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OPEN Variability of environmental, contextual and individual factors in human-shark interactions in New Caledonia, 1980–2022, with some comparisons to Reunion Island

François Taglioni^{1✉}, Sébastien Guiltat², Mathieu Delsaut³, Philippe Tirard⁴ & Denis Payet⁵

This paper analyses data related to 62 human–shark interactions in New Caledonia and 60 in Reunion Island from 1980 to 2022. A database on human–shark interactions in New Caledonia and Reunion Island was developed using the same variables and similar time steps for both locations. The discussion focuses on human–shark interactions in New Caledonia, with some comparisons to those on Reunion Island where possible. Environmental, contextual and individual variables related to human–shark interactions were analysed to identify potential influencing factors. The data analysis for New Caledonia revealed some correlations between variables related to the human–shark interactions. The main results showed that there was a concomitant increase in human–shark interactions since 2010 in the bays of Noumea and in the prevalence of human–shark interactions among people practising boardsports since 2007. The year 2007 was a pivotal year with respect to differences in important parameters of human–shark interactions. The results of this comparison between Reunion Island and New Caledonia were as follows: fatal human–shark interactions occurred among individuals practising boardsports and in turbid environments, whereas nonfatal human–shark interactions among individuals engaged in spearfishing and in clear water in New Caledonia.

Keywords Human–shark interactions, Hazard, Vulnerability, Spatial and environmental analysis, New caledonia, Reunion Island

“Conflicts between people and wild animals occur when the action of one has a negative effect on the other”¹. Such conflicts have been recorded worldwide, including terrestrial, aquatic and aerial environments². The most common causes of these conflicts are the direct interactions of animals with humans, domestic animals, economies and social and political relations. Thus, the study of human–shark interactions raises important issues, as sharks are among the few groups of animals on the marine realm that interact negatively with humans, often resulting in serious injury, mutilation or even death. Despite their low frequency, human–shark interactions have a strong impact on the social and media spheres, often exceeding real human, economic, social and political impacts^{3–8}.

Many studies have focused on human–shark interactions both on a global scale^{9–11} and at the local scale^{12–15}. Indeed, the number of human–shark interactions has increased worldwide in recent decades. Between 30 and 45 human–shark interactions per year (Fig. 1) were recorded in the early 1980s; this figure has exceeded 100 each year since the 2000s, and an increasing consistent trend of approximately 10 fatal human–shark interactions per year was observed. Unexpectedly, the incidence of bites does not result in an increase in the annual number of deaths over the period. This can be explained by improved emergency response over time, as well as by the triptych of attack location, shark species, and type of sea users^{11,15}.

Moreover, the world’s population increased steadily between 1980 (by nearly 4.5 billion) and 2022 (nearly 8 billion). Elsewhere, the number of people participating in coastal water sports has increased due to improvements in living standards, the world’s population shifting to coastal areas, the development of new leisure activities (kitesurfing, stand-up paddling, sea kayaking, wakeboarding, windsurfing, etc.) and new equipment that

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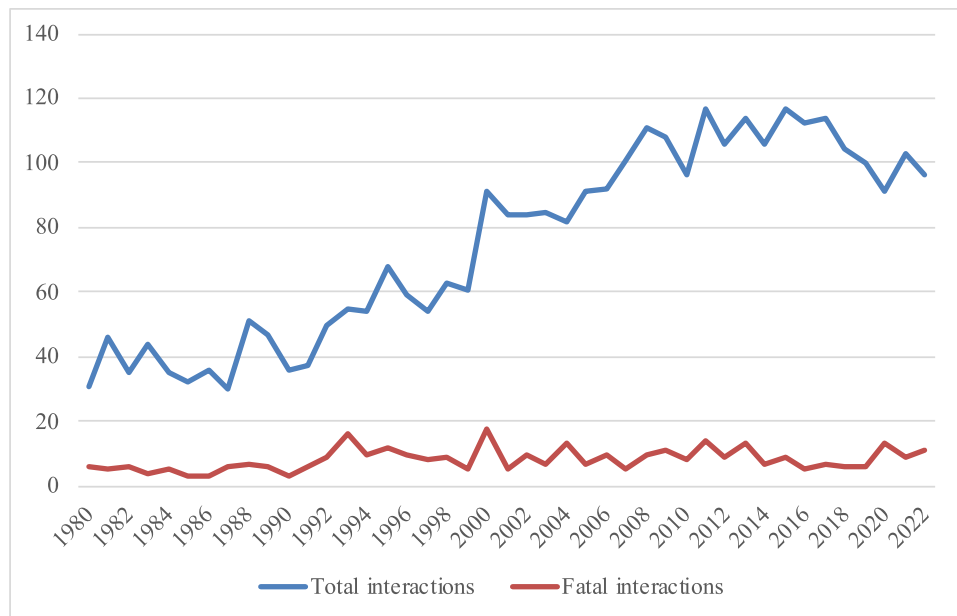


Fig. 1. Distribution of the number of reported human–shark interactions by year worldwide (1980–2022). Source: Global Shark File Attacks²⁰.

provides opportunities to practise these sports all year. Moreover, human–shark interaction remains a complex, multifactorial event, and only detailed analyses can help strike a balance between the needs of sea users and the necessary preservation of sharks^{11,16,17}. This trend can be observed in New Caledonia, which has seen a steady increase in the number of coastal sports users and uses since the 1960s¹⁸ and an almost doubled population from (170,000 in 1980 to 270,000 in 2022)¹⁹.

The number of human–shark interactions²¹ in New Caledonia has increased over the past forty years. We have documented²² 62 human–shark interactions between 1980 and 2022, which can be divided into 3 periods. The first period was from 1980 to 1999, with an average of 1 human–shark interaction per year; the second period was from 2000 to 2006, with an average of 2 human–shark interactions per year; and the third period was from 2007 to 2022, with an average of almost 3 human–shark interactions per year. As everywhere in the world²³, these interactions lead to consequences for humans and present problems for the protection and management of the shark species involved in human–shark interactions in the New Caledonian archipelago.

This article analysed a database of these human–shark interactions from 1980 to 2022 that was compiled by the authors²². Since 1980, environmental, contextual and individual variables during human–shark interactions have been analysed (univariate and multivariate) to identify potential influencing factors of human–shark interactions and evolutions in the trends of this phenomenon. This research complements a recent study¹² that aimed to establish the risk factors for human–shark interactions in New Caledonia (food stimulation appears to be the main factor).

Although this research has focused primarily on characterizing human–shark interactions in New Caledonia since 1980, a comparative analysis with Reunion Island provides elements of perspective on human–shark interaction risk. New Caledonia and Reunion Island are two territories that are institutionally attached to France to varying degrees. They are in two very similar geographical areas (climate, underwater fauna, and flora) in the Southern Hemisphere. These two territories have reported similar numbers of human–shark interactions from 1980–2022 (New Caledonia, $n = 62$; Reunion Island, $n = 60$), thus indicating that they are particularly exposed to sharks^{12,15} relative to the size of their territory and population. For comparative purposes, the databases²² for Reunion and New Caledonia are based on the same variables and a similar time step. Human–shark interactions in Reunion are well documented¹⁵ which can help provide a better understanding of the situation in New Caledonia. Factor analysis of mixed data (FAMD), used to compare data from New Caledonia and Reunion Island, supplies information on any common features to both territories during human–shark interactions, as well as any features specific to each territory.

Materials and methods

New Caledonia is an archipelago with an area of 18,575 sq. km and a population of approximately 270,000. New Caledonia is in the Pacific Ocean, east of Australia (Fig. 2). It consists mostly of a main island (Grande Terre), a small archipelago of Loyalty Island (Lifou, Mare, Ouvéa, Tiga), the Belep archipelago, the Isle of Pins, and a few uninhabited or uninhabited islands. 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), and there is an uneven distribution of rainfall in different locations (leeward or windward).



Fig. 2. Location of new caledonia in the western pacific ocean.

Data collection and preparation

We defined¹⁵ a human–shark interactions as contact, unprovoked or provoked by a shark (or sharks) that results in injuries or death to humans or damage to their equipment (surfboard, bodyboard, windsurfing board, kitesurfing board, kayak, canoe, flippers, foil, etc.). The definition used in this study is similar to that of Neff & Hueter²¹. The only difference is that Neff & Hueter's definition considers shark sightings close to people as interactions. From our point of view, shark sightings close to people are not reported in our human–shark interaction databases as these are subjective. The ethogram of shark behaviour recently published by Klimley et al. (2023)²⁴ can now be used to categorize the motivations behind shark bites. However, the aim of this article is not to reduce human–shark interactions to a mere act of predation, but rather to analyse the environmental, contextual, and individual variables associated with such interactions to identify potential influencing factors. Individual variables are specific to the person being observed or studied. Contextual variables relate to the immediate or specific conditions in which the action or event takes place. Environmental variables refer to the physical, geographical, climatic, or ecological characteristics of the natural or anthropized environment.

To perform analyses and design an interactive map (Fig. 3), a database on human–shark interactions in New Caledonia since 1980 has been built²². This database is founded on meticulous compilation work using data between 1980 to 2000 from Dreyer's Ph.D.²⁵, between 1980 to 2010 from the book of Tirard²⁶, and between 2010 to 2022 from a thorough review of the local (New Caledonia) and national (mainland France). The press between January 1980 to December 2022 as well as the human–shark interactions database (GSAF²⁰) were also used to complete the data when necessary.

The resulting database of human–shark interactions in New Caledonia includes the 62 interactions falling within the authors' definition that occurred between 1980 and 2022. Data prior to 1980 were too approximate and incomplete to be used. Prior to 1980, censuses of human–shark interactions in New Caledonia were very incomplete both in terms of numbers and related information. Thus, the international GSAF database²⁰ lists only 50 human–shark interactions since 1950.

For each human–shark interaction, the 21 following data points were integrated into the authors' database (Table 1); they were mostly the same as those retained for studies on the conditions of human–shark interaction occurrence in various regions worldwide. For the comparative analyses between human–shark interactions in New Caledonia and Reunion¹⁵, the variables in the two databases were strictly formatted in the same way.

All the data sources collected on human–shark interactions between 1980 and 2022 in New Caledonia are present in Table S1.

Data analysis

A thorough descriptive analysis was performed using univariate analysis of the environmental, contextual, and individual risk factors for human–shark interactions (see data collection and preparation). The variability of each factor during the 62 human–shark interactions was analysed retrospectively to determine whether one or several of them could predict human–shark interactions.

Two periods (before and after January 2008) were compared to identify hypotheses that could explain possible changes in environmental, contextual, and individual variables. For each variable included in the study, a statistical analysis was conducted to evaluate differences in either the means (for quantitative variables) or

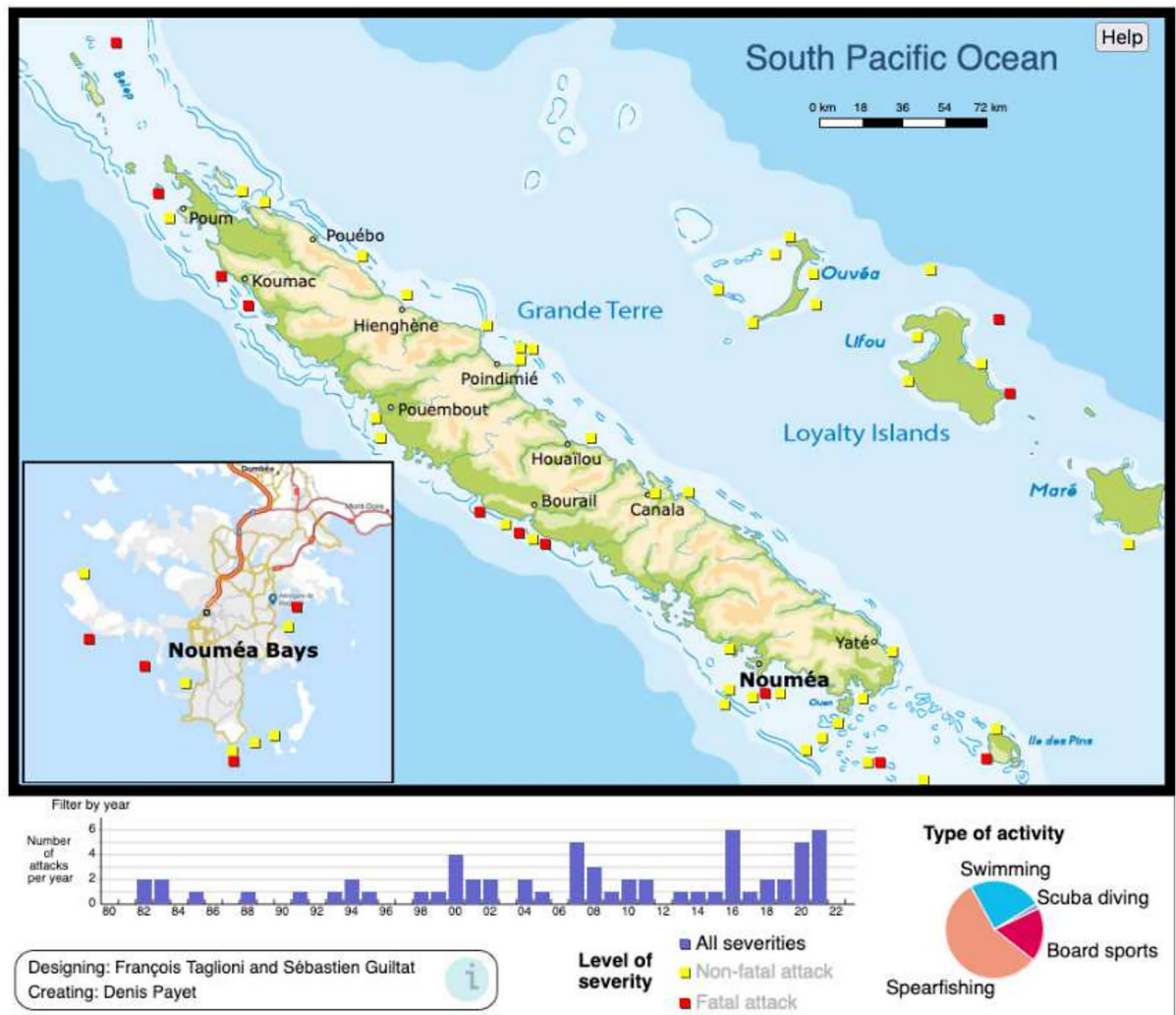


Fig. 3. Interactive map of human–shark interactions in New Caledonia <http://www.taglioni.net/Recherche/Interactivemap/42>.

	<ul style="list-style-type: none"> - Date (day of week [DAY]; month [MONTH]; year of human–shark interaction [YEAR])^{10,13} - Season of human–shark interaction [SEASON], classified into two categories: summer (October to March) or winter (April to September)^{10,13,27} - Time, sometimes approximate, of human–shark interaction [HOURTYPO], classified from 7 to 20^{10,13} - Hour of human–shark interaction [MORNING], classified into two categories: before or after 12 pm^{10,13} - Human–shark interaction location [ZONE]^{10,28} - Human–shark interactions orientation, classified in two categories: leeward or windward [WIND]¹⁰ - Shark species [SHARKTYPE]²⁸ - Shark size [SHARKSIZE]¹⁶ - Most dangerous sharks [SHARKCAT], classified into two categories: the large sharks (tiger/<i>Galeocerdo cuvier</i>, bull/<i>Carcharhinus leucas</i> and white/SF <i>Carcharodon carcharias</i>)²⁹ or others species
Contextual factors	
Victim characteristics	<ul style="list-style-type: none"> - Age of victim [AGE]^{10,13} - [SEX](male/female)¹⁰ - Victim's activity at time of human–shark interactions [ACTIVITY]. These activities have been grouped into four categories: practising a boardsport (surfing, windsurfing, kitesurfing, wing foiling, foil bumping), spearfishing, swimming, scuba diving^{10,13} - Severity of injuries or material damage expressed as a score of severity [GRAV] (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)^{30,31} - Human–shark interactions outcomes [INJURY], classified into two categories: fatal or non-fatal^{30,31}
Environmental factors	<ul style="list-style-type: none"> - Rainfall on day of human–shark interaction [RAIN]^{10,32} - Cumulated rainfall over the three days preceding the human–shark interaction [RAIN3]^{10,32} - Percentage of cloud cover [CLOUD]¹⁰ - Swell height [SWELL]^{10,13} - Estimated seawater turbidity [TURB] expressed as a score (1 = clear; 2 = slightly turbid; 3 = turbid; 4 = highly turbid)^{10,33} - Moon phase expressed as a score [SCOREMOON] (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 new⁴. Full moon or new moon phases score 4 while first or last quarter score 1^{34–36}. 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)

Table 1. Data collection on human–shark interactions 1980–2022 in New Caledonia.

the distributions (for qualitative variables). Specifically, either the Welch t test, Fisher test (utilised for sample sizes less than 5), or chi-square test was used. These tests^{37,38} were chosen due to their ability to accurately determine whether any observed differences in the data were statistically significant or whether they could be due to random chance alone.

In addition to the univariate analysis, a multivariate analysis^{39–41} was also used to investigate the relationships between multiple variables simultaneously. Specifically, multiple correspondence analysis (MCA) was employed. MCA is a data reduction method used to identify patterns and relationships among categorical variables. This method allows us to visualize the relationships between variables in a two-dimensional plot, thereby enabling us to identify clusters of variables that share similar characteristics. MCA was used to identify complex relationships and uncover hidden structures in the data that were not evident in the univariate analysis. This approach provides a more comprehensive understanding of the data and enables us to make more informed conclusions about the relationships between the investigated variables.

Finally, to extend our analysis, a comparative study was conducted between New Caledonia and Reunion Island. This study used a multivariate technique called Factor analysis of mixed data (FAMD). FAMD is a powerful multivariate analysis tool that can be used to analyse complex datasets that include both quantitative and qualitative variables. FAMD allowed us to compare the relationships between variables in the two territories and identify any differences or similarities in the patterns that emerged. This comparative study provides insights into the ecological and environmental factors that influence the risks of human–shark interactions in these two territories.

Results and discussion

Human–shark interactions worldwide compared to New Caledonia

A comparison of the number of human–shark interactions worldwide ($n = 3229$) and New Caledonia ($n = 62$) since 1980 revealed that New Caledonia has accounted for 2% of all human–shark interactions and that 4.3% of these interactions were fatal ($n = 15$ in New Caledonia and $n = 352$ worldwide). Considering the population of New Caledonia in 2022, New Caledonia is overrepresented in terms of the number of human–shark interactions per inhabitant, similar to Reunion Island¹⁵. Thus, New Caledonia and Reunion Island are two of the world's hotspots for human–shark interactions (i.e., small areas with relatively high human–shark interaction rates in comparison to some other coastal areas in the world)^{9,12,23}. Nevertheless, there have been no human–shark interactions on Reunion Island since May 2019; however, these interactions have continued to occur in New Caledonia. In New Caledonia, there were 62 human–shark interactions between 1980 and 2022 (Fig. 3). An increasing trend was observed since the 2000s, with an average of more than 2 human–shark interactions per year after 2000 compared with an average of 1 human–shark interaction per year before 2000. This increasing trend in human–shark interactions has been reinforced since 2007, with an average of approximately 3 human–shark interactions per year. Moreover, there were 10 years without human–shark interactions between 1980 and 1999, whereas there were only 4 years without human–shark interactions between 2000 and 2022.

Using data from the GSFA database²⁰ for the period 1980–2022, we calculated the distribution of interactions by shark species when this information was available. The results show that in 40% of interactions, the shark species is identified. Among these, white sharks, bull sharks, and tiger sharks alone account for 51% of interactions. This finding confirms that, globally, the three main shark species involved in human–shark interactions are the white shark (*Carcharodon carcharias*), bull shark (*Carcharhinus leucas*), and tiger shark (*Galeocerdo cuvier*)^{9,11}.

In New Caledonia, the most frequently involved species are the Bull Shark and the Tiger Shark, accounting for 65% of interactions¹⁹ where the species is known (78%).

In Reunion, the most frequently involved species are also the bull shark and the tiger shark, representing 92% of interactions¹⁹ where the species is identified (62%).

Univariate analysis of data from 1980–2022 with comparative elements of the Reunion Island situation

The database on human–shark interactions developed herein is partly illustrated in the interactive map (Fig. 3). This map shows the human–shark interaction location, type of activity practised at the time of human–shark interaction, human–shark interaction severity (fatal or nonfatal), date, time, and filter by year.

The map shows that there is a heterogeneous distribution of human–shark interactions in New Caledonia (Fig. 4). The western coast (western zone, $n = 11$, and Greater Noumea, $n = 23$) accounted for more than 50% of the human–shark interactions ($n = 34$ out of 62). In the western region, Greater Noumea (Noumea town, Mont-Dore, Paita and Dumbea) accounted for 67% of the total population of the New Caledonian archipelago and 37% of total human–shark interactions from 1980–2022. This relatively low representation of total human–shark interactions in Greater Noumea can be partly explained by the activity of the victims. Before 2008, human–shark interactions had almost exclusively occurred among individuals who were spearfishing (23 out of 29), which was less prevalent in Greater Noumea than in the rest of the archipelago. From 2010 onwards, a completely new phenomenon was noted, with a concentration of human–shark interactions in the bays of the Noumea area ($n = 10$ out of 29; 34% of human–shark interactions), where there had never been a human–shark interaction prior to 2010. Among these 10 human–shark interactions, boardsports enthusiasts ($n = 7$ of the 10; 70% of human–shark interactions) were the most common victims.

For the Loyalty Islands ($n = 13$), the ratio of the number of human–shark interactions per inhabitant was greater than that for the rest of the archipelago, as the Loyalty Islands only has 18 000 inhabitants (7% of the total population of New Caledonia) and accounted for 21% of all human–shark interactions between 1980 and 2022. This proportion can be explained in part by the high number of underwater fishermen, who accounted for 10 of the 13 human–shark interactions in this area (77%); the other three human–shark interactions involved



Fig. 4. Spatial distribution of human–shark interactions in New Caledonia since 1980 (source Fig. 3).

swimmers. A similar pattern was observed for the east coast ($n=15$), with the spearfisherman being victims in 10 of the 15 human–shark interactions and swimmers representing the remaining 5 victims.

Indeed, in the Loyalty Islands as well as on the east coast, there is a significant number of spearfishers and swimmers, primarily due to cultural reasons, whereas boardsports enthusiasts¹⁸ are more commonly found on the west coast, particularly in Greater Noumea. This reflects the population distribution in New Caledonia¹⁸, where the majority of the indigenous population is located on the east coast and in the Loyalty Islands, whereas the European-origin population is predominantly settled in Greater Noumea and along the west coast.

The highest proportion of human–shark interactions occurred in the 15:00 to 15:59 time slot. The 10:00 to 12:59 time slot also stood out in the analyses for the last forty years. These two time periods (Fig. S1) represent the times of day when the greatest abundance of recreational users are in the sea. There were also more human–shark interactions on weekends, which are traditionally dedicated to leisure activities (Fig. S2). Nevertheless, the daily distribution was mostly homogeneous and did not seem to follow a particular pattern. This finding confirmed that the risk of shark interactions is possible at any time of the day and on any day of the week. These findings were also valid for Reunion Island¹⁵.

The monthly distribution of human–shark interactions in New Caledonia was heterogeneous (Fig. S3 7). There are two periods: the period from December to May accounts for the highest proportion of human–shark interactions (82%), while the period from June to November accounts for 18% of all interactions. In the first period, March represents a pronounced peak, with at least 15 human–shark interactions observed (24%). One hypothesis is that the austral summer is more favourable for all ocean users because of good weather conditions. The seasonality of interactions is not linked to the presence of tourists on the island. Indeed, tourism in New Caledonia remains very limited in absolute terms (78,000 tourists in 2022¹⁹). Moreover, according to the database, very few tourists are among the 62 recorded cases of human–shark interactions. The monthly distribution is reversed on Reunion Island due to the type of sports that are practised there. One hypothesis is that the austral winter on Reunion Island is more favourable for boardsports due to the optimal wave conditions. However, the austral winter is also the riskiest time of year in terms of human–shark interactions due to the high turbidity, which is linked to a greater number of swell days during the austral winter²⁷. Turbid water is a risk factor for interaction between bull sharks and humans on Reunion Island^{13,32}, especially during the austral winter²⁷.

A full moon or a new moon strongly influences the tidal range. One hypothesis proposed in previous studies^{13,34,36} posits that both moon phases could influence the frequency of human–shark interactions. Therefore, the potential influence of moon phases on human–shark interactions in New Caledonia was explored herein. However, as the score analysis demonstrated, this “moon effect” was not strong in New Caledonia, as only 32 (52%) of the 62 human–shark interactions occurred during a full or new moon. The results were similar for Reunion Island¹⁵.

Sixty-eight percent of the human–shark interactions (42 out of 62) occurred when the cloud cover was equal to or less than 50%. This finding can mostly be explained by the tendency of sea users to go to the coast on the sunniest days. Therefore, the amount of sunshine is not directly correlated with the risk of human–shark interactions.

The same explanation applies to the effect of rainfall in the past 3 days on the risk of human–shark interaction. The prevalence of rainfall on the day of human–shark interactions was very low, with 94% (n = 58) of the interactions occurring on days with less than 20 mm of rainfall. With respect to the rainfall from D-3 to D-1, 76% (n = 47) of the human–shark interactions occurred with a cumulative rainfall of less than 20 mm over 3 days.

These levels were not significant enough to consider rainfall as a risk factor for human–shark interactions in New Caledonia. Similar results were observed on Reunion Island. However, depending on the location and shark species, a strong correlation can be observed on the global scale between rainfall and the incidence of human–shark interactions on^{13,43}. Most of the time, rainfall influences the degree of turbidity. However, in the case of New Caledonia and Reunion, there is not necessarily a correlation between rainfall, turbidity, and the occurrence of interactions, as there is little to no rain in the three days preceding the interaction, as well as on the day itself. Moreover, in the case of New Caledonia, most attacks (3 out of 4) occur in waters that are slightly or not at all turbid.

In New Caledonia, swells have an average amplitude ranging from 1.50 m to 2.50 m⁴⁴. The lagoon of Grande-Terre, which is protected by a coral reef, is not very exposed to the swell; the Loyalty Islands are more strongly affected. On the days of the human–shark interactions, the dataset for 1980–2022 revealed that the average swell was approximately 0.6 m²², which was low. This finding can be explained by the type of sport practised by the victims. The most common sports were spearfishing (35 = 56.5%), swimming (15 = 24%), boardsports (17.5%) and scuba diving (1 = 1.5%). Except for boardsports, these activities are practised in rather calm seas. The findings were very different on Reunion Island, where 61.5% of victims were practising boardsports in pursuit of waves and thus experienced a swell on the day of the human–shark interaction.

With respect to turbidity, 77% of the human–shark interactions (n = 48 out of 62) took place in clear or slightly turbid water. This finding was in line with the sports practised by the victims, including spearfishing and swimming, which mostly take place in clear water. The results on Reunion Island were very different, with 68% of the human–shark interactions occurring in turbid or very turbid water. This high level of turbidity on Reunion Island can be explained by the swell that suspends the benthic substratum, meaning that surfing sports are the most likely activity to be affected by human–shark interactions, as these sports are practised in rough waters.

The distribution of the severity scores of the human–shark interactions in New Caledonia revealed that 24% of the interactions were fatal (score of 5), 47% were serious or very serious (scores of 3 and 4) and 29% were not very serious (scores of 1 and 2). The overall very high severity (71% score 3, 4 or 5) can be explained by the type of shark involved in the human–shark interactions.

When known (80% in New Caledonia and 44% in Réunion), the size of sharks involved in interactions is derived either from forensic studies conducted on the victims or from observations made on the victims by one of the co-authors of this article, in consultation with other local shark specialists who directly perform medical assessments on the victims or indirectly from photographic testimonies or reports from witnesses or the victims themselves. All these direct or indirect sources of shark size data, provided by one of the co-authors of this article, have enabled the determination of the sharks' sizes. Of the 48 sharks identified in the 62 human–shark interactions (78%), two-thirds were either tiger sharks (42%) or bull sharks (23%). Moreover, these two species are longer than 3 m (70% of bull sharks and 80% of tiger sharks). With such sizes, there are very few immature individuals. More specifically, the mortality rate of 24% (n = 15 out of 62) was significantly higher than the global average of 9%²⁰. This difference can be explained by the type of shark often involved in fatal human–shark interactions, since 12 of the 15 fatal human–shark interactions were caused by 9 tiger sharks, 2 bull sharks and 1 white shark. These three types of sharks are known to be very dangerous to humans^{11,29}, and their sizes range from 2.5 m to 4.5 m. Therefore, interactions with these sharks are likely to cause worse injuries, thus leading to more fatal interactions than interactions with other sharks. On Reunion Island, the mortality rate was even higher than that in New Caledonia, at 46%. This difference can be explained by the type of shark involved (bull sharks and tiger sharks) and by the type of sea users, who were mainly people practising boardsports and were very vulnerable to human–shark interactions.

The four types of activity recorded during human–shark interactions in New Caledonia were as follows:

- Spearfishing (35 = 56.5%).
- Swimming (15 = 24%).
- Boardsports (11 = 18%).
- Scuba diving (1 = 1.5%).

Over the period 1980–2022, most human–shark interactions in New Caledonia involved spearfishers. However, this observation needs to be qualified over time; when considering the first 31 human–shark interactions since 1980, i.e., half of the series (n = 62), 81% of the human–shark interactions involved spearfishers, and the other 19% involved swimmers. For the next 31 human–shark interactions, 39% involved spearfishers, while the others involved people practising a boardsport (a new development since 2007) (32%), swimmers (26%) and one scuba diver (3%).

The vulnerability of sea users to human–shark interactions was assessed according to the type of activity and its percentage of fatal human–shark interactions. The risk of mortality significantly differed according to the type of activity (decreasing percentage of fatal human–shark interactions compared with the number of human–shark interactions per activity):

- Boardsports (45.5%) (11 human–shark interactions, 5 of which were fatal).
- Swimmers (27%) (15 human–shark interactions, including 4 fatal interactions).

- Spearfishers (17%) (35 human–shark interactions, of which 6 were fatal).
- Scuba divers (0%) (1 human–shark interaction and no fatalities).

Although spearfishers were the most affected by human–shark interactions, they had a much lower risk of mortality than swimmers but a higher risk of mortality than boardsports enthusiasts. This hierarchy was very similar on Reunion Island. The main difference was the risk of mortality among swimmers, which reached 83% on Reunion Island¹⁵. On this island, the known size (44%) of sharks during human–shark interactions was between 2 and 3.5 m, which could explain this high mortality rate. In New Caledonia, the average size of sharks that attack swimmers has increased since 2015, which could change the risk among swimmers in the coming years. Before 2015, the sharks that interacted with swimmers were much smaller (between 1 and 2 m) except one human–shark interaction. Since 2015, the average size of sharks has been approximately 3.5 m.

Univariate analysis before and after 2008

After significance tests (Student's *t* test or chi-square test), the appropriate pivot year to examine variations in the number of human–shark interactions and differences between modalities was determined. Several hypotheses and years between 2006 and 2011 were tested. It appeared that using the year 2007 as the pivot point yielded the lowest *p* values and the maximum number of significant variables (*n* = 5) to compare the two periods. Furthermore, using 2007 as the pivotal year was consistent with the univariate analysis (cf. above) and yielded two main findings: the occurrence of human–shark interactions among boardsports enthusiasts and an overrepresentation of human–shark interactions in the bays of Noumea. Moreover, the conditions under which human–shark interactions occur have changed since 2008. The number of human–shark interactions increased from 29 between 1980 and 2007 (i.e., an average of 1.6 human–shark interactions per year) to 33 between 2008 and 2022 (i.e., an average of 2.2 human–shark interactions per year).

The potential relevance of diachronic changes was therefore tested for several parameters. Among the 15 variables tested prior to 2008 (1980–2007) and after 2008 (2008–2022), five demonstrated statistically significant changes (Table 2 and Fig. 5), including in the swell height, victim activity, human–shark interaction outcome, most dangerous shark and human–shark interaction location.

Swell height (*p* = 0.00028) during human–shark interactions was significantly greater after 2008. An examination of victims' activities shows that the proportion of victims who were practising boardsports (*p* = 0.002) when they were attacked increased from 3.5% (1/29) to 30% (10/33) after 2008. There is no reason why sharks suddenly target people based on their activity. It has been observed that there are increasingly more people practising boardsports in New Caledonia (mostly kite surfing and wing foil), particularly in the bays of Noumea. These people are looking for the most suitable riding conditions with stronger winds and consequently a greater swell height.

Of the 10 human–shark interactions among people practising boardsports since 2008, 7 (70%) have taken place in the bays of Noumea. This finding confirms the evolution of location change for practises and human–shark interactions on boardsports. The latter are carried out by urban dwellers who practise their boardsports in the bays of Noumea¹⁸.

The severity score distribution for human–shark interactions in New Caledonia before and after 2008 revealed an increase in lethality (score 5), with mortality rates of 17% before 2008 and 45% after 2008. There was also a decrease in less severe cases (scores of 1 and 2): 41.5% before 2008 and 18% after 2008. Finally, the number of severe or very severe cases was consistent before and after 2008. These changes before and after 2008 are explained mainly by the increase in human–shark interactions from the following shark species: tiger sharks, bull sharks and white sharks, which are known to be the most dangerous sharks for humans^{23,45}. The number of human–shark interactions by tiger sharks, bull sharks and white sharks increased from 44% before 2008 to 83% after 2008 (for which the sharks are known).

Multivariate analysis in New Caledonia

In MCA, the new axes (i.e., dimensions) represent the different association patterns between the categorical variables. Each axis explains a certain amount of variance in the data and can be interpreted as a specific relationship between the variables. The interpretation of the new axes is based on the categorical coordinates of these axes.

The analysis focused on 5 categorical variables: TURB, ZONE, ACTIVITY, INJURY, and SUP2007. The results showed that this group maximized the MCA's amount of explained variance. GRAV, the qualitative supplementary variable, was added to appreciate the expression of gravity. SWELL, CLOUD, RAINJ, and RAINJ3 were added as quantitative supplementary variables to obtain further information on the environmental conditions during human–shark interactions. The role of supplementary qualitative and quantitative variables in MCA is to provide additional information that is not captured by the categorical variables included in the analysis and to help interpret the relationships between the categories. MCA requires modalities with at least two individuals because single-individual modalities lack internal variance, potentially leading to unstable or disproportionate influences in factorial representation, thereby complicating meaningful interpretation. Thus, one human–shark interaction with a scuba diver was removed because it was the only interaction with scuba divers. 61 human–shark interactions were analysed via MCA.

Table S2, the 5 first axes of MCA explain 67% of the variance in the data (eigen over 1/*p* with *p* number of variables), thus indicating the dispersion of individuals.

Fig. 6 shows a representation of the variables in factorial planes 1 and 2 and the confidence ellipses (Fig. 7). They were naturally close to the centres of gravity because of the small number of human–shark interactions (*n* = 61) and the nonhomogeneous nature of the conditions where a human–shark interaction occurs. Nevertheless, significant correlations were observed on Axis 1 (Fig. 8, Fig. 9, and Table S3). According to the *R*² values, most of the variables contributed to the highlighting of dimension 1, mainly ZONE (70%), ACTIVITY (68%), SUP2007

Variable	p-value ¹³	Average for human–shark interactions before January 2008	Average for human–shark interactions after January 2008
Time of human–shark interaction (day of the week) ¹ [DAY]	0.917f.	-	-
Time of human–shark interaction (season) ² [SEASON]	0.408f.	-	-
Hour of human–shark interaction ³ [HOURTYPO]	0.113f.	-	-
Time of human–shark interaction (time of day) ⁴ [MORNING]	0.119f.	-	-
Human–shark interaction's location⁵ [ZONE]	0.001f.	-	-
Human–shark interaction orientation ⁶ [WIND]	1.0 ^k	-	-
Shark type [SHARKTYPE]	0.1637f.	-	-
Shark size [SHARKSIZE]	0.7237 ^w	2.70 m	2.80 m
Most dangerous sharks⁷ [SHARKCAT]	0.03f.	-	-
Victim's age [AGE]	0.4213 ^w	31 y.o	34 y.o
[SEX]	0.32 ^k	-	-
Victim's activity⁸ [ACTIVITY]	0.0019f.	-	-
Human–shark interactions outcomes (severity score)⁹ [GRAV]	0.041f.	-	-
Human–shark interactions outcomes (fatal or not fatal) ¹⁰ [INJURY]	0.368 ^k	-	-
Rainfall the day of a human–shark interaction [RAIN]	0.2153 ^w	2.6 mm	7.2 mm
Cumulated rainfall during the three days preceding a human–shark interaction [RAIN]3	0.6553 ^w	12 mm	10.2 mm
Cloud cover [CLOUD]	0.171 ^w	37.8%	46.1%
Swell height [SWELL]	0.00028^w	0.75 m	1.2 m
Water turbidity ¹¹ [TURB]	0.534 ^k	-	-
Moon phase ¹² [SCOREMOON]	0.435 ^k	-	-

Table 2. Comparison of the environmental conditions of human–shark interactions in New Caledonia before and after January 2008. ¹ Day of the week when the human–shark interaction occurred (Monday, Tuesday, etc.). ² Month of human–shark interaction, classified into two categories: summer (October to March) or winter (April to September). ³ Hour of human–shark interaction, classified into periods of 1 h from 7 to 20. ⁴ Hour of human–shark interaction, classified into two categories: before or after 12 pm. ⁵ Human–shark interaction location (zone), classified into five categories: East, West, Loyalty Islands, Noumea suburban, Bays of Noumea. ⁶ Orientation of the coastline to the prevailing winds (leeward or windward). ⁷ Most dangerous sharks, classified into two categories: large sharks (tiger, bull and white) or other species. ⁸ Victim's activity, classified into four categories: practising boardsports, spearfishing, swimming, and scuba diving. ⁹ Human–shark interactions outcomes (severity score), classified into five categories: 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. ¹⁰ Human–shark interactions outcomes, classified into two categories: fatal or non-fatal. ¹¹ Classified into four categories: clear, slightly turbid, turbid, highly turbid. ¹² Classified into four categories: new moon, first quarter, last quarter, full moon. ¹³ The letter beside the p-value indicates the test used (w for Welch's t test, k for the chi-squared test, f for the Fischer test).

(51%) and, to a lesser extent, GRAV, TURB, and INJURY. Thus, the modalities (Fig. 10) that highlight the first dimension were found: boardsports in Noumea Bay in the period 2008–2021, in turbid waters and most often leading to death (positive on Axis 1). This contrasts with human–shark interactions in the Loyalty Islands, which were in clear water and were not fatal in the period before 2008 (negative on Axis 1). The additional quantitative variables (Fig. 7) SWELL and CLOUD were positively correlated on Axis 1 with mortality in the bays of Noumea human–shark interactions. Although these factors (SWELL and CLOUD) are not explanatory, it seems that cloud cover and especially swell were present during human–shark interactions from 2008 onwards, in contrast to before 2008. This may be explained by the fact that the practise of boardsports (kiteboarding) requires wind, which itself generates swell.

Axes 2, 3, 4 and 5 (Fig. 6, Fig. 7, and Table S3) were not sufficiently characteristic with respect to the variance explained.

Severity was added as an additional qualitative variable (Fig. 8 qualitative) to clarify the links between the modalities and not to penalize the variance explained by the MCA. This approach highlighted the links between practises and consequences. Thus, human–shark interactions with spearfishers were linked to “low injury”, and interactions with humans practising boardsports were linked to either “death” or “light injury or damage”. Only two interactions were reported in the latter category. This finding confirmed the results of the univariate analysis.

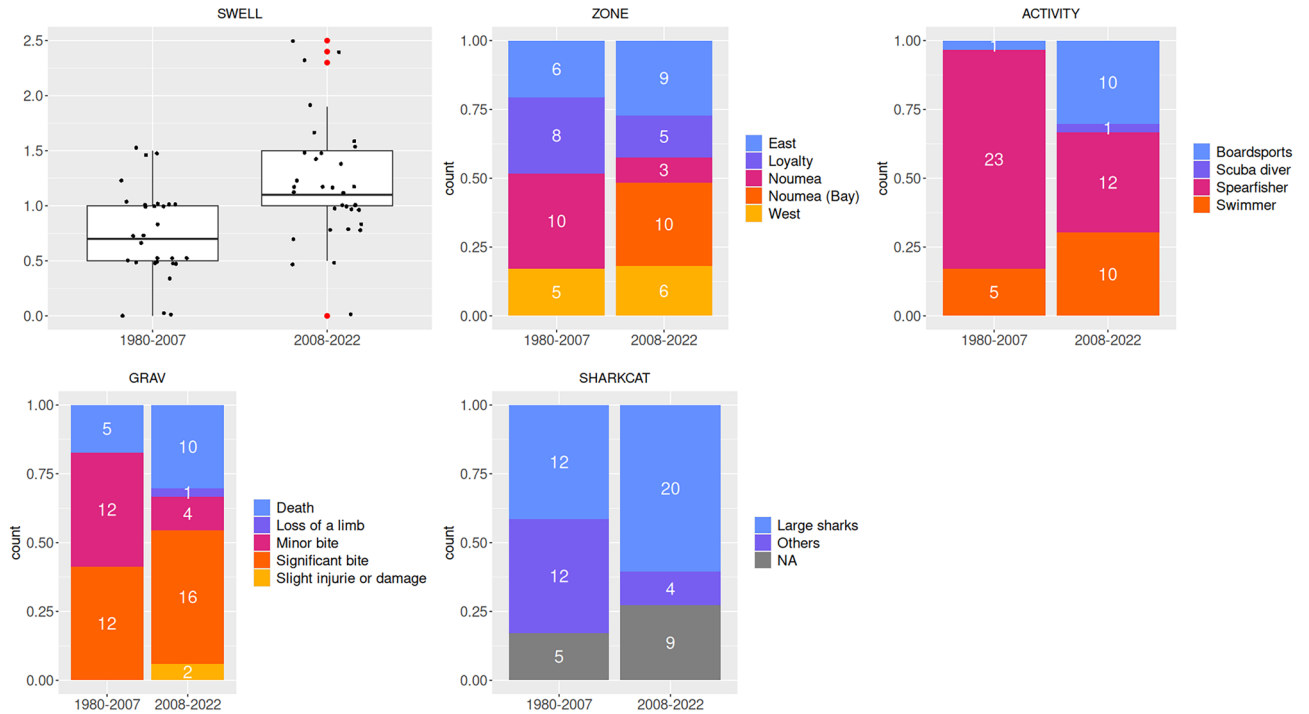


Fig. 5. Distribution of the significant variables describing the environment conditions and human–shark interactions characteristics before and after 2008 in New Caledonia.

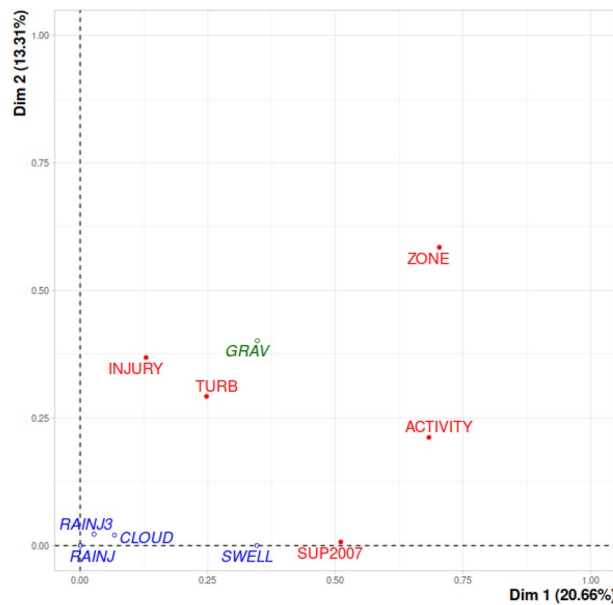


Fig. 6. Graph of the variables in New Caledonia.

Multivariate comparative analysis of databases (New Caledonia and Reunion Island)

Factor analysis of mixed data (FAMD) was used to compare data from New Caledonia and Reunion Island. Thus, the contributions of each variable to these new factorial axes were analysed to better understand the significance of each axis in relation to the original variables. Location (SITE variable) was included as an additional qualitative variable and was not included in the new spatial representation. This approach enabled the analysis to focus on variables common to both sites and their possible correlations.

This method provides information on any common features between New Caledonia and Reunion during human–shark interactions, as well as any features specific to each territory.

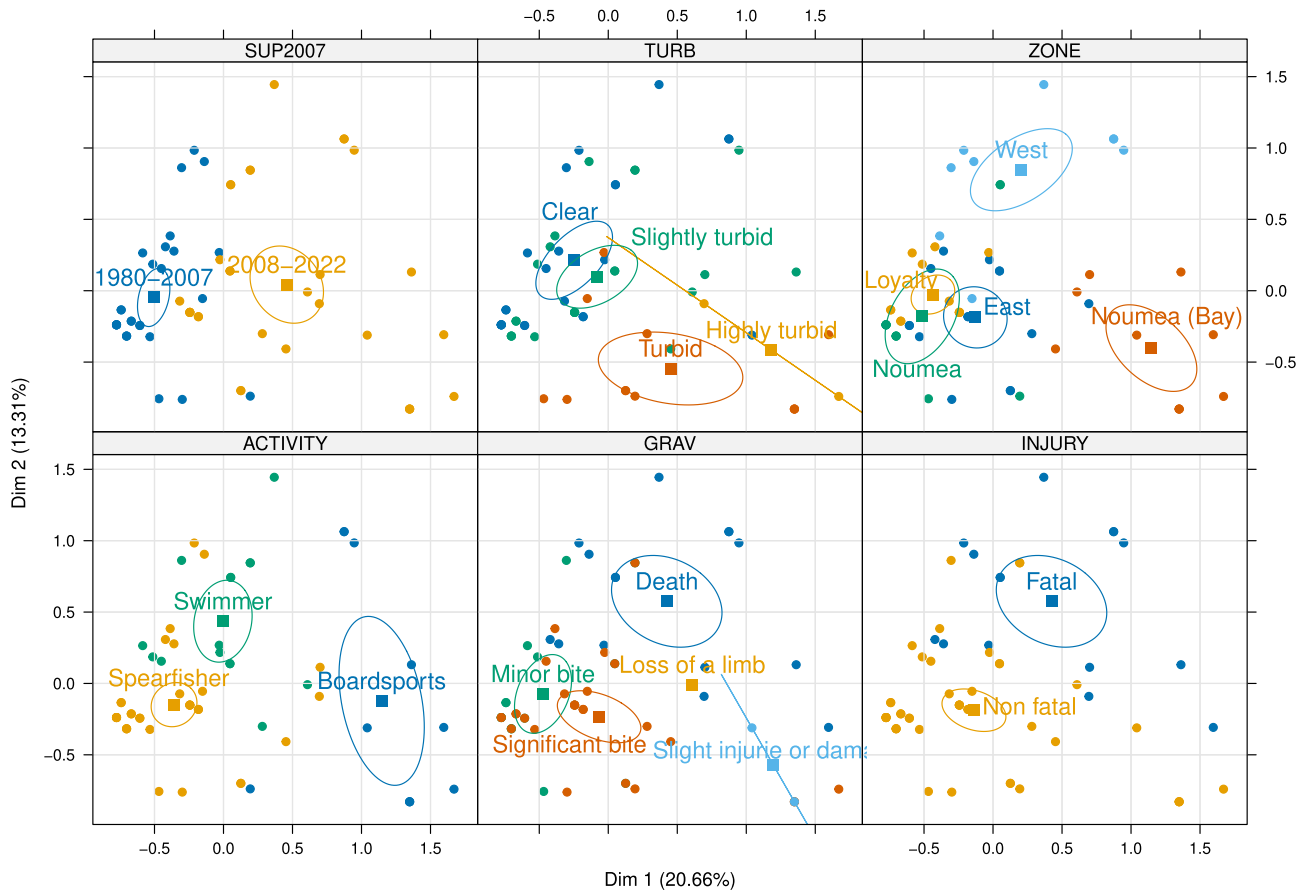


Fig. 7. Modality graph and confidence ellipses in New Caledonia.

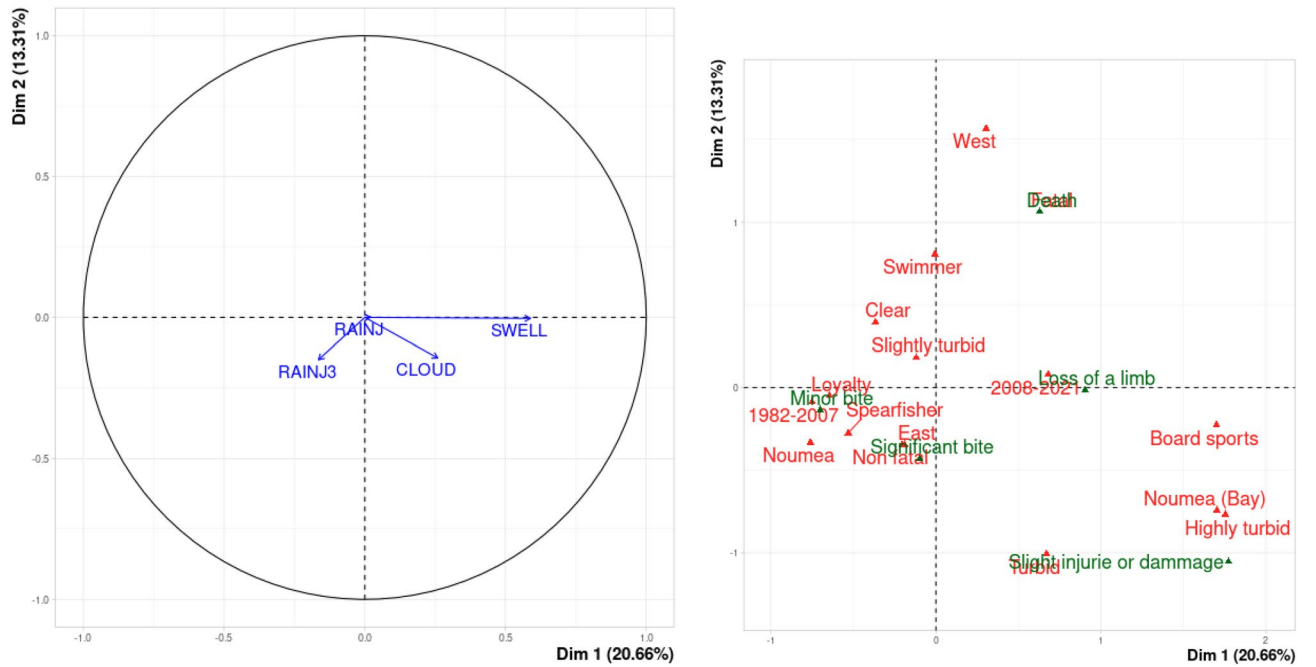


Fig. 8. The additional variables in New Caledonia.

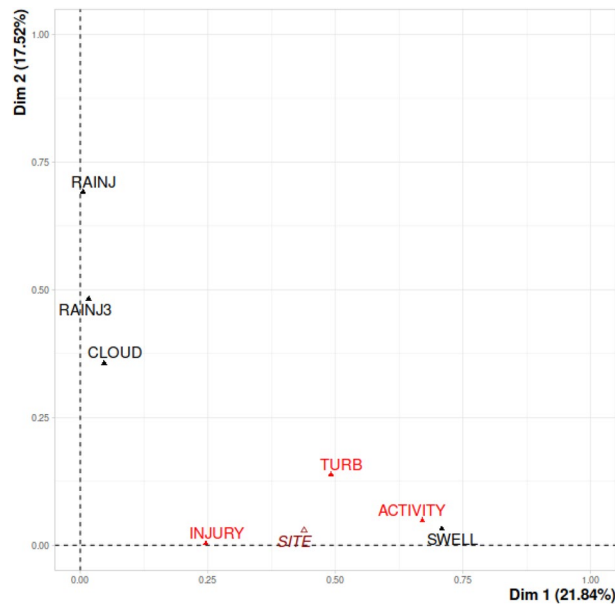


Fig. 9. Graph of the variables in New Caledonia and Reunion Island.

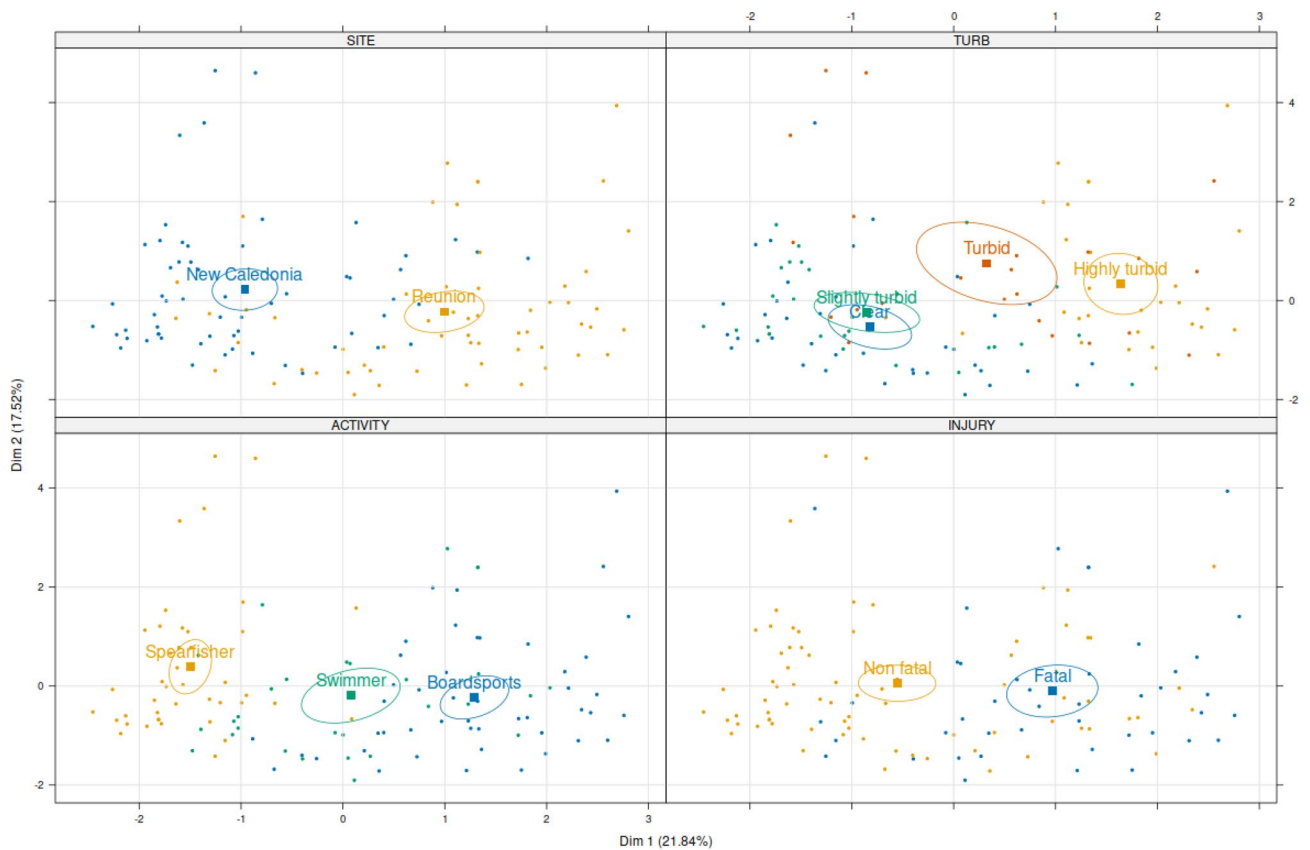


Fig. 10. Modalities graph and confidence ellipses in New Caledonia and Reunion Island.

For the sake of consistency, one attack was considered an outlier due to unusual rainfall at +3 days (RAINJ3) and was not included for analysis. Similarly, three scuba diving-related attacks were not included in the analyses because of their low frequency.

Axis 1 (Fig. 8, Fig. 9, Table S4) shows a correlation mainly between the variables site, swell, activity, turbidity and, more marginally, mortality. Axis 1 thus highlights the typology of each site. Thus, most human–shark

interactions on Reunion Island occurred during sliding sports in a turbid environment, with fatal outcomes. Conversely, on this axis, New Caledonia presents a dataset where human–shark interactions are more often the result of underwater hunters in clear waters, with a nonfatal outcome. The latter can be explained by the fact that hunters equipped with a harpoon can repel sharks. Wearing a scuba mask is also a protective factor, as hunters can have eye contact with sharks⁴⁶.

These different results between New Caledonia and La Réunion are due to the differential development of coastal sports between the two territories. In New Caledonia, for example, there is a long history of spearfishing, as well as a recent craze for aerotow sports (e.g., windsurfing, kitesurfing, wing foiling), which do not necessarily require waves. On the other hand, Reunion Island has experienced a massive increase in the number of board sports enthusiasts since the 1990s (surfing and bodyboarding), as well as the historic presence of underwater hunters.

Nevertheless, these analyses do not prejudge future developments in New Caledonia since 2007 (appearance of human–shark interactions on boardsports in the bays of Noumea).

Conclusion

In New Caledonia, human–shark interactions were heterogeneously distributed across the territory and over time. The most striking results were the concomitant increase in human–shark interactions since 2010 in the bays of Noumea and, since 2007, human–shark interactions among people practising boardsports.

Moreover, turbidity was another strong characteristic of human–shark interactions, where 3 out of 4 human–shark interactions took place in clear or slightly turbid water. These data indicate that slight water turbidity is not a protective factor in New Caledonia. In contrast, on Reunion Island, 2 out of 3 human–shark interactions took place in turbid or very turbid water. This increased turbidity on Reunion Island is explained by the type of sports practised, which requires swelling, which itself generates turbidity.

Furthermore, the mortality rate from human–shark interactions in New Caledonia was specific, as it was three times higher than the global average due to the shark species and their large height. These fatal human–shark interactions particularly affected boardsports enthusiasts and swimmers, although the mortality rate for the latter group was relatively low.

For the multivariate analysis in New Caledonia, it seemed that cloud cover and especially swells were present during human–shark interactions from 2008 onwards. These weather conditions are related to the evolution of coastal sports practises that require either wind or swelling. The variables' representation in the factorial plane and the confidence ellipses show significant correlations between the modalities of the human–shark interactions. Axis 1 is the most decisive in separating the different modalities, whereas the other axes are not sufficiently characteristic. The addition of severity as a supplementary qualitative variable enhanced the understanding of the links between practises and consequences.

Finally, the comparative multivariate analysis of the New Caledonia and Reunion Island databases revealed that when the site variable was used as an additional qualitative variable in the analysis, the common variables were compared to identify differences between the two sites and to understand the factors that contribute to their characteristics. Axis 1 highlights the typology of each site, showing that Reunion Island experienced fatal human–shark interactions during boardsports practise in turbid environments, whereas New Caledonia experienced nonfatal human–shark interactions during spearfishing in clear water.

Regarding possible prevention measures to limit human–shark interactions, only swimmers currently benefit from collective protection in the bays of Noumea, from the installation of two protective nets in 2023 and 2024. For others, such as spearfishers, boardsports enthusiasts, and scuba divers, setting up nets is not feasible due to the area required for these activities. However, the use of personal electric deterrents can reduce human–shark interactions⁴⁷ for swimmers, spearfishers, scuba divers, and surfers. Complementarily, reducing the risk of human–shark interaction can also involve limiting the severity of injuries through technological innovations and providing the most appropriate care for the injured whenever possible. For other boardsports enthusiasts, who have become increasingly numerous in the bays of Noumea since 2010, recommendations remain very limited.

Beyond this study, it would be advisable, as we have done in Reunion Island and New Caledonia, to continue comparative analyses in other marine areas where human–shark interactions occur. Thus, it would involve using the same variables as those used in the article for comparison purposes and producing an interactive map based on the model of the one designed and created in this study.

Future research should further explore behavioural factors and shark ecology using ethological approaches, such as ethograms, to better understand shark motivations during interactions. Additionally, given the increasing urban use of coastal waters, especially for emerging watersports, there is a growing need for targeted public awareness strategies, context-specific risk mitigation policies, and sustainable coexistence frameworks that balance human safety with shark conservation.

Software and data analyses

The data were exploited using Microsoft Excel Version 16 and R Software⁴⁸, version 4.2.2 and the R library FactoMineRV2.11⁴⁹. The interactive map⁴² was created using JavaScript V13/HTML5, jQuery V3.6.0 and jCanvas v21.0.1

Data availability

Datasets on human–shark interactions in New Caledonia and Reunion Island (1980–2022) produced and analysed by the authors of the study are available (<https://doi.org/10.5281/zenodo.12549370>).

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References

- Torres, D. F., Oliveira, E. S. & Alves, R. R. N. Understanding human–wildlife conflicts and their implications. in *Ethnozoology* 421–445 (2018).
- Conover, M. R. *spsampsps Conover, D. O. Human-Wildlife Interactions: From Conflict to Coexistence.* (CRC Press, 2022).
- Losen, B. Uses of scientific discourses and markers in shark attack risk management on Reunion Island. *Mar. Policy* **161**, 106011 (2024).
- Hardiman, N., Burgin, S. & Shao, J. How sharks and shark–human interactions are reported in major Australian newspapers. *Sustainability* **12**, 2683 (2020).
- Le Busque, B., Roetman, P., Dorrian, J. & Litchfield, C. An analysis of Australian news and current affair program coverage of sharks on Facebook. *Conserv. Sci. Pract.* **1**, e111 (2019).
- Sabatier, E. & Huvneers, C. Changes in media portrayal of human–wildlife conflict during successive fatal shark bites. *Conserv. Soc.* **16**, 338–350 (2018).
- Le Busque, B., Dorrian, J. & Litchfield, C. The impact of news media portrayals of sharks on public perception of risk and support for shark conservation. *Mar. Policy* **124**, 104341 (2021).
- Losen, B. Shark attack risk on Reunion Island: Emphasis on local media construction. *Mar. Policy* **157**, 105851 (2023).
- Chapman, B. K. & McPhee, D. Global shark attack hotspots: Identifying underlying factors behind increased unprovoked shark bite incidence. *Ocean Coast. Manag.* **133**, 72–84 (2016).
- Baldrige, H. D. *Shark Attack: A Program of Data Reduction and Analysis. Contributions from the Mote Marine Laboratory.* 98 (1974).
- Midway, S. R., Wagner, T. & Burgess, G. H. Trends in global shark attacks. *PLoS ONE* **14**, e0211049 (2019).
- Maillaud, C. *et al.* Attaques de requins en Nouvelle-Calédonie de 1958 à 2020: revue de cas. *Médecine Trop. Santé Int.* **2**, (2022).
- Hazin, F. H., Burgess, G. H. & Carvalho, F. C. A shark attack outbreak off Recife, Pernambuco, Brazil: 1992–2006. *Bull. Mar. Sci.* **82**, 199–212 (2008).
- Trape, S. Shark attacks in Dakar and the Cap Vert Peninsula, Senegal: low incidence despite high occurrence of potentially dangerous species. *PLoS ONE* **3**, e1495 (2008).
- Taglioni, F., Guiltat, S., Teurlai, M., Delsaut, M. & Payet, D. A spatial and environmental analysis of shark attacks on Reunion Island (1980–2017). *Mar. Policy* **101**, 51–62 (2019).
- West, J. G. Changing patterns of shark attacks in Australian waters. *Mar. Freshw. Res.* **62**, 744–754 (2011).
- Ferretti, F., Jorgensen, S., Chapple, T. K., De Leo, G. & Micheli, F. Reconciling predator conservation with public safety. *Front. Ecol. Environ.* **13**, 412–417 (2015).
- Gay, J.-C. *Vivre dans le Grand Nouméa.* in *Atlas de la Nouvelle-Calédonie* (2012).
- Institut de la statistique et des études économiques de Nouvelle-Calédonie. <https://www.isee.nc/>.
- Global Shark Attack File. <http://www.sharkattackfile.net/>.
- Neff, C. & Hueter, R. Science, policy, and the public discourse of shark “attack”: a proposal for reclassifying human–shark interactions. *J. Environ. Stud. Sci.* **3**, 65–73 (2013).
- Taglioni, F., Guiltat, S. & Delsaut, M. Datasets of Human–shark interactions in New Caledonia and Reunion Island (1980–2022). <https://doi.org/10.5281/zenodo.12549370> (2025).
- McPhee, D. Unprovoked Shark Bites: Are they becoming more prevalent?. *Coast. Manag.* **42**, 478–492 (2014).
- Klimley, A. P., Porcher, I. F., Clua, E. E. & Pratt, H. L. A review of the behaviours of the Chondrichthyes: A multi-species ethogram for the chimaeras, sharks, and rays. *Behaviour* **160**, 967–1080 (2023).
- Dreyer, F. *Les attaques de requins en Nouvelle-Calédonie.* (Strasbourg, 2001).
- Tirard, P. *Requins Du Caillou.* (Edition Philippe Tirard, Nouméa, 2011).
- Blaison, A. *et al.* Seasonal variability of bull and tiger shark presence on the west coast of Reunion Island, western Indian Ocean. *Afr. J. Mar. Sci.* **37**, 199–208 (2015).
- Gauthier, C. *Expertise médicale des victimes d’attaques de requins à l’île de La Réunion. Médecine vol. Thèse* (Université de Bordeaux II, Bordeaux, 2012).
- Tucker, J. P. *et al.* Increased shark bite survivability revealed by two centuries of Australian records. *Sci. Rep.* **12**, 14121 (2022).
- Lentz, A. K. *et al.* Mortality and management of 96 shark attacks and development of a shark bite severity scoring system. *Am. Surg.* **76**, 101–106 (2010).
- Davies, D. H. & Campbell, G. D. The aetiology, clinical pathology and treatment of shark attack. *J. R. Nav. Med. Serv.* **48**, 110–136 (1962).
- McPherson, G. *Shark Control Operations, Mogadishu, Somalia. Overseas Trip Report.* 16 (1994).
- Martin, R. A. Conservation of freshwater and euryhaline elasmobranchs: A review. *J. Mar. Biol. Assoc. U. K.* **85**, 1049–1073 (2005).
- French, L. A., Midway, S. R., Evans, D. H. & Burgess, G. H. Shark Side of the Moon: Are Shark Attacks Related to Lunar Phase?. *Front. Mar. Sci.* **8**, 745221 (2021).
- Ritter, E., Amin, R. & Zambesi, A. Do lunar cycles influence shark attacks. *Open Fish Sci. J.* **6**, 74–74 (2013).
- Weltz, K., Kock, A. A., Winker, H., Attwood, C. & Sikweyiya, M. 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**, (2013).
- Kanji, G. K. *100 Statistical Tests.* (SAGE Publications, 2006).
- Lewis, N. D., Da Costa Lewis, N. & Lewis, N. D. *100 Statistical Tests in R: What to Choose, How to Easily Calculate, with Over 300 Illustrations and Examples.* (Heather Hills Press, 2013).
- Benzécri, J.-P. *Correspondence Analysis Handbook.* (2019).
- Tuffery, S. *Data Mining et Statistique Décisionnelle.* (2012).
- Escofier, B. & Pagès, J. *Analyses Factorielles Simples et Multiples.* (2008).
- Taglioni, F. & Guiltat, S. Interactive map of shark attack on New Caledonia (2025).
- Ryan, L. A. *et al.* Environmental predictive models for shark attacks in Australian waters. *Mar. Ecol. Prog. Ser.* **631**, 165–179 (2019).
- Bosserelle, C., Reddy, S. & Lal, D. *WACOP, Wave Climate Report. Noumea New Caledonia.* [https://wacop.gsd.spc.int/Atlas/Region al/Pdf/NC/Noumea.pdf](https://wacop.gsd.spc.int/Atlas/Region%20al/Pdf/NC/Noumea.pdf) (2015).
- Lee, K. A., Roughan, M., Harcourt, R. G. & Peddemors, V. M. Environmental correlates of relative abundance of potentially dangerous sharks in nearshore areas, southeastern Australia. *Mar. Ecol. Prog. Ser.* **599**, 157–179 (2018).
- Ritter, E., Amin, R. & Farquhar, E. Does the Type of Dive Mask Matter to a Shark?. *Open J. Anim. Sci.* **10**, 618–626 (2020).
- Clarke, T. M. *et al.* Personal electric deterrents can reduce shark bites from the three species responsible for the most fatal interactions. *Sci. Rep.* **14**, 16307 (2024).
- Team, R. C. R. *A language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria, 2012. (2014).
- Lê, S., Josse, J. & Husson, F. FactoMineR: An R package for multivariate analysis. *J. Stat. Softw.* **25**, 1–18 (2008).
- Météo France <http://www.meteofrance.com/accueil>.

51. National Oceanic and Atmospheric Administration- WAVEWATCH III <http://polar.ncep.noaa.gov/waves/index2.shtml>.

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FT: Conceptualization, Data curation, Formal analysis, Writing—original draft, Writing—review & editing SG: Conceptualization, Data curation, Formal analysis, Writing—original draft, Writing—review & editing. MD: Data curation, Formal analysis, Writing—original draft, Writing—review & editing PT: Data curation, Formal analysis DP: Data curation, Formal analysis.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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