Marine Policy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

A spatial and environmental analysis of shark attacks on Reunion Island (1980–2017)

François Taglioni[a,*], Sébastien Guiltat[b], Magali Teurlai[c], Mathieu Delsaut[d], Denis Payet[e]

[a] EA 12 OIES/CREGUR et UMR 8586 PRODIG, Université de La Réunion, Reunion Island, France
[b] EA 4075 IRISSE, Université de La Réunion, Reunion Island, France
[c] UMR 182 LOCEAN & UMR 228 ESPACE-DEV, Institut de Recherche pour le Développement (IRD), New-Caledonia, France
[d] EA 4079, Laboratoire d'Energétique, d'Electronique et Procédés (LE2P), Université de La Réunion, Reunion Island, France
[e] EA 2525, Laboratoire d'Informatique et de Mathématiques (LIM), Université de La Réunion, Reunion Island, France

ARTICLE INFO

Keywords:
Reunion Island
Human-shark interaction
Hazard
Vulnerability
Coastal water sports
Spatial & environmental analysis

ABSTRACT

This paper analyses data related to the 57 shark attacks that were recorded on Reunion from 1980 to 2017, against the backdrop of an Indian Ocean island that is particularly vulnerable to shark attacks. To address this issue of vulnerability, the discussion focuses on the respective weight of environmental, contextual and individual variables. The most pertinent parameters to explain the occurrence of attacks on Reunion are as follows: time of day, month and turbidity. Two specific features of Reunion Island can be added to those: first, the high mortality rate of the attacks (46% vs a world average of 11%), and secondly, the average increase in the number of attacks between 2011 and 2017, despite the average drop in the number of ocean users. To understand and explain this rise, three variables are identified: water turbidity, swell height and victim activity.

In addition, the multiple correspondence analysis, despite the limited number of attacks, provides correlations between some variables: on the one hand, attack outcome, turbidity, swell height, and, as regards attacks before or after 2011, board sports and swell height.

1. Introduction

The risk of shark attacks has increased dramatically worldwide in recent decades [1], from a few attacks recorded in the early 1980s to over 100 per year since the 2000s, with a relatively regular number of fatal attacks (about 10 per year). It should be stressed that the world population has increased by nearly 3 billion since 1980, with a parallel rise in the number of those who engage in water sports. Such growth in leisure activities is also explained by the improvements in living standards and the introduction of new leisure opportunities and equipment, enabling year-long activity.

In order to reach a better understanding of the risk of human-shark interaction, numerous studies have been conducted at various levels, both worldwide [1–4] as well as on Reunion Island [5–7]. If sharks do play an important role in marine food webs, they likewise remain at the heart of a heated debate, with public authorities in a quandary as to necessary shark preservation against coastal recreational activities.

Coastal water sports have been practiced on Reunion Island (Western Indian Ocean) for roughly 50 years [8]. Seaside tourism has developed in parallel since the 1970s [9]. Often at the foreground of the imagery linked to tourism promotion of Reunion Island, the island's west coast symbolises the tropical beach resort ideal. Yet, as in other areas of the world, Reunion Island has not been spared of the risk of shark attacks [10]. However, it can be considered that shark attack risk for the Reunionese population and tourists visiting the island is much lower than many other risks present on the territory. Nevertheless Reunion Island is vulnerable to shark attacks as evidenced by the series of 24 attacks between 2011 and 2017, of which 9 were fatal. This uncommon succession of attacks on an area that is so small, and with marked structural social and economic vulnerability [11], has had a particular impact on Reunion's insular society [5]. The political and social malaise caused by these attacks is compounded by economic damage and indirect financial losses linked to the sharp drop in coastline use [12,13].

This paper proposes to analyse the data relating to shark attacks on Reunion Island since 1980 (n = 57). Following a preliminary framing of Reunion Island within the world ranking of shark attacks, the environmental, contextual and individual variables will be analysed in order to find some possible explanations for the attacks. The rise in the number of attacks since 2011 will also lead to research possible

* Correspondence to: Université de la Réunion, 15 Avenue René Cassin, Sainte-Clotilde 97715, La Réunion, Reunion Island, France.
E-mail address: francois.taglioni@univ-reunion.fr (F. Taglioni).

https://doi.org/10.1016/j.marpol.2018.12.010
Received 6 June 2017; Received in revised form 30 October 2018; Accepted 10 December 2018

Please cite this article as: Taglioni, F., Marine Policy, https://doi.org/10.1016/j.marpol.2018.12.010

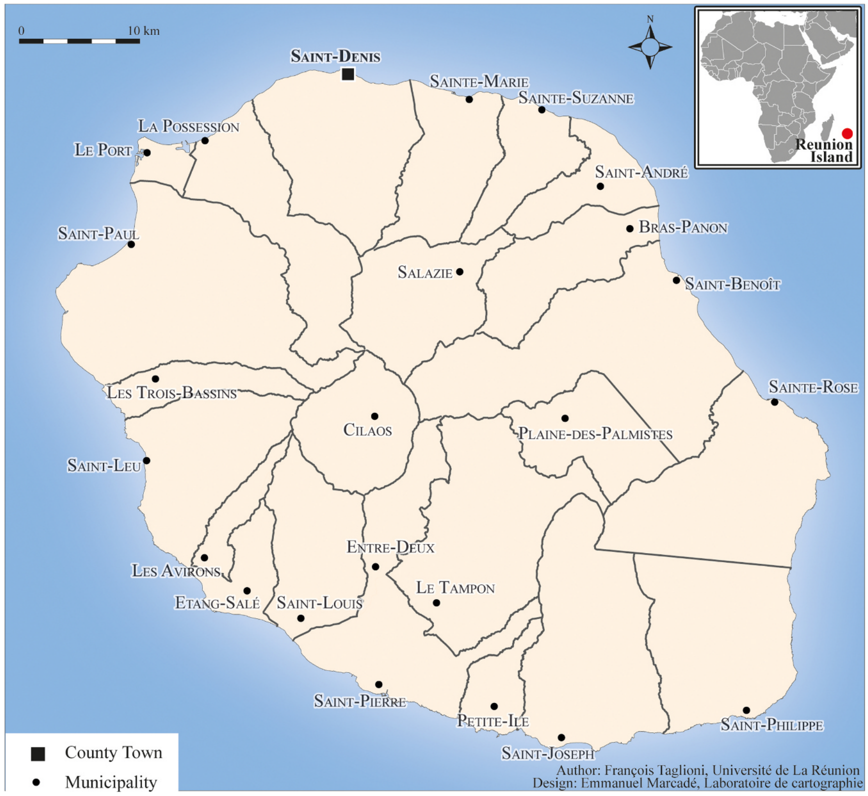


Fig. 1. Map of Reunion Island.

variables to understand and explain this increase as well as probe into their specificities. Finally, possible correlations between explanatory and significant variables of the dataset will be assessed.

2. Materials and methods

2.1. Study area

Reunion Island is a small island of 2512 sq km with a population of 860,000 inhabitants, located east of Madagascar (Fig. 1). This volcanic island is institutionally linked to mainland France (of which it is an Overseas Department). The climate is tropical with a cool, dry season from April to September (austral winter) and a warm, humid season from October to March (austral summer). The island's climatology is made even more complicated by its rugged terrain, several dozen micro-climates [14] making the rainfall pattern complex.

2.2. Data collection and preparation

Shark attacks are defined as an aggressive, unprovoked contact by a shark (or sharks) on a living human being, resulting in injuries or the victim's death, or in damage to their equipment (surfboard, bodyboard, windsurfing board, kitesurf board, kayak, canoe, flippers, etc.). Several authors retain the same basic defining criteria [15–18], while others diverge from them [19]. For international comparisons (Fig. 2 and Table 1) with Reunion Island, data from the Global Shark Attack File (GSAF) database [20] were filtered in accordance with the authors' definition. Shark attack risk is the probability of occurrence of harm according to the interactions between the hazard (a shark attack), the degree of vulnerability of the victims, and the risk (defined here as the people at risk of being affected by the hazard). Clearly, the shark risk applied to humans can also be envisaged in its social, economic and political dimension [5,12,13].

To perform the analyses and design an interactive map, a database on shark attacks on Reunion Island since 1980 has been built. This database is founded on meticulous compilation work using (i) a thorough review of the local (Reunion Island) and national (mainland France) press from January 1980 to December 2017, and (ii) a comparison with international databases on shark attacks. Whenever there was some doubt regarding an attack, interviews with local players involved in monitoring these attacks were conducted.

This **database** includes the 57 attacks falling within the authors' definition that occurred between 1980 and 2017. Data prior to 1980 proved too approximate and incomplete to be used.

For each attack the 16 following data were integrated into the authors' base (Table 1); they are basically the same as those retained for studies [2,4] on the conditions of shark attack occurrences in various regions worldwide.

2.3. Sources of collected data

See Table 2 here.

2.4. Data analysis

A thorough descriptive analysis was performed using univariate analysis of the environmental, contextual and individual factors likely to influence the risk of shark attacks (see data collection and preparation). The variability of each of the factors during the 57 attacks was analysed retrospectively to try and determine whether one or several of them had a predictive potential for attack risk. The data were exploited using Microsoft Excel Version 16 and R Software, version 3.2.0 [37]. The interactive map was created using JavaScript/HTML5, jQuery and jCanvas.

To identify potential hypotheses that could explain the sharp increase in the number of attacks from 2011 on, environmental conditions, location and timing of attacks, outcome of attacks (fatal or not), as well as victim activity at time of attack were compared in two

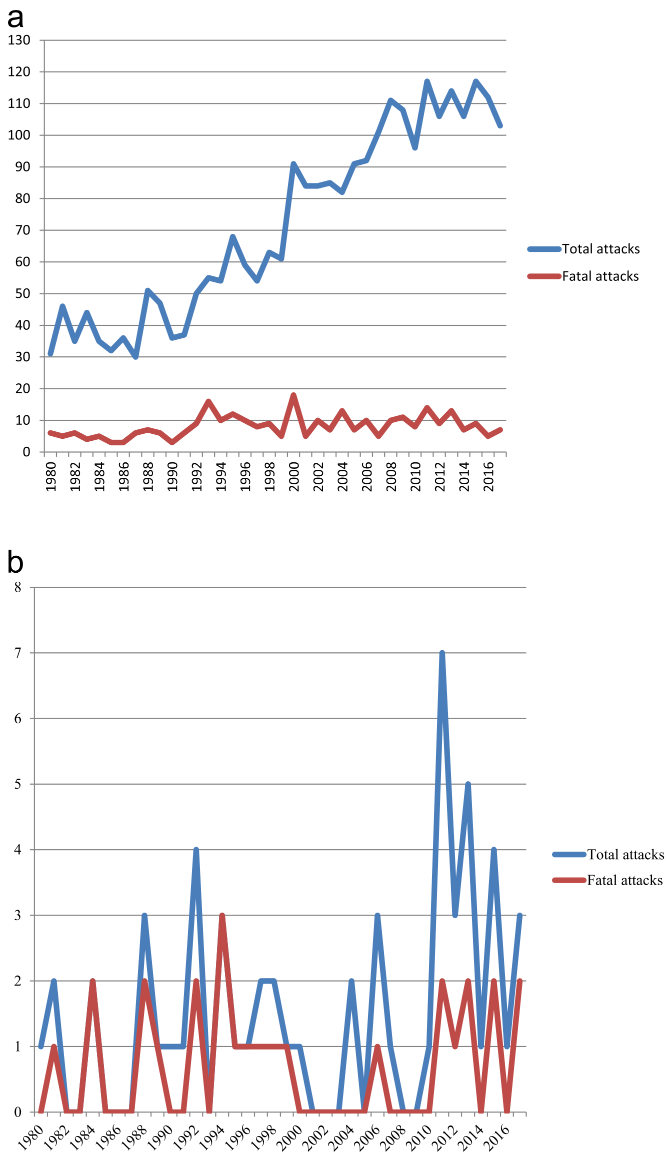


Fig. 2. a. Trend in the number of shark attacks worldwide between January 1980 and December 2017 (Source: [20]). b. Trend in the number of shark attacks on Reunion Island between January 1980 and December 2017, (Source: Fig. 3a).

periods: before and after January 2011. The following variables with potential influence on the shark species involved or on shark behaviour were selected to characterise environmental conditions: water temperature, rainfall during the day of the attack, cumulated rainfall over the three days preceding an attack, swell height, water salinity, cloud cover, moon phase, and water turbidity. Regarding location, the attacks were grouped depending on whether they occurred in the western or eastern part of the island. Attack times were grouped depending on: (i) whether the attack occurred in the morning (before 12 p.m.) or in the afternoon (after 12 p.m.); (ii) whether the attack occurred in winter (April to September) or in summer (October to March); (iii) the day of the week when the attack occurred. For victim activity, attacks were classified depending on whether the person was practising a board sport (surf, bodyboard, windsurf, sea kayak, outrigger canoe) or doing something else at the time of attack. For each variable, a Student's *t*-test, or a chi-squared test was performed to compare their respective mean (for quantitative variables) or distribution (for qualitative variables) before and after January 2011. For qualitative variables, a Fisher's exact test was used when the conditions required to perform a chi-squared test were not met. For quantitative variables, a Mann-Whitney *U* test or a Welch's *t*-test was used when the conditions required to perform a Student's *t*-test were not met [38].

In order to verify whether the explanatory variables were correlated or not, a Multiple Correspondence Analysis (MCA) was performed using 5 qualitative variables: water turbidity (low, medium and high), wave height (low [0.497, 1.6], medium [1.6, 2.7] and high [2.7, 3.8]), activity (board sports and other activities), attack outcome (non-fatal and fatal) and attack after or before 2011. Multivariate statistics allowed to find complex structures within a large number of variables and modalities. Due to the low number of observations (n = 57), the number of explicative variables was limited. Also, due to victim's unknown activity at the time of attack, one fatal attack (15 September 1994) was removed.

3. Results and discussion

3.1. Shark attacks worldwide

The number of shark attacks has increased worldwide over the past decades. From just between 30 and 45 attacks a year (Fig. 2a) recorded in the early 1980s, the number has topped a hundred annually since the 2000s, with relative regularity in the number of fatal attacks, at around 10 per year on average. These first data taken from the Global Shark Attack File compilation database [20] are reliable and have been improved over the years. However, they include some sources of bias in their data collection and methodology, meaning that they can be improved upon, notably for the 1980s and 1990s. Moreover, the world's population has grown steadily since 1980 (up by nearly 3 billion) and simultaneously the number of people participating in coastal water sports has risen markedly with the improvement in living standards, the world's population shifting to coastal areas, the development of new leisure activities (kitesurfing, stand up paddle, sea kayaking, wakeboarding, windsurfing, and so on) and new equipment making it possible to practise such sports all year round. This trend is the same on Reunion Island, with a steady increase in the number of coastal sports users since the 1960s [8].

The comparison between the number of shark attacks worldwide (n = 2547) (Fig. 2a) and that of Reunion Island (n = 57) (Fig. 2b) since 1980 shows that Reunion Island has been the scene of 2.2% of attacks worldwide and 9.2% of fatal attacks (n = 26 on Reunion Island and n = 283 worldwide). Considering the population of Reunion Island (860,000 inhabitants in 2017), it is clear that as per both aforementioned percentages, Reunion Island is over-represented in terms of the number of attacks per inhabitant, all the more so for fatal attacks.

3.2. Analyses of risk factors on Reunion Island from 1980 to 2017

The assembled database on attacks is partly illustrated in the interactive map (Fig. 3a) which, via multiple queries, indicates the location of attacks, type of activity practised at time of attack, attack severity, date, time and filter by year. Map data are complemented by details on the age of victims and environmental parameters (surface water temperature, water salinity, moon phase, cloud cover, cumulated rainfall over the three days preceding the attack and that of the day of attack, swell height and seawater turbidity).

A 2014 study [39] highlighted that 80% of Reunion Islanders frequent the lagoons of the island, 50% practising at least one coastal water sport. This suggests high frequentation of Reunion Island coastlines. Concerning shark attacks, **spatial distribution** (Fig. 3b) shows a very clear dissymmetry between east and west, along a line stretching from the district of Le Port to that of Saint-Joseph. The western part of the island has been the main scene of attacks since 1980. Indeed, the western part concentrates over 80% of the attacks (46 out of 57) over the study period. This dissymmetry is explained first by high concentration of Reunion Island's population in the west of the territory

Table 1
Data collection and preparation.

Contextual factors	– date (day of week; month; year of attack) [2,4] – attack location [4,21] – time, sometimes approximate, of attack [2,4] – shark species [21]
Activity factors	– victim's activity at time of attack. These activities have been grouped into five categories: board sports (surfing, bodyboarding, windsurfing, sea kayaking, outrigger canoeing); spearfishing; swimming; scuba diving; others (two attacks, one on a coastal fisherman, and another for which the victim's activity at the time of the fatal attack is unknown) [2,4]. The first four categories are defined here as "coastal water sports."
Victim demographics	– age of victim [2,4] – gender (male/female) – type of injuries expressed as a score of severity (1 = material damage but no physical harm and/or slight abrasion injuries; 2 = minor bites requiring stitches; 3 = significant bites, injuring the ligaments; 4 = loss of a limb; 5 = death) [22,23]
Environmental factors	– sea surface temperature [2] – rainfall on day of attack [2,24] – cumulated rainfall over the three days preceding the attack [2,24] – percentage of cloud cover [2] – swell height [2,4] – estimated seawater turbidity expressed as a score (1 = clear; 2 = slightly turbid; 3 = turbid; 4 = highly turbid) [2,25] – seawater salinity (data available since 2002) [4,24,26] – moon phase expressed as a score (1 = first quarter or last quarter; 4 = full moon or new moon) with the hypothesis that the moon's influence is at its maximum when it is full or new [4]. Full moon or new moon phases score 4 while first or last quarter score 1 [27,28]. The lunar cycle is divided into 4 phases of 7 days each, the full moon being considered as the period 3.5 days before and after the exact time. The same goes for other phases (first quarter; last quarter; new moon)

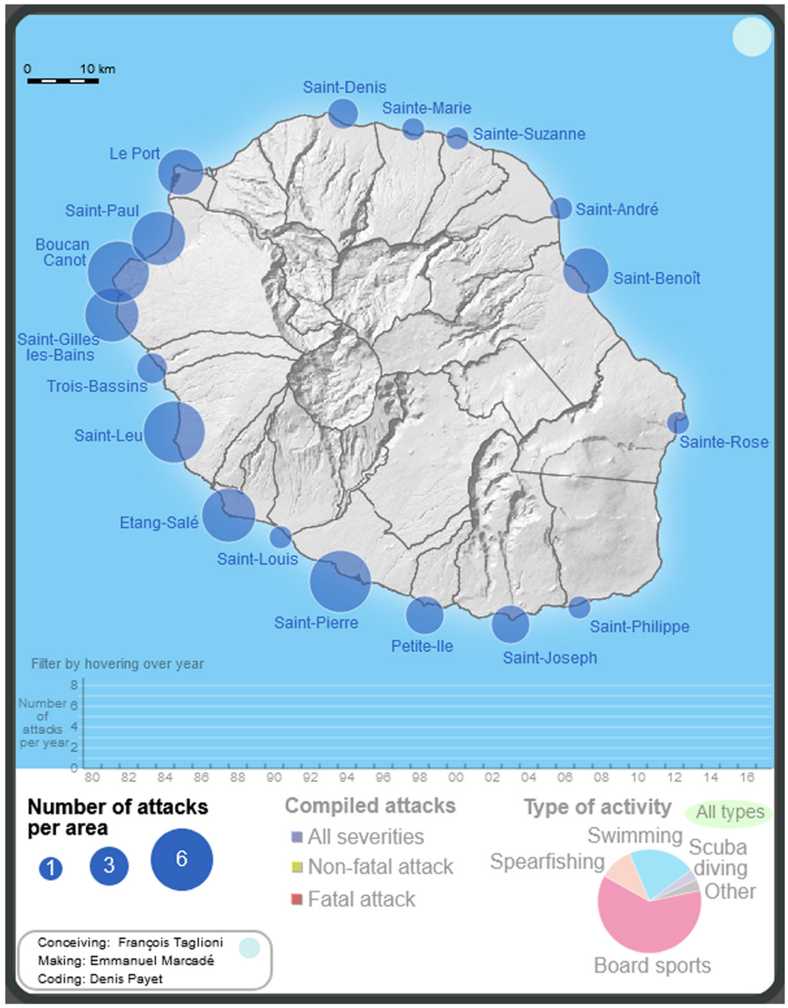
(70% in total); secondly, the existence and use of coastal water sport spots are determining elements in this distribution: board sports, scuba diving and bathing sites are almost exclusively located in the west [40]. Thus the west of the island concentrates roughly 90% [41] of people taking part in coastal water sports. The situation for spearfishing sites is a little different because this activity is almost entirely practised in the east [41], with the notable exception of the more remote and hard-to-access volcano coastline (between Saint-Philippe and Sainte-Rose, Fig. 3b).

As for **victims' activity** (Fig. 3a) at the time of attack, the people most affected are those taking part in board sports, with two thirds (61%) of the total, i.e. 35 of the 57 attacks. Surfers are the most represented, followed by bodyboarders and marginally (n = 2) windsurfers. Then in decreasing order come swimmers (21%) and spearfishers (10.5%). Board sport predominance can be explained by the fact that most users of the coastline are board riders [8] and that among people practising surface coastal sports, board riders are the ones who go the farthest away from the shore compared to swimmers. Thus, board sport riders are at the forefront for sharks. As for swimmers, it is assumed that people at the time of attack were more or less isolated in the sea (no matter the distance to the shore). It is interesting to note that no person among a group of swimmers was ever attacked by a shark on Reunion Island.

Scuba divers (3.5% of attacks) are the least concerned despite the high estimated number of people practising this activity [8]. One reason is that Reunion Island scuba divers practise their sport in clear water in order to enjoy their dive. Not only can scuba divers see sharks around them under water, but sharks (especially bull sharks) prefer to swim in

Table 2
Source of collected data.

Contextual and activity factors	– date, attack location, time, shark species, victim's activity at time of attack, according to: ● various articles in the French national and Reunion Island local press (analyses from 1980 to 2017) ● various interviews with local stakeholders (fishermen, lifeguards, water sports enthusiasts, etc.) ● Global Shark Attack File (GSAF) [20] ● International Shark Attack File (ISAF) [29] ● Shark Attack File (SAF) [30]. The dataset from this base have not been available since 2015
Victim demographics	– age of victim, gender (male/female), severity of injuries (score: authors), according to: ● various articles in the French national and Reunion Island local press (analyses from 1980 to 2017) ● various interviews with local stakeholders (fishermen, lifeguards, water sports enthusiasts, etc.) ● Global Shark Attack File (GSAF) [20] ● International Shark Attack File (ISAF) [29] ● Shark Attack File (SAF) [30]. The dataset from this base have not been available since 2015
Environmental factors	● sea surface temperature: *National Oceanic and Atmospheric Administration* (NOAA) [31] ● rainfall: Météo France (French National Meteorological Service) [32]. Data extracted from the nearest rainfall station (22 stations) on the day of the attack and cumulated rainfall over the three days preceding the attack ● cloud cover expressed as percent variables: ● NOAA from 2004 to 2017 [31]; ● review of the Météo France weather forecasts from 1980 to 2004 (data from Météo France published on Reunion Island local press: *Journal de l'île de La Réunion* and *Le Quotidien de La Réunion et de l'océan Indien*) – swell height: ● from February 1997: Candhis (Buoy No. 97403: Pointe des Galets, recording period from 1997 to 2017 [33]; Buoy No. 97405: Saint-Pierre, recording period from 2000 to 2010 [34]); ● WaveWatch 3 (NOAA) data, from 2004 to 2017 [35] ● review of the Météo France weather forecasts from 1980 to 2004 (data from Météo France published on Reunion Island local press: *Journal de l'île de La Réunion* and *Le Quotidien de La Réunion et de l'océan Indien*) – turbidity: empirical estimated score from the swell, rainfall, and knowledge of the benthic substrate, local people knowledge, information from the local press; score: authors – salinity: Institut français de recherche pour l'exploitation de la mer (IFREMER) [36]. Data have been collected since 2002 monthly through a network of 24 stations spread over the entire coast of Reunion Island. The data are extracted from the nearest station on the day of the attack – moon phase: ephemeris; score: authors



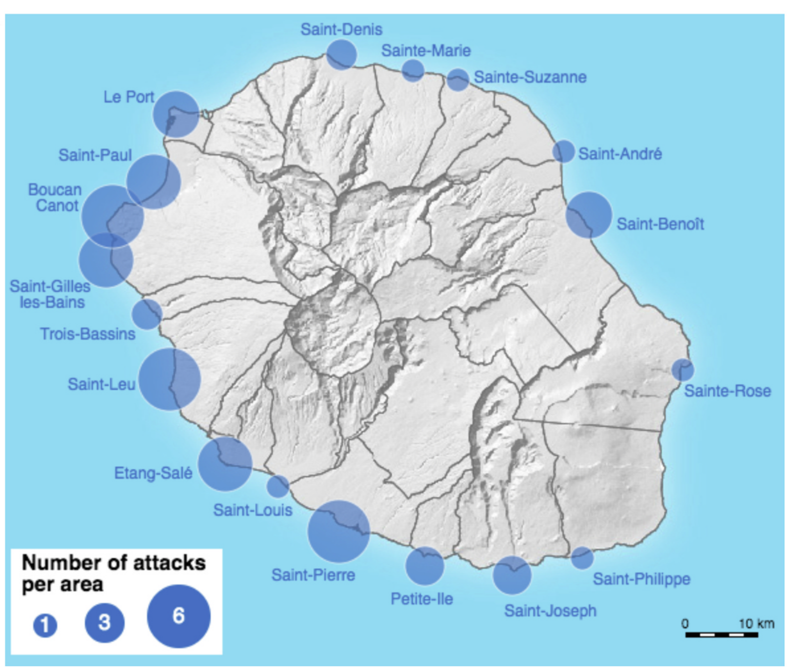


Fig. 3. a. Interactive map of shark attacks on Reunion Island since 1980. (please click below). http://www.taglioni.net/Recherche/fig3/. b. Spatial distribution of shark attacks on Reunion Island since 1980, (Source: Fig. 3a).

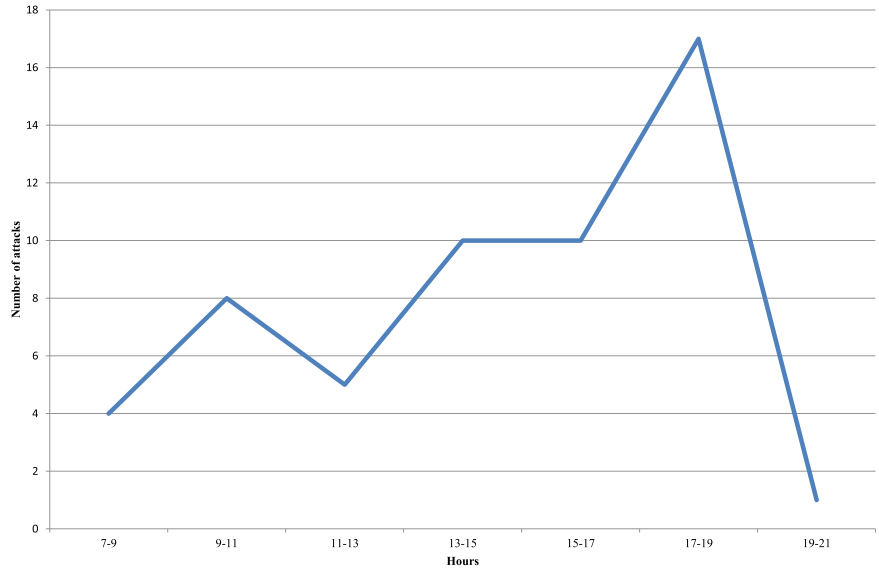


Fig. 4. Distribution of attacks according to the time of day between January 1980 and December 2017 (Source: Fig. 3a).

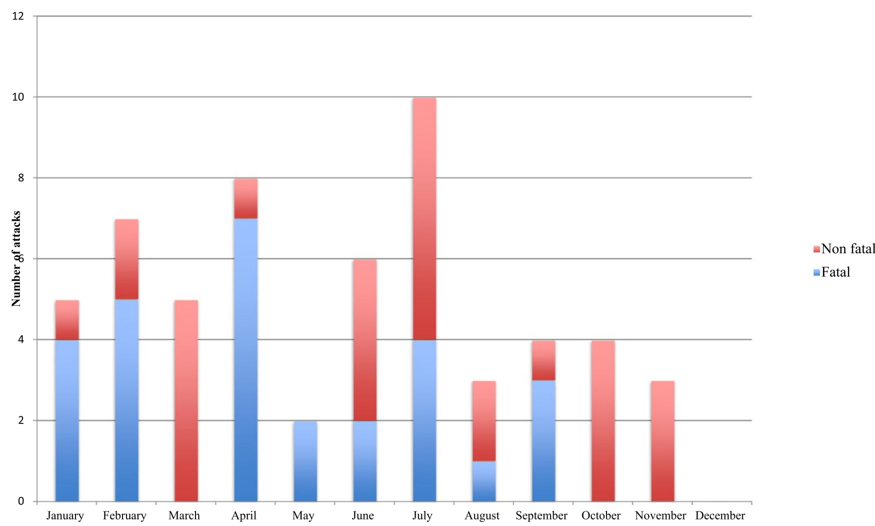


Fig. 5. Monthly distribution of attacks between January 1980 and December 2017 (Source: Fig. 3a).

unclear water [25], less commonly in clear water. In contrast, there were six attacks, one fatal (17%), on spearfishers who are more likely to be exposed to the risk of human-shark interaction. Actually, the stimuli caused by the presence of fish injured by a hunter is susceptible to attract sharks. The category “others” refers to two attacks (one on a coastal fisherman and one of unknown activity at the time of attack), and is difficult to discuss owing to the insignificant (statistically speaking) number of victims.

Analysis of the proportion of fatal attacks out of the total number of attacks for each activity type since 1980 sheds light on the **vulnerability** of the people involved. Of the 57 attacks recorded in the database between 1980 and 2017, 26 were fatal (Fig. 3a). The mortality rate is therefore 46%, which places Reunion Island well above the world average of 9% [20] for the same period. Such exceptionally high mortality is no doubt partly due to the shark species involved on Reunion Island's attacks. Whilst the available data is incomplete (shark species identified for 40 out of 57 attacks), it has been established that bull sharks (*Carcharhinus leucas*), which are responsible for 63% of the attacks, and more marginally tiger sharks (*Galeocerdo cuvier*), 28% of the attacks, are the main protagonists. For non-fatal attacks (n = 31), the **severity of injuries** is high: scores of 3 and 4 (n = 20) are the most frequent (65% of non-fatal attacks). People practising board sports make up half (50%) of victims of fatal attacks (13 out of 26 fatal attacks). Bodyboarders (n = 6) top this category, followed by surfers (n = 5) and windsurfers (n = 2). In contrast, it clearly emerges that bodyboarders are more vulnerable than surfers, with a death rate of 50% (6 fatal attacks out of 12) whilst surfers have a mortality rate of 26% (5 fatal attacks out of 19). An initial explanation for this greater vulnerability is probably that bodyboarders are more immersed in the water during a surf session. Moreover, surfers can use their board more easily to shield themselves during attacks, compared to bodyboarders whose board is much shorter. Indeed, for certain attacks on surfers, the interaction was limited to damage on the equipment, with the surfer unscathed, which is less often the case for bodyboarders. While windsurfer mortality rate is 100%, it is impossible to draw conclusions because the sample of attacks is limited to two and the position of the victims in relation to their board at the time of attack is unknown. They may have been in the same situation as a swimmer, and not on their board when the attack occurred. Indeed, swimmers make up a very vulnerable category. They represent 38% of fatal attacks, but their fatality rate is 83% (10 fatal attacks out of the 12 recorded attacks). They have no means of protection when the attack is made, which makes them the most vulnerable category. For underwater activities, it is difficult to make a realistic estimate of the vulnerability of scuba

Table 3
Data (January 2011 to December 2017) on attacks worldwide compared to Reunion Island.

	Number of attacks/Proportion of attacks worldwide Absolute value and %	Number of fatal attacks/ Proportion of fatal attacks worldwide Absolute value	Proportion of fatal attacks in the total number of attacks %	Rate of attacks per million inhabitants	Rate of fatal attacks per million inhabitants	Rate of attacks per 100 km of coastline	Rate of fatal attacks per 100 km of coastline
United States (total)	359/51	4/6.5	1.1	1.10	0.01	0.25	0.003
– Florida	179/25	0/0	0	8.50	0	2.60	0
– Hawaii	60/8.5	3/5	5	**42.85**	2.15	3.65	0.18
Australia	142/20	18/29	12.7	6	0.75	0.20	0.03
Republic of South Africa	39/5.5	8/13	20.5	0.7	0.15	1.10	0.23
Reunion	24/3.1	9/14	**37.5**	28	**10.5**	**11.4**	**4.28**
Proportion of these 4 countries as a % of total worldwide	80	63					

Sources: [20] for international data; sources of Fig. 3a for Reunion Island; calculations by Olivier Hoffer [50] for coastline measurements.

divers owing to the small number of attacks (n = 2, neither fatal). Ultimately, divers, whether scuba divers or hunters, are no doubt the least vulnerable to shark attacks.

Considering that the risk is “what you stand to lose” [42], and knowing that the average **age of attack victims** since 1980 is 29.5 (all victims male, excepting two female), one cannot help but be profoundly affected by these attacks. A shark attack is all the more shocking as the victims are young. In this instance, the people participating in coastal water sports are generally teenagers or young adults [2]. The impact is all the greater as the attacks are given a great deal of media coverage both locally and nationally, indubitably against a backdrop of dramatizing the accidents, due to a specific fear (the *Jaws* effect [43,44]).

An examination of the **distribution of attacks according to the time and season** complements the main preceding analyses referring to the interactive map.

The **time** (Fig. 4) of attack is known—at least approximately—in 55 out of the 57 attacks. Nearly 70% of the attacks (38 of those 55) occurred after midday (matching the maximum frequentation of sea users [2,9]) and nearly 33% after 5 p.m. (corresponding to sunset, depending on the season on Reunion Island).

Monthly distribution (Fig. 5) of the attacks is fairly homogenous over the year, except in July, when there is a clear peak with no fewer than 10 attacks (out of 57), 4 of them fatal. However, the period from April to September (austral winter) concentrates a high proportion of fatal attacks (70%). One hypothesis is that the austral winter is more favourable for board sports, owing to optimal wave conditions. This is also the riskiest time of year because of the high turbidity of the water linked to the higher number of swell days during austral winter [45]. Indeed, turbid water (see below) is a predictive factor [25,46] of the presence of bull shark, the species responsible for most attacks on Reunion Island especially during austral winter [45].

Austral winter is also risky because of the behaviour of sharks, which are in their breeding season, especially in the sector of Saint-Gilles-les-Bains, with possible over-aggressiveness of males linked to mating between males and females at the time of breeding [47,48].

Regarding the environmental parameters of the attacks, **water temperature** is relatively narrow in range (min: 23 °C; max: 30.5 °C) and is not a determining variable of attacks distributed evenly (30 attacks at under 26.1 °C compared to 27 attacks at above 26.1 °C) on either side of the average (n = 26.1 °C). This is because people practising coastal water sports can use wetsuits during their session, so they can take to the water all year round.

Our data on **salinity** for the period 2004–2017 show that salinity is relatively constant in time and space. Mean salinity in the attack zones stands at 35.25 with a minimum of 34.65 at Saint-Gilles-les-Bains on 19 February 2011 and maximum of 35.82 at Saint-Paul (Cap La Houssaye) on 5 October 2011. Although the ecology of the bull shark is influenced by salinity [26], on Reunion Island the homogeneity of the data regarding the time of the attacks cannot prove that salinity is a factor influencing the occurrence of attacks.

A full **moon** or a new moon has an obvious influence on tidal range. One hypothesis retained by certain authors [4,28] is that both of these moon phases could have an influence on the occurrence of attacks. The possible influence of moon phases on shark attacks on Reunion was therefore explored. However, as the analysis of the scores demonstrates, this “moon effect” is not convincing on Reunion Island, as only 28 (50%) of the 57 recorded attacks took place at full moon or at new moon.

86% of the attacks (49 out of 57) occurred with **cloud cover** equal to or less than 50%. This is echoed in the rainfall on the day of attack, which for the 57 attacks stands on average at roughly 1 mm of water with most often 0 mm and sometimes (n = 4) 10 mm. For the most part this can be explained by the tendency for sea users to frequent the coastlines on the sunniest days. The degree of sunshine per se is therefore not a variable directly correlated with the risk of shark attack.

In 61% of attacks (35 out of 57), **rainfall** from D-3 to D-1

Table 4
Comparison of the environmental conditions of attacks before and after January 2011.

Variable	p-value of student's *t*-test, chi-squared, welsch's *t*-test, mann-withney u test or fisher's exact test[9]	Average for attacks before January 2011	Average for attacks after January 2011
Water temperature	0.0985[s]	26.5 °C	25.6 °C
Rainfall the day of an attack	0.7042[s]	1.6 mm	1.2 mm
Cumulated rainfall during the three days preceding an attack	0.6100[w]	9.3 mm	12.3 mm
Swell height	**0.0041[m]**	**1.9 m**	**2.5 m**
Water salinity	0.2295[s]	35.1 g/l	35.3 g/l
Cloud cover	0.3354[s]	39.4%	33.2%
Victim's age	0.2185[s]	28 y.o.	31 y.o.
Water turbidity[1]	**0.0033[f]**	–	–
Moon phase[2]	0.6645[f]	–	–
Practising a board sports[3]	**0.0055[f]**	**45%**	**83%**
Attack outcome[4]	0.4356[k]	51,5% were fatal	37,5% were fatal
Attack location[5]	0.3257[f]	76% western part	87,5 western part
Time of attack (time of day)[6]	0.7399[k]	66% after 12 p.m.	66% after 12 p.m.
Time of attack (season)[7]	0.2323[k]	51,5% winter	71% winter
Time of attack (day of the week)[8]	0.4218[f]	–	–

[1] Classified into four categories: clear, slightly turbid, turbid, highly turbid.
[2] Classified into four categories: new moon, first quarter, last quarter, full moon.
[3] Victim's activity, classified into two categories: practising a board sports vs other activities.
[4] Attack outcome, classified into two categories: fatal or non-fatal.
[5] Attack location, classified into two categories: western part of Reunion Island vs eastern part.
[6] h of attack, classified into two categories: before or after 12 p.m.
[7] Month of attack, classified into two categories: summer (October to March) or winter (April to September).
[8] Day of the week when the attack occurred (Monday, Tuesday, etc.).
[9] The letter beside the p-value indicates the test used (s for Student's *t*-test, w for Welsch's *t*-test, m for Mann-Withney u test, k for chi-squared test, f for Fisher's exact test).

(cumulated rainfall over the three days preceding the attack) was below 2 mm, i.e. with no or very little rain. In 25% of attacks (14 out of 57), rainfall was above 10 mm. Those levels are not significant enough to consider that rainfall is a factor influencing shark attacks on Reunion Island.

Between 1980 and 2017, 61% of the attacks (35 out of 57) took place when **swell height** was over two metres. As regards **turbidity** a little bit more than two thirds of attacks occurred in turbid (18%) or highly turbid (50%) waters; this ties in with observations in other parts of the world [2]. The correlation of swell height and turbidity is to be assessed in relation to the benthic substrate: turbidity will be all the greater when swell is strong and benthic substrate silty. For attack locations on Reunion Island, swell height and substrate were taken into account to produce a turbidity score (from 1 to 4). The fact that the attacks tend to take place in turbid water and with a swell height of over two metres is closely linked to the victims' activity types. 61.5% of victims were practising board sports, in quest of waves and therefore a swell [49]. Another explanatory factor is linked to the ecology of the main predators, the tiger shark and especially the bull shark, which have a special predilection for highly turbid waters [25] where they are hard to observe. In this connection, bull sharks are the species most involved in the attacks (where the species is known, n = 40) on people practising board sports, amounting to roughly 60% between 1980 and 2017 and 80% since 2011.

In the light of this univariate analysis, only the victims' activity type, time, month and turbidity/height swell appear to have a degree of influence on the risk of attack. Therefore no obvious hierarchy emerged that would lead to consider those environmental, contextual and individual variables individually and approach them analytically. To a great extent, they are interdependent, at times permeable, and combine to produce interactions that do not have the same intensity according to the relations under consideration. As matters stand, a shark attack is the complex outcome of the accumulation of human, animal and environmental elements [5].

3.3. Characterisation of shark attacks

3.3.1. Attacks worldwide compared with Reunion Island before and after January 2011

To fine-tune these initial analyses, a few indicators relative to Reunion Island's position in the world ranking for attacks are required. The period of reference retained for the following table (Table 3) is the one starting in 2011 and corresponding to what is referred to as the "shark crisis" on Reunion Island [5].

The areas with the highest occurrences of shark attacks worldwide have been selected for territorial analysis. In descending order these are the United States (with two states, Florida and Hawaii, particularly affected), Australia, the Republic of South Africa and Reunion Island. Over the period under study, those countries and territories alone concentrate more than three quarters (n = 563; 80%) of the world's attacks (n = 705), with half (n = 288; 51%) occurring in the United States. For fatal attacks the ranking is modified, with Australia leading, followed by Reunion Island, the Republic of South Africa and the USA. The proportion of fatal attacks (n = 62) compared with the total number of attacks places Reunion Island at the top of the list, with more than one fatal attack out of three. Similarly, and by far, Reunion Island outranks the other zones for almost all other indicators, such as the number of fatal attacks per million inhabitants and the number of fatal or non-fatal attacks per 100 km of coastline. As regards the rate of attacks per million inhabitants, higher in Hawaii than on Reunion Island, this should be weighted by the number of incoming tourists. Reunion Island, with its population of 860,000, receives roughly 450,000 tourists a year, while the Hawaiian archipelago, with a population of 1.4 million, receives 9 million. Those tourists take a major part in coastal water sports [51], and so automatically increase the risk of shark attacks in Hawaii; Hawaii's ratio of number of attacks per million inhabitants should therefore be revised downwards to remain comparable with that of Reunion Island, which receives few tourists, many of which are mountain sports-oriented [8].

Table 3 shows that since 2011 Reunion Island has been much more vulnerable to shark attacks (and particularly fatal ones) than other countries affected worldwide. This observation requires further study

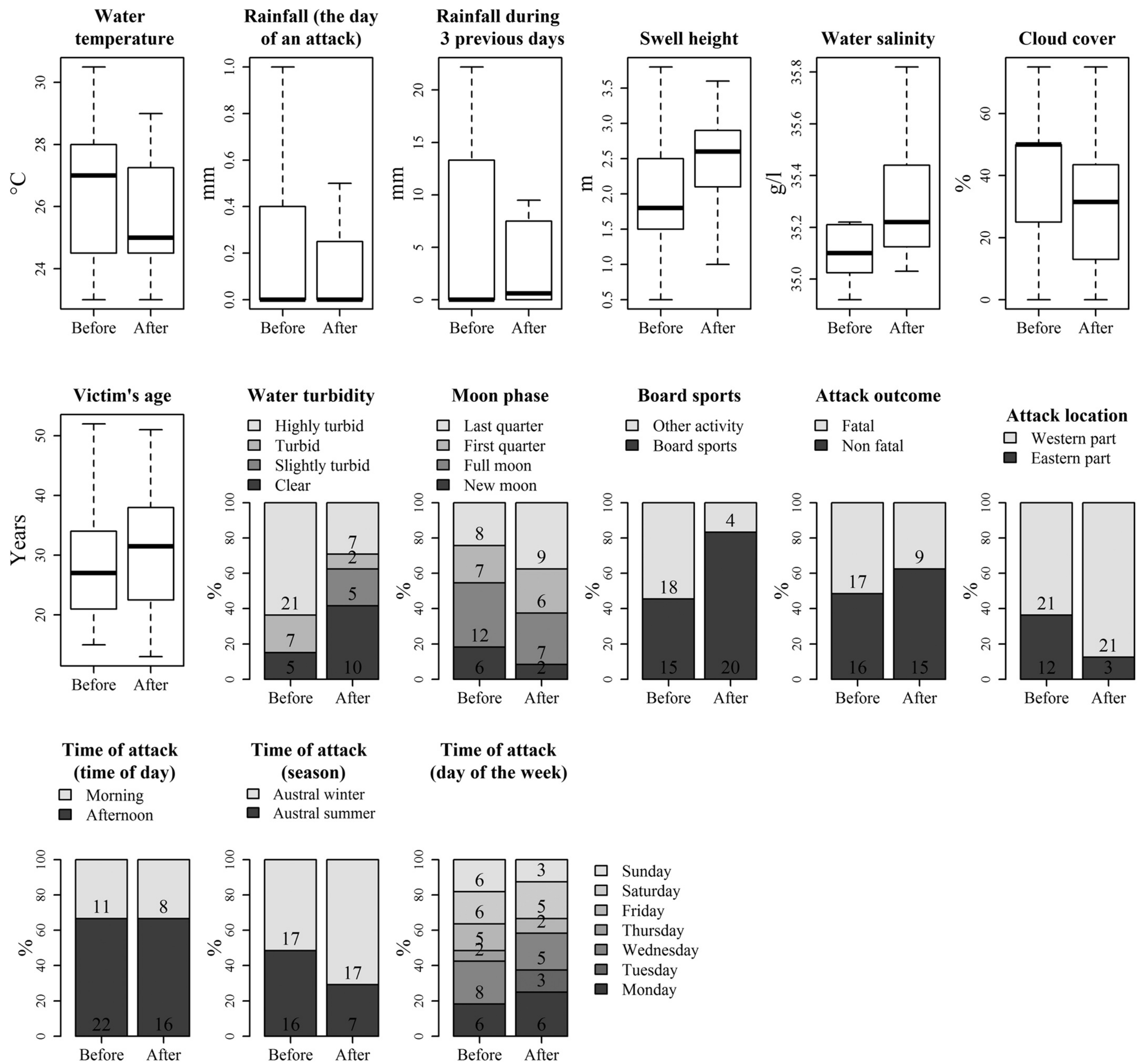


Fig. 6. Distribution of the variables describing environmental conditions and attack characteristics before and after 2011.

Table 5
Variance of multiple correspondence analysis (Source: Fig. 3a).

	Dim. 1	Dim. 2	Dim. 3	Dim. 4	Dim. 5	Dim. 6	Dim. 7
Eigen value	0.392	0.279	0.216	0.203	0.157	0.089	0.064
% of variance	28.030	19.930	15.416	14.498	11.192	6.384	4.551
Cumulative % of variance.	28.030	47.960	63.376	77.873	89.065	95.449	100.000

through more detailed analysis on Reunion Island, where the distribution of attacks is not homogenous over the entirety of its area; not only does this reinforce the island's top ranking worldwide, but it also generates true limitations for its socio-economic development.

3.3.2. Univariate analysis of the environmental conditions of attacks on Reunion Island before and after January 2011

The conditions in which shark attacks take place may be assumed to have changed since 2011. The number of attacks rose from 33 between 1980 and 2010 (i.e. an average of one attack per year) to 24 between 2011 and 2017 (i.e. an average of 3,5 attacks per year). Taking into account only people practising board sports (Fig. 3a) over the same period of time (1980–2017), the average number of attacks per year was 0.5 between 1980 and 2010 (17 attacks) and 2.9 between 2011 and 2017 (20 attacks). This underscores the rise of attacks before and after 2011 for this category of practisers.

Table 6
Description of multiple correspondence analysis axes (Source: Fig. 3a).

Dimension 1		
	Qualitative	
	R2	p-value
Attack after or before 2011	0.6168153	7.690922e-13
Board sports vs other activies	0.6011151	2.302134e-12
Swell height	0.6123580	1.239990e-11
	Modality	
	Estimate	p-value
after 2011	0.4970832	7.690922e-13
board sports	0.5016113	2.302134e-12
big swell	0.6938939	4.958186e-11
high turbidity	-0.2242412	4.434736e-02
small swell	-0.5266497	9.837830e-06
other activity	-0.5016113	2.302134e-12
before 2011	-0.4970832	7.690922e-13
Dimension 2		
	Qualitative	
	R2	p-value
Swell height	0.5375308	1.332587e-09
Attack outcome	0.4953392	1.444396e-09
Turbidity	0.2986009	8.280895e-05
	Modality	
	Estimate	p-value
non-fatal	0.3739160	1.444396e-09
small swell	0.4991423	3.854386e-09
low turbidity	0.3688563	8.260862e-05
high turbidity	-0.3257922	2.663514e-04
medium swell	-0.4109365	1.886121e-06
fatal	-0.3739160	1.444396e-09
low turbidity	0.6464509	5.870458e-19
medium turbidity	-0.1840866	2.939035e-02
medium swell	-0.5182232	8.904999e-08

Dimension 3		
	Qualitative	
	R2	p-value
Turbidity	0.55885012	3.815342e-10
Board sports vs other activitie	0.14089942	4.362717e-03
Attack outcome	0.13394818	5.537214e-03
Swell height	0.14553499	1.548455e-02
Attacks after or before 2011	0.09988994	1.764604e-02
	Modality	
	Estimate	p-value
low turbidity	0.2325481	7.490299e-04
medium turbidity	0.2307860	1.457540e-03
medium swell	0.2443920	3.765672e-03
other activity	0.1801023	4.362717e-03
fatal	0.1710118	5.537214e-03
after 2011	0.1483504	1.764604e-02
before 2011	-0.1483504	1.764604e-02
non fatal	-0.1710118	5.537214e-03
board sports	-0.1801023	4.362717e-03
high turbidity	-0.4633341	3.614385e-11
Dimension 4		
	Qualitative	
	R2	p-value
Turbidity	0.9007122	2.616645e-27
	Modality	
	Estimate	p-value
low turbidity	0.6464509	5.870458e-19
medium turbidity	-0.1840866	2.939035e-02
medium swell	-0.5182232	8.904999e-08

The annual general rate of attack since 2011 is even more remarkable owing to the sharp drop in the number of people practising coastal water sports. In the board sports category, this is all the more significant considering the sharp drop—roughly 75%—in the number of surfers and bodyboarders since 2011 [52]. The Decree dated 27 September 2013 [53], implementing a total ban on board sports outside the lagoon (which is very shallow and in theory shark-free), was enacted to protect practitioners from shark attacks. Since this decree came into effect, the number of board sports riders has plummeted. Nevertheless, the average incidence of attacks rose after 2011 but decreased globally since 2014 (with an exception in 2015, n = 4). This goes with some studies claiming that there might be a correlation between the increase in the number of shark attacks and the increase in the number of sea users [54,55].

The potential relevance of diachronic changes was therefore tested in some parameters. Of the 15 variables tested prior to 2011 (1980–2010) and after 2011 (2011–2017), only three demonstrate statistically significant changes (Table 4 and Fig. 6): environmental conditions of water turbidity and swell height on the one hand, and the practise of board sports versus other activities on the other hand.

Water turbidity ($p = 0.0033$) at the moment of an attack changed significantly as of 2011: 28 out of 33 attacks (85%) occurred in turbid to highly turbid water before 2011, whereas 10 out of 24 attacks (42%) occurred in turbid to highly turbid water after 2011. One explanation could be that people have modified their habits since 2011, being more careful to bathe in clear water, thus modifying the population at risk of an attack. Nonetheless, this possible change in behaviour has not modified the number of attacks—far from it—and this despite the fall in the number of sea users, and their taking more precautions.

Swell height ($p = 0.0041$) during attacks is significantly higher after 2011. Examination of victims' activity shows that the proportion of victims who were **practising a board sport** ($p = 0.0055$) when they were attacked rose from 45% (15/33) to 83% (20/24) after 2011. There is no reason why sharks would suddenly target people based on their activity. The increase in swell height during attacks observed after 2011 therefore probably results from a change in people's behaviour, modifying the composition of the population at risk. Indeed, board sport lovers who keep pursuing their activity despite high risk increase and the decree banning coastal water sports in 2013 are by far the most motivated and expert. This can assuredly be explained by the fact that they seek out more challenging surfing conditions, i.e. higher waves.

3.3.3. Multivariate analysis of environmental conditions of attacks on Reunion Island

Multiple correspondence analysis (MCA) allows to detect underlying structures in the dataset. In Tables 5, 4 axes account for 77.8% of the dataset variance (eigen over 1/p with p number of variable). Where new axes are introduced (Table 6), it appears that main component 1 separates attack before and after 2011: board sport versus other activities and swell height. Component 2 focuses more on the fatality of attacks and a graduation of turbidity and swell height. Components 3 and 4 provide less explanation, mostly showing turbidity.

Fig. 7 seems to show that fatal attacks (46% of total attacks on Reunion Island) happen mostly in highly turbid water and with medium swell; non-fatal attacks occur in clear water and with low swell. This can be explained by the ecology of sharks species (especially bull shark), which prefer to hunt in turbid water [46]. Moreover, people exposed to shark attacks in turbid water are much more vulnerable if they cannot see the shark during the interaction. Regarding medium swell, there is a link between turbidity and swell level (depending on benthic substrate); medium swell is favourable to multiple uses of the sea by practisers; a human-shark interaction will be more difficult to

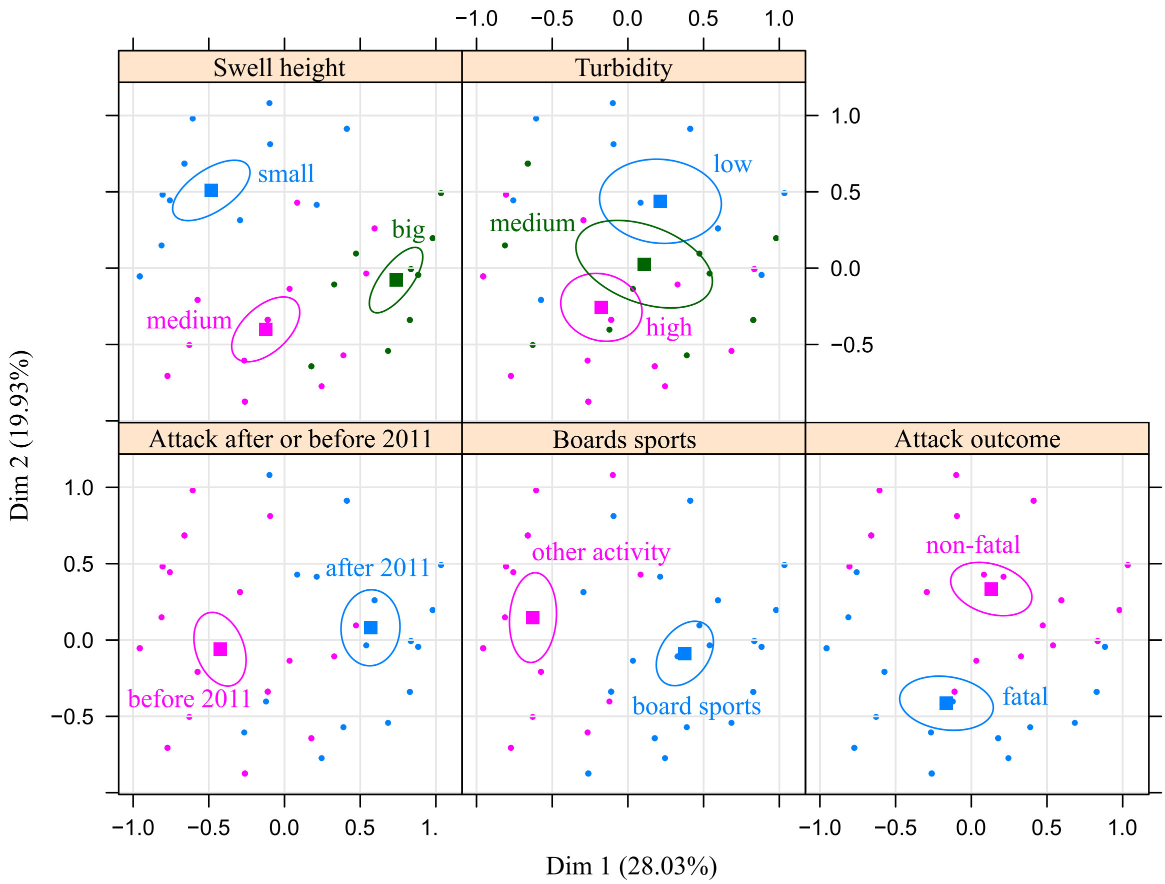


Fig. 7. Projection of the variables of the dataset in the first two principal components from the MCA (Source: Fig. 3a).

manage with medium swell than with low swell or flat sea conditions.

It can also be observed that after 2011, more board sport riders were attacked in high swell whereas people attacked before 2011 were mostly practicing other activities. This confirms the result of univariate analysis for swell height and board sports practice.

The main limit of this multivariate analysis is that it is difficult to establish a strong result with only 56 observations.

4. Conclusion

In this study of shark attacks that occurred between 1980 and 2017 on Reunion Island, database analysis (57 attacks since 1980) enables identification of several variables which might influence the occurrence of attacks. The apparently most relevant parameters in this context are the following: time of day, month, and turbidity. As for vulnerability, the type of activity performed by victims seems decisive, with swimmers and bodyboarders being the most vulnerable group for fatal attacks. Two Reunionese specificities can be added: high mortality rate (46% vs a world average of 11%) and the average increase in the number of attacks between 2011 and 2017, despite the average drop in the number of ocean users. Nevertheless, admittedly the average incidence of attacks rose after 2011 but decreased globally after 2014 (with an exception in 2015, n = 4).

Comparison of situations before and after 2011 shows that three variables underwent a statistically significant change: water turbidity, swell height and victim activity. This shows that a vast majority of sea users after 2011 were those engaging in a board sport, while most other people discontinued their sea activities.

Shark attacks are all the more complex to analyse as the number of recorded attacks is, to a point, too limited over the 37 years encompassed by this study for interpretations to be highly significant and predictions possible. Nevertheless, the multiple correspondence analysis provides correlations between some variables: on the one hand, attack outcome, turbidity, swell height, and, as regards attacks before or after 2011, board sports and swell height.

Consequently, interactions between humans and sharks remain a subject of scientific research requiring further in-depth studies. To quantify shark attack risk with accuracy, it would be necessary to analyse with more precision the characteristics of the population at risk, and the way it changes over time. Thus, precise quantification of the attack risk in a given area of the island is subordinate to determining the populations of different species of sharks and the number of sea users in those locations. To date, the main relevant issue is to obtain this dataset, to be used as a base for the production of a reliable indicator of the risk of shark attacks, with the perspective of implementing an efficient strategy of warning and prevention.

CRediT authorship contribution statement

François Taglioni: Conceptualization, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **Sébastien Guiltat:** Conceptualization, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **Magali Teurlai:** Formal analysis. **Mathieu Delsaut:** Formal analysis. **Denis Payet:** Formal analysis.

Acknowledgments

Our many thanks for their precious help and advice go to Dr Dominique Gay (University of Reunion Island/UR), Emmanuel Marcadé (UR), Dr. Hélène Magalon (UR), Magali Duval (Ifremer), Pr. Sébastien Jacquemet (UR), Pr. Vilasnee Tampoe-Hautin (UR) and Jean-Luc Clairambault (UR).

Conflicts of interest

None.

References

[1] D. McPhee, Unprovoked Shark Bites: are they becoming more prevalent? Coast. Manag. 42 (5) (2014) 478–492.
[2] H.D. Baldridge, Shark Attack: A Program of Data Reduction and Analysis. Contributions from the Mote Marine Laboratory Sarasota, Florida, 1974, p. 98.
[3] S. Trape, Shark attacks in Dakar and the Cap Vert Peninsula, Senegal: low incidence despite high occurrence of potentially dangerous species, PloS One 3 (1) (2008) e1495.
[4] F.H. Hazin, G.H. Burgess, F.C. Carvalho, A Shark Attack Outbreak Off Recife, Pernambuco, Brazil: 1992–2006, Bull. Mar. Sci. 82 (2008), pp. 199–212.
[5] F. Taglioni, S. Guiltat, Le risque d'attaques de requins à La Réunion. Éléments d'analyse des attaques et contextualisation d'une gestion contestée, EchoGéo, 2015.
[6] A. Lemahieu, A. Blaison, E. Crochelet, G. Bertrand, G. Pennober, M. Soria, Human-shark interactions: the case study of Reunion island in the south-west Indian Ocean, Ocean Coast. Manag. 136 (2017) 73–82.
[7] E. Lagabrielle, A. Allibert, J.J. Kiszka, N. Loiseau, J.P. Kilfoil, A. Lemahieu, Environmental and anthropogenic factors affecting the increasing occurrence of shark-human interactions around a fast-developing Indian Ocean island, Sci. Rep. 8 (1) (2018) 3676.
[8] S. Guiltat, Le rôle des sports côtiers dans le développement territorial de l'ouest de La Réunion: entre nouvelle maritimité et jeux d'acteurs, Département de STAPS, Université de La Réunion, Saint-Denis, 2011, p. 321.
[9] A. Lemahieu, Fréquentation et usages littoraux dans la Réserve Naturele Marine de la Réunion: élaboration d'un suivi pour l'analyse des dynamiques spatio-temporelles et apports de l'outil à la gestion et la recherche interdisciplinaire, Geography, Université de La Réunion, 2015, p. 352.
[10] B.K. Chapman, D. McPhee, Global shark attack hotspots: identifying underlying factors behind increased unprovoked shark bite incidence, Ocean Coast. Manag. 133 (2016) 72–84.
[11] N. Roinsard, Pauvreté et inégalités de classe à La Réunion, Etudes Rural. 194 (2014) 173–189.
[12] P. Fabing, Impact économique de la crise requin à la Réunion, SAGIS/DEAL, Saint-Denis de La Réunion, 2014, p. 50.
[13] A. Jacoud, Mieux comprendre pour mieux agir. Approche sociale de la crise requin, DEAL, Saint-Denis de La Réunion, 2014, p. 172.
[14] R. Robert, Les régions climatiques de l'île de La Réunion: évolution des connaissances depuis quarante ans, 1958–1998, Université de la Réunion. Faculté des lettres et des sciences humaines, Saint-Denis, 2002.
[15] G. Burgess, M. Callahan, Worldwide patterns of white shark attacks on humans, in: A. Klimley, D. Ainley (Eds.), Great White Sharks: The Biology of Carcharodon Carcharias, Academic Press, San Diego, 1996, pp. 457–469.
[16] G. Cliff, Shark attacks on the South African coast between 1960 and 1990, South Afr. J. Sci. 87 (1991) 513–518.
[17] G. Cliff, A review of shark attacks in False Bay and the Cape Peninsula between 1960 and 2005, in: D.C. Nel, T.P.(Eds.) Finding a balance: White shark conservation and recreational safety in the inshore waters of Cape Town, South Africa. in: Proceedings of a specialist workshop. WWF South Africa Report Series–2006/Marine/001 Annexure.
[18] J.G. West, White shark attacks in Australian waters, in: A. Klimley, D. Ainley (Eds.), Great White Sharks. The Biology of Carcharodon Carcharias. Academic, Academic Press, San Diego, 1996, pp. 449–455.
[19] C. Neff, R. Hueter, Science, policy, and the public discourse of shark "attack": a proposal for reclassifying human–shark interactions, J. Environ. Stud. Sci. 3 (1) (2013) 65–73.
[20] Global Shark Attack File 〈http://www.sharkattackfile.net/〉.
[21] C. Gauthier, Expertise médicale des victimes d'attaques de requins à l'île de La Réunion, Médecine, Université de Bordeaux II, Bordeaux, 2012, p. 528.
[22] D.H. Davies, G.D. Campbell, The aetiology, clinical pathology and treatment of shark attack, J. R. Nav. Med. Serv. 48 (1962) 110–136.
[23] A.K. Lentz, G.H. Burgess, K. Perrin, J.A. Brown, D.W. Mozingo, L. Lottenberg, Mortality and management of 96 shark attacks and development of a shark bite severity scoring system, Am. Surg. 76 (1) (2010) 101–106.
[24] G. McPherson, Shark Control Operations, Mogadishu, Somalia. Overseas Trip Report, UN- OSOM (United Nations Operation Somalia). Northern Fisheries Centre, Cairns, Australia, 1994, p. 16.
[25] R.A. Martin, Conservation of freshwater and euryhaline elasmobranchs: a review, J. Mar. Biol. Assoc. U. Kingd. 85 (05) (2005) 1049–1073.
[26] M.R. Heithaus, B.K. Delius, A.J. Wirsing, M.M. Dunphy-Daly, Physical factors influencing the distribution of a top predator in a subtropical oligotrophic estuary, Limnol. Oceanogr. 54 (2) (2009) 472–482.
[27] E. Ritter, R. Amin, A. Zambesi, Do lunar cycles influence shark attacks, Open Fish. Sci. J. 6 (2013) 74 (74).
[28] K. Weltz, A.A. Kock, H. Winker, C. Attwood, M. Sikweyiya, The influence of environmental variables on the presence of white sharks, Carcharodon carcharias at two popular Cape Town bathing beaches: a generalized additive mixed model, PloS One 8 (7) (2013).
[29] International Shark Attack File 〈https://www.flmnh.ufl.edu/fish/sharks/Statistics/statistics.htm〉.
[30] Shark Attack File 〈http://sharkattacksurvivors.com/shark_attack/viewforum.php〉.
[31] National Oceanic and Atmospheric Administration 〈https://www.nnvl.noaa.gov/view/globaldata.html〉.
[32] Météo France 〈http://www.meteofrance.com/accueil〉.
[33] Candhis Buoy No. 97403: Pointe des Galets 〈http://candhis.cetmef.developpement-durable.gouv.fr/campagne/?Idcampagne=3295c76acbf4caaed33c36b1b5fc2cb1〉.
[34] Candhis Buoy No. 97405: Saint-Pierre 〈http://candhis.cetmef.developpement-durable.gouv.fr/campagne/?idcampagne=a3f390d88e4c41f2747bfa2f1b5f87db〉.
[35] National Oceanic and Atmospheric Administration- WAVEWATCH III 〈http://polar.ncep.noaa.gov/waves/index2.shtml〉.
[36] Institut français de recherche pour l'exploitation de la mer 〈http://www.ifremer.fr/lareunion/〉.
[37] R.C. Team, R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, Austria, 2012 (2014).
[38] B. Scherrer, Biostatistique. Volume 1, Gaëtan Morin, Montreal, 2008.
[39] Ipsos, Analyse de la crise requin. Enquête quantitative auprès de la population réunionnaise, Ipsos, Saint-Denis de La Réunion, p. 125.
[40] O. Bessy, O. Naria, Loisirs et tourisme sportif de nature à La Réunion: état des lieux, enjeux et perspectives en matière de développement durable, Conseil de la culture, de l'éducation et de l'environnement, Saint- Denis de La Réunion, 2004, p. 130.
[41] M. Rard, A. Menou, Bilan sur les activités nautiques à l'île de La Réunion, Observatoire Marin de La Réunion, Saint-Denis de La Réunion, 2011, p. 80.
[42] P. Metzger, R. D'Ercole, Les risques en milieu urbain: éléments de réflexion, EchoGéo 18 (2011).
[43] A. Curmi, Taking a Bite Out of Fiction-Media Effects and Social Fears. A Case Study on 'Jaws', University of Malta, 2005, p. 71.
[44] C. Neff, The jaws effect: How movie narratives are used to influence policy responses to shark bites in Western Australia, Aust. J. Political Sci. 50 (1) (2014) 114–127.
[45] A. Blaison, S. Jaquemet, D. Guyomard, G. Vangrevelynghe, T. Gazzo, G. Cliff, P. Cotel, M. Soria, Seasonal variability of bull and tiger shark presence on the west coast of Reunion Island, western Indian Ocean, Afr. J. Mar. Sci. 37 (2) (2015) 199–208.
[46] P. Tirard, Requins du caillou, Edition Philippe Tirard, Nouméa.
[47] M. Soria, M. Soria (Ed.), Bilan de l'analyse des données de marquage collectées du mois de décembre 2011 au mois de septembre 2013 dans le cadre du programme CHARC, Institut de recherche pour le développement (IRD), Saint- Denis de La Réunion, 2014, p. 31.
[48] M. Soria, M. Soria (Ed.), Rapport scientifique final du programme CHARC (Connaissances de l'écologie et de l'HAbitat de deux espèces de Requins Côtiers sur la côte Ouest de La Réunion), Institut de recherche pour le développement (IRD), Saint-Denis de La Réunion, 2015, p. 132.
[49] R. Bonnefille, Cours d'hydraulique maritime, Masson, Paris, 1980.
[50] O. Hoffer, Quand le littoral se ferme. Quelle gouvernance de l'accès et des usages de l'interface littorale dans les agglomérations d'Auckland, Nouméa et Port-Vila? Université de La Réunion, Saint-Denis, 2013, p. 418.
[51] N. Lazarow, M.L. Miller, B. Blackwell, Dropping in: a case study approach to understanding the socio-economic impact of recreational surfing and its value to the tourism industry, in: Proceedings of the 5th International Coastal and Marine Tourism Congress, 2007, pp. 448–461.
[52] A. Lemahieu, Synthèse des études sur les facteurs biotiques et abiotiques analysés au cours du programme (CHARC), in: M. Soria (Ed.), Rapport non publié, Institut de recherche pour le développement (IRD), Saint-Denis de La Réunion, 2015, pp. 108–113.
[53] Arrêté préfectoral, n° 1821 du 27 septembre 2013 portant réglementation temporaire de la baignade et de certaines activités dans la bande des 300 mètres à partir du littoral du département de La Réunion, in: P.d.L. Réunion(Ed.), 2013.
[54] J.G. West, Changing patterns of shark attacks in Australian waters, Mar. Freshw. Res. 62 (6) (2011) 744–754.
[55] G. Burgess, R. Buch, F. Carvalho, B. Garner, C. Walker, Factors contributing to shark attacks on humans: a Volusia County, Florida, case study, in: J.C. Carrier, J.A. Musick, M.R. Heithaus (Eds.), Biology of Sharks and Their Relatives, CRC press, Boca Raton, Florida, 2011, pp. 541–565.