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Managing bite risk for divers in the context of shark feeding ecotourism: A case study from French Polynesia (Eastern Pacific)

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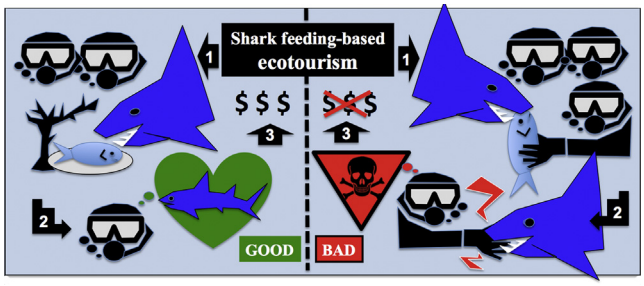
GRAPHICAL ABSTRACT



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ABSTRACT

Shark-based ecotourism has been recently expanding around the world. Provisioning sharks, however, is not without risk and accidental bites on humans are regularly reported. Such events may jeopardise the shark ecotourism industry and local economies. Through a case study from French Polynesia, I investigated whether changes in feeding practices of lemon sharks between the early 1990s and 2013 are related to recent accidental bites of divers. Hand-feeding, 'smelling' and surface feeding facilitated the development of agonistic behaviour in sharks, which resulted in accidental bites. The level of interaction between sharks and humans appears to be the most important driver for analysing bite-risk. This paper presents the very first framework for risk-analysis and will allow managers to better manage the risk associated with current practices in shark-feeding around the world. The paper also provides technical guidelines for the design of adequate legal frameworks that will support any sustainable shark feeding operation.

1. Introduction

Shark-based ecotourism operations are widespread around the world and occur in at least 40 different countries mainly in tropical and subtropical oceans in the Caribbean (Bahamas, Cuba, West Indies), Central and South America (Costa Rica, Belize, Mexico, Ecuador), Southern and East-northern coasts of South Africa, Pacific (Australia, Palau, Fiji, Hawaii and French Polynesia) (Brena, Mourier, Planes, & Clua, 2015). Shark tourism, however, occurs even in cold oceans such as the central and north Atlantic (UK, Azores, Canary islands) (Gallagher & Hammerschlag, 2011; Topelko & Dearden, 2005). Globally, c. 590,000 tourists participate in shark watching and spend USD 314 million per year, directly supporting 10,000 jobs (Cisneros-Montemayor, Barnes-Mauthe, Al-Abdulrazzak, Navarro-Holm, & Sumaila, 2013). Although valuations made at the scale of single animals are frequently based on assumptions that may not withstand critique (Catlin, Hughes, Jones, Jones, & Campbell, 2013), Clua, Buray, Legendre, Mourier, and Planes (2011) estimated that each of the 13

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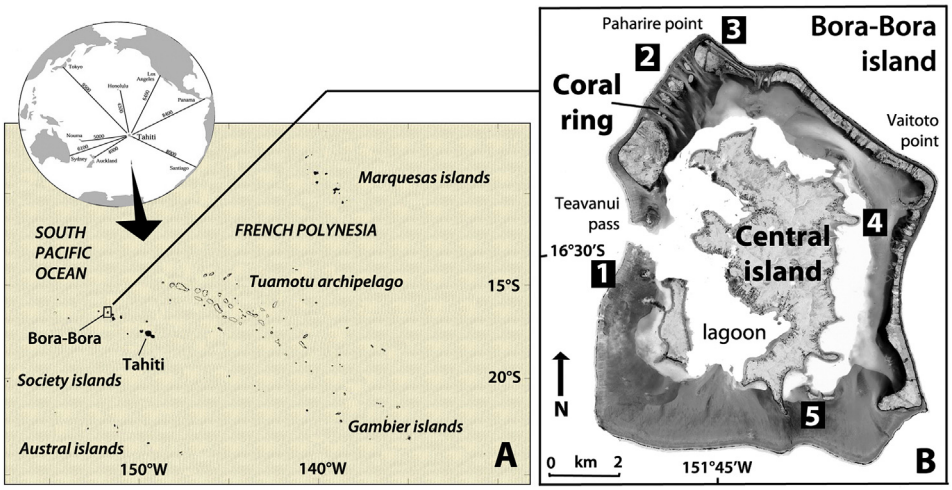

Fig. 1. (A) Location of Bora-Bora in the eastern Central Pacific. (B) The island is composed of a central islet surrounded by a medium-sized lagoon (78 km^2) defined by a large barrier reef that includes in the West a large passage (Teavanui pass) and several 'motu' (hard soil areas with trees on the barrier). Sites 1, 2 and 3 are dedicated to outer slope diving and snorkelling, targeting large sharks, while sites 4 and 5 are the most favoured lagoonal sites for small shark observations. Site 1, called 'Tapu site' and located at around 1000 m from the passage, has been and is still the most used site for both scuba-diving and snorkelling with large sharks.

lemon sharks most often observed at a feeding site off Moorea (French Polynesia) had an average contribution to the local economy of around USD 315,000 per year. Similar results were found for Palau (South Pacific) where shark diving generates USD 1.2 million in salaries and USD 1.5 million in taxes annually (Vianna, Meekan, Pannell, Marsh, & Meeuwig, 2012). In addition to economic benefits, there is also a view that non-consumptive wildlife tourism provides substantial conservation value to vulnerable and endangered species, through educating tourists about the need for conservation of animals that play a critical role in ecosystems (Bookbinder, Dinerstein, Rijal, Cauley, & Rajouria, 1998; Heithaus, Frid, Wirsing, & Worm, 2008) and limiting pressure for extractive use of these species.

Although not all shark tourism involves scuba diving and feeding, artificial provisioning is the most common form of interaction and takes several forms. Chumming (also called 'berleying') involves placing blood and/or liquidised fish parts in the water to create a slick that sharks can sense and follow to the chumming location (Laroche, Kock, Dill, & Oosthuizen, 2007). In many instances, animals are not fed during chumming. In contrast, at many shark tourism sites, large pieces of fish are fed to the sharks (Dobson, 2007, pp. 49–65, Clua, Buray, Legendre, Mourier, & Planes, 2010, Clua et al., 2011). Such provisioning of animals over long time periods may lead to negative impacts to animals and humans (Brena et al., 2015; Dobson, 2006; Gallagher et al., 2015; Newsome & Rodger, 2008). For example, based on a 5-year study of an aggregation of sicklefin lemon shark (*N. acutidens*) at a feeding site in Moorea (French Polynesia), Clua et al. (2010) showed that intra- and interspecific aggression was witnessed, leading to a potentially increased risk of severe bites to humans, mainly during and immediately after the mating season. These findings potentially confirm the fact that shark feeding may pose significant safety hazards for recreational divers (Orams, 2002).

Shark bites occur in the context of underwater provisioning activities. The International Shark Attack Files (ISAF) database (2016) reports 9 cases of shark attacks that occurred during feeding worldwide between 1971 and 2013. None of these cases were fatal, except one in 2008 in Bahamas (ISAF 2008). For the same period, the Global Shark Attack File (GSAF) database reports 12 cases (GSAF 2017). However, it is likely that, due to the risk of a strong negative impact on the ecotourism activity with subsequent economic impacts (Topelko & Dearden, 2005), bites in the context of ecotourism are not publicised by professionals and are globally under-reported. As a demonstrative example, the analysis of 54 cases of shark bites (most not reported to international databases) that occurred between 1979 and 2001 in French Polynesia (Eastern Pacific) showed that up to 25 cases (45%) were actually linked to shark feeding (Maillaud & Van Grevelynghe, 2005). This under-reporting should not hamper the need to efficiently address the issue of bite-risk in order to minimise the danger and optimise the sustainability of these activities. More recently, Richards et al. (2015) interviewed 45 diving/snorkelling shark operators, and found out that nine reported 'troublesome behaviours' from sharks, suggesting a more precautionary approach to provisioning.

Sharks are probably one of the most demonised species groups in human history. A number of newspaper articles and television programs (CBS, 2001, Wordpress, 2007, Discovery channel, 2013) have specifically speculated that shark attacks are linked to the potential conditioning of sharks to humans through chumming and feeding during shark dives and/or simple observation from the surface. Due to the particular 'hysteria' that can surround sharks and diving with potentially aggressive sharks, State interventions in terms of either banning the activity (such as in Florida, Hawaii, Maldives, California, etc.) or using licensing (such as in the Commonwealth of Northern Mariana islands CNMI, South Africa, Australia, etc.) to control the activity are becoming increasingly preferred options around the world (Dobson, 2006). When regulations take over on banning, the technical approach is either based on geographical considerations (feeding operations are displaced far from other recreational marine activities, such as in Australia and French Polynesia) or on vague definitions of the concept of 'feeding' (such as in CNMI). Nowadays, governance regimes are deeply affected by the quantity and quality of available scientific data (Dobson, 2007, pp. 49–65; Techera & Klein, 2013). The identification of best practice legal regulation requires therefore scientific research and objective data on biological and ecological issues that drive the real risk for human safety induced by shark-based ecotourism.

Here, I use a case study in French Polynesia to suggest how feeding practices influence and potentially increase bite risk for divers. I then propose a framework of risk-analysis associated with underwater feeding practices in order to facilitate the management of bite risk among feeding-based shark diving activities.

2. Material and methods

2.1. Description of the study site

French Polynesia encompasses 118 islands that are gathered in five archipelagos across a 5.5 million km^2 Exclusive Economic Zone in the Eastern Central Pacific (Fig. 1). The two main sources of income for a population below 260,000 inhabitants are the black pearl oyster industry and tourism with an average of 180,000 visitors per year (IEOM 2016). Reef scuba-diving represents around 20% of the leisure activities of tourists, but was threatened during the mid-and late 1990s after several catastrophic events degraded reefs. These included a crown-of-thorns starfish (*Acanthaster planci*) outbreak (1984) on the main diving