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Human-shark interactions: The case study of Reunion island in the south-west Indian Ocean

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ABSTRACT

An uncommon series of shark attacks, mostly involving surfers, occurred on the West coast of Reunion Island between 2011 and 2013, causing eight deaths. Following these events, which resulted in social, economic and political upheaval, and referred to as the "shark crisis", a scientific program with the aim of understanding shark behavior and ecology in Reunion Island was launched in 2012. It integrated spatial and temporal monitoring protocol of coastal uses allowing for the study of shark attack repercussions on the dynamics of 15 types of uses. In this paper, we bring shark and users observations together in order to assess human-shark interactions. Firstly, we assess the impacts that shark attacks have triggered in terms of users spatiotemporal distribution between 2011 and 2013. Secondly, we explore human-shark interactions in 2013 using cross-mapping techniques. Results show that three areas (*Saint-Gilles, Trois-Bassins, Etang-Salé*) have high levels of potential interaction and should be of high interest for the local authorities and stakeholders for further mitigation policies. Although further studies are needed to better understand the link between shark presence and shark attack, this study provides a first insight into human-shark interactions in Reunion Island.

1. Introduction

As the human population increases, there is an increasing need for land settlement, both for agriculture and recreational use (Stoate et al., 2001; Henle et al., 2008). This causes a reduction in wild habitats triggering Human-Wildlife Conflicts (HWC) which have increased worldwide (Madden, 2004). These conflicts have both direct implications i.e. humans being injured or killed by wild animals (Löe and Röskaft, 2004), and indirect implications i.e. material and crop destructions, death of farm animals, decline in tourism or competition for resources or habitats (Patterson et al., 2004; Tsakem et al., 2015). Traditionally, the human response to this threat consists in setting up a lethal population control program on the involved species and modifying the habitat to avoid human-wildlife interactions (Liu et al., 2001). There has been a shift in human perception and mentality of human-wildlife interactions over the past decade (Treves et al., 2006), with a rising interest in new strategies involving a reduction of human-wildlife interactions and a conservation of the habitat. Thus, an increasing number of worldwide authorities integrate lethal and/or nonlethal control, research programs, communication and education programs to their management plans.

In marine ecosystems, human-shark interactions give rise to one of the most important HWC. In terms of shark attack rates, USA, Australia and South Africa rank among the most affected countries (Caldicott et al., 2001). Even when the risk of shark attack is very low, shark attack events trigger a state of fear in the local

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population and may have strong economic repercussions (Hazin et al., 2008). Historically, the first response to shark attacks has been to set up shark control programs as seen in Australia, Hawaii and South Africa. These shark control programs aim to mitigate shark risk by reducing the coastal shark population (Wetherbee et al., 1994; Dudley, 1997; Dudley and Simpfendorfer, 2006). More recently, where the main purpose of shark control programs has been to secure human activities, biodiversity conservation and research axis has also been integrated in order to better understand, characterize and quantify human-shark interactions. Thus, many authors stress the need to improve the knowledge of human perception and activities at a local scale in order to ensure an effective human-shark interaction management (Muter et al., 2013; Neff and Hueter, 2013; Hazin and Afonso, 2014; Gibbs and Warren, 2015).

In a conservation context such as a Marine Protected Area (MPA) network, it is assumed that a better understanding of the patterns of recreational uses is required for an effective management plan (Dwight et al., 2007; David et al., 2006; Thomassin, 2011). Thus, recreational uses surveys on coastal environments have been increasingly carried out over the last 10 years (Le Corre et al., 2011; Lemahieu, 2015). Despite a predominance of social disciplines, an increasing interest from marine biologists can be seen in relation to addressing the impact of scuba diving (Rodgers and Cox, 2003; Zakai and Chadwick-Furman, 2002), swimming (Cambert et al., 2007), boating pollution (Warnken and Leon, 2006) and global recreational uses (Liu et al., 2012). Uses surveys are carried out in order to develop some performance indicators (Veiga et al., 2010; Alós and Arlinghaus, 2012; Smallwood et al., 2012) to optimize the tourism potential of these natural areas (Brigand et al., 2005; Robert et al., 2008), coastal lands planning (Breton et al., 1996), or more rarely, to optimize water quality (James, 2000; Turbow et al., 2003) or bathing security services (Dwight et al., 2007; Harada et al., 2011). Nevertheless, no studies were carried out as a contribution to shark attack mitigation policies.

In Reunion Island, a French overseas territory located in the Western Indian Ocean, shark attacks occurred at a rate of 1.23 per year between 1980 and 2011 (Squal'idées, unpublished data). The bull shark (*Carcharhinus leucas*) and the tiger shark (*Galeocerdo cuvier*) were the two species commonly involved in these attacks (Gauthier, 2012). In 2011, following a series of 6 shark attacks along the west coast, of which two were fatal, local authorities officially recognized the Human-Shark Conflict (HSC) by referring to it as a "shark crisis". Since then, this new HSC has had economic, social, ecological and political impacts on the island (Fabing, 2014; Jaccoud, 2014; Taglioni and Guiltat, 2015). Facing the lack of knowledge on shark behavior, a shark research program called CHARC[2] devoted to the study of bull and tiger shark behavior along the west coast was launched at the end of 2011. To promote a systemic and integrated approach, the program integrated an existing marine uses monitoring protocol. This uses monitoring survey has been carried out annually since 2010, feeding the local MPA pressure and governance indicators (Lemahieu, 2015).

The aim of this study is to explore human-shark interactions by bringing the spatial patterns of shark presence and human uses together. We first mapped the shark attacks which occurred between 2011 and 2013 and put it against the 2010–2013 spatial uses evolution maps. Therefore, we were able to evaluate how shark attacks impacted spatial and temporal uses distribution patterns over time. Finally, 2013 shark presence data was spatially mapped against 2013 uses distribution to assess human-shark interactions and discuss research contribution into shark attack mitigation policies strategies.

[2] Connaissances de l'écologie et de l'HAbitat de deux espèces de Requins Côtiers sur la côte ouest de La Réunion.

2. Materials and methods

2.1. Study area

Reunion Island is a two million-year old volcanic island located in the south-western Indian Ocean. The 2512 km^2 island has a 12 km^2 fringing reef belt on its West coast. The study area stretched over a 44 km coast from *Saint-Paul* to *Etang-Salé* within the MPA perimeter, which was created in 2007. The MPA management zoning is comprised of 115 area grids of an average size of 30 ha, based on geomorphologic homogeneity criteria, and demarcated *in situ* by yellow buoys and coastal benchmarks (Fig. 1).

2.2. Shark attack data

Shark attack data was extracted from the Reunion Shark Attack File (Squal'Idées, unpublished data). We selected only unprovoked shark attack from 01/01/2010 to 08/30/2013 in the MPA perimeter and its surroundings. An unprovoked shark attack is defined as physical contact between a human and a shark causing injury or death to the person or damage to their equipment with no human provocation of the shark. Human-shark interactions that did not result in injury or damage (e.g. shark encountering/spotting) were not taken into account.

In 2011, six shark attacks occurred in the northern areas of the MPA (Fig. 1). Apart from an attack on the 15th of July, which involved a kayaker, they all involved surfers. Most of the shark attacks occurred during austral winter (May–October), except one which occurred during summer (19th of February). The year 2012 was marked by two attacks on surfers at two very popular surf spots during the austral winter. A first fatal shark attack occurred on the 23th of July at *Trois-Bassins pass* and a second non fatal attack on the 5th of August at *Saint-Leu*.

In 2013, two fatal shark attacks were recorded during austral winter, one at *Ermitage nord* (*Brisants spot*) on a bodyboarder and a second in *St Paul Bay* on a young swimmer. We considered the latter in this study because of its proximity to the study area and its potential influence on users distribution.

2.3. Shark surveys

2.3.1. Acoustic telemetry

Shark presence data were recorded within the CHARC program framework which ran from December 2011 to April 2015. The program mainly focused on bull shark habitat use along the West coast of Reunion Island, using passive acoustic telemetry (Voegeli et al., 2001). Thirty-four adult bull sharks were tagged with 3 types of VEMCO acoustic tags, either a V16TP-4H (battery life of 845 days) or a V16-5H (battery life of 482 days) or a V13TP (battery life of 806 days, see Table A.1). Detailed shark fishing and tagging methods are described in Blaison et al. (2015).

Shark presence along the West coast of Reunion Island was studied from November 2012 to June 2015 through a network of 36 underwater receivers of which 24 were within the study area (Table A.1 and Fig. 6). Receivers' detection limits ranged from 200 to 400 m. Receivers were removed from the water 4 times a year to allow for datasets to be downloaded onto computers using VUE software (VEMCO Ltd.)

2.3.2. Shark presence and data analysis

Shark detection data in 2013 were gathered on receivers located within the MPA perimeter. Detections were grouped into a "visit" or