et al.* 2006) may also be considered threats to dolphins, but are infrequently documented in Bimini (Kessel 2010). Blacktip sharks (*C. limbatus*), although abundant in Bimini (Kessel 2010) likely target prey smaller than dolphins (Heithaus 2001*a*). Great hammerheads (*Sphyrna mokarran*), despite their size, likely do not prey on dolphins given their typical prey are bottom fishes (Heithaus 2001*a*). Yet, Wood *et al.* (1970) report a possible hammerhead attack on *T. truncatus*; Heithaus (2001*a*) considers evidence to be insufficient regarding hammerhead (and blacktip) attacks on living, small cetaceans. Many shark species are opportunistic feeders; therefore, interaction between sharks and dolphins may vary between locations (Heithaus 2001*a*).

The exact feeding habits of the *S. frontalis* off Bimini are not known at this time; however, it is likely they feed primarily in the deep water, possibly at night (DCP, unpublished data 2001–2012), as seen in other coastal populations (Hawaiian spinner dolphins, Norris *et al*. 1985, Norris 1994; *S. frontalis*, Dudzinski 1996, Herzing and Elliser 2013). Bimini *S. frontalis* also feed on the shallow Great Bahama Bank (Herzing *et al.* 2003, Dudzinski *et al.* 2012), like other *S. frontalis* (Herzing 1996), although this may be opportunistic. The diverse feeding habitats mean that *S. frontalis* are possibly vulnerable to shark predation in both shallow and deep water. Although survey effort is highly skewed to the shallow bank, the high sighting rate in the shallow, clear, sandy-bottom areas suggests that *S. frontalis* prefer this habitat. It is possible they spend the majority of nonfeeding time (*e.g.,* resting, socializing) on the bank in order to avoid/reduce predation; dusky dolphin (*Lagenorhynchus obscurus*) nursery groups may prefer shallow waters to avoid deep water predators (Weir *et al.* 2008) and Heithaus (2001*a*) suggests that even infrequent or unsuccessful predation attempts can elicit a behavioral response from prey (*e.g.,* habitat use). Continued study efforts in this area will allow researchers to better understand predator effects on this group of dolphins.

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