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Ateret Shabtay, Erwann Lagabrielle, Virginie Plot, Gaël Potin, David Guyomard

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Marine spatial planning provides a comprehensive framework for building evidence-based shark risk management policies with sea-users

Shabtay Ateret [1,*] , Lagabrielle Erwann [1], Plot Virginie [2], Potin Gaël [2], Guyomard David [3]

[1] UMR ESPACE-DEV, Université de La Réunion, Saint-Denis, La Réunion, France
[2] UMR ENTROPIE, IRD-CNRS-Université de La Réunion, Saint-Denis, La Réunion, France
[3] Centre Sécurité Requin, La Réunion, France

* Corresponding author : Ateret Shabtay, email address : ateret.shabtay-yanai@univ-reunion.fr

Abstract :

Marine spatial planning (MSP), a process aimed at negotiating the spatial allocation of human activities at sea, has to integrate new challenges arising from growing human activities and their impacts on threatened marine ecosystems. Yet, human–wildlife interactions that result in threat to humans are rarely explicitly addressed in planning and almost not at all in MSP. Rare events of unprovoked shark bites can significantly impact local economies while leading to polarized social debates that often hinder the development of evidence-based shark risk public policy. Here, we suggest an approach for integrating shark risk and its management into MSP. The method addresses simultaneously the spatial, social, and ecological components of shark risk and its inherent uncertainties. The approach is applied on Reunion Island case study where shark risk management is implemented as a response to a rapid increase in the frequency of shark bite events over the past decade. Similar to other countries where shark risk management is implemented, sharks' removal is in the heart of social debate in Reunion Islands (3860 shark fishing operations in 5 years) and data gaps provide a fertile ground for alternative discourses and social conflicts about shark risk. Through a structured public consultation involving 200 stakeholders we demonstrate how MSP can be used to address shark risk while considering multiple sea-uses and conservation objectives. The results suggest that the approach is ideal, both for integrating shark risk as a driver to the MSP process, and for developing a transparent, sustainable and evidence-based shark risk public policy as it places shark risk management within a broader social-ecological spectrum of stakes.

Highlights

► MSP is an effective platform for addressing human-shark related conflicts. ► MSP contributes to the development of shark risk management policies. ► Suggested planning approach highlights risk-related data gaps.

Keywords : Marine spatial planning, Shark risk management, Human–wildlife interactions

1. Introduction

Marine spatial planning (MSP) is a political process that aims to bring multiple ocean users to negotiate informed and coordinated decisions about the sustainable future use of marine resources (Ehler and Douvere, 2009). Being useful for realizing the ecosystem approach by analyzing and allocating human activities in the marine space, MSP initiatives are applied in about 70 countries around the world, which face multiple and various challenges (MSP Programme IOC-UNESCO, 2019; Santos et al., 2019). Moreover, MSP mechanisms and principles has been integrated within the legal framework of several countries including the EU member states (EC, 2014).

The theory and practice of MSP have significantly developed in the past decade and adapted to new challenges. The growing concern to marine ecosystems and impacts of climate change, along with increasing human activity at sea, drove this evolution and demonstrated the adaptability of the MSP framework (e.g., Gissi et al., 2019; Santos et al., 2016; Young, 2015; Zanuttigh et al., 2016). The ability of MSP to adapt to new challenges might therefore be useful also for planning the management of specific human-wildlife interactions at sea.

Although most of those interactions result in threat to wildlife, some interactions such as shark bites on humans receive significant attention. Shark bite events in the past 30 years were recorded in more than 50 countries, most of them (83%) in United States, Australia, South Africa, Brazil, and Reunion Island (ISAF, 2019). Despite being a global phenomenon, fatality rates of unprovoked shark bite are relatively low (average of <10 people per year globally) (ISAF, 2019). Yet, public response to these events is often impacting local economies due to following reduction in marine recreation activities and tourism (Lemahieu et al., 2017; Simmons and Mehmet, 2018). In addition, shark risk management that involves shark removal often triggers disputes regarding management’s effectiveness and its impact on marine ecosystems. Therefore, shark risk and its related management should be addressed from holistic perspective within an interdisciplinary framework that considers the ecological and social aspect of it (Lagabrielle et al., 2018a).

In the present study, we use MSP as a backbone structure to frame shark risk and its related management within the wider scope of managing multiple human activities in the marine space. We suggest an approach for integrating shark risk into MSP-related spatial analyses, consultation processes, and decision-making. The approach identifies the social and ecological issues related to spatial overlap between humans and sharks, and supply a solid ground for negotiations regarding shark risk management allocation. We first explore how human-wildlife interactions are referred to in spatial planning and how shark risk is managed, to prescribe an adjusted and relevant MSP approach that addresses shark risk within a broader social-ecological scope. Then, we apply the prescribed methodology on an MSP process in Reunion Island (France, Indian Ocean), where the rate of lethal shark bite events is one of the world's highest (ISAF, 2019).

2. Integrating shark risk management into MSP

2.1 Human-wildlife interactions and spatial planning

Threats to humans as a result of human-wildlife interactions are rarely addressed through spatial planning and especially not in the marine environment. In most cases, planning considers human impact on wildlife and not the other way around. As evidence are the numerous tools and approaches developed in the past decade to use planning for mitigating threats to wildlife caused by human activities and to ensure ecosystem-based management (Lombard et al., 2019; Pınarbaşı et al., 2017). Therefore, using MSP to address threat to humans as a result of human-wildlife interactions, may require adoption of perspective that captures both the ecological and social dimensions of those interactions, across time and spatial scales.

A key step towards understanding the complexities of conflicting human-wildlife interactions, is exploring their related social factors .Dickman (2010) suggests that human-wildlife conflicts represent conflicts between social groups with antagonistic opinions. Planners and authorities who direct MSP and who are usually familiar with social conflicts in general but less with specific human-wildlife conflicts, can therefore use their skills to investigate social factors related to human-wildlife interaction, to initiate conflict's mitigation process.

Stakeholders and public participation in MSP processes is an opportunity to investigate social conflicts about human-wildlife interactions. A broad-scoped public consultation can reach beyond antagonistic debates about these interactions and develop an understanding of the mental representations involved. The consultation process can also be used to estimate the extent and intensity of the conflict which is needed to determine whether sufficient grounds for negotiation exist (The Consensus Building Institute, 2000). Thus, understanding the stakes and history of the conflict, and identifying social groups in early stages, may direct the organization of stakeholders' interactions within the MSP process at later stages.

2.2 Shark risk management

Shark risk management is applied where events of unprovoked shark bite occurred several times, in attempt to reduce the probability of their occurrence. Management measures include warning and education, surveillance, at-sea devices such as lethal shark nets and drumlines, exclusion shark nets, and personal electromagnetic devices for sea users. The effectiveness of these measures is still unclear despite their constant assessment by scientists and management authorities (Clua and Linnell, 2019; CSR, 2017; Curtis et al., 2012; Guyomard et al., 2019). Especially controversial is whether management effectiveness in terms of reducing risk to humans worth its impact on marine ecosystems (Atkins et al., 2016; EPA, 2014; Gibbs and Warren, 2015). Moreover, impacted by the reaction of people to the risk, management is often an adaptive, sometime erratic, process that responds to random variations in locations of shark bite events, changing legislations, instruments availability, social tolerance to the risk, and social acceptance of the management (Gibbs and Warren, 2015; Pepin-Neff and Wynter, 2018; Pepin-Neff, 2019; Simmons and Mehmet, 2018). Therefore, shark risk management is often applied under condition of uncertainty and remains a matter of social controversies.

2.3 Addressing shark risk through marine spatial planning

The random character of the risk and the ad hoc, emotion-driven, character of shark risk management policies is a challenge for MSP which is a long and wide process that considers multiple marine uses, their long-term development stakes and environmental impacts at once. Still, the integration of shark risk management into MSP may contribute to better conceptualizing and contextualizing the risk, its management, and the associated social representations.

We suggest that shark risk and related management should be conceptualized within a three components framework (Figure 1). The first component is the ecological system, its structure and dynamics that might influence shark presence and might be impacted as a result of shark risk management. The second component is the social system with stakeholders and social groups of opinions, building up representations of the issue and competing to influence shark risk management. The third component is the geographic area of interaction where the ecological system and the social system meet. In this geographic area human-shark interactions may result in a threat to people, sharks, or ecosystems as a whole. The management of this area is a stake of negotiations in the social system and therefore in the MSP process. At the same time, MSP can be conceptualized as a framework to shape shark risk management public policy, and address social demand in a sustainable way. MSP which is embedded within a robust legal framework, might also enable the public policy to be negotiated and implemented.

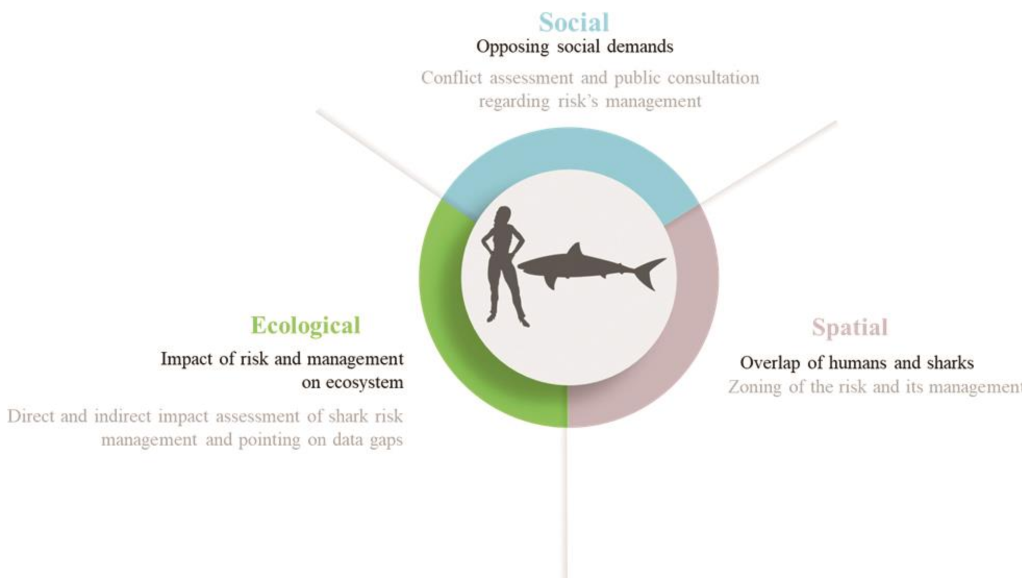

Figure 1. The three components of socioecological interaction, the challenges they pose for MSP (black text) and how they are addressed through MSP (gray text).

The three components of the interaction can be addressed using tools and consultation processes that are often being used in MSP as presented in Figure 2. Directing those tools towards shark risk and related management, will advance the understanding of the multicomponent nature of the shark-risk issue and the dependencies that may exist between these components. Sharks play an important ecological role in marine ecosystems and therefore human activities primarily designed for sharks' removal, have considerable potential for negatively impacting marine ecosystems (Ferretti et al., 2010). Therefore, impact assessment in the MSP process should include an overlap of shark risk management with areas prioritized for marine conservation and direct impact of shark risk management on sharks' populations and other taxa (e.g. bycatch of shark control operations or wildlife entangled in shark nets, see Atkins et al. 2013). Ideally, the indirect impact on the ecosystem should be assessed as well. Ecological modelling and especially food-web modelling could be highly useful for these assessments (Shabtay et al., 2018).

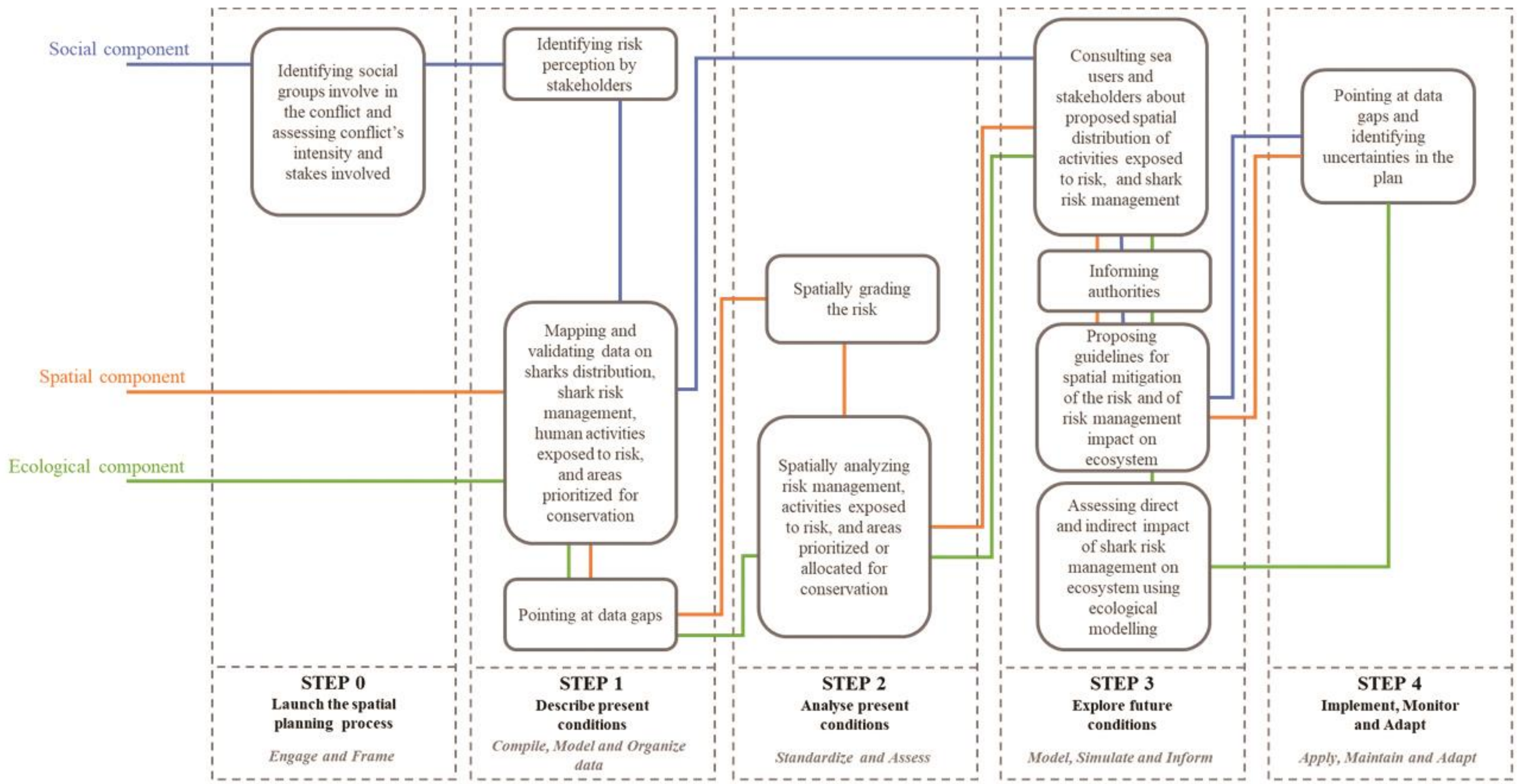

Figure 2. Tools and consultation processes that can be used throughout the marine spatial planning process to address the social, spatial, and ecological components of human-shark interaction. Simplified version of marine spatial planning stages (Ehler and Douvere, 2009) is adopted from Lagabrielle et al. (2018b).

3. Case-study: Integrating shark risk and related management into MSP in Reunion Island

3.1.1 Study site

Reunion Island is a French volcanic island in the Southwestern Indian Ocean (21°07'S/55°32'E) with an overall area of 2512 km^2. After rapid population growth since 1980, the island inhabits today about 860,000 people. The majority of the population resides along the coasts of the island and especially along the most urbanized northern and western coasts.

3.1.2 Shark risk management

Shark bite events have been known throughout the history of Reunion Island. However, the frequency of these events has increased dramatically by a factor of 23 since 2010 with 25 events of shark-bite that resulted in 11 fatalities up to this day (CSR, 2019a; Lagabrielle et al., 2018a). The majority of bite events was of surfers (i.e. wave-based activities) and caused by bull sharks (*Carcharhinus leucas*) and tiger sharks (*Galeocerdo cuvier*). The causes for the increased frequency of shark-bite events are still unclear to scientists.

Yet, studies suggested that among the potential causes are changes in sea water temperature, increased freshwater and sewage discharge along the west coast, and changes in shark's behavior due to degradation of prey populations including depletion of reef sharks by overfishing (Chapman and McPhee, 2016; Lagabrielle et al., 2018a). Furthermore, Guyomard et al. (2020) suggest that ban on sharks' finning and sharks' meat selling due to ciguatera concern, decreased sharks' fishing and therefore increased potentially dangerous sharks' abundance along the coasts. (see also Guyomard, 2016; Le Manach et al., 2015). In addition, Thiann-Bo Morel (2019) presented social groups debated ideas about the causes of this increased frequency that include the establishment of a coastal marine protected area (MPA) in 2007.

Following a series of shark bite events in 2011, shark risk management measures were developed to reduce the risk. In 2013, the local government released a prefectural decree (Arrêté préfectoral n°222 du 15 février 2018, 2018) that bans bathing and wave-based activities along most of the island's coasts up to a distance of 300 m from the shore. The ban is excluding areas of shallow lagoons, coastal pool, and areas of surveillance. Since 2014, preventive shark control is operated and targeting individuals of bull shark and tiger shark that approach the coast. Control operations include lethal horizontal longline and SMART drumline devices (Guyomard et al., 2020). Later, in 2015, two large shark exclusion nets totalizing ~1km length were placed at two locations to allow surfing and bating activities, but are no longer operational due to unsustainable maintenance costs. Yet, 3 smaller nets for bathing remained operational.

At the same time, an innovative in-situ surveillance program was launched along the west coast of the island. Surveillance operations include in-water observers, water crafts, and a beach-based team that provides emergency response in case of shark observation or shark bite event. Both, exclusion nets and surveillance operations are located in 5 designated areas named ZONEXs (zone for experimental shark risk management measures) and are distributed along the west coast of the island.

Since 2016, shark risk management in the island is developed and coordinated primarily by Le Centre Sécurité Requin (CSR), which is a boundary organization placed under the authority of the state, regional council and municipalities. Daily information on shark management are accessible on http://www.info-requin.re, but no spatially explicit long-term analysis and synthesis of this information has been developed and released to the public so far.

3.1.3 Marine Spatial Planning process: The Ocean Metiss project

In Reunion Island, the on-going MSP process, named Ocean Metiss (see https://www.oceanmetiss.re, 2019), aims to develop a sustainable, integrated, long-term maritime development strategy and to implement it through a marine spatial plan of the exclusive economic zone of the island. Ocean Metiss is a partnership project cofunded by the European Maritime and Fisheries Fund, France state, and Reunion Island regional council. The interdisciplinary project is associating with the University of Reunion for its implementation, and the Indian Ocean Commission as a technical partner. From a European Commission perspective, Ocean Metiss is a pilot-project aiming to investigate innovative MSP processes, tools and methods that will facilitate the implementation of the European Directive on MSP (EC, 2014).

3.2 Methods

The Ocean Metiss project serves as a backbone structure for developing and testing our approach for addressing shark risk in MSP and designing MSP-based shark risk management, throughout the five planning stages as presented in Figure 2 and Table 1.

Table 1. Applying the integrative approach for marine spatial planning and shark risk in Ocean Metiss project, following Ehler and Douvere (2009) planning stages.

Planning stage	Objectives	Methods	Tools
Stage 0- Launch the spatial planning process	0.1. Formulate vision, goals, and objectives for the planning process. 0.2. Identify and describe conflicts related to shark risk.	Three stakeholders' meetings (200 participants each) were organized. Stakeholders from various marine sectors discussed opportunities and challenges relating to their sectors in several working groups. Meetings transcription was analyzed following statistical methods described in Kuckartz (2019) to identify major topics discussed and their links with specific sectors. This was also used to examine how stakeholders perceive shark risk in relation to other topics and sectors driving the MSP process. A literature review provided further information about shark risk management and related conflicts as it is today.	igraph package (Csardi and Nepusz 2006) for R (R Core Team 2014)
Stage 1- Describe present conditions	1.1. Collect spatial data on habitats, species and human activities including those exposed to shark risk[a], shark risk management[b], and marine protected areas. 1.2. Identify data gaps relating to shark risk and shark risk management.	Data layers were collected from multiple sources. An exhaustive list of data layers and data sources is available in Appendix A1. (see also https://www.oceanmetiss.re 2019, https://www.seasketch.org 2019). All data layers were gridded and mapped in planning units of 100x100 m and 1x1 km each from the coastline to 4 nautical miles.	ArcMap version 10.2

Stage 2- Analyze present conditions	2.1. Analyze spatial relationships (overlap and proximity) between human activities, species and habitats.	Spatial analysis was used to calculate spatial overlap of shark presence[c], human activities, and spatial management zones (both for conservation and shark management purpose). The relative high exposure of surfers to shark risk (see Arrêté préfectoral n°222 du 15 février 2018, 2018; Lagabrielle et al., 2018a), was represented by areas where surfing is practiced within and outside risk management areas[d] in a 1x1 km grid.	ArcMap version 10.2
Stage 3- Explore future conditions	3.1. Develop and negotiate a spatial plan for shark risk management (among a set of optional spatial plans) in the broader framework of a multi-sectorial marine spatial plan. 3.2. Propose guidelines for spatial mitigation of the risk and of risk management impact on ecosystem.	Stakeholders explore alternative management options, using an online tool for collaborative planning. This stage is expected to be finalized at the end of the consultation process in August 2020. Limited biomass data and planning resources did not allow using ecological modelling in the current planning cycle.	Seasketch
Stage 4- Implement, manage and assess	4.1. Implement shark risk management spatial plan as part of the broader marine spatial plan. 4.2. Assess spatial plan.	This stage is expected to be executed from September 2020.	ArcMap version 10.2 Policy instruments

[a] Activities exposed to shark risk were assumed to be any type that includes the immersion of the human body in the water, meaning bathing, diving, wave-based activities (hereafter = surfing), and wind-based activities. Freediving and spearfishing were also considered as activities exposed to risk, yet they were not investigated due to lack of updated data on their spatial distribution around the island. All activities exposed to risk are operated from the coast or from small boats.

[b] Shark risk management include ZONEXs (where shark nets and surveillance operations are implemented), and preventive shark control (drumlines and longlines).

[c] Due to limited data on sharks' species distribution around the island, we assumed sharks' presence in the entire area of interest.

[d] Preventive shark control operations were excluded from this analysis due to high level of uncertainty associated to its impact on the risk.

3.3 Results

3.3.1 Stage 0

Along the cycle of MSP conferences, the “sharks” theme, was identified by the stakeholders as one of the major themes of the MSP process. (Figure 3). The theme was found to be linked to several other themes by 17 causative or impacting factors. Out of all the linked themes, the greatest number of links to the “sharks” theme was to tourism (6) and fishing (3).

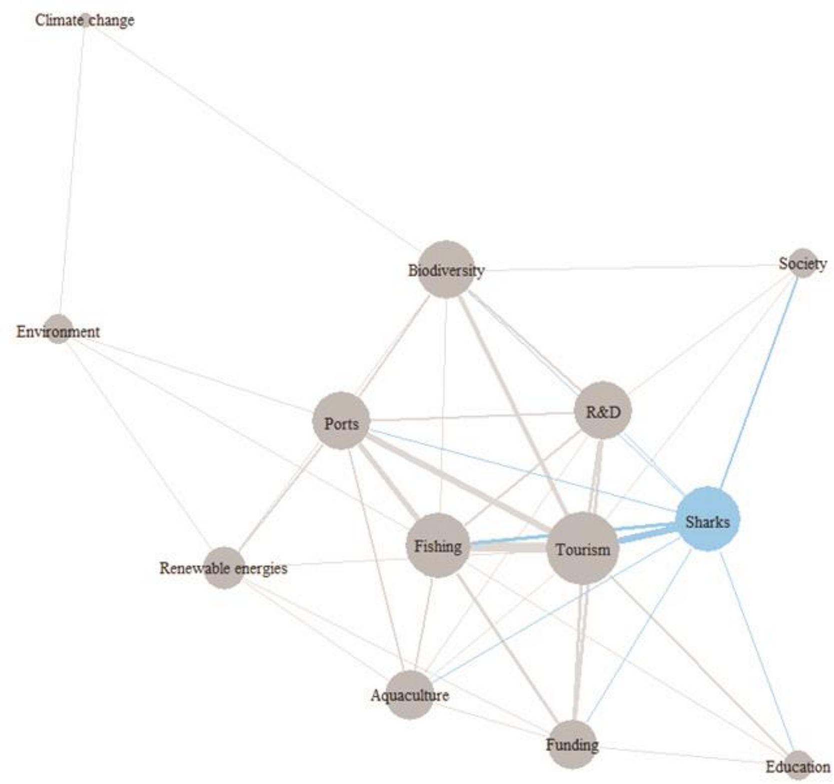

Figure 3. Thematic analysis of MSP drivers as viewed by the stakeholders. Each node represents a theme and lines represent link between themes in the form of cause or impact. The size and position of the node represent the number of other nodes linked to it (the larger and central the node, the more links it has). The width of the line represents the number of links that were identified between two nodes. The node that

represents the “sharks” theme and the links between shark’s theme and other themes are highlighted in blue.

Identification of social groups involved in the shark risk debate significantly profited from the study of Thiann-Bo Morel (2019). She identifies surfers and their supporters in Reunion Island as a social group claiming sharks’ removal in addition to other management measures. The study also sheds light on the complex context of the conflict to ethno-racial issues in a post-colonial community and environmental inequalities. The results of this study are also echoed by a survey which follows the work of Gibbs and Warren (2015) and is currently being processed by Lagabrielle (2019, unpublished) with support from the CSR. The preliminary results confirm that the main disagreements are between surfers and other sea users and revolve around shark removal policy. This study also shows the consensus among groups of users about other non-lethal shark management measures, including unanimous opposition against the decree that bans bathing around the island. The social component of shark risk and shark risk management in Reunion Island was also translated by Dupéré (2019) into legal basis for integrating shark risk into marine spatial planning.

3.3.2 Stages 1 and 2

In spatial terms, all activities exposed to shark risk besides freediving and spearfishing take place in an overall area of 23 km^2, most of it along the west coast of the island. About 60% of this area is within an MPA (Figure 4).

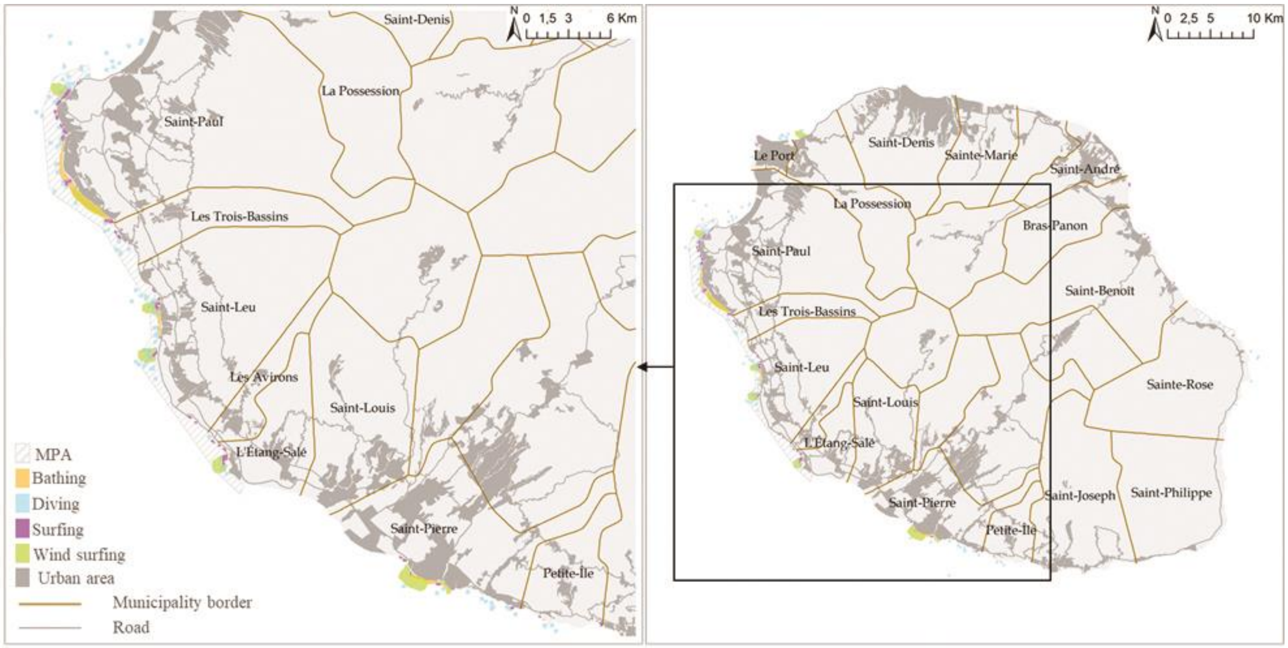

Figure 4. Recreation activities exposed to shark risk in Reunion Island

Regularly, shark risk management is applied in ZONEXs areas which include surveillance, and shark nets, in an area of 1.1 km^2. In addition, preventive shark control is applied regularly but in changing locations, and concentrated along the west coast of the island. The latest preventive shark control program was released in May 2018 and lists areas where preventive shark control is regularly applied. In the first seven months of the program 155 bull sharks and tiger sharks were removed (CSR, 2019b). Since the beginning of preventing shark control operations in January 2014 until November 2019, a total area of 31.3 km^2 was used, 28% of it within MPA. Out of the 9559 drumline and longline devices which were deployed during that period, 3121 were deployed within zones 1 and 609 within zone 2B of the MPA where professional fishing including preventive shark control is permitted. Deployments of devices at the edges of zones 2A of the MPA where fishing is prohibited are recorded as well (130 devices), yet are assumed to be unintentional or due to unprecise location reporting (Figure 5A). Along this period, the number of devices per planning unit (100x100 m) where preventive shark control was applied varied between 1 and 376 (Figure 5B). Most (70%) of the devices were deliberately located within 1 km of activity exposed to risk, which reflects management objective of targeting sharks that frequent areas of activities exposed to risk.

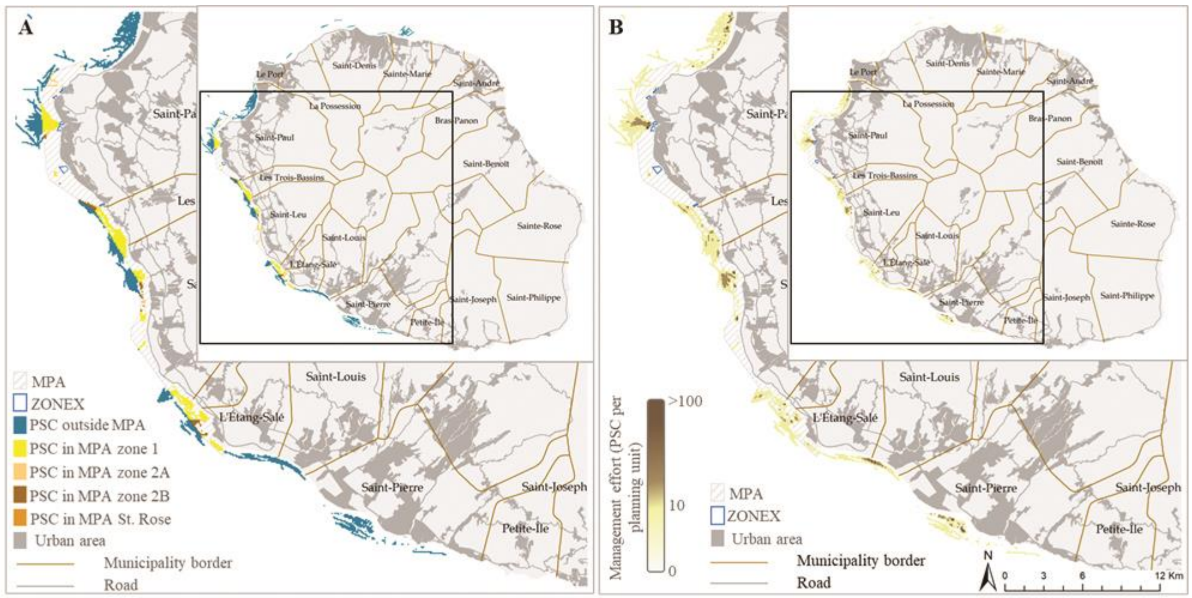

Figure 5. Shark risk management around the island and along the west coast. **A.** Location of ZONEXs and preventive shark control devices deployed between January 2014 and November 2019 in relation to MPAs. **B.** PSC effort (per 100x100 m planning unit). MPA= marine protected area, ZONEX= area where shark risk management is constant and includes bathing nets and surveillance. PSC= preventive shark control device (drumlines and horizontal longlines).

Surfing activity which is considered to be most exposed to shark risk is practiced along 3.2 km^2, 24% of this area is within ZONEXs (Figures 4 and 6). Therefore, 2.4 km^2 (76% of the surfing area) is still being used for surfing in an area banned for surfing by the prefectural decree (yet, at least 10 times less frequently than before 2011; see Lagabrielle et al. 2018a).

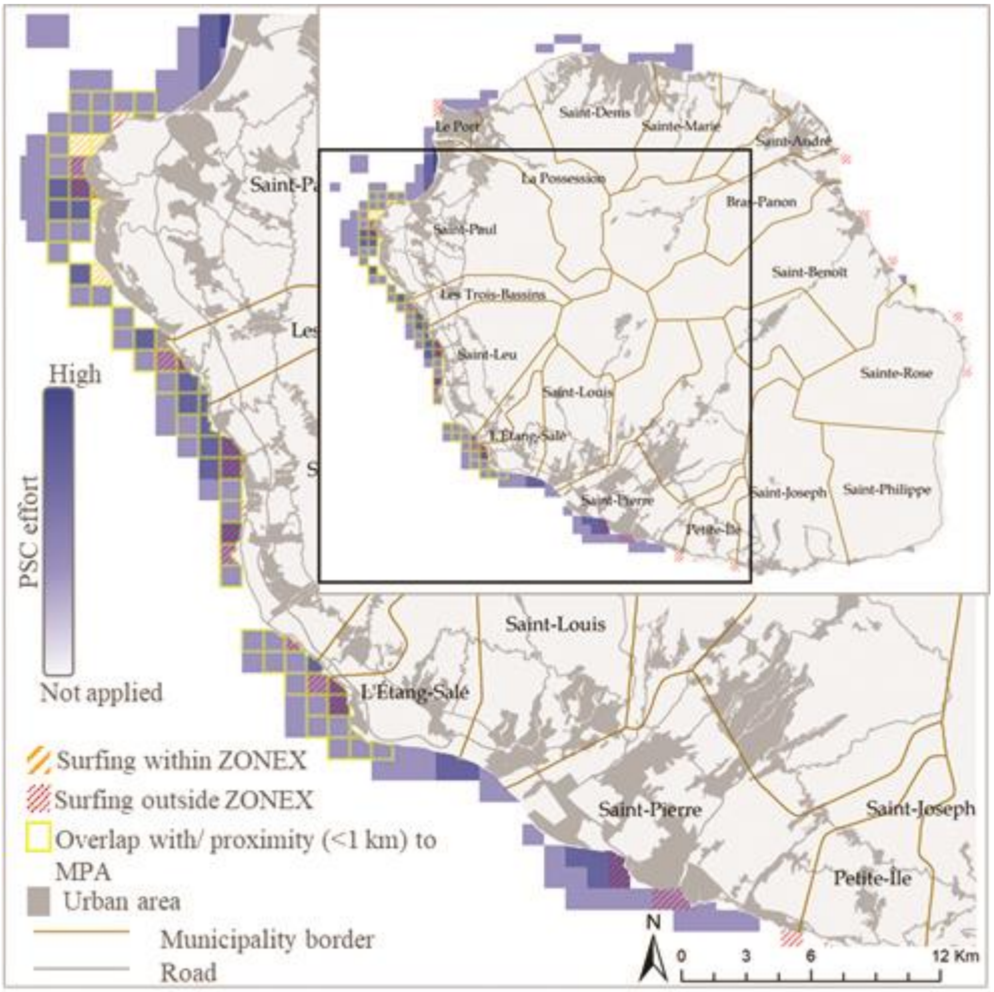

Figure 6. Preventive shark control (PSC) effort, overlap with MPA, and surfing within and outside ZONEXs, presented in 1x1 km grid around the island.

Attempts to identify and assess the ecological impact of shark risk management faced difficulties due to significant data gaps. Most gaps are related to the biology, ecology, and behavior of bull sharks and tiger sharks in the area. However, others relate to the impact of management on the ecosystem and the effectiveness of the management in decreasing the risk. While some gaps are a consequence of data scarcity, others might emerge from poor synthesis or lack of data communication. Table 2 presents the main data gaps which were identified in this study and the implications they might have on planning.

3.3.3 Stage 3

Stage 3 of the planning process is currently being implemented and is expected to be completed by August 2020. Seasketch online zoning negotiation platform is currently being used (http://reunion.seasketch.org, 2019). The platform allows participation of stakeholders and sea users that can comment on existing data and propose spatial management planning scenarios (Figure 7). Those scenarios involve alternative zoning options for nautical activities exposed to shark risk and shark risk management measures. The platform includes more than 100 data layers of various environmental features and marine uses. The CSR aims to use Seasketch to design territorial management of shark risk. They expect it to improve the zoning of their actions, and to facilitate interactions and negotiations with stakeholders being impacted by shark risk management.

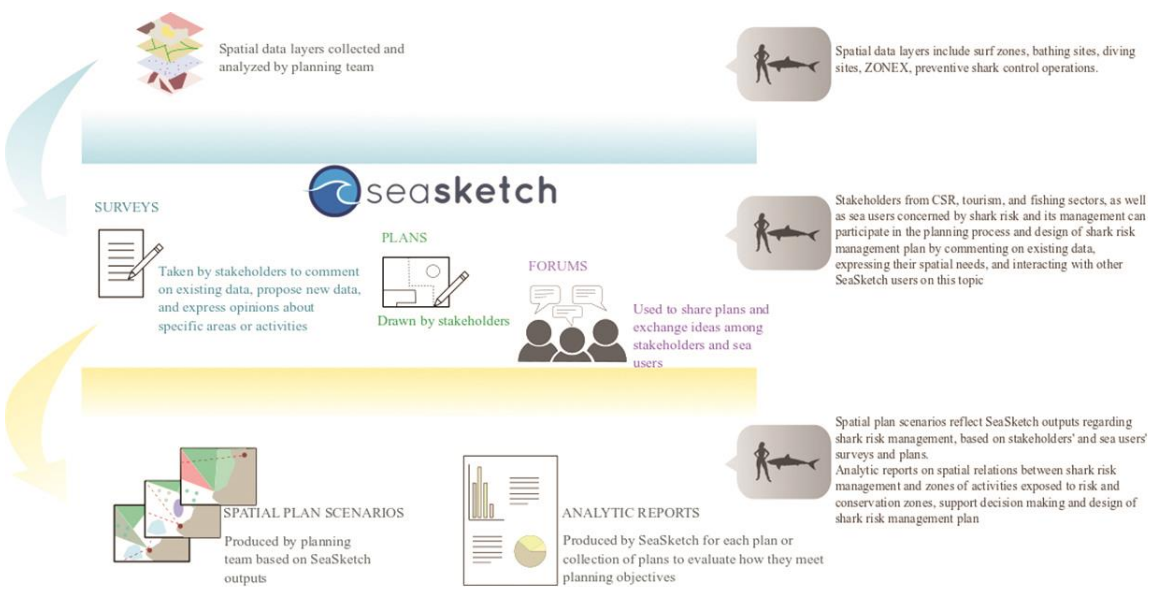

Figure 7. Using Seasketch tool in marine spatial planning to promote collaborative process and address shark risk.

Table 2. Data gaps and sources for uncertainty identified when addressing shark risk and its management through MSP in Reunion Island. Available and missing data refer to local data only.

Topic	Available data	Missing data	Uncertainty to account for in MSP	Data sources
Sharks' biology and ecology	• Partial data on bull shark population and their presence along the island west coast and along the year. • Partial data on trophic ecology, reproductive biology, population genetics, population dynamics, and behavioral ecology of bull sharks and tiger sharks. • Bull and tiger sharks are both considered apex predators, yet they demonstrate different foraging niches.	• Sharks' population size and structure (sex ratio, average age etc.) *. • Sharks' species distribution around the entire island. • Trends in sharks' distribution and use of habitat*. • Drivers of distribution trends (e.g. water quality, climate change, prey population). • Trends in consumption and production* (biomass, prey, and predators).	• Exposure of users to sharks' presence in an area. • Cumulative long-term impact of uses on marine ecosystem.	The CHARC program (2015) The ECoReCo-Run program (2017) Blaison et al. (2015) (Trystram et al., 2016) (Pirog et al., 2017) (Pirog et al., 2019a) Pirog et al. (2019c) Pirog et al. (2019b)

Shark risk management impact on ecosystem	• SMART drumlines are suggested to have the lowest impact on non-target species compared to longlines and gill nets. In addition, a link was found between variables such as hour of device deployment and the catch ratio of targeted versus non-targeted species.	• Impact of shark risk management on target shark populations (structure, dynamic, and behavior). • Indirect impact of target shark capturing on the marine ecosystem (structure and dynamics). • Impact of bycatch capturing by shark removal devices on bycatch populations.	• Existence and/or extent of conflict between uses objectives (shark risk management and MPAs, see Figure 5). • Ability of spatial alternatives and management plans to enhance ecosystem-based management.	Guyomard et al. (2019) Guyomard et al. (2020)

Impact of shark risk management on the risk	• Evaluation of shark risk management performed by the authorities expressed lack of satisfaction from the performance of shark nets that protect surfing zones due to poor resistance to sea condition. • Shark nets that protect bathing areas were found more effective yet require high maintenance. • Experimental surveillance programs were found to be somewhat effective yet further evaluation of the program is required. • Preventive shark control was found to be effective in decreasing the risk, yet require further assessment. • Warning and prevention measures were found highly effective. • Population of sea users exposed to the risk is defined and partially mapped.	• The degree in which shark risk management of all types reduces shark risk. • Complete and updated spatial data on the distribution and intensity of activities exposed to risk.	• Identifying ideal locations and effort of management.	CSR (2016) CSR (2017) Lagabrielle et al. (2018) Lemahieu et al. (2017) Guyomard et al. (2019)

* Data is unavailable due to an ongoing processing, lack of processing, or lack of data communication.

4. Discussion

The increased use in MSP framework to promote sustainable development around the world, reveals various interactions between human and marine ecosystems. In our study we disassembled the human-shark interaction that is primarily described as potentially dangerous for human, and acknowledged its multicomponent nature. We demonstrate that the MSP framework has the ability of addressing shark risk when it reaches beyond spatial solutions to the conflict. The MSP process can then be used in that case to design public policies related to shark risk through comprehensive, inclusive, and transparent consultation processes.

Targeting social debates within the framework of MSP, could be constrained by time and other planning resources such as knowledge and funding. Especially, intense social conflicts related to shark risk may require use of conflict mitigation tools which are not commonly applied in MSP (e.g. Hanssen et al., 2009; Peltonen and Sairinen, 2010). In this case, the contribution of MSP to conflict's mitigation might be hindered but could initiate and drive forward a process of mitigation that use social-conflict-oriented tools as a preparatory step for MSP (Lecourt and Baudelle, 2004; Oteros-Rozas et al., 2015). Alternatively, instead of trying to mitigate the conflict, effort could be directed towards providing the practice and institutions that allow conflicts to take an agonist form and make the conflicts explicit in the process as management issues (Albrechts, 2015; Nursey-Bray, 2016). This radical planning approach that was originally suggested as an urban planning approach by Grabow and Heskin (1973), is not common in MSP process, but it may benefit from the significant driving force of conflicts to enhance social capacity as suggested by Nursey-Bray (2016).

Understanding the ecological impact of shark risk management could also be a challenge under the constrains of planning resources. The lack of sharks' ecological data results in high uncertainty regarding the effectiveness of management measures. The ability of MSP to account for the ecological dimension of the conflict is therefore depended on the existence of environmental data, how data reflect the interconnectivity between ecosystem components, and how it is translated into policy if at all.

In cases where shortfalls in data exist, we suggest that data gaps and related uncertainties should be strongly emphasized in the MSP process. This could direct resources towards biological and ecological research, which can be used for plan adaptation in the next planning cycles. We also suggest that those research products can be used for shark risk management strategy design in cases where the MSP is also used as a platform to construct shark risk public policy.

The results of this study suggest that MSP process is an opportunity to set guidelines for conflict mitigation when proposing a spatial marine plan (Table 3). Overall, those guidelines highlight the need to zone shark risk management, define target of each zone, and assure that areas developed for recreation will include the spatial requirements of shark risk management. Zoning of shark risk management can also be used to minimize or avoid overlap with other uses in cases of uncertainty such as overlap with MPAs. Evaluation of the marine plan can refer to the degree in which those guidelines are met.

Reunion Island case study demonstrates a rapid evolution of shark risk management that responded to sudden increase in a number of shark bite events in an unplanned environment. Shark risk management strategy that was and still being developed in "as-we-go" mode was spatially oriented mostly by the locations of activities exposed to risk and of shark bite events (see Section 3.2 and CSR, 2017; Guyomard et al., 2019). As a result, management measures such as preventive shark control and shark nets are located in or in proximity to an MPA which hosts most of the area of recreational activities around the island and which was primarily allocated to protect coral reef ecosystem. Although lack of evidence of a conflict between the MPA and shark risk management was found, significant data gaps were identified regarding the impact of shark risk management on the marine environment (see Table 2). Therefore, we suggest that the coexistence of these uses should be carefully considered in light of this high uncertainty.

5. Conclusions

The first attempt to address shark risk and its management through the MSP process, suggests that significant weight should be given to shark risk when considering development of sectors and designing public participation in decision makings. Framing of the risk and of the management in terms of space, people, and impact on ecosystem is a big step towards mainstreaming shark risk into transparent and participative decision making. This may balance both social responses to shark risk and the impact of management on the marine ecosystem.

The ability of MSP to adapt to new challenges and shed light on issues that are more than merely spatial overlaps of uses, allows the process to effectively address socioecological conflicts such as human-shark interactions. Even if complex decision support tools or analysis tools are not being used in the process, MSP can still reveal social and ecological aspects of uses and suggest systematic solutions. These solutions eventually contribute to sustainable development and ecosystem-based management which are in the heart of the recent worldwide legislations such as the European Directive for MSP (EC, 2014).

We suggest that the approach proposed in this study could be adopted by other MSP initiatives worldwide where shark risk management is applied, and that it could encompass various management measures and social groups. Yet, we suggest that local knowledge and personal as possible consultation process would best promote sustainable solutions to shark risk and therefore, when applied to large marine areas or to heavily populated regions, the approach should be adapted accordingly (for example, by graduating the process or applying it to sub-regions).

Table 3. Guidelines for spatially mitigating human-shark conflict in MSP

	Guidelines	**Examples**
Zoning shark risk management	Setting management targets. Each zone should address specific target or risk. Management type and intensity should differ from one zone to another according to zone's targets.	- Protection of bathing or surfing zone by nets/ surveillance. - Removing specific individuals (such as adults vs. juveniles, males vs. females, daily vs. nightly catches, bull vs. tiger sharks, etc.) in attempt to control the presence of sharks or reduce immediate threat to sea users while minimizing impact on population or ecosystem.
Coupling recreation activities and shark risk management	Development of zones for recreational activities should include consideration and perhaps allocation of shark risk management.	- Allocating multiuse areas of activities and shark risk management (e.g. surveillance or shark nets in bathing or surfing sites). - Creating buffer zones dedicated to shark risk management around popular areas of recreation activities while considering management limitations (e.g. depth and currents). - Allocating coastal zones for warning against shark risk (signs, alerts etc.) and preparedness for shark bite events, such as medical cabin in popular recreation sites.

Minimizing impact on ecosystem	Uncertainty regarding impact on ecosystem should prevent or at least restrict and minimize allocation of shark risk management in proximity to vulnerable habitats.	- Excluding preventive shark control and shark nets from MPA areas. - Expanding, reallocating, adapting the regulation or rezoning MPA

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